GEOLOGIC MAP OF THE COULEE DAM 1:100,000 QUADRANGLE, WASHINGTON

Compiled by

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

WASHINGTON STATE DEPARTMENT OF
Natural Resources

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INTRODUCTION

The Coulee Dam quadrangle is one of sixteen 1:100,000-scale quadrangles that cover the northeast quadrant of Washington (Fig. 1). Geologic maps of these quadrangles were compiled by Washington Division of Geology and Earth Resources (DGER) geologists and are the principal data sources for a new 1:250,000-scale geologic map of northeastern Washington. Except for the Chelan and Wenatchee quadrangles the 1:100,000-scale quadrangles are available as DGER open-file reports (listed below). The Chelan and Wenatchee quadrangles (Tabor and others, 1982, 1987) have been published by the U.S. Geological Survey (USGS).

This report consists of a geologic map compilation and a description of map units. Tables present new whole-rock geochemical data and isotopic ages for some intrusive and extrusive rocks in the quadrangle. All tables follow the list of cited references.

Sources of geologic mapping used in the compilation of the Coulee Dam 1:100,000-scale quadrangle are shown in Figure 2. Areas where mapping was inadequate were mapped or field checked by DGER geologists (Fig. 2). R. W. Holder and G. M. Holder (under contract to DGER) mapped the pre-Miocene rocks exposed on the south side of Franklin D. Roosevelt Lake (hereafter Roosevelt Lake) between Grand Coulee Dam and the mouth of Hawk Creek (Figure 2). E. P. Kiver and D. A. Stradling of Eastern Washington University (EWU) provided mapping of the Quaternary sedimentary deposits surrounding Roosevelt Lake (Fig. 2).

Rocks of greenschist facies are described under the heading Metasedimentary Rocks, whereas rocks below greenschist facies are included under the heading Sedimentary and Volcanic Rocks and Deposits and Intrusive Rocks. Rocks described under the heading Metamorphic Rocks are limited to those of amphibolite facies or higher. If modal analyses are given in source data, intrusive rock names are assigned using the system recommended by the International Union of Geological Sciences (IUGS) (Streckeisen, 1973). On the basis of new whole-rock geochemical data, volcanic rock names are assigned using the total alkali-silica (TAS) diagram (Zanettin, 1984).

Age assignments of geologic units are made following the flow chart in Figure 3. The Phanerozoic time scale devised by the American Association of Petroleum Geologists for the Correlation of Stratigraphic Units of North America (COSUNA) project (Salvador, 1985), with slight modification of the Eocene-Oligocene and Pliocene-Pleistocene boundaries (Aguirre and Pasini, 1985; Armentrout and others, 1983; Montanari and others, 1985; Prothero and Armentrout, 1985), is used for this report. Additionally, the Precambrian time scale adopted by the North American Commission on Stratigraphic Nomenclature (Harrison and Peterman, 1982) is used for this report. K-Ar ages, originally calculated using constants not currently accepted by the IUGS (see Steiger and Jaeger, 1977), are recalculated using the accepted constants.

Geologic map symbols designate age and lithology. Upper-case letters of the map symbol indicate unit age, and lower-case letters indicate lithology; subscripts identify formal or informal names of units. Thus, the Ordovician marine metasedimentary rocks of the Covada Group are portrayed on the map as Omm_c.

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.

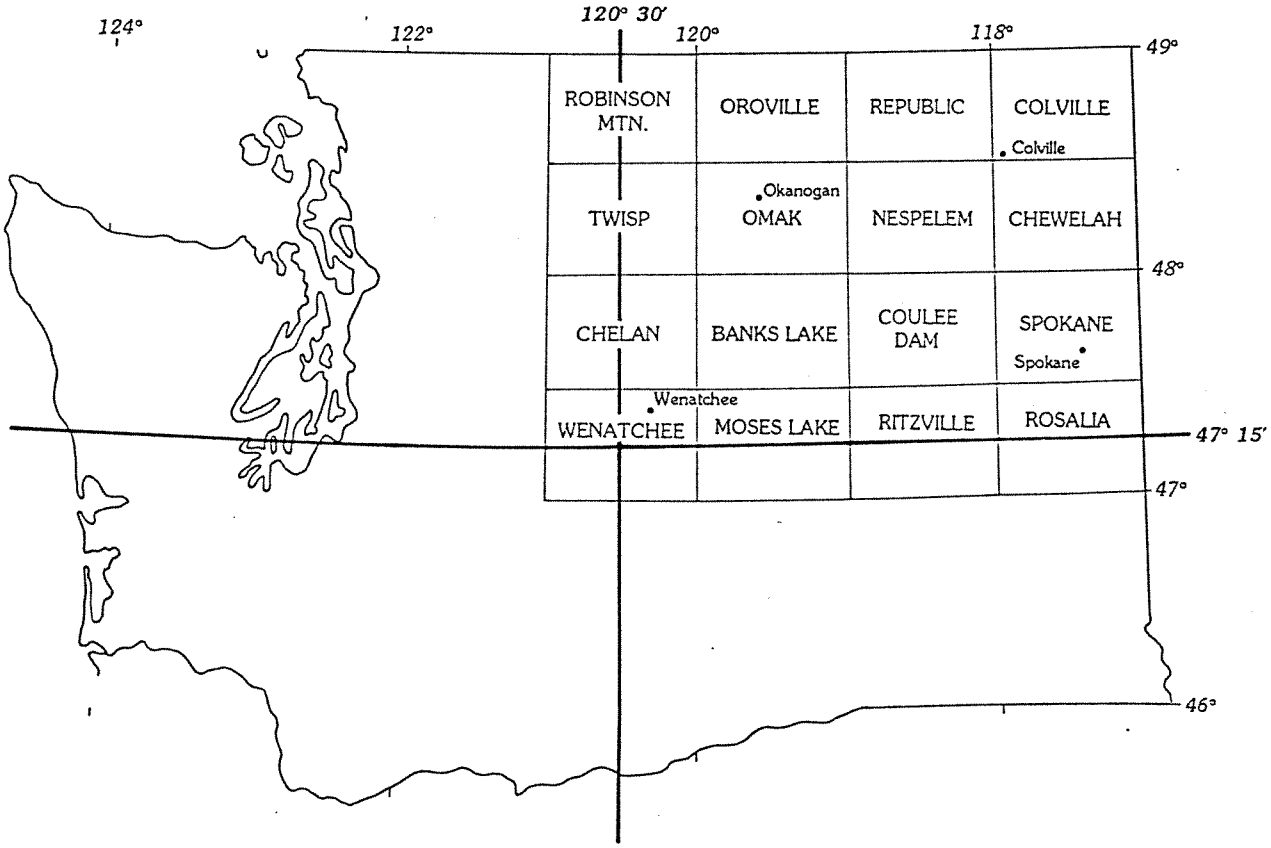
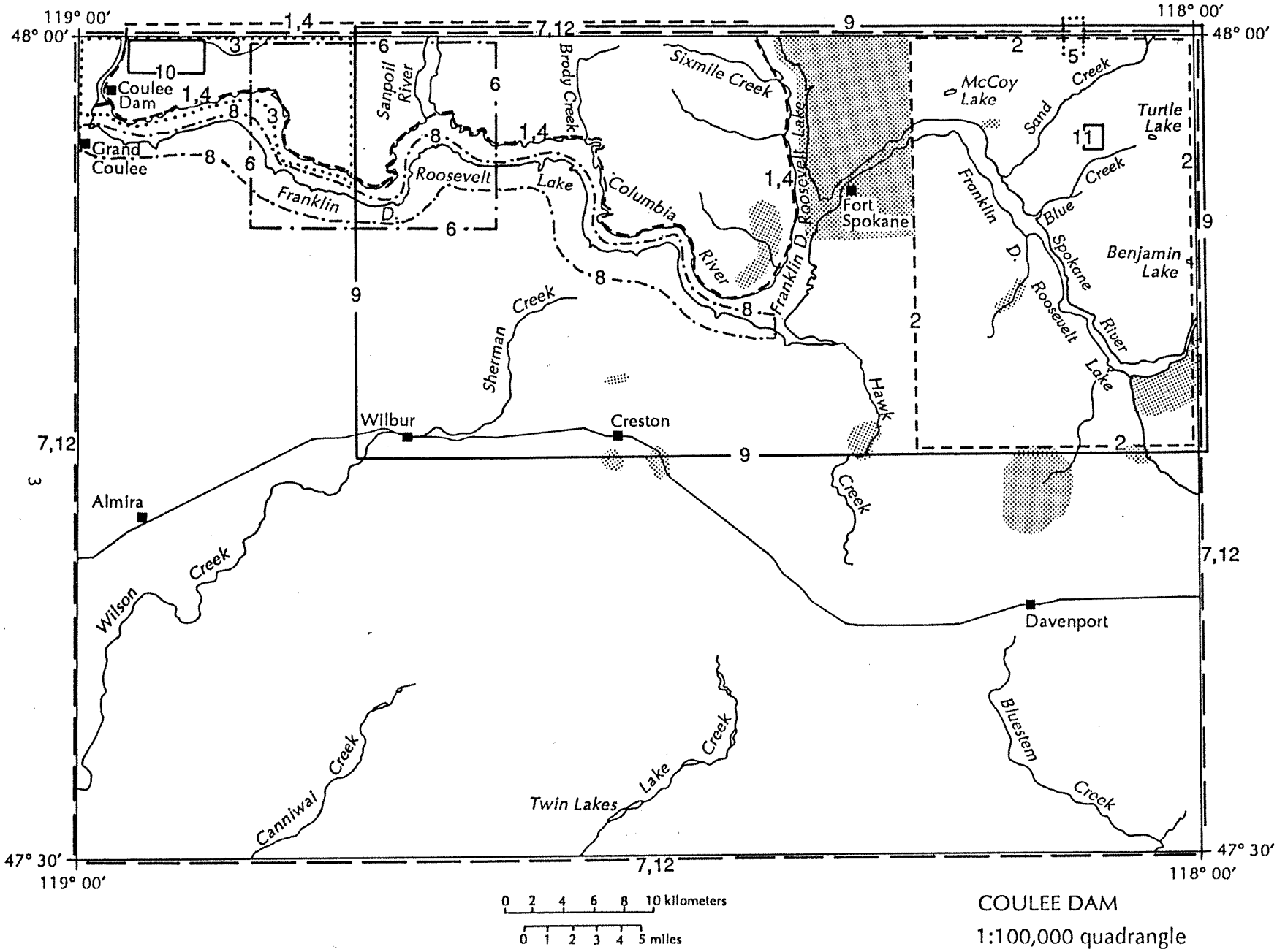


Figure 1. 1:100,000-scale quadrangles in the northeast quadrant of Washington.

Explanation for Figure 2 (facing page)

1. Atwater and Rinehart, 1984, plate 3, scale 1:100,000.
2. Becraft and Weis, 1963, plate 1, scale 1:62,500.
3. Carlson, 1984, plate 1, scale 1:48,000.
4. Colville Confederated Tribes Geology Department, 1984, plate 1, scale 1:250,000.
5. Du, 1979, figure 2, scale 1:12,000.
6. Fleshman and Dodd, 1982, plate 9, scale 1:66,700.
7. Hanson and others, 1979, 1 sheet, scale 1:250,000.
8. Holder, R. W.; Holder, G. A. M., Georgia Southern College, written commun., 1987, 5 maps, scale 1:24,000.
9. E. P. Kiver and D. F. Stradling, Eastern Washington University, written commun., 1986, 38 maps, scale 1:24,000.
10. Milliken, M. D., 1981, figure 4, scale 1:12,000.
11. Nash, 1978, sheet 2, scale 1:1,200.
12. Swanson and others, 1979a, plate 4, scale 1:250,000.

DGER mapping (this report) shown by shaded areas.



COULEE DAM
1:100,000 quadrangle

COULEE DAM 1:100,000 QUADRANGLE

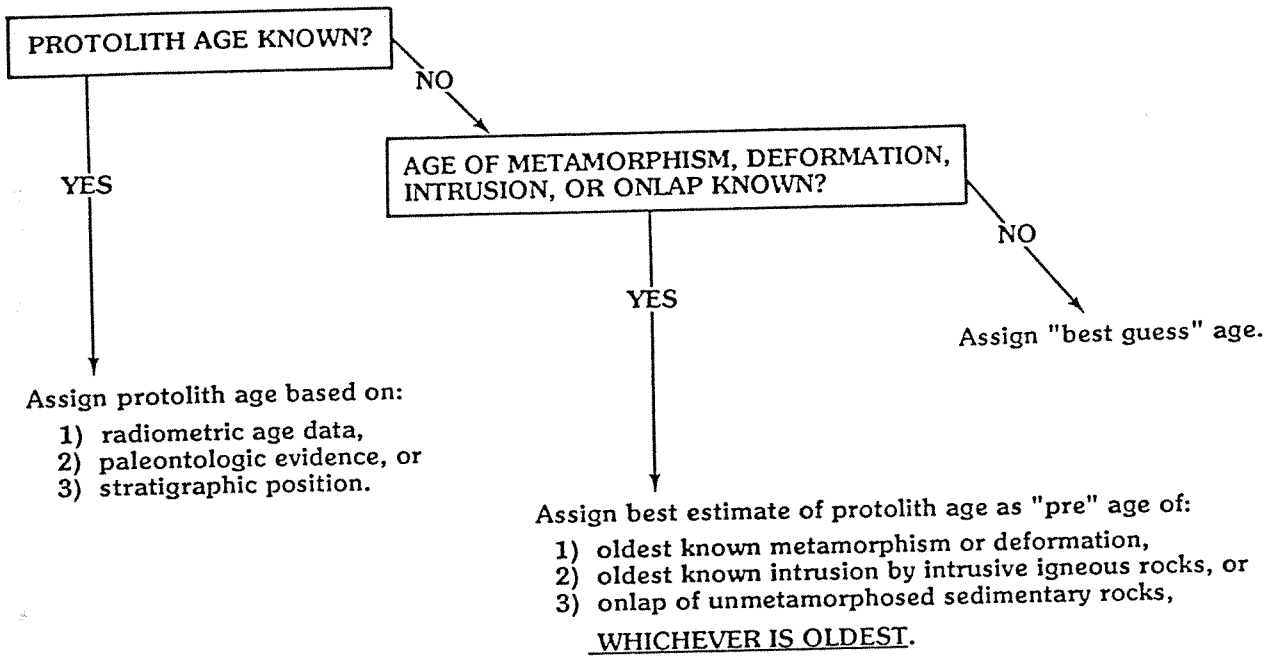


Figure 3. Flow chart for age assignment of geologic units, Protolith age or estimated protolith age can be assigned by correlation with other units. The unit description includes information on how the age of the unit was determined.

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.

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.

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.

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DESCRIPTION OF MAP UNITS

Sedimentary and Volcanic Rocks and Deposits

Quaternary Unconsolidated Sedimentary Deposits

Nonglacial deposits

Qa

Alluvium (Holocene)--Fluvial deposits of gravel and coarse sand confined to channel and coulee floors occupied by modern streams. This unit also includes undissected alluvial fans. In some depressions this unit includes organic-rich deposits, lacustrine silt, and eolian silt. Some alluvium contains discontinuous layers and lenses of volcanic ash.

Qp

Peat deposits (Holocene)--Fibrous and sedimentary peat, muck, and organic-rich alluvium and subordinate woody peat. Some deposits include layers or lenses of ash, diatomite, and clay. Drill data indicate that many deposits are floored by basalt (Rigg, 1958). Most peat deposits are found in depressions occupied by ponds and meadows; some are in scabland coulees.

Qd

Dunes (Holocene)--Dunes, as much as 3 m thick, consisting of fine to medium sand composed chiefly of quartz and basalt grains (Becraft and Weis, 1963). Most dune sand was winnowed from Pleistocene unconsolidated sedimentary deposits. Dunes modify several terrace surfaces, and in some places, deflation hollows are associated with dune fields.

Qls

Mass-wasting deposits (Holocene to Pleistocene)--Landslide deposits, talus, and colluvium composed predominantly of unstratified, unsorted clay, silt, sand, gravel and/or rock debris and minor stratified material in slump blocks (Hanson and others, 1979). Most slide surfaces are hummocky; ancient slides are typically dissected and blanketed by a veneer of loess. Landslides typically occur in terraces composed of glaciolacustrine and outburst flood material along the Columbia River valley and its tributaries. Because most landslide debris is removed by flowing water, many terrace slides are recognizable only by alcoves and scarps in the terraces. Many recent slides occurred in response to fluctuations in the reservoir level of Roosevelt Lake after the construction of Grand Coulee Dam (Jones and others, 1961). Some landslides are present along bluffs where poorly consolidated sedimentary interbeds of the Latah Formation (~~M4c~~$_l$) are intercalated with basalt flows of the Columbia River Basalt Group (~~M4v~~$_{wp}$, ~~M4v~~$_{gN2}$, ~~M4v~~$_{gR2}$). Most talus lies at the base of cliffs and steep slopes of resistant rock.

Ql

Loess (Holocene to Pleistocene)--Chiefly massive eolian silt and fine sand ranging from light tan to yellow-brown to dark red- or orange-brown. Older loess layers typically have deeper coloration. The unit ranges from 75 m to <2 m thick. Accumulations of less than 2 m are not shown on Plate I (Hanson and others, 1979).

Regionally, as many as six upward-fining, unconformity-bounded loess sequences are present (McDonald and Busacca, 1989). Each sequence is made up of one or more loess layers. In most loess sequences the unconformity bounding the base of the sequence is overlain by water-laid sediments consisting of either (1) basaltic gravel, lenses of basaltic sand, and indurated gravel- to sand-size clasts of paleosols; or (2) poorly to well-bedded and laminated silt and sand, commonly containing layers of lag gravel. These water-laid sediments are overlain by mixed quartzo-feldspathic and basaltic dune sand that grades upward into the massive and unstratified eolian silt typifying the unit. In some loess sequences eolian sand and silt directly overlie unconformities. Unconformities are characterized by scoured and channeled paleosol surfaces. Paleosols typically cap each loess layer in these sequences. The paleosols range from soil profiles that have weakly to well-developed B and C horizons (accumulation of clays, Fe- and Al-oxides, and carbonate minerals) to profiles that display well-developed siliceous petrocalcic (caliche) layers (Patton and Baker, 1978). Tephras from Mount St. Helens and Mount Mazama are locally present in the loess sequences.

In the Coulee Dam 1:100,000-scale quadrangle, loess deposits reflect wind deposition and erosion by multiple cataclysmic glacial outburst floods through the Davenport-Creston tract of the Channeled Scabland during the Pleistocene. Streamlined loess islands preserve the best sections of multiple, unconformity-bounded loess sequences. Gravels at the base of these sequences were deposited by high-energy currents of outburst floods, whereas laminated silts and sands were deposited by backwashing and ponding flood waters. The silt which composes the bulk of each loess sequence was deposited by prevailing southwest winds and was probably derived from the outburst-flood slackwater sediments and the Pliocene-late Miocene Ringold Formation found in the Pasco Basin. Paleosols formed during periods of landscape stability (McDonald and Busacca, 1988, 1989).

The age of the loess ranges from Holocene to early Pleistocene. The youngest loess sequence blankets both erosional and depositional scabland topography formed by late Wisconsin (<~35 ka; Richmond and Fullerton, 1986) outburst floods, and it contains Mount Mazama tephra (~7 ka) (Patton and Baker, 1978). These youngest loess layers display only weakly developed soil profiles and lack petrocalcic horizons. A pre-late Wisconsin (>~35 ka) age for the older loess sequences is suggested by the degree of soil development, oxidation, glass hydration, and weathering-rind development on basalt clasts. Mount St. Helens tephra correlations and a radiocarbon age indicate a minimum age of about 36 to 40 ka for the most recent episode of pre-late Wisconsin outburst floods (Baker and others, 1988; Kiver and Stradling, 1982; McDonald and Busacca, 1988, 1989; Moody, 1987). The oldest recognized loess layers are reversely magnetized and therefore were deposited during the early Pleistocene prior to 790 ka (McDonald and Busacca, 1988, 1989).

The unit includes the Palouse Formation of Treasher (1925). As defined, the Palouse Formation consisted of as many as three laterally accreted loess sequences unconformably underlying the youngest loess sequence (Patton and Baker, 1978). McDonald and Busacca (1988) suggest all Palouse-region Holocene and Pleistocene loess sequences be informally referred to as the Palouse loess.

Glacial deposits

In the map area most glacial deposits lie north of the Columbia and Spokane Rivers, but some are found south of the Spokane River in the Fort Spokane area. Even though most glacial deposits are reworked and eroded, many geomorphic features such as moraines, drumlins, outwash plains, and kame terraces are still evident. Glaciolacustrine deposits are present as terraces in the Columbia River valley and its tributary valleys. Most outburst flood deposits are in the Columbia River and Spokane River valleys and in the Davenport-Creston tract of the Channeled Scabland; minor flood deposits can be found on the divides that separate the river valleys from the scabland tract and in the channels of Goose and Williams Creeks.

Qfg, Qfs

Outburst flood deposits (Pleistocene)--Flood deposits comprising two units: gravel; and sand and silt. Most late Wisconsin flood deposits are present in deeply incised coulees and are overlain by a veneer of young loess. Pre-late Wisconsin deposits are sparsely exposed in the higher coulees and loess islands.

Qfg

Gravel--Dominantly poorly sorted coarse gravel and sand composed of subrounded to angular clasts of diverse lithologies. Older gravels generally contain a higher percentage of basalt clasts. In some places the deposits include layers of graded sand, poorly laminated to nonlaminated silt, and tephra. Gravels commonly display foreset bedding. Late Wisconsin flood gravels have only weakly developed soil profiles. Older gravels are typically capped by well-developed paleosols; clasts have distinct weathering rinds or are so deeply weathered that rinds are no longer discernible (Moody, 1987). Gravel and coarse sand were deposited by high-energy currents during outburst floods from glacial Lake Missoula.

Qfs

Sand and silt--Dominantly graded sand and nonlaminated silt and subordinate gravel. Sediments were deposited as distal turbidites or by low-energy backwash (Kiver and Stradling, 1982; Rigby, 1982) during outburst floods.

Qgl

Glaciolacustrine deposits (Pleistocene)--Compact, well-bedded, typically laminated (varved) clay, silt, and fine sand; locally includes boulder-size erratics. In the Sanpoil River valley and in the Columbia River valley north of its confluence with the Spokane River, layers ($\leq$1 m thick) of well-sorted and stratified outwash gravel are included in this unit (E. P. Kiver, EWU, oral commun., 1990; E. P. Kiver and D. A. Stradling, EWU, written commun., 1987). Upper surfaces of the terraces containing these deposits have been modified by outburst floods and eolian and recent fluvial processes.

Qglf

Glaciolacustrine and outburst flood deposits, undivided (Pleistocene)--Layers of poorly sorted to graded gravel, sand, and silt alternating with layers of finely laminated clay, silt, and fine sand. In the map area layers near the base of the exposed sections consist mostly of granule-size clasts and subordinate pebble- to cobble-size clasts, and layers higher in the section grade upward from fine sand to silt. Boulders are locally abundant. Some coarse sediment layers contains rip-up clasts from the underlying laminated layer. Coarse-sediment layers average about 1 m thick, although they tend to be thinner upsection; the highest flood beds are only 5-10 cm thick (Atwater, 1986). Most coarse-sediment layers are graded, but some are cross-laminated or cross-bedded, contorted (pinch-and-swell) or disrupted by flame structures. Finely laminated layers capping each coarse-sediment layer consist of varves made up of as many as 55 couplets and as few as 1 couplet of alternating light- and dark-colored laminae. Laminae are typically continuous but are contorted (pinch-and-swell) or truncated in some places. Typical couplet thicknesses are 1-4 cm but range from 0.5 cm to as much as 17 cm (Atwater, 1986).

The finely laminated layers represent lacustrine deposition in a glacial lake. Most of the coarse-sediment layers were deposited by outburst flood waters flowing into a glacial lake; however, some of these layers probably represent backwash or slackwater deposition. Some structureless layers of medium to coarse sand are interpreted as turbidites, and layers of coarse clasts supported in a mud or silt matrix (diamicton) are interpreted as debris flows or water-laid till (Atwater, 1986; Kiver and others, 1989).

Even though Atwater (1986) concludes the glaciolacustrine-outburst flood section in the Sanpoil River valley is late Wisconsin in age, it is likely that some deposits are older (Kiver and Stradling, 1982; Rigby, 1982).

Qgo, Qgpo

Outwash (Pleistocene)--Compact, well-sorted, and well-stratified sand, pebble to cobble gravel, and minor silt and clay; in some places, the deposits contain boulders.

Qgo

Late Wisconsin outwash--Sand and gravel displaying weakly developed soil profiles and whose clasts have only a thin weathering rind. These deposits are exposed in the Enterprise Valley, in terraces along the Sanpoil River valley, and in the Columbia River valley north of its confluence with the Spokane River.

Qgpo

Pre-late Wisconsin outwash--Sand and gravel displaying deep coloration and soil profiles that have well-developed B horizons. Gravel clasts have thick weathering rinds or are so deeply weathered that a rind is no longer discernible. This older outwash is exposed in the Enterprise Valley.

Qgt, Qgpt

Till (Pleistocene)--Unsorted and unstratified deposits of rounded to subangular pebbles, cobbles, and boulders of various lithologies in a matrix of clay and sand. In some places the deposits contain minor stratified sediments.

Qgt

Late Wisconsin till--Coarse deposits that exhibit thin, weakly developed soil profiles. Most clasts are striated (Kiver and others, 1989). Deposits are exposed northeast of Grand Coulee Dam and in the Columbia River valley north of its confluence with the Spokane River and east to the Enterprise Valley.

Qgpt

Pre-late Wisconsin till--Characterized by deep red-brown to yellow-brown coloration and by soil having well-developed B horizons (Kiver and others, 1989). Clasts are deeply weathered, and striations are poorly preserved. Geomorphic features are typically subdued and eroded. Older till is well preserved in the Columbia River valley north of its confluence with the Spokane River and along the broad ridge separating the Columbia River from the Enterprise Valley. Older till is sparsely preserved in the Sixmile, Threemile, and George Creek drainages, northeast of Grand Coulee Dam, surrounding Lilienthal Mountain, and at the head of Green Canyon.

Qgd

Drift (Pleistocene)--Unstratified and stratified deposits of clay, silt, sand, gravel, and boulders deposited directly by glacial ice or by water emanating from glacial ice. Drift includes well-sorted outwash, unsorted till, thin-bedded glaciolacustrine silt and sand, and, locally, outburst flood sediments (Becraft and Weis, 1963; Griggs, 1966; Hanson and others, 1979; E. P. Kiver, EWU, oral commun., 1990; Kiver and Stradling, 1982, 1986); all deposits are covered by a veneer of loess.

Tertiary Volcanic and Sedimentary Rocks

$\cancel{M}c_l$

Latah Formation (middle Miocene)--Poorly indurated siltstone, claystone, and sandstone; locally tuffaceous. Some sandstone beds are graded, cross-bedded, and cemented by iron oxides. The Latah Formation is defined as the lacustrine and fluvial sedimentary rocks interlayered with flows of the Columbia River Basalt Group in the northeastern part of the Columbia Basin (Swanson and others, 1979b). Mapped exposures of the unit are present about 3 km southeast of Fort Spokane and about 5 km south of the mouth of Mill Canyon. The formation is commonly covered by talus from the overlying basalt. In some places the poorly indurated rocks have failed, causing the overlying basalt flow(s) to slide.

Columbia River Basalt Group

Extensive flows of tholeiitic basalt of the Columbia River Basalt Group underlie the Columbia Basin region. North-northwest-striking dike swarms in southeastern Washington and adjacent Idaho are interpreted to represent the fissure systems that fed the flows. Flows of the Columbia River Basalt Group were erupted between 17 Ma and 6 Ma (early to late Miocene) (Hooper and Swanson, 1987; Wright and others, 1989). In the map area the Columbia River Basalt Group consists of two basalt formations, the Wanapum Basalt and the Grande Ronde Basalt.

$\cancel{M}v_{wp}$, $\cancel{M}v_{wr}$, $\cancel{M}v_{wf}$

Wanapum Basalt (middle Miocene)--The Priest Rapids Member, the Roza Member, and the Frenchman Springs Member make up the Wanapum Basalt in the map area.

$\cancel{M}v_{wp}$

Priest Rapids Member--Fine- to coarse-grained basalt flows of reversed magnetic polarity. The basalt is typically aphyric to sparsely plagioclase phyric; olivine is visible in many hand specimens (Swanson and others, 1979b). Whole-rock geochemical data for this member in the map area are presented in Tables 1 and 2. The member typically overlies the Roza Member ($\cancel{M}v_{wr}$) of the Wanapum Basalt in the west half of the map area and the N_2 magnetostratigraphic unit ($\cancel{M}v_{gN2}$) of the Grande Ronde Basalt in the east half. However, the eastern- and northernmost flows overlie pre-Miocene volcanic, intrusive, and metasedimentary rocks. Along the northern margin of the Columbia Basin, the Priest Rapids Member is commonly separated from the underlying Grande Ronde Basalt by sedimentary rocks of the Latah Formation ($\cancel{M}c_l$); locally, thin, discontinuous interbeds separate flows of the member. The basal flow of the Priest Rapids Member is commonly pillowed. Flows of the Priest Rapids Member were erupted about 14.5 Ma (Beeson and others, 1985; Reidel and Fecht, 1987) (Fig. 4).

$\cancel{M}v_{wr}$

Roza Member--Characterized by numerous (5-8%), evenly distributed plagioclase phenocrysts averaging 10 mm long. The Roza Member has a higher MgO content than the Frenchman Springs Member ($\cancel{M}v_{wf}$) (Swanson and others, 1979b; Wright and others, 1989, table 13). In the southwestern corner of the map area the Roza Member overlies the Frenchman Springs Member ($\cancel{M}v_{wf}$), but elsewhere it overlies the N_2 magnetostratigraphic unit of the Grande Ronde Basalt ($\cancel{M}v_{gN2}$). The Roza Member is absent in the northwestern and eastern parts of the map area.

SERIES		GROUP	SUB-GROUP	FORMATION	MEMBER	K-Ar AGE (m.y.)	MAGNETIC POLARITY
MIOCENE	UPPER	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	SADDLE MOUNTAINS BASALT	LOWER MONUMENTAL MEMBER	6	N
					Erosional Unconformity		
					ICE HABOR MEMBER	8.5	
					Basalt of Goose Island		N
					Basalt of Martindale		R
					Basalt of Basin City		N
					Erosional Unconformity		
					BUFORD MEMBER		R
	MIDDLE				ELEPHANT MOUNTAIN MEMBER	10.5	R,T
					Erosional Unconformity		
					POMONA MEMBER	12	R
					Erosional Unconformity		
					ESQUATZEL MEMBER		N
					Erosional Unconformity		
					WEISSENFELS RIDGE MEMBER		
					Basalt of Slippery Creek		N
					Basalt of Lewiston Orchards		N
					ASOTIN MEMBER	12.6	N
					Local Erosional Unconformity		
					WILBER CREEK MEMBER		
					Basalt of Lapwai		N
					Basalt of Wahluke		N
					UMATILLA MEMBER		
					Basalt of Sillusi		N
					Basalt of Umatilla		N
					Local Erosional Unconformity		
				WANAPUM BASALT	PRIEST RAPIDS MEMBER	14.5	
					Basalt of Lolo		R
					Basalt of Rosalia		R
					ROZA MEMBER	~14.5	T,R
					FRENCHMAN SPRINGS MEMBER		
					Basalt of Lyons Ferry		N
					Basalt of Sentinel Gap		N
					Basalt of Sand Hollow	15.5	N
					Basalt of Silver Falls		N,E
					Basalt of Ginkgo		E
					Basalt of Palouse Falls		N
					ECKLER MOUNTAIN MEMBER		
					Basalt of Shumaker Creek		N
					Basalt of Dodge		N
					Basalt of Robinette Mountain		N
	LOWER			GRANDE RONDE BASALT		15.5→	N_2
						15.5-16.5	R_2
				PICTURE GORGE BASALT	(Basalt of Dayville, Basalt of Monument Mountain, Basalt of Twickenham)	(14.6-15.8)	N_1
							R_1
				IMNAHA BASALT		16.5-17.0	R_1
							T
							N_0
							R_0

Figure 4. Columbia River Basalt Group stratigraphy. Modified from Beeson and others (1985, fig. 1). N, normal magnetic polarity; R, reversed magnetic polarity; T, transitional magnetic polarity; E, excursional magnetic polarity.

The Roza Member typically consists of no more than two flows that have a total thickness of about 50 m. Where the member consists of two flows, the upper flow possesses reversed polarity, and the lower flow has transitional polarity (Swanson and others, 1979b) (Fig. 4). In the western part of the Columbia Basin, the presence of thick sedimentary interbeds between the Roza Member and the Frenchman Springs Member (Ꝑv$_{wf}$) (Fig. 4) suggests that a significant amount of time elapsed between eruption of these two members. Therefore, the Roza Member is considered nearer in age to the overlying Priest Rapids Member (Ꝑv$_{wp}$) (about 14.5 Ma) than to the Frenchman Springs Member.

Ꝑv$_{wf}$

Frenchman Springs Member--Fine- to medium-grained, aphyric basalt flows of normal magnetic polarity. Some flows contain widely scattered glomerophyric clots of plagioclase at least 1 cm in diameter, and some contain sparse olivine phenocrysts (Swanson and others, 1979b). The member is exposed along Wilson Creek in the southwestern corner of the map area. It thins to the north and pinches out just south of Almira. In the map area, the base of the member is generally not exposed, or it overlies the sedimentary rocks of the Vantage Member (Ellensburg Formation) (Fig. 4) that are less than 0.5 m thick (Swanson and others, 1979a). Flows of the Frenchman Springs Member were erupted about 15.5 Ma (Beeson and others, 1985; Reidel and Fecht, 1987) (Fig. 4).

Ꝑv$_{gN2}$, Ꝑv$_{gR2}$

Grande Ronde Basalt (middle to lower Miocene)--Black, dense, and fine-grained, aphyric to slightly phyric basalt flows; phyric varieties contain sparse plagioclase phenocrysts and plagioclase-clinopyroxene clots. Olivine occurs only in minor amounts (<0.5%) in the groundmass (Swanson and others, 1979b). Near pre-basalt topographic highs the Grande Ronde Basalt is commonly overlain by weakly lithified sedimentary rocks of the Latah Formation (Ꝑc$_l$). Flows range from 1 m to 100 m thick but average 20 m thick (Swanson and others, 1979a). Whole-rock geochemical data for the Grande Ronde Basalt in the map area are presented in Tables 1 and 2. Flows of the Grande Ronde Basalt were erupted between about 15.5 Ma and about 16.5 Ma (Beeson and others, 1985; Reidel and Fecht, 1987) (Fig. 4). Two magnetostratigraphic units are present in the map area.

Ꝑv$_{gN2}$

Magnetostratigraphic unit N_2--Normal magnetic polarity.

Ꝑv$_{gR2}$

Magnetostratigraphic unit R_2--Reversed magnetic polarity. This is the oldest unit of the Columbia River Basalt Group exposed in the map area.

In the map area most exposures of both magnetostratigraphic units are in and near the Columbia River valley; the N_2 unit is also exposed along the east edge of the map area in the Little Chamokane Creek drainage. Along the south side of the Columbia River valley, flows of the N_2 unit underlie flows of the Wanapum Basalt (Ꝑv$_{wp}$, Ꝑv$_{wr}$) and overlie flows of the R_2 unit; north of the Columbia River valley erosional remnants of the N_2 unit overlie both the R_2 unit and pre-Miocene intrusive rocks.

Eva$_s$, Evt$_s$, Ev$_s$, Evd$_s$

Sanpoil Volcanics (Eocene)--Chiefly andesitic flows, flow breccia, tuff and minor intercalated sandstone, shale, and conglomerate exposed in the Enterprise Valley and in the southwest-trending segment of the Spokane River valley. Just west of the confluence of the Spokane River with the Columbia River, dacitic flows and

flow breccia are present. On the east side of the Enterprise Valley the section of Sanpoil Volcanics is estimated to be about 450 m thick (Becraft and Weis, 1963). The belt of Sanpoil Volcanics that extends from the Enterprise Valley southeastward along the Spokane River valley forms a broad, shallow syncline; near the edge of the belt the sedimentary rocks dip 20°-30° toward the Spokane River (Becraft and Weis, 1963). The volcanic sequence probably occupies a tectonic depression (Fig. 5). The composition and age of these volcanic rocks suggest they are correlative with the Sanpoil Volcanics of Muessig (1962) exposed north of the map area in the Republic graben (Fig. 5) (Pearson and Obradovich, 1977) and thus, the name Sanpoil Volcanics is used in this report. Andesitic flow rock in the map area yielded a K-Ar hornblende age of about 50 Ma (Table 3).

Eva_s

Andesite flows and flow breccia--Porphyritic flows containing phenocrysts (2-10 mm long) of hornblende, pyroxene, and locally plagioclase, in a stony groundmass. The andesitic rock is typically dark gray on fresh surfaces and reddish brown or purplish and greenish gray on weathered surfaces. The groundmass consists of plagioclase (An_{40-45}), biotite, and pyroxene or hornblende microlites in an aphanitic to glassy feldspathic matrix (Becraft and Weis, 1963; Pearson and Obradovich, 1977). Plagioclase and pyroxene are typically fresh; hornblende is chloritic and surrounded by rims of magnetite. In some places the rocks are flow-banded, and individual flows are 20-30 m thick. Hornblende from andesitic flow rock yielded a K-Ar age of 50.3 Ma (Table 3).

Evt_s

Tuff and tuff breccia--Tuff, lapilli tuff, tuff breccia, and crystal tuff and subordinate tuffaceous sandstone, feldspathic to arkosic sandstone, conglomerate and carbonaceous shale or coal (Becraft and Weis, 1963). Most rocks are tan, light gray, or white. Tuff and tuff breccia consist of quartz and plagioclase crystals in a matrix of devitrified glass and material too fine grained to identify. Most crystal tuff contains abundant euhedral to subhedral, zoned (An_{35-65}) plagioclase crystals and moderate amounts of hornblende, pyroxene, biotite, and magnetite in a groundmass of devitrified glass and glass shards. Tuffs are typically massive to poorly bedded. All the sedimentary rocks of this unit contain crystals or crystal fragments and volcanic glass. Most sandstone is composed mainly of quartz, K-feldspar, and lithic fragments in a fine-grained matrix. Conglomerate is composed dominantly of rounded to subangular granitic and quartzite clasts in a feldspathic sandstone matrix (Becraft, 1959). Sedimentary rocks are well bedded. Most beds are 5 cm to 1 m thick. Carbonaceous shale and coal are exposed at the surface in thin seams and stringers and are reported to be several meters thick in underground workings near Orazada Creek.

Ev_s

Andesite flows, flow breccia, tuff, and sedimentary rocks, undivided--These rocks are exposed at the mouth of Mill Canyon and in the NW/4 sec. 24, T. 27 N., R. 38 E. (Becraft and Weis, 1963).

Evd_s

Dacite flows and flow breccia--Flows and flow breccia and subordinate tuff and sedimentary rocks and minor hypabyssal intrusive rocks (Atwater and Rinehart, 1984). Abundant plagioclase phenocrysts, some hornblende, pyroxene, and biotite phenocrysts, and sparse quartz phenocrysts are set in a stony to glassy groundmass.

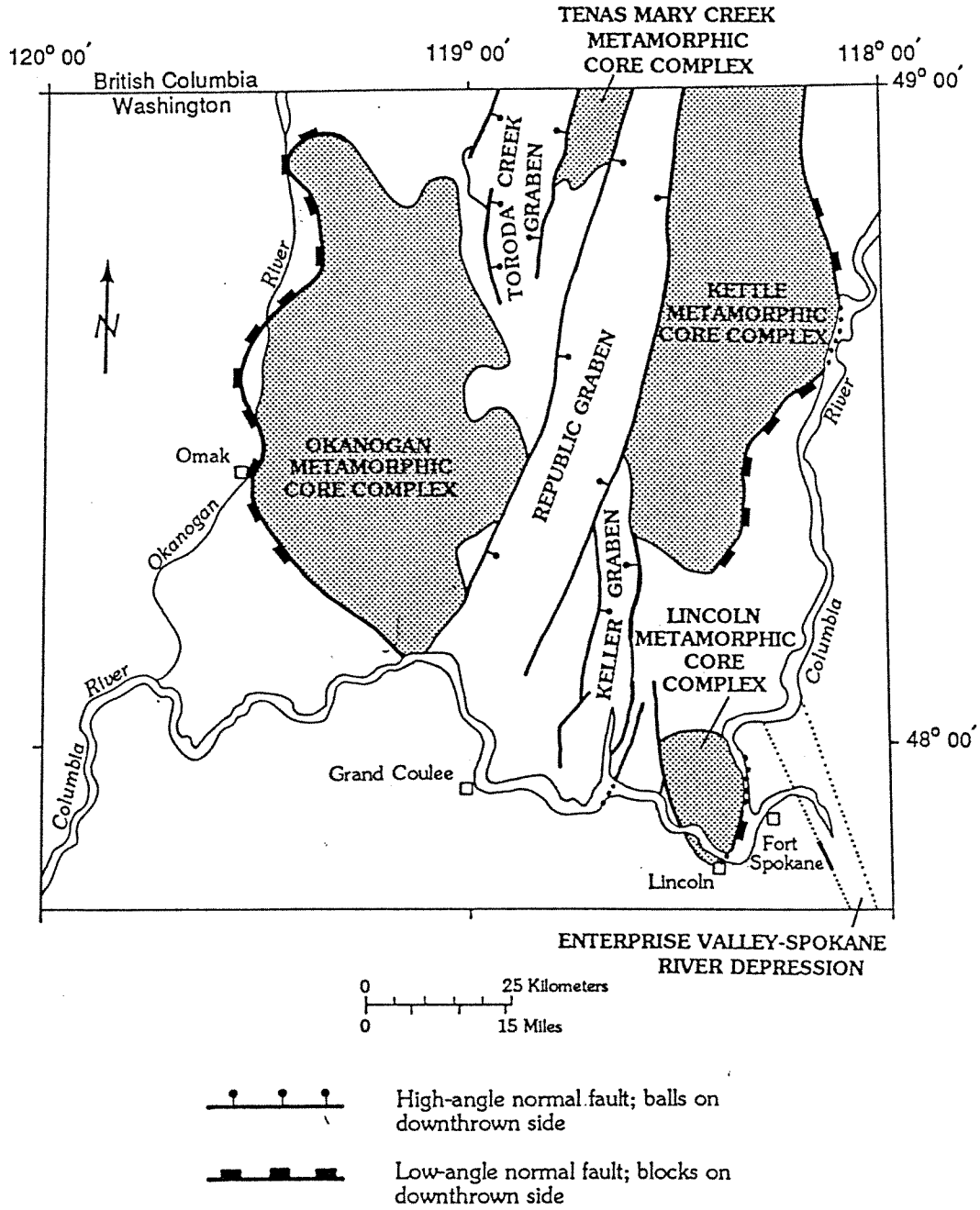

Figure 5. Metamorphic core complexes and tectonic depressions of northeastern Washington (modified from Fox and Rinehart, 1988).

Metasedimentary Rocks

Lower Paleozoic to Precambrian Metasedimentary Rocks

Omm_c

Covada Group (Upper to Lower Ordovician)--Dominantly fine- to coarse-grained, gray, greenish-gray, and tan, impure quartzite and wacke (>10% argillaceous matrix), subordinate phyllite and slate, and minor fine-grained greenstone and limestone; in some places the rocks are gritty or conglomeratic (Atwater and Rinehart, 1984; DGER mapping, this report). Most quartzite and wacke are quartzofeldspathic and have abundant to sparse lithic fragments; other constituents include muscovite, biotite, tourmaline, zircon, and varied amounts of opaque minerals. Most lithic fragments and mineral grains are subangular to subrounded. Locally, quartzite is well sorted, vitreous, and quartz-rich. Most fine-grained rocks are poorly exposed, but where exposed, phyllite and slate are typically dark-colored. Phyllite is composed of muscovite, biotite, quartz, and feldspar, and it is commonly spotted with chlorite porphyroblasts. Most limestone is interbedded with the finer grained rocks and is dark, fine grained, and impure; however, some limestone is white, coarsely crystalline, and pure. Greenstone layers are generally thin ($\leq$1 m) thick. North of the map area in the Nespelem 1:100,000-scale quadrangle, greenstone is associated with phyllite/limestone intervals (M. T. Smith, Univ. of Arizona, written commun., 1990). Clastic rocks are thin-bedded to massive; in some places beds are graded or laminated (DGER mapping, this report; M. T. Smith, Univ. of Arizona, written commun., 1990); other sedimentary structures are rare. Many of the coarser grained clastic rocks occupy channels in the finer grained rock. Near intrusive rocks, rocks of the Covada Group are commonly thermally upgraded to micaceous metaquartzite, quartz-mica schist, coarse-grained phyllite, quartzofeldspathic hornfels, calc-silicate hornfels, marble, and amphibolite.

Covada Group rocks are exposed in three parts of the map area: the Castle Rock Creek-Mitre Rock area north of the confluence of the Columbia and Spokane Rivers, the area between the Eagle Peak and the Brody Creek faults, and near Mica Mountain west of the Sanpoil River. In the Castle Rock Creek-Mitre Rock area, greenstone layers are present throughout the exposed Covada section, and because the greenstone is resistant, it forms ridges (DGER mapping, this report). Clastic rocks of the Castle Rock Creek-Mitre Rock area contain granitic lithic fragments. Covada Group rocks in this area are folded; bedding strikes nearly north-south and dips steeply (DGER mapping, this report). Covada Group rocks exposed between the Eagle Peak and Brody Creek faults lack greenstone and limestone layers. In this area, bedding is typically planar, and there is little evidence of folding (White, 1981). Covada Group rocks in the Mica Mountain area consist chiefly of andalusite-bearing biotite-muscovite schist; kink folds are visible in outcrops.

No fossils have been found in the Covada Group rocks in the map area, but rocks to the north in the Nespelem 1:100,000-scale quadrangle have yielded macrofossils and conodonts indicating an age range of Early to early Late Ordovician (Snook and others, 1981).

$O\epsilon cb_d$, $O\epsilon cb_l$, $O\epsilon cb_m$

Metaline Formation (Middle Ordovician to Middle Cambrian)--South of the Spokane River, the Metaline Formation consists of a lower unit of bedded limestone and an upper unit of massive dolomite (DGER mapping, this report); north of the Spokane River, the formation consists entirely of limestone (Becraft and Weis, 1963). The Metaline Formation was originally named by Park and Cannon (1943) for exposures in northern Pend Oreille County, but in central and southern Stevens County, the carbonate rocks overlying the Addy Quartzite (ϵZq_a) were originally named the Old Dominion Limestone by Weaver (1920). Because these formations occupy the same stratigraphic position and are laterally correlative (Lucas, 1980; Mills, 1977; Miller and Clark, 1975; Snook and others, 1981), use of the name Old Dominion Limestone is abandoned for this report.

$O€cb_d$

Dolomite--Mostly massive to poorly bedded dolomite typically recrystallized to dolomitic marble, calc-silicate hornfels, tactite, and calcareous dolomitic marble. Most dolomite is white, light gray, blue-gray, greenish gray, tan, or red and is medium to coarse grained; some rock is schistose. Tremolite, titanite(?), and silica veinlets can be found in some exposures. The dolomite is locally silicified. The dolomite unit has a maximum estimated thickness of 1,500-1,800 m; in westernmost exposures, parts of the unit are probably repeated by faulting (Bennett, 1944).

$O€cb_l$

Limestone--A heterogeneous mixture of well-bedded, typically recrystallized limestone, calc-silicate hornfels, tactite, and subordinate quartzose hornfels, micaceous quartzite, and dolomite (DGER mapping, this report). The rocks are thin to medium bedded (about 5 cm to 0.3 m thick). Most limestone is gray and fine grained. Most calc-silicate hornfels have purple, green, and gray bands. Coarse-grained tactite is composed mostly of garnet, epidote, idocrase, calcite, and minor tremolite, wollastonite, and scapolite. Many tactite beds grade upward from fine-grained, greenish rock to coarse-grained (as much as 1 cm) rock consisting of garnet and calcite with subordinate epidote and idocrase. Quartzose hornfels are typically very fine grained and dark colored. Most micaceous quartzite is poorly sorted and fine grained, but some is schistose. Dolomite is typically recrystallized.

Although most contacts are occupied by Eocene dacite dikes (Eida), the limestone unit appears to grade into the overlying dolomite unit ($O€cb_d$) and into the underlying Lower Cambrian-Upper Proterozoic Addy Quartzite ($€Zq_a$). The unit is estimated to be about 210 m thick (DGER mapping, this report).

$O€cb_m$

Metaline Formation, undivided--Fine- to coarse-grained limestone that is locally recrystallized (Becraft and Weis, 1963). The limestone is black where it is fine grained and white where it is coarsely recrystallized; it weathers gray or yellow-gray. Where bedding is visible, the rock is typically thin-bedded. Near the base of the formation, bedding is parallel to bedding in the underlying Addy Quartzite ($€Zq_a$). The Eocene Sanpoil Volcanics (Eva_s) unconformably overlie the Metaline Formation. The formation has an exposed thickness of about 1,300 m near the northern border of the map area.

Conodonts and fossil fragments of Anatolepis (the oldest known fish) indicate that the Metaline Formation ranges in age from Middle Cambrian to early Middle Ordovician (Repetski, 1978; Schuster and others, 1989). The early Middle Ordovician age for the upper part of the formation is confirmed by a fossil assemblage from the upper 30 m of the formation (Schuster and others, 1989).

$€Zq_a$

Addy Quartzite (Lower Cambrian to Upper Proterozoic)--Chiefly well-sorted, pure quartzite with intervals of impure quartzite and argillaceous rock. In the map area the Addy Quartzite is exposed near Mitre Rock, east of the Enterprise Valley, and on the western flank of Lilienthal Mountain.

Limited exposures of the formation near Mitre Rock consist mostly of white, vitreous, well-sorted quartzite that contains thin beds of pink to purple-red quartzite and thin beds or laminae of micaceous quartzite (DGER mapping, this report). White quartzite is typically fine grained and composed of clear and gray, translucent quartz grains. Purple quartzite is typically stained by iron oxide and contains scattered specular hematite grains.

East of the Enterprise Valley three quartzite intervals separated by intervals of argillaceous rock constitute the formation (Becraft and Weis, 1963). The quartzite intervals consist dominantly of well-bedded, medium-grained, moderately to well-sorted, massive, well-cemented quartzite. Most quartzite is white and light yellow-gray, but some is reddish- to purple-brown and exhibits Liesegang banding. The quartzite is composed mostly of quartz, but sparse, scattered grains of feldspar and garnet are found locally. Most purple quartzite is stained by iron oxide. Graded bedding, cross-bedding, and minor ripple marks are present in the quartzite intervals except in the lowermost 30-90 m of the basal quartzite interval. The argillaceous intervals consist of fine-grained, laminated to thin-bedded, green to brown argillite that contains thin, discontinuous quartzite lenses. In some places the quartzite and argillite are thermally upgraded to quartz-mica schist and phyllite. The formation has a total thickness of about 1,200 m (Becraft and Weis, 1963). The uppermost quartzite interval is about 40 m thick and overlies the upper argillite interval that is about 100 m thick; the middle quartzite interval is about 45 m thick and is separated from the 800-m-thick basal quartzite interval by an argillite interval about 200 m thick.

On the western flank of Lilienthal Mountain, the Addy Quartzite has been thermally upgraded to quartzite, quartz-mica schist, phyllite, and minor calc-silicate hornfels and micaceous wacke (DGER mapping, this report). The typically well-sorted, well-cemented, vitreous quartzite ranges from fine to coarse grained, and in some places it contains layers or pods of coarse grit or pebble conglomerate. Most quartzite is white and gray, but some is pale green, dark gray, pink, red, or orange. Much of the quartzite contains Liesegang banding and heavy minerals. Most quartzite is thin to medium bedded, and some is laminated; the quartzite locally contains abundant graded beds, cross-beds, and ripple marks. Fine- to coarse-grained quartz-mica schist typically is present as beds in quartzite, but in some places schist is the dominant lithology. Fine- to coarse-grained phyllite is poorly exposed, but it appears to be the dominant lithology in several places. Much of the phyllite is spotted with dark, micaceous porphyroblasts; spotted phyllite is probably recrystallized bioturbated, argillaceous rock similar to that found northeast of the map area in the Chewelah 1:100,000-scale quadrangle (K. A. Lindsey, Westinghouse Geoscience Group, oral commun., 1984). Most calc-silicate hornfels are purple and green banded and are typically separated from the quartzite by spotted phyllite. Micaceous wacke beds consists of muscovite (>50%), quartz, feldspar, and sparse lithic fragments (quartzite?). Most micaceous wacke is interbedded with phyllitic rock, but in some places is interbedded with the white, vitreous quartzite.

In some places bedding is visibly folded; in outcrop, fold axes trend and plunge northward; beds are steeply dipping, and some are overturned to the west (Becraft and Weis, 1963; DGER mapping, this report). Near the summit of Lilienthal Mountain quartzite is fractured and recemented breccia constitutes some exposures (DGER mapping, this report). The formation here is estimated to be one-half to one-third the thickness of the section exposed east of the Enterprise Valley. Becraft and Weis (1963) suggest the Addy Quartzite unconformably overlies the Middle Proterozoic Togo Formation (Yar_t) with an angular discordance of about 15°; the unconformity cuts down about 2,600 m through the Precambrian section, over a distance of about 25 km from north of the map border south to Lilienthal Mountain.

The Addy Quartzite is Early Cambrian to Late Proterozoic in age (Lindsey, 1987, 1988; Lindsey and others, 1990). The sequence of rock above the lowest horizon containing trilobite body and trace fossils is Early Cambrian in age, and at least part of the sequence of rock below the fossil-bearing horizon is late Late Proterozoic in age. North of the map area trilobite trace fossils Rusophycus and Cruziana and the body fossil of Nevadella addyensis (Lindsey and others, 1990) occur only in the upper part of the formation. Down-section strata that are lithologically similar to those in the fossil-bearing horizon do not contain trilobite fossils. The Cambrian-Precambrian time boundary is inferred to be at least 500 m below the base of the trilobite-bearing zone.

ϵYq_c

Quartzite of Creston Butte (Cambrian? or Middle Proterozoic?)--White to light-gray, medium-grained quartzite and subordinate muscovite schist. The well-sorted and well-cemented quartzite is composed of clear, vitreous, interlocking quartz grains that are elongate along some surfaces. Small ($\leq$1 mm) cubes and blebs of

pyrite are widely scattered throughout the rock. Most rock has sericite and iron-oxide stains on parting (bedding?) and fracture surfaces; some rocks contain Liesegang bands. This unit is poorly exposed on the summit of Creston Butte about 1.5 km south of Creston. Correlation of this isolated quartzite with other rock units in the region is uncertain, but because the rock resembles parts of the Lower Cambrian-Upper Proterozoic Addy Quartzite ($€Zq_a$) and parts of the quartzite of the Middle Proterozoic Togo Formation (Yq_t), this quartzite is assigned a Cambrian? to Middle Proterozoic? age for this report.

OYcb, OYph, OYmm, $OYmm_h$, OYq

Metasedimentary rocks of the Cayuse Mountain-Mill Canyon area (Ordovician? to Middle Proterozoic?)--Thermally upgraded rocks consisting predominantly of hornfels, phyllite, and marble, as well as subordinate quartzite and tactite (Becraft and Weis, 1963; DGER mapping, this report). On Cayuse Mountain the rocks consist of a sequence of marble and phyllite overlying a sequence of hornfels; because the sequence overlying the hornfels is poorly exposed east of Mill Canyon, the phyllite and marble are undivided in that area. Quartzite exposed west of Cayuse Mountain is included as part of this sequence.

The resemblance of parts of the Cayuse Mountain-Mill Canyon sequence to the Lower Cambrian-Upper Proterozoic Addy Quartzite ($€Zq_a$) and to the Ordovician-Cambrian Metaline Formation ($O€cb_m$) (Becraft and Weis, 1963) suggests that these rocks may be Ordovician to Cambrian in age, but on the basis of the unit's possible gradational contact with the probable Middle Proterozoic quartzite exposed east of the map area, these rocks may be Middle Proterozoic in age. Additionally, parts of the sequence resemble parts of the Ordovician Covada Group (Omm_c) exposed in the Fort Spokane area, so these rocks may be, at least in part, correlative with the Covada Group (DGER mapping, this report). However, because the Cayuse Mountain-Mill Canyon rocks lack fossils and their contact relations and structural position are uncertain, the absolute age of the sequence is unknown.

OYcb

Metacarbonate rock--Thin-bedded to massive, fine- to coarse-grained, calc-silicate marble and almost pure calcite marble. The rock is white or dark gray and is composed of calcite with varied amounts of diopside, wollastonite, scapolite, idocrase, garnet, olivine, serpentine, K-feldspar (orthoclase), and plagioclase (An_{70-80}) (Becraft and Weis, 1963). Metacarbonate rock typically occurs in isolated outcrops.

OYph

Phyllite--Quartzitic phyllite to fine-grained muscovite schist. The rock is light to dark gray and is composed of 60-90 percent quartz, 10-40 percent muscovite, and minor amounts of tourmaline, zircon, apatite, magnetite, and biotite (Becraft and Weis, 1963). The amount of quartz and muscovite varies from layer to layer. Where bedding is visible, schistosity is parallel with it.

OYmm

Metacarbonate and phyllite, undivided--Chiefly phyllite and marble or tactite and minor quartzite (Becraft and Weis, 1963; DGER mapping, this report). Most of the strata are compositionally similar to the metacarbonate and phyllite mapped separately on Cayuse Mountain. The easternmost strata consist of tactite and spotted phyllite; these rocks appear to grade into calc-silicate-bearing, feldspathic quartzite exposed east of the map area in Spokane 1:100,000-scale quadrangle. In the map area the quartzite is typically fine grained, white to light gray or light green, and thin-bedded to laminated; laminae are composed of muscovite or a pale-green, acicular calc-silicate mineral (DGER mapping, this report). This rock resembles some Middle Proterozoic quartzites exposed in the Spokane 1:100,000-scale quadrangle.

$OYmm_h$

Hornfels--Calc-silicate hornfels, quartzofeldspathic hornfels, marble, and fine-grained, micaceous quartzite. Hornfels are banded; brown and green layers are about 2.5-7 cm thick. Brown layers are composed mostly of quartz, K-feldspar, plagioclase (An_{30-35}), and minor biotite and actinolite; green layers are composed of quartz, plagioclase (An_{30-35}), epidote, and clinozoisite; some bands contain diopside, tremolite, and sparse calcite (Becraft and Weis, 1963). Marble and micaceous quartzite are present only as thin interbeds. The hornfels grade upward into the overlying marble and phyllite, but the base of the hornfels is nowhere exposed. The unit is estimated to be about 600 m thick (Becraft and Weis, 1963).

OYq

Quartzite--Dark-gray, light-brown, and purple quartzite composed of quartz and as much as 25 percent unoriented, interstitial muscovite and biotite (Becraft and Weis, 1963). The abundance of interstitial mica varies considerably from bed to bed, but biotite typically exceeds muscovite. Beds range from about 0.5 cm to about 0.6 m thick; cross-bedding is locally present. About 90 m of this fine- to medium-grained, impure quartzite is exposed about 3 km west of Cayuse Mountain. Neither the upper or lower contact of the quartzite is exposed and thus, the relation with the other metasedimentary rock units in the Cayuse Mountain area is unknown.

Precambrian Metasedimentary Rocks

Deer Trail Group

In the map area, the Deer Trail Group consists of four formations: the Stensgar Dolomite, McHale Slate, Edna Dolomite, and Togo Formation.

Ycb_s

Stensgar Dolomite (Middle Proterozoic)--Thin-bedded, light-gray dolomite. The formation is poorly exposed at the northern border of the map area (T. 29 N., R. 37 E.). There, it is about 120 m thick, but it pinches out about 1 km to the south (Becraft and Weis, 1963). Erosion of the Stensgar Dolomite occurred prior to the deposition of the overlying Lower Cambrian-Upper Proterozoic Addy Quartzite ($€Zq_a$).

Yar_m

McHale Slate (Middle Proterozoic)--Green- to brown-gray, fine-grained, thin-bedded slate or slaty argillite. Some slate is banded and displays layers, about 15 mm to 1 cm thick, of light-green-gray rock alternating with layers of dark-green or brown-gray rock. In many places the slate is poorly bedded, but most of the unit has a well-developed cleavage. In northern exposures, where the unit is conformably overlain by the Stensgar Dolomite (Ycb_s), the slate contains thin ($\leq$2.5 cm thick) beds of dolomite near the top of the unit. Dolomite beds increase upward in abundance so that the uppermost part of the formation consists of about 60 percent dolomite; the upper contact is placed at the top of the highest slaty layer (Becraft and Weis, 1963). In southern exposures, the McHale Slate is unconformably overlain by the Addy Quartzite ($€Zq_a$). The formation ranges from about 730 m thick at the northern map boundary to about 220 m thick about 5 km to the south of the map boundary. Southward thinning is attributed to erosion prior to deposition of the Addy Quartzite.

Ycb_e

Edna Dolomite (Middle Proterozoic)--Dominantly light-yellow-gray to dark-gray or black, fine-grained, ferruginous, and calcareous dolomite that contains minor white and reddish-gray, medium-grained quartzite and dark-gray to black, green, and brown fine-grained slate or argillite (Becraft and Weis, 1963). The dolomite is typically poorly exposed, but the residual soil that forms over it is characteristically deep red or red-brown. Dolomite is commonly recrystallized. Most dolomite is poorly bedded, but in some places, where visible, bedding is thin and contorted. Most quartzite is moderately well sorted, fairly pure, and massive to poorly bedded. Randomly oriented quartz veins are characteristic of the quartzite. Most slate is siliceous and massive; however, some slate is thin bedded and has a well-developed bedding-plane cleavage. At the northern boundary of the map area, a thin (about 8 m thick) interval of quartzite and a thicker (about 120 m thick) interval of slate are present in the dolomite; the quartzite and slate intervals are absent about 3 km south of the northern map boundary. The Edna Dolomite ranges from about 400 m thick in the south to about 670 m thick at the northern border of the map area (Becraft and Weis, 1963). The contact between the Edna Dolomite and the overlying McHale Slate (Yar_m) is considered conformable.

Yq_t, Yar_t

Togo Formation (Middle Proterozoic)--An upper 180-500-m-thick interval of quartzite underlain by a thick, monotonous sequence of argillite, which includes some carbonate rock and sparse quartzite (Becraft and Weis, 1963; Nash, 1978). North of the Spokane River the maximum exposed thickness of the Togo Formation is estimated to be about 6,000 m (Becraft and Weis, 1963). North of the Spokane River the upper contact of the quartzite at the top of the formation with the Edna Dolomite (Ycb_e) is conformable. South of the Spokane River on Lilienthal Mountain the Togo Formation is unconformably overlain by the Addy Quartzite (ϵZq_a)(Becraft and Weis, 1963). The unconformable contact is believed to be the result of erosion prior to the deposition of the Addy Quartzite. The base of the formation is truncated by intrusive rocks.

Yq_t

Quartzite--Chiefly medium- to fine-grained, poorly to moderately well sorted quartzite. In many places the quartzite is feldspathic and displays orange-weathering carbonate spots, and in some places it is white and vitreous and has Liesegang bands. Most quartzite is light gray, pale green-gray, or red-brown and massive to poorly bedded. Where well-bedded, most quartzite beds are capped by partings or grade into thin (<0.5 cm thick) layers of pale-green argillite or siltite. Massive quartzite commonly forms ridges. The contact between the quartzite interval at the top of the formation and the underlying argillite sequence is gradational through a zone about 15 m thick (Becraft and Weis, 1963).

Yar_t

Argillite--Light- to dark-gray, graphitic argillite and zones of thin- to thick-bedded white to pale-green-gray metacarbonate rock (Becraft and Weis, 1963; Nash, 1978). Even though abundant graphite gives the unoxidized rock a dark color, weathered rock is tan or rusty brown. Bedding in the argillite is typically thin, even, and continuous; in some places beds are graded. Most of this argillite has a well-developed bedding-plane cleavage, and in some exposures small-scale folds are visible. Most argillite is thermally upgraded to phyllitic or slaty argillite. The phyllitic rock commonly contains dark porphyroblasts consisting of aggregates of fine-grained magnetite or biotite or both; some phyllite contains andalusite, cordierite, and tourmaline (Becraft and Weis, 1963). In some places the rock is thermally upgraded to hornfels and schist where mica-rich schist typically alternates with mica-poor hornfels. Hornfels are dark to light colored and coarse to very fine grained. Most carbonate rock is thermally upgraded, but original lithologies were probably limy argillite and siltstone, impure limestone, and minor pure limestone (Nash, 1978). Thermally upgraded carbonate rocks consist of calc-silicate hornfels, tactite, and minor dolomitic marble composed of varied amounts of calcite, diopside, wollastonite, titanite, quartz, magnetite, muscovite or phlogopite, epidote, idocrase, garnet, tremolite, and scapolite (Becraft and Weis, 1963; Nash, 1978). Minor quartzite beds are present in the argillite.

Intrusive Rocks

Tertiary Hypabyssal Rocks

Eida, ++++

Dacite dikes and plugs (Eocene)--Dikes and plugs (<0.5 km^2) of dark- to light-gray porphyritic dacite (Becraft and Weis, 1963; DGER mapping, this report). Much of the dacite is tinted pink or green; narrow dikes and chill margins are black and dark green-gray. Dacite dikes are composed of 25-50 percent phenocrysts (Carlson, 1984) in an aphanitic, stony to glassy groundmass; phenocrysts consist of plagioclase, biotite, hornblende, K-feldspar, pyroxene, and sparse quartz. Magnetite and apatite are common accessory minerals. Dikes included in this unit are of two types: hornblende-bearing, quartz-poor dacite and andesite, and medium- to light-gray, hornblende-free, quartz-bearing dacite and rhyolite (Atwater and Rinehart, 1984). These two types are not distinguished on Plate I. Dikes in the Mitre Rock area are chloritic. Some dikes are vesicular or have miarolitic cavities; some flow banded dikes have banding typically contorted near contacts with the surrounding country rocks (DGER mapping, this report). Dikes range from <2 m to >1 km long and vary in width.

Porphyritic dacite plugs consist of phenocrysts of bimodal grain size in a groundmass that is typically aphanitic but in some places is holocrystalline. The larger (5-12 mm) phenocrysts include plagioclase (An_{40-50}), biotite, hornblende, pyroxene, and in some places K-feldspar(?) and sparse quartz; finer grained phenocrysts include plagioclase, biotite, hornblende, and K-feldspar (Becraft and Weis, 1963; DGER mapping, this report). Apatite and magnetite are common accessory minerals.

Whole-rock geochemical data indicate the dikes and plugs are dacite in composition (Table 1 and Table 2) (Becraft and Weis, 1963, table 3). Geochemical data also show these hypabyssal intrusive rocks typically have higher silica and potassium contents than their equivalent extrusive rocks. K-Ar ages (Table 3) indicate the porphyritic dacite dikes and plugs are Eocene in age.

Many dacite dikes and plugs are exposed on the southwest side of the northwest-trending segment of the Spokane River valley and its northwestward extension the Enterprise Valley. Most dikes typically strike northwest and dip steeply either side of vertical. The dikes were probably emplaced along northwest-striking structures parallel to the Enterprise Valley-Spokane River depression (Fig. 5). The dikes and plugs cross-cut metasedimentary rocks of the Covada Group (Omm_c), the Metaline Formation ($O€cb_m$), and the Addy Quartzite ($€Zq_a$) as well as various Cretaceous intrusive rocks.

On Plate I the shaded areas north of Roosevelt Lake on either side of the Sanpoil River represent areas where the ratio of dike rock to country rock is >1:10 (Atwater and Rinehart, 1984); along the south shore of Roosevelt Lake areas where the dike rock to country rock ratio is about 10:1 are shown as Eida (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987). Hornblende-bearing, quartz-poor dikes cross-cut hornblende-free, quartz-bearing dikes; hornblende-free dikes do not cross-cut the plutonic complex of Johnny George ($EPAia_j$). In some places hornblende-bearing dikes cut and grade downward into porphyritic dacite plugs. Outside the map area, hornblende-bearing dikes grade upward into flow rock of the Eocene Sanpoil Volcanics (Evd_s) and downward into the plutonic rocks of the Devils Elbow suite; older hornblende-free dikes grade upward into the tuffs and flows of the Eocene O'Brien Creek Formation.

Tertiary Plutonic Rocks

Tertiary plutonic rocks are widespread and voluminous in northeastern Washington. In much of the Okanogan Highlands they are subdivided into three intrusive suites, from oldest to youngest: the Keller Butte suite, the Devils Elbow suite, and the Herron Creek suite (Holder and Holder, 1988; Holder and others, 1989). Each of the three suites is represented by plutonic rocks exposed in the Coulee Dam 1:100,000-scale

quadrangle (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987; Holder and Holder, 1988). In the map area the Keller Butte suite includes the Keller Butte pluton, the plutonic complex of Johnny George, and the granite of George Creek; the Devils Elbow suite includes part of the Friedlander Meadows pluton and unnamed monzodiorite bodies; the Herron Creek suite includes small bodies of monzonitic rock.

Structural and cross-cutting relations of the Tertiary plutonic rocks with the Eocene volcanic and sedimentary rocks in the Republic, Keller, and Toroda Creek grabens and with the amphibolite-facies metamorphic rocks in the Kettle, Tenas Mary Creek, and Okanogan metamorphic core complexes (Fig. 5) indicate that 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 intrusions are post-tectonic with respect to ductile deformation in the metamorphic core complexes, but north of the map area, these intrusions are brecciated and sheared along graben-bounding faults.

K-Ar biotite and hornblende ages ranging from 53 to 45 Ma are reported from the Devils Elbow and Herron Creek suites, suggesting that they were "comagmatic with the Sanpoil Volcanics and rhyolite domes that intrude the Sanpoil" (Holder and Holder, 1988, p. 1976). K-Ar biotite ages between 61 and 49 Ma are reported from the Keller Butte suite plutons. It is unclear whether these ages are crystallization ages or reset ages that represent a middle Eocene regional thermal event.

Herron Creek suite

Eii

Monzonitic rock (Eocene)--Leucocratic, inequigranular, medium- to coarse-grained hornblende-biotite monzonite and monzodiorite (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987) with minor porphyritic hornblende-biotite granodiorite (Atwater and Rinehart, 1984). The rock is characterized by abundant pink K-feldspar and abundant accessory titanite. Pods, dikes, and small (<0.25 km^2) bodies of this unit cut the migmatite of Johnny George (EPAmg), but the only body large enough to show on Plate I is south of Roosevelt Lake near the mouth of Halverson Canyon. Based on compositional and textural similarities to Eocene intrusive rocks of the Herron Creek suite exposed north and west of the map area, this unit is included in the Eocene Herron Creek suite (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987).

Devils Elbow suite

$Eimd_f$

Friedlander Meadows pluton (Eocene)--Mesocratic, medium-grained, equigranular biotite-hornblende quartz monzodiorite and quartz diorite that contain abundant accessory titanite. In some places the pluton is cut by aplitic biotite granite dikes and hornblende-bearing porphyritic dacite dikes (Eida) (Atwater and Rinehart, 1984; Colville Confederated Tribes Geology Department, 1984). The major part of the Friedlander Meadows pluton is exposed north of the map area in the Nespelem 1:100,000-scale quadrangle. Along the north shore of Roosevelt Lake small (<0.25 km^2), tabular and irregular bodies of dioritic rock cut the migmatite of Johnny George (EPAmg); these small bodies are included in the Friedlander Meadows pluton for this report. North of Sixmile Creek similar bodies, too small to show on Plate I, cut the deformed and undeformed granitic rocks of the plutonic complex of Johnny George ($EPAia_j$) (Atwater and Rinehart, 1984). The Friedlander Meadows pluton in the map area yielded K-Ar hornblende and biotite ages (Table 3) that support an Eocene age for the pluton.

The Friedlander Meadows pluton is one of at least six plutons that compose the Devils Elbow suite (Holder and Holder, 1988; Holder and others, 1989) in the Okanogan Highlands. Gradational contacts, similar composition, and similar K-Ar ages suggest that Devils Elbow suite plutons were the source of some of the Eocene hornblende-bearing porphyritic dacite dikes and plugs (Eida) (Carlson, 1984; Colville Confederated Tribes Geology Department, 1984).

Eimd

Monzodiorite (Eocene)--Mesocratic to leucocratic biotite-hornblende monzodiorite forming a small (<0.25 km^2) plug about 2 km east of the town of Grand Coulee. The rock is inequigranular and characterized by abundant elongate, green hornblende crystals and light-brown titanite crystals (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987). Based on compositional and textural similarities to intrusive rocks of the Devils Elbow suite, this unit is included in that suite in this report (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987).

Keller Butte suite

In the Okanogan Highlands the Keller Butte suite includes at least seven plutons consisting dominantly of leucocratic, hornblende-free granite and granodiorite (Holder and Holder, 1988; Holder and others, 1989). Three plutons, the Keller Butte pluton, the plutonic complex of Johnny George, and the granite of George Creek, of the Keller Butte suite are present in the map area.

EPA ig_m, EPA ig_k, EPA ia_s, EPA iat_s, EPA ia_m

Keller Butte pluton (Eocene or Paleocene)--The quartz porphyry of Mount Tolman, porphyritic granite of Keller Butte, granite of Swawilla Basin, and porphyritic granodiorite of Manila Creek together compose the Keller Butte pluton. The quartz porphyry of Mount Tolman is the most interior phase of the Keller Butte pluton, and the porphyritic granodiorite of Manila Creek is its most exterior (border) phase (Carlson, 1984).

Intrusions of the Keller Butte pluton are considered Eocene or Paleocene in age on the basis of K-Ar ages on biotite. The porphyritic granite of Keller Butte in the map area yielded ages of about 53 Ma and 61 Ma (Table 3). The biotite granite of Swawilla Basin north of the map area in the Nespelem 1:100,000-scale quadrangle yielded an age of about 59 Ma, and, in the Coulee Dam 1:100,000-scale quadrangle, an age of 53.5 Ma (Table 3).

EPA ig_m

Quartz porphyry of Mount Tolman--A leucocratic biotite granite characterized by rounded to elongate quartz crystals and K-feldspar megacrysts in a fine-grained groundmass composed of plagioclase, K-feldspar, quartz, and biotite. Most K-feldspar megacrysts (2-6 cm) are present in segregations about 5-15 m in diameter (Carlson, 1984). Accessory minerals are sparse but include apatite, magnetite, and epidote. In the map area one small (<0.25 km^2) body of this unit is exposed about 1 km north of Hells Gate Canyon. Textural similarities and gradational contacts with the porphyritic granite of Keller Butte (EPA ig_k) outside the map area imply that these two units are probably textural variants of the same intrusion (Atwater and Rinehart, 1984).

EPA ig_k

Porphyritic granite of Keller Butte--A leucocratic biotite granite with K-feldspar megacrysts ($\leq$ 11 cm) in a medium- to coarse-grained, mostly equigranular groundmass (Atwater and Rinehart, 1984; Carlson, 1984). K-feldspar megacrysts typically are found in pod-like zones, and elongate quartz crystals are abundant near the margins of the unit (Carlson, 1984). Plagioclase, K-feldspar, and quartz are present in nearly equal amounts; biotite makes up <5 percent of the rock (Atwater and Rinehart, 1984). Accessory minerals include zircon, apatite, epidote, and magnetite. Contacts with the biotite granite of Swawilla Basin (EPA ia_s) are sharp and dip steeply; neither unit is chilled. Pegmatite dikes are common in the contact zone with both the biotite granite of Swawilla Basin and the porphyritic granodiorite of Manila Creek (EPA ia_m).

EPA ia_s

Biotite granite of Swawilla Basin--Leucocratic, medium-grained granite to granodiorite. The rock is typically equigranular, but in some places it is seriate (Atwater and Rinehart, 1984; Carlson, 1984); near the contact with the porphyritic granodiorite of Manila Creek (EPA ia_m) most of the granite is porphyritic and contains subequant K-feldspar megacrysts as large as 4 cm. Biotite is the only mafic mineral. Accessory minerals include allanite, epidote, titanite, apatite, and zircon (Carlson, 1984). The biotite granite is exposed from Grand Coulee Dam east to the Brody Creek fault. Near contacts with the porphyritic granite of Keller Butte (EPA ig_k), biotite-rich xenoliths or schlieren are common, and the unit is cut by pegmatite dikes that contain garnet and K-feldspar megacrysts. Contacts with the porphyritic granodiorite of Manila Creek (EPA ia_m) are gradational through a distance of about 500 m (Carlson, 1984).

EPA iat_s

Muscovite-biotite granite of Swawilla Basin--White and pale-yellow-tan, medium-grained granite most of which is equigranular. The muscovite to biotite ratio decreases toward the margins of the unit. Near the center of the unit muscovite makes up as much as 7 percent of the rock; near the margins the amount of muscovite is less than or equal to the amount of biotite (Fleshman and Dodd, 1982). In addition to muscovite and biotite, the major constituents of the granite are quartz, K-feldspar, and plagioclase; accessory minerals include opaque minerals, zircon, apatite, and garnet. The two-mica granite underlies about 21 km^2 north of Swawilla Basin and south of Mica Mountain. Because the contacts between the muscovite-biotite granite of Swawilla Basin and the biotite granite of Swawilla Basin (EPA ia_s) are poorly exposed, the contact relations are not definitely known (Fleshman and Dodd, 1982), but the two-mica granite is probably an interior phase of the biotite granite.

EPA ia_m

Porphyritic granodiorite of Manila Creek--Biotite granite and granodiorite characterized by subequant, pink K-feldspar megacrysts (3-5 cm across) in a medium- to coarse-grained groundmass composed of plagioclase, biotite, and quartz. Megacrysts contain abundant inclusions of quartz, biotite, and plagioclase (Carlson, 1984). Accessory titanite and apatite are present as clusters associated with biotite. A higher color index and lack of K-feldspar in the groundmass distinguishes this unit from the other intrusions of the Keller Butte pluton. Contacts with the biotite granite of Swawilla Basin (EPA ia_s) are gradational, and west of Mica Mountain the porphyritic granodiorite is cut by abundant aplite-pegmatite dikes associated with the muscovite-biotite granite of Swawilla Basin (EPA iat_s) (Atwater and Rinehart, 1984). Contacts with the Covada Group metasedimentary rocks (Omm_c) are sharp, and in some places xenoliths of metasedimentary rock are extremely abundant. Contact relations and rare-earth-element geochemistry suggest that the porphyritic granodiorite of Manila Creek is a border phase of the Keller Butte pluton (Carlson, 1984).

EPA ia_j

Plutonic complex of Johnny George (Eocene or Paleocene)--Undeformed and mylonitically deformed leucocratic, typically hornblende-free granitic rocks. Homogeneous, undeformed granitic rocks, indicated by the hachured pattern on Plate I, consist of medium-grained, equigranular to seriate biotite granite, porphyritic biotite granite, aplite, fine-grained alaskite, and pegmatite. Some of the granitic rocks contain muscovite (Atwater and Rinehart, 1984). The porphyritic biotite granite contains white K-feldspar phenocrysts in a coarse-grained groundmass (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987). Undeformed granitic rocks grade into mylonitically deformed granitic rocks. Mylonitic foliation is defined by alignment and flattening of mineral grains. Lineation, typically in the plane of foliation, is defined by trails of crushed grains, striae, and streaked-out feldspar, quartz, biotite, and muscovite or sericite. The foliated and lineated fabric of the rock becomes more pronounced toward the low-angle fault bounding the southeast side of the complex. In some places near the fault the rock exhibits incipient segregation banding, and feldspar augens are well developed (DGER mapping, this report).

Contact relations between the granitic rocks of the plutonic complex of Johnny George and the Friedlander Meadows pluton (Eimd$_f$) are ambiguous, but the granitic rocks are probably cut by the monzodiorite. In the map area the plutonic complex of Johnny George yielded K-Ar biotite and hornblende ages of about 49 Ma and 50 Ma, respectively (Table 3).

In the map area, the mylonitically deformed rocks of the plutonic complex of Johnny George and the migmatite of Johnny George (EPA mg) make up the Lincoln metamorphic core complex (Fig. 5). This core complex may be the southern extension of the Kettle metamorphic core complex (Rhodes and Hyndman, 1988). Lineation in the Lincoln core complex typically trends nearly west. The core complex is bounded to the southeast by a low-angle, east-dipping fault toward which the intensity of the mylonitic deformation progressively increases. The Lincoln core complex is bounded on the west by the high-angle Brody Creek fault.

EPA ig$_g$

Granite of George Creek (Eocene? or Paleocene?)--Leucocratic, medium-grained, typically equigranular biotite granite (Atwater and Rinehart, 1984). The biotite granite of George Creek lies along the east shore of Roosevelt Lake in a zone extending north about 5 km from George Creek. This granite is distinguished from the mylonitically deformed biotite granite of the plutonic complex of Johnny George (EPA ia$_j$) only by the lack of foliation and lineation; the granite of George Creek may be an undeformed part of the plutonic complex of Johnny George in the upper plate of the Lincoln metamorphic core complex.

Tertiary to Cretaceous Plutonic Rocks

TKid

Diorite of Johnny George (Tertiary? or Cretaceous?)--Medium-grained titanite-biotite-hornblende diorite (Atwater and Rinehart, 1984). Two bodies (<0.5 km^2) of this diorite are exposed about 5 km and 6 km southeast and northwest, respectively, of Johnny George Mountain. The diorite bodies are reported to be xenoliths of older (pre-Tertiary) rock (Colville Confederated Tribes Geology Department, 1984), but because the rock is not known to be deformed and is similar to rocks of the Devils Elbow suite, the diorite may be Eocene in age.

TKig$_c$

Biotite granite near Creston (Tertiary or Cretaceous)--Leucocratic, medium-grained, seriate biotite granite (DGER mapping, this report). Disseminated grains ($\leq$ 1 mm) and clots ($\leq$ 2 mm) of fresh to altered biotite occur in a groundmass composed mostly of feldspar and clear and gray subhedral quartz. Most K-feldspar is altered. Sericite is common along fracture surfaces. In most exposures the rock is not visibly foliated, but in some places an extremely crude foliation, defined by sub-parallel alignment of biotite, is visible. The age of the biotite granite near Creston is unknown; however, the granite is compositionally and texturally similar to the granitic rocks of the plutonic complex of Johnny George (EPA ia$_j$) exposed 12 km to the north and thus could be Tertiary in age, but it may be as old as Cretaceous.

Cretaceous Hypabyssal Rocks

Kir, ⋙

Porphyritic rhyolite dikes and bodies (Cretaceous)--Dikes and small rhyolite bodies (<0.25 km^2) composed of abundant gray and clear quartz phenocrysts (1-4 mm) and sparse white and pale-tan feldspar phenocrysts ($\leq$2 mm) in an aphanitic to fine-grained groundmass (Becraft and Weis, 1963; DGER mapping, this report).

The rock is white, pale tan, light gray, and blue-gray on fresh surfaces; weathered and fractured surfaces are typically iron-oxide stained. Most quartz phenocrysts are subhedral or rounded and fractured; most feldspar phenocrysts are anhedral and argillically altered. Some rhyolite contains altered biotite phenocrysts or glomerophyric clots ($\leq$1 mm). The groundmass consists dominantly of altered feldspar and as much as 75 percent quartz (Becraft and Weis, 1963); some rhyolite contains muscovite in the groundmass. Whole-rock geochemical data for rhyolite in the map area are presented in Table 1. Some rhyolite contains miarolitic cavities, and some is crudely flow-banded.

In the Castle Rock Creek-Mitre Rock area, porphyritic rhyolite dikes cut the metasedimentary rocks of the Covada Group (Omm_c); additionally, rhyolite dikes and bodies (<0.2 km^2) typically separate the Paleozoic metasedimentary rocks from the Cretaceous plutonic rocks to the east (DGER mapping, this report). Much of the rhyolite is brecciated, silicified, sericitic, and pyritized; in some places unbrecciated and brecciated rhyolite occur together. East of the Enterprise Valley several porphyritic rhyolite bodies and dikes, too small to show on Plate I, intrude metasedimentary rocks of the Middle Proterozoic Deer Trail Group. An isolated exposure of porphyritic rhyolite is present about 5 km north of Davenport.

Because the porphyritic rhyolite dikes and bodies are compositionally similar to Cretaceous alaskite dikes and bodies (Kiaa) in the map area, the rhyolite is probably Cretaceous in age.

Ki, ⊸

Lamprophyre dikes and bodies (Cretaceous)--Medium- to dark-green-gray rock consisting of pyroxene ($\leq$4 mm) and biotite ($\leq$2 mm) phenocrysts in an aphanitic groundmass composed of plagioclase, pyroxene, and biotite. In some places plagioclase and a feldspathoid(?) mineral are present as phenocrysts. Magnetite and apatite are the most abundant accessory minerals. Much of the rock is altered and contains abundant chlorite and calcite and sparse blebs (<1 mm) of pyrite (Becraft and Weis, 1963; DGER mapping, this report). Whole-rock geochemical data for a lamprophyre dike in the map area indicate the rock is basaltic andesite in composition (Table 1). Most lamprophyre dikes weather more rapidly than the surrounding country rock and thus are poorly exposed. Most exposures of lamprophyre dikes are in Cretaceous plutonic rocks in and east of the Enterprise Valley; in some places the dikes contain xenoliths of plutonic rock.

No isotopic ages are reported for lamprophyre dikes and bodies in the map area, but because the lamprophyre dikes and bodies are spatially associated with Cretaceous plutonic rocks, they are probably Cretaceous in age.

Cretaceous Plutonic Rocks

Kia_g, Kig_g

Granite near the Germania mine (Cretaceous)--A zoned pluton composed of an equigranular border phase of monzogranite and a porphyritic interior phase that ranges in composition from monzogranite to granodiorite (Du, 1979). Both phases of the pluton are cut by aplite-alaskite-pegmatite dikes. The pluton is exposed along the northeast border of the map area and is informally named herein for the exposure near the Germania mine about 1 km north of the map area in the Nespelem 1:100,000-scale quadrangle. Becraft and Weis (1963) originally mapped the equigranular border phase as part of their equigranular quartz monzonite (Kig_l, this report) and the porphyritic interior phase as part of their porphyritic quartz monzonite (Kia_m, this report). No isotopic ages are reported for the granite near the Germania mine, but because it is compositionally similar to other Cretaceous plutons in the area, the pluton is probably Cretaceous in age.

Kia_g

Equigranular granite--Light- to medium-gray, medium- to coarse-grained equigranular granite composed of quartz, plagioclase, K-feldspar, and biotite (typically >5%) (Du, 1979). In some places the rock contains sparse K-feldspar phenocrysts. The equigranular granite is typically deeply weathered. Contacts with the metasedimentary rocks are sharp, discordant, and gently dipping. Equigranular granite grades into the porphyritic granite phase of the pluton.

Kig_g

Porphyritic--Light-gray porphyritic granite consisting of K-feldspar, plagioclase, and quartz phenocrysts in a coarse-grained groundmass composed of quartz, plagioclase, K-feldspar, and biotite (Du, 1979). K-feldspar forms large (about 5 cm across) phenocrysts, which are light gray and subhedral to euhedral; quartz, plagioclase, and K-feldspar form smaller ($\leq$0.6 cm across) phenocrysts. The porphyritic granite is typically deeply weathered, producing a soil cover that contains abundant K-feldspar crystal fragments, which distinguishes it from the soil cover formed over the equigranular granite.

Kig_o

Granite of Owl Creek (Cretaceous)--Light-gray, fine- to medium-grained, mostly equigranular monzogranite composed of quartz, plagioclase, K-feldspar, and accessory biotite (Du, 1979); accessory muscovite is present in some places. Contacts with the granite of the Germania mine (Kia_g) are sharp. The granite of Owl Creek is distinguished from the granite of the Germania mine by its higher silica and total alkali content and by the presence of accessory muscovite (Du, 1979). Becraft and Weis (1963) originally mapped this as part of their equigranular quartz monzonite (Kig_l, this report). Because the granite of Owl Creek is compositionally similar to other Cretaceous plutons in the area, the pluton is probably Cretaceous.

Kiaa,

Alaskite bodies and dikes (Cretaceous)--Small bodies ($\leq$0.5 km^2) and dikes of leucocratic alaskite, aplite, and pegmatite characterized by extreme textural variation, Na-rich plagioclase, and sparse mafic minerals. Most rocks are monzogranite in composition and are typically composed of quartz, K-feldspar, Na-rich plagioclase, muscovite, and biotite (<5%) (Becraft and Weis, 1963; DGER mapping, this report). Magnetite is the most abundant accessory mineral, but pyrite and pink garnet are locally present. Most quartz is clear or smoky; some dikes are composed of nearly 100 percent milky quartz. Most K-feldspar is white or pale tan but is pale green, pale yellow or pink in some places. Some plagioclase is sericitic, and some biotite is chloritic. Aplitic to graphic to coarsely pegmatitic textures commonly can be found in a single dike or body, but many bodies are medium grained and equigranular.

Alaskitic rocks intrude Cretaceous plutonic rocks and are typically more resistant than those rocks; contacts are sharp to gradational. Alaskitic rocks also cut metasedimentary rocks in the Castle Rock Creek-Mitre Rock, the Cayuse Mountain, and the Germania Consolidated mine-Midnite mine areas (Becraft and Weis, 1963; DGER mapping, this report; Du, 1979; Nash, 1978). Dikes range from tens of centimeters wide to as much as 2 m wide and 500 m long (Du, 1979). Alaskite bodies and dikes appear to be more abundant and larger west of the Enterprise Valley, but extensive Quaternary sediments limit bedrock exposures. The association and gradational contact of the alaskite bodies and dikes with the Cretaceous plutonic rocks suggest the alaskite is Cretaceous in age.

$Kiat_p$

Granite of Pitney Butte (Cretaceous)--Light-yellow-gray, fine-grained (0.5-2 mm), uniformly equigranular monzogranite with an average modal composition of Q30:A35:P29 with 2-7 percent muscovite, 1-6 percent biotite, and 0.5 percent magnetite (Becraft and Weis, 1963; Fleshman and Dodd, 1982); traces of apatite are

locally present. Most plagioclase (An_{10-15}) is sericitic and argillically altered; K-feldspar is also argillically altered, and most biotite is chloritic. In some places the granite is cut by alaskite bodies and dikes (Kiaa) and sulfide-bearing quartz veins. The granite is uranium-enriched.

The pluton occupies about 3 km^2 on Pitney Butte south of the Spokane River. Contacts with the granite of Lilienthal Mountain (Kig_l) are gradational over as much as 90 m (Becraft and Weis, 1963). Near contacts, the grain-size increases and the muscovite content decreases. No isotopic ages are reported for the granite of Pitney Butte, but because the granite is compositionally similar to and gradational into the granite of Lilienthal Mountain, it is probably Cretaceous in age.

Kig_l

Granite of Lilienthal Mountain (Cretaceous)--Light-yellow-gray and medium-gray, medium- to coarse-grained (3-8 mm) monzogranite with an average modal composition of Q35-40:A28-31:P28-30; the rock contains 1-5 percent biotite and trace amounts of hornblende and pyroxene(?) (Becraft and Weis, 1963; DGER mapping, this report); sparse accessory apatite, magnetite, muscovite, and titanite are locally present. Some granite is porphyritic; quartz and feldspar phenocrysts are as much as 4 cm across. Most plagioclase (average An_{10}) is sericitic. Whole-rock geochemical data for granite in the map area are presented in Table 1. The granite is stained by iron oxide and is Liesegang banded in many places. Most exposures of this unit are deeply weathered, but in fresh exposures the rock is massive.

The granite of Lilienthal Mountain is exposed west of the northwest-trending segment of the Spokane River valley and the Enterprise Valley. The granite intrudes Paleozoic and Precambrian metasedimentary rocks. Conacts with metasedimentary rocks are sharp; xenoliths and inclusions are extremely sparse (DGER mapping, this report). On the east flank of Lilienthal Mountain, contacts with the Midnite mine pluton (Kia_m) are gradational (Becraft and Weis, 1963). The granite of Lilienthal Mountain is cut by or grades into alaskite dikes and bodies (Kiaa); Eocene porphyritic dacite dikes and plugs (Eida) also cut this granite. No isotopic ages are reported for the granite of Lilienthal Mountain, but because it is texturally and compositionally similar to other Cretaceous plutons in the map area, the pluton is probably Cretaceous in age.

Kig_b

Granite of Blue Creek (Cretaceous)--Light- to medium-gray, fine-grained ($\leq$1 mm) monzogranite with sparse, widely scattered phenocrysts (Becraft and Weis, 1963). The granite has a modal composition of Q25-30: A20-35:P30-40 and contains 5-13 percent biotite, as much as 1.5 percent hornblende, and sparse magnetite and muscovite; apatite, zircon, and titanite are the most abundant accessory minerals. The granite is massive and is more resistant than the surrounding granite of the Midnite mine pluton (Kia_m). The granite of Blue Creek grades into granite of the Midnite mine pluton over a distance of 15-30 m; near contacts, mafic minerals are less abundant. Gradational contacts with the Midnite mine pluton and the compositional similarity to other Cretaceous plutons in the area suggest that the granite of Blue Creek is Cretaceous in age.

Kia_m

Midnite mine pluton (Cretaceous)--Leucocratic, pink, tan, light-yellow-gray, and pale-green, porphyritic monzogranite consisting of K-feldspar phenocrysts in a coarse- to medium-grained (4-6 mm) groundmass; some rock contains plagioclase and smoky quartz phenocrysts. Phenocrysts range in size from 15 mm to 5.5 cm. The rock has a modal composition of Q35-40:A25-35:P25-35 and includes 3-5 percent biotite and <1 percent (total) accessory apatite, magnetite, titanite, zircon, and muscovite (Becraft and Weis, 1963); locally, rutile, pyrite, epidote, garnet, and allanite are present as sparse accessory minerals (Asmerom and others, 1988). Most plagioclase (An_{10-15}) is sericitic, and most biotite is chloritic. Most muscovite is probably secondary (Ludwig and others, 1981); some muscovite-bearing rock is biotite deficient (Fleshman and Dodd, 1982). The monzogranite is texturally varied; within 50 m of the margins of the pluton the rock is fine

grained and equigranular. Xenoliths and inclusions are sparse, but biotite-rich schlieren are present near contacts with the metasedimentary rocks (Nash and Lehrman, 1975). Most rock is deeply weathered but is massive where fresh. Whole-rock geochemical data for monzogranite in the map area are presented in Tables 1 and 2. The pluton is enriched in thorium and uranium; uranium is associated with accessory magnetite (Fleshman and Dodd, 1982).

In the map area the Midnite mine pluton covers about 55 km^2 where it intrudes the Middle Proterozoic Togo Formation (Yar_t). Near contacts with the metasedimentary rocks, the monzogranite contains miarolitic cavities. The pluton is cut by and in some places grades into many alaskite bodies and dikes (Kiaa) (Ludwig and others, 1981); cross-cutting dikes of coarse-grained pegmatite are sparse (Fleshman and Dodd, 1982). In the Midnite mine area the granite is cut by Eocene porphyritic dacite (Eida) (Nash, 1978). Contacts with the granodiorite of Benjamin Lake ($Kigd_b$) are sharp, and dikes of porphyritic monzogranite extend into the granodiorite. Contacts between the Midnite mine pluton and the granite of Lilienthal Mountain (Kig_l) south of the Spokane River are gradational.

In the map area the Midnite mine pluton has yielded isotopic ages between about 63 Ma and 105 Ma (Table 3). The younger ages (from the western part of the pluton (Ludwig and others, 1981)) were probably reset during the Eocene thermal event associated with volcanism and graben and metamorphic core complex development. Contact relations with the granodiorite of Benjamin Lake ($Kigd_b$) indicate this unit is younger than the granodiorite (Asmerom and others, 1988).

Kig

Granite porphyry (Cretaceous)--Light-gray to pink granite that contains equant quartz ($\leq$2 mm) and K-feldspar phenocrysts in a medium- to coarse-grained (2-5 cm) groundmass composed of quartz, K-feldspar, Na-rich plagioclase (as much as 10-15% of rock), and biotite (Becraft and Weis, 1963); magnetite is the only common accessory mineral. In some places phenocrysts make up as much as 60 percent of the rock, but elsewhere phenocrysts constitute only a few percent. The granite porphyry is exposed east of the Spokane River east of Sand Flat. Because the granite porphyry is compositionally similar to other Cretaceous plutons in the area, it is probably Cretaceous in age. Dikes of this unit, too small to be shown on Plate I, cut the granodiorite of Benjamin Lake ($Kigd_b$) (Becraft and Weis, 1963).

$Kigd_b$

Granodiorite of Benjamin Lake (Cretaceous)--Leucocratic, medium-gray, medium-grained (3 mm average), equigranular hornblende-biotite granodiorite that has a modal composition of Q25-30:A10-15:P35-40 and 7-15 percent biotite and 7-15 percent hornblende (Becraft and Weis, 1963; DGER mapping, this report). Accessory minerals make up as much as 2 percent of the rock and include titanite, apatite, magnetite, and zircon. Most plagioclase (An_{40-50}) is sericitic (Asmerom and others, 1988). K-feldspar is interstitial to quartz and plagioclase. Hornblende is present as subhedral to euhedral crystals. Biotite occurs as euhedral grains or as anhedral clots. In some places the rock is deficient in hornblende or biotite. Hornblende and biotite are partially chloritic. Whole-rock geochemical data for granodiorite in the map area are given in Tables 1 and 2.

In many places the granodiorite is cut by abundant alaskite dikes and a few larger bodies (Kiaa); near Wellpinit Mountain the granodiorite is cut by several lamprophyre dikes and bodies (Ki). The few exposed contacts between the granodiorite of Benjamin Lake and the Midnite mine pluton (Kia_m) are sharp, and dikes extend from the Midnite mine pluton into the granodiorite (Asmerom and others, 1988). Contacts between the granodiorite of Benjamin Lake and the granite of Lilienthal Mountain (Kig_l) are also poorly exposed, but near these contacts the granodiorite contains pink K-feldspar phenocrysts. Contacts with the metasedimentary rocks of the Cayuse Mountain-Mill Canyon area (OYcb, OYph, $OYmm_h$) are sharp and typically can be located within one meter.

Several Pb-α whole-rock ages (Table 3) suggest the granodiorite of Benjamin Lake was emplaced about 100 Ma and thus is Cretaceous in age.

$Kigd_h$

Granodiorite of Hawk Creek (Cretaceous)--Medium- to dark-gray, medium-grained hornblende-biotite granodiorite characterized by abundant epidote (DGER mapping, this report). Epidote is present as dispersed grains (≤1 mm) and as clusters of grains; epidote veinlets as much as 2 mm wide cut the granodiorite. Anhedral biotite and hornblende occur together in the interstices between quartz and feldspar. Most biotite is fresh, and most hornblende is chloritic. Quartz is gray or clear; feldspar is white and flesh-colored. Fine-grained biotite-hornblende clots (xenoliths?) are common. Whole-rock geochemical data for the granodiorite of Hawk Creek are presented in Tables 1 and 2.

The granodiorite is cut by pegmatite dikes (Kiaa) composed of quartz and feldspar. The granodiorite is also cut by porphyritic dacite dikes that contain sparse quartz and epidote and by a porphyritic dacite plug (Eida).

The granodiorite of Hawk Creek is weakly foliated. Foliation is defined by the crude alignment of mafic minerals. Slickenside striae are common on surfaces that are coated with a dark-gray-brown mineraloid(?) (Fe-Mn oxide?); the slickenside surfaces have a strike similar to that of the foliation. Foliation is more pronounced as the slickenside surfaces are approached. The cross-cutting pegmatite dikes (Kiaa), porphyritic dacite dikes (Eida), and porphyritic dacite body (Eida) are not visibly deformed.

Because the granodiorite of Hawk Creek is compositionally similar to the Cretaceous granodiorite of Benjamin Lake ($Kigd_b$), it is tentatively assigned a Cretaceous age.

Kia_{mr}

Altered granitoid rocks of Mitre Rock (Cretaceous)--Medium-gray to green-gray, fine- to medium-grained, equigranular to aplitic granitoid rocks characterized by chloritically altered mafic minerals, pink quartz, pale-green to chalky white feldspar, and accessory calcite (DGER mapping, this report). The unit is exposed for about 3 km along the eastern shore of Roosevelt Lake from the cove south of Mitre Rock northward. In some exposures the rocks are light yellow-tan and stained by iron oxide. Most of the rocks are composed of about 15-20 percent quartz, 20-30 percent chloritically altered mafic minerals, and 50 percent feldspar. Secondary minerals include chlorite, calcite, epidote, and magnetite. In the least altered rocks mafic minerals consist of euhedral biotite and clots of hornblende. In some places the granitoid rocks contain dark-green, rounded biotite-hornblende inclusions and large (≤100 m) xenoliths or pendants of Covada Group metasedimentary rocks (Omm_c). Whole-rock geochemical data for a sample of green-gray, medium-grained, equigranular granitoid rock are presented in Tables 1 and 2.

In most places the granitoid rocks are cut by porphyritic dacite dikes and plugs (Eida); cross-cutting alaskite bodies and dikes (Kiaa) are sparse. Porphyritic dacite plugs and porphyritic rhyolite dikes (Kir) are common along the contact between the granitoid rocks and the Covada Group.

The granitoid rocks of Mitre Rock are commonly sheared and brecciated in zones that strike nearly due north. Extensive alteration and brecciation of the granitoid rocks probably occurred during brittle deformation along the north-striking fault that bounds the southeast side of the Lincoln metamorphic core complex (Fig. 5).

Because the least altered rocks of the granitoid rocks of Mitre Rock resemble the Cretaceous granodiorite of Benjamin Lake ($Kigd_b$), the granitoid rocks are tentatively assigned a Cretaceous age.

Precambrian Intrusive Rocks

Zib

Basic intrusive dikes and sills (Upper Proterozoic)--Dikes and sills of dark-green, fine-grained, equigranular rock composed of 60-80 percent hornblende, 20-25 percent plagioclase, and in some places as much as 3 percent pyrite; accessory minerals include biotite, magnetite, and titanite (Becraft and Weis, 1963). Most hornblende is chloritic, and most feldspar is partially altered. Calcite is a common secondary mineral. Some of the rocks contain relict hornblende phenocrysts $\leq$2 mm long. Quartz xenocrysts are found in the basic intrusions in the Midnite mine area (Nash, 1978). Most of the dikes and sills are $\leq$30 m long and $\leq$6 m wide and thus are too small to be shown on Plate I. Many of the basic intrusive bodies are sheared, and some exhibit cataclastic texture. Strongly sheared rocks have a well-developed foliation parallel to the plane of shearing. Sills(?) of basic intrusive rock commonly lie at or near the top of the Middle Proterozoic Edna Dolomite (Ycb_e). Basic intrusive bodies cut the rocks of the Middle Proterozoic Togo Formation (Yar_t).

Except for the sills(?) at or near the top of the Edna Dolomite (Ycb_e), the basic dikes and sills are thought to represent feeder dikes for the Upper Proterozoic extrusive metavolcanic rocks of the greenstone member of the Huckleberry Formation exposed north of the map area (Campbell and Loofbourow, 1962; Evans, 1987). Therefore, the basic intrusive rocks are considered to be Late Proterozoic in age. However, because sills(?) are present near the top of the Edna Dolomite almost everywhere the top of the formation is exposed, these sills(?) may actually be extrusive metavolcanic rocks of Middle Proterozoic age, even though no extrusive features are observed (Miller and Whipple, 1989).

Mixed Igneous and Metamorphic Rocks

EPAmg

Migmatite of Johnny George (Eocene or Paleocene)--The migmatite consists of, from oldest to youngest: (1) scattered bodies of leucocratic to mesocratic, medium-grained, equigranular biotite gneiss; (2) leucocratic, medium-grained, equigranular biotite granite and granodiorite; (3) aplite and pegmatite; and (4) dikes of mesocratic, fine-grained biotite diorite(?) (Atwater and Rinehart, 1984). The granitic rocks locally contain white K-feldspar phenocrysts in some places. All phases of the migmatite are cut by dikes and irregular bodies of the Eocene monzonitic rock (Eii); north of Roosevelt Lake the migmatite is cut by bodies of dioritic rock included in the Eocene Friedlander Meadows pluton ($Eimd_f$). Foliation and lineation range from well developed to indistinct; the orientation of foliation varies among exposures. Lineation trends nearly due west and is more pronounced to the east. The migmatitic rocks underlie about 25 km^2 on the southwest flank of Johnny George Mountain; additional exposures are found south of Roosevelt Lake (R. W. Holder and G. A. M. Holder, Georgia Southern College, written commun., 1987).

Metamorphic Rocks

pTbg

Gneiss near Elmer City (pre-Tertiary)--Layered, fine- to coarse-grained, biotite-muscovite-sillimanite gneiss (Atwater and Rinehart, 1984; Carlson, 1984). Carlson (1984) suggests that the gneiss is xenolithic, having been brought up from depth by intrusion of the biotite granite of Swawilla Basin (EPAia_s); thus, the gneiss near Elmer City is probably not correlative with the metasedimentary rocks of the Ordovician Covada Group (Omm_c) exposed to the east.

Tectonic Rocks

Tbx

Tectonic breccia west of Fort Spokane (Tertiary)--Weakly lithified breccia consisting of a heterogeneous mixture of volcanic and granitic rock fragments ranging in size from <1 mm to 1 m. Various degrees of chloritic and argillic alteration commonly obscure parent rock identity; identifiable fragments include porphyritic dacite flows of the Sanpoil Volcanics (Evd_s) and lineated granitic rock of the plutonic complex of Johnny George ($EPAia_j$). In some places the breccia includes shattered, green, siliceous dikes that were probably emplaced during late stages of brecciation (DGER mapping, this report). Locally, the breccia displays a subtle, gently east-dipping layering resulting from the crude alternation of volcanic and granitic fragments (Atwater and Rinehart, 1984). The tectonic breccia west of Fort Spokane marks the trace of the low-angle, east-dipping fault separating the mylonitically deformed rocks in the Lincoln metamorphic core complex (lower plate) to the west from the brittlely deformed rocks in the upper plate (Fig. 5). The unit is discontinuously exposed in a zone about 6 km long along the west shore of Roosevelt Lake west of Fort Spokane.

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Table 1. Major-oxide analyses (weight percent) of igneous rocks in the Coulee Dam 1:100,000 scale quadrangle. Analyses performed by Washington State University XRF laboratory. All analyses normalized to 100 percent on a volatile-free basis. FeO* is total iron expressed as FeO.

Sample no.	Map	Subsection	Sec.	Twp.	Rge	SiO_2	Al_2O_3	TiO_2	FeO*	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
2636171FZ	Eida	NE/4 SE/4 NE/4	17	26	36E	66.65	15.05	0.61	3.76	0.06	3.76	2.12	4.51	3.35	0.24
2636167HZ	$Kigd_h$	NE/4 NW/4 NW/4	16	26	36E	66.64	15.42	0.72	4.71	0.14	4.39	1.86	3.25	2.69	0.18
2738098DZ	$Kigd_b$	NW/4 NW/4 SW/4	9	27	38E	65.29	15.20	0.72	5.32	0.10	4.52	2.18	4.15	2.31	0.20
2735108DZ	$\cancel{M}v_{wp}$	NW/4 NW/4 SW/4	10	27	35E	50.47	12.80	3.51	15.21	0.25	8.46	4.51	1.32	2.70	0.78
2038081BZ	Kia_m	NE/4 SE/4 SE/4	8	28	38E	74.09	13.53	0.30	2.01	0.08	1.67	0.57	4.36	3.29	0.10
2837135CZ	Kia_m	SE/4 NE/4 SW/4	13	28	37E	73.63	14.16	0.31	1.76	0.05	1.37	0.46	5.09	3.09	0.09
2835352G2	$\cancel{M}v_{gR2}$	SW/4 NE/4 NE/4	35	28	35E	55.83	13.77	2.27	12.17	0.20	6.93	3.37	1.81	3.19	0.47
2835352G1	$\cancel{M}v_{gR2}$	SW/4 NE/4 NE/4	35	28	35E	56.37	13.85	2.30	11.35	0.20	7.03	3.31	1.84	3.26	0.47
2836206G	$\cancel{M}v_{gR2}$	SW/4 NE/4 NW/4	20	28	36E	55.80	13.79	2.27	12.26	0.20	6.91	3.38	1.73	3.21	0.46
2836184D	$\cancel{M}v_{gN2}$	NW/4 NW/4 SE/4	18	28	36E	54.58	13.99	2.04	11.74	0.25	8.40	4.39	1.32	2.83	0.47
2836175D	$\cancel{M}v_{wp}$	NE/4 NE/4 SW/4	17	28	36E	50.65	12.89	3.55	15.10	0.24	8.45	4.31	1.31	2.71	0.79
2836171E	$\cancel{M}v_{gR2}$	SE/4 SE/4 NE/4	18	28	36E	55.98	13.87	2.28	12.11	0.20	6.87	3.33	1.72	3.18	0.46
2836043G	$\cancel{M}v_{wp}$	SE/4 NW/4 NE/4	4	28	36E	50.64	13.00	3.55	15.07	0.27	8.49	4.31	1.30	2.61	0.78
2836087D	$\cancel{M}v_{wp}$	NE/4 NW/4 SW/4	8	28	36E	50.88	12.87	3.58	14.76	0.23	8.55	4.32	1.31	2.70	0.81
2836036H1	Ki	NW/4 NE/4 NW/4	3	28	36E	56.34	14.88	1.66	8.77	0.12	6.85	4.85	2.52	2.88	1.12
2835011G2	Kir	SE/4 NE/4 NE/4	1	28	35E	76.70	13.95	0.17	1.27	0.02	0.32	0.03	4.56	2.91	0.07
2936327H	$\cancel{M}v_{wp}$	NE/4 NW/4 NW/4	32	29	36E	50.74	12.92	3.51	14.96	0.25	8.42	4.58	1.24	2.59	0.80
2936323G	$\cancel{M}v_{wp}$	SE/4 NW/4 NE/4	32	39	36E	50.92	13.01	3.56	14.59	0.25	8.49	4.50	1.31	2.59	0.78
2936322H	$\cancel{M}v_{wp}$	NW/4 NE/4 NE/4	32	29	36E	51.27	13.21	3.63	14.43	0.24	8.74	3.84	1.21	2.62	0.80
2935254A	Kia_{mr}	SW/4 SW/4 SE/4	25	29	35E	69.60	15.54	0.58	3.62	0.09	2.80	1.69	3.21	2.69	0.18
2936314E4	Kir	SW/4 SW/4 NE/4	31	29	36E	75.46	14.11	0.16	1.12	0.06	1.10	0.15	4.90	2.88	0.07
2936346A1	Kig_1	SW/4 SE/4 SW/4	34	29	36E	69.52	16.00	0.37	2.68	0.09	2.76	0.81	4.50	3.09	0.16
2936358C1	Eida	SW/4 NW/4 SW/4	35	29	36E	65.90	14.97	0.68	4.64	0.09	3.96	2.44	4.06	2.95	0.29
2936358C2	Eida	SW/4 NW/4 SW/4	35	29	36E	65.98	14.98	0.66	4.40	0.08	3.91	2.44	4.28	2.98	0.28

Table 2. Trace-element analyses (in parts per million) of igneous rocks in the Coulee Dam 1:100,000 scale quadrangle. Analyses performed at Washington State University XRF laboratory. Same samples as in Table 1.

Sample no.	Map unit	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn
2636171FZ	Eida	19	52	11	91	1170	171	583	248	23	20.0	20	15	52
2636167HZ	$Kigd_h$	8	14	17	97	619	170	280	167	28	12.0	20	24	103
2738098DZ	$Kigd_b$	11	27	17	111	893	161	321	182	29	15.3	14	10	64
2735108DZ	Mv_{wp}	11	31	39	427	548	32	288	208	48	20.1	26	17	144
2838081BZ	Kia_m	13	3	9	32	497	258	240	152	30	37.6	15	7	45
2837135CZ	Kia_m	14	0	8	27	621	286	239	152	26	37.8	19	1	36
2835352G2	Mv_{gR2}	7	22	32	340	709	49	325	193	39	14.8	23	13	125
2835352G1	Mv_{gR2}	4	22	32	342	734	48	336	196	40	16.2	21	19	133
2836206G	Mv_{gR2}	4	18	28	339	662	46	315	190	39	14.0	18	20	128
2836184D	Mv_{gN2}	5	40	35	283	704	28	318	165	36	13.0	22	30	121
2836175D	Mv_{wp}	9	27	32	420	519	32	292	209	47	22.0	23	43	152
2836171E	Mv_{gR2}	3	16	30	326	715	47	319	191	37	14.0	22	24	124
2836043G	Mv_{wp}	9	29	36	417	544	31	290	206	46	19.0	21	25	146
2836087D	Mv_{wp}	6	27	36	406	508	32	294	207	47	19.0	27	32	146
2836036H1	Ki	0	0	0	0	0	0	0	0	0	0.0	0	0	0
2835011G2	Kir	0	0	0	0	0	0	0	0	0	0.0	0	0	0
2936327H	Mv_{wp}	7	30	36	404	540	30	290	208	47	19.0	20	33	153
2936323G	Mv_{wp}	10	28	36	428	548	31	287	206	47	20.0	22	26	153
2936322H	Mv_{wp}	10	34	37	433	548	29	301	210	48	21.0	25	31	153
2935254A	Kia_{mr}	0	0	0	0	0	0	0	0	0	0.0	0	0	0
2936314E4	Kir	0	0	0	0	0	0	0	0	0	0.0	0	0	0
2936346A1	Kig_1	0	0	0	0	0	0	0	0	0	0.0	0	0	0
2936358C1	Eida	0	0	0	0	0	0	0	0	0	0.0	0	0	0
2936358C2	Eida	0	0	0	0	0	0	0	0	0	0.0	0	0	0

Table 3. Isotopic ages for rocks in the Coulee Dam 1:100,000 quadrangle. Sample locations shown on Plate I.

Unit	Map loc. no.	Age (Ma)	Method	Material	Reference	Location	Sample no.
Eva_s	1	50.3±1.4	K-Ar	hornblende	Pearson and Obradovich (1977)[1]	NW/4NW/4 sec. 16, T28N, R37E	A8
Eida	2	47.2±1.9 47.5±3.6 51.8±3.1	fission track K-Ar	zircon apatite hornblende	Ludwig and others (1981)[2]	47°56.3′ 118°05.8′	Midnite mine (530)
$Eimd_f$	3	46.9±1.2 48.1±1.2	K-Ar	hornblende biotite	Atwater (1987)[3]	47°59.03′ 118°33.00′	BA-81-81D
$EPia_j$	4	49.4±0.4 50.3±0.5	K-Ar	biotite hornblende	Atwater (1987)[3]	47°56.4′ 118°30.5′	JW-83-23D
$EPig_k$	5	52.9±0.4	K-Ar	biotite	Atwater (1987)[3]	47°59.40′ 118°51.10′	837-12C
$EPia_s$	6	53.5±0.3	K-Ar	biotite	Atwater (1987)[3]	47°57.48′ 118°58.30′	837-12B
$EPig_k$	7	61.3±2.3	K-Ar	biotite	Atwater and Rinehart (1984)[4]	47°59.67′ 118°50.30′	A65677
Kia_m	8	63.6±0.4 65.0±0.4	$^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$	zircon nonmag #1	Ludwig and others (1981)[5]	47°56.3′ 118°05.8′	Midnite mine
Kia_m	9	69.3±6.4	fission track	apatite	Ludwig and others (1981)[2]	do	do
Kia_m	10	69.5±3.0 74.1±3.9 74.6±3.9	$^{208}Pb/^{232}Th$ $^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$	monazite	Ludwig and others (1981)[5]	do	do
Kia_m	11	70.8±3.3	fission track	zircon	Ludwig and others (1981)[2]	47°56.2′ 118°02.3′	Turtle Lake
Kia_m	--	74.7	Rb-Sr isochron	whole rock	Asmeron and others (1988)[6]	--	--
Kia_m	12	75±10	Pb-alpha	whole rock	Becraft and Weis (1963)[7]	47°56.2′ 118°02.3′	6W501
Kia_m	13	75.3±0.5 76.6± 0.6 78.0±1.8	$^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$ $^{208}Pb/^{232}Th$	zircon mag	Ludwig and others (1981)[5]	47°56.3′ 118°05.8′	Midnite mine
Kia_m	14	76.5±0.7 77.9±0.7 79.0±2.0	$^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$ $^{208}Pb/^{232}Th$	zircon nonmag #2	Ludwig and others (1981)[5]	do	do
Kia_m	15	79.5±8.0	fission track	apatite	Ludwig and others (1981)[2]	47°56.2′ 118°02.3′	Turtle Lake

Table 3. Isotopic ages for rocks in the Coulee Dam 1:100,000 quadrangle (continued).

Unit	Map loc. no.	Age (Ma)	Method	Material	Reference	Location	Sample no.
Kia^m	16	82.4±3.4	fission track	titanite	Ludwig and others (1981)[2]	do	do
Kia_m	17	91.4±0.6 93.1±0.6	$^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$	zircon	Ludwig and others (1981)[5]	do	do
Kia_m	18	95±10	Pb-alpha	whole rock	Becraft and Weis (1963)[7]	47°56.3′ 118°05.9′	8W5
$Kigd_b$	19	95±10	Pb-alpha	whole rock	Becraft and Weis (1963)[7]	47°51.1′ 118°00.8′	8W1
$Kigd_b$	20	100+10	Pb-alpha	whole rock	Becraft and Weis (1963)[7]	47°49.8′ 118°00′	6B499
$Kigd_b$	21	105 + 10	Pb-alpha	whole rock	Becraft and Weis (1963)[7]	47°51.2′ 118°02.3′	8W2
$Kiat_m$	22	105 + 10	Pb-alpha	whole rock	Becraft and Weis (1963)[7]	47°54.5′ 118°03.3′	8W3

[1] Pearson and Obradovich, 1977: No constants reported. Analytical data reported in table 2.

[2] Ludwig and others, 1981: Analytical data for fission tract ages reported in table 4; (si?)(^{238}U)=7.03 x 10^{-17}/yr. Analytical data for K-Ar age reported in table 5; $^{40}K/K_{total}$ = 1.167 x 10^{-4} mol/mol, λ_β = 4.962 x $10^{-10}yr^{-1}$, and $\lambda_\varepsilon + \lambda_{\varepsilon'}$=0.581 x $10^{-10}yr^{-1}$ ("new" constants).

[3] B. F. Atwater, USGS, written commun., 1987: No analytical data given; $^{40}K/K_{total}$ = 1.167 x 10^{-4} mol/mol, λ_β = 4.962 x $10^{-10}yr^{-1}$, and $\lambda_\varepsilon + \lambda_{\varepsilon'}$ = 0.581 x $10^{-10}yr^{-1}$ ("new" constants).

[4] Atwater and others, 1984: No analytical data given; $^{40}K/K_{total}$ = 1.167 x 10^{-4} mol/mol, λ_β = 4.962 x $10^{-10}yr^{-1}$, and $\lambda_\varepsilon + \lambda_{\varepsilon'}$=0.581 x $10^{-10}yr^{-1}$ ("new" constants).

[5] Ludwig and others, 1981: Analytical data given in table 2. ^{238}U = 1.55125 x 10^{-10}/yr, ^{235}U = 9.8485 x 10^{-10}/yr, ^{232}Th = 4.49475 x 10^{-11}/yr.

[6] Asmeron and others, 1988: Rb-Sr isochron age determination made using 10 separate whole rock sample whose locations were not given; analytical data given in table 2; isochron shown in figure 3.

[7] Becraft and Weis, 1963: Analytical data reported in table 2; assuming a Th to U ratio of 1, C(zircon)=2485.