GEOLOGIC MAP OF THE

BANKS LAKE

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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GEOLOGIC MAP OF THE BANKS LAKE 1:100,000 QUADRANGLE

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INTRODUCTION

The Banks Lake 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 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 have not been open-filed because they have been published recently by the U.S. Geological Survey (Tabor and others, 1982, 1987).

Literature review for, and preliminary compilation of the Banks Lake 1:100,000-scale quadrangle began in 1985. Sources of geologic data for the map are shown in Figure 2. Principal sources of geologic map data used to construct the map for this report were Hanson and others (1979) (geologic contacts) and Swanson and others (1979a) (structures and subdividing the Columbia River Basalt Group into members). Between 1986 and 1988, substantial new reconnaissance and detailed geologic mapping was performed by DGER geologists in areas where previous geologic mapping was either inadequate or lacking. New geologic mapping was also acquired during that time through a DGER graduate student mapping program (Raviola, 1988; Holder and Holder, 1987). Areas covered by the new mapping include the Chelan Falls, Azwell, and Wells Dam 7 1/2-minute quadrangles, and the north end of Banks Lake.

Radiometric ages from the Banks Lake 1:100,000-scale quadrangle are listed in Table 1 and include one new K-Ar age. New whole-rock geochemical data for samples collected for this project are given in Tables 2 and 3. The data include 40 new major- and trace-element analyses. (The tables are at the end of this text.)

Units on this geologic map are age-lithology units. Upper-case letters in the map symbol indicate unit age, and lower-case letters indicate lithology. Map symbol subscripts identify the formal or informal name of the unit. 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). In most instances, age of the protolith has been used for the unit symbol. For mixed igneous and metamorphic rocks, the age of "mixing", complexing, and/or migmatization is shown. Figure 3 shows the method of assigning ages to metamorphic rocks.

Plutonic rock names were assigned using modal analyses and 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). "High-grade" refers to metamorphic rocks of amphibolite facies or higher.

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

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

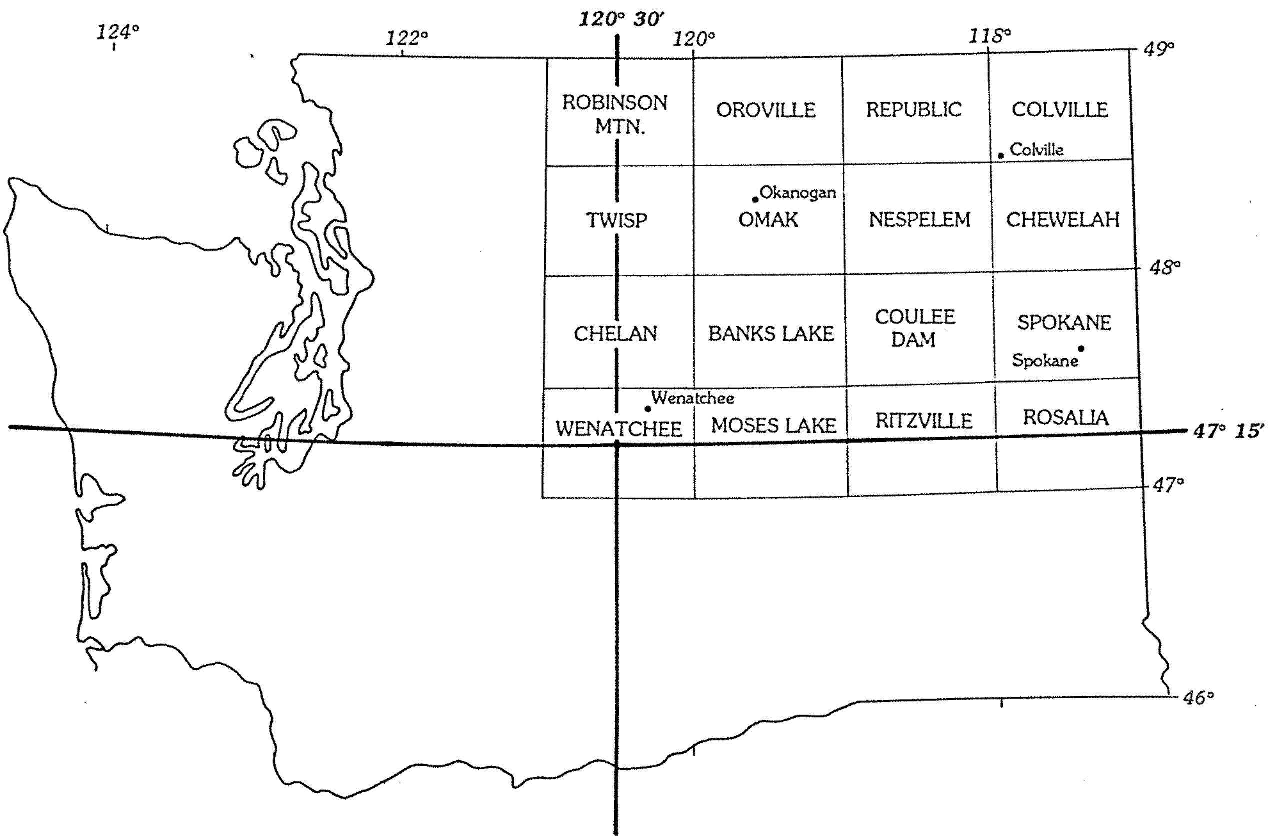

Figure 1. 1:100,000-scale quadrangles in the northeast quadrant of Washington.

Sources of Map Data

(to accompany Figure 2 on facing page)

1. Hanson and others, 1979
2. Swanson and others, 1979a
3. Raviola, 1988
4. Korosec, 1987
5. Hopson, 1955
6. Holder and Holder, 1987
7. Grolier and Bingham, 1971

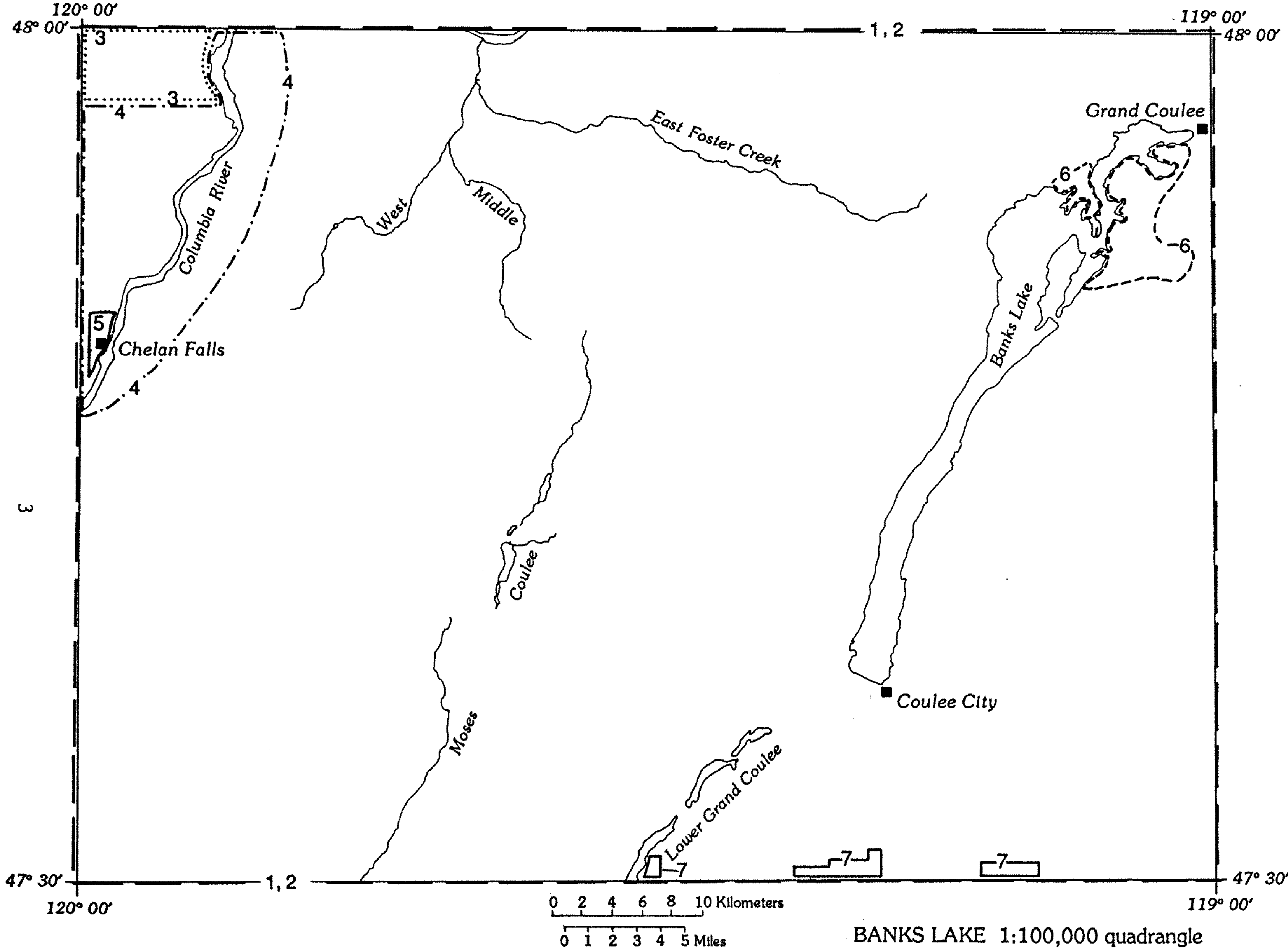

Figure 2. Index map showing sources of geologic map data.

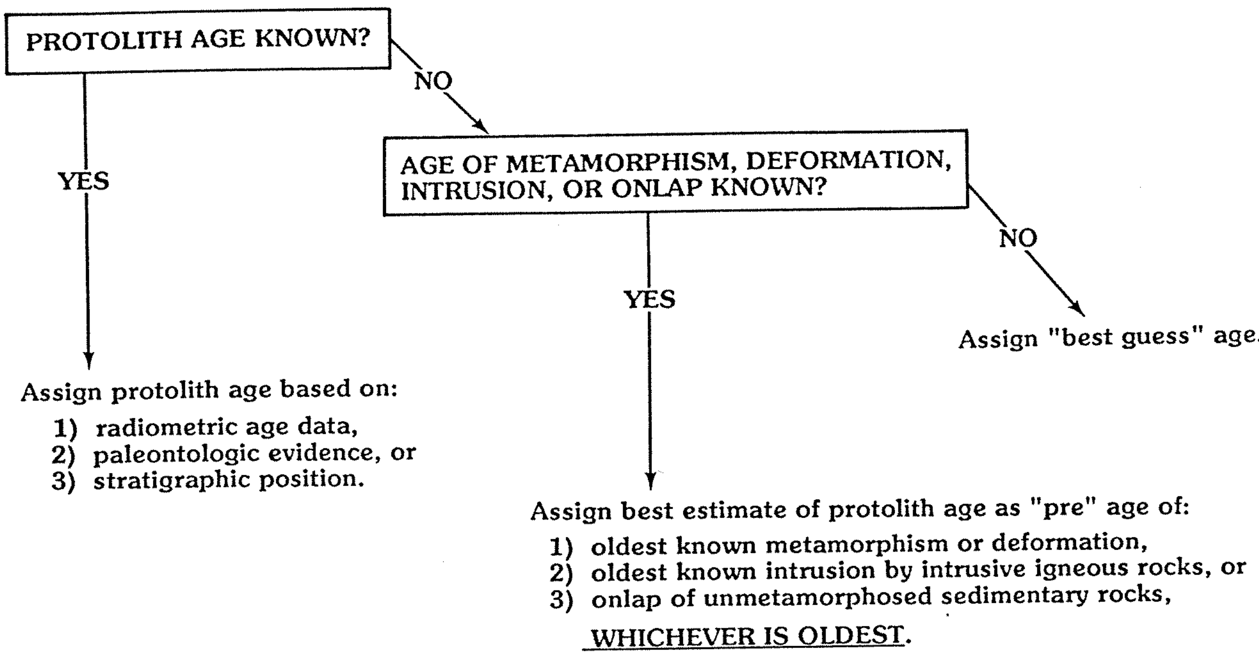

Figure 3. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age may be assigned by correlation with other geologic units. The unit description will include information on how the age of the unit was determined.

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 Omak 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-12, 52 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.

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 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.

Stoffel, K. L.; McGroder, M. F., compilers, 1990, Geologic map of the Robinson Mountain 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.

Acknowledgments

We thank DGER staff geologists Keith L. Stoffel, Bonnie B. Bunning, William M. Phillips, Robert L. Logan, and Timothy J. Walsh for assisting the authors with geologic mapping in the northwest corner of the Banks Lake 1:100,000-scale quadrangle. Stephanie Z. Waggoner (DGER) drafted the Banks Lake quadrangle map, and Keith Stoffel, Tim Walsh, Rowland Tabor (USGS), and Don Swanson (USGS) edited and reviewed early versions of the manuscript.

DESCRIPTION OF MAP UNITS

Quaternary Sedimentary Deposits

Qa

Alluvium (Holocene to Pleistocene)--Silt, sand, and gravel in streambeds, floodplains, and terraces and stratified sand and gravel in alluvial fans; locally includes eolian, lacustrine, and bog deposits.

Qls

Landslide deposits (Holocene to Pleistocene)--Unstratified and poorly sorted clay, silt, sand, and gravel forming landslide deposits; colluvium composed predominantly of sand and gravel, and talus deposits.

Ql

Loess (Holocene to Pleistocene)--Eolian deposits of clay, silt, and fine sand, as much as 75 m thick; locally contains caliche and tephra beds.

Qd

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

Quaternary Catastrophic Flood Deposits

Qfg

Catastrophic flood deposits, gravel (Pleistocene)--Sand and coarse gravel deposited along the Columbia River and in the Moses and Grand Coulees and an unnamed coulee in the southeast corner of the map area by high-energy flows of catastrophic Pleistocene floods, especially the Missoula floods that occurred between 15,300 and 12,700 years ago (Waitt, 1985; Atwater, 1986).

Qfs

Catastrophic flood deposits, slackwater deposits (Pleistocene)--Silt, sand, and minor gravel deposited by low-energy slack waters of catastrophic floods east of the Grand Coulee northeast of Dry Falls Dam. Most of these deposits are rhythmically bedded and graded (Hanson and others, 1979).

Glacial Deposits

Qgd

Glacial drift, undivided (Pleistocene)--Till, glacial outwash, and ice-contact stratified materials; deposited by the Okanogan lobe of the Cordilleran ice sheet during the late Wisconsin. The deposits form moraines, till plains, and meltwater channels and terraces (Hanson and others, 1979).

Qgt

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

Qgo

Glacial outwash (Pleistocene)--Glaciofluvial, fluvial, and ice-contact stratified silt, sand, and gravel deposits in terraces and bars along the Columbia River, East Foster Creek, and Grand Coulee. These deposits were originally named "terrace and bar deposits, undifferentiated" by Hanson and others (1979) and include some of the deposits of the Great Terrace (local terminology) along the Columbia River. They were formed during retreat of the Okanogan lobe of the Cordilleran ice sheet during the late Wisconsin.

Qgl

Glaciolacustrine deposits (Pleistocene)--Silt, sand, and minor gravel deposited in glacial lakes. Some glaciolacustrine terrace surfaces were locally modified by fluvial processes and catastrophic floodwaters (Hanson and others, 1979). Most deposits were formed during the waning stages of late Wisconsin glaciation by the Cordilleran ice sheet.

Tertiary Sedimentary Rocks

QPlc

Ringold Formation (Pleistocene-Pliocene)--Weakly lithified claystone, siltstone, sandstone, conglomerate, and fanglomerate of fluvial and lacustrine origin; locally mantled by a thick caliche layer. Hanson and others (1979) assigned these deposits to the Ringold Formation but recognized that they may be in part correlative with the uppermost Ellensburg Formation. The unit occurs in two small exposures west of Billy Clapp Lake along the south boundary of the map.

Mc

Ellensburg Formation (Miocene)--Weakly lithified subarkosic deposits of fluvial and lacustrine sandstone, siltstone, claystone, and conglomerate. These deposits are interbedded with and overlie the Yakima Basalt Subgroup of the Columbia River Basalt Group. They are composed of detritus eroded from rocks older than the Columbia River Basalt Group (Swanson and others, 1979a).

Tertiary Volcanic Rocks

Yakima Basalt Subgroup of the Columbia River Basalt Group

Mv_{wp}

Wanapum Basalt, Priest Rapids Member (middle Miocene)--Grayish-black, fine- to coarse-grained basalt flows; sparsely plagioclase phyric or with glomerophyric clots of plagioclase and olivine; groundmass olivine visible with handlens in fine-grained samples; slightly diktytaxitic. The four flows of the Priest Rapids Member have reversed magnetic polarity. The thickness of the unit in the map area is unknown, but a total thickness of approximately 67 m is exposed near the Priest Rapids Dam approximately 100 km south of the map area (Grolier and Bingham, 1971).

Two chemical types, the Rosalia and Lolo, have been identified in the Priest Rapids Member. The older flows, of the Rosalia chemical type, are characterized by high TiO_2 and high FeO relative to the younger Lolo type flows. Only flows of the Rosalia chemical type occur on the Banks Lake 1:100,000-scale quadrangle (Swanson and others, 1979b).

Wanapum Basalt erupted between 15.5 and 14.5 Ma (Long and Duncan, 1983). The Priest Rapids Member has been dated at 14.5 Ma outside the map area (Beeson and others, 1985).

Mv_{wr}

Wanapum Basalt, Roza Member (middle Miocene)--Dark blue-gray, medium- to coarse-grained plagioclase-phyric basalt flows. Uniformly distributed plagioclase phenocrysts averaging about 5 mm in length make up 5-8 percent of the Roza. The Roza Member consists of two flows, which attain a maximum combined thickness of 50 m.

The Roza Member has transitional magnetic polarity. Its age is bracketed by the 14.5 Ma Priest Rapids Member above and the 15.5 Ma Frenchman Springs Member below.

Mv_{wrf}

Wanapum Basalt, Roza and Frenchman Springs Members, undivided (middle Miocene)--This map symbol is used at several localities on the map where steep topography prohibits separation of the Roza and Frenchman Springs Members at the 1:100,000 scale.

Mv_{wf}

Wanapum Basalt, Frenchman Springs Member (middle Miocene)--Fine- to medium-grained basalt of normal magnetic polarity, forming as many as nine flows but generally three to six flows in the map area. It typically contains irregularly distributed glomerophyric clots of plagioclase as much as 1 cm in diameter, but some aphyric flows are present and are particularly common in the eastern part of the Columbia Basin.

The Frenchman Springs is the most extensive member of the Wanapum Basalt (Swanson and others, 1979a, 1979b). It overlies sandstone and siltstone of the Vantage Member of the Ellensburg Formation, best observed along the Columbia River. Elsewhere, it directly overlies the Grande Ronde Basalt. The Frenchman Springs Member has been K-Ar dated at 15.5 Ma outside the map area (Long and Duncan, 1983; Beeson and others, 1985).

Mv_{gN2}, Mv_{gR2}, Mv_{g}

Grande Ronde Basalt (middle Miocene)--Dark-gray to black, fine-grained, aphyric basalt flows forming the most areally extensive, voluminous (85 percent), and thickest formation of the Columbia River Basalt Group. Grande Ronde Basalt flows erupted between 17 and 15.5 Ma (Long and Duncan, 1983; Beeson and others, 1985). The Grande Ronde Basalt consists of many, perhaps hundreds, of individual flows with a variety of physical characteristics. It is divided into four magnetostratigraphic units. Only the upper two are present in the map area:

Mv_{gN2}

Magnetostratigraphic unit N2; upper Grande Ronde Basalt flows of normal magnetic polarity.

Mv_{gR2}

Magnetostratigraphic unit R2; upper Grande Ronde Basalt flows of reversed magnetic polarity.

The Grande Ronde Basalt west of the Columbia River on Deer Mountain is shown by the symbol Mv_g because magnetostratigraphic measurements have not been made.

Igneous Intrusive Rocks

Hypabyssal Intrusive Rocks

$Eida_g$,

Dacite-porphyry dike swarm of Goat Mountain (Eocene)--Light- to dark-gray dacite-porphyry dikes; consists of plagioclase phenocrysts as much as 5 cm long and euhedral quartz crystals in a microcrystalline groundmass of quartz, K-feldspar, and plagioclase; glomeroporphyritic clots of biotite and hornblende are common. Individual dikes range from 50 cm to more than 30 m wide. They are proximal to the margin of the Cooper Mountain batholith in the northwest corner of the map area, striking within 20 degrees of north and dipping 75 to 90 degrees. Textural and mineralogic similarities between the dikes and the Cooper Mountain granodiorite ($Eigd_c$) suggest that they are genetically related, but the dikes intrude the granodiorite and are therefore younger (Raviola, 1988).

$Eida_b$,

Hypabyssal dacite porphyry dikes near Banks Lake (Eocene)--Biotite, quartz, ± K-feldspar, porphyritic dacite dikes and hornblende-dacite-porphyry dikes at the northeast end of Banks Lake. The dikes in this area are much more numerous than can be shown at the map scale. They have well-developed chilled margins, which are locally vitrophyric (Holder and Holder, 1987). The dacite porphyry is probably related to the dacitic volcanic rocks in the Republic graben to the northeast of the map area.

Eitr,

Trachyte dikes (Eocene)--Trachyte porphyry dikes northeast of Beebe that contain 0.5-cm K-feldspar phenocrysts in a fine-grained groundmass. Mafic minerals are altered and unrecognizable; green epidote is present.

Eir,

Rhyolite dikes (Eocene)--Biotite rhyolite dikes consisting of small phenocrysts of biotite, feldspar, and euhedral quartz in a light-gray, aphanitic groundmass; grades(?) into fine-grained holocrystalline rhyolite. The dikes are present east of the Columbia River in the vicinity of Chelan Falls.

Eida,

Dacite and andesite dikes (Eocene)--Undivided andesitic to dacitic, fine-grained, holocrystalline porphyritic andesite and dacite dikes in the vicinity of the Columbia River.

Eian

Andesite dikes (Eocene)--Primarily hornblende-plagioclase lamprophyres (spessartite). These are fine- to medium-grained, aphanitic to sparsely porphyritic rocks that intrude both the Alta Lake metamorphic rocks and the Arbuckle Mountain tonalite in the northwest corner of the map area. The dikes are commonly altered to chlorite, calcite, and prehnite.

Plutonic Intrusive Rocks

$Eigd_c$

Cooper Mountain batholith (Eocene)--Light-gray to tan, medium-grained (2-3 mm average) granodiorite; contains 50 percent plagioclase, 15-20 percent K-feldspar, 15-20 percent quartz, 6-7 percent fine-grained biotite, 1-5 percent hornblende, 1 percent sphene, and accessory apatite, rutile, ilmenite, and zircon; minor epidote and calcite veins. The grain size and porphyritic nature of the unit increase to the west (Raviola, 1988).

The granodiorite covers less than 1 km^2 in the northwest corner of the map area, where it intrudes the amphibolite, schist, and gneiss of Alta Lake. Contacts are typically sharp and discordant. Most of the Cooper Mountain batholith lies northwest of the map area in the Twisp quadrangle (Barksdale, 1975), from which a K-Ar biotite age of 48.1 ± 4.5 Ma has been reported (Tabor and others, 1987).

Eimd

Biotite-hornblende monzodiorite (Eocene)--Medium-grained, equigranular to inequigranular, biotite-hornblende monzodiorite to granodiorite. The rocks contain abundant sphene and, locally, altered white plagioclase phenocrysts and have a color index of 8 to 30. The unit crops out near the north end of Banks Lake. (Holder and Holder, 1987).

$EPig_s$

Granite of Swawilla Basin (Eocene or Paleocene)--Fine- to medium-grained leucocratic biotite granite and granodiorite with sparse, small, equant K-feldspar phenocrysts and rounded smoky quartz grains; color index of 3 to 8. These rocks are exposed at the north end of Banks Lake. Near the contact with the migmatitic granodiorite of Gibraltar Rock ($Mzmg_g$), the unit contains sphene and minor, possibly xenocrystic black, elongate hornblende (Holder and Holder, 1987).

The granite of Swawilla Basin is part of the Eocene-Paleocene Keller Butte pluton of Carlson (1984) and the Keller Butte Suite of Holder and Holder (1988). The unit was named by Atwater and Rinehart (1984) for rocks in the Coulee Dam and Nespelem 1:100,000-scale quadrangles.

$EPig_c$

Granite of Coffee Lake (Eocene or Paleocene)--Coarse-grained, equigranular biotite granite; color index of 3 to 5. The unit, informally named here, appears to grade into the migmatitic granodiorite of Gilbraltar Rock ($Mzmg_g$) at the north end of Banks Lake, but contacts are poorly exposed and deeply weathered (Holder and Holder, 1987). The granite is believed to be part of the Keller Butte pluton of Carlson (1984) and the Keller Butte Suite of Holder and Holder (1988).

EPigd

Granodiorite (Eocene(?) or Paleocene(?))--Medium-grained biotite granodiorite, with weak foliation and textural banding; forms deeply weathered outcrops in the northeast corner of the map area. The granodiorite may be part of the Keller Butte pluton of Carlson (1984) and the Keller Butte Suite of Holder and Holder (1988).

$TKit_a$

Arbuckle Mountain tonalite (early Tertiary(?) or late Cretaceous(?))--Equigranular, medium- to coarse-grained tonalite composed of 60 percent plagioclase (An_{25-35}), 25 percent quartz, 6 to 10 percent biotite, 1 percent large subhedral sphene, and accessory amounts of hornblende, apatite, and opaque minerals. In places, yellow-brown to dark-green pleochroic hornblende is relatively fresh and not resorbed. Deformation indicators such as quartz subgrain development and bent plagioclase twin lamellae occur at the margin of the pluton.

The Arbuckle Mountain tonalite is cut by medium-grained aplitic dikes, most of which are less than 1 m wide. Dikes of fine-grained diorite and schlieren of fine-grained amphibolite occur near the margin of the tonalite. Along its north and northwest edge, the Arbuckle Mountain tonalite intrudes the amphibolite, schist, and gneiss of Alta Lake ($pKhm_a$) and the migmatite of the Alta Lake metamorphic rocks ($KJmg_a$). The contact is sharp and marked by rotated xenoliths of coarse-grained amphibolite (Raviola, 1988). Along its south and southwest edge, the contact of the Arbuckle Mountain tonalite with banded gneiss of the Chelan Complex (Kbg_c) is largely obscured by glacial drift. A few poor exposures indicate that dikes of Arbuckle Mountain tonalite intrude the tonalite and tonalite gneiss of the Chelan Complex (Ktg_c).

A K-Ar biotite age of 81.2 ± 3.0 Ma was determined for this report (Table 1), but the biotite in this rock is commonly partially altered to chlorite. Since the Arbuckle Mountain unit intrudes the Chelan Complex (which produces dates suggesting crystallization and metamorphism at about 70 to 86 Ma and uplift through hornblende and biotite blocking temperatures at 60 and 56 Ma (Tabor and others, 1987)), and since the Arbuckle Mountain tonalite shows a lack of metamorphism and relatively minor alteration, we question the 81.2 Ma K-Ar date and believe that a Paleocene to Eocene age cannot be ruled out.

Mixed Igneous and Metamorphic Rocks of Plutonic Complexes

Chelan Complex

$Kigb_c$

Gabbro of the Chelan Complex (Cretaceous)--Medium- to coarse-grained to pegmatitic, directionless hornblende gabbro with euhedral to subhedral hornblende prisms in a groundmass of plagioclase and accessory sphene, apatite, epidote, and rare muscovite. The gabbro is enclosed by leucocratic tonalite of the Chelan Complex (Ktg_c). Hopson (1955, p. 11) suggests that "The gabbro formed by recrystallization of pre-batholithic basic rock...based on the presence of uralitic pyroxenite intermingled with the gabbro, and the uralitic character (relict pyroxene cores) of some of the hornblendes." The gabbro occurs in two small exposures 1.6 km north of Chelan Falls.

Ktg_c

Leucocratic tonalite and tonalite gneiss of the Chelan Complex (Cretaceous)--White to light-gray, medium-grained (3-4 mm), leucocratic (color index of 3-12), weakly to strongly foliated and locally directionless biotite tonalite gneiss. The unit contains tabular and irregularly shaped dike-like bodies of fine-grained biotite gneiss and schist that are both concordant and discordant to foliation. The unit locally contains amphibolite schlieren.

The leucocratic tonalite gneiss is generally homogeneous but is varied in composition and texture in proximity to migmatite, mesocratic tonalite gneiss, and banded tonalite gneiss of the Chelan Complex. The leucocratic tonalite gneiss resembles the leucocratic parts of the migmatitic rocks which may have been magmatically or anatectically derived.

This unit was called "leucocratic quartz diorite" by Hopson (1955) and assigned to the "Chelan batholith". Hopson and Mattinson (1971) and Mattinson (1972) assigned these and associated rocks to the Chelan Complex and demonstrated with U-Pb dating that the "complexing" took place during the Cretaceous. The protolith may be Jurassic or older, with zircon crystallization at 70 to 86 Ma and uplift and cooling through the K-Ar blocking temperatures for hornblende and biotite at 60 and 56 Ma (Tabor and others, 1987).

$Ktgm_c$

Mesocratic tonalite gneiss of the Chelan Complex (Cretaceous)--Mesocratic, biotite-hornblende tonalite gneiss, hornblende tonalite gneiss, and minor biotite tonalite gneiss and amphibolite; gradational with the leucocratic tonalite gneiss, banded tonalite gneiss, and migmatite of the Chelan Complex. Strongly banded parts of the unit consist of alternating layers of weakly gneissic granitoid rocks, strongly lineated and foliated mesocratic gneisses, and massive granoblastic to schistose "microdiorites" (Hopson, 1955). Mattinson (1972) reported U-Pb zircon and sphene ages ranging from 87 to 111 Ma from the mesocratic tonalite gneiss just east of the Columbia River (Table 1).

Kmg_c

Migmatite of the Chelan Complex (Cretaceous)--Includes: migmatitic leucocratic tonalite gneiss, migmatitic mesocratic and melanocratic tonalite gneiss, migmatitic banded tonalite gneiss, and mixed to brecciated igneous and high-grade metamorphic rocks. In places, strongly migmatitic amphibolite, gneiss, and schist are preserved as mafic schlieren in predominantly leucocratic tonalite gneiss.

Two generations of migmatization are evident in some areas (Hopson, 1955). Mattinson (1972) obtained U-Pb zircon and sphene ages ranging from 82 to 113 Ma from part of the migmatite (Table 1).

Kbg_c

Banded tonalite gneiss of the Chelan Complex (Cretaceous(?))--Biotite tonalite gneiss, biotite-hornblende tonalite gneiss, amphibolite gneiss, and minor biotite and biotite-hornblende schist. The banding is concordant, with discontinuous bands, minor swirling, and gradational boundaries between bands. The banded tonalite unit is commonly associated with leucocratic tonalite gneiss, which cross cuts and injects the banded gneiss *lit par lit*.

The banded tonalite gneiss is probably metamorphosed sedimentary and volcanic rocks of pre-Cretaceous age. The banding may represent relict primary bedding, but some of the bands may be the result of metamorphic segregation or magmatic injection. West of the map area, the unit was called "banded migmatite" by Hopson (1955) and "migmatite and banded migmatite" by Tabor and others (1987).

$pKam_c$

Amphibolite within the Chelan Complex (pre-Cretaceous)--Massive to weakly foliated amphibolite and granoblastic microdiorite composed of plagioclase, hornblende, epidote, and ± biotite, with minor quartz and sphene. The unit consists of banded coarse-grained amphibolite that contains quartzo-feldspathic layers and finely laminated amphibolite. Banding is thought to be the result of metamorphic segregation of light and dark minerals (Hopson, 1955). These rocks may be older than the Cretaceous formation of the Chelan Complex, and are therefore shown as pre-Cretaceous.

$pKhm_c$

Heterogeneous metamorphic rocks within the Chelan Complex (pre-Cretaceous)--Biotite-hornblende gneiss, biotite schist, amphibolite schist, garnet schist, and quartzite. These paragneisses and schists are parts of the country rocks that were intruded(?) by and included in the Chelan Complex during the Cretaceous. The rocks are exposed in the cliffs along the east side of the Columbia River northeast of Beebe. These metamorphic rocks may correlate with the Alta Lake metamorphic rocks ($pKhm_a$) and/or the amphibolite and schist of Twentyfive Mile Creek ($pKhm_t$); if so, the correlation would suggest an upper Paleozoic protolith age.

Other Plutonic Complexes

$KJmg_a$

Migmatite, Alta Lake metamorphic rocks (Cretaceous-Jurassic(?))--Strongly migmatized portions of the amphibolite, schist, and gneiss of Alta Lake. The unit is composed of 25-60 percent leucosomes of granite, trondhjemite, pegmatite, and aplite, and melanosomes of schistose amphibolite, gneiss, and schist. The unit is characterized by highly irregular layering and complex cross-cutting relations among the melanocratic, mesocratic, and leucocratic rocks (Raviola, 1988). This unit is probably the result of migmatization of the amphibolite, schist, and gneiss of Alta Lake by the intrusion of the Methow Gneiss and the Okanogan complex.

$Mzmg_g$

Migmatitic granodiorite of Gibraltar Rock (Mesozoic(?))--Heterogeneous intrusive suite composed of granodiorite and granite intermixed with tonalite gneiss and quartz-feldspar pegmatite veins and pods. The migmatite is dominated by fine- to coarse-grained, inequigranular biotite-hornblende granodiorite with locally abundant brown sphene. The granodiorite varies texturally from medium grained porphyritic with euhedral potassium feldspar phenocrysts 2-4 cm in length, to medium to coarse grained seriate, to fine to medium grained with irregular pods and patches of potassium feldspar 2-10 cm in length. The color index is 3 to 20. The granodiorite is mostly unfoliated but locally exhibits well-developed biotite banding.

Nebulitic inclusions of biotite-hornblende tonalite gneiss are also common in the granodiorite. These inclusions dominate in exposures along Washington State Route 155 (SE1/4SW1/4 sec. 6, T27N, R30E). The inclusions are heterogeneous, with leucocratic to melanocratic and fine- to coarse-grained components, but are generally darker than the surrounding granodiorite or granite. Mesocratic, well-foliated, medium-grained biotite tonalite gneiss forms the dominant lithology of the inclusions. Hornblende crystals as much as 4 mm in length are locally abundant. Gneissic foliation in inclusions is commonly folded into complex disharmonic structures. Contacts between the gneissic inclusions and unfoliated granodiorite are typically gradational and highly irregular; locally, contacts are sharp, and outcrops have the appearance of a plutonic breccia with inclusion blocks as much as 2 m in length.

Numerous quartz-feldspar pegmatite veins and pods cut all of the lithologies of the migmatite, and they are in turn cut by Eocene rhyodacite sills and dikes. Chlorite- and epidote-bearing shear zones, with offsets of as much as 0.5 m, are common and cut all lithologies.

The unit is exposed in the hills along the northeast shore of Banks Lake. The migmatite of Gibraltar Rock may be the extension of the plutonic complex of Boot Mountain, which crops out north of the map area on the Omak 1:100,000-scale quadrangle (Atwater and Rinehart, 1984; Gulick and Korosec, in press). Both units were probably formed by migmatization and complexing of older Mesozoic and upper Paleozoic igneous and sedimentary rocks in the Cretaceous(?).

High-Grade Metamorphic Rocks

KJog

Tonalite gneiss near Chief Joseph Dam (Cretaceous-Jurassic(?))--Light-gray to white, directionless to weakly foliated tonalite gneiss; leucocratic and homogeneous; schlieren locally abundant. The tonalite gneiss near Chief Joseph Dam may correlate with an extensive unit of grossly homogeneous directionless to gneissic leucocratic trondhjemite in the Okanogan complex to the northwest on the Omak and Robinson Mountain 1:100,000-scale quadrangles (see Gulick and Korosec, in press; Stoffel, 1990). Those rocks, which range in age from Jurassic to Cretaceous, form a nearly continuous north-northwest-trending belt that extends into southern British Columbia.

The unit crops out from near Chief Joseph Dam to about 5 km south along Washington State Route 17.

pKhm$_a$

Amphibolite, schist, and gneiss of Alta Lake (pre-Cretaceous)--Banded heterogeneous, high-grade metamorphic rocks consisting of 55-60 percent schistose amphibolite and layers of quartz-hornblende-plagioclase gneiss; 25-30 percent leucocratic tonalite gneiss; 5-6 percent hornblende-quartz-biotite-plagioclase schist, which forms discontinuous, well-layered, oxidized, sharply bounded bands; and 1-2 percent calc-silicate schist, biotite schist, and coarse-grained actinolite schist. Trondhjemitic dikes and sills, 0.3 to 5 m wide, cut the banded rocks. Banding in the Alta Lake unit varies from planar lenticular to discrete and is locally swirled near the migmatite (KJmg$_a$). Nematoblastic hornblende prisms commonly define lineation that is in most places coplanar with the foliation in the gneiss and schist. Tight to isoclinal folds, locally boudinaged, are common (Raviola, 1988). The unit is exposed near the northwest corner of the map.

The Alta Lake metamorphic rocks are intruded by the Cooper Mountain batholith and the porphyry dike swarm of Goat Mountain. A K-Ar hornblende age of 104 ± 5 Ma has been determined from an amphibolite 6 km north of the map area on the Omak 1:100,000-scale quadrangle (Gulick and Korosec, in press), but this represents a metamorphic age and not the age of the protolith. The amphibolite, schist, and gneiss of Alta Lake are correlative with the Leecher Metamorphics to the north on the Omak and Twisp 1:100,000-scale quadrangles, and may be correlative with the amphibolite and schist of Twentyfive Mile Creek ($pKhm_t$) to the west. These correlations would suggest an upper Paleozoic age (Permian) for the Alta Lake rocks, but they are shown as pre-Cretaceous because of the uncertainty of the correlations.

$pKhm_t$

Amphibolite and schist of Twentyfive Mile Creek (pre-Cretaceous, probably Permian)--Schistose amphibolite, biotite schist, siliceous schist, and rare marble (Tabor and others, 1987); correlated with Permian "younger gneissic rocks of the Holden area"; possibly correlative with the amphibolite, schist, and gneiss of Alta Lake ($pKhm_a$). The unit occupies one small area on the west edge of the Banks Lake 1:100,000-scale quadrangle just north of Antoine Creek. See Tabor and others (1987) for a more detailed description of the unit.

$pJhm_l$

Metamorphic rocks east of Leahy (pre-Jurassic)--Layered gneiss, schist, and quartzite intruded by medium-grained biotite granodiorite(?) and pegmatite. The pegmatite is muscovite-bearing and contains accessory tourmaline and garnet. The unit consists of several small outcrops just north of, and one roadcut along Washington State Route 174 just east of Leahy. These metamorphic rocks may be correlative with the north-northwest-trending belt of compositionally similar rocks on the Omak 1:100,000-scale quadrangle to the north (Gulick and Korosec, in press); therefore, a pre-Jurassic age is assigned.

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Table 1. Radiometric age data for the Banks Lake 1:100,000 quadrangle

Location no.	Sample no.	Unit	Map symbol	N.Lat.	W.Long.	Method	Material	Age (Ma)	Reference
1	68-4	Migmatite, Chelan Complex	Kmg_c	47°49.0'	119°59.0'	Pb^{206}/U^{238}	zircon	113	
							sphene	82	Mattinson (1972)
						Pb^{207}/U^{235}	zircon	113	
						Pb^{207}/Pb^{206} [1]	zircon	107 ± 25	
2	68-5	Mesocratic tonalite gneiss, Chelan Complex	$Ktgm_c$	47°48.8'	119°58.1'	Pb^{207}/Pb^{206} [1]	zircon	111 ± 15	
							zircon	101	Mattinson (1972)
						Pb^{206}/U^{238}	zircon	100	
							sphene	87	
3	AM-123	Arbuckle Mtn. tonalite	$TKit_a$	57°30.15'	119°52.5'	K-Ar [2]	biotite	81.2 ± 3.0	This report
4	UO-100KAr	Grande Ronde Basalt (N_2)	Mv_{gN2}	47°56.4'	119°00.2'	K-Ar [3]	whole rock	16.8 ± 0.5	Gray and Kittleman (1967)
5	UO-101KAr	Grande Ronde Basalt (N_2)	Mv_{gN2}	47°56.4'	119°00.2'	K-Ar [3]	whole rock	15.7 ± 0.4	Gray and Kittleman (1967)

[1] Mattinson (1972): $Pb^{206}/Pb^{204} = 18.9$; $Pb^{207}/Pb^{204} = 15.6$

[2] Unpublished DGER data, this report: $K^{40}/K = 1.193 \times 10^{-4}$g/g; $\lambda_e + \lambda_{e'} = 5.81\ 10^{-10}$/yr; $\beta = 4.962 \times 10^{-10}$\yr

[3] Gray and Kittleman (1967): $K^{40}/K = 1.19 \times 10^{-4}$g/g; $\lambda_e + \lambda_{e'} = 0.585 \times 10^{-10}$/yr; $\beta = 4.72 \times 10^{-10}$/yr

Table 2. Major-element analyses for igneous rocks of the Banks Lake 1:100,000 quadrangle; analyses by XRF, Dept. of Geology, Washington State University, October 1987; all analyses normalized on a volatile-free basis with FeO* = Total Fe as FeO. Reported as weight percent oxide.

Sample no.	Geologic unit	Chemical data										Location					
		SiO_2	Al_2O_3	TiO_2	FeO*	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	1/4	1/4	1/4	Sec.	Twp.	Rge.
AC276B	Eian(dike)	57.09	16.64	1.162	6.47	0.114	6.48	6.36	2.42	2.73	0.543	SE	NE	SE	30	29	23E
2824061H	Eii$_d$	65.91	15.96	0.596	3.64	0.059	4.03	3.21	2.35	4.04	0.219	NE	NE	NE	06	28	24E
2723283G	Eir	74.35	14.08	0.246	1.42	0.044	1.13	0.36	4.31	3.97	0.098	SE	NW	NE	28	27	23E
MK870623	Eir	74.07	14.28	0.25	1.28	0.04	1.46	0.39	4.53	3.61	0.10		NE	NW	9	27	23E
2723104B	Eitr	68.25	16.38	0.357	2.74	0.044	1.27	0.28	6.27	4.35	0.062	NW	SW	SE	10	27	23E
MK870628AB	Kiqd$_a$	73.70	15.22	0.17	1.08	0.03	2.31	0.27	2.30	4.88	0.04		SE	SW	6	28	24E
AM540	Kit	65.07	17.70	0.768	4.22	0.041	4.27	1.26	2.36	4.05	0.267	NW	SE	SE	28	29	23E
ALE122	Kmg$_a$	59.50	19.14	0.576	5.50	0.099	7.09	2.67	0.98	4.21	0.234	SE	NW	SE	21	29	23E
MK870641	Ktg$_c$	67.12	18.46	0.36	2.28	0.03	4.16	0.53	0.87	6.06	0.12		SW	SW	22	28	23E
MK870642	Ktg$_c$	66.86	18.38	0.35	2.24	0.05	4.15	0.59	0.86	6.39	0.12		SW	NW	22	28	23E
2529031C	Mv$_{gN2}$	54.78	14.04	2.180	11.56	0.211	8.41	4.16	1.36	2.85	0.446	SE	NE	SE	03	25	29E
2529098D	Mv$_{gN2}$	54.43	14.12	1.975	11.74	0.209	8.45	4.65	1.26	2.77	0.393	NW	NW	SW	09	25	29E
2625111E	Mv$_{gN2}$	54.26	14.14	1.755	11.41	0.201	8.81	5.06	1.18	2.90	0.275	SE	SE	NE	11	26	25E
2723056B	Mv$_{gN2}$(?)	55.48	14.65	1.912	9.99	0.214	8.65	4.51	1.26	2.96	0.384	NW	SE	SW	05	27	23E
2723087H	Mv$_{gN2}$(?)	55.91	14.93	1.975	9.16	0.192	8.67	4.57	1.25	2.96	0.400	NE	NW	NW	08	27	23E
2723335H	Mv$_{gN2}$(?)	56.22	14.25	2.282	10.58	0.191	7.74	3.39	1.84	3.12	0.397	NE	NE	NW	33	27	23E
2529098H	Mv$_{wf}$(?)	52.85	13.51	2.816	13.48	0.212	8.33	4.22	1.32	2.70	0.548	NW	NW	NW	09	25	29E
2523366A	Mv$_{wp}$	50.77	12.96	3.582	15.10	0.223	8.55	4.24	1.26	2.51	0.790	SW	SE	SW	36	25	23E
2526038E	Mv$_{wp}$	50.58	12.93	3.558	15.00	0.245	8.52	4.44	1.40	2.55	0.784	SW	SW	NW	03	25	26E
2625321H	Mv$_{wp}$	50.79	12.93	3.576	14.92	0.238	8.64	4.23	1.27	2.61	0.793	NE	NE	NE	32	26	25E
2626101G	Mv$_{wp}$	50.79	12.91	3.534	14.92	0.247	8.39	4.57	1.26	2.59	0.786	SE	NE	NE	10	26	26E
2626222F	Mv$_{wp}$	50.44	12.89	3.522	15.07	0.249	8.49	4.58	1.30	2.69	0.775	NW	SE	NE	22	26	26E
2626361F	Mv$_{wp}$	50.67	12.82	3.603	14.92	0.253	8.58	4.40	1.33	2.64	0.792	NE	SE	NE	36	26	26E
2723014A	Mv$_{wp}$	50.58	12.88	3.563	15.02	0.241	8.47	4.39	1.28	2.78	0.794	SW	SW	SE	01	27	23E
2824052F	Mv$_{wp}$	50.89	13.05	3.530	14.72	0.244	8.48	4.50	1.22	2.58	0.786	NW	SE	NE	05	28	24E
2827014F	Mv$_{wp}$	51.01	12.89	3.598	14.58	0.234	8.60	4.33	1.33	2.64	0.789	NW	SW	NE	01	28	27E
2526038C	Mv$_{wr}$	51.43	13.90	3.042	13.48	0.222	8.74	4.66	1.32	2.59	0.625	SW	NW	SW	03	25	26E
2625351G	Mv$_{wr}$	51.33	13.34	3.129	14.39	0.224	8.69	4.34	1.21	2.66	0.681	SE	NE	NE	35	26	25E
2626365F	Mv$_{wr}$	51.30	13.76	3.163	13.78	0.214	8.82	4.43	1.11	2.76	0.661	NE	SE	NW	36	26	26E
WC609	pKhm$_a$	61.48	17.02	0.67	4.77	0.09	7.15	2.94	1.44	4.24	0.20		NW	NW	19	29	23E
AC587	pKhm$_a$	48.12	16.98	0.99	11.05	0.25	11.24	8.59	0.28	2.31	0.17		SE	NW	21	29	23E
WC608	pKhm$_a$	61.39	15.19	0.70	5.95	0.10	8.95	2.79	1.98	2.77	0.19		NW	NW	19	29	23E
AC283	pKhm$_a$	63.17	15.07	0.782	7.13	0.165	6.00	3.23	0.27	4.10	0.093	SW	NW	NW	29	29	23E
AC555X	pKhm$_a$	68.53	15.27	0.372	3.77	0.090	2.92	3.45	1.49	4.05	0.056	SE	SW	SW	22	29	23E
MK870628A	TKit$_a$	73.63	15.22	0.17	1.05	0.03	2.28	0.25	2.51	4.80	0.04		SW	SW	6	28	24E
MK870915A	TKia$_a$	75.91	14.22	0.09	0.51	0.15	1.10	0.08	4.28	3.76	0.03		NW	SW	32	29	24E
MK870612	TKit$_a$	66.43	16.92	0.68	3.81	0.06	3.92	1.27	2.40	4.31	0.21		SE	SW	31	29	24E
MK870622	TKit$_a$	70.97	15.77	0.31	1.91	0.04	3.05	0.61	2.89	4.34	0.11		SE	SW	31	29	24E
MK870668	TKit$_a$	68.45	15.97	0.62	3.63	0.06	3.56	1.27	2.20	4.04	0.21		NW	NE	2	28	23E
MK870915	TKit$_a$	58.68	15.25	1.19	5.74	0.09	5.53	6.39	3.21	3.23	0.68		SW	SW	32	29	24E

Table 3. Trace-element analyses for igenous rocks of the Banks Lake 1:100,000 quadrangle; analyses by XRF, Department of Geology, Washington State University, October, 1987. Reported in parts per million

SAMPLE	NI	CR	SC	V	BA	RB	SR	ZR	Y	NB	GA	CU	ZN
AC276B	109	244	20	137	977	36	749	252	23	23.0	12	23	70
2824061H	80	84	11	88	832	63	790	171	12	10.0	22	42	71
2723283G	12	0	2	8	588	167	137	103	18	10.0	20	22	41
MK870623	12	0	8	0	6220	182	163	106	17	10.0	17	33	49
2723104B	9	0	7	0	593	118	39	507	29	14.0	23	21	64
MK870628AB	9	0	4	23	820	53	459	74	8	4.7	17	9	36
AM540	8	0	9	33	1110	57	731	214	8	7.0	21	20	66
ALE122	16	11	20	132	503	24	1007	93	12	4.0	17	49	73
MK870641	10	0	10	43	652	19	1100	135	5	3.3	20	18	49
MK870642	7	0	9	33	665	14	1155	141	6	5.0	20	21	63
2529031C	6	36	31	288	550	30	317	168	35	13.0	24	37	123
2529098D	8	44	34	289	505	30	307	160	33	13.0	19	34	116
2625111E	9	51	34	323	436	26	307	149	31	10.0	21	45	108
2723056B	8	47	33	307	581	28	344	163	36	12.0	19	39	118
2723087H	13	44	36	285	685	29	348	168	37	13.0	25	37	122
2723335H	8	23	32	377	752	49	321	180	35	14.0	21	40	129
2529098H	9	51	31	396	602	30	323	182	39	17.0	20	21	130
2523366A	8	25	33	431	541	34	302	208	45	20.0	24	20	148
2526038E	12	29	33	413	575	32	296	209	48	20.0	22	31	155
2625321H	5	25	35	407	584	30	304	209	46	21.0	17	26	153
2626101G	9	23	35	414	534	31	286	206	47	20.0	25	33	147
2626222F	7	25	35	420	520	31	291	203	45	20.0	24	42	150
2626361F	10	23	33	431	519	30	292	209	46	20.0	25	29	153
2723014A	8	25	38	423	551	34	292	209	47	18.0	23	43	151
2824052F	8	25	37	416	524	31	288	205	46	19.0	26	37	151
2827014F	10	24	33	430	533	30	300	210	48	20.0	25	22	149
2526038C	14	51	32	413	491	29	309	172	39	16.0	23	32	132
2625351G	14	40	35	408	506	28	321	186	40	16.0	24	43	141
2626365F	16	50	36	432	512	22	321	183	40	17.0	25	47	139
WC609	20	42	23	176	712	28	1025	118	20	1.6	14	16	68
AC587	87	206	36	268	92	5	353	52	27	0.0	15	48	104
WC608	15	37	22	156	1364	35	1089	123	26	2.8	18	51	130
AC283	16	41	23	198	58	3	198	95	28	2.0	15	37	85
AC555X	13	18	16	88	251	37	197	152	36	2.0	18	32	60
MK870628A	11	0	7	7	891	54	452	71	8	5.2	18	10	40
MK870915A	12	0	6	9	684	115	198	54	10	6.4	18	14	18
MK870612	8	6	10	54	851	60	671	150	12	9.1	22	13	90
MK870622	10	0	8	15	976	63	619	118	9	7.3	17	16	60
MK870668	9	1	11	37	778	53	624	140	11	8.8	21	11	85
MK870915	123	260	17	130	1167	77	831	256	20	20.0	18	58	89