
GEOLOGIC MAP OF THE

OMAK

1:100,000 QUADRANGLE, WASHINGTON

Compiled by

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WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES

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This report has not been edited or reviewed for conformity with
Division of Geology and Earth Resources standards and nomenclature



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Natural Resources

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GEOLOGIC MAP OF THE OMAK 1:100,000 QUADRANGLE, WASHINGTON

compiled by
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INTRODUCTION

The Omak 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 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 quadrangles will be released as DGER open-file reports (listed below). The Chelan and Wenatchee quadrangles will not be open-filed because they have been published by the U.S. Geological Survey (Tabor and others, 1982, 1987).

Literature review and preliminary compilation of the Omak map began in 1985. Sources of geologic data used to construct the geologic compilation of the Omak quadrangle are shown in Figure 2. Between 1986 and 1988, new reconnaissance and detailed geologic mapping was conducted by DGER geologists in areas where previous geologic mapping was either inadequate or lacking. Geologic mapping was also acquired through a DGER graduate-student mapping program.

All known radiometric ages from the Omak quadrangle are listed in Table 1. Twelve new major element whole-rock geochemical analyses are given in Table 2. Both tables follow the list of references cited.

Age assignments of geologic units on the Omak 1:100,000-scale quadrangle were made following the flow chart in Figure 3. The geologic time scale used is from the "Correlation of Stratigraphic Units of North America (COSUNA)" project of the American Association of Petroleum Geologists (Salvador, 1985).

Most unit names have been retained from the original sources of mapping.

In several instances, where modes were available, plutonic rock types were assigned using the International Union of Geological Sciences rock classification (Streckeisen, 1973). Volcanic rock names were assigned using whole rock geochemical data and the total alkali-silica (TAS) diagram (Zanettin, 1984).

DGER Northeast Quadrant Open-File Reports

Bunning, B. B., compiler, 1990, Geologic map of the east half of the Twisp 1:100,000 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 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 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 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-6, 20 p., 1 pl.

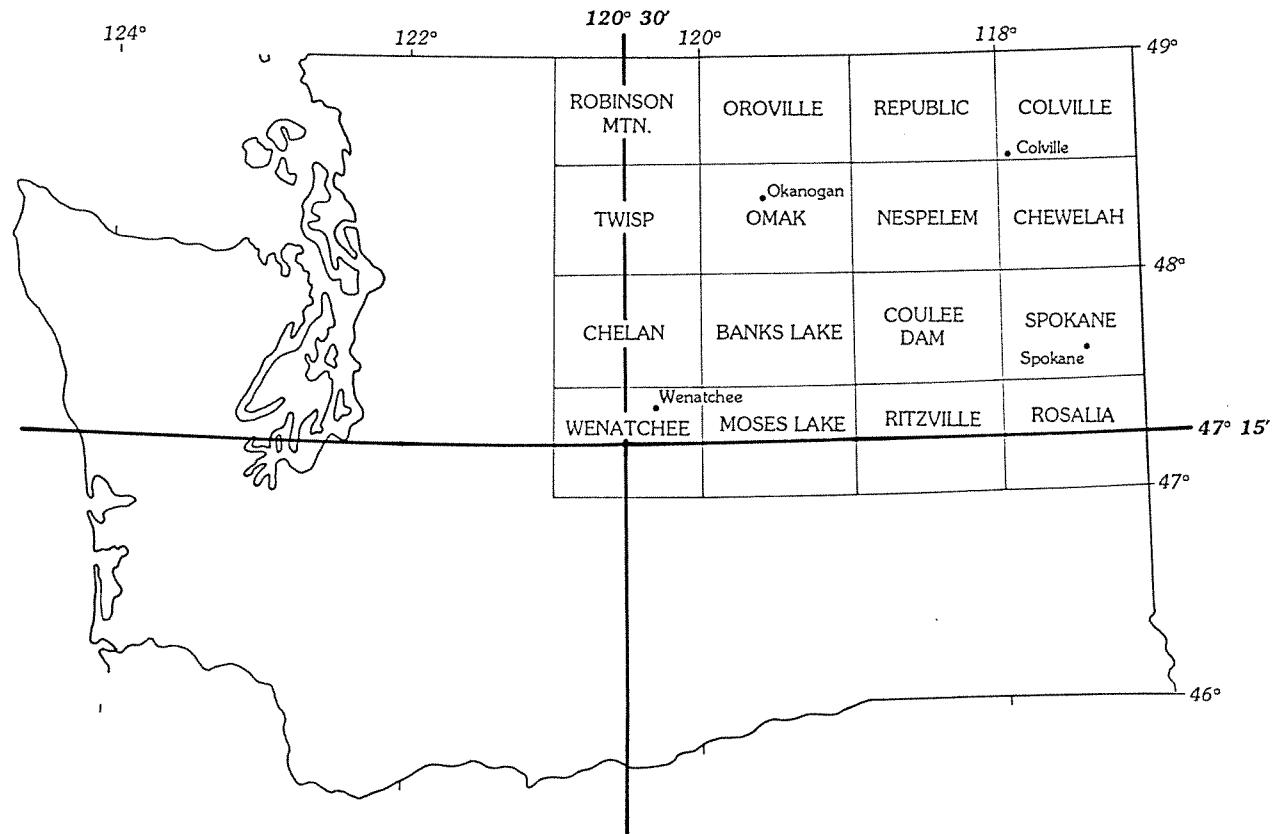


Figure 1. 1:100,000-scale quadrangles in the northeast quadrant of Washington.

Sources of Map Data

(Explanation for Figure 2, facing page)

1. Atwater and Rinehart, 1984, scale 1:100,000
2. Broch, 1979, scale 1:12,000
3. Buddington, 1986, scale 1:24,000
4. K. F. Fox Jr., USGS, written commun., 1988, scale 1:62,500
5. A. M. Frey, Univ. of Pittsburgh, written commun., 1988, scale 1:24,000
6. Fritz, 1978, scale 1:62,500
7. J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988, scale 1:62,500
8. Hanson, 1979, scale 1:250,000
9. Menzer, 1964, scale 1:44,000; 1982, scale 1:63,360
10. Minard, 1985, scale 1:24,000
11. Raviola, 1988, scale 1:24,000
12. Sims, 1984, scale 1:24,000
13. Singer, 1984, scale 1:24,000
14. Swanson and others, 1979, scale 1:250,000
15. J. R. Wilson, formerly USGS, written commun., 1987, scale 1:100,000
Shaded area, DGER unpublished mapping, this report

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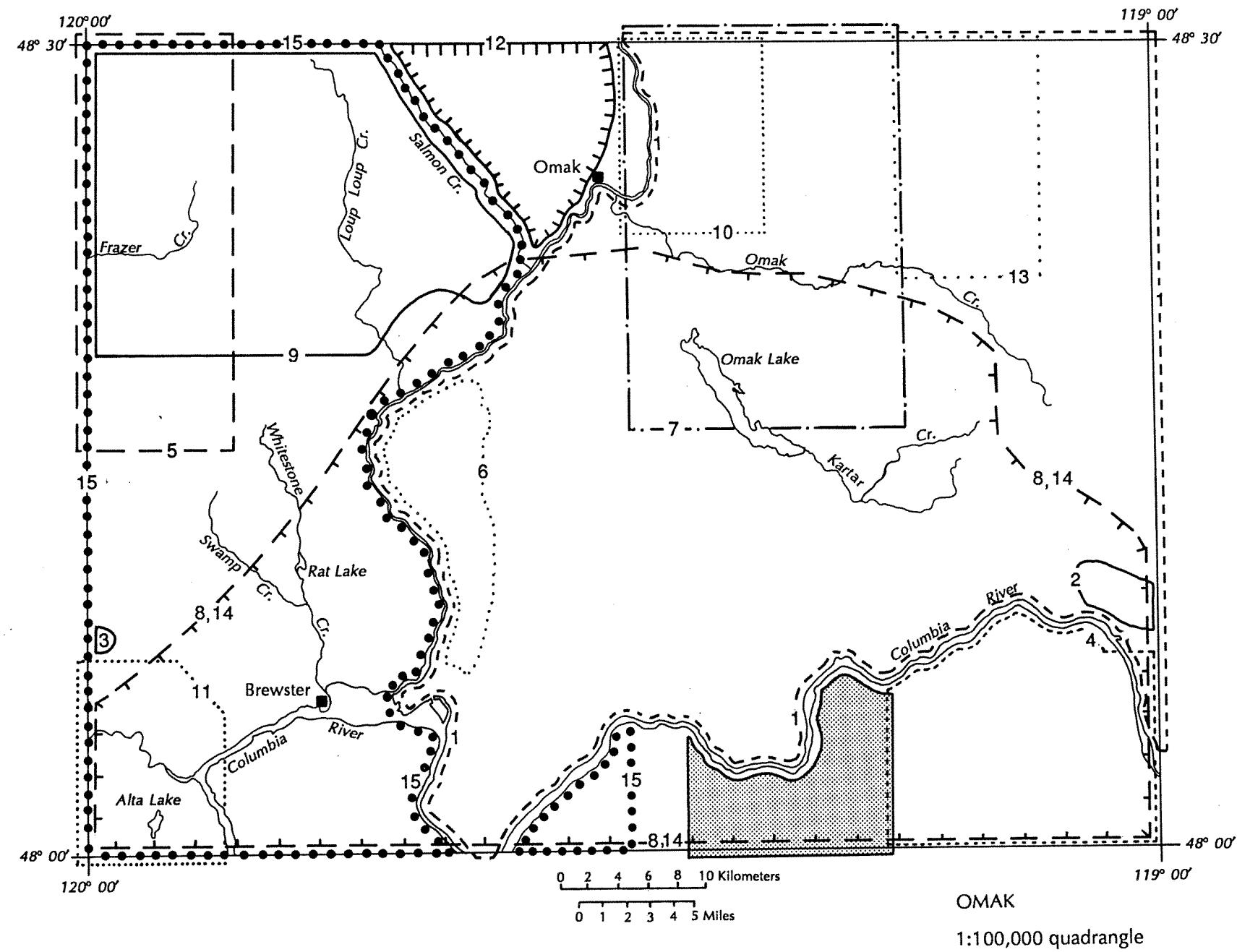


Figure 2. Sources of geologic map data, Omak 1:100,000-scale quadrangle.

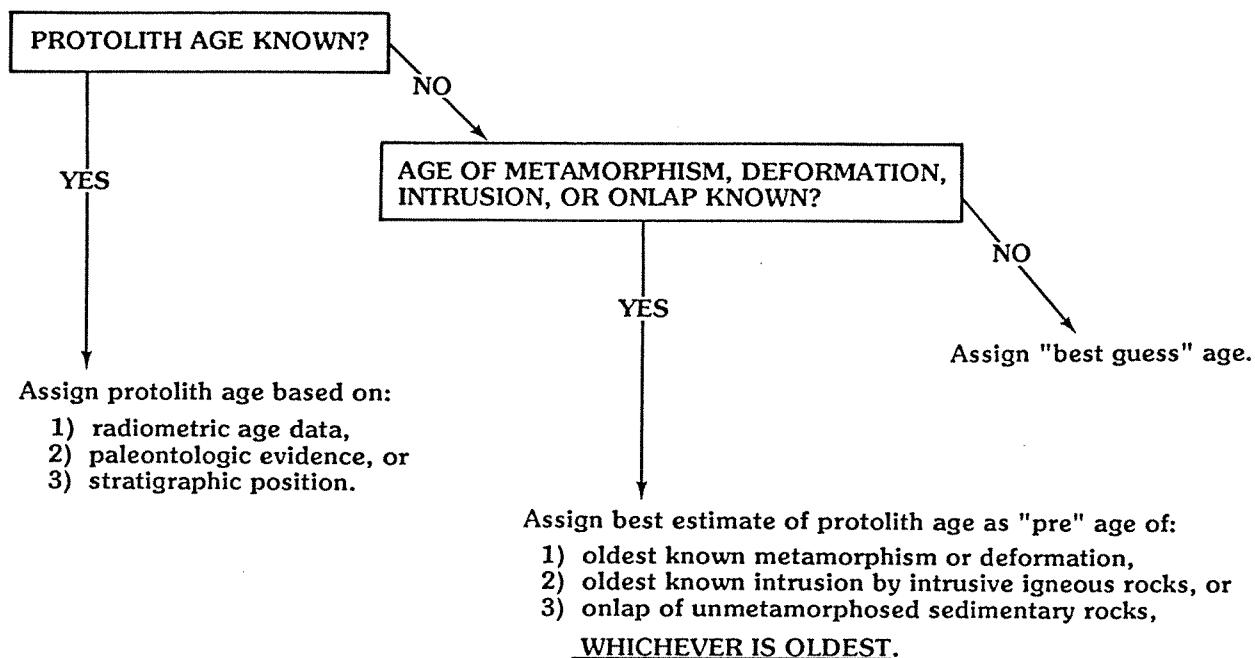


Figure 3. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age can be assigned by correlation with other units. The unit description will include information on how the age of the unit was determined.

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

Joseph, N. L., compiler, 1990, Geologic map of the Colville 1:100,000 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 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 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 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-11, 58 p., 1 pl.

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

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Stoffel, K. L.; McGroder, M. F., compilers, 1990, Geologic map of the Robinson Mtn. 1:100,000 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 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 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 quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-7, 20 p., 1 pl.

Acknowledgements

Thanks to the following individuals for vital contributions to this compilation: B. F. Atwater, K. F. Fox, Jr., and C. D. Rinehart (all USGS), F. R. Sims, and J. R. Wilson (Law Environmental Services) for unpublished geologic mapping. F. J. Menzer, Jr. (FMC Gold Corp.), and A. M. Frey (Univ. of Pittsburgh) for leading an instructional field trip in the Okanogan range. J. R. Snook (Eastern Washington Univ.) for the loan of airphotos. J. Hohle (Dept. of Geology, Colville Confederated Tribes) for geological research permits for Colville Confederated Tribal land. W. M. Phillips and H. W. Schasse for DGER geologic field mapping. K. L. Stoffel (DGER) and B. F. Atwater for critical review and discussions of an earlier draft of this report. N. A. Eberle and J. R. Snider of DGER prepared the final version.

GEOLOGIC SETTING

The Omak 1:100,000-scale quadrangle contains eight generalized rock packages (Fig. 4): (1) Late(?) Triassic eugeoclinal metasedimentary and metavolcanic rocks; (2) amphibolite-facies metamorphic rocks of unknown age; (3) orthogneisses of unknown age; (4) a complex of Late Jurassic to Early Cretaceous igneous and metamorphic rocks; (5) Late Cretaceous igneous intrusions; (6) Tertiary igneous intrusions; (7) Eocene volcanic and sedimentary rocks; and (8) Miocene basalt flows.

The Triassic metasedimentary and metavolcanic rocks (unit T ms) are eugeoclinal rocks that were accreted to the North American continent during the Late Triassic or Early Jurassic. The amphibolite-facies metamorphic rocks (am) and the metamorphosed igneous intrusions (og) may have formed during the regional metamorphism associated with the accretionary event. Protolith age of the amphibolite facies rocks is uncertain, but cross-cutting relations with younger igneous intrusions suggest that they are pre-Jurassic.

Upper Jurassic to Lower Cretaceous tonalitic and granodioritic igneous intrusions (Kjt), orthogneiss (Kjog), migmatite (Kjmg), and mixed metamorphic and igneous rocks (Kjmi) form the large northwest-trending Summit-Frazer complex in the western one-third of the quadrangle. Upper Cretaceous igneous intrusions (Ki) cut the complex, forming a northwest-trending belt across the center of the map area.

Regional extension during the latest Cretaceous(?) and early Tertiary resulted in the formation of the Okanogan metamorphic core complex, the emplacement of Tertiary igneous intrusions (Ti), and the deposition of Eocene volcanic and sedimentary rocks (Ev). Basalt flows of the Columbia River Basalt Group (Mv) covered the southern part of the Omak 1:100,000-scale quadrangle during the middle Miocene.

Explanation

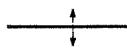
- Q Quaternary sediments (includes the Columbia and Okanogan Rivers, Lake Pateros, and Rufus Woods Lake)
- Mv Miocene volcanic rocks (Columbia River Basalt Group)
- Ev Eocene volcanic and sedimentary rocks
- Ti Tertiary intrusive rocks
- TKi Tertiary-Cretaceous(?) intrusive rocks
- Ki Cretaceous intrusive rocks
- KJi Cretaceous-Jurassic(?) intrusive rocks
- KJmg Cretaceous-Jurassic(?) migmatite
- KJog Cretaceous-Jurassic(?) orthogneiss
- KJmi Cretaceous-Jurassic(?) mixed metamorphic and igneous rocks
- T ms Triassic metasedimentary and metavolcanic rocks
- og pre-Tertiary orthogneiss
- am pre-Tertiary amphibolite-facies metamorphic rocks

Contact

— — — . . . Fault, dashed where inferred; dotted where concealed

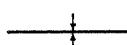
— ▲ ▲ ▲ . . . Thrust fault, dashed where inferred; dotted where concealed

— — — — . . . Low-angle normal fault, dotted where concealed

 Anticline

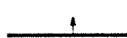


Mylonitically deformed rocks on
the border of the Okanogan
metamorphic complex

 Syncline

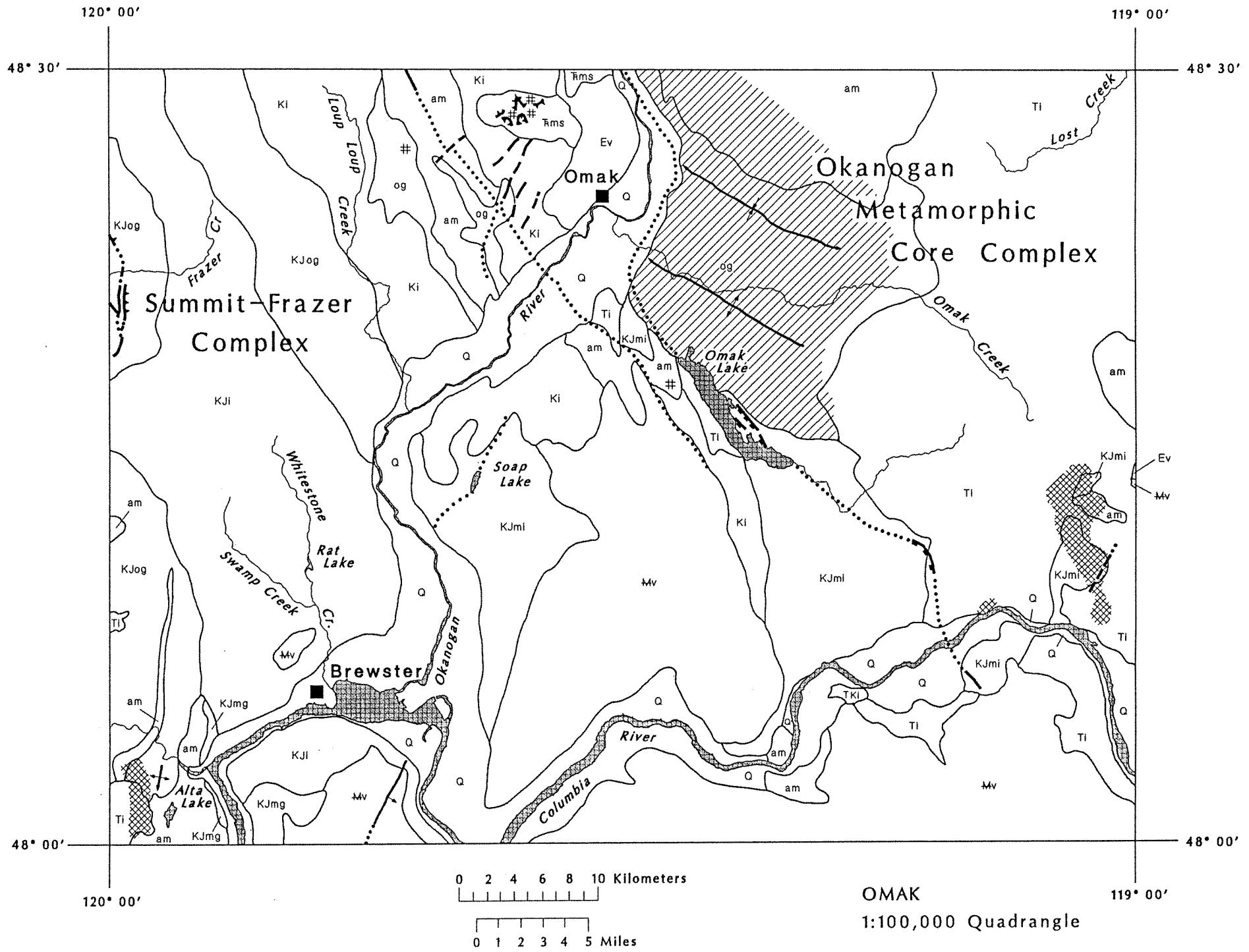


Dacite dike swarm

 Monocline

Ultrabasic Rocks

Figure 4. Generalized geologic map, Omak 1:100,000-scale quadrangle.



DESCRIPTION OF MAP UNITS

Sedimentary and Volcanic Deposits and Rocks

Quaternary Sedimentary Deposits

Nonglacial Deposits

Qa

Alluvium (Holocene)--Silt, sand, and gravel in streambeds, floodplains, and terraces; stratified sand and gravel in alluvial fans; locally includes minor eolian, lacustrine, and bog deposits. Alluvium is as much as 20 m thick along the Okanogan River, where it typically grades upward from lower stratified coarse sand and pebble to cobble gravel into fine sand and silt (Minard, 1985).

Qls

Landslide deposits (Holocene)--Unstratified to poorly stratified clay, silt, sand, and gravel in landslide deposits and colluvium. The unit includes talus deposits below cliffs and ridges of Columbia River basalt in the southern part of the map area.

Qd

Dune sand (Holocene)--Fine to medium sand in active to stabilized dunes; composed chiefly of quartz and basalt grains reworked from older sedimentary deposits (Hanson, 1979).

Deposits of Outburst Floods from Glacial Lakes

Qfg

Flood deposits, gravel (Pleistocene)--Gravel and coarse sand along the Columbia River deposited by high-energy flood waters generated by the abrupt drainage of ice-dammed glacial lakes.

Qfs

Flood deposits, slackwater sediments (Pleistocene)--Medium to fine sand and silt deposited by slackwaters of catastrophic floods from glacial lakes; present along the Columbia River.

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Glacial Deposits

Qgl

Glaciolacustrine deposits (Pleistocene)--Thinly laminated clay, silt, and sand along the Columbia and Okanogan River valleys that was deposited in glacial lakes during the waning stages of late Wisconsin glaciation. The glaciolacustrine deposits along the Columbia River valley near the mouth of the Nespelem River consist of varved silt and clay, as much as 240 m thick, that were originally named the Nespelem Silt (Pardee, 1918) and may have been associated with glacial Lake Columbia, east of the map area and described by Atwater (1986).

Qgo, Qgo_i

Glacial outwash (Pleistocene)--Poorly stratified clay, silt, sand, and gravel deposited by glacial meltwater streams; as much as 35 m thick (Minard, 1985). The unit includes part of the "terrace and bar deposits, undifferentiated" unit and the Great Terrace of Hanson (1979). Glacial outwash deposits were deposited by the Cordilleran ice sheet during late Wisconsin glaciation. Outwash labeled Qgo_i, near the west edge of the Omak 1:100,000-scale quadrangle (T. 31 N., R. 23 E.), is ice-contact drift consisting of stratified clay, silt, sand, and gravel in kames and moraines.

Qgt

Till (Pleistocene)--Heterogeneous mixture of unsorted and unstratified clay, silt, sand, pebbles, cobbles, and boulders deposited by the Okanogan lobe of the late Wisconsin Cordilleran ice sheet.

Qgd

Glacial drift, undivided (Pleistocene)--Till, outwash, and glaciolacustrine deposits, undivided, deposited by the Okanogan lobe of the late Wisconsin Cordilleran ice sheet. In French Valley, this unit includes much glaciolacustrine silt and clay.

Tertiary Volcanic and Sedimentary Rocks

Columbia River Basalt Group and Associated Sedimentary Rocks

ΔV_{wp}

Wanapum Basalt, Priest Rapids Member (Miocene)--Grayish black, fine- to coarse-grained basalt flows that are sparsely plagioclase phryic or contain glomerophyric clots of plagioclase and olivine. Groundmass olivine is visible with a hand lens in fine-grained samples. The unit is weakly diktytaxitic and of reversed magnetic polarity.

Two chemical types, the Rosalia and Lolo, have been recognized in the Priest Rapids Member. Older flows of the Rosalia chemical type, characterized by high TiO₂ and high FeO relative to the younger Lolo chemical type flows, are present in the northern and northeastern parts of the Columbia Basin, including the map area.

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The Priest Rapids Member in the map area generally overlies sedimentary rocks or magnetostratigraphic unit N₂ of the Grande Ronde Basalt, but at one exposure south of the Columbia River, Priest Rapids flows overlie the Roza flows of the Wanapum Basalt.

The Wanapum Basalt flows were erupted between 15.5 and 14.5 Ma (Long and Duncan, 1983). No ages are reported from the Priest Rapids Member in the map area, but the member has yielded several K-Ar ages of approximately 14.5 Ma (Beeson and others, 1985).

ΔV_{wr}

Wanapum Basalt, Roza Member (Miocene)--Dark blue-gray, medium- to coarse-grained phryic basalt flows. Uniformly distributed plagioclase phenocrysts as much as 1.0 cm in length (average 5 mm) form 5 to 8 percent of the Roza flows. Of transitional magnetic polarity, the Roza Member consists of two flows, which have a combined maximum thickness of 50 m in the map area. The age of the Roza Member is bracketed by the overlying 14.5 Ma Priest Rapids Member and the 15.5 Ma Frenchman Spring Member that underlies the Roza Member outside the map area.

ΔV_c

Sedimentary rocks (Miocene)--Weakly indurated, fine-grained sandstone, siltstone, and claystone that form several small outcrops along the eastern margin of the Columbia River Basalt Group in the south-central part of the map area and in T. 29 N., R. 24-25 E.

$\Delta V_{gN2}, \Delta V_{gR2}$

Grande Ronde Basalt (Miocene)--Dark-gray to black, fine-grained, aphyric basalt flows. The Grande Ronde Basalt flows were erupted between 16.5 and 15.5 Ma (Long and Duncan, 1983; Beeson and others, 1985). The Grande Ronde Basalt consists of dozens of flows of similar chemical compositions. It is divided into four magnetostratigraphic units, two of which are present in the map area:

ΔV_{gN2}

Magnetostratigraphic unit N2; upper flows of normal magnetic polarity

ΔV_{gR2}

Magnetostratigraphic unit R2; upper flows of reversed magnetic polarity

Eocene Volcanic Rocks

Eocene volcanic and volcaniclastic rocks crop out on Pogue Flat between Riverside and Omak and along the east-central border of the map area.

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Evc

Volcaniclastic rocks (Eocene)--Olive-gray, thick-bedded, poorly sorted and poorly stratified volcanic agglomerate composed of angular to subangular clasts of argillite, quartzite, and volcanic rocks in a sandstone matrix of quartz, plagioclase, and clay minerals. The clasts were derived from the metamorphic complex of Conconully (T_{mm_x}) (chiefly in the Oroville 1:100,000-scale quadrangle to the north), the Cave Mountain Formation (T_{mm} , T_{cb} , T_{mv}), and Eocene dacitic volcanic rocks (Evd). The poor sorting, crude stratification, moderate primary dips, subangular to subrounded heterolithic components, and dacitic matrix suggested a nearby source for these rocks called the Mount Olive conglomerate by Sims (1984).

Evd

Dacite flows (Eocene)--Massive to flow-layered dacite porphyry flows containing 1- to 5-mm phenocrysts of plagioclase, quartz, and minor hornblende (Sims, 1984). The flows are present between Riverside and Omak. They were named the Shellrock Point Volcanics by Menzer (1982) and described as quartz keratophyres consisting of phenocrysts of quartz and pink albite in a dense, propylitically altered groundmass of glass, quartz, biotite, and calcite. The dacite flows are probably correlative with dacite flows at Carter Mountain (10 km north of the map area) and at Whitestone Mountain (26 km to the north-northeast). Those flows have yielded K-Ar ages between 45 and 49 Ma (Rinehart and Fox, 1976).

Evd_s

Sanpoil Volcanics (Eocene)--Dacitic lava flows, subordinate pyroclastic and sedimentary rocks, and minor hypabyssal intrusive rocks that crop out along the eastern margin of the map area near Whitelaw Creek (Atwater and Rinehart, 1984). Similar volcanic rocks extend east into the Nespelem 1:100,000-scale quadrangle, where Staatz (1964) assigned these rocks to the Sanpoil Volcanics. Farther east, Moye (1984) recognized a younger phase of more silicic, less potassic, and strontium-enriched volcanic rocks that she named the rhyodacite of Cub Hill. She suggested that these rhyodacites are dominant at the southern end of the Republic graben, but their relation to the volcanic rocks in the Omak quadrangle is unknown.

Metasedimentary and Metavolcanic Rocks

T_{mm_x}

Metamorphic complex of Conconully (Triassic?)--Dark-gray to black slate and phyllite, orange-brown, thinly layered to bedded metasiltstone, and argillaceous quartzite. The unit forms a narrow, 7-km-long, northwest-trending belt that straddles the border between the Omak and Oroville 1:100,000-scale quadrangles near Evans Lake. The rocks have undergone greenschist-facies metamorphism and are typically foliated parallel to bedding. The unit crops out in two small exposures along the north-central border of the map, west of Riverside.

The metamorphic complex of Conconully was intruded by the Evans Lake pluton (Kia_e). Along the contact, the rocks are upgraded to amphibolite-facies biotite-hornblende schist and gneiss, locally containing garnet, andalusite, and sillimanite.

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The metamorphic complex of Conconully is older than the Evans Lake pluton, which has a K-Ar biotite age of 88.2 ± 2.8 Ma. The metamorphic complex of Conconully overlies and interfingers with the Late(?) Triassic Cave Mountain Formation (Rinehart and Fox, 1976). These relations suggest that at least a part of the metamorphic complex of Conconully is Late Triassic in age.

Tr mm, Tr cb, Tr mv

Cave Mountain Formation (Triassic)--Interbedded metalimestone, metadolomite, metasiltstone, slate, and metavolcanic rocks in a folded and faulted, 1300-m-thick sequence. The Cave Mountain Formation is limited to several small exposures along the north-central border of the quadrangle; it covers approximately 75 km² northwest of Riverside, mainly in the adjacent Oroville 1:100,000-scale quadrangle. North of the map area, Rinehart and Fox (1976) divided the Cave Mountain Formation into five members, in ascending order: (1) dark-gray metalimestone; (2) metasiltstone; (3) metadolomite and metalimestone; (4) slate and metalimestone; and (5) basaltic metavolcanic rocks. The slate and metalimestone member has yielded Late(?) Triassic pelecypods and an ammonite.

The Cave Mountain Formation may be correlative with part of the Nicola Group in southern British Columbia (Tempelman-Kluit, 1989). It may also be correlative with part of the Kobau Formation, which forms extensive outcrops in the northern part of the Oroville 1:100,000-scale quadrangle (Stoffel, 1990a).

Tr mm

Cave Mountain Formation, undivided--A sequence of five conformable units, from bottom (west) to top (east): (1) dark olive-green vesicular basaltic agglomerate in a schistose, actinolite-diopside matrix that locally contains flattened vesicles; elongation of clasts, averaging 30 cm in length, is concordant to foliation; (2) dark grayish-black, coarse micrite with discontinuous zones of white coarse-grained dolomitic marble at the base and lenses of chert above; (3) medium dark-gray, thinly laminated to bedded, fine-grained limestone alternating with layers of fine-grained white marble; (4) dark-gray to black fissile limestone alternating with massive gray and white limestone; and (5) actinolite diopside hornfels (Sims, 1984).

Tr cb

Metalimestone and metadolomite member--Dark-gray, fine-grained, carbonaceous, thinly laminated to thinly bedded metalimestone and calcareous metasiltstone containing thin layers or lenses of folded or pinch-and-swell white calcite marble and concordant to discordant veinlets of white calcite marble. The metalimestone is locally siliceous and/or argillaceous. Randomly oriented tremolite crystals are common in bedding/foliation planes.

Metadolomitic components of the member consist of buff, pale yellow to pale orange-brown, medium- to coarse-grained dolomitic marble which in places grades into medium- to coarse-grained calcite marble. The metadolomite is locally brecciated.

T mv

Metavolcanic member--Dark forest-green, schistose to phyllitic, intermediate metatuff and dark olive-green to greenish-black metabasalt and basaltic agglomerate. The metabasalt is typically blastoporphyritic and is composed of black, equant hornblende crystals, 1 to 5 mm across, in an olive-gray, fine-grained, carbonate-rich matrix. The hornblende is pseudomorphic, probably after pyroxene. Amygdules of feldspar, calcite, and actinolite indicate that some of the metabasalt may represent lava flows. The basaltic agglomerate, or metabasaltic breccia, contains subangular to subrounded clasts of metabasalt, 2 to 30 cm in diameter, along with small to large bombs, lapilli, and fine-grained volcanic rock clasts in a schistose, carbonate-rich matrix. Some of the metabasalt clasts contain flattened vesicles that are concordant with foliation (Sims, 1984).

Igneous Intrusive Rocks

Tertiary Hypabyssal Intrusive Rocks

Eida_c, +++,

Hypabyssal intrusive suite of Cody Lake (Eocene)--Porphyritic dikes of intermediate to acidic composition; includes hornblende-biotite rhyodacite to diorite dikes and biotite rhyolite to rhyodacite dikes. The hornblende-biotite rhyodacite and diorite dikes are medium gray to dark greenish gray and porphyritic. Phenocrysts are chiefly euhedral white plagioclase and hornblende; biotite is subordinate; fine-grained pyrite and quartz phenocrysts are rare.

The biotite rhyolite to rhyodacite dikes are light gray to light greenish gray and porphyritic. Phenocrysts are euhedral plagioclase, biotite, and quartz. Fine-grained pyrite is common (Colville Confederated Tribes Geology Dept., 1984, plate II).

The hornblende-bearing dikes are probably hypabyssal intrusive equivalents of the Sanpoil Volcanics. The biotite-rhyolite dikes may be the hypabyssal intrusive equivalents of the O'Brien Creek Formation in the Nespelem and Republic 1:100,000-scale quadrangles.

The Coyote Creek pluton (EPig_c) and the Boot Mountain complex (KJmi_b) in the vicinity of Squaw Mountain and the porphyritic granodiorite of Manila Creek (EPigd_m) in the Mineral Ridge area (all in T. 31 N., R. 30 E.) are cut by extensive swarms of the hypabyssal intrusive suite of Cody Lake. The ratio of dikes to country rock typically exceeds 1:10 (Atwater and Rinehart, 1984).

No radiometric ages are reported from the hornblende-bearing dikes in the map area, but similar dikes in the adjacent Nespelem 1:100,000-scale have yielded K-Ar ages between 47 and 50 Ma (Atwater and Rinehart, 1984).

The unit was named by Atwater and Rinehart (1984) for occurrences near Cody Lake in the adjacent Nespelem 1:100,000-scale quadrangle. The hypabyssal intrusive suite of Cody Lake is probably related to a group of chemically and mineralogically similar dikes outside the map area, to which workers have assigned a variety of names, including the Scatter Creek Rhyodacite (Meussig, 1967) and Tsh₁/Tsh₂ (Colville Confederated Tribes Geology Dept., 1984).

Eida_g

Porphyry dike swarm of Goat Mountain (Eocene)--Dikes of light- to dark-gray dacite porphyry and microgranodiorite porphyry composed of plagioclase phenocrysts (as much as 5 cm long) and euhedral quartz phenocrysts in a microcrystalline groundmass of quartz, K-feldspar, and minor plagioclase. Glomeroporphyritic clumps of biotite and hornblende are common. Average composition is 40-45 percent plagioclase, 20-25 percent K-feldspar, 5-10 percent biotite, 5-10 percent hornblende, and minor apatite, sphene, rutile, zircon and opaque minerals. Individual dikes range from 50 cm to more than 30 m thick. The dikes apparently emanate from the margins of the Cooper Mountain batholith (Raviola, 1988). The dikes commonly strike within 20 degrees of north and dip 75 to 90 degrees.



Dacite dikes (Eocene)--Several isolated dacite dikes that may be related to the porphyry dike swarm of Goat Mountain (Eida_g) in T. 30-31 N., R. 23 E. Other unnamed dacite dikes cut the granite of Felix Creek (Kig_f) and the granodiorite of Soap Lake Mountain (Kigd_s).



Andesite dikes (Eocene)--Fine- to medium-grained, aphanitic to subporphyritic hornblende-plagioclase lamprophyre commonly altered to chlorite, calcite, and prehnite (Raviola, 1988). Eight of these dikes are present in the southwest corner of the map area, where they intrude the amphibolite, schist, and gneiss of Alta Lake (pKhm_a) and the Methow gneiss (pKog_m).

A 1,500-ft-long lamprophyre (vargasite), containing hornblende phenocrysts as much as 1.3 cm long, in an altered groundmass of plagioclase, sericite, carbonate, epidote, opaque minerals, and chlorite, cuts the granite of Felix Creek. A small black andesite dike intrudes the orthogneiss of Wakefield (KJmi_w) east of Monse; the dike contains plagioclase, epidote, biotite, chlorite, opaque minerals, and sericite (Fritz, 1978).



Basalt dikes (Eocene)--Dark-gray to black hornblende-clinopyroxene basalt containing sparse plagioclase phenocrysts (Raviola, 1988).



Porphyritic microdiorite dikes (Eocene)--Narrow (< 15 m) and short (< 50 m) dikes of massive, light- to medium-gray, fine-grained, equigranular diorite containing sparse 2- to 4-mm-long plagioclase and hornblende phenocrysts. The dikes trend NNE and dip steeply to the northwest; they cut across mylonitic lineation in wall rock. The groundmass contains plagioclase, hornblende, biotite, minor quartz, orthoclase(?), sphene, and iron oxides. The dikes cut the gneissic porphyritic granodiorite of Mission Creek (pTog_m), the Boot Mountain complex (KJmi_b), and the Coyote Creek pluton (EPig_c).

Tertiary Plutonic Rocks

Plutons West of the Okanogan River

Eigd_c

Cooper Mountain batholith (Eocene)--Light-gray to tan, medium-grained (2-3 mm average) granodiorite with K-feldspar phenocrysts as much as 8 mm long and that consists of 50 percent plagioclase, 15-20 percent K-feldspar, 15-20 percent quartz, 6-7 percent finer grained biotite, 1-5 percent hornblende, 1 percent sphene, and accessory apatite, rutile, ilmenite, and zircon. Epidote-calcite veins and iron-oxide stains are common.

The Cooper Mountain batholith intrudes the amphibolite, schist, and gneiss of Alta Lake (pKhm_a) and the Methow gneiss (pKog_m), typically forming sharp and discordant contacts. The grain size and porphyritic nature of the unit increase to the west (Raviola, 1988). Most of the Cooper Mountain batholith lies west of the map area in the Twisp 1:100,000-scale quadrangle (Barksdale, 1975). A K-Ar biotite age of 48 ± 4.5 Ma has been reported from the Twisp quadrangle (Tabor and others, 1987).

Eigd_n

Noname stock (Eocene)--Medium-grained, pink to white leucocratic granodiorite with biotite books (0.5-1.0 cm) and honey-brown sphene. The stock contains xenoliths (5-10 cm) of amphibolite interlayered with granoblastic plagioclase and quartz. These mafic inclusions were probably derived from the Leecher Metamorphics (pKhm_i). The Noname stock crosscuts foliation in the Methow Gneiss (pKog_{gm}). An early Eocene age is indicated by a zircon fission-track age of 55 ± 5 Ma and a sphene fission-track age of 53.6 ± 5 Ma for samples collected just west of the map area (Buddington, 1986).

The Noname stock is an elongate 1.6 km x 5.0 km west-trending body along French Creek on the western edge of the map area. It extends west onto the Twisp 1:100,000-scale quadrangle (Barksdale, 1975). It has also been called the Methow stock (Buddington, 1986) and the French Creek stock (J. R. Wilson, formerly USGS, written commun., 1987).

Plutons East of the Okanogan River

Lower Tertiary plutonic rocks underlie hundreds of square kilometers in the eastern one-third of the Omak 1:100,000-scale quadrangle and much of the Okanogan highlands in the Nespelem, Republic, and Oroville 1:100,000-scale quadrangles. They have been subdivided into three intrusive suites, in order of decreasing age, the Keller Butte, Devils Elbow, and Herron Creek suites (Holder and Holder, 1988; Holder and others, 1989). The Keller Butte suite is composed of leucocratic, fine- to coarse-grained, equigranular to porphyritic, biotite granite and granodiorite. The Devils Elbow suite consists of medium-grained, equigranular, biotite- and hornblende-bearing plutons that range in composition from monzodiorite to granodiorite. The Herron Creek suite is composed of an older phase of medium- to coarse-grained, hornblende-biotite quartz monzonite or monzonite plutons and a younger phase of fine-grained, equigranular, hornblende-biotite granite.

Radiometric ages indicate that the three intrusive suites were emplaced in the early Tertiary. K-Ar biotite ages ranging from 61 to 49 Ma are reported from the Keller Butte suite plutons, suggesting intrusion in the late Paleocene and early Eocene. K-Ar biotite and hornblende ages between 53 and 45 Ma have been obtained from Devils Elbow and Herron Creek suite plutons, indicating early to

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middle Eocene emplacement. Intrusion of the Devils Elbow and Herron Creek suites was largely coeval, and they are probably comagmatic with the Sanpoil Volcanics and rhyolite domes that intrude the Sanpoil Volcanics (Holder and Holder, 1988; Holder and others, 1989). The relation between Keller Butte suite plutons and the Eocene volcanic rocks is unclear.

Structural relations among the early Tertiary plutonic rocks, the Eocene volcanic and sedimentary rocks in the Republic and Toroda Creek grabens, and the amphibolite-facies metamorphic rocks in the Kettle and Okanogan metamorphic core complexes indicate the Keller Butte and Devils Elbow suites were emplaced during formation of the grabens and metamorphic core complexes (Holder and Holder, 1988; Holder and others, 1989). Herron Creek suite plutons postdate core complex formation, but predate final movement of graben-bounding faults. Thus, the emplacement of the early Tertiary plutons was broadly contemporaneous with volcanism, graben formation, and metamorphic core complex deformation in northeastern Washington (Holder and Holder, 1988; Parrish and others, 1988; Holder and others, 1989).

Keller Butte suite plutons in the map area include the granite west of Armstrong Mountain, Moses pluton, Coyote Creek pluton, granite porphyry of Condon Spring, porphyritic granodiorite of Manila Creek, and the porphyritic granodiorite of Omak Lake(?). Devils Elbow suite intrusions in the map area include the Swimpotkin Creek pluton and the diorite of Little Moses Mountain. The varied granite near Stepstone Creek is the only Herron Creek suite pluton. The intrusive complex north of Grant Lake consists of a Keller Butte suite pluton that is intimately mixed with a Devils Elbow suite intrusion.

Eig_s

Varied granite near Stepstone Creek (Eocene)--Fine- to medium-grained, massive, and texturally varied leucocratic (color index 5) granite that is present as small bodies near Stepstone Creek between Moses and Little Moses Mountains (Atwater and Rinehart, 1984). It consists of an older phase of medium- to coarse-grained, inequigranular or K-feldspar-phyric, gray to pink, hornblende-biotite quartz monzonite to monzogranite and a younger, fine-grained, gray to brown hornblende-biotite monzogranite or microgranite (Holder and Holder, 1988). Locally, the microgranite is cut by seriate or quartz-K-feldspar phyric granite dikes or plugs. The unit intrudes the diorite of Little Moses Mountain (Eid_s) and cuts the main phase of the Moses Mountain pluton (EPig_m) (Atwater and Rinehart, 1984).

Eimds_s

Swimpotkin Creek pluton (Eocene)--Medium-grained, equigranular, hornblende-biotite quartz monzodiorite and minor quartz diorite, ranging to granodiorite in the eastern parts of the pluton (Singer, 1984). Average composition of the quartz monzodiorite (color index 10-25) is 50 percent plagioclase, 20 percent K-feldspar, 15 percent quartz, and 15 percent hornblende and biotite (Gulick, 1987). Some of the hornblende crystals contain pyroxene cores. Accessory minerals include sphene (as much as 1 percent of the total rock), apatite, and magnetite. The Swimpotkin Creek pluton contains numerous pendants of layered para(?)gneiss (Pzhm) and inclusions of gneiss, hornblende gabbro, and diorite, particularly along the west-central part of the pluton. Metamorphic grade of the inclusions and pendants is sillimanite zone of the amphibolite facies. The inclusions may be banded gneisses (Tonasket Gneiss) of the Okanogan metamorphic core complex.

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The Swimptkin Creek pluton is generally massive, but it is locally foliated and lineated. The north-northwest-trending lineation is defined by the alignment of tabular hornblende crystals. It is parallel to the prominent lineation in the metamorphic rocks of the Okanogan metamorphic core complex. The pluton intrudes cataastically deformed, amphibolite-facies metamorphic rocks of the Okanogan metamorphic core complex. Along the southern margin, the pluton has been cataastically deformed along with the gneissic rocks that it intrudes.

The Swimptkin Creek pluton was informally named by Fox and others (1976) and referred to as the hornblende-bearing granitoid rocks of Swimpktin Creek by Atwater and Rinehart (1984). Early workers described rocks of the Swimpktin Creek pluton as diorite (Pardee, 1918) or granodiorite (Newcomb, 1937) and suggested that they were a late differentiate of the "Colville Batholith".

Some workers believe the Swimpktin Creek pluton is younger than the Moses pluton (Newcomb, 1937; Fox and others, 1976, 1977), but others believe that the Moses pluton includes blocks of the Swimpktin Creek pluton and is therefore slightly older or roughly contemporaneous with the Moses pluton (Singer, 1984; Atwater and Rinehart, 1984). The pluton has yielded concordant K-Ar ages of 49.4 ± 1.5 Ma and 45.3 ± 1.1 Ma (hornblende) and 49.2 ± 1.5 Ma and 49.5 ± 1.2 Ma (biotite) (Atwater and Rinehart, 1984).

Eid_l

Diorite of Little Moses Mountain (Eocene)--Fine- to medium-grained, massive hornblende diorite in a small exposure in the valley of Stepstone Creek between Moses Mountain and Little Moses Mountain. The diorite intrudes the main phase of the Moses pluton (EPig_m) and is cut by dikes of the varied granite near Stepstone Creek (Eig_s) (Atwater and Rinehart, 1984). The unit is probably part of the Devils Elbow suite, but it contains more hornblende and less biotite than other members of the suite (Holder and Holder, 1988)

Eic_g

Intrusive complex north of Grant Lake (Eocene)--A complex mixture of porphyritic dacite, medium-grained biotite-hornblende diorite, and medium-grained biotite granite. Both the diorite and granite contain partially digested pieces of porphyritic dacite. The diorite also contains sparse inclusions of Coyote Creek pluton granite (EPig_c). All three units in the intrusive complex are cut by closely spaced faults of diverse orientation that postdate emplacement (Atwater and Rinehart, 1984).

The granite correlates with part of the biotite-bearing quartz monzonite of Orazulike (1982). The porphyritic dacite and biotite-hornblende diorite are probably Devils Elbow suite intrusions, and the biotite granite is part of the Keller Butte suite.

EPig_a

Granite west of Armstrong Mountain (Eocene-Paleocene?)--Fine- to medium-grained, homogeneous, equigranular, leucocratic biotite granite and granodiorite. The granite cuts the Coyote Creek pluton and is intruded by biotite-hornblende porphyritic dikes similar to those in the intrusive complex north of Grant Lake. A K-Ar biotite age of 52.5 ± 1.3 Ma is reported for this unit (Singer, 1984; Atwater and Rinehart, 1984).

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EPig_m, EPig_{mc}, EPia_{mw}

Moses pluton (Eocene-Paleocene?)--A composite pluton of leucocratic granite to granodiorite (Singer, 1984). It extends north and east of the map area into the Oroville, Republic and Nespelem 1:100,000-scale quadrangles (Atwater and Rinehart, 1984; Gulick, 1987; Holder and Holder, 1988; Stoffel, 1990a, 1990b; Joseph, in press). The Moses pluton has been subdivided into three roughly coeval phases:

EPig_m

Main phase--Coarse-grained, leucocratic (color index 2-5), white to gray, massive granite, generally equigranular but locally containing zones of seriatel porphyritic K-feldspar phenocrysts (1-2 cm). It consists of 25 percent dark-gray anhedral quartz, 30-40 percent subhedral microcline with abundant inclusions of zoned plagioclase crystals, 30-40 percent subhedral plagioclase (oligoclase), and less than 5 percent brown subhedral biotite and minor magnetite, as well as sparse secondary and primary(?) muscovite (Singer, 1984; Atwater and Rinehart, 1984).

The main phase granite is locally mylonitically deformed and has a northwest-trending lineation parallel to the lineated rocks in the Okanogan metamorphic core complex. In the penetratively deformed rocks, quartz grains are recrystallized and display undulatory extinction, and biotite is commonly smeared around microcline and plagioclase grains. The main phase grades into the Clark Creek phase. The gradational zone is as much as 1.5 km wide.

EPig_{mc}

Clark Creek phase--East-trending body of massive, medium-grained, leucocratic granite to granodiorite. The granodiorite consists of 20-30 percent anhedral quartz, 15-30 percent anhedral to subhedral orthoclase, 30-50 percent subhedral plagioclase (oligoclase and anorthite), 1-3 percent biotite, and accessory sphene, apatite, magnetite, and muscovite. The orthoclase is commonly poikilitic and has small, round inclusions of plagioclase and biotite. The quartz has been partially recrystallized (Singer, 1984).

The Clark Creek phase lies between the main phase and the aplitic to pegmatitic Whitelaw phase of the Moses pluton. This phase locally contains weakly porphyritic zones and zones of penetrative deformation; development of the mylonitic fabric increases to the west.

Contact relations between the Clark Creek phase and the Swimpkin Creek pluton (Eimd_s) are ambiguous; Atwater and Rinehart (1984, p. 5) noted that "thin dikes of probable Clark Creek phase cut and include rocks of the Swimpkin Creek pluton near the eastern edge of their mutual contact." Newcomb (1937) thought that the Clark Creek phase (his leuco-granite) was intruded by the Swimpkin Creek pluton (his granodiorite). In many places, mixed contacts between the units suggest that the two plutons may be roughly contemporaneous.

One K-Ar biotite age of 49.4 ± 1.2 Ma is reported for the Clark Creek phase (Atwater and Rinehart, 1984). Because 50 Ma K-Ar ages are also reported from other Keller Butte suite plutons that have also yielded older fission-track ages, the 49 Ma age from the Clark Creek phase should be considered a minimum age.

EPi_a_{mw}

Whitelaw phase--Leucocratic granite with abundant dikes and pods of aplite-alaskite-pegmatite. The granite consists of 30-50 percent anhedral to subhedral quartz, 30-40 percent orthoclase, and 15-30 percent subhedral plagioclase, and minor amounts of muscovite, biotite, and garnet. The orthoclase varies in size and is commonly poikilitic and has myrmekitic inclusions of plagioclase (Singer, 1984).

The contact between the Whitelaw and Clark Creek phases of the Moses pluton are gradational, commonly over tens of meters. Contacts between the Whitelaw phase and the Coyote Creek pluton are sharp, and the Coyote Creek pluton is cut by a Whitelaw dike at one locality (Atwater and Rinehart, 1984).

EPi_g_c, EPi_a_c

Coyote Creek pluton (Eocene-Paleocene?)--Light-gray, medium- to coarse-grained, leucocratic (color index 3-5), porphyritic, biotite granite and granodiorite containing 3-7 percent euhedral K-feldspar megacrysts that are typically 5 to 15 cm long. Average composition is approximately 20 percent anhedral quartz, 15 percent euhedral to subhedral K-feldspar, 60 percent subhedral plagioclase (oligoclase), and 5 percent subhedral biotite. Minor constituents include muscovite, sphene, zircon, allanite, and magnetite (J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988). The megacrysts of K-feldspar are commonly poikilitic and have small inclusions of quartz, plagioclase, and biotite.

From north to south, the grain size of the pluton grades from medium grained and sparsely megacrystic to coarse grained and megacrystic. The megacrystic rocks contain distinctive round quartz crystals (Singer, 1984). In Hopkins Canyon the Coyote Creek pluton is alaskitic and commonly brecciated and is delineated by the symbol EPi_a_c.

Northwest of Kartar Creek, at the contact with the Boot Mountain complex (KJmi_b) (T. 32 N., R. 28 E.), the Coyote Creek pluton contains more mafic minerals and is weakly foliated (as defined by concordantly aligned biotite and ellipsoidal quartz grains). Sparse bands of mylonitic foliation and lineation are preserved along the northwest margin of the pluton. They are discordant with the mylonitic fabric in the rocks of the Okanogan metamorphic core complex.

On the southeast margin of the Coyote Creek pluton (T. 31-32 N., R. 30 E.) along the contact with the Boot Mountain complex (KJmi_b), the Coyote Creek is cut by swarms of dacite dikes in the hypabyssal intrusive suite of Cody Lake (Eida_c). One dike of the Whitelaw phase of the Moses pluton apparently cuts the Coyote Creek 3.2 km north of Armstrong Mountain. The Coyote Creek is also cut by a dike of the granite west of Armstrong Mountain (EPi_g_a). Diorite in the intrusive complex north of Grant Lake (Eic_g) contains inclusions of the Coyote Creek pluton. The Boot Mountain complex is cut by the Coyote Creek east of Omak Lake (Atwater and Rinehart, 1984).

K-Ar biotite ages of 50.3 ± 1.5 Ma (Fox and others, 1976) and 51.1 ± 1.3 Ma (Atwater and Rinehart, 1984) are reported for the Coyote Creek pluton. They are probably metamorphic ages that represent thermal reheating during intrusion of the younger Devils Elbow suite and Herron Creek suite plutons.

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EPig_{cs}

Granite porphyry of Condon Spring (Eocene-Paleocene?)--Porphyritic biotite granite composed of large K-feldspar phenocrysts, rounded to oblate quartz crystals, and still smaller plagioclase crystals set in a fine-grained groundmass. The granite contains primary white mica and numerous masses of aplite. The unit crops out at the mouth of Coyote Creek near Condon Spring and is distinguished from the Coyote Creek pluton (EPig_c) by its fine-grained groundmass and fewer phenocrysts. Concordant K-Ar ages of 50.3 ± 0.4 Ma (white mica) and 50.4 ± 0.4 Ma (biotite) are reported for this unit (B. F. Atwater, USGS, written commun., 1987). Rb-Sr ages of 50.1 ± 0.7 Ma (biotite-whole rock pair) and 58.8 ± 1.1 Ma (white mica-whole rock pair) are also reported by R. Fleck (USGS, oral commun., 1988).

EPigd_m

Porphyritic granodiorite of Manila Creek (Eocene-Paleocene?)--Massive to weakly foliated, light- to medium-gray (color index 7-15), medium- to fine-grained, porphyritic biotite granite and granodiorite with subhedral, subequant K-feldspar megacrysts. Hornblende is rare. The unit locally contains abundant xenoliths of metasedimentary rocks and pancake-shaped inclusions of mafic rocks, as much as 1 m long (Broch, 1979). West of Panama Canyon (T. 32 N., R. 30 E.), the unit is riddled with swarms of porphyry dacite dikes of the hypabyssal intrusive suite of Cody Lake (Eida_c).

The porphyritic granodiorite of Manila Creek is correlative with the Colville granodiorite of Broch (1979), the porphyritic granodiorite of Carlson (1984), and parts of the biotite-bearing granodiorite of Orazulike (1982). Carlson (1984) considered the porphyritic granodiorite to be an older, outer phase of the Keller Butte pluton.

No radiometric ages are reported for the porphyritic granite of Manila Creek. Outside the map area, the granite of Swawilla Basin, which has yielded a K-Ar biotite age of 58.8 ± 2.2 Ma (Atwater and Rinehart, 1984), cuts the Manila Creek unit.

EPigd_o

Porphyritic granodiorite of Omak Lake (Eocene-Paleocene?)--Coarse-grained, generally porphyritic biotite granodiorite (color index 7-10) containing pink and gray K-feldspar megacrysts (Atwater and Rinehart, 1984). J. W. Goodge and V. L. Hansen (formerly USGS, written commun., 1988) report an average composition of 25 percent quartz, 30 percent K-feldspar, 35 plagioclase, and 10 percent biotite. Minor constituents include hornblende, sphene, allanite, epidote, and iron oxide. This unit contains inclusions of hornblende-biotite amphibolite and is cut by alaskite, particularly along the contact with the Salmon Creek Schists and Gneisses (pjhm_s). The inclusions are stretched parallel to the foliation. Sphene and hornblende contents increase near the inclusions (Atwater and Rinehart, 1984). The unit forms two intrusions southwest of Omak Lake, and it is characterized by a flow foliation defined by elongate euhedral quartz and plagioclase, as well as by aligned biotite and K-feldspar phenocrysts.

The porphyritic granodiorite of Omak Lake is correlative with parts of the K-feldspar megacrystic biotite granodiorite of Hansen (1983) and may be correlative to the porphyritic granodiorite of Manila Creek (EPigd_m). A K-Ar biotite age of 53.4 ± 1.3 Ma has been reported (Atwater and Rinehart, 1984). The Eocene or Paleocene age of the unit is queried owing the proximity of many pre-Tertiary intrusives to the west and the possibility that the 53 Ma K-Ar age is reset.

Tertiary-Cretaceous Intrusive Rocks

TKigd

Granodiorite near Victor Spring (early Tertiary or Cretaceous?)--Biotite granodiorite and granite containing tabular white or pink K-feldspar phenocrysts. Grain size and color index are varied. The unit is locally weakly to moderately foliated, particularly near biotite-rich schlieren zones. It crops out south of the Columbia River near Victor Spring (T. 30 N., R. 28 E.).

Mesozoic Intrusive RocksKig_v, Kia_v

Equigranular granite of Virginia Lake (Cretaceous)--Stocks of leucocratic granite that lie along a 40-km-long southeast trend from east of Malott to the south flank of Whitmore Mountain near the Columbia River (T. 30-31 N., R. 29 E.) The granite is typically coarse grained; however, medium- to fine-grained zones are present in the western exposures. Rocks east of Malott (Kia_v) are leucocratic, fine grained, and aplitic. The eastern part of this unit contains mafic inclusions and appears to grade into the Boot Mountain complex. South of Omak Lake, the equigranular granite of Virginia Lake contains inclusions of hornblende gabbro and intrudes the Reed Creek quartz diorite gneiss (Mzog_g) (Atwater and Rinehart, 1984).

Fritz (1978) named the largest exposure of the equigranular granite of Virginia Lake (north of Soap Lake) the Soap Lake quartz monzonite and described the unit as leucocratic, medium- to coarse-grained quartz monzonite and granite containing 10-30 percent plagioclase, 30-50 percent quartz, 30-50 percent K-feldspar, 0-15 percent biotite, with chlorite, muscovite, sericite, zircon, apatite, epidote, allanite, and opaque minerals. Undulatory extinction in strained quartz from samples near Soap Lake valley suggest postcocrystalline deformation (Fritz, 1978).

Two K-Ar biotite ages, 74.9 ± 0.5 Ma and 64.9 ± 0.3 Ma, are reported from coarse-grained rocks in the equigranular granite of the Virginia Lake (B. F. Atwater, USGS, written commun., 1987).

The four stocks may be contemporaneous. This unit may be correlative with the Pogue Mountain quartz monzonite (Kiqm_p) (Menzer, 1983). Both have been described as intensely disintegrated. The Virginia Lake may also be contemporaneous with the Conconully pluton which it, in part, resembles.

Kigd_s

Granodiorite of Soap Lake Mountain (Cretaceous?)--Gray (color index 10-12), medium-grained, equigranular biotite granodiorite with minor hornblende and sphene that contains abundant xenoliths of metamorphic and mafic plutonic rocks, as well as autoliths and dikes. Rocks along the borders of the pluton are characterized by a steeply dipping flow foliation. Contact relations between the granodiorite of Soap Lake Mountain and the Cretaceous equigranular granite of Virginia Lake (Kig_v) are ambiguous, suggesting that the two units are co-magmatic (Atwater and Rinehart, 1984). Therefore, a Cretaceous age is suspected for the granodiorite of Soap Lake Mountain.

An approximately 3-mi² area of the granodiorite of Soap Lake Mountain west of BJ Lake (T. 32 N., R. 25 E.) was described by Fritz (1978) as leucocratic porphyroblastic granodiorite gneiss, which he correlated with the Leader Mountain porphyroblastic granodioritic gneiss of Menzer (1964). The

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southern outcrop of the granodiorite of Soap Lake Mountain was likewise mapped as the Leader Mountain granodioritic gneiss by Fritz (1978); however, Atwater and Rinehart (1984) make no mention of gneissic foliation (aside from flow foliation) and did not recognize any K-feldspar porphyroblasts in the unit.

The granodiorite of Soap Lake Mountain may be correlative in part with the granite of Felix Creek (Kig_f) (B. F. Atwater, USGS, written commun., 1987). A K-Ar biotite age of 54.8 ± 0.4 Ma is reported for the granodiorite (B. F. Atwater, USGS, written commun., 1987). Fritz correlated the northeasternmost exposure of the granodiorite of Soap Lake Mountain, from which the K-Ar age was derived, with the Reed Creek quartz dioritic orthogneiss of Menzer (1964) and mapped its northeastern contact with the granite of Felix Creek (Kig_f) as a fault.

Kig_f

Granite of Felix Creek (Cretaceous?)--Medium-grained, foliated granite (orthogneiss?) which has a low, but varied color index that ranges from 2 to 10 (Atwater and Rinehart, 1984). The unit contains biotite schlieren that form thin streaks to banded layers (as much as 1 m thick), in the granite. Large inclusions of Salmon Creek Schists and Gneisses (pjhm_s) are found locally and are common along the east side of the intrusion. The contact between the granite of Felix Creek and the Salmon Creek Schists and Gneisses is gradational.

The contact between the granite of Felix Creek and the porphyritic granite and granodiorite of Cook Lake (Kia_c) is also gradational and ambiguous, which suggests that the two intrusions are co-magmatic (Atwater and Rinehart, 1984). The granite of Felix Creek may be correlative in part with the granodiorite of Soap Lake Mountain (Kig_d). The granite of Felix Creek has also been called the Patterson Lake gneiss (Snook, 1962; Fritz, 1978).

Kia_c

Porphyritic granite and granodiorite of Cook Lake (Cretaceous?)--Leucocratic (color index 3-7), medium-grained, porphyritic biotite granite and granodiorite composed of elongate K-feldspar megacrysts and 0.5-2-cm phenocrysts and surrounded aggregates of quartz. The unit contains biotite and minor sphene, garnet, hornblende, tourmaline, and epidote. Biotite is bimodal in size in the north and forms wormy books in the south. Garnet-bearing aplite and pegmatite dikes are common (Atwater and Rinehart, 1984). The unit forms a south-southeast-trending belt of discontinuous exposures about 8 km west of Omak Lake, extending from Cameron Lake on the north to Goose Lake on the south. The Columbia River Basalt Group unconformably overlies the pluton.

Foliation in the granite and granodiorite is developed to various degrees near contacts with the granite of Felix Creek (Kig_f) and the Salmon Creek Schists and Gneisses (pjhm_s). The rocks grade into the granite of Felix Creek, suggesting that the two units are co-magmatic (Atwater and Rinehart, 1984). The Cook Lake unit intrudes the Reed Creek quartz diorite gneiss (Mzog). Foliation is parallel to the intrusive contact (Atwater and Rinehart, 1984).

The relations among the Cook Lake unit and other plutonic rocks suggest that it is Cretaceous in age.

OMAK 1:100,000 QUADRANGLE

Kiqm₁

Leader Lake quartz monzonite (Cretaceous)--Fine- to medium-grained quartz monzonite that has approximately equal amounts of quartz, zoned oligoclase, and microcline, approximately 2 percent biotite, and minor magnetite, apatite, sphene, zircon, and primary muscovite. The Leader Lake unit intrudes the Conconully granodiorite (Kigd_c), but may be roughly comagmatic with it; a Rb-Sr mineral isochron age of 81.1 ± 0.8 Ma is reported for samples collected from these two plutons. The Leader Lake quartz monzonite crops out on the knolls southeast of Leader Lake (T. 33 N., R. 25 E.) (Menzer, 1983).

Kigd_c, Kigd_{cm}, Kigd_{cr}

Conconully granodiorite (Cretaceous)--Predominantly medium- to coarse-grained, directionless, leucocratic equigranular granodiorite; subordinate quartz diorite to quartz monzonite; locally porphyritic. The unit is commonly strongly weathered, and many exposures carry a rind of light brownish grus. Plagioclase is typically the most abundant constituent, exceeding quartz by a factor of 2 and K-feldspar by a factor of 3. The plagioclase is generally anhedral to subhedral, but is rarely euhedral; it ranges from calcic andesine to sodic albite and is normally zoned. It is commonly altered to white mica, saussuritic pistacite, and clinozoisite. Quartz is present as interstitial grains, euhedral crystals, glomeroporphyritic clusters, and inclusions in K-feldspar phenocrysts. K-feldspar is generally pink, typically interstitial to plagioclase and quartz, ranges in size from small blebs to megacrysts 5 cm long, and varies from predominantly orthoclase on the west side to microcline on the east. Principal accessory minerals include biotite, green hornblende altered to biotite, magnetite, apatite, sphene, and zircon.

The Conconully granodiorite occupies about 200 km² in the northwestern part of the Omak 1:100,000-scale quadrangle (T. 34 N., R. 24 E.) and the southwestern part of the Oroville 1:100,000-scale quadrangle. It intrudes the Salmon Creek Schists and Gneisses (pjhm_s), Summit-Frazer trondhjemite gneiss (Kjog), the Leader Mountain granodioritic gneiss (Mzog_l), and the granodioritic gneiss near Granite Mountain (Kjog). The Conconully granodiorite is distinguished, with some difficulty, from the Leader Mountain granodioritic gneiss by sparseness of K-feldspar phenocrysts larger than 1 cm, lower color index, and scarcity of amphibole.

Three phases are recognized in the Conconully granodiorite:

Kigd_c

Main phase--Most widespread and best fitting the above description of the pluton as a whole; subporphyritic in part.

Kigd_{cm}

Mineral Hill phase--Contains sparse K-feldspar megacrysts as much as 5 cm long and local green hornblende in a groundmass that is otherwise similar to the main phase. This phase is equivalent to the Mineral Hill granodiorite of Goldsmith (1952) and was previously called the Little Peacock Mountain porphyritic granodiorite phase by Menzer (1964). This phase is gradational with the main phase.

Kigd_{cr}

Ritchie Ridge phase--Mineral assemblage similar to that of the main phase but having a distinctly finer grained texture attributable to more rapid cooling at a higher level. It is in fault contact with the main phase on two sides; the third side's contact is concealed (Menzer, 1983).

Eight age determinations have been made on the Conconully granodiorite. The Rb-Sr isochron reported by Menzer (1970) is from the map area, but the remaining seven dates are from the adjacent Oroville quadrangle.

<u>Age</u>	<u>Type of analysis</u>	<u>Source of data</u>
89 ± 9 Ma	Fission track, apatite	Menzer (1970)
84 ± 8 Ma	Fission track, sphene	Menzer (1970)
90 ± 20 Ma	Pb-alpha, zircon	Menzer (1970)
81.1 ± 0.8 Ma	Rb-Sr isochron	Menzer (1970)
81.2 ± 2.4 Ma	K-Ar hornblende	Berry and others (1976)
78.8 ± 2.4 Ma	K-Ar hornblende	Berry and others (1976)
72.7 ± 4.6 Ma	K-Ar hornblende	Rinehart and Fox (1976)
62.4 ± 2.2 Ma	K-Ar hornblende	Rinehart and Fox (1976)

Kiqm_p

Pogue Mountain quartz monzonite (Cretaceous?)--Massive, directionless, medium- to coarse-grained, anhedral quartz monzonite and granite; locally strongly disintegrated. The rocks are composed of more than 40 percent quartz, 20-30 percent plagioclase (oligoclase), 30-40 percent K-feldspar, and minor biotite, hornblende, rutile, opaque minerals, zircon, muscovite, apatite, sphene, and allanite. The anhedral quartz is interstitial to plagioclase and locally replaces it. Plagioclase is locally replaced by calcite, quartz, and sericite. The K-feldspar consists of subhedral microcline microperthite, which is interstitial to and replaces plagioclase and quartz (Menzer, 1983; Sims, 1984).

The Pogue Mountain quartz monzonite is an elliptical 13-km² intrusion on the south slope of Pogue Mountain 5 km west of Omak. It is in fault contact with or intrudes the Salmon Creek Schists and Gneisses (pjhm_s) and the Reed Creek quartz dioritic orthogneiss (Mzog_r) and is unconformably overlain by Eocene dacite flows (Evd) (Menzer, 1983; Sims, 1984).

Much of the Pogue Mountain quartz monzonite is hydrothermally altered. Quartz and calcite veins and veinlets are common, as are pyrite and manganese oxides (rhodochrosite). Lead, zinc, and gold minerals occur locally. Altered quartz monzonite and fine-grained rhyolite porphyry dikes cut the main phase quartz monzonite in places (M. Herdrick, Herdrick Mining Co., oral commun., 1987).

The Pogue Mountain quartz monzonite (Menzer, 1983; Sims, 1984) may be correlative with the equigranular granite of Virginia Lake (Kig_v) because the two intrusions are compositionally and texturally similar and both are strongly disintegrated in places (Atwater and Rinehart, 1984). Menzer (1983) believed that a Rb-Sr biotite age of 82.6 Ma reported from the Reed Creek quartz diorite gneiss (Mzog_r), 3 km south of Pogue Mountain, is a reset age that represents the age of intrusion of the Pogue Mountain quartz monzonite. If so, the Pogue Mountain quartz monzonite and the Conconully granodiorite (Kigd_c) are probably contemporaneous.

Kia_e

Evans Lake pluton (Cretaceous)--The Evans Lake pluton is an elliptical, northwest-trending intrusion of granodiorite and quartz monzonite along the northern edge of the map area, west of Riverside. The pluton consists of an interior phase of medium- to coarse-grained porphyritic granodiorite and quartz monzonite and a discontinuous border phase of fine- to medium-grained granodiorite that locally grades into diorite. The two phases are separated by sharp to gradational contacts.

The interior phase is dominantly porphyritic granodiorite. Euhedral to subhedral K-feldspar (microcline) megacrysts, from 12 mm to 8 cm long, are riddled with subhedral to bleb-like inclusions of plagioclase, quartz, biotite, myrmekite, perthite, and microcline. Plagioclase (chiefly oligoclase) is weakly to moderately altered to epidote and sericite. Quartz is present as subhedral phenocrysts, annealed grains, and very fine subgrains. Biotite is present as both coarse-grained individual crystals and fine-grained flakes in zones, clusters, and streaks. Accessory minerals include ferrohastingsite, hornblende, epidote, allanite, sphene, apatite, tourmaline, and rutile (Sims, 1984).

The fine- to medium-grained border phase lacks the microcline megacrysts and has more chlorite and less biotite than the main phase. The texture varies from hypidiomorphic-granular to crystalloblastic. Secondary minerals include chlorite, calcite, sericite, and kaolin (Sims, 1984).

The Evans Lake pluton is in fault contact with and intrudes the Cave Mountain Formation (T mm, T cb) and is unconformably overlain by Eocene dacite flows (Evd). It intrudes the metamorphic complex of Conconully in the Oroville 1:100,000-scale quadrangle to the north (Stoffel, 1990a). Bent plagioclase twin lamellae and blastomylonitic textures in the border-phase granodiorite indicate that the Evans Lake pluton was cataastically deformed and recrystallized after magmatic crystallization (Sims 1984).

A K-Ar biotite age of 88.2 ± 2.8 Ma is reported from the Evans Lake pluton (Rinehart and Fox, 1976), but the biotite age should be considered a minimum age because hornblende in the intrusion is too altered to date.

Kigd_g

Granodiorite near Gaviota Bend (Cretaceous?)--Directionless to weakly foliated, medium-grained biotite granodiorite, tonalite, and minor quartz diorite; locally contains euhedral K-feldspar megacrysts. The unit forms three small outcrops south of the Columbia River at Gaviota Bend (T. 29 N., R. 27 E.).

Kjigb,

Red Shirt gabbro (Cretaceous-Jurassic)--Massive gabbro and diorite composed chiefly of labradorite and green hornblende. The rocks are poorly exposed in the foothills on the east side of the Methow Valley west of the Red Shirt mine (T. 33 N., R. 23 E.) (Menzer, 1982, 1983). Most of the rocks are characterized by magmatic textures, but along the Red Shirt thrust fault, the rocks have been strongly sheared and have undergone retrograde metamorphism and alteration to epidote and chlorite (A. M. Frey, Univ. of Pittsburgh, written commun., 1988).

The Red Shirt gabbro is part of the Frazer Creek complex (Barksdale, 1975), which also includes hornblende diorite and hornblende quartz diorite just west of the map area in the Twisp 1:100,000-scale quadrangle (Bunning, 1990). Quartz diorite from the Frazer Creek complex in the Twisp 1:100,000-scale quadrangle has yielded K-Ar ages ranging from 139 to 103 Ma (Bunning, 1990). Therefore, the Frazer Creek complex and the Red Shirt gabbro are probably Late Jurassic to Early Cretaceous in age.

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Mzibg_d

Darling Lake gabbro (Mesozoic?)--Medium- to coarse-grained, hypidiomorphic hornblende metagabbro and minor (5 percent) medium- to coarse-grained, predominantly anhedral hornblende-plagioclase peridotite (Menzer, 1983). This stock, which lies 2 mi north of Leader Mountain (T. 33-34 N., R. 25 E.), intrudes paragneisses in the Salmon Creek Schists and Gneisses (pjhm_s).

Intrusive Rocks in the Summit-Frazer Complex

The western one-third of the Omak 1:100,000-scale quadrangle is comprised of a heterogeneous assemblage of directionless to gneissic leucogranodiorite and tonalite, layered metamorphic rocks, and complexes of mixed metamorphic and igneous rocks. These rocks have been assigned to the Okanogan batholith complex (Barksdale, 1975), the Okanogan Range (Menzer, 1983), and the Okanogan Complex (Royse, 1965), but no widely accepted name has emerged from the literature. In order to eliminate confusion with the Okanogan metamorphic core complex to the east, these rocks are herein referred to as the Summit-Frazer complex, after the two streams that cut the complex in the northwestern part of the map area. The foliated rocks and mixed igneous/metamorphic rocks in the Summit-Frazer complex are described in the section titled Metamorphic rocks in the Summit-Frazer complex. The directionless rocks are described below.

Kjit

Summit-Frazer trondhjemitic gneiss, tonalite (Cretaceous or Jurassic?)--Light gray to white, medium-grained, directionless to weakly foliated, leucocratic tonalite (trondhjemite) composed of approximately 60-65 percent oligoclase, 10-50 percent (ave. 30) quartz, less than 5 percent K-feldspar, and 5-10 percent biotite. Accessory minerals include epidote, muscovite, magnetite, titanite, zircon, and apatite.

The Summit-Frazer trondhjemitic gneiss, tonalite, includes the Summit Creek pluton of Barksdale (1975), which he described (p. 9) as "the western limit of the large body of a faintly gneissic rock that Menzer (1964, p. 22) mapped as trondhjemitic gneiss." The Summit Creek pluton is primarily granoblastic and contains recrystallized elongate mosaics of quartz. A large portion of this pluton lies west of the map area in the Twisp 1:100,000-scale quadrangle, where it intrudes the Leecher Metamorphics (pKhm_p) parallel to the foliation in the metamorphic rocks, forming sills from 5 to more than 100 m thick. K-Ar biotite ages of 100.6 ± 1.1 Ma and 100.0 ± 1.1 Ma have been reported for the Summit Creek unit west of the map area (V. R. Todd, USGS, written commun., 1988), but they are probably reset, thus minimum ages.

The Summit-Frazer trondhjemitic gneiss was originally described by Menzer (1982, 1983) and included both gneissic and directionless tonalite. Subsequent mapping (J. R. Wilson, formerly USGS, written commun., 1987) delineated the largely directionless core of the pluton (Kjit), thereby differentiating it from the foliated tonalite (Kjog) of the Summit-Frazer complex. The Summit-Frazer trondhjemitic gneiss, tonalite, is probably equivalent to the trondhjemite of Doe Mountain on the Robinson Mountain 1:100,000-scale quadrangle (Stoffel and McGroder, 1990).

Kjigd

Granodiorite near Brewster (Cretaceous or Jurassic?)--Directionless, K-feldspar-bearing granodiorite of the Summit-Frazer trondhjemitic gneiss that crops out near Brewster (T. 30-31 N., R. 24 E.). Except for a higher K-feldspar content, this unit is compositionally similar to the Summit-Frazer trondhjemitic gneiss, tonalite (Kjt), to the north (J. R. Wilson, formerly USGS, written commun., 1987).

Kjigd_m

Megacrystic granodiorite near Bridgeport (Cretaceous or Jurassic?)--Directionless megacrystic K-feldspar-bearing porphyritic granodiorite exposed southeast of Brewster and north of Bridgeport (T. 29-30 N., R. 24-25 E.) (J. R. Wilson, formerly USGS, written commun., 1987). The megacrystic granodiorite is compositionally similar to the granodiorite near Brewster, but is distinguished from it by its porphyritic texture.

Kjid

Diorite near Indian Dan Canyon (Cretaceous or Jurassic?)--Diorite and granodiorite breccia and diorite dikes that crop out on both sides of Lake Pateros (Columbia River) southwest of Brewster (T. 30 N., R. 24 E.).

Ultrabasic Rocks

u

Ultrabasic rocks (Mesozoic-Paleozoic)--Three small exposures of ultrabasic rocks are present in the map area. Peridotite is exposed within the Windy Hill quartz dioritic orthogneiss north of Woolloomooloo Creek (T. 34 N., R. 25 E.). Dunite forms a small mass in an elongate body of Salmon Creek Schists and Gneisses 1 mi south of Omak Lake (Atwater and Rinehart, 1984). Serpentinite crops out south of the Red Shirt mine near the west boundary of the map area (A. M. Frey, Univ. of Pittsburgh, written commun., 1988), but it is too small to depict at the 1:100,000 scale of the Omak quadrangle.

pKcs

Calc-silicate rocks near Brown Lake (pre-Cretaceous)--A calc-silicate unit that consists of (1) spotted, pale orange-brown, olive-green, and dark-green structureless calc-silicate granofels composed of megacrystic forsterite in a magnesite/talc/tremolite matrix, (2) foliated, mottled bluish-green and pale orange-brown serpentinized magnesite talc schist composed of antigorite, magnesite, and talc, and (3) garnet-diopside calc-silicate granofels, hornblende schist, and serpentinized carbonate that are cut by garnetiferous pegmatite and aplite dikes. These rocks may have been derived from the metamorphism of dolomitic and argillaceous metasedimentary rocks, but Sims (1984) thought that at least some of the rocks are altered ultrabasic rocks that are located along a thrust fault at the base of the Cave Mountain Formation.

Metamorphic Rocks

Metamorphic Rocks in the Okanogan Metamorphic Core Complex

The Okanogan metamorphic core complex is a 90-km-long by 45-km-wide belt of upper amphibolite-facies metamorphic rocks and orthogneisses that forms most of the northeastern part of the Omak 1:100,000-scale quadrangle and extends north and east into the Oroville, Nespelem, and Republic 1:100,000-scale quadrangles. It is the westernmost of four metamorphic core complexes in the Okanogan highlands of northeastern Washington that occupy the southern end of the Omineca crystalline belt (Figs. 5 and 6).

The Okanogan metamorphic core complex is a heterogeneous assemblage of banded gneiss, schist, and amphibolite, leucocratic granitoid orthogneiss, and directionless granodioritic to monzodioritic plutons (Snook, 1962, 1965; Fox and others, 1976, 1977; Cheney and others, 1982; Orr and Cheney, 1987; Hansen and Goodge, 1988). All metamorphic rocks in the Okanogan complex were assigned to the Tonasket Gneiss by Snook (1962, 1965), but Fox and others (1976) redefined the Tonasket Gneiss to include only the layered metamorphic rocks. The granitoid orthogneisses and plutonic rocks that were excluded from the Tonasket Gneiss were subsequently assigned a variety of informal names.

The rocks in the Okanogan metamorphic core complex have been cataastically deformed and recrystallized to various degrees (Krauskopf, 1938; Waters and Krauskopf, 1941; Snook, 1965; Fox and Rinehart, 1988). Ultramylonitic¹, mylonitic, and protomylonitic rocks form a belt less than 5 km wide along the western and southern margin of the complex. They grade inward into blastomylonitic rocks, which in turn grade into recrystallized, typically nonmylonitic gneiss in the interior of the complex. Mylonitic rocks preserved in synforms in interior parts of the core complex (Gulick, 1987; Fox and Rinehart, 1988) may record a period of ductile deformation that preceded mylonitization and later chloritic brecciation along the west margin of the core complex (Hansen and Goodge, 1988) or may be remnants of a previously continuous mylonitic carapace formed through shearing at the interface between brittle and ductile crust (Fox and Rinehart, 1988).

The metamorphic rocks in the Okanogan core complex are foliated, lineated, folded, and faulted. In general, the dip of the foliation is subhorizontal in the interior of the complex and steeper along the margins of the complex (Fox and Rinehart, 1988). In detail, the attitudes of foliation and layering in the Okanogan metamorphic core complex define three broad, northwest-trending antiforms separated by two narrow, northwest-trending synforms (Fig. 7). Lineations in the recrystallized metamorphic rocks in the interior and eastern parts of the complex are defined by aligned hornblende crystals; they generally trend N60°W. Lineations in the penetratively deformed mylonitic rocks are defined by crushed and smeared-out mineral fragments; they generally trend N60°E. Isoclinal recumbent folds, characterized by large amplitude/wavelength ratios, are common in both the recrystallized and mylonitically deformed rocks. Axes of the folds typically trend northwest and plunge shallowly northwest or southeast. Broad, open folds with northwest-trending axes are also common in the mylonitic rocks. North-northeast-trending, steeply dipping faults and fractures cut the mylonitic rocks, particularly along the west side of the core complex.

¹Cataclastic rock definitions after Higgins (1971):

Ultramylonite--A rock composed of sparse porphyroclasts, typically less than 2 mm in diameter, scattered throughout an aphanitic matrix of finely crushed minerals.

Mylonite--A rock composed of 10 to 50 percent porphyroclasts, typically greater than 2 mm in diameter, in an aphanitic matrix of finely crushed minerals.

Protomylonite--A rock composed of lenticular lithic masses separated by thin films of finely crushed minerals.

Blastomylonite--A rock with a megascopic fabric similar to any of the above, but with a granoblastic matrix of recrystallized minerals instead of finely crushed minerals.

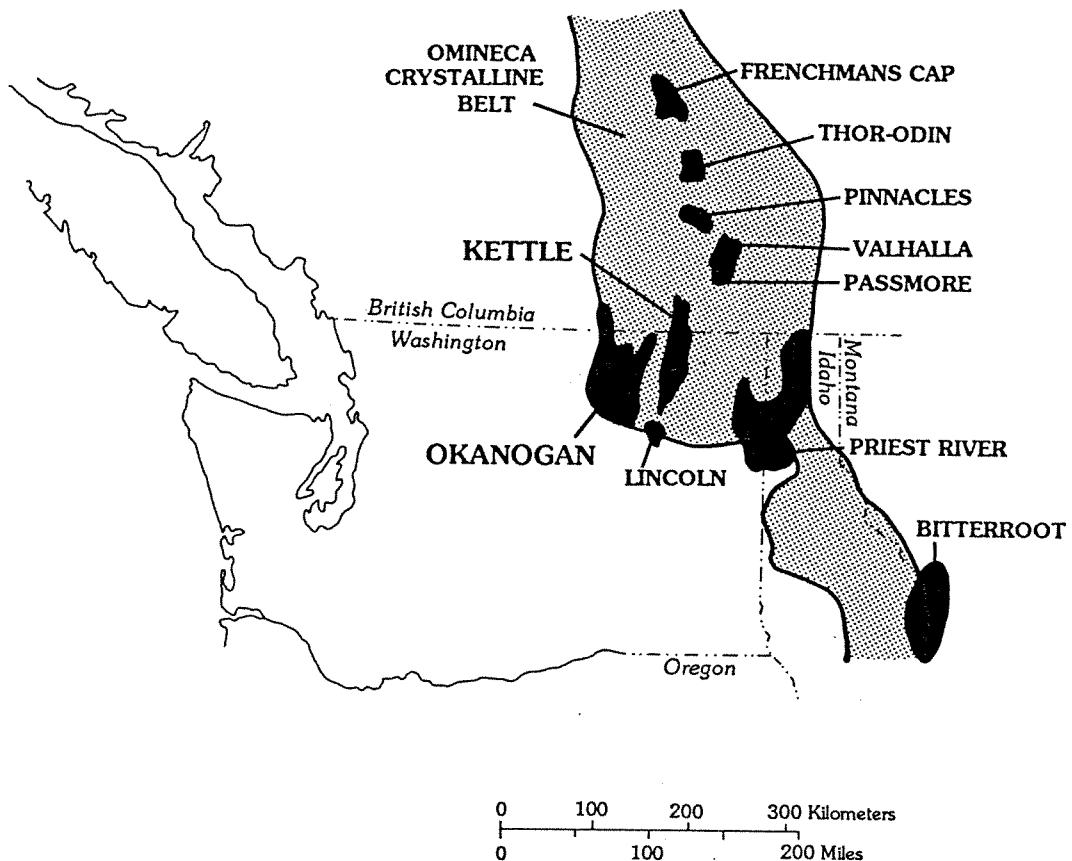


Figure 5. Metamorphic core complexes in the Omineca crystalline belt of northeastern Washington and adjacent areas (after Orr and Cheney, 1987).

The Okanogan metamorphic core complex is bordered on the west by the Okanogan and Omak Lake faults (Snook, 1965). These faults separate the amphibolite-facies metamorphic rocks of the complex from Mesozoic greenschist-facies metasedimentary and metavolcanic rocks, Mesozoic intrusive igneous rocks, and Eocene volcanic and sedimentary rocks.

K-Ar and fission-track ages from the Tonasket Gneiss and the orthogneisses in the Okanogan metamorphic core complex range from 66 Ma to 46 Ma (Fox and others, 1976). These ages suggest that uplift and cooling of the complex began approximately 65 Ma, and that the core complex "cooled slowly through the successive temperature thresholds for sphene, epidote-allanite, hornblende, and finally apatite-muscovite-biotite..." (Fox and others, 1976, p. 1223). Thus, the metamorphic rocks in the Okanogan core complex are all pre-Tertiary in age. Three U-Pb zircon ages between 87 and 100 Ma are reported for the Tonasket Gneiss (Fox and others, 1976) in the Oroville 1:100,000-scale quadrangle.

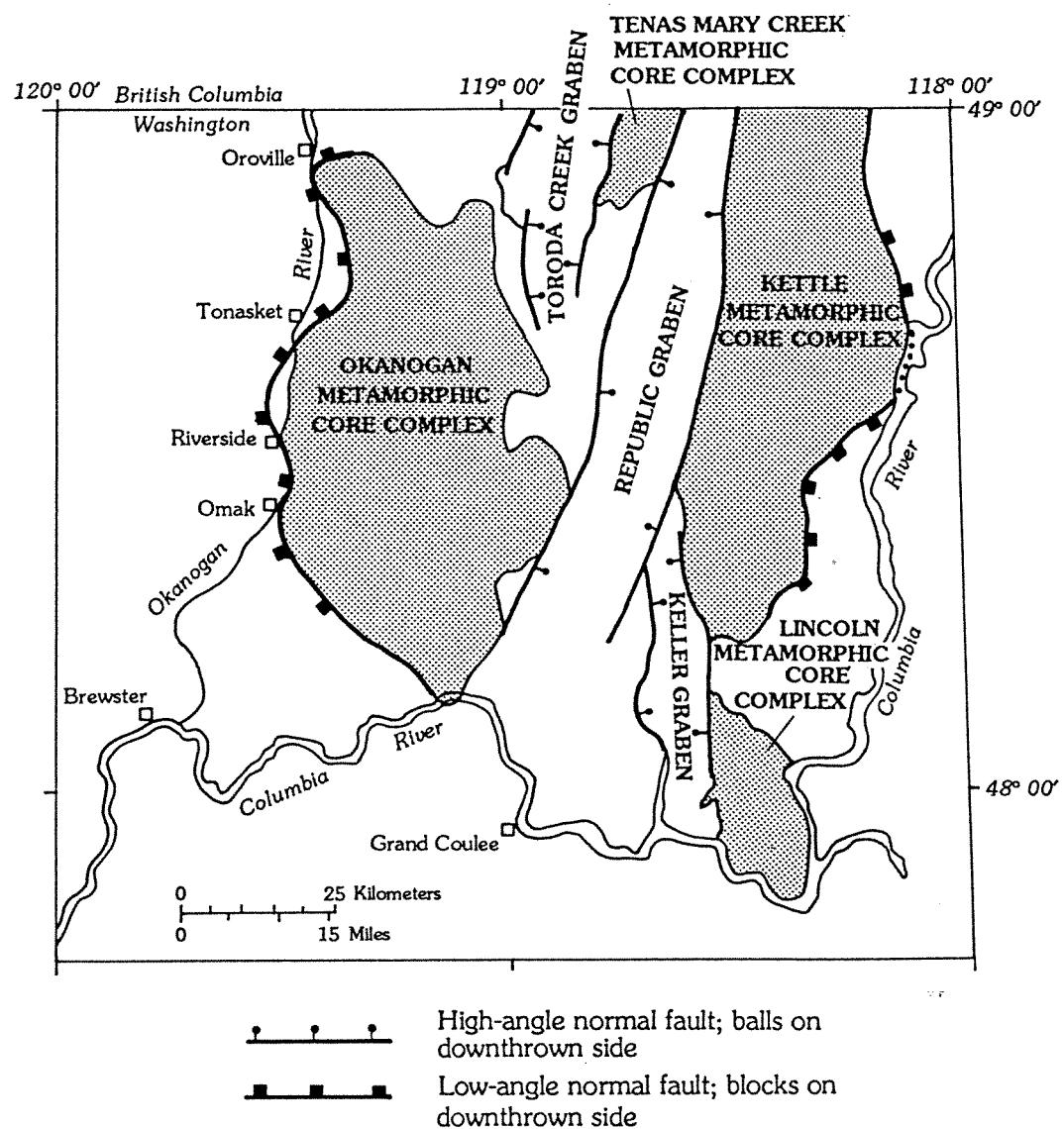


Figure 6. Metamorphic core complexes in the Okanogan highlands of northeastern Washington (after Fox and Rinehart, 1988).

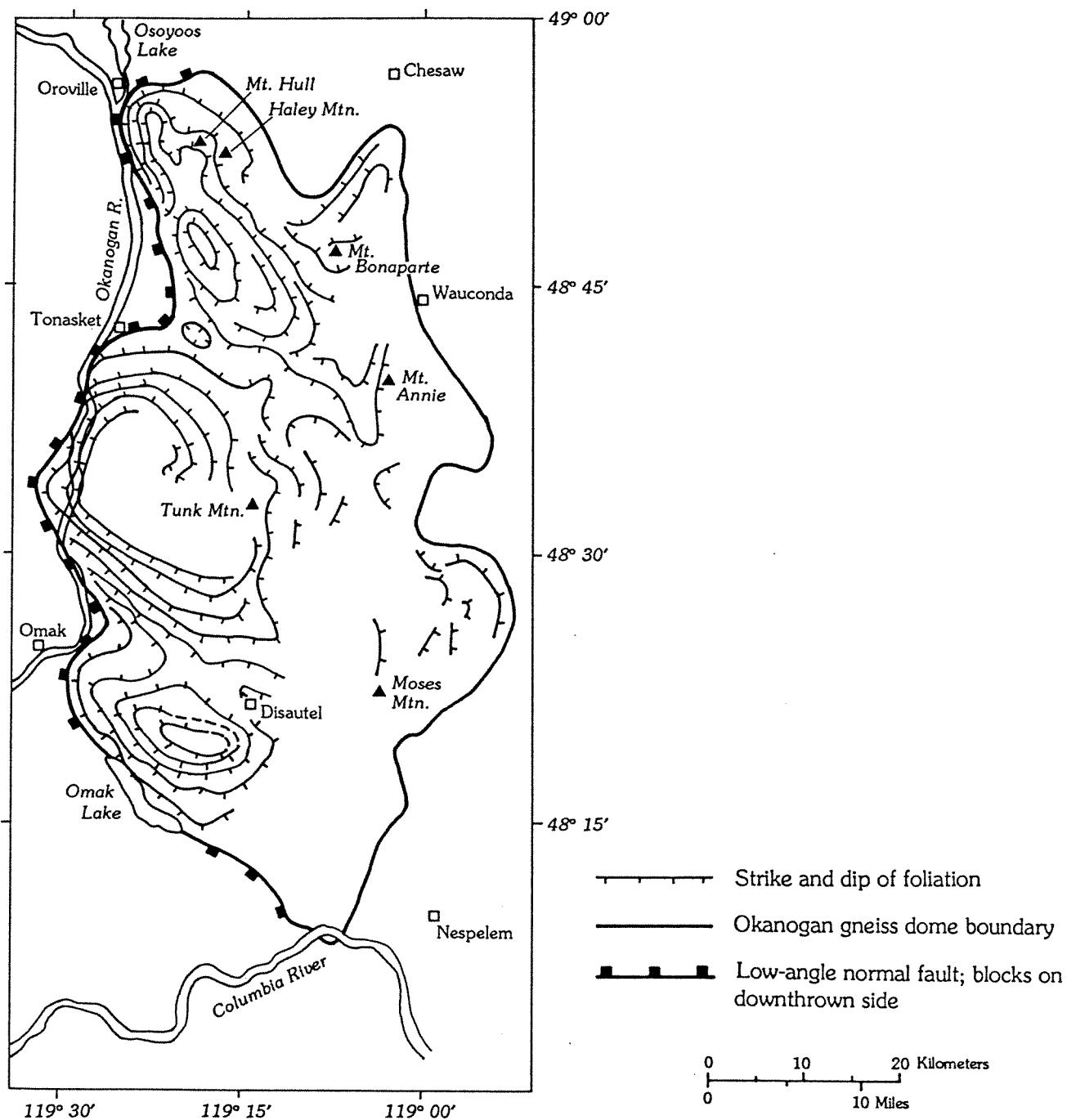


Figure 7. Geologic structures in the Okanogan metamorphic core complex (after Fox and Rinehart, 1988).

Meta-igneous Rocks

pTog_f

Gneissic granodiorite of French Valley (pre-Tertiary?)--Weakly to strongly foliated, light- to medium-gray, medium-grained, equigranular biotite granodiorite gneiss. Near the contact with the gneissic porphyritic granodiorite of Mission Creek (pTog_m), the granodiorite of French Valley contains sparse K-feldspar megacrysts. The average composition of the gneiss is 25 percent quartz, 10 percent K-feldspar, 60 percent plagioclase, and 5 percent biotite (J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988). Hornblende, sphene, apatite, and iron oxides are minor constituents.

Contacts between the gneissic granodiorite of French Valley and the gneissic porphyritic granodiorite of Mission Creek are generally gradational, but xenoliths of the gneissic porphyritic granodiorite of Mission Creek are locally present in the gneissic granodiorite of French Valley. Contacts between the French Valley unit and the Swimpptkin Creek pluton (Eimd_s) are sharp. Near contacts with the older Tonasket Gneiss (pTbg), the gneissic granodiorite of French Valley contains more hornblende than it does away from the contacts (Atwater and Rinehart, 1984).

Textural homogeneity and the presence of mafic inclusions and schlieren and euhedral zircons suggest that the French Valley unit is a metamorphosed pluton (Singer, 1984). Early workers (Snook, 1962, 1965) thought that the gneissic granodiorite of French Valley was part of the Tonasket Gneiss, but Hansen (1983) recognized that the French Valley rocks are a metamorphosed intrusion that cuts the Tonasket Gneiss.

pTog_c

Crawfish Lake tonalite gneiss (pre-Tertiary?)-Gray (color index 10), porphyroclastic biotite and biotite-hornblende tonalite and granodiorite gneiss that consists of plagioclase, quartz, biotite, and minor hornblende and K-feldspar megacrysts (porphyroclasts). Zircon, sphene, allanite, and epidote are common accessory minerals.

The Crawfish Lake tonalitic gneiss consists of two phases that grade into each other, a fine-grained equigranular phase and a medium-grained, weakly porphyritic phase (Singer, 1984). The homogeneous fine-grained phase consists of 20-25 percent quartz, 2-3 percent orthoclase, 50-70 percent plagioclase, 10 percent biotite, and accessory sphene, zircon, hornblende, apatite, and allanite. Foliation is defined by small discontinuous layers of subidioblastic biotite, elongate, xenoblastic quartz grains and equant, xenoblastic plagioclase grains (Singer, 1984). The medium-grained phase is tonalitic to granodioritic in composition. The rocks consist of approximately 20 percent quartz, 5-10 percent K-feldspar, 60-70 percent plagioclase (andesine to oligoclase), 5 percent biotite, 2-4 percent hornblende, and accessory sphene, apatite, zircon, and allanite. The granodioritic rocks contain K-feldspar megacrysts as much as 3 cm across. Gneissic layering, defined by aligned biotite and hornblende crystals and elongate quartz grains, is only weakly developed.

Protomylonitic textures dominate the Crawfish Lake tonalitic gneiss (Singer, 1984). Local thin zones of blastomylonite are oriented subparallel to the pervasive protomylonite fabric (Singer, 1984).

The Crawfish Lake tonalite gneiss intrudes the Tonasket Gneiss. It is cut by the Swimpptkin Creek pluton (Eimd_s). The Crawfish Lake unit may be correlative with the gneissic granodiorite of French Valley (Atwater and Rinehart, 1984) or the gneissic porphyritic granodiorite of Mission Creek.

pTog_m

Gneissic porphyritic granodiorite of Mission Creek (pre-Tertiary?)--Light- to medium-gray, homogeneous, foliated, porphyritic biotite granodiorite composed of 1-5 percent K-feldspar megacrysts (2-8 cm) in an equigranular matrix of quartz, plagioclase, biotite, K-feldspar, sphene, and iron oxides. Average composition is approximately 25 percent quartz, 15 percent K-feldspar, 55 percent plagioclase, and 5 percent biotite (J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988). The Mission Creek contains dikes of aplite, pegmatite, and granite and tabular, rounded, dark inclusions of amphibolite and biotite schist (Atwater and Rinehart, 1984).

The Mission Creek unit is an elongate, cataastically deformed intrusion along the southwestern margin of the Okanogan metamorphic core complex that extends north into the Oroville 1:100,000-scale quadrangle. Penetrative mylonitic foliation and lineation are strongly developed along the southwestern margin of the core complex, but they are less clear to the northeast (Atwater and Rinehart, 1984). The western margin of the intrusion is distinctly layered and has alternating bands of light-gray felsic rocks, gray microporphyroclastic rocks, and black ultramylonitic rocks. The layers are commonly folded into tightly appressed, recumbent S-folds (Fox and Rinehart, 1988).

The Mission Creek unit intrudes the Boot Mountain complex (KJmi_b) and the Tonasket Gneiss (pTbg). Contacts between the Mission Creek unit and the gneissic granodiorite of French Valley (pTog_v) are primarily gradational, but in some places, xenoliths of probable Mission Creek granodiorite are present in the French Valley unit, suggesting that the gneissic granodiorite of French Valley intruded the Mission Creek unit. The Mission Creek unit is intruded by the hypabyssal intrusive suite of Cody Lake (Eida_c).

The gneissic porphyritic granodiorite of Mission Creek is equivalent to part of the Omak Lake K-feldspar megacryst biotite granodiorite of Hansen (1983), the Omak Lake granodiorite gneiss of Singer (1984), and the orthogneiss of Omak Lake of Fox and Rinehart (1988). A K-Ar biotite age of 47.2 ± 1.4 Ma is reported (Atwater and Rinehart, 1984), but it is probably a reset age.

Layered Metamorphic Rocks**pTbg, pTam**

Tonasket Gneiss (pre-Tertiary)--Banded hornblende-biotite gneiss, biotite gneiss, K-feldspar augen gneiss, sillimanite-garnet-muscovite-biotite schist, biotite quartzite, amphibolite, pyroxene calc-silicate gneiss, garnet-bearing alaskite gneiss, and migmatite (Snook, 1965; Atwater and Rinehart, 1984). Principal constituents of the rocks are plagioclase (andesine to oligoclase), K-feldspar (primarily orthoclase), quartz, biotite, hornblende, garnet, and muscovite. Mafic mineral content varies from 10 to 50 percent. Northeast of Wanacut Basin (T. 34 N., R. 28 E.) a small body of amphibolite (pTam) is delineated.

The heterogeneous nature of the gneiss, schist, and amphibolite, and the presence of thin interlayers of marble and calc-silicate rocks suggest that the Tonasket Gneiss was derived from metasedimentary and metavolcanic rocks (Waters and Krauskopf, 1941; Snook, 1965; Fox and others, 1976). However, Cheney and others (1982) and Orr and Cheney (1987) think that the Tonasket Gneiss is part of a compositionally zoned batholith.

The Tonasket Gneiss was originally named by Snook (1965). It was redefined by Fox and others (1976), who restricted the unit to the layered metamorphic rocks in the Okanogan metamorphic core complex.

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The Tonasket Gneiss was intruded by the gneissic porphyritic granodiorite of Mission Creek ($pTog_m$), the granodiorite of French Valley ($pTog_f$), and the Crawfish Lake tonalite gneiss ($pTog_c$). No radiometric ages are reported from the Tonasket Gneiss in the map area, but three U-Pb zircon ages between 87 and 100 Ma are reported from the unit in the Oroville 1:100,000-scale quadrangle (Fox and others, 1976). These ages should be regarded

"as an estimate of the maximum time since either crystallization, recrystallization, or metamorphism resulted in lead loss or uranium gain by the zircon" (Fox and others, 1976, p. 1223).

Metamorphic Rocks in the Summit-Frazer Complex

Meta-igneous Rocks

KJog

Summit-Frazer trondhjemitic gneiss, tonalitic and granodioritic gneiss (Cretaceous or Jurassic?)-- Weakly to strongly foliated, light-gray to white, leucocratic, tonalitic gneiss composed of approximately 60 percent oligoclase, 30 percent quartz, less than 10 percent biotite, and accessory epidote and sphene (A. M. Frey, Univ. of Pittsburgh, written commun., 1988). Foliation in the gneiss, which is defined by aligned biotite and stretched and flattened quartz, strikes northwest and dips steeply.

The tonalitic and granodioritic gneiss (KJog) is compositionally and texturally similar to the directionless tonalite (KJit) in the Summit-Frazer complex. However, on the west side of the Summit-Frazer complex, in the Robinson Mountain 1:100,000-scale quadrangle to the northwest, the directionless tonalite (trondhjemite of Doe Mountain) appears to cut the tonalitic gneiss (trondhjemite of Lamb Butte; trondhjemite of Eightmile Creek). On the east side of the complex, in the Oroville 1:100,000-scale quadrangle to the north, the directionless tonalite cuts mixed metamorphic and igneous rocks (gneissic trondhjemite of Tiffany Mountain). Along the eastern margin of the tonalitic and granodioritic gneiss in the Omak 1:100,000-scale quadrangle, the gneiss contains abundant rafts and inclusions of amphibolitic schist, schistose metamorphic rocks, mesocratic to melanocratic gneiss, and basic plutonic rocks that form a discontinuous belt of mixed metamorphic and igneous rocks (KJmi, KJmi_{bm}, KJmi_I, KJmi_w).

The tonalitic gneiss (KJog) that crops out east of the Okanogan River at Monse was originally included in the orthogneiss near Wakefield (KJmi_w) by Atwater and Rinehart (1984), but it is herein reassigned on the basis of Fritz's (1978) description of the unit (his Chicken Creek trondhjemitic gneiss), as a gneissic to directionless trondhjemitic gneiss.

Five radiometric ages (Rb-Sr, fission track, and Pb-alpha) between 76 ± 8 Ma and 104.2 ± 0.5 Ma are reported from the Summit-Frazer trondhjemitic gneiss (Menzer, 1970), but they are probably metamorphic ages, not magmatic crystallization ages. Menzer (1983) observed inclusions of the Summit-Frazer trondhjemitic gneiss in the Leader Mountain granodioritic gneiss, which has yielded a 129 ± 1.8 Ma Rb-Sr age (in the Oroville 1:100,000-scale quadrangle). Therefore, the age of the Summit-Frazer trondhjemitic gneiss is thought to be early Cretaceous or older.

The Summit-Frazer trondhjemitic gneiss, tonalitic and granodioritic gneiss, may be correlative with part of the Eagle complex in southern British Columbia that recently yielded numerous K-Ar ages from 95 to 100 Ma and several Late Jurassic to Early Cretaceous U-Pb zircon ages (Greig, 1988). The Summit-Frazer trondhjemitic gneiss is probably correlative with the trondhjemite of Lamb Butte and the trondhjemite of Eightmile Creek on the Robinson Mountain 1:100,000-scale quadrangle to the north.

Kjog_g

Summit-Frazer trondhjemitic gneiss, garnetiferous granitic gneiss (Cretaceous or Jurassic?)--Fine- to medium-grained gneiss composed of plagioclase, quartz, biotite, and minor red garnets (1 mm wide), muscovite, and minor K-feldspar (A. M. Frey, Univ. of Pittsburgh, written commun., 1988). The foliated garnetiferous gneiss is sheared and mylonitic near the contacts with the Summit-Frazer trondhjemitic gneiss (Kjog). The euhedral garnets and at least some of the muscovite are apparently postdeformational (A. M. Frey, Univ. of Pittsburgh, written commun., 1988). The unit is present as two fairly small exposures along the Middle Fork Beaver Creek west of Bobcat Mountain (T. 34 N., R. 23 E.).

Kjog_m

Quartz diorite gneiss near Malott (Cretaceous or Jurassic?)--Hornblende-bearing quartz diorite gneiss that forms a northwest-trending elliptical body west of Malott (T. 32 N., R. 25 E.). The unit may be comagmatic with quartz diorite gneiss in the orthogneiss near Wakefield (Kjmi_w), which is on trend across the Okanogan River to the southeast.

Kjog_i

Granodiorite gneiss near Granite Mountain (Cretaceous or Jurassic?)--Weakly to strongly foliated gneiss that has an average composition of granodiorite. The rocks consist of K-feldspar porphyroblasts as much as 5 cm long in a medium- to coarse-grained matrix of plagioclase (oligoclase to andesine), K-feldspar (microcline and orthoclase), quartz, biotite, and hornblende. Allanite is a ubiquitous accessory mineral, and myrmekite is common; other accessory minerals include apatite, sphene, ilmenite, leucoxene, magnetite, zircon, clinzoisite, and pistacite.

The granodioritic gneiss near Granite Mountain consists of several northwest-trending, linear intrusions that extend northwest from near Malott to the northern map boundary near Granite Mountain and into the southwestern corner of the Oroville 1:100,000-scale quadrangle (Menzer, 1964, 1982, 1983; Rinehart, 1981). Menzer (1982) originally included two separate belts of gneiss in the Leader Mountain granodioritic gneiss; however, the western belt is herein differentiated as the granodiorite gneiss near Granite Mountain because the two belts may not be equivalent. (See Leader Mountain granodioritic gneiss for a discussion of the eastern belt.) The eastern belt may be a different pluton, possibly associated with an earlier period of intrusion; it is therefore assigned a Mesozoic age.

The granodioritic gneiss near Granite Mountain is weakly to strongly foliated. Foliation is generally most pronounced near contacts with older rock units and typically parallels the foliation in the older rocks.

This granodioritic gneiss unit is a synkinematic pluton that has been modified by late- or postkinematic recrystallization and potassium metasomatism (Menzer, 1964, 1983). Most of the gneiss exhibits crystalloblastic textures, but relict igneous textures are locally preserved. The K-feldspar porphyroblasts are late metamorphic minerals that probably formed at the expense of plagioclase during potassium metasomatism (Menzer, 1964, 1983). The porphyroblasts are commonly aligned parallel to the foliation in the gneiss, but some have grown across the foliation.

The granodioritic gneiss near Granite Mountain is correlative with the Old Baldy pluton of Rinehart (1981).

Kjog_c

Coyote Ridge quartz diorite gneiss (Cretaceous or Jurassic?)--An 800-m-wide hornblende-bearing quartz diorite gneiss characterized by rolled or lensoidal hornblende and plagioclase porphyroclasts surrounded by a finer mortar of feldspar, quartz, and biotite. Biotite is shredded and smeared along foliation (A. M. Frey, Univ. of Pittsburgh, written commun., 1988). Microcline porphyroblasts are locally abundant (Menzer, 1983). Epidote is locally present (A. M. Frey, University of Pittsburgh, written commun., 1988). Cataclasis along the Pasayten(?) fault has transformed Coyote Ridge gneiss into ultramylonite and pseudotachylite (Menzer, 1983). The degree of development of cataclastic textures in the gneiss decreases to the east, with increasing distance from the fault. The Coyote Ridge quartz diorite gneiss is distinguished from the Summit-Frazer trondhjemitic gneiss by the former's greater mafic mineral content, the presence of hornblende, and its cataclastic textures.

Menzer (1983) named the unit the Coyote Ridge quartz dioritic gneiss phase, and he thought that it is a border phase of the Summit-Frazer trondhjemitic gneiss. He noted gradational contacts in some places and intrusive contacts in others. A. M. Frey (Univ. of Pittsburgh, written commun., 1988) believes that the contact between the Coyote Ridge quartz diorite gneiss and the Summit-Frazer trondhjemitic gneiss is a sheared intrusive contact. She thinks that the Coyote Ridge quartz diorite gneiss intruded the trondhjemitic gneiss.

Similar mylonitic rocks are found along the Pasayten fault in the Robinson Mountain 1:100,000-scale quadrangle to the northwest (V. R. Todd, USGS, written commun., 1988). They probably represent a discrete pluton that was intruded along the Pasayten fault during regional ductile deformation (V. R. Todd, USGS, written commun., 1988).

pKam_c

Amphibolite near Finley Canyon (pre-Cretaceous?)--Melanocratic diorite gneiss forms a north-south belt in the Coyote Ridge quartz diorite gneiss (Kjog_c), parallel to the thrust fault along the western margin of the Summit-Frazer trondhjemitic gneiss. The rocks consist of hornblende, biotite, feldspar, and quartz. The constituents are locally segregated into leucocratic and melanocratic bands.

The amphibolite near Finley Canyon is strongly deformed. Mylonitic foliation, isoclinal intrafolial folds, box folds, and brittle faults are all common. Some fractures are filled with epidote; epidote is also present in some of the rock as a retrograde metamorphic mineral.

Mixed Metamorphic and Igneous Rocks

Kjmi

Mixed metamorphic and igneous rocks (Cretaceous or Jurassic?)--A heterogeneous complex of tonalite, biotite granodiorite, intermediate to basic plutonic rocks (typically diorite), tonalitic and granodioritic orthogneiss, hornblende-biotite gneiss, amphibolite, schistose metamorphic rocks, migmatite, and pegmatite. The mixed metamorphic and igneous rocks are present along the margins of tonalitic and granodioritic orthogneiss bodies in the Summit-Frazer complex and are locally associated with younger Cretaceous intrusions. The mixed metamorphic and igneous rocks in the Summit-Frazer complex (Kjmi) are compositionally similar to mixed rocks in the Boot Mountain complex to the east (Kjmi_b). The approximate boundary between the mixed metamorphic and igneous rocks in the Summit-Frazer complex (Kjmi) and the Boot Mountain complex (Kjmi_b) is somewhat arbitrarily drawn near Stubblefield Point (T. 30 N., R. 28 E.), but a distinction is important because the parent magma and relative age of these two Cretaceous-Jurassic? units could be different.

OMAK 1:100,000 QUADRANGLE

The mixed rocks east of the Okanogan River, which were originally assigned to the plutonic complex of Boot Mountain (Atwater and Rinehart, 1984), are herein re-assigned to the Summit-Frazer complex because they contain components that strongly resemble the tonalite and the tonalitic to granodioritic gneiss (KJit, KJog) of the Summit-Frazer complex.

The large outcrop of mixed rocks east of Little Soap Lake (T. 32 N., R. 26 E.) was mapped by Fritz (1978) as Reed Creek quartz dioritic orthogneiss and Leader Mountain porphyroblastic granodioritic gneiss (after Menzer, 1964) and has abundant amphibolite north of Stevens Lake. For this reason, it is likely to contain a major component of orthogneiss.

A K-Ar hornblende date of 87.5 ± 2.2 Ma is reported from the small outcrop of KJmi that lies 0.5 mi southwest of Monse (J. R. Wilson, formerly USGS, oral commun., 1987).

The mixed metamorphic and igneous rocks (KJmi) in the northwest corner of the map area are contiguous with similar mixed rocks in the gneissic trondhjemite of Tiffany Mountain in the Oroville 1:100,000-scale quadrangle to the north (Stoffel, 1990a).

KJmi_l

Mixed metamorphic and igneous rocks near Lightning Creek (Cretaceous or Jurassic?)--Mixed tonalite, tonalitic gneiss, layered melanocratic gneiss and schist, agmatite/migmatite that contains granodiorite intrusions (possibly Conconully granodiorite (Kigd_c), and aplite and pegmatite dikes, as well as components that resemble the granodiorite gneiss near Granite Mountain (KJog). This unit is probably correlative with the gneissic trondhjemite of Tiffany Mountain in the Oroville 1:100,000-scale quadrangle to the north (Stoffel, 1990a).

KJmi_{bm}

Mixed metamorphic and igneous rocks near Buck Mountain (Cretaceous or Jurassic?)--Altered metasedimentary rocks and blocks of gabbro, quartz-gabbro, diorite, and quartz-diorite as much as 30 m across in the Summit-Frazer trondhjemitic gneiss. Angular shapes and knife-sharp contacts of some of these blocks suggest that they were brittle when they were engulfed by the tonalite (Menzer, 1983). The rocks crop out directly south of Buck Mountain and approximately 4 mi northwest of Buck Mountain on the northwest side of Beaver Lake (T. 34 N., R. 24 E.).

KJmi_w

Orthogneiss near Wakefield (Cretaceous or Jurassic?)--Medium- to coarse-grained gneiss with varied textures and various compositional types that include quartz diorite, tonalite, leucocratic trondhjemite, and amphibolitic schist. The unit is present directly east of the Okanogan River from Malott to about the latitude of Monse.

Fritz (1978) delineated several large areas of his Monse amphibolitic schist and suggested that they had gradational contacts with his Little Soap Lake quartz diorite gneiss, which, taken together, are roughly analogous to the orthogneiss near Wakefield.

A K-Ar biotite age of 80.2 ± 0.6 Ma has been determined (B. F. Atwater, USGS, written commun., 1987) (Table 1).

KJmg

Migmatite (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 tonalite and granodiorite. Migmatite is present east of the Columbia River (Lake Pateros) (T. 29 N., R. 24 E.), north of Bridgeport (T. 29 N., R. 25 E.), and near Tombstone Rocks (T. 30 N., R. 28 E.). The migmatite west of the Columbia River, in the southwest corner of the map area, contains elements of the amphibolite, gneiss and schist of Alta Lake (pKh_{m_a}) and is therefore called Alta Lake migmatite (KJmg_a). Its relation to migmatite (KJmg) directly east of the Columbia River is unknown.

Other Metamorphic Rocks

Meta-igneous Rocks

$pKog_m$

Methow Gneiss (pre-Cretaceous)--Strongly foliated, white to light gray tonalite gneiss composed of 60-65 percent plagioclase, 20-25 percent quartz, 6-8 percent biotite, 2-3 percent epidote, and minor hornblende and sphene. Apatite and sphene are common accessory minerals. The epidote is both primary and secondary. The gneiss is locally sheared and highly altered to chlorite and actinolite.

The Methow Gneiss covers approximately 50 km² along the west edge of the map area and an additional 125 km² in the adjacent Twisp quadrangle. The gneissic character of the unit is emphasized by distinctive clots of biotite, which have been appropriately called leopard spots and which define a weak lineation.

The Methow Gneiss is in contact with Alta Lake metamorphic rocks (pKh_{m_a}) to the south and southeast. There is a general concordance of both units at the contact, suggesting that the Methow was emplaced at a moderate to deep level (Raviola, 1988). Subsequent metamorphism affected the two units under similar pressure-temperature conditions. Migmatite commonly occurs along this contact.

To the north and northwest, the Methow gneiss intrudes the Leecher metamorphics (pKh_m). To the southwest, the Methow gneiss is intruded by the Cooper Mountain batholith ($Eigd_c$); the sharp, discordant contact between the two units is riddled by porphyritic dikes of the Goat Mountain swarm.

The composition, texture, and distribution of the Methow Gneiss suggest that it may be related to similar foliated tonalitic gneiss (KJog) in the Summit-Frazer complex.

$Mzog_w$

Windy Hill quartz dioritic orthogneiss (Mesozoic)--Quartz diorite gneiss that is mineralogically similar to the Reed Creek quartz dioritic gneiss (Mzog_r), but is distinguished from the Reed Creek by its higher color index and lower quartz to plagioclase ratio.

The Windy Hill quartz dioritic orthogneiss is equivalent in part to the "metagranitoid rocks" of Rinehart (1981), which vary from quartz dioritic to quartz monzonitic in composition.

OMAK 1:100,000 QUADRANGLE

The Windy Hill unit crops out on the slopes of Windy Hill east of Buzzard Lake (T. 34 N., R. 25 E.). It intrudes the Salmon Creek Schists and Gneisses (pjhm_s) and is intruded by the Conconully granodiorite (Kigd_c). Intrusive contact relations with the Salmon Creek Schists and Gneisses, and relict plagioclase zoning indicate that the Windy Hill quartz dioritic orthogneiss is a metamorphosed pluton (Menzer, 1983; Rinehart, 1981).

Mzog_i

Leader Mountain granodioritic gneiss (Mesozoic)--Megacrystic gneiss with an average composition of granodiorite but ranges from diorite to granite. Along the east margin of the unit, the gneiss is characterized by microcline porphyroblasts as much as 5 cm long that replace plagioclase crystals.

The Leader Mountain granodioritic gneiss of Menzer (1983) includes a belt of granodiorite gneiss near Granite Mountain (KJog), that is herein excluded from the Leader Mountain granodioritic gneiss because it is compositionally dissimilar.

The Leader Mountain granodioritic gneiss intrudes the Salmon Creek Schists and Gneisses. Both concordant and discordant contacts have been found. The Leader Mountain is compositionally similar to the Reed Creek quartz dioritic orthogneiss (Mzog_i), but it contains more K-feldspar megacrysts and sodic plagioclase than the Reed Creek (Menzer, 1983).

Mzog_r

Reed Creek quartz dioritic orthogneiss (Mesozoic)--A narrow northwest-trending belt of orthogneiss that extends north from the Columbia River into the Oroville 1:100,000-scale quadrangle. Northwest of the Okanogan River, the unit is chiefly weakly to strongly foliated quartz diorite gneiss composed of white plagioclase phenocrysts in a medium-grained groundmass (Menzer, 1983; Sims, 1984). Southeast of the Okanogan River, this orthogneiss is chiefly medium- to coarse-grained granite and granodiorite composed of quartz, plagioclase, K-feldspar, biotite, minor hornblende, epidote, tourmaline(?), sphene(?), and garnet(?) (Atwater and Rinehart, 1984; J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988). Hornblende content and color index increase to the south, as do inclusions of country rock.

"Textures range from fully igneous to entirely metamorphic. Most samples contain both igneous and metamorphic textural features; the igneous features...invariably are the older" (Menzer, 1983, p. 493).

Aligned biotite, hornblende, and elongate quartz aggregates define a distinct foliation that parallels the foliation in the Salmon Creek Schists and Gneisses. The foliation is strongest along the margins of the intrusive.

The Reed Creek quartz dioritic orthogneiss intrudes, and locally hornfelses, the layered, migmatitic rocks of the Salmon Creek Schists and Gneisses (pjhm_s). It is intruded by the porphyritic granite and granodiorite of Cook Lake (Kia_c) and by the equigranular granite of Virginia Lake (Kig_v) (Rinehart, 1984). Discordant K-Ar hornblende and biotite ages of 75.2 ± 1.9 Ma and 57.4 ± 1.4 Ma (Atwater and Rinehart, 1984) and a Pb-alpha zircon age of 170 ± 20 Ma (Menzer, 1983) are reported for the Reed Creek unit (Table 1).

Mixed Metamorphic and Igneous Rocks

KJmi_b

Boot Mountain complex (Cretaceous or Jurassic?)--Mixed unit that consists of: (1) directionless to foliated, medium-grained, dark-gray granite to tonalite, and local thin (<1 m thick) aplite and fine-grained granite dikes; (2) fine-grained dark diorite that contains lenses of metamorphosed country rock and/or dikes; (3) aplite and pegmatite; (4) layered gneiss and schist; (5) mylonitic rocks; and (6) discrete bodies of high-grade metamorphic rocks described as the heterogeneous metamorphic rocks in the Boot Mountain complex (pJhm_b). Along the Omak Lake fault, the Boot Mountain complex is brecciated.

At Squaw Mountain (T. 31 N., R. 30 E.), the Boot Mountain complex consists of greenstone, metadiorite, layered schist and gneiss, and calc-silicate rocks mixed with equigranular, medium-grained granitoid rocks. This part of the complex is riddled with swarms of north-trending hypabyssal dacite porphyry dikes of the hypabyssal intrusive suite of Cody Lake (Eida_c). The linear intrusive contact between the complex and the Coyote Creek pluton west of Squaw Mountain, which Atwater and Rinehart (1984) originally mapped as the Multnomah fault, may represent the western margin of the southern extension of the Republic graben (Atwater, 1985).

Northwest of Omak Lake, the Boot Mountain complex is dominated by massive, equigranular, medium-grained, light-gray to gray (color index 7-12) granodiorite composed of plagioclase, quartz, biotite, K-feldspar, hornblende, and minor sphene, apatite, epidote, and chlorite. It is locally brecciated and altered. This part of the complex is distinguished from the rest of the complex on the basis of its relatively greater homogeneity, equigranular nature, and general lack of migmatitic character. Along the contact with the Salmon Creek Schists and Gneisses, an increase in color index, titanite content, and the hornblende to biotite ratio occurs (J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988).

The Boot Mountain complex includes the plutonic and metamorphic complex of Squaw Mountain and parts of the plutonic complex of Boot Mountain of Atwater and Rinehart (1984). A somewhat arbitrary north-south line through Stubblefield Point separates the Boot Mountain complex from mixed metamorphic and igneous rocks in the Summit-Frazer complex (KJmi), which may have a different parent magma and relative age.

The Boot Mountain complex is intruded by the porphyritic granodiorite of Manila Creek (EPigd_m) and the porphyritic granite of Coyote Creek (EPig_c). Discordant K-Ar hornblende and biotite ages of 72.1 ± 1.8 Ma and 48.9 ± 1.2 Ma, respectively, are reported (Atwater and Rinehart, 1984). The age of mixing is uncertain. A Cretaceous-Jurassic age is tentatively assigned, but an earlier Mesozoic age cannot be ruled out (K. F. Fox, Jr., USGS, written commun., 1989).

KJmg_a

Alta Lake migmatite (Cretaceous or Jurassic?)--Migmatitic parts of the amphibolite, schist, and gneiss of Alta Lake (pKhm_a). The migmatite is gradational with the layered metamorphic rocks and is characterized by irregular, lenticular, swirled, and contorted granitic, tonalitic, aplitic, and pegmatitic leucosomes, from 10 cm to 3 m thick, that form 30-60 percent of the unit (Raviola, 1988). The Alta Lake migmatite also contains medium-grained hornblendite and porphyroblastic plagioclase-hornblende-biotite schist. Migmatization appears to have been a polyphase event that involved processes of both anatexis and igneous injection (Raviola, 1988). The age of migmatization is uncertain; a Cretaceous-Jurassic age is tentatively assigned to this unit.

Layered Metamorphic Rocks

pKhm_l

Leecher Metamorphics (pre-Cretaceous)--Schistose amphibolite, hornblende schist, quartzose schist, biotite schist, paragneiss, and schistose biotite-calcite marble (Menzer, 1983). The unit forms two small exposures along the west edge of the map area that extend west into the Twisp 1:100,000-scale quadrangle (A. M. Frey, Univ. of Pittsburgh, written commun., 1988). In the map area, near the contact with the Summit-Frazer trondhjemitic gneiss, the Leecher Metamorphics are migmatitic and are intruded by the Summit-Frazer trondhjemitic gneiss. A K-Ar hornblende age date of 114.6 ± 1.1 Ma is reported from the Leecher Metamorphics in the Twisp 1:100,000-scale quadrangle (V. R. Todd, USGS, written commun., 1988); it is undoubtedly a metamorphic age.

The Leecher Metamorphics may be correlative with the Salmon Creek Schists and Gneisses, but the Leecher Metamorphics do not contain abundant marble and sillimanite-bearing schists that are present in the Salmon Creek unit (Menzer, 1983). The Leecher Metamorphics may be correlative with part of the amphibolite, schist, and gneiss of Alta Lake (pKhm_a), which are probably correlative to the Permian amphibolite and schist of Twenty five Mile Creek on the Twisp and Chelan 1:100,000-scale quadrangles.

pKhm_a

Amphibolite, schist, and gneiss of Alta Lake (pre-Cretaceous)--Schistose amphibolite intercalated with quartz-hornblende-plagioclase gneiss, leucocratic tonalitic gneiss, and minor hornblende-quartz-biotite-plagioclase schist, calc-silicate schist, and biotite-actinolite schist. The layered metamorphic rocks are cut by 0.3- to 5-m-thick trondhjemitic dikes and sills (Raviola, 1988).

Banding in the Alta Lake unit varies from planar to lenticular and is locally swirled near the migmatite. Nematoblastic hornblende prisms commonly define a lineation in the banded rocks that is, in most places, co-planar with the foliation. Tight to isoclinal folds are common; they are locally boudinaged.

The long linear outcrop of the northern extension of the Alta Lake unit may be an oversimplification of discontinuous, discrete amphibolite bodies that define the linear trend.

The amphibolite, schist, and gneiss of Alta Lake are intruded by the Cooper Mountain batholith (Eigd_c) and the porphyry dike swarm of Goat Mountain (Eida_g). The Methow Gneiss contains inclusions of the Alta Lake rocks, which suggests that the Methow Gneiss intruded the Alta Lake metamorphic rocks (Raviola, 1988). Migmatitic zones 50-100 m wide are present at the contacts between the two units. Amphibolite in the Alta Lake unit has yielded a K-Ar hornblende age of 104 ± 5 Ma (Table 1); this is probably a metamorphic age.

pJqz_s, pJmb_s, pJhm_s

Salmon Creek Schists and Gneisses (pre-Jurassic)--Hornblende-biotite gneiss, feldspar augen gneiss, biotite gneiss, sillimanite-muscovite-biotite schist, biotite quartzofeldspathic schist, amphibolite, quartzite, biotite quartzite, marble, garnet-pyroxene calc-silicate gneiss, coarse hornblendite, and migmatitic rocks. The unit forms a narrow belt along Salmon Creek that extends northwest from west of Omak Lake into the Oroville 1:100,000-scale quadrangle to the north (Menzer, 1970, 1982, 1983; Sims, 1984; Atwater and Rinehart, 1984). Southwest of Omak Lake, the Salmon Creek unit contains a small body of dunite.

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The rocks are strongly foliated and lineated parallel to compositional layering, and they are locally isoclinally folded. The rocks are migmatitic in places. Regional metamorphism of the Salmon Creek rocks reached the sillimanite zone of the amphibolite facies.

The Salmon Creek Schists and Gneisses were named by Goldsmith (1952). They are equivalent to the metamorphic complex of Conconully (Rinehart and Fox, 1976), the metasedimentary and metavolcanic rocks of Rinehart (1981), and the paragneiss of Hansen (1983).

The Salmon Creek Schists and Gneisses are cut by the porphyritic granite and granodiorite of Cook Lake (Kia_c), the porphyritic granodiorite of Omak Lake ($EPigd_o$) (Atwater and Rinehart, 1984), equigranular granodiorite within the Boot Mountain complex ($Kjmi_b$), and the Reed Creek quartz dioritic orthogneiss ($Mzog$) (J. W. Goodge and V. L. Hansen, formerly USGS, written commun., 1988).

pJqz_s

Quartzite--Quartzite, including small, isolated bodies of massive to foliated emerald-green fuchsitic quartzite and minor quartzose phyllite, metaconglomerate, and dark-gray to black andalusite schist along the west side of Salmon Creek (Sims, 1984).

pJmb_s

Marble--White calcite marble, with lesser grayish white, thinly layered to bedded, calc-silicate rocks (Sims, 1984).

pJhm_s

Heterogenous metamorphic rocks--Gneiss, schist, quartzite, amphibolite, marble, and calc-silicate rocks, undivided.

pJhm_b

Heterogeneous metamorphic rocks in the Boot Mountain complex (pre-Jurassic?)--Layered biotite schist, quartzite, and gneiss in the Boot Mountain complex ($Kjmib$) that forms a belt of isolated bodies between Whitmore Mountain and China Creek. South of the Columbia River and east of Alameda Flat, the layered metamorphic rocks are sheared along a northwest-trending fault. This unit may be correlative with the Salmon Creek Schists and Gneisses ($pJhms$) or the heterogeneous metamorphic rocks near Crawfish Lake ($Pzhm$).

pJhm_t

Heterogeneous metamorphic rocks of Trefry Canyon (pre-Jurassic?)--Layered biotite schist, biotite garnet gneiss, quartzite, amphibolite schist, marble, and minor calc-silicate rocks exposed along Trefry Canyon south of the Columbia River and in the hills north of the river. Compositional layering and foliation trend northwest. This unit may be correlative to the Salmon Creek Schist, and Gneisses to the northwest.

Pzhm

Heterogeneous metamorphic rocks near Crawfish Lake (Paleozoic?)--Biotite-rich schist and gneiss, calcareous quartzite, marble, amphibolite, and quartzofeldspathic gneiss, most of which has been partially or totally converted to hornfels and granofels (Singer, 1984).

"Orthoquartzite is a noteworthy constituent southeast of Moses Mountain and is associated at one locality with sharpstone conglomerate, a rock type common in metasedimentary assemblages of the Permian Anarchist Group..." (Atwater and Rinehart, 1984, p. 11-12).

These rocks are cut by and form a series of pendants in the Swimpotkin Creek pluton southeast of Crawfish Lake.

Pzhm_p

Heterogeneous metamorphic rocks near Parmenter Creek (Paleozoic?)--Quartzite, schist, quartz-mica hornfels, marble, and calc-silicate rocks that form extensive outcrops near Parmenter Creek, Great Western Lake, and Mineral Ridge (Atwater and Rinehart, 1984; Broch, 1979). The rocks along Parmenter Creek merge with metasedimentary rocks in the Bald Knob 15' quadrangle to the east (Nespelem 1:100,000-scale quadrangle) that Staatz (1964) described as light- to dark-gray, well-laminated, limonite-stained mica-quartz schist with sericite, chlorite, and biotite. On the west side of Parmenter Creek, the schist contains as much as 10 percent andalusite and minor tourmaline, pyrite, zircon, apatite, garnet, magnetite, hematite, sphene, and epidote. These metamorphic rocks are intruded by the early Tertiary Moses and Coyote Creek plutons.

Tectonic Zone

tz

Tectonic zone--Breccia composed of crushed fragments of the granite of the Coyote Creek pluton (EPig_c) and equigranular granodiorite of the Boot Mountain complex (KJmi_b); present along the Omak Lake fault zone northwest of Omak Lake.

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Table 1. Radiometric age data, Omak 1:100,000-scale quadrangle

Location									
Loc. no.	Sample no.	Unit	Map symbol	Lat. N.	Long. W.	Method	Material	Age	Reference
1	OK-2	Reed Creek quartz dioritic orthogneiss	Mzog,	48°20'	119°37'	Pb-alpha Rb-Sr isochron	zircon whole rk/ biotite	170+/-20 82.6+/-0.3	Menzer (1970) ¹
						fission track fission track	sphene apatite	72+/-7 56+/-6	
2	OK-6	Summit-Frazer trondhjemitic gneiss, trondhjemite	KJit	48°22'	119°55'	Rb-Sr isochron	whole rk/ biotite	104.2+/-0.5	Menzer (1970) ¹
						fission track fission track	apatite zircon	92+/-9 90+/-9	
3	OK-3	Summit-Frazer trondhjemitic gneiss, tonalitic and granodioritic gneiss	KJog	48°27'	119°55'	Rb-Sr isochron	whole rk/ biotite	104.2+/-0.5	Menzer (1970) ¹
						Pb-alpha fission track	zircon apatite	90+/-10 76+/-8	
4	A-7797	Amphibolite, schist, and gneiss of Alta Lake	pKhm _a	48°03.31'	119°55.56'	K-Ar	hornblende	104+/-5.0	This report DGER data (1988) ²
5	OK-4	Leader Lake quartz monzonite	Kiqm _i	48°20'	119°40'	fission track Rb-Sr isochron	apatite apatite/ biotite/ muscovite/ whole rk	94+/-12 81.1+/-0.8	Menzer (1970) ¹
6	T-154	Summit-Frazer trondhjemitic gneiss, tonalitic and granodioritic gneiss	KJog	48°29.5'	119°56.4'	K-Ar K-Ar	biotite muscovite	91.7+/-2.7 88.5+/-2.8	Berry and others (1976) ³
7	C-554	Evans Lake pluton	Kia _e	48°29.7'	119°36.3'	K-Ar	biotite	88.7+/-2.8	Rinehart and Fox (1976) ⁴
8	837-18C	Orthogneiss near Wakefield	KJmi _w	48°14.29'	119°42.28'	K-Ar	biotite	80.2+/-0.6	B. F. Atwater (USGS, written commun., 1987) ⁵
9	HOL-276	Reed Creek quartz dioritic orthogneiss	Mzog,	48°16.68'	119°26.91'	K-Ar K-Ar	hornblende biotite	75.2+/-1.9 57.4+/-1.4	Atwater and Rinehart (1984) ⁶

Table 1. Radiometric age data, Omak 1:100,000-scale quadrangle, continued

Location

Loc. no.	Sample no.	Unit	Map symbol	Lat. N.	Long. W.	Method	Material	Age	Reference
10	837-18A	Equigranular granite of Virginia Lake	Kig _v	48°15.05'	119°39.13'	K-Ar	biotite	74.9+/-0.5	B. F. Atwater (USGS, written commun., 1987) ⁵
11	HOL-277	Boot Mountain complex, equigranular granodiorite	KJmi _b	48°19.57'	119°29.30'	K-Ar K-Ar	hornblende biotite	72.1+/-1.8 48.9+/-1.2	Atwater and Rinehart (1984) ⁶
12	837-11G	Equigranular granite of Virginia Lake	Kig _v	48°07.72'	119°11.78'	K-Ar	biotite	64.9+/-0.3	B. F. Atwater (USGS, written commun., 1987) ⁵
13	BA-84-4E	Granite porphyry of Condon Springs	EPig _a	48°10.35'	119°06.95'	Rb-Sr isochron	whole rk/ white mica whole rk/ biotite	58.8+/-1.1 50.1+/-0.7	R. J. Fleck (USGS written commun., 1989) ⁷
14	837-11J	Boot Mountain complex	KJmi _b	48°10.62'	119°20.94'	K-Ar K-Ar	biotite muscovite	50.4+/-0.4 50.3+/-0.4	B. F. Atwater (USGS, written commun., 1987) ⁵
15	837-18B	Granodiorite of Soap Lake Mountain	Kigd _s	48°16.98'	119°36.18'	K-Ar	biotite	54.8+/-0.4	B. F. Atwater (USGS, written commun., 1987) ⁵
16	HOL-39	Porphyritic granodiorite of Omak Lake	EPigd _o	48°17.63'	119°26.39'	K-Ar	biotite	53.4+/-1.3	Atwater and Rinehart (1984) ⁶
17	SS-351	Granite west of Armstrong Mountain	EPig _a	48°15.40'	119°08.37'	K-Ar	biotite	52.5+/-1.3	Atwater and Rinehart (1984) ⁶
18	BA-82-54E	Coyote Creek pluton	EPig _c	48°09.16'	119°08.11'	K-Ar	biotite	51.1+/-1.3	Atwater and Rinehart (1984) ⁶

Table 1. Radiometric age data, Omak 1:100,000-scale quadrangle, continued

Loc. no.	Sample no.	Unit	Map symbol	Lat. N.	Long. W.	Method	Material	Age	Reference
19	0-424B	Coyote Creek pluton	EPig _e	48°16.8'	119°08.5'	recalculation of K-Ar	biotite	50.3+/-1.5	Atwater and Rinehart (1984) ⁶
						K-Ar	biotite	49.1	Fox and others (1976) ⁸
20	SS-340	Swimptkin Creek pluton	Eimd _s	48°24.80'	119°10.58'	K-Ar K-Ar	biotite hornblende	49.5+/-1.2 45.3+/-1.1	Atwater and Rinehart (1984) ⁶
21	0-419	Swimptkin Creek pluton	Eimd _s	48°25.65'	119°09.15'	recalculation of K-Ar	hornblende	49.4+/-1.5	Atwater and Rinehart (1984) ⁶
50						K-Ar	hornblende	48.2	Fox and others (1976) ⁸
						recalculation of K-Ar	biotite	49.2+/-1.5	Atwater and Rinehart (1984) ⁶
						K-Ar	biotite	48.0	Fox and others (1976) ⁸
22	SS-341	Moses pluton, Clark Creek phase	EPig _{mc}	48°24.20'	119°10.84'	K-Ar	biotite	49.4+/-1.2	Atwater and Rinehart (1984) ⁶
23	D-34A-1	Swimptkin Creek pluton	Eimd _s	48°26.10'	119°04.99'	K-Ar K-Ar	biotite hornblende	49.0+/-1.2 46.8+/-1.2	B. F. Atwater (USGS, written commun., 1987) ⁵

Table 1. Radiometric age data, Omak 1:100,000-scale quadrangle, continued

Loc. no.	Sample no.	Unit	Map symbol	Location				Material	Age	Reference
				Lat. N.	Long. W.	Method				
24	D-6B-2	Moses pluton, Clark Creek phase	EPig _{mc}	48°20.68'	119°03.29'	K-Ar		biotite	47.8+-1.2	B. F. Atwater (USGS, written commun., 1987) ⁵
25	0-425	Gneissic porphyritic granodiorite of Mission Creek	pTog _m	48°23.45'	119°26.52'	recalculation of K-Ar		biotite	47.2+-1.4	Atwater and Rinehart (1984) ⁶
						K-Ar		biotite	46.0	Fox and others (1976) ⁸

1 Menzer (1970): ^{87}Rb t_{1/2} = 5×10^{-10} /yr; normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$; $\lambda_f = 7.03 \times 10^{-17}$ /yr

2 DGER data (1988): $^{40}\text{K}/\text{K}^{\text{total}} = 1.193 \times 10^{-4}$; $\lambda_\epsilon = 0.581 \times 10^{-10}$ /yr; $\lambda_\beta = 4.962 \times 10^{-10}$ /yr

3 Berry and others (1976): $^{40}\text{K}/\text{K}^{\text{total}} = 1.19 \times 10^{-4}$; $\lambda_\epsilon = 0.585 \times 10^{-10}$ /yr; $\lambda_\beta = 4.72 \times 10^{-10}$ /yr

4 Rinehart and Fox (1976): constants not reported

5 B. F. Atwater (USGS, written commun., 1987): "1976 IUGS decay and abundance constants"

6 Atwater and Rinehart (1984): $^{40}\text{K}/\text{K}^{\text{total}} = 1.167 \times 10^{-4}$; $\lambda_\epsilon = 0.581 \times 10^{-10}$ /yr; $\lambda_\beta = 4.962 \times 10^{-10}$ /yr

7 R. J. Fleck (USGS, written commun., 1989): constants not reported

8 Fox and others (1976): $^{40}\text{K}/\text{K}^{\text{total}} = 1.19 \times 10^{-4}$; $\lambda_\epsilon = 0.585 \times 10^{-10}$ /yr; $\lambda_\beta = 4.72 \times 10^{-10}$ /yr

Table 2. Major oxide geochemical data, Omak 1:100,000-scale quadrangle

Sample No.	Geologic unit	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	CaO	MgO	K ₂ O	Na ₂ O	P ₂ O ₅	1/4	1/4	1/4	Sec.	Twp.	Rng.	
3024174h	Mv _{gN2}	54.85	14.31	1.832	11.42	0.200	8.44	4.65	1.12	2.81	0.367	NW	NW	NE	17	30N	24E	
3026077b	Mv _{gN2}	54.52	14.36	1.800	11.49	0.199	8.49	4.81	1.15	2.84	0.340	NE	SW	SW	07	30N	26E	
3126091b	Mv _{gN2}	55.05	14.84	1.915	10.74	0.188	8.63	4.09	1.29	2.89	0.375	NE	SE	SE	09	31N	26E	
3126154c	Mv _{gN2}	54.61	14.47	1.826	11.28	0.195	8.58	4.70	1.15	2.84	0.348	SW	NW	SE	15	31N	26E	
3227194a	Mv _{gN2}	54.79	14.58	1.835	10.93	0.193	8.70	4.52	1.24	2.86	0.348	SW	SW	SE	19	32N	27E	
GM-034-1	-H-H-	50.81	13.18	2.020	9.21	0.135	8.39	9.56	2.72	2.73	1.244	NW	NW	NW	03	29N	23E	
GM-098	Eigd _c	70.72	15.55	0.379	1.96	0.040	2.35	1.08	4.02	3.76	0.138	SE	SE	NW	08	29N	23E	
MR-207D	pKog _m	69.57	17.74	0.235	1.51	0.043	3.78	0.42	1.01	5.61	0.073	NE	SE	NE	34	30N	23E	
MR-300	pKog _m	64.43	19.21	0.426	3.01	0.071	5.44	0.96	0.66	5.63	0.164	SE	SW	SW	21	30N	23E	
52	MR-015-L	KJmg _a	75.26	14.48	0.248	1.22	0.022	3.38	0.67	0.54	4.14	0.036	NE	NE	NE	02	29N	23E
GM-384	pKhm _a	50.53	18.09	0.986	9.12	0.199	10.40	6.19	0.56	3.66	0.275	NE	NE	NW	16	29N	23E	
ALE-4-1	PKhm _a	51.83	14.25	1.603	15.05	0.259	8.68	5.28	0.51	2.39	0.157	NE	NE	SE	10	29N	23E	

Analyses by XRF, Department of Geology, Washington State University, October 1987. All analyses are normalized on a volatile-free basis to 100%. Values are expressed in weight percent. FeO = total iron as FeO.