# GEOLOGIC MAP OF THE

# EAST HALF OF THE TWISP

# 1:100,000 QUADRANGLE, WASHINGTON


Compiled by

BONNIE B. BUNNING



WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES

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*This revised version supersedes the previous release, which is no longer available.*

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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# GEOLOGIC MAP OF THE EAST HALF OF THE TWISP 1:100,000 QUADRANGLE, WASHINGTON

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## INTRODUCTION

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

Literature review and preliminary compilation of the DGER geologic maps began in 1984. The maps were compiled at a scale of 1:100,000 in order to preserve most of the detail of 1:24,000-scale and smaller source maps, yet portray the regional geologic picture. Between 1984 and 1988, substantial new reconnaissance and detailed geologic mapping was performed by the DGER staff in areas where previous geologic mapping was either inadequate or lacking. New geologic mapping was also acquired through a DGER graduate student mapping program, which supported 24 mapping projects in the northeast quadrant since its inception in 1984. To further improve geologic interpretations, DGER funds were used to obtain new radiometric age data and whole-rock geochemical data.

This report consists of a geologic map and accompanying text with descriptions of map units, whole-rock geochemistry data, radiometric age data, a source of data map (Fig. 2), and reference citations. A mixture of formal, informal, and unnamed geologic units is shown on the map (Plate 1). Unit symbols provide information about the age, lithology, and name (if any) of the units: upper-case letters indicate age; lower-case letters indicate lithology; and subscripts identify named units. Example: the Winthrop Formation, a Cretaceous continental sandstone, is shown with the symbol $Kc_w$.

Age assignments of geologic units were made following the flow chart in Figure 3. The geologic time scale devised for the "Correlation of Stratigraphic Units of North America (COSUNA)" project of the American Association of Petroleum Geologists (Salvador, 1985) was used, with slight modifications of the Eocene-Oligocene and Pliocene-Pleistocene boundaries (Armentrout and others, 1983; Prothero and Armentrout, 1985; Montanari and others, 1985; Aguirre and Pasini, 1985).

Plutonic rock names were assigned using modal analyses and the International Union of Geological Sciences rock classification (Streckeisen, 1973). Volcanic rocks names were assigned using whole-rock geochemistry and the total alkali-silica (TAS) diagram (Zanettin, 1984). "High-grade metamorphic rocks" refer to rocks of amphibolite grade or higher; rocks of greenschist grade are shown as metasedimentary or metavolcanic rocks; rocks metamorphosed to less than greenschist grade are included within sedimentary, volcanic, or intrusive rock packages.

Results of geochemical, K-Ar, U-Pb, Rb-Sr, fission-track, and Pbα analyses are given in Tables 1 through 7, which follow the list of references cited.

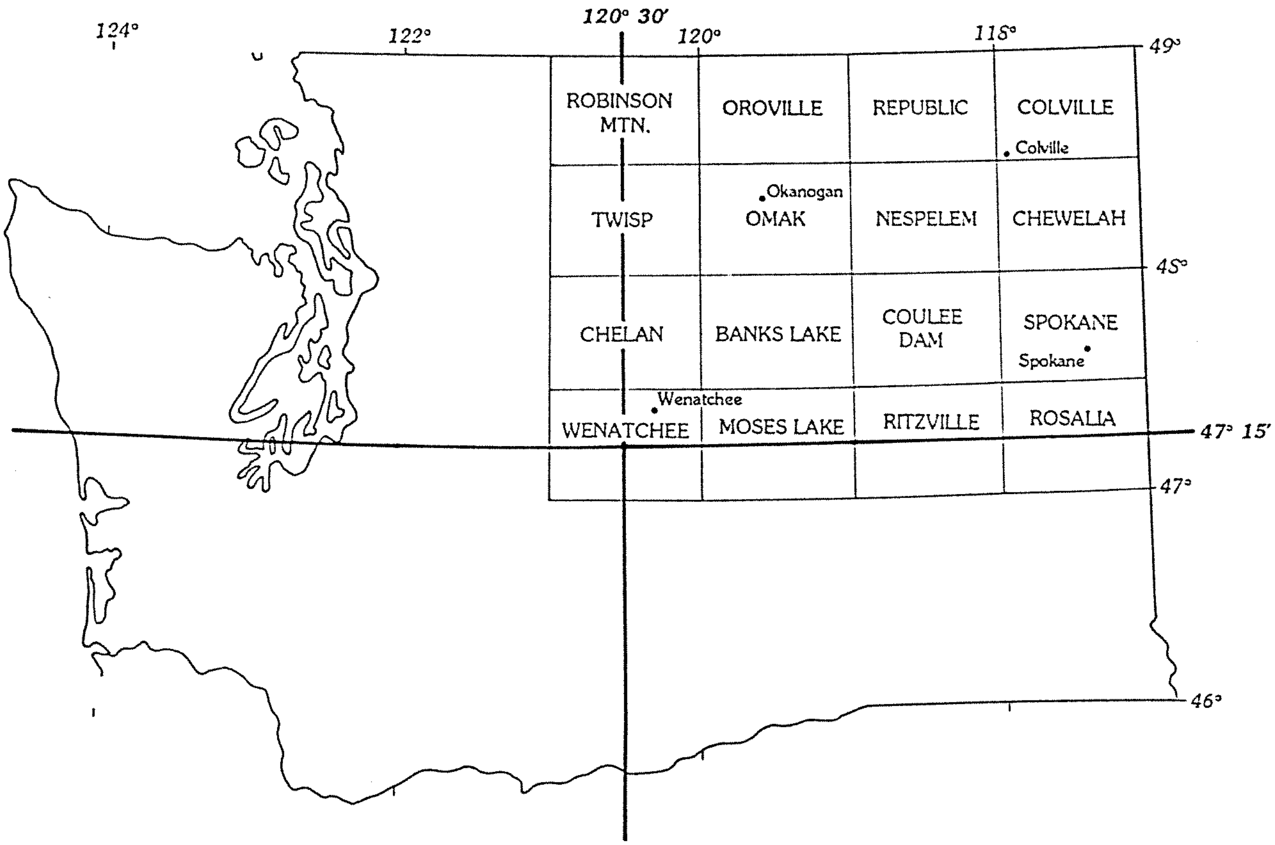


**Figure 1.** 1:100,000-scale quadrangles in the northeast quadrant of Washington.

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## Sources of Map Data

(Explanation for Figure 2, facing page)

1. Adams, 1961, scale 1:63,360
2. Barksdale, 1975, scale 1:125,000
3. Burnet, 1976, scale 1:24,000
4. Buddington, 1986, scale 1:24,000
5. Cater and Crowder, 1967, scale 1:62,500
6. DiLeonardo, 1987, scale 1:24,000
7. Frey, 1988, scale 1:24,000
8. Hopkins, 1987, scale 1:24,000
9. Hopson, 1955, scale 1:23,760
10. Libby, 1964, scale 1:31,680
11. M. F. McGroder and others, Exxon Production Research Co., 1989, written commun., scale 1:100,000
12. Bates McKee, 1968, written commun., scale 1:32,000
13. Menzer, 1982, scale 1:63,360
14. Miller, 1987, scale 1:100,000
15. Raviola, 1988, scale 1:24,000
16. Ryason, 1959, scale 1:15,580
17. Wade, 1985, scale 1:24,000

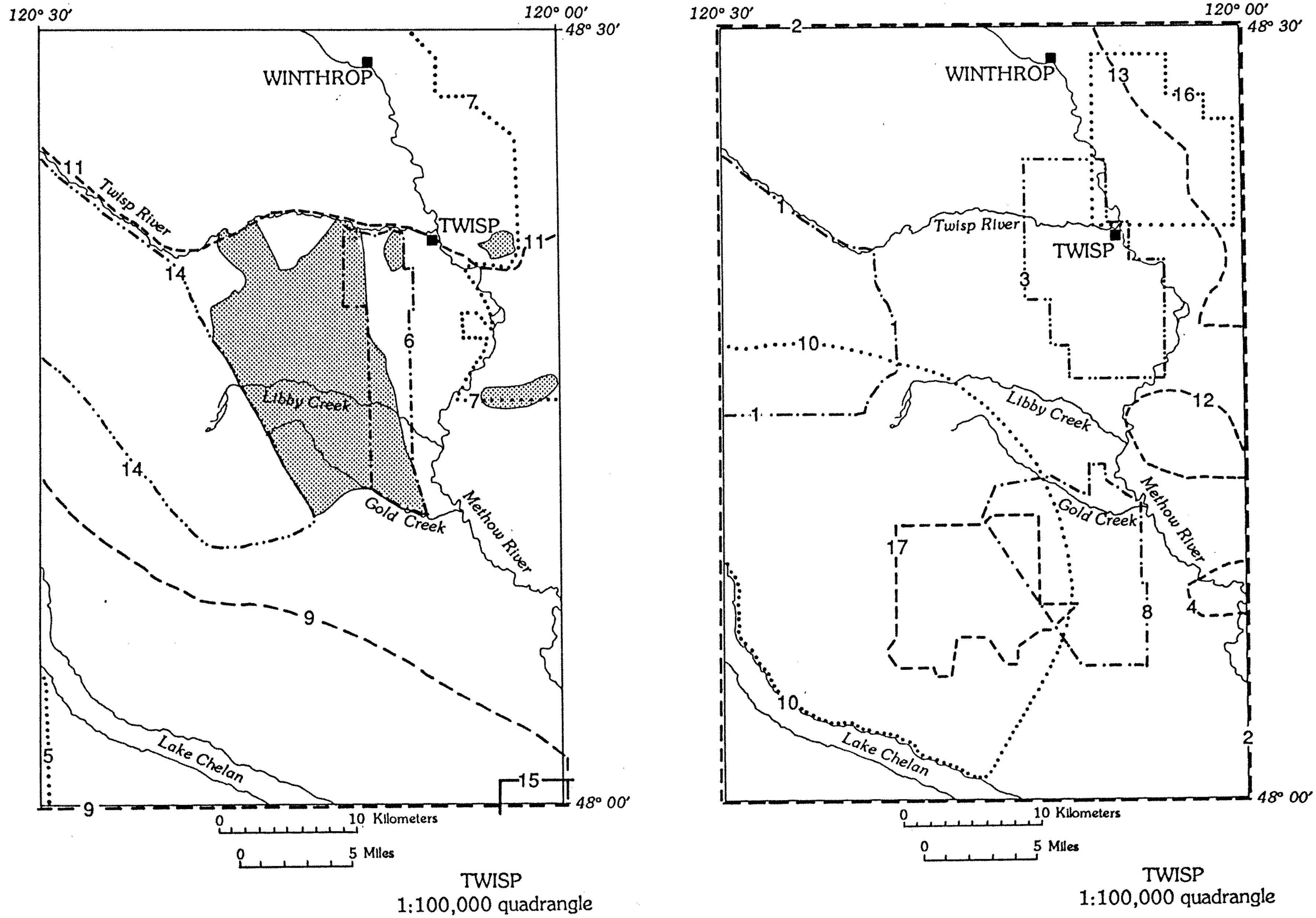


**Figure 2.** Sources of map data, east half of Twisp 1:100,000 quadrangle, Washington. See facing page for explanation.

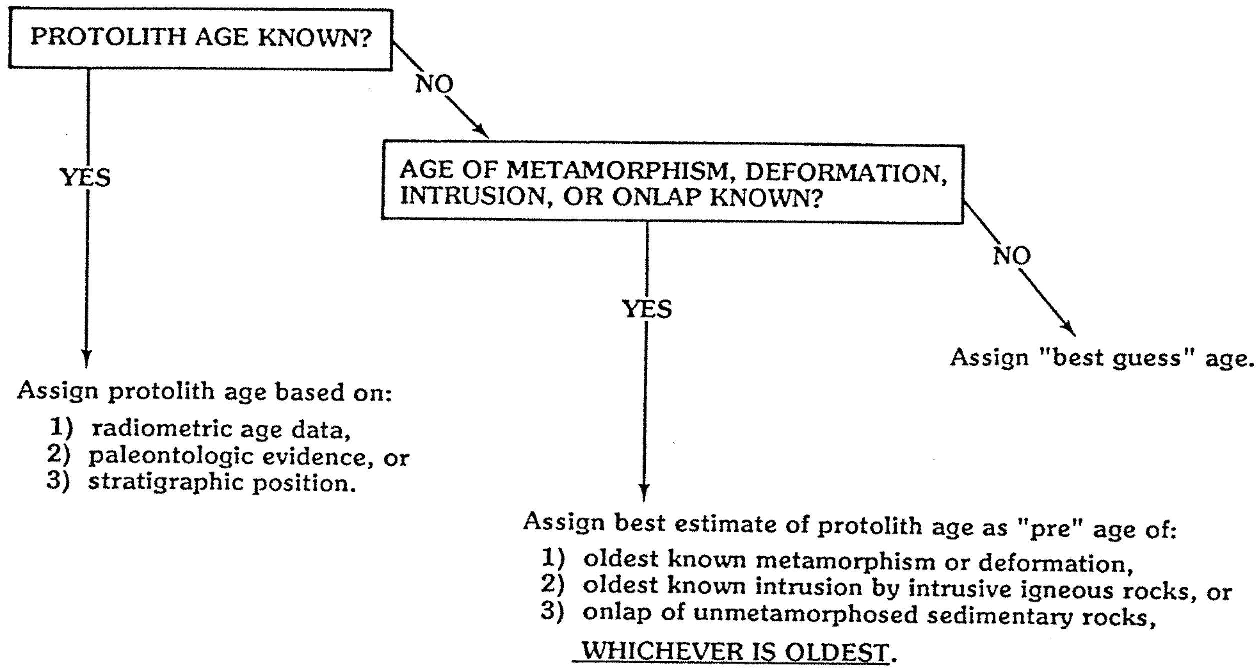


**Figure 3.** Flow chart for age assignment of geologic units. Protolith age or estimated protolith age can be assigned by correlation with other units. The unit descriptions include information on how the age of the unit was determined.

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DGER Northeast Quadrant Open-File Reports

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

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

Gulick, C. W., 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., l pl.

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

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

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

## Acknowledgments

I greatly appreciate the efforts of R. B. Miller (San Jose State University), V. R. Todd (USGS), A. M. Frey (University of Pittsburgh), M. F. McGroder (Exxon Production Research Co.), and A. M. Buddington (Western Washington University), who made unpublished data available and freely discussed ideas and interpretations. Thanks also to Kirk Johnson (Yale University) for his review and identification of the Pipestone Canyon Formation floral assemblage at the Burke Museum, and to F. J. Menzer, Jr. (F.M.C. Corp.) and A. M. Frey for leading a field trip in the map area.

Thanks also to Division geologists W. M. Phillips and H. W. Schasse, who mapped and subdivided rocks in the Newby Group during the summer of 1987; to M. A. Korosec, who provided mapping and sampling support in a number of areas on the map; to R. L. Logan, who assisted with sampling; and to K. L. Stoffel, for help with descriptions of the units of the Methow basin.

Reviews and helpful comments by R. B. Miller, V. R. Todd, and M. F. McGroder were valuable and appreciated. Portions of this report were revised and edited by V. R. Todd, M. A. Korosec, W. M. Phillips, and H. W. Schasse.

## DESCRIPTION OF MAP UNITS

### Sedimentary Rocks and Deposits

### Quaternary Unconsolidated Deposits

Qs

Sediments, undivided (Pleistocene through Holocene)--Unconsolidated sediments, including both alluvium and glacial deposits not separately mapped in original sources. Some of the sediments may be outwash deposits contributed to the Methow Valley from the Okanogan lobe of the Cordilleran ice sheet, which, according to Waitt (1972) and Barksdale (1975), flowed into the Methow Valley drainage basin at Benson and Canyon Creeks.

#### Nonglacial Deposits

Qls

Talus and landslides (Pleistocene(?) through Holocene)--Gravel, blocks, and sand forming talus slopes and landslide chutes along the crest of the Chelan divide (Wade, 1985).

#### Glacial Deposits

Qgd

Glacial drift (Pleistocene)--Undivided glacial deposits along the east side of the Methow River in the drainage of Texas Creek and on Cumbo Flat and, on the west side of the Methow River, in the drainages of Gold and Libby Creeks and the latter's south-flowing tributaries, Foggy Dew and Buttermilk Creeks; considered by Waitt (1972) to be deposits of a continental glaciation which followed an earlier alpine phase.

Qgt

Till (Pleistocene)--Heterogeneous mixture of unsorted, unstratified clay, silt, sand, cobbles, and boulders in the headwaters of Texas Creek.

Qgl

Glaciolacustrine deposits (Pleistocene)--Thinly laminated clay, silt, and sand deposited in glacial lakes dammed by stagnant ice tongues and moraines; present in many side canyons and valleys of the Okanogan River, but shown on the map only in Leecher Canyon (T. 32 N., R. 22 E.)

Qgo

Glacial outwash deposits (Pleistocene)--Poorly stratified clay, silt, sand, and gravel deposited by glacial meltwater streams and on flood plains. The unit is preserved along the southeast border of the map at the town of Methow (J. R. Wilson, formerly USGS, written commun., 1983).

## Tertiary Sedimentary Rocks

Ꝑ$c_p$

Pipestone Canyon Formation (Paleocene)--Siltstone, sandstone, and conglomerate forming three informal members: A basal member of conglomerate, a middle member of feldspathic sandstone, and an upper member of arenaceous siltstone and shale. These three members are not delineated on Plate 1.

The basal conglomerate member is poorly sorted and consists of fairly well rounded pebbles and boulders ranging in diameter from a few millimeters to more than 0.3 m in a matrix of arkose. Conglomerates in the formation fall into three distinct units separable by cobble type. The lowest conglomerate unit is 42 m thick (Ryason, 1959) and is composed of large, light-colored granitic boulders. Conglomerates of the middle unit are predominantly composed of boulders, cobbles, and pebbles of chert and granitic rocks with minor amounts of andesite cobbles and pebbles. The upper conglomerate unit contains mostly light-colored volcanic, andesite, and chert clasts and fewer granitic cobbles and pebbles.

The middle member consists of gray to buff, coarse- and medium-grained feldspathic sandstone beds 15 to 20 cm thick. The feldspars are weathered, leaving an argillaceous matrix with subangular grains of quartz. Coarse-grained units are characterized by the presence or absence of chert. The sandstone beds are purple tinged and contain carbonized plant fragments.

The upper, shaly member is fairly well indurated, but weathers easily and crops out poorly. The thin-bedded, darker layers contain carbonaceous material and fossil floras.

The Pipestone Canyon Formation is approximately 705 m thick at the type locality (Barksdale, 1975) and thins abruptly to the north. The rocks were deposited quickly from eroding highlands to the east and west. The unit has been folded into a series of northwest-trending synclines and anticlines, and crops out for the most part in large, fault-bounded blocks at the head of Pipestone Canyon and to the north and east of Bonner Lake. The rocks lie unconformably on the volcanic rocks of the Newby Group to the west (out of the map area) and are in fault contact with the Okanogan complex on the east along the Pasayten fault. The Frazer Creek complex is poorly exposed near the contact with the Pipestone Canyon Formation. The ages of the two units are similar, and the contact is inferred to be nonconformable. Barksdale (1975) considered it possible that the Frazer Creek complex intruded the Pipestone Canyon Formation. However, rocks in the complex not far from the contact have yielded a cluster of K-Ar dates ranging from 103.7 ± 2.6 to 130.1 ± 3.3 Ma (V. R. Todd, USGS, written commun., 1989; DGER, Table 3). The ages and the composition of the sediments suggest strongly that the Pipestone Canyon Formation was deposited on an eroded plutonic complex of earliest Cretaceous or latest Jurassic age.

Leucocratic feldspar-quartz-biotite porphyry occurs as a flow (?) within the formation (Frey, 1988). The upper part of the flow is reworked into a sandstone. Similar volcanic rocks are exposed at the base of the cliff in sec. 32, T. 34 N., R. 22 E., W.M. The flow in the Pipestone Canyon Formation is similar and may be related to leucovolcanic dikes (Tia) mapped to the south (Frey, 1988).

Kirk Johnson (written commun., 1988) recently reviewed the collection of Pipestone Canyon plant material, at the Burke Museum at the University of Washington, and concluded "this flora is of low diversity and contains plants found in both Eocene and Paleocene floras in western North America. The only exception to this are partial specimens of leaves that resemble "*Viburnum*" *asperum*, a taxon that is restricted to the Paleocene. This and the low diversity of the Pipestone assemblage hint at a Paleocene age for the deposit." The minor volcanic unit in the formation, a feldspar-quartz-biotite porphyry flow(?), was sampled for zircons for fission-track dating, but no datable material was found.

Vertical jointing and erosion have created the vertical pipe-like landforms which lend to the formation name. The rocks were first named and mapped by Barksdale (1948) and further described by Mallory and Barksdale (1963), Ryason (1959), Royse (1963), and Barksdale (1975).

## Mesozoic Sedimentary and Volcanic Rocks

### Cretaceous Sedimentary and Volcanic Rocks

$Kc_m$, $Kv_m$

The Midnight Peak Formation is the youngest Cretaceous unit in the Methow Basin. Although no fossils have been found in the formation, it is probably Cenomanian or Turonian in age, but could be as old as Albian because it unconformably overlies the Albian Winthrop Sandstone (this map) and is intruded by the Fawn Peak stock (88 Ma) (Riedell, 1979) and by dikes emanating from the Pasayten stock (88 Ma) to the north of this map area.

The Midnight Peak Formation was named by Barksdale (1948) who later redefined and subdivided it into two members, the volcanic member ($Kv_m$) and Ventura Member ($Kc_m$) (Barksdale, 1975). Subsequent workers (Tennyson, 1974; Tennyson and Cole, 1978) further defined the unit and identified a third member which crops out to the north of this map area.

$Kc_m$

Midnight Peak Formation, Ventura Member (Cretaceous)--Dominantly pink to maroon mudstone, siltstone, fine- to coarse-grained sandstone, and conglomerate, with minor gray to green andesitic breccia. The poorly sorted and crudely bedded conglomerates consist of rounded pebbles and cobbles of gray, green, and red chert, green and buff sandstone, and minor limestone, granitic rocks, and andesite in a sand matrix of quartz, feldspar, chert, and andesite. Sandstone constituents are similar to those in the conglomerate matrix. Cross-beds, channels, and coarsening-upward sequences are common. Maximum thickness is approximately 620 m (Barksdale, 1975).

The Ventura Member is interbedded with the volcanic member of the Midnight Peak Formation ($Kv_m$). On the map, the Ventura indicates areas dominated by the non-volcanic sediments.

The Ventura Member of the Midnight Peak Formation was originally named the Ventura Formation by Russell (1900), but was subsequently renamed and assigned to the Midnight Peak Formation by Barksdale (1975). More recently the Ventura Member has been mapped and described by M. F. McGroder and others (written commun., 1989).

$Kv_m$

Midnight Peak Formation, volcanic member (Cretaceous)--Purple, red, gray, and green altered andesitic breccias, tuffs, and flows with subordinate andesitic lithic conglomerate and sandstone and minor interbedded reddish-purple sandstone and shale (Barksdale, 1975). The poorly sorted breccias, tuffs, and conglomerates consist of angular to rounded clasts of hornblende-pyroxene-plagioclase andesite porphyry set in a fine-grained matrix of andesitic debris. The flows are massive, homogeneous, aphyric to slightly phyric rocks of similar composition. The volcanic member is 3,170 m thick and conformable and gradational with the underlying Ventura Member ($Kc_m$).

$Kc_w$

Winthrop Sandstone (Cretaceous)--Massive, white to greenish-gray, very fine to very coarse grained lithofeldspathic sandstone with thin siltstone and shale partings and sparse lenses of matrix-supported pebble conglomerate. The average sandstone mode is $Q_{32}$:$F_{48}$:$L_{20}$; lithic fragments are angular to subangular volcanic rocks, chert, and very fine grained lithofeldspathic sandstone (intraclasts).

Planar and trough cross-beds, scour-and-fill structures, ripple drift laminae, horizontal laminae, and graded beds are all common. These sedimentary structures and paleocurrent data indicate that the unit was deposited in a fluvio-deltaic system with sediment transport to the west (Rau, 1987). Fossil floral assemblages indicate an Albian age (Rau, 1987; Coates, 1974).

Maximum thickness of the Winthrop is 4,115 m, along the east side of the Methow basin in the Goat Peak syncline, but it thins and disappears to the west (Rau, 1987).

The Winthrop Sandstone is unconformably overlain by the Midnight Peak Formation and interfingers with and grades into the Virginian Ridge Formation, which is in part contemporaneous. It is intruded by the Fawn Peak stock (88 Ma) to the north of the map area. The Winthrop Sandstone crops out parallel to the northwest-trending Methow basin. On the Twisp quadrangle, the southeast extent of the unit is truncated by an unnamed, northeast-trending fault which brings the Winthrop Sandstone and rocks of the Midnight Peak Formation in contact with the older volcanic and sedimentary rocks of the Newby Group.

The Winthrop Sandstone was named by Russell (1900) and further described by Barksdale (1948, 1975), Pitard (1958), Mallory and Barksdale (1963), Cole (1973), Tennyson (1974), Rau (1987), and M. F. McGroder and others (written commun., 1989).

$Kvs_w$

Winthrop Sandstone, volcanic member (Cretaceous)--Interbedded volcaniclastic sandstone, fine-grained crystal-lithic tuff-breccias, minor lavas, and arkosic sandstones. Volcanic breccias are finer grained and more heterolithic than those in the Midnight Peak Formation. Clasts in the breccias consist of olivine basalt, chert pebbles, argillite chips, and vein quartz (M. F. McGroder and others, written commun., 1989).

The unit was originally included in the Midnight Peak Formation by Barksdale (1975), but because the clasts are distinctly different from those in the Midnight Peak Formation and the volcanic breccias are clearly interbedded with feldspathic sandstone, subsequent workers (M. F. McGroder and others, written commun., 1989) have mapped this as the informal volcanic member of the Winthrop Sandstone. Floral data constrain the Winthrop Sandstone to an Albian age. The Winthrop Sandstone (and the volcanic member) are assumed to be middle to late Albian because they overlie lower and middle Albian rocks (M. F. McGroder and others, written commun., 1989).

$Km_v$, $Kcg_v$

Virginian Ridge Formation (Cretaceous)--Black mudstone, siltstone, and lenticular beds of chert-lithic sandstone and chert-pebble conglomerate with minor lithofeldspathic sandstone near the top of the unit. The chert-pebble conglomerates are comprised of subrounded to subangular pebbles and cobbles of gray to black chert in a sandy matrix of chert, quartzite, altered mafic volcanic rocks, and feldspar and quartz grains. The feldspatholithic sandstones have an average mode of $Q_{30}$:$F_{25}$:$L_{45}$; lithic grains are chert and altered mafic volcanic rocks (Tennyson and Cole, 1978). The formation has been subdivided into two informal map units: $Km_v$, which contains less than 40 percent conglomerate beds, and $Kcg_v$, which contains more than 40 percent conglomerate beds.

The Virginian Ridge Formation interfingers with and grades into the Winthrop Sandstone and unconformably overlies the Harts Pass, Panther Creek, and Goat Creek Formations and rocks of the Newby Group (Twisp Formation) on the Robinson Mtn. quadrangle to the north. In the map area, the Virginian Ridge Formation is in probably depositional contact with the Patterson Lake conglomerate on the east. It is in fault contact with volcanic and sedimentary rocks of the Newby Group on the south. An unnamed fault defines the southern limit of the formation.

The Virginian Ridge Formation reaches a maximum thickness of greater than 4,000 m near Cady Point to the north of this map area in the Robinson Mtn. 1:100,000-scale quadrangle. It thins and disappears to the east as it interfingers with the Winthrop Sandstone (Barksdale, 1975). Eastward-thinning and -fining trends, paleocurrent data, and the presence of chert pebbles probably derived from the Hozameen Group indicate that the source of the clastics lay to the west. Sedimentary structures such as ripple drift cross-laminations, convolute laminations, graded beds, and rare cross-beds suggest that the Virginian Ridge sediments were deposited in a fan delta or deltaic environment (Tennyson and Cole, 1978; Trexler, 1984). Marine fossils, including pelecypods and gastropods, indicate that the formation is mostly Albian in age, but may range into the early Cenomanian (M. F. McGroder and others, written commun., 1989).

The Virginian Ridge Formation was mapped and named by Barksdale (1948, 1975) and further described by Pitard (1958), Maurer (1958), Tennyson (1974), and Tennyson and Cole (1978).

$Kcg_p$

Patterson Lake conglomerate (Cretaceous)--Black to red mudstone and interbedded dark feldspathic sandstone and greenish-black conglomerate containing well-rounded clasts, generally 2.5 to 20 cm in diameter. Locally, clasts reach 1 m in diameter, and in those places the boulder conglomerate may represent syndepositional faulting (M. F. McGroder and others, written commun., 1989). Pebbles are predominantly clastic sedimentary rock fragments (Trexler, 1984), with some breccia and metavolcanic rocks. Black and white chert and vein quartz, as well as granitic debris, are sparse or absent (Maurer, 1958). Sandstones range from volcanic-lithic to arkosic (Trexler, 1984). Bedding is massive. The matrix of the conglomerate consists of medium-grained, subrounded, altered mafic minerals, quartz, feldspar, and volcanic material with little silica or calcareous cement (Maurer, 1958).

The Patterson Lake conglomerate is well exposed on the west side of Patterson Lake. Its contact with the underlying Twisp Formation, where unfaulted, is an angular unconformity (Maurer, 1958). Overlying the Patterson Lake conglomerate are the Virginian Ridge Formation (middle to upper Albian) and the Winthrop Sandstone, which has a probable upper Albian age (M. F. McGroder and others, written commun., 1989).

The Patterson Lake conglomerate contains brachiopods, pelecypods, and gastropods indicative of a middle to upper Albian age. Because it is overlain by a substantial thickness of Winthrop Sandstone (considered to be upper Albian), the unit is likely middle Albian.

The Patterson Lake conglomerate was informally named and mapped by Maurer (1958). Barksdale (1975) considered the unit to be the basal conglomerate of the Virginian Ridge Formation. Recent workers again recognize the unit as distinct from the Virginian Ridge Formation on the basis of the composition of conglomerate clasts and sharpness of contacts (M. F. McGroder and others, written commun., 1989).

**Cretaceous-Jurassic Sedimentary and Volcanic Rocks**

$KJm_n$, $KJcb_n$, $KJvs_n$, $KJvd_n$, $KJvt_n$, $Jm_t$

Newby Group (Cretaceous(?)-Jurassic)--Volcanic lithic sandstone, conglomerate, siltstone, black shale and argillite, carbonate pods, and andesitic to dacitic volcanic rocks. Barksdale (1948) originally gave the name Newby Formation to the altered andesitic volcanic rocks, black shales and argillites, and interbedded volcanic lithic sandstones cropping out along Lookout Ridge in T. 33 N., R. 20-21 E. The Newby was elevated to group status by Barksdale (1975) on the basis of subdivision of the unit into the Lower to Middle Jurassic(?) Twisp Formation (black argillites and lithic sandstones) and the Lower Cretaceous Buck Mountain Formation (volcanic and volcaniclastic rocks). "Newby Group, undifferentiated" was mapped by Barksdale (1975) in those areas where the Newby Group was not subdivided into the Twisp and Buck Mountain Formations.

As mapped by Barksdale (1975), the "Newby Group, undifferentiated" included the original Lookout Ridge type section, whereas correlative rocks north of the Twisp River were subdivided into the Twisp and Buck Mountain Formations. More recent geologic mapping (Burnet, 1976; Hopkins, 1987; DiLeonardo, 1987; unpublished DGER mapping by W. M. Phillips and H. R. Schasse, 1987) permit division of the Lookout Ridge type area and exposures to the south into dominantly volcaniclastic rocks ($KJvs_n$), epiclastic sedimentary rocks ($KJm_n$), carbonate pods ($KJcb_n$), andesitic tuff ($KJvt_n$), and dacite ($KJvd_n$). These units may be correlative with all or portions of the Twisp Formation (V. R. Todd, U.S.G.S., written commun., 1990) but are not correlative with the type Buck Mountain Formation of Barksdale (1975).

In this report, rocks in the Twisp 1:100,000-scale quadrangle previously assigned to the Buck Mountain Formation of the Newby Group by Barksdale (1975) and Burnet (1976) are excluded from the Buck Mountain Formation and are shown as volcaniclastic rocks of the undivided Newby Group ($KJvs_n$), dacite of the undivided Newby Group ($KJvd_n$), or tuff of the undivided Newby Group ($KJvt_n$). Observed stratigraphic relations suggest that these rocks are significantly older than rocks at the type section of the Buck Mountain Formation. Hauterivian to middle Barremian (Early Cretaceous) fossils are present in the type section of the Buck Mountain Formation in the Robinson Mtn. 1:100,000-scale quadrangle (Barksdale, 1975). The Alder Creek stock (139 Ma) (see $KJiq_a$) intrudes the undivided Newby Group in T. 33 N., R. 21-22 E. (Plate 1); therefore, the undivided Newby Group is older than Early Cretaceous and older than the type Buck Mountain Formation. The same relation exists for the Frazer Creek Complex (139 Ma) (see $KJiq_f$), which intrudes volcaniclastic rocks previously mapped as Buck Mountain Formation in T. 33 N., R. 22 E. The undivided Newby Group is therefore shown as earliest Cretaceous-Late Jurassic in age.

The depositional setting of the Newby Group was probably a fore-arc or back-arc basin. Epiclastic detritus was most likely shed from a partially dissected magmatic arc, transported by turbidity currents, and deposited as submarine fans (Tennyson and Cole, 1978; Hopkins (1987). Andesitic to dacitic volcanism also occurred in the basin. The total thickness of this group has not been determined, but Barksdale (1975) estimated a minimum thickness of 1,830 m.

$KJm_n$

Sedimentary rocks of the undivided Newby Group (Cretaceous-Jurassic)--Interbedded, fine- to coarse-grained feldspathic-volcanic lithic (subquartzose) sandstones, conglomerate, siltstones, and silty black shales.

Typical sandstones are poorly sorted and graded and contain ripple laminations and flame structures, as well as rip-up clasts of shale, all of which suggest an origin as turbidites (Hopkins, 1987). Sequences typical of turbidites include medium- to coarse-grained, fining-upward, poorly sorted, well-layered wackes overlain by poorly sorted, fine-grained wackes commonly exhibiting ripple and parallel laminations; the wackes are overlain by well-layered siltstone and weakly fissile silty shales that are commonly disrupted by overlying turbidites. Pebble layers occur at various intervals in the medium- to coarse-grained beds (Hopkins, 1987).

The sandstones contain subrounded to subangular clasts of quartz, plagioclase, and volcanic rocks. The matrix consists of clay and silt-sized particles of quartz, plagioclase, opaque minerals, and white mica. The matrix and clasts are altered to calcite, sericite, pyrite, hematite, and other opaque minerals in places. Locally, the unit has been metamorphosed to prehnite-pumpellyite facies assemblages. Where intruded, the undivided Newby Group has been metamorphosed statically to hornblende-hornfels- and epidote-amphibolite-facies assemblages. In some areas, such as the Gold Creek and Buckhorn Canyon shear zones and the Smith Canyon fault zone, these rocks have been dynamothermally metamorphosed under greenschist-facies conditions and deformed in the ductile and/or brittle-ductile-transitional regimes (DiLeonardo, 1987; Hopkins, 1987). Rocks in these areas are foliated, lineated, and, in places, mylonitized. Quartz and calcite occur in both composite and monomineralic veins.

Sandstone and argillite beds 1.5 to 6 m thick and containing carbonate pods ($KJcb_n$) are exposed south of the town of Twisp near the Alder mill. The volcanic-lithic sandstones are composed of angular volcanic fragments and plagioclase grains. The argillite is gray to black and has shaly partings. Near the Alder mill the argillite appears to be folded about steep axes.

$KJcb_n$

Carbonate pods in the undivided Newby Group (Cretaceous-Jurassic)--Calcareous rocks locally recrystallized to coarse calcite. The marble contains a few percent of rounded quartz grains and veinlets of sericite and quartz (Burnet, 1976). Recrystallization has likely destroyed any megafossils that may have been present in the unit. The unit is exposed just south of the town of Twisp.

$KJvs_n$

Volcanic and sedimentary rocks of the undivided Newby Group (Cretaceous-Jurassic)--Unstratified to thickly bedded, greenish-gray to purple andesitic volcanic breccia, conglomerate, and feldspatholithic sandstone; intercalated with massive andesite and minor thin-bedded tuff. Rocks are locally interbedded with well-bedded black argillite and light-gray feldspatholithic sandstone and conglomerate (unpublished DGER mapping by W. M. Phillips, 1987).

The volcanic breccia is well indurated, unsorted, and unstratified. Breccia clasts consist of blocks and lapilli of dense aphanitic volcanic rocks and sparsely to abundantly plagioclase-phyric andesite. Rare blocks of vesiculated, fine-grained andesite and white hornblende-quartz dacite are also present. Clast boundaries are commonly diffuse or vague. Breccia is dominantly matrix-supported. The breccia matrix consists of fine-grained feldspatholithic sandstone or crystal-lithic tuff, typically with abundant milky-white plagioclase phenoclasts or phenocrysts.

Conglomerate is gradational with and very similar to breccia except that clasts are rounded.

Feldspatholithic sandstone is unstratified to thickly bedded, dense, resistant, poorly sorted, and fine to coarse grained. Sandstone is gradational with conglomerate and breccia. Milky-white plagioclase and aphanitic volcanic lithic fragments make up most of the sandstone. In hand specimen, the sandstone is distinguished with difficulty from massive andesite.The massive andesite is hard, dense, and aphanitic to plagioclase-phyric. In many exposures the unit consists of a massive, fine-grained "greenstone" with no visible volcanic textures. No primary lava flow structures such as pillows were observed.

In thin section, samples from the massive andesite, breccia, and conglomerate lithologies contain mineral grains and rock fragments that are pervasively altered. Plagioclase contains patchy inclusions of albite, zeolites, prehnite, and epidote. Mafic minerals such as hornblende or pyroxene are typically completely replaced by chlorite. Secondary calcite, quartz, and epidote are common along fractures or in vugs. The groundmass or matrix typically consists of a murky assortment of chlorite, epidote, zeolite(?), calcite, and silt-sized quartz.

On the basis of the lack of unambiguous primary lava flow textures and the abundance of breccia and sandstone, the unit appears dominantly epiclastic and pyroclastic rather than lava-flow dominated. Geochemical data (Tables 1 and 2) suggest a basaltic-andesitic to andesitic composition for the volcanic rocks. The elevated total alkalies ($K_2O$+$Na_2O$) in some samples may reflect the albitization evident in most samples. None of the samples appears to be true keratophyre.

The unit crops out in two belts on the Twisp 1:100,000 scale quadrangle. Volcanic breccia, conglomerate, and massive andesite are present east of the Foggy Dew fault zone in T. 31-33 N., R. 20-21 E. These rocks are locally metamorphosed and tectonized to phyllonites with well-developed foliation and lineations, especially along the Gold Creek shear zone in T. 32 N., R. 21 E. (Hopkins, 1987; DiLeonardo, 1987) and on Foggy Dew Ridge in T. 31 N., R. 21 E. (unpublished DGER mapping by W. M. Phillips, 1987). Best exposures of the unit are along Lookout Ridge in T. 32-33 N., R. 21 E. On Lookout Ridge, the volcanic and sedimentary unit is interbedded at the base and at several higher stratigraphic levels with well-bedded black argillite, sandstone, and conglomerate characteristic of map unit $KJm_n$. The unit is separated from the Twisp Formation of Barksdale (1975) by faults, and no direct correlation can be made.

$KJvd_n$

Dacite and rhyolite of the undivided Newby Group (Cretaceous-Jurassic)--Dacite to rhyolite tuff and tuff breccia containing quartz, albite, oligoclase or potassium feldspar, and no preserved mafic minerals (Burnet, 1976). These rocks are pale green to brown and fine grained and weather reddish brown from oxidation of ubiquitous pyrite. The felsic rocks occur as pods 1.5 to 91 m wide and from nearly 100 m to 2.4 km long. They are overlain by pyroclastic andesite, lithic sandstone, calcareous siltstone, or thin, discontinuous chert of other units of the undivided Newby Group.

This unit includes outcrops Burnet (1976) mapped as quartz-sericite phyllites, interpreted to have originally been rhyolite tuffs. Fresh exposures of these rhyolite tuffs are white and contain blue-white quartz megacrysts (Burnet, 1976). These rocks are well exposed near the summit of McClure Mountain and are noticeable from the Methow Valley as a bright yellow-orange scar on the flank of McClure Mountain.

The dacitic breccias of the undivided Newby Group are host to the Alder mine. The mine is in a volcanogenic massive sulfide deposit that produced gold, silver, and copper in the late 1930s through the early 1950s from fairly high-grade ore.

East of the Smith Canyon fault and north of the McClure Mountain thrust on the west side of the Methow River, Burnet (1976) mapped andesitic breccia and less common flows, which he correlated with the lower member of the Buck Mountain Formation, and dacite, dacitic tuff and tuff breccia, volcanic-lithic sandstone, and carbonate rocks, which he also considered to be parts of the Buck Mountain Formation. Recent dates of about 137 and 139 Ma (Table 3; V. R. Todd, USGS, written commun., 1989) on the Alder Creek stock, which intrudes the rocks mapped by Burnet, suggest that the intruded rocks are older than the fossil-bearing parts of the Buck Mountain Formation near its type section to the north. These volcanic rocks are therefore shown here as part of the undivided Newby Group.

$KJvt_n$

Altered andesitic tuff of the undivided Newby Group (Cretaceous-Jurassic)-- Blue-gray (most common) to green, purple, and reddish-brown, altered andesite tuff and tuff breccia. In many places, plagioclase is the only optically identifiable mineral in a groundmass of microlitic felsic fragments. Most of the plagioclase has been saussuritized; some fragments are identifiable as andesine and oligoclase. Augite, hornblende, and hypersthene phenocrysts are present locally. Clustered plagioclase phenocrysts and fragmental textures are present; flow-banding, vesicles, and amygdules are rare (Burnet, 1976). This unit is interbedded with other undivided Newby Group units, which determines its age.

$Jm_t$

Twisp Formation (Jurassic)--Thin-bedded black argillites and interbedded lithic sandstones (Barksdale, 1975). The complexly folded and faulted argillites are very hard and characteristically weather into pencil-like fragments. Bedding varies from a few millimeters to 10 cm in thickness; some beds are laminated. Uncommon dark volcanic siltstones (in places irregularly concretionary) and beds of volcanic-lithic sandstone (in places conglomeratic) are interbedded with the argillite. The unit is considered to be of marine origin because of its color, fine grain size, poorly preserved fossils, and consistent regular bedding.

Fragments of both cycads and molds of belemnites have been recovered from the Twisp Formation, but are not age-diagnostic. According to Barksdale (1975), the Twisp Formation was complexly folded prior to deposition of the Buck Mountain Formation, which unconformably overlies the Twisp Formation. Folding and faulting make estimating the thickness difficult. Barksdale (1975) measured at least 1,219 m on the west limb of a vertically plunging fold, but found neither the top nor the base of the formation.

Barksdale (1975) noted the similarity of the Twisp Formation to the sedimentary rocks on Lookout Ridge in T. 32-33 N., R. 21 E. and defined the Newby Group to include the Twisp and Buck Mountain Formations. He further suggested that the Twisp Formation may be equivalent to part of the Ladner Group in British Columbia. Tennyson (1974) correlated the Twisp Formation with the Dewdney and Ladner Groups of British Columbia, and suggested that rocks of the Twisp Formation are turbidites derived from an active volcanic highland east of a westward-deepening basin in Late Jurassic to earliest Cretaceous time. O'Brien (1986) describes the Dewdney Creek Formation as the upper part of the Ladner Group. The Dewdney Creek Formation and, by extension, the Twisp Formation, are Toarcian to lower Bajocian (late-Early to early-Middle Jurassic) in age.

## Low-Grade Metamorphic Rocks

$pTmt_m$

McClure Mountain unit (pre-Tertiary)--In its southern exposure, quartzose sandstones, shales, and silicic and intermediate volcanic rocks metamorphosed to schist, hornfels, and quartzite with amphibolite- and locally greenschist-facies assemblages. High strain along the Smith Canyon and Vinegar faults has developed schistose to mylonitic fabrics and cataclastic textures accompanying retrograde metamorphism to greenschist-facies assemblages (Hopkins, 1987).

The McClure Mountain unit is distinguished from similarly deformed and metamorphosed rocks of the undivided Newby Group by its much higher quartz content in the sandstones and volcanic rocks.

The informal name McClure Mountain unit was given by DiLeonardo (1987) to the rocks lying in a wedge between the Smith Canyon, Vinegar, Methow Valley, and McClure Mountain faults in T. 32 N., R. 22 E. Near Booth Canyon, the McClure Mountain unit is deformed into phyllonites with folds whose axes lie within the foliation, which, in turn, runs parallel to the McClure Mountain, Methow Valley, and Vinegar faults. The rocks in this area are all strongly foliated and vary from fine-grained phyllonites to medium-grained quartz dioritic gneisses with phacoidal hornblende porphyroblasts. Rare blue chert is included in this unit.

The McClure Mountain unit is intruded by the southern Carlton stock, which has statically metamorphosed the unit in hornblende-hornfels- and greenschist-facies assemblages. Deformation textures along the Smith Canyon fault zone overprint the contact metamorphic effects (Hopkins, 1987).

This unit was originally mapped as Leecher Metamorphics by Barksdale (1975), who considered it to be retrograded to greenschist-facies assemblages deformed and mylonitized by faulting. Burnet (1976) followed Barksdale's interpretation, but repositioned the northern limit of these rocks--the McClure Mountain thrust fault--to exclude rocks he concluded were part of the Newby Group on the north side of Booth Canyon. While the rocks north of Booth Canyon strongly resemble volcanic and sedimentary portions of the Newby Group (particularly near the McClure Mountain fault), they are strongly foliated and metamorphosed to greenschist-facies assemblages and are here included in the McClure Mountain unit.

The McClure Mountain unit may be a separate group of rocks, or it may be a metamorphosed block of the various adjacent lithologies (undivided Newby Group, Alder Creek stock, and Leecher Metamorphics). Frey and Anderson (1987) suggest that the Methow Valley reverse fault thrust the high-grade Leecher Metamorphics, Methow Gneiss, and Summit-Frazer Gneiss (Okanogan complex) westward over the McClure Mountain unit, the Newby Group, and the Frazer Creek complex. The mixed McClure Mountain unit may thus represent lower plate rocks of mixed affinity, deformed and upgraded to greenschist-facies assemblages as a result of thrusting. Subsequent intrusion and faulting along the Smith Canyon and Vinegar faults may have further deformed and locally upgraded the McClure Mountain rocks, obscuring the original contact relations.

The McClure Mountain unit is at least in part older than the southern Carlton stock (129 Ma) ($Kiq_c$). It is thus early Cretaceous or older, so is here simply given a pre-Tertiary age.

$pKmv_n$

North Creek Volcanics (pre-Cretaceous)--Altered andesitic lavas and tuffs with minor intercalated arkosic sedimentary rocks. The andesites contain abundant hornblende, but most of the primary mineralogy has been obscured by greenschist-facies metamorphism. Metamorphic minerals include chlorite, calcite, albite, epidote, white mica, quartz, actinolite, and locally biotite. The sandstones are feldspathic to lithic. Minor pebble conglomerates, fragmental volcanic rock types, and argillites are also present (M. F. McGroder and others, written commun., 1989).

The North Creek Volcanics, which crop out east of the old mining town of Gilbert, were named by Peter Misch, who considered the rocks possible correlatives either of the late Paleozoic Chilliwack Group or of the Jurassic-Cretaceous Nooksack Group to the west. According to Misch (1966), the North Creek Volcanics grade northwestward into the Elijah Ridge Schist. Barksdale (1975) included theNorth Creek unit in the undivided Newby Group. Although parts of the undivided Newby Group in the wedge between the Cooper Mountain batholith and the Smith Canyon fault are andesitic volcanics and volcanic sediments metamorphosed to the greenschist facies, lack of direct data and the confusion regarding the age of the Newby Group and its members prevent us from correlating the units at this time.

The North Creek Volcanics are intruded by the Black Peak batholith (90 Ma). The unit is in fault contact with the Cretaceous Virginian Ridge Formation along the North Creek fault, which may be the extension of the Twisp River-Foggy Dew and Hozameen faults (McGroder, 1987). No fossils have been found in the North Creek Volcanics, and no radiometric age has been determined. The unit is given a pre-Cretaceous age on the basis of its intrusion by the Cretaceous Black Peak batholith.

## Intrusive Igneous Rocks

### Tertiary Intrusive Igneous Rocks

Tia

Leucovolcanic unit of Frey (1988) (Tertiary, Paleocene(?))--Quartz-feldspar porphyry which crops out mainly as dikes intruded parallel to local foliations in the Leecher Metamorphics and Summit-Frazer gneiss. The rock contains 1-4-mm phenocrysts of embayed quartz, white feldspar, and biotite in a fine-grained, white to buff groundmass of quartz, feldspar, biotite, and opaque minerals. The dikes are not foliated or deformed like the surrounding units, and the quartz is unstrained. Parting parallels the local foliation, which also parallels the dike walls.

The rocks resemble the Shellrock Point volcanics of Menzer (1983), which crop out about 32 km to the east; however, the rocks in the Methow area are less extensively altered. A flow with similar mineralogy and pebbles of quartz-feldspar-biotite porphyry also crops out in the Pipestone Canyon Formation. The Shellrock Point volcanic rocks are considered to be Eocene, while the Pipestone Canyon Formation is considered to be Paleocene. The leucovolcanic unit may be equivalent to either of these rock units. Because of its hypabyssal character and lack of deformation, the unit is assigned a Tertiary age.

### Eocene Hypabyssal Intrusive Rocks

$Ei_s$

Stock of St. Louise Creek (Eocene(?))--Highly altered, red to dark reddish-brown, fine-grained stock composed of quartz, chlorite, and muscovite with minor hornblende and actinolite. The stock crops out entirely in the Cooper Mountain batholith and covers about 0.3 km$^2$ on the ridge northwest of St. Louise Creek. Its age is unknown, but the stock is presumed to be contemporaneous with the Cooper Mountain batholith. The stock was mapped and informally named by Wade (1985, 1988).

$Ei_{sr}$

Stocks and dikes of Sawtooth Ridge (Eocene(?))--Very fine grained, dark-brown to black dikes and small stocks in the foliated margin of the Cooper Mountain batholith. Primary constituents are biotite, hornblende, quartz, and plagioclase; minor constituents are chlorite, calcite, and unidentified opaque minerals. These stocks and dikes were named and described by Wade (1985, 1988).

$Eia_{sf}$

Dike swarm of South Fork Ridge (Eocene(?))--Porphyritic plagioclase- and quartz-rich dikes that contain minor amounts of hornblende, actinolite, chlorite, muscovite, and calcite. About 60 percent of the rock consists of phenocrysts of plagioclase and quartz. Dikes in this swarm cut the Newby Group parallel to foliation, which is sub-parallel to the trend of the Foggy Dew fault zone.

The dikes crop out on South Fork Ridge along the margin of the Cooper Mountain batholith. They are presumed to be Eocene in age, as are other dike swarms and dated stocks in the area. The swarm was informally named and described by Wade (1985, 1988).

$Eia_{f}$

Stock of Fox Peak (Eocene(?))--Small, plagioclase quartz porphyry stock. Approximately 60 percent of the rock is phenocrysts of plagioclase and quartz. Minor minerals forming the groundmass are muscovite, biotite, chlorite, hornblende, epidote, calcite, and actinolite, as well as unidentified opaque minerals and glass. Plagioclase crystals are extensively saussuritized, biotite is largely replaced by chlorite, and hornblende is replaced by chlorite and actinolite.

The stock crops out in the Cooper Mountain batholith and is assumed to be contemporaneous with or slightly younger than the batholith. The unit was mapped and informally named by Wade (1985, 1988).

$Eigd_{b}$

Stock of Bryan Butte (Eocene (?))--Biotite granodiorite to quartz monzonite. This small stock, in part porphyritic, intrudes the foliated portion of the Cooper Mountain batholith. The stock is inferred to be a late phase of the batholith. It was informally named the Bryan's Butte stock by Wade (1985). It is herein referred to as stock of Bryan Butte to conform to geographical nomenclature.

$Eida_{g}$

Porphyry dike swarm of Goat Mountain (Eocene(?))--Light- to dark-gray porphyry dikes of dacitic composition along the southeast margin of the Cooper Mountain batholith, locally forming as much as 90 percent of all outcrops. Primary constituents are plagioclase (45 percent), quartz (20 percent), potassium feldspar (20 percent), biotite (7-8 percent), and hornblende (5-6 percent). Accessory minerals are apatite, magnetite, and sphene. Euhedral plagioclase phenocrysts as much as 5 mm long and euhedral quartz phenocrysts (commonly embayed) occur in a groundmass of microcrystalline quartz and potassium feldspar. Plagioclase phenocrysts are commonly saussuritized and sericitized. Glomerocrystic biotite and hornblende are subhedral and extensively chloritized.

Individual dikes vary in thickness from 50 cm to more than 30 m. The dikes dip between 75 and 90 degrees and commonly strike within 20 degrees of north-south along the margin of the batholith. Thickness and abundance of dikes decrease away from the batholith. The dikes cut the Cooper

Mountain batholith and its contacts with country rocks and are considered slightly younger than the Cooper Mountain batholith.

The porphyry dike swarm of Goat Mountain was mapped and informally named by Raviola (1988). Similar dike swarms have been mapped on the southwest, west, and northwest margins of the Cooper Mountain batholith by Barksdale (1975), Tabor and others (1980, 1987), and Hopkins (1987).

$Eida_s$

Porphyry dike swarm of South Fork Gold Creek (Eocene(?))--Highly altered porphyritic dikes of quartz dioritic composition. Primary constituents are plagioclase, hornblende, and biotite in a microcrystalline groundmass of plagioclase, quartz, and minor potassium feldspar. Plagioclase is altered to albite and sericite, hornblende is altered to epidote and chlorite, and biotite is altered to chlorite and sphene.

Dikes in the swarm are parallel, varying from 2 to 10 m in thickness. They strike NNW, and some extend several kilometers along strike. The dikes crop out along the South Fork of Gold Creek near its confluence with Rainy Creek, and are the youngest rocks in the area. Swirled contacts and xenoliths of the stock of Hungry Mountain (44.5 Ma) in the dikes suggest that the dikes intruded the stock while it was still hot, and thus are considered to be contemporaneous with the stock of Hungry Mountain (Hopkins, 1987).

The dikes also intrude the Vinegar fault zone and rocks of the Newby Group, the stock of McFarland Creek, the Cooper Mountain batholith, and the Methow Gneiss. The dike swarm was mapped and informally named by Hopkins (1987).

$Eim_r$

Dike of Rainy Creek (Eocene (?))--Intermediate intrusion of biotite monzonite with clinopyroxene. The 0.4-km-diameter plug intrudes the Cooper Mountain batholith and was informally named by Wade (1985, 1988).

Eigb

Gabbro (Eocene)--Stocks and dikes of hornblende gabbro to diorite with biotite and local pyroxene, inferred to be part of Eocene plutonism of the multi-phased Cooper Mountain batholith. The stocks and dikes cut Skagit Gneiss and the foliated portion of the Cooper Mountain batholith (Wade, 1985, 1988).

**Eocene Plutonic Rocks**

$Eig_c$

Quartz monzonite to granite phase of the Cooper Mountain batholith (Eocene)--Quartz monzonite, granite, and coarse-grained pegmatite containing 50 to 60 percent potassium feldspar that is common along Coyote Ridge. Potassium feldspar is porphyritic with minor myrmekitic texture. Plagioclase is locally saussuritized, and quartz has been recrystallized in places. This phase is locally foliated at its contact with the Skagit Gneiss. K-Ar ages on biotite reported on the main phase of the batholith ($Eigd_c$) are 48.1 ± 1.7 Ma, and 48.1 ± 1.4 Ma (Table 3). A more detailed description of this unit can be found in Wade (1985, 1988).

$Eiqm_c$

Biotite quartz monzonite phase of the Cooper Mountain batholith (Eocene)--Fine- to medium-grained biotite quartz monzonite. Minor saussuritization of plagioclase and perthitic orthoclase have been noted. The quartz monzonite, a phase of the Cooper Mountain batholith, crops out in an elongate area near the confluence of South Fork, Fisher, and St. Louise Creeks.

Biotite from the main phase of the batholith ($Eigd_c$) yields K-Ar ages of 48 Ma, 48 ± 1.4 Ma, and 48.1 ± 1.7 Ma (Table 3). Wade (1985, 1988) and Hopkins (1987) also describe the quartz monzonite.

$Eigd_c$

Biotite-granodiorite to quartz monzonite phase (main phase) of the Cooper Mountain batholith (Eocene)--Medium- to coarse-grained, commonly porphyritic; principal constituents consisting of plagioclase, orthoclase, quartz, and biotite, with minor chlorite and hornblende. Accessory minerals are sphene, apatite, rutile, ilmenite, and zircon. Average grain size is 2 to 3 mm, but some potassium feldspar crystals reach a length of 7 to 8 mm. Potassium feldspar and plagioclase are euhedral, biotite is altered to chlorite at crystal margins, and plagioclase is commonly saussuritized. The rock is light gray to tan; red and pink iron-oxide stains are common. Epidote and chlorite veins occur along the batholith margin.

Five phases of the batholith have been mapped by Wade (1985, 1988) and are shown on this map as four units: $Eigd_c$, $Eiqm_c$, $Eig_c$ and $Eog_c$ (gneissic). Dike swarms are common at the north and south border of the batholith.

The Cooper Mountain batholith intrudes metamorphic rocks of the Chelan Complex on the south, the Skagit Gneiss on the west, the Methow Gneiss and the stock of McFarland Creek on the northeast, and sedimentary and volcanic rocks of the Newby Group on the north. Contacts are sharp and discordant; weak flow foliation is found at the margins in a zone 100 to 200 m wide. Rocks of the undivided Newby Group have been hornfelsed along the border with the batholith. The 300-$km^2$ batholith is elongate northwest to southeast and was intruded along the Foggy Dew fault zone.

This phase of the batholith has yielded K-Ar ages on biotite of 48 Ma, 48.1 ± 1.4 Ma, and 48.1 ± 1.7 Ma (Table 3). The unit was first named and described by Barksdale (1975); see also Barksdale (1983), Wade (1985, 1988), Hopkins (1987), and Raviola (1988).

$Eigd_n$

Noname stock (Eocene)--Biotite hornblende granodiorite; pink to white and medium-grained. The unit consists of oligoclase with poikilitically enclosed quartz and orthoclase, biotite, hornblende, and accessory sphene and magnetite. Biotite is altered to sphene on the surface.

The stock, which is fairly unaltered, is elongate east-west and covers less than 8 $km^2$. It passively intruded the Methow Gneiss, forming a 10-m-wide contact zone which crosscuts foliation in the gneiss. Mafic xenoliths of amphibolite with aligned hornblende are considered to be part of the Leecher Metamorphics. The stock crops out at the town of Methow on both sides of the Methow River.

Zircon and sphene yield fission-track ages of 55.5 ± 5 Ma and 53.6 ± 5 Ma respectively (Table 6). The stock was named by Barksdale (1975), but has been called the French Creek stock by J. R. Wilson (formerly USGS, written commun., 1983) and the Methow stock by Buddington (1986).

Eiq$_h$

Stock of Hungry Mountain (Eocene)--Medium- to coarse-grained hornblende-quartz diorite to diorite with subhedral granular texture. Primary constituents are plagioclase ($An_{35-50}$) and hornblende. Hornblende is generally twinned and euhedral. Quartz occurs as anhedral grains and fracture fillings. Biotite is a minor component, occurring as inclusions in plagioclase and interstitially among plagioclase, quartz, and hornblende. Most of the biotite is altered to chlorite. Apatite, microcline, zircon, and epidote are accessory minerals.

The stock of Hungry Mountain intruded and upgraded rocks of the Newby Group and also intruded, deformed, and thermally altered rocks of the Cooper Mountain batholith and the stock of McFarland Creek. A K-Ar determination on hornblende yielded an age of 44.5 ± 0.9 Ma (Table 3). The stock was informally called the Hungry Mountain stock by Hopkins (1987).

Eiq$_d$

Duncan Hill pluton (Eocene)--Biotite-hornblende to biotite-quartz diorite and granodiorite, light gray to gray, medium grained, massive to gneissic texture. Allanite is a common accessory mineral. Contacts with surrounding rocks are sharp to gradational, forming a contact complex in some areas. The contact complex is a migmatite with *lit-par-lit* injection zones of hornblende-biotite quartz diorite and gneiss, and includes partly assimilated blocks of country rock. The quartz diorite is extensively diked.

Biotite and hornblende yield K-Ar ages of 45 ± 2.0 Ma and 44.8 ± 2.0 Ma, respectively (Cater and Crowder, 1967; Table 3). U-Pb determinations on zircon yield a cluster of ages ranging from 45.3 to 49.7 Ma (Tabor and others, 1987; Table 4). A Pbα age from zircon is 40 ± 10 Ma (Engels and others, 1976; Table 7). The pluton was first described by Cater and Wright (1967).

### Paleocene Intrusive Igneous Rocks

PAit$_o$

Oval Peak batholith (Paleocene)--Directionless to weakly foliated tonalite. Primary constituents are plagioclase ($An_{32}$ (cores), $An_{10}$ (rims)), biotite, quartz, and sphene. Magmatic epidote is common in all but the southernmost portion of the pluton. Hornblende and orthoclase are minor constituents. The composition is fairly uniform throughout the 120 km$^2$ covered by the batholith. Well-foliated portions of the unit are mapped as PAog$_o$ and are described in the section on Tertiary Metamorphic Rocks.

The batholith is elongate southeast and is intrusive into and in fault contact with the Twisp Valley Schist. The northeastern border of the pluton is mylonitized along the Twisp River-Foggy Dew fault zone. The southwestern contact is gradational with unit PAog$_o$. Sphene from a weakly foliated sample of the batholith yielded a U-Pb age of 60 ± 2 Ma (Miller and others, 1989). A sample from the foliated margin of the batholith yielded a similar U-Pb zircon age (61.3 ± 2 Ma) (Miller and others, 1989). Sphene from weakly foliated tonalite has been dated by U-Pb at 65.3 Ma (Miller and Walker, 1987). These ages record crystallization of the batholith at about 61 Ma (Miller and others, 1989).

The Oval Peak batholith was informally named the Oval Peak pluton by Adams (1961) and later called the Oval Peak batholith by Barksdale (1975). The area was also mapped by Libby (1964) and Miller (1987).

## Tertiary-Cretaceous Intrusive Igneous Rocks

TKigd

Granodiorite near Elbow Canyon (Tertiary or Cretaceous(?))--Minor granodiorite pluton that contains minor amounts of poikilitic orthoclase, which also distinguishes this body from the others nearby. The rock contains plagioclase, euhedral hornblende (15 percent), sphene (2 percent), and minor amounts of biotite. Hornblende is locally replaced by chlorite, and plagioclase is somewhat saussuritized (DiLeonardo, 1987). It lies alongside and west of the fault in Elbow Canyon. It is coarser grained and more siliceous than the nearby Cretaceous-Jurassic Alder Creek stock or the other Cretaceous quartz dioritic plutons in the area. Age control is poor, but the unit is believed to be part of either the Cretaceous or the Paleocene to Eocene episodes of intrusion.

$TKiq_y$

Stock of Yockey Creek (Tertiary or Cretaceous(?))--Medium- to coarse-grained hornblende diorite, consisting of about 75 percent plagioclase, 23 percent dark-green amphibole, and 2 percent biotite. Locally, plagioclase crystals exceed 15 mm in length. Fabric is predominantly directionless. However, where coarse-grained plagioclase crystals are oriented vertically, the fabric is sub-parallel to the direction of flow. Mafic hornblendite nodules several centimeters in diameter are common.

The stock of Yockey Creek intrudes the foliated Summit-Frazer trondhjemite gneiss but is not itself foliated. The stock is intruded by porphyritic andesite dikes and by potassium feldspar-quartz-biotite pegmatites that intrude along parallel joint sets (Frey, 1988). The intruding dikes are probably of Eocene age. The stock intrudes a Cretaceous or Jurassic gneiss that was folded in the Cretaceous.

## Mesozoic Intrusive Igneous Rocks

### Cretaceous Plutonic Rocks

$Kigd_t$

Texas Creek stock (Cretaceous)--Directionless biotite-hornblende granodiorite that grades into quartz monzonite near the center of the intrusion (Bates McKee, written commun., 1968). Principal constituents are plagioclase ($An_{35}$, with rims of $An_{28}$), orthoclase, quartz, biotite, and equal or lesser amounts of hornblende. Near the center of the intrusion, plagioclase and orthoclase approach a ratio of 1:1. Sphene is the most common accessory mineral, apatite and magnetite are common, and epidote is present alone or in association with fresh biotite. Alteration of orthoclase to kaolinite and plagioclase to sericite is described as mild (Barksdale, 1975).

Contacts of the Texas Creek stock are sharp where it intrudes the foliated Summit-Frazer gneiss, the Leecher Metamorphics, and a marginal hornblende diorite phase (KJid, hornblende diorite in Texas Creek unit). Locally, the contact of the stock with the marble beds of the Leecher Metamorphics forms small skarn deposits mineralized with scheelite, chalcopyrite, molybdenite, pyrite, hematite, and magnetite in a gangue of calcite, epidote, and garnet. There are numerous prospects along the contact; the best known prospect is the Dutch John claim in sec. 2, T. 31 N., R. 22 E., W.M.

The Texas Creek stock yields K-Ar replicate ages of 88.8 and 87.5 Ma on hornblende and 91.9 and 96.0 Ma on biotite (V. R. Todd, USGS, written commun., 1989; Table 3).

$Kid_t$

Hornblende diorite phase of the Texas Creek stock (Cretaceous)--Medium-grained, directionless hornblende diorite. Principal constituents are 50 to 55 percent twinned and zoned andesine ($An_{45}$ with rims of $An_{35}$), 30 percent hornblende, 5 to 10 percent quartz, and about 5 percent biotite. Magnetite is the most common accessory mineral; epidote and, more rarely, sphene are also present (Barksdale, 1975).

The hornblende diorite unit forms a small, elongate stock in the Texas Creek drainage (T. 32 N., R. 22 E.). The hornblende diorite is clearly intruded by the main phase of the Texas Creek stock. It forms a gradational contact with the amphibolite of the Leecher Metamorphics in a zone about 100 m wide that is migmatitic in places. Although the actual contact is indistinct, the numerous dikes, veins, and rotated inclusions in the zone suggest an intrusive contact (Bates McKee, written commun., 1968).

Barksdale (1975) described the hornblende diorite as an older phase of the Texas Creek stock, while Bates McKee (written commun., 1968) believed the unit to be distinct from the Texas Creek stock. Replicate hornblende K-Ar ages of the unit are 84.4 and 86.5 Ma, suggesting that the unit is a marginal phase of the Texas Creek stock (V. R. Todd, USGS, written commun., 1989; Table 3). Because it lacks foliation and it intrudes the Leecher Metamorphics, the diorite is probably younger than the Cretaceous-Jurassic tonalite gneiss of the Okanogan complex, whose contact with the diorite is not exposed.

$Kiq_c$

Carlton stocks (Cretaceous)--Two stocks of coarse-grained quartz diorite with subhedral granular texture and a distinctive pinkish color. Principle constituents are about 65 percent plagioclase ($An_{38}$ to $An_{45}$), 25 percent hornblende, and as much as 25 percent quartz, with local biotite and microcline. Hornblende is commonly twinned and cataclastic. In some specimens, quartz displays mosaic texture, and microcline shows some fractures (Hopkins, 1987). The distinctive color is due to iron oxide in cracks in the feldspars and along grain boundaries. Cores of plagioclase are altered to sericite, epidote, and an unidentified gray material; in places, hornblende and biotite are altered to chlorite and epidote.

All the information about the age of the unit comes from the southern Carlton stock, which crops out near the town of Carlton and intrudes the McClure Mountain unit (Hopkins, 1987) and is cut on the east and west by the Vinegar and Smith Canyon faults, respectively. In the shear zone of the Smith Canyon fault, the stock is deformed, well-foliated, and metamorphosed to greenschist- and epidote-amphibolite facies assemblages (DiLeonardo, 1987; Hopkins, 1987). This stock yield a hornblende K-Ar age of 129.6 ± 1.1 Ma (Hopkins, 1987; Table 3). The unit was first described by Barksdale and named by Hopkins (1987).

$Kiq_{cp}$

Cardinal Peak pluton (Cretaceous)--Hornblende-biotite and biotite quartz diorite, granodiorite, and calcic hornblende diorite and quartz diorite. The hornblende and hornblende-biotite quartz diorite and granodiorite range from conspicuously spotted rock to gray, slightly foliated medium-grained hypidiomorphic granular rock with minor protoclastic modifications (Cater and Wright, 1967). The spotted rock consists of porphyroclasts of andesine in a dark, very fine grained protoclastic groundmass of andesine and biotite with rare hornblende, orthopyroxene, and orthoclase.

In places the rock is characterized by anastomosing mylonitic (?) or protomylonitic shear zones. Parts of the pluton, especially in the Milham Pass area, show very strong lineation, but only weak foliation (R. B. Miller, San Jose State University, written commun., 1989).

The calcic hornblende diorite and quartz diorite are described as gray to dark gray and fine to medium grained and ranging from massive to locally gneissic (Cater and Wright, 1967). Quartz and accessory orthoclase are interstitial. This unit grades into a migmatitic "contact complex" consisting of hornblende gneiss and schist, coarse-grained hornblendite, and fine-grained pegmatitic hornblende diorite and gabbro cut by anastomosing dikes of calcic hornblende diorite and quartz diorite (Cater and Wright, 1967).

The Cardinal Peak pluton is similar to plutonic rocks of the Chelan Complex mapped to the south in the Chelan 1:100,000-scale quadrangle. It probably formed during the same period of metamorphism and deformation and so is assigned a Cretaceous age. This is supported by a U-Pb age on zircon of about 75 Ma obtained by R. Zartman (USGS, cited in Miller and others, 1989).

$Kid_m$

McFarland Creek stock (Cretaceous(?))--Medium-grained diorite and quartz diorite of subhedral texture. Hornblende is the dominant mafic constituent; biotite is present in minor amounts. The unit is extensively sheared, altered, and metamorphosed in the shear zone of the Smith Canyon fault and in the Gold Creek shear zone. Except in the Vinegar fault zone, where original composition is preserved, principal constituents are difficult to determine. The stock has a fine-grained border phase tens of meters thick, except where the stock narrows in the Vinegar fault zone (Hopkins, 1987).

In the Gold Creek shear zone and in the shear zone of the Smith Canyon fault, the McFarland Creek stock has undergone greenschist-facies metamorphism and consists of albite, quartz, calcite, chlorite, and local biotite or actinolite. Albite is fractured; quartz has undulose extinction and the grains are elongate parallel to the lineation. Foliation in the shear zones is defined by layers of quartz and albite alternating with layers of chlorite and biotite or actinolite. Rocks in the Gold Creek shear zone are schistose to mylonitic. In the shear zone of the Smith Canyon fault, the rocks are gneissic to mylonitic. The border phase of the stock is metamorphosed to greenschist- and epidote-amphibolite-facies assemblages. In some places, it is indistinguishable from the surrounding metamorphic rocks of the undivided Newby Group (Hopkins, 1987).

The McFarland Creek stock intruded the Vinegar fault zone as an elongate body, and it has undergone subsequent brittle deformation. Crystals of hornblende and plagioclase are extensively fractured. In the fault zone, the stock contains numerous xenoliths, including rocks of the Newby Group, the Methow Gneiss, and the McClure Mountain unit (Hopkins, 1987).

The stock of McFarland Creek is undated. It is intruded by the Cooper Mountain batholith (about 48 Ma) and the stock of Hungry Mountain (44.5 Ma) (Table 3), and it intrudes and is further deformed by the Vinegar fault. About 6 km to the north, the Vinegar fault cuts the southernmost of the Carlton stocks (about 129 Ma) (Hopkins, 1987). Assuming that faulting was contemporaneous along the length of the Vinegar fault, then the stock of McFarland Creek is at least slightly younger than the Carlton stock, which does not intrude the fault but is cut by it. This brackets the likely age of the stock of McFarland Creek between 129 Ma and 48 Ma, placing it most likely in the middle to Late Cretaceous. The stock of McFarland Creek was first mapped and informally named by Hopkins (1987).

## Cretaceous-Jurassic Intrusive Igneous Rocks

$KJiq_a$

Alder Creek stock (Cretaceous-Jurassic)--Composite stock of hornblende- and hornblende and biotite-bearing quartz diorite with a minor phase of hornblende diorite. The stock is moderately to well foliated, especially where it is affected by movement on the Smith Canyon fault and other faults on its north and west sides. Principal constituents are: plagioclase ($An_{32}$), as much as 75 percent of the rock; quartz, rarely more than 5 percent of the rock; and as much as 20 percent hornblende and biotite. Potassium feldspar is present in minor amounts. The hornblende is fairly unaltered, but biotite is commonly altered to chlorite and epidote. In some samples, lozenges of prehnite have grown along the biotite cleavages (Barksdale, 1975). Plagioclase ranges from fresh to strongly sericitized.

The hornblende diorite phase consists of equal amounts of strongly sericitized feldspar and fresh, euhedral hornblende. Quartz is almost totally lacking (Barksdale, 1975).

The unit crops out over about 10 $km^2$ south of the town of Twisp. Foliation in the western portion of the Alder Creek stock dips steeply and trends roughly south, parallel to the Smith Canyon fault. In sec. 13, T. 33 N., R. 21 E., W.M., the foliation shifts abruptly to a southeast orientation, parallel with the unnamed fault that cuts the northernmost extent of the stock. Evidence of cataclasis is locally bent and, in places, broken twin lamellae in plagioclase and marked undulatory extinction in quartz (Barksdale, 1975). The presence of prehnite and epidote indicates low-grade metamorphism, which may be related to shearing in the Smith Canyon fault zone or to a more pervasive episode of metamorphism which affected most Cretaceous rocks in the Methow basin.

Contacts of the Alder Creek stock with surrounding rocks are steep and somewhat ambiguous. The stock is in thrust contact with quartzites of the McClure Mountain unit to the south along the south-dipping McClure Mountain fault. It is truncated by the Smith Canyon fault on part of its western boundary (DiLeonardo, 1987). Barksdale (1975) and DiLeonardo (1987) report numerous xenoliths of volcanic and volcaniclastic rocks in the main body of the intrusion, which suggests an intrusive contact with the surrounding undivided Newby Group.

According to Burnet (1976), albite-epidote and, locally, hornblende hornfels occur in adjacent country rocks, which he interprets to be a result of intrusion of the stock. Field work by M. A. Korosec (DGER, written commun, 1987) and by the compiler of this report in 1987 has shown that volcaniclastic rocks mapped as Buck Mountain Formation and shown on this map as undivided Newby Group (near the Alder mill in secs. 17 and 18, T. 33 N., R. 22 E., W.M., and along the north side of the stock) are indeed hornfelsed, indicating intrusion by the Alder Creek stock.

Hornblende in the Alder Creek stock has yielded K-Ar ages of 137 ± 3.4 Ma and 139 ± 6 Ma (V. R. Todd, USGS, written commun., 1989; Table 3). Those ages are considered to be minimum due to the deformation and low-grade metamorphism of the stock. That places the age of the stock at latest Jurassic or earliest Cretaceous.

$KJit_f$

Frazer Creek complex tonalite (Cretaceous-Jurassic)--Leucocratic biotite-bearing tonalite phase of the Frazer Creek complex. Principal constituents of this minor phase are 70 percent plagioclase (with cores ranging from $An_{45}$ to $An_{32}$, rims ranging from $An_{27}$ to $An_{13}$), 20 percent quartz, 5 percent biotite, 5 percent potassium feldspar, and rare hornblende. Potassium feldspar occurs as micropegmatitic intergrowths with quartz. This phase of the complex crops out in secs. 22 and 23, T. 33 N., R. 22 E., W.M.

KJiq$_f$

Frazer Creek complex quartz diorite (Cretaceous-Jurassic)--Hornblende quartz diorite predominant; range of composition from tonalite to gabbro. Mafic minerals constitute approximately 20 to 25 percent of the volume. Irregular crystals of green hornblende are molded against the earlier formed plagioclase. Biotite is minor and was formed late. Plagioclase in the calcic andesine range is fresh, subhedral, and well twinned, but weakly zoned. Quartz seldom reaches 15 percent and is commonly less than 10 percent of the rock. Hornblende crystals enclose well-formed feldspar and small magnetite crystals, indicating that the hornblende formed later (Barksdale, 1975). According to Frey (1988), andesite dikes are a significant part of the complex west of the Red Shirt thrust.

The unit was first mapped and named by Barksdale (1975). The eastern exposures of the Frazer Creek complex were subsequently named the Wolf Canyon quartz diorite and Red Shirt gabbro by Menzer (1983).

Contact relations with the surrounding volcaniclastic rocks of the undivided Newby Group are uncertain. In a highway borrow pit (sec. 15, T. 33 N., R. 22 E., W.M.), leached, silicic (silicified?), and fractured volcaniclastic rocks suggest that the Frazer Creek complex has an intrusive contact with the Newby Group, although there are no igneous rocks exposed there. This supports Barksdale (1975), who describes the western contact as leached, bleached, and silicified.

K-Ar ages determined from hornblende and biotite in the complex (V. R. Todd, USGS, written commun., 1989) are 130.1 ± 3.3 Ma on hornblende and 103.7 ± 2.6 Ma and 107.6 ± 2.7 Ma on biotite from the quartz diorite of the complex (Table 3). The biotite dates are considered reset; all are considered minimum ages. Further dating (Table 3) on hornblende extends the age range (139 ± 6.0 Ma, 139 ± 9.0 Ma), and a biotite age is 109 ± 4 Ma. On the basis of the concordance of hornblende ages, which are considered minimums, the unit is considered to be latest Jurassic to earliest Cretaceous in age.

KJigb$_f$

Frazer Creek complex gabbro (Cretaceous-Jurassic)--Coarse-grained gabbro, consisting of plagioclase and hornblende. Crystals of plagioclase attain lengths of more than 1 cm in these rocks. One small outcrop is present in the center of the Frazer Creek complex northeast of the town of Twisp.

KJigb$_r$

Red Shirt gabbro (Cretaceous-Jurassic)--Calcic to sodic labradorite; green hornblende as the principal mafic mineral. Textures are wholly magmatic (Menzer, 1983). Hornblende gabbro is part of the Frazer Creek complex of Barksdale (1975). According to Frey (1988), andesite dikes are a significant part of the outcrops west of the Red Shirt thrust, where both Red Shirt gabbro and Frazer Creek complex are present.

The nature of the contact of the Red Shirt gabbro with other parts of the Frazer Creek complex is not known. To the east, the Red Shirt gabbro is phyllonitized along the Red Shirt thrust. The unit was named by Menzer (1982) for the Red Shirt mine, whose portal is cut in the gabbro. Based on the chemical similarities and spacial relations to the rest of the Frazer Creek complex and lack of deformation, the Red Shirt gabbro is presumed to be contemporaneous with the other phases of the Frazer Creek complex, which have been K-Ar dated as latest Jurassic to earliest Cretaceous.

## Mixed Igneous and Metamorphic Rocks of Plutonic Complexes

### Skagit Gneiss complex

$TKmi_s$

Skagit Gneiss (Tertiary-Cretaceous)--Fundamentally tonalitic to trondhjemitic orthogneisses and plutons with pods and rafts of biotite schist, meta-quartzite, amphibolite, calc-silicate, and rare marble; minor migmatite and pegmatites; pegmatites with very coarse grained quartz and minor plagioclase.

In the map area, the unit includes the southern heterogeneous crystalline complex of Miller (1987), the Skagit suite of Hopkins (1987), the Skagit orthogneisses of Wade (1985), the Chelan batholithic complex of Barksdale (1975), and the Skagit gneiss of Libby (1964). Barksdale (1975) included in the Chelan batholithic complex rocks that were mapped by Hopson (1955), Adams (1961), and Libby (1964) as mixed igneous and metamorphic rocks. Barksdale also noted similarities of the Skagit Gneiss to the Custer Granite Gneiss of Daly (1912) and to the Custer gneiss mapped by McTaggart and Thompson (1967) near the Canadian Border. Barksdale specifically excluded the Twisp Valley Schist from the Chelan batholithic complex. On this map, the Twisp Valley Schist and large outcrop areas of isolated xenoliths of heterogeneous metamorphic rocks are treated separately.

In the Chelan divide region, the mixed rocks of the Skagit Gneiss are predominantly weakly deformed trondhjemitic orthogneisses with numerous bodies of massive and foliated tonalite and granodiorite (Miller, 1987). To the southeast, the unit consists predominantly of hornblende-biotite-quartz-oligoclase orthogneisses with oblate spheroidal inclusions of biotite schist, quartzite, and rare calc-silicates; these orthogneisses consist of alternating melanocratic and leucocratic layers a few centimeters to tens of centimeters thick which define a well-developed foliation (Hopkins, 1987).

In the southern part of the unit, the mineralogy, in order of decreasing abundance, is plagioclase ($An_{23-28}$), quartz, biotite, hornblende, and potassium feldspar, with minor sphene, apatite, and zircon. Hornblende and potassium feldspar each make up less than 5 percent of most samples. The texture is granoblastic. Plagioclase commonly has bent twin planes. Quartz displays undulose extinction and is elongate parallel to foliation. Quartz defines the lineation (Hopkins, 1987).

At the northeastern margin of the Cooper Mountain batholith, Wade (1985) describes the Skagit unit as quartz diorite, granodiorite, and quartz monzonite orthogneisses and biotite schist metamorphosed to the amphibolite facies. The orthogneisses are generally medium grained, consisting of plagioclase, quartz, and potassium feldspar and minor biotite, chlorite, and hornblende and accessory epidote/clinozoisite and apatite.

Numerous xenoliths and rafts of biotite schist occur along the southern margin of the Skagit Gneiss. According to Hopkins (1987) and Wade (1985), who mapped in that area, the biotite schist, quartzite, and calc-silicate schist probably represent country rock that was intruded by the plutonic protolith of the gneisses. The xenoliths are stretched parallel to the foliation and range in length from meters to hundreds of meters and in width from tenths to tens of meters. Foliation in the biotite schists is strong and is commonly isoclinally folded at microscopic and macroscopic scales. Both the foliation and lineation are defined by biotite. Quartzite occurs in minor amounts, most commonly as well-foliated micaceous quartzite containing either biotite or muscovite.

The contact of Miller's southern heterogeneous complex (Skagit Gneiss) with the Lake Juanita leucogneiss is gradational and arbitrarily located. The deformed trondhjemitic orthogneiss and the Lake Juanita leucogneiss may be its equivalent in part.

Libby (1964) noted that the heterogeneous granodioritic to trondhjemitic and quartz dioritic Skagit Gneiss are cut by abundant synkinematic and post-kinematic dikes and irregular coarse-grained intrusive bodies. He and others have interpreted the Skagit Gneiss in this area as derived from sedimentary and volcanic rocks by granitization and migmatization. More recent workers have described synneusis and other possible relict igneous textures, in addition to micrograniitoid enclaves, which suggest that the unit formed through anatexis and/or intrusion.

The age of the Skagit Gneiss cannot be determined with certainty as the unit is a complex of rock types that is poorly mapped and barely dated. Cretaceous plutons and Late Cretaceous through Eocene orthogneisses are known from the more completely mapped portions of the Cascade core north and south of the Chelan divide region. Metamorphism is considered by many to be Cretaceous in age, as it is in the Chelan Complex to the south. Deformation in the Ross Lake fault zone on the northeast side of the Skagit Gneiss outcrop area can be documented only from 65 Ma to 45 Ma. While the metamorphic inclusions and the protoliths of some of the orthogneisses in the Skagit Gneiss may be much older, the tonalitic orthogneiss and granodiorite, which formed during the last metamorphic and deformational episodes, indicate a Cretaceous to early Tertiary age for the Skagit Gneiss.

pKhm

Heterogeneous metamorphic xenoliths in the Skagit Gneiss--Abundant septa of hornblende calc-silicate and biotite schist. Numerous bodies of biotite schist, quartzite, and calc-silicate schist probably represent the country rock that was intruded by the plutonic protolith of the gneisses. The xenoliths are elongate parallel to the foliation and range in length from meters to hundreds of meters and in width from tenths to tens of meters.

Foliation in the biotite schists is commonly isoclinally folded at microscopic and macroscopic scales. Lineation defined by biotite and minor hornblende. Quartzite occurs in minor amounts, most commonly as well-foliated micaceous quartzite containing either biotite or muscovite. Libby (1964) noted one septum of marble in this unit. Descriptions of this unit can be found in Wade (1985), Libby (1964), and Hopkins (1987).

Very little is known about the age range of these metamorphic rocks, except that they were involved in the complexing of the Skagit Gneiss unit during the Cretaceous and early Tertiary.

**Chelan Complex**

$Kog_c$

Tonalite of the Chelan Complex (Cretaceous)--A leucocratic hornblende-biotite and biotite tonalite and tonalite gneiss with minor epidote, allanite, and sphene. Euhedral plagioclase of the oligoclase-andesine range is euhedral and has oscillatory zoning that is sharp and pronounced to faint and partially destroyed by secondary twinning. Plagioclase is medium to coarse grained, locally containing large poikiloblastic biotite plates. The Chelan tonalite is commonly white (color index = 3-5, locally as high as 15). Texture is subidiomorphic granular and xenomorphic to crystalloblastic gneissic. The rock is strongly gneissic in outcrop and rich in mafic schlieren and grades into migmatite. Locally, the tonalite is cut by even lighter colored tonalite dikes.

The Chelan tonalite is extensively mapped on and described for the Chelan 1:100,000-scale quadrangle to the south (Tabor and others, 1987), where U-Pb dates indicate formation of the complex in the mid-Cretaceous.

$Kmg_c$

Migmatite of the Chelan Complex (Cretaceous)--Heterogeneous hornblende tonalite and biotite tonalite and tonalite gneiss, mixed with mafic to feldspathic amphibolite, gneissic amphibolite, and blastoporphyritic feldspar gneiss. Microdiorite, a fine-grained granoblastic to xenomorphic hornblende-biotite-plagioclase rock, is an important constituent and forms dikes and irregular bodies gradational to amphibolite (Hopson, 1955). The migmatite is criss-crossed by small light-colored tonalitic to alaskitic dikes, sills, and irregular bodies, most of which have sharp contacts (Hopson, 1955). Less common rocks in the migmatite are hornblende schist, biotite schist, and marble. The migmatite grades into gneissic to massive tonalite commonly rich in mafic schlieren.

The migmatite of the Chelan Complex crops out on the south side of the Cooper Mountain batholith north of Lake Chelan and on the south side of Lake Chelan. That area was cursorily mapped by Hopson in 1955. The unit is extensively mapped on the Chelan 1:100,000-scale quadrangle to the south (Tabor and others, 1987).

**Okanogan complex**

$KJmi_t$

Gneissic trondhjemite of Tiffany Mountain (Cretaceous-Jurassic)--A heterogeneous unit composed of leucocratic trondhjemitic and quartz dioritic gneisses interlayered with biotite-hornblende gneiss and schist, amphibolite, and calc-silicate rocks (Rinehart, 1981; V. R. Todd, USGS, written commun., 1988).

The trondhjemite forms a northwest-trending belt along the eastern border of the Robinson Mtn. 1:100,000-scale quadrangle, extending southeast into the Oroville, Twisp, and Omak 1:100,000-scale quadrangles. In the Twisp quadrangle, it includes parts of the banded gneiss and Summit-Frazer gneiss of Frey (1988).

The banded gneiss of Frey (1988) is itself a mixed unit containing a variety of gneisses. Where this unit was mapped by Frey, Summit-Frazer gneiss (tonalite gneiss of the Okanogan complex), Coyote Ridge quartz diorite gneiss, and an unnamed diorite gneiss are interbanded with other biotite quartz diorite gneisses and biotite-hornblende schists on a scale that is too fine to be mapped. Near the major fault zones, the rocks are mostly mylonitic gneisses. Original contact relations among the gneisses and with the diorite and schists are not clear. Isoclinal intrafolial folding is observed in these rocks.

Because this unit is considered a part of the Okanogan complex, it is given an age of Cretaceous-Jurassic. This indicates the time during which the unit became a complex and the time of metamorphism. Many elements of this unit are probably significantly older. Leucosomes from the trondhjemite yield biotite K-Ar ages of 94.1 and 96.1 Ma (V. R. Todd, USGS, written commun., 1989). These ages are considered reset ages.

$KJog_o$

Tonalite gneiss of the Okanogan complex (Cretaceous-Jurassic)--A homogeneous, light-colored orthogneiss of trondhjemitic composition. Average primary constituents are 60 percent oligoclase, 30 percent quartz, and 7 percent biotite. Potassium feldspar is present locally. Epidote and sphene are locally important accessory minerals. Small pink garnets are present in places. The unit is also referred to as the Summit-Frazer gneiss by numerous previous workers, including F. J. Menzer, Jr., and A. M. Frey.

The rock can be distinguished by its quartz lenses, which are commonly a centimeter or more in length. Along with biotite, the lenses, which are best observed on a joint face, define the foliation in the rock. The quartz, which is fairly equant in the center of the unit, has been stretched and flattened into quartz ribbons near the Chewack-Pasayten fault trace. Locally, biotite ovoids (locally referred to as leopard spots) are present, which, although mineralogically similar to those in the Methow Gneiss, are smaller and less well defined (Frey, 1988).

The tonalite gneiss has a mylonitic contact with the Coyote Ridge quartz diorite. In large outcrops the intrusive nature of the Coyote Ridge quartz diorite into the tonalite gneiss is evident. Rocks of the Okanogan complex intrude the Leecher Metamorphic rocks and have developed a sheared foliation subsequent to intrusion. The stock of Yockey Creek, minor diorite intrusions, leucocratic volcanic dikes, and andesite and basalt dikes have intruded the tonalite gneiss of the Okanogan complex after development of its foliation (Frey, 1988).

This tonalite gneiss, as used in this report, includes the Summit Creek pluton of Barksdale (1975), parts of the Okanogan batholithic complex of Barksdale (1975), and parts of the Summit-Frazer trondhjemite gneiss of Menzer (1982, 1983). The unit is correlative with the Loup Loup plutonic complex of J. R. Wilson (formerly USGS, written commun., 1983) on the Omak 1:100,000-scale quadrangle to the east, and with the trondhjemite of Doe Mountain and the trondhjemite of Lamb Butte (V. R. Todd, USGS, written commun., 1988) on the Robinson Mtn. 1:100,000-scale quadrangle to the north.

V. R. Todd (USGS, written commun., 1989) reports K-Ar ages of 100.6 ± 2.5 Ma and 100.0 ± 2.5 Ma on biotite in the Summit Creek pluton (Table 3). Menzer (1970) reports a Pbα age of 90 ± 10 Ma on zircon (Table 7); fission-track ages on sphene and apatite of 90 ± 9 Ma, and 76 ± 8 Ma and 92 ± 9 Ma, respectively (Table 6); and Rb-Sr isochron ages of 104.2 ± 0.5 Ma from the Summit-Frazer trondhjemite gneiss (Table 5). North of the map area, concordant K-Ar biotite and muscovite ages of 96.3 ± 2.4 Ma and 96.4 ± 2.4 Ma, respectively (V. R. Todd, USGS, written commun., 1989), and discordant K-Ar biotite and muscovite ages of 108 ± 3.0 Ma and 94.6 ± 2.8 Ma, respectively (Engels and others, 1976), are reported from the trondhjemite of Doe Mountain. A fine-grained granitic dike that cuts the trondhjemite of Doe Mountain, but is thought to be genetically related to it, yielded concordant K-Ar biotite and muscovite ages of 95.7 ± 2.4 Ma and 96.1 ± 2.4 Ma, respectively (V. R. Todd, USGS, written commun., 1989).

Equivalent K-Ar ages are reported from strikingly similar muscovite-biotite granodiorite plutons in the Eagle Complex of southern British Columbia, which has also yielded U-Pb zircon ages of approximately 111 Ma (C. J. Greig, Univ. of British Columbia, oral commun. to K. L. Stoffel, DGER, 1988). Greig believes that the U-Pb age records the time of crystallization and the K-Ar ages represent the time of uplift and cooling. The trondhjemite of Doe Mountain and, by extension, that of the tonalite gneiss of the Okanogan complex may have a history similar to that of the Eagle Complex. The trondhjemite of Doe Mountain and the tonalite gneiss of the Okanogan complex (Summit-Frazer gneiss) are assigned a Cretaceous-Jurassic age, similar to that of all other units in the Okanogan complex.

$KJog_c$

Coyote Ridge quartz diorite gneiss (Cretaceous-Jurassic)--A sheared and commonly protomylonitic hornblende-biotite quartz diorite. The rock is characterized by rolled or lensoidal hornblende and plagioclase porphyroclasts surrounded by a finer mortar of feldspar, quartz, and biotite. Biotite is shredded and smeared along the foliation. Epidote is locally present. Plagioclase with relict igneous texture is rare. Where pegmatite veins are common, microcline is also a major component of the rock. Microcline porphyroblasts are locally abundant. Hydrous alteration minerals are common.

The Coyote Ridge quartz diorite gneiss is distinguished from the Summit-Frazer gneiss (tonalite gneiss of the Okanogan complex) by its higher proportion of mafic minerals and a more pronounced foliation. The unit was named by Menzer (1983).

According to Frey (1988), the contact of Coyote Ridge gneiss with the tonalite gneiss of the Okanogan complex is a sheared intrusive contact. Menzer (1983) interpreted the Coyote Ridge unit to be a border phase of the Summit-Frazer gneiss (Okanogan complex), citing gradational and *lit-par-lit* contacts of the two units. The contact of the Coyote Ridge quartz diorite gneiss with diorite and gabbro of the Frazer Creek complex is mylonitic along the Red Shirt thrust fault (Frey, 1988).

KJog$_p$

Mylonitic gneiss along the Pasayten fault (Cretaceous-Jurassic(?))--Medium- to dark-gray and locally banded gneiss, with layers from a few millimeters to 1 cm thick. The composition ranges from trondhjemite to granodiorite. Biotite is the chief mafic mineral. Textures are dominantly mylonitic, but relict igneous plagioclase and quartz grains are common.

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

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

The mylonitic gneiss along the Pasayten fault may represent a discrete pluton that was intruded along the fault during ductile deformation (V. R. Todd, USGS, written commun., 1988). V. R. Todd (written commun., 1989) reports a K-Ar biotite age of 101.4 ± 2.5 Ma for these rocks north of the map area on the Robinson Mtn. 1:100,000-scale quadrangle. This age probably is a minimum age for ductile shearing along this portion of the Pasayten fault and is thus only a minimum crystallization age for the rocks.

KJam$_o$

Amphibolite in the Okanogan complex (Cretaceous-Jurassic(?))--Amphibolite ranging from diorite through quartz diorite, interbanded in some areas with leucocratic bands that alternate with more mafic hornblende diorite bands.

The mafic hornblende-biotite-feldspar rock appears to have been derived from a fine-grained intrusive or porphyritic extrusive of andesitic composition, possibly related to the Coyote Ridge quartz diorite (Frey, 1988). The leucocratic banding is derived in part from quartzo-feldspathic veins which have been sheared and folded into the foliation. Other leucocratic banding containing biotite and feldspar (with or without quartz) may have been derived from primary bedding. This unit is severely deformed and contains a mylonitic foliation with isoclinal intrafolial folds. Box folds and brittle faults are also present. Some fractures are epidote-filled, and some epidote is a retrograde mineral.

The rocks of this unit are intruded by rocks of the Okanogan complex. They crop out in thin zones in the outcrop area of the Coyote Ridge quartz diorite gneiss and at the contact of the Coyote Ridge quartz diorite gneiss with the tonalite gneiss of the Okanogan complex. The age is broadly constrained by these relations.

## High-Grade Metamorphic Rocks

### Tertiary Metamorphic Rocks

**Eocene Orthogneiss**

$Eog_c$

Gneissic part of the Cooper Mountain batholith (Eocene)--Medium-grained, foliated biotite quartz monzonite to granodiorite orthogneiss. Principal constituents are potassium feldspar, plagioclase, quartz, and biotite with minor hornblende and chlorite. Biotite-rich xenoliths of schist are common at the northwest margin of the batholith. In one area, mafic blocks, pods, and small veins mix with leucocratic material composed of quartz and plagioclase to form migmatite. Foliation, presumed to be flow-foliation due to intrusion, is oriented from north to northeast and has a shallow (25°-45°) dip to the west and northwest. The unit is cut by the informally named stock of Bryan Butte and stock of Sawtooth Ridge (both Eocene) (Wade, 1988).

**Paleocene Orthogneiss**

$Paog_o$

Oval Peak batholith orthogneiss (Paleocene)--Moderately to well-foliated, light-colored tonalitic orthogneiss. Gneiss is recrystallized to plagioclase, quartz, biotite, and sphene, with or without epidote, hornblende, opaque minerals, and microcline. Epidote occurs in the northwestern portion of the foliated zone, and hornblende is restricted to the southernmost portion. The compositions of recrystallized plagioclase and the variance in pleochroism in biotite suggest that recrystallization may have occurred at higher temperatures in the south (Libby, 1964). The orthogneiss displays a mixture of igneous and recrystallization textures.

Aplite and garnet-bearing pegmatite are common in the foliated margins of the pluton. Foliation is defined by alignment of aggregates of recrystallized biotite. A lineation marked by streaked quartz and biotite occurs within 50 m of the south and west margins of the pluton and adjacent to the mylonites of Twisp River-Foggy Dew fault zone.

The unit is gradational to the northeast with the unfoliated portion of the Oval Peak batholith ($Pait_o$). Its southwestern border is on strike with the mylonitic Gabriel Peak tectonic belt of the Ross Lake fault zone, which also includes the Twisp River-Foggy Dew fault zone. The Twisp River-Foggy Dew fault zone cuts this unit on the southeast.

The Oval Peak batholith was informally named the Oval Peak pluton by Adams (1961) and called the Oval Peak batholith by Barksdale (1975). The foliated portion was first mapped as a separate unit by Miller (1987).

Zircon from the weakly foliated portion of the batholith ($Pait_o$) yielded a U-Pb date of 60 ± 2 Ma (Miller and others, 1989). A sample from the foliated margin of the batholith yielded a similar U-Pb zircon age (61.3 ± 2 Ma) (Miller and others, 1989). Sphene from a weakly foliated tonalite ($Pait_o$) has been U-Pb dated at 65.3 Ma (Miller and Walker, 1987). These various ages record crystallization of the batholith, probably at about 61 Ma (Miller and others, 1989).

Pa $og_j$

Lake Juanita leucogneiss (Paleocene)--Coarse-grained trondhjemitic and leucogranodioritic orthogneisses. Most of the unit is lineated, but displays only a weak foliation. The unit is strongly foliated only near its contact with the Tuckaway Lake gneiss (Pa $og_t$). Foliation is defined by aggregates of weakly to moderately aligned biotite and muscovite, elongate quartz and recrystallized quartz lenses, and bands of recrystallized mosaic. Plagioclase occurs as both large relict grains and as fine- to medium-grained mosaics with quartz. Perthitic orthoclase and quartz are commonly interstitial. Pegmatites and other silicic dikes are common. The Lake Juanita leucogneiss has a significantly lower color index than either the Battle Mountain gneiss (Pa $og_b$) or the Tuckaway Lake gneiss (Pa $og_t$).
Small bodies of massive plutonic rocks ranging in composition from granite to diorite are volumetrically important in places and appear to intrude the leucogneiss. Xenoliths and rafts of biotite schist, possibly the Twisp Valley Schist, are locally present.

The northeastern part of the unit is deformed by the Gabriel Peak tectonic belt of the Ross Lake fault zone. This fault zone is a 15-km-wide system of faults and shear zones which marks a major crustal boundary separating the crystalline core (Skagit Gneiss) of the North Cascades from the sedimentary and volcanic rocks of the Methow basin. Intrusive rocks, mylonites, and orthogneisses in the Ross Lake fault zone yield Paleocene and Eocene dates, suggesting that plutonism and deformation occurred between 65 and 45 Ma (R. B. Miller and S. A. Bowring, San Jose State Univ., written commun., 1988). Ar-Ar and K-Ar hornblende cooling ages in nearby amphibolite of the Twisp Valley Schist indicate that amphibolite facies metamorphism ended by about 54-57 Ma (Miller and others, 1989). The Lake Juanita unit appears to share the same metamorphic history as the Twisp Valley Schist.

The unit intrudes both the Tuckaway Lake gneiss (Pa $og_t$) and the Battle Mountain gneiss (Pa $og_b$). The leucogneiss yields a U-Pb zircon age of 59 Ma (Paleocene) (Miller and others, 1989). The Lake Juanita leucogneiss was first named and mapped by Miller (1987).

Pa $og_t$

Tuckaway Lake gneiss (Paleocene)--Strongly foliated and lineated, medium-grained tonalite orthogneiss which grades into mylonite. The metamorphic assemblage is biotite, plagioclase, and quartz. Foliation in the weakly porphyroclastic gneiss is defined by fine-grained biotite, quartz, and plagioclase, and by lenses and layers of biotite and of quartz (Miller, 1987).

Thin (<10 m) sheets of the Tuckaway Lake gneiss are intrusive into the Battle Mountain gneiss (Pa $og_b$). The unit is intruded by the structurally lower, lighter colored Lake Juanita leucogneiss, by dikes and sills of leucogneiss, and by undeformed granitoids. In the south, the volume of younger intrusive rocks precludes mapping the Tuckaway Lake gneiss as a distinct unit (Miller, 1987).

The Tuckaway Lake gneiss has not been dated. However, the unit intrudes and is deformed along the Ross Lake fault zone, a major crustal boundary which separates the crystalline core (Skagit Gneiss) of the North Cascades from the sedimentary and volcanic rocks of the Methow trough. Intrusive rocks, mylonites, and orthogneisses in the Ross Lake fault zone yield Paleocene and Eocene ages, suggesting that plutonism and deformation occurred between 65 and 45 Ma. Ar-Ar and K-Ar hornblende cooling ages in nearby amphibolite of the Twisp Valley Schist indicate that amphibolite-facies metamorphism ended by about 54-57 Ma (Miller and others, 1989). The Tuckaway Lake gneiss appears to share the same metamorphic history as the Twisp Valley Schist, and for these reasons, the Tuckaway Lake gneiss is assigned a Paleocene age. The unit was first named and mapped by Miller (1987).

PA og$_b$

Battle Mountain gneiss (Paleocene)--Medium- to coarse-grained tonalitic orthogneiss metamorphosed to amphibolite facies. Primary constituents are hornblende, biotite, epidote, plagioclase, and quartz. Plagioclase commonly occurs as porphyroclasts. The unit is strongly foliated and lineated and commonly protomylonitic. Foliation is defined by biotite, hornblende, and sphene. Plagioclase porphyroclasts show relict oscillatory zoning. Recrystallized plagioclase ($An_{16}$ to $An_{30}$) forms a fine- to medium-grained mosaic with quartz. The quartz displays deformation bands and subgrains (Miller, 1987). Rocks in this unit have a higher color index and are coarser grained than adjacent gneisses. The thickness is varied.

The Tuckaway Lake gneiss intrudes the Battle Mountain gneiss, the oldest of the orthogneisses structurally underlying the Oval Peak batholith. In some places the Battle Mountain gneiss occurs as screens in the Lake Juanita leucogneiss (PA og$_j$) and less commonly in the Tuckaway Lake gneiss (PA og$_t$). The Battle Mountain gneiss bears a superficial resemblance to the Reynolds Peak phase of the Black Peak batholith (Kog$_{br}$), and the two may be part of the same unit. They are in close proximity northeast of Battle Mountain, where the nature of the northern termination of the Battle Mountain gneiss is unclear. The unit was first named and described by Miller (1987).

The Battle Mountain gneiss has not been dated. However, the unit intrudes and is deformed along the Ross Lake fault zone. (See PA og; PA og$_t$.) The correlation of the unit's plutonic age with that of the Reynolds Peak phase of the Cretaceous Black Peak batholith is speculative. Deformation may have been latest Cretaceous, but was most likely Tertiary. Ar-Ar and K-Ar hornblende cooling ages in nearby amphibolite of the Twisp Valley Schist indicate that amphibolite facies metamorphism ended by about 55-57 Ma (Miller and others, 1989). The Battle Mountain gneiss appears to share the same metamorphic history as the Twisp Valley Schist, and for this reason, the Battle Mountain gneiss is assigned an age of Paleocene.

PA og$_w$

War Creek gneiss (Tertiary-Cretaceous)--Medium-grained, leucocratic tonalitic to trondhjemitic orthogneiss consisting of quartz, plagioclase, biotite, and sphene. Small but distinct differences in composition and grain size in the unit suggest that it represents several metamorphosed plutons. The War Creek gneiss is strongly foliated and lineated in the southwest near its contact with the Lake Juanita leucogneiss, but only weakly to moderately well foliated in the northeast. It is distinguished from the Gabriel Peak orthogneiss (exposed in the west half of the Twisp 1:100,000-scale quadrangle) by its weaker foliation and lower color index. The unit was first named and mapped by Adams (1961) and further described and mapped by Miller (1987) and R. B. Miller and S. A. Bowring (San Jose State Univ., written commun., 1988).

The War Creek gneiss intrudes the Reynolds Peak phase of the Black Peak batholith and contains large inclusions and screens of the Reynolds Peak phase. The War Creek gneiss is distinguished from the Reynolds Peak phase by its lack of hornblende, lower color index, and smaller grain size.

The War Creek gneiss together with the Gabriel Peak orthogneiss form the northeastern side of the Gabriel Peak tectonic belt, a zone of strongly deformed and, in part, mylonitic rocks which extends for at least 35 km northwest from the western edge of the map area. The zone is part of the Ross Lake fault zone and is nearly on strike with the strongly deformed margin of the Oval Peak batholith (Miller, 1987).

The War Creek gneiss has not been dated; however, intrusive and metamorphic relations can be used to infer its age range. Directionless rocks of the Black Peak batholith yield both K-Ar and U-Pb ages of approximately 90 Ma, whereas the Gabriel Peak orthogneiss, interpreted to be the deformedmargin of the batholith, yields a U-Pb age of approximately 65 Ma. The War Creek gneiss is younger than the Reynolds Peak phase of the Black Peak batholith (90 Ma) which it intrudes, and it may be as old as or younger than the Gabriel Peak orthogneiss (65 Ma). According to R. B. Miller (San Jose State Univ., written commun., 1988), deformation in the Ross Lake fault zone took place between 65 and 45 Ma, and no direct evidence of Cretaceous motion in the Ross Lake fault zone can be found. The War Creek gneiss may have been a Late Cretaceous pluton, but it was deformed sometime between 65 and 45 Ma. Because of these relations, the War Creek gneiss is assigned a Paleocene age.

## Mesozoic Metamorphic Rocks

$Mzog_a$

Hornblende tonalite gneiss of Antoine Creek (pre-Cretaceous)--Fairly uniform, medium- to coarse-grained (average 5 mm) biotite-hornblende-quartz-plagioclase gneiss. The rock is strongly recrystallized and has a cataclastic appearance. Elongate aggregates of hornblende give the rock a pronounced lineation. Stretched quartz aggregates are common. Biotite occurs in sparse clumps (Raviola, 1988).

According to Tabor and others (1987), healed cataclasis and well-recrystallized fibrous aggregates or porphyroblasts of hornblende indicate metamorphism of a coarsely crystalline igneous rock, although no relict igneous textures or structures were found.

The gneiss, which crops out in the extreme southeastern corner of the map area, is intruded on the north by the Cooper Mountain batholith (ca. 48 Ma). The contact is sharp and marked by numerous chlorite and epidote veins. Contacts of the Antoine Creek unit with the amphibolite and schist of Twentyfive Mile Creek are not as clear cut. There, Raviola (1988) noted numerous tonalitic dikes similar in grain size and mineralogy to the hornblende tonalite gneiss of Antoine Creek in outcrops of the older amphibolite and schist of Twentyfive Mile Creek, and he suggests the contact with that unit may have originally been intrusive. In other places, the two units are in fault contact, forming a zone of mylonite that indicates a dextral sense of shear. Highly sericitized plagioclase porphyroclasts are set in a quartz-feldspar-chlorite matrix resulting from extreme grain-size reduction of the original rock under ductile conditions.

The age of the hornblende tonalite gneiss of Antoine Creek is not known. Tabor and others (1987) noted similarities between the Antoine Creek unit and the Entiat pluton and considered them to be of the same metamorphic age. Tabor further speculates that the protolith of the Antoine Creek orthogneiss may be correlative with that of the Bearcat Ridge plutons (Tabor and others, 1987). The Bearcat Ridge plutons are possibly correlative with the Dumbell Mountain plutons, which have a Triassic protolith age. This assignment of protolith age is consistent with the probable Permian protolith age of the amphibolite and schist of Twentyfive Mile Creek, which the hornblende tonalite gneiss of Antoine Creek likely intruded. However, because the extension of a single age over such distances is tentative at best, the hornblende tonalite of Antoine Creek is assigned a Mesozoic age here to indicate its existence prior to the Late Cretaceous metamorphism.

## Cretaceous Orthogneiss

$Kog_{br}$

Reynolds Peak phase of the Black Peak batholith (Cretaceous)--Tonalitic orthogneiss characterized by a moderately developed tectonic foliation forming the southernmost portion of the Black Peak batholith. The dominant assemblage in these rocks is biotite, plagioclase, quartz, epidote, and sphene. Hornblende is present locally. Epidote replaces plagioclase. More mafic portions of the phase are abundant locally, particularly between Tony basin and Williams Butte in the west half of the Twisp 1:100,000-scale quadrangle.

The Reynolds Peak phase is riddled with ductile shear zones ranging from less than 5 cm to about 4 m in thickness. Significant recrystallization and grain-size reduction occurred in these zones, producing mylonites and, locally, ultramylonites. Asymmetric folds of the mylonitic foliation are rare. Gently dipping mylonite zones with a down-dip lineation are common in the Boulder Creek drainage, whereas steeper ductile shear zones occur in the Reynolds Creek drainage. Foliation in the Reynolds Peak phase is commonly rotated into parallelism with the fabric in the ductile shear zones. These relations suggest that reverse dip-slip motion occurred in many of the ductile shear zones.

The Reynolds Peak phase is distinguished from the weakly foliated to directionless phase of the Black Peak batholith by its stronger fabric and slightly higher color index. The Reynolds Peak phase is coarser grained and also has a higher color index than the War Creek gneiss, and it commonly contains hornblende, in contrast to the latter unit. The War Creek gneiss intrudes the Reynolds Peak phase; large inclusions and screens of the Reynolds Peak phase occur in the gneiss (Miller, 1987).

The Reynolds Peak phase is assumed to have been intruded at approximately 90 Ma. Recent work by R. B. Miller and S. A. Bowring (San Jose State Univ., written commun., 1988), suggests deformation probably occurred between 65 Ma and 45 Ma, the documented age of movement within the Ross Lake fault zone. From these relations, the unit is given a Cretaceous age.

## Pre-Cretaceous Orthogneiss

$pKog_{m}$

Methow Gneiss (pre-Cretaceous)--Compositionally uniform, distinctive tonalitic gneiss consisting of 60 to 65 percent plagioclase ($An_{25-40}$), 20 to 25 percent quartz, 6 to 8 percent biotite, and 2 to 3 percent epidote, with minor hornblende and sphene. Apatite and magnetite are common accessory minerals. Ferric, poikilitic epidote probably is both primary and late retrogressive (Raviola, 1988). Plagioclase twin lamellae are commonly bent, and quartz forms well-developed mosaics. The rock is white where fresh, gray to brown where weathered.

Characteristic of the gneiss are oval clots of biotite (nicknamed leopard spots by previous workers, especially Barksdale) which define a crude lineation on surfaces cut parallel to the foliation (Barksdale, 1975). Foliation is well developed and is defined by aligned subhedral biotite. Hornblende and epidote also lie in the foliation plane.

Structural attitudes of the Methow Gneiss are consistent over the outcrop area and roughly concordant with those of the amphibolite, schist, and gneiss of Alta Lake (in the Omak 1:100,000-scale quadrangle) and the Leecher Metamorphics. Dips are generally shallow (10°-30°), but steepen somewhat near the contacts with the older units. Orthogonal joint sets are pervasive, becoming more closely spaced near faults. Locally, the gneiss is sheared and highly altered to chlorite and actinolite.

Intrusion of the Methow Gneiss probably occurred at moderate crustal levels (Raviola, 1988). The gneiss was subsequently metamorphosed under lower amphibolite facies conditions together with the amphibolite, schist, and gneiss of Alta Lake and the Leecher Metamorphics (Raviola, 1988).

In its northwestern outcrop area, the Methow Gneiss has undergone ductile shearing. The characteristic ovoids of biotite have been smeared into stripes along the foliation plane, forming a lineation that is nearly down-dip on the foliation.

The Methow Gneiss intruded both the amphibolite, schist, and gneiss of Alta Lake and the Leecher Metamorphics. On the adjacent Omak 1:100,000-scale quadrangle, migmatites are commonly developed at its contact with the Alta Lake rocks. The southwestern part of the Methow Gneiss is intruded by the Eocene Cooper Mountain batholith. The sharp and discordant contact is marked by numerous small xenoliths of gneiss in the batholith and by extensive veining and chlorite-epidote alteration. Both units are intruded by later porphyry dikes.

Pods or boudins of Methow Gneiss have been found in the Leecher Metamorphics near Canyon Creek, suggesting that the Methow Gneiss intruded the Leecher prior to the latest ductile deformation there (Frey, 1988). After the latest ductile deformation, the Leecher Metamorphics were intruded by the tonalite of the Okanogan complex.

On the west, the Methow Gneiss is cut by the Vinegar fault. The Vinegar fault is associated with a zone of brittle to brittle-ductile deformation. In the fault zone, the Methow Gneiss shows predominantly cataclastic microstructures, but in the southern 3 km of the fault zone, gneisses have a protomylonitic fabric (Hopkins, 1987). On the northwest, the Methow Gneiss is bounded by the Methow River fault, a reverse fault which places Methow Gneiss, Okanogan complex, and Leecher Metamorphics over rocks of the undivided Newby Group, McClure Mountain unit, and the Frazer Creek complex (Frey and Anderson, 1987).

The Methow Gneiss has been dated by K-Ar on biotite at 61.7 ± 1.5 Ma, an age that is considered to be reset (V. R. Todd, USGS, written commun., 1989). Its upper age range is crudely limited by the Okanogan complex, which intruded the Leecher Metamorphics after the Methow Gneiss had intruded and been ductilely deformed with the Leecher rocks. The Methow Gneiss is younger than the Leecher Metamorphics and Alta Lake rocks, which it intrudes; however, little is known about the age of either of these metamorphic rock packages.

On the basis of correlations with similar rocks to the east and north on the Omak and Robinson Mtn. 1:100,000-scale quadrangles, the younger, intruding Okanogan complex is interpreted to have intruded and cooled during the Jurassic and early Cretaceous, between 140 Ma and 100 Ma. The Okanogan complex on the Twisp quadrangle has yielded K-Ar ages on biotite of approximately 100 Ma (V. R. Todd, USGS, written commun., 1990). Thus, the Methow Gneiss is at least pre-100 Ma.

Preliminary U-Pb data from the Methow Gneiss suggest an original age of about 170 Ma (middle Jurassic), with a reset event at about 122 Ma (R. B. Miller, San Jose State Univ., oral commun., 1989). Because of uncertainties with these preliminary data, the Methow Gneiss is shown as pre-Cretaceous.

pKog$_l$

Diorite gneiss of the Leecher Metamorphics (pre-Cretaceous)--Blocky black hornblende, plagioclase feldspar, and biotite in diorite gneiss. Sphene and epidote are also present in some samples. Grain size ranges from 2 to 5 mm.

The rock has a foliation and a lineation defined by hornblende orientation and biotite, which is smeared along the foliation. The degree of deformation is varied, and can be measured in part by the degree of biotite smearing. In some less deformed samples biotite occurs along the foliation in elongate ovals as long as 3 cm. This habit is similar to that of the biotite in the Methow Gneiss, but is less obvious in the Leecher unit because the dominant mafic mineral is hornblende. As deformation becomes more intense, biotite is smeared out into streaks, similar to those observed in the strongly deformed Methow Gneiss. Further deformation has led to the development of a mortar structure and protomylonite fabrics in the gneiss (Frey, 1988).

### Triassic Orthogneiss

Ʀ$og_b$

Bearcat Ridge plutons (Triassic)--Quartz diorite gneiss and flaser gneiss, and biotite quartz diorite and granodiorite gneiss. The quartz diorite gneiss is characterized by varied ratios of biotite to hornblende and is gray to dark gray (color index = 20-35) and fine to medium grained in broad zones parallel to foliation. Swirled foliation and lineation of hornblende are common. Texture is generally granoblastic, but more massive facies are hypidiomorphic and locally cataclastic. Coarse-grained sphene is characteristic. The unit contains much fine-grained foliated biotite granodiorite, quartz monzonite, and leucocratic quartz diorite and granodiorite as dikes and irregular masses with sharp to gradational contacts (Cater and Wright, 1967).

Contacts of the Bearcat Ridge plutons are sharp to interlayered with the country rock (biotite and hornblende schist and gneiss of the younger gneissic rocks of the Holden area).

Biotite quartz diorite and granodiorite gneiss are light gray to gray (color index = 15-25) and medium to medium coarse grained. Texture is granoblastic to hypidiomorphic and locally cataclastic. Foliation is swirled. Lineation is defined by streaks of biotite. Some coarser grained varieties contain muscovite (Cater and Wright, 1967).

Cater and Wright (1967) show the Bearcat Ridge plutons to be correlative with the Dumbell Mountain plutons. Both are represented as some of the oldest plutonic rocks in the area, metamorphosed in the Late Cretaceous. Mattinson (1972) obtained U-Pb ages from zircon in the Dumbell Mountain plutons that range from 278 ± 15 Ma to 212 Ma but cluster around 220 Ma (Table 4), leading him to assign the Dumbell Mountain plutons a Triassic age. That is equivalent to the ages assigned to quartz diorite orthogneisses in the Marblemount Belt of Misch farther to the north. Following Cater and Wright, the Bearcat Ridge plutons are herein assigned to the Triassic.

## Mesozoic to Paleozoic Layered Metamorphic Rocks

pTgn

Gneiss east of Elbow Canyon (pre-Tertiary)--A quartz-rich, light-gray gneiss. The unit is exposed in one small area on the ridge east and northeast of Elbow Canyon, 3 km west-southwest of Twisp. Exposures are poor, but the biotite-quartz-oligoclase gneiss appears to be banded (M. A. Korosec, DGER, written commun., 1987).

Contacts with the adjacent Alder Creek stock and undivided Newby Group rocks are covered. Barksdale (1975) referred to this unit as biotite-quartz-oligoclase gneiss of unknown affinity and noted that it is separated from the Alder Creek stock by a branch of the Smith Canyon fault. He further noted xenoliths of hornblende gneiss in the Alder Creek stock north of Elbow Coulee. Burnet (1976) mapped the gneiss as two klippen of Leecher Metamorphics. Strong foliation in the rocks and overall composition of the gneiss is reminiscent of the Leecher Metamorphics.

In places, the overall composition and grain size of the gneiss also resemble the leucocratic portion the Cretaceous-Jurassic Frazer Creek complex, and the gneiss could be a foliated leucocratic portion of the similar Cretaceous-Jurassic Alder Creek stock.

If the foliation is due to deformation in a fault zone, these rocks are possibly as young as Cretaceous in age. However, if the rocks correlate with the Leecher Metamorphics, they may be significantly older than Cretaceous. Due to the uncertainty of origin, this gneiss is designated as pre-Tertiary in age.

$pKhm_t$

Twisp Valley Schist (pre-Cretaceous)--Heterogeneous biotite schist, phyllite, and impure quartzite (meta-chert) with some amphibolite, greenschist, and minor marble, calc-silicate rocks, and metaperidotite. Metamorphosed, thin-bedded (2-10 cm) siltstones and shales may represent distal turbidites. The marbles and metaperidotites occur as lenses less than 1 m to 50 m wide which are elongate parallel to foliation.

The interleaving of the metaperidotite with supracrustal rocks suggests that significant tectonic mixing predated the complicated folding and metamorphic history of the Twisp Valley Schist (Miller, 1987). According to Adams (1961), the Twisp Valley Schist also contains several layers of metaconglomerate near the Crescent mine in the west half of the Twisp 1:100,000-scale quadrangle. The metaconglomerate contains stretched and deformed quartz pebbles in a finer grained matrix of biotite, green hornblende, quartz, and minor oligoclase and zoisite.

Metamorphism was in the greenschist and amphibolite facies and apparently of the low P/T Buchan- or Abukuma-type facies series. Andalusite porphyroblasts are present in several biotite schists near Scaffold Peak. Inclusions in the porphyroblasts define an internal fabric that is discordant with the external foliation. The andalusite has been partially replaced by sillimanite and muscovite. Sillimanite helps define the foliation, which wraps around the andalusite porphyroblasts. The unit is upgraded to amphibolite facies near the batholiths which intrude it.

The Twisp Valley Schist is intruded by the Cretaceous Black Peak batholith, the Paleocene Lake Juanita leucogneiss, and by the Paleocene Oval Peak batholith. Its northeastern contact is mylonitized in the Twisp River-Foggy Dew fault zone shown as unit "tz" on this map.

The age of the Twisp Valley Schist is unknown, but the unit may be correlative with the upper chert-rich section of the Permian to Jurassic Hozameen Group (Miller, 1987). The Twisp Valley Schist includes the Horsehead Pass schist of Libby (1964) and the Rainbow Lake schist of Adams (1961). It was first named and mapped by Adams (1961) and subsequently mapped and described by Miller (1987; R. B. Miller and S. A. Bowring, San Jose State Univ., written commun., 1988).

$pKhm_{tm}$

Amphibolite and schist of Twentyfive Mile Creek (pre-Cretaceous (Permian (?)))--Predominantly fine-grained amphibolite. It consists of 40 percent hornblende, 40 percent plagioclase, 5 to 6 percent quartz, and 5 to 6 percent clinozoisite. Foliation is defined by alignment of hornblende. The rocks are medium to dark gray and commonly stained by iron oxide. Fine banding, on a scale of a few millimeters to 4 to 5 cm, is pervasive. This heterogeneous unit originally described from exposures in the Chelan quadrangle to the south contains schistose amphibolite, biotite schist, siliceous schist, and rare marble.

The amphibolite is interbanded with calc-silicate schist consisting of diopside, hornblende, and quartz. The schist is pale greenish gray and slightly coarser grained than the amphibolite. The relative abundance of and the fine scale of banding in the calc-silicate schist and amphibolite distinguish the amphibolite and schist of Twentyfive Mile Creek from the similar amphibolite, schist, and gneiss of Alta Lake.

Tonalite dikes and sills similar to the hornblende tonalite gneiss of Antoine Creek are common in the amphibolite outcrops of the Twentyfive Mile Creek unit and suggest an original intrusive contact between the orthogneiss and layered rocks (Raviola, 1988). The amphibolite and schist of Twentyfive Mile Creek is also in fault contact with the hornblende tonalite gneiss of Antoine Creek in a zone of ductile deformation that produced mylonites on the Chelan 1:100,000-scale quadrangle to the south.

Rocks of the Twentyfive Mile Creek unit on the west side of Lake Chelan are continuous with the younger gneissic rocks of the Holden area to the north (west half of the Twisp 1:100,000-scale quadrangle). A discordant U-Pb analysis of zircon from a biotite-quartz-oligoclase granofels in the younger gneissic rocks of the Holden area gives an older concordia intercept of 265 ± 15 Ma, if the younger intercept is assumed to be 60 to 90 Ma (age range of Late Cretaceous metamorphism (Mattinson, 1972)). The dated granofels, interpreted to be a metamorphosed keratophyre by C. A. Hopson (as reported in Mattinson, 1972), thus has a Permian depositional age, which is considered the protolith age of the younger gneissic rocks of the Holden area and, by extension, the amphibolite and schist of Twentyfive Mile Creek (Tabor and others, 1987).

The extension of a Permian age to the rocks mapped as amphibolite and schist of Twentyfive Mile Creek is largely speculative. The unit is given a pre-Cretaceous age to indicate a protolith age that is older than the Late Cretaceous metamorphism. It may well be as old as Permian.

$pKhm_l$, $pKbg_l$ (see also pre-Cretaceous orthogneiss, $pKog_l$)

The Leecher Metamorphics (pre-Cretaceous)--A heterogeneous unit ($pKhm_l$), a diorite gneiss ($pKog_l$), and a banded granite to diorite and amphibolite gneiss ($pKbg_l$) (Frey, 1988). The unit was originally named by Barksdale (1948).

The Leecher Metamorphics are intruded on the east by the Cretaceous-Jurassic Okanogan complex (Summit-Frazer gneiss) and internally by the Tertiary-Cretaceous stock of Yockey Creek and the Cretaceous Texas Creek stock. The pre-Cretaceous Methow Gneiss intrudes the unit on the south and west.

The Methow Gneiss, Summit-Frazer gneiss, and the Leecher Metamorphics are faulted westward and northwestward over rocks of the Newby Group, Frazer Creek complex, and the McClure Mountain unit along the reverse Methow River fault (Frey and Anderson, 1987). One small outcrop of Leecher Metamorphics is mapped on the west side of the Methow River, where it is folded and deformed in the Vinegar fault zone.

The rocks west of the Methow River and east of the Smith Canyon fault were originally mapped as Leecher Metamorphics by Barksdale (1975), who considered the mylonitized and phyllonitized greenschist-facies rocks to be products of shearing and retrograde metamorphism of Leecher

Metamorphic rocks. Although these rocks may have been formed from the Leecher Metamorphics, they are distinctly different in metamorphic and structural characters and have been assigned here to the McClure Mountain unit ($pTmt_m$).

Skarn zones in marble, formed at the contact of the Leecher Metamorphics with the Texas Creek stock, contain scheelite, chalcopyrite, molybdenite, pyrite, magnetite, and hematite in a gangue of calcite, epidote, and garnet. Heterogeneous metamorphic rocks of the Leecher also serve as host to a gold deposit at the Minnie mine.

The age of the Leecher unit is not known. It is assigned an age of pre-Cretaceous because it is intruded by the Cretaceous Texas Creek stock and the Cretaceous-Jurassic Okanogan complex (Summit-Frazer gneiss). Field relations of the Leecher to the Methow Gneiss suggest that the latter intruded the Leecher and together they were ductilely deformed before intrusion of the Okanogan complex. Thisrelation allows the possibility that the Leecher is considerably older than Cretaceous. The Leecher may be equivalent to the amphibolite, schist, and gneiss of Alta Lake and to the amphibolite and schist of Twentyfive Mile Creek, which, by extension to the younger gneissic rocks of the Holden area, may be Permian. This correlation with the Leecher is highly speculative. A single K-Ar determination on hornblende in Leecher amphibolite yields an age of 114.3 ± 2.9 Ma, which is considered to be a reset age (V. R. Todd, USGS, written commun., 1989; Table 3).

$pKhm_l$

Heterogeneous rocks of the Leecher Metamorphics (pre-Cretaceous)--Unit consists of marble, biotite schist; and muscovite schist, and amphibolite and biotite schist.

The marble has an average grain size of 1 to 2 mm. The marble is composed of 98 percent white to salmon-colored calcite and or dolomite, which are interbanded in places. Roughly 2 percent of rusty magnetite and minor phlogopite are concentrated along foliation planes. Near one contact with amphibolite schists, the rock also contains forsterite and garnet. The unit has been subject to brittle faulting after an earlier ductile deformation (Frey, 1988).

Biotite schists in the Leecher contain chiefly biotite, feldspar, and quartz with some muscovite, chlorite, pyrite, and amphibole. These rocks have been ductilely sheared, but more recrystallization of micas has taken place here than in the amphibolite and biotite schist subunit. The biotite schist is highly varied, but in part appears to be metamorphosed sandstone. These rocks are folded along with the other Leecher Metamorphic units (Frey, 1988).Amphibolite to biotite schist mapped as subunits of the Leecher Metamorphics are schists or phyllonites composed of various combinations of amphibole, biotite, and feldspar with minor quartz and garnet. The unit is predominantly amphibolite interbedded with leucocratic biotite-rich layers. The protolith is probably basalt or andesite flows. All of these rocks have been mylonitized, and foliation planes are extremely flat. Intrafolial folds are common, and large refolded isoclinal folds affect the unit. Much of the rock shows evidence of recrystallization after mylonitization, probably due to the intrusion of the Okanogan complex. Locally, hornblende-plagioclase "sweats" contain hornblende crystals exceeding 25 cm in length (Frey, 1988).

$pKbg_l$

Banded gneiss of the Leecher Metamorphics (pre-Cretaceous)--Fine- to medium-grained quartz diorite to granodiorite gneisses containing plagioclase, biotite, and quartz, with or without hornblende and potassium feldspar. The rocks are intrusive into the heterogeneous Leecher Metamorphics unit, commonly in a *lit-par-lit* style, and in many places form migmatites. Some of these rocks may be related to the Okanogan complex and the Methow Gneiss. The degree of deformation is varied, including foliated to strongly mylonitic rocks. Because some of the rocks are migmatitic, the unit also includes various amounts of other Leecher Metamorphics such as amphibolite (Frey, 1988).

## Tectonic Zone

tz

Tectonic zone--Mylonitized rocks along the trace of the Twisp River-Foggy Dew fault zone separating greenschist- to amphibolite-facies metamorphic rocks and Cretaceous and Paleocene plutons from the relatively unmetamorphosed rocks of the Methow trough. Rocks in the 1.5-km-wide zone consist mainly of mylonitic tonalite orthogneiss, amphibolite, biotite schist, and phyllonite. Biotite schist and greenschist are present in minor amounts.

These rocks characteristically display a strong mineral lineation, and the mylonitic foliation commonly marks asymmetric folds. Steep faults with small offsets are common locally and are oriented nearly perpendicular to the foliation (Miller, 1987).

Some of the orthogneiss is clearly derived from the Oval Peak batholith, whereas amphibolite and schist are of uncertain origin. They may represent reworked Twisp Valley Schist or, less likely, upgraded undifferentiated Newby Group rocks. Pre- or syn-mylonitization intrusive contacts between mylonitic Oval Peak gneiss and amphibolite are preserved in several places. Boudinaged mylonitic Oval Peak dikes are clearly discordant to foliation in the amphibolite. Intrusive tongues of Oval Peak gneiss in amphibolite are more than 10 m thick in places.

Mineral-streaking lineation and foliation in the tectonic zone and foliation in the mylonitic conglomerate of the adjacent Virginian Ridge Formation indicate that oblique, dextral strike-slip motion occurred along the Twisp River-Foggy Dew fault zone (Miller, 1987). The latest movement is known to have occurred after intrusion of the Oval Peak batholith (61-62 Ma), which is mylonitized along its northeastern margin. The absence of dikes or contact effects of the batholith in the Cretaceous-Jurassic rocks of the adjacent Methow basin suggest that the Oval Peak was moved into its present location after emplacement, but before intrusion of the Cooper Mountain batholith (48 Ma). A K-Ar age determination on hornblende in mylonite from this zone yields an age consistent with this interpretation, 55.8 ± 3.6 Ma (Table 3).

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**Table 1.** Major element geochemical analyses for units occurring on the east half of the Twisp 1:100,000-scale quadrangle. Analyses by XRF, Department of Geology, Washington State University. All analyses normalized to 100% on a volatile-free basis and FeO* = total iron as FeO. **Indicates that unit area is too small to be shown on map.

| Unit | Sample | Subsection | Sec | Twp | Rge | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | FeO* | MnO | CaO | MgO | $K_2O$ | $Na_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KJigb$_f$ | FCC2 | N1/2 SW/4 | 10 | 33N | 22E | 43.97 | 26.18 | 0.43 | 8.78 | 0.10 | 13.62 | 5.37 | 0.34 | 1.20 | 0.02 |
| KJigb$_f$ | FCC1 | NE/4 SE/4 | 10 | 33N | 22E | 45.44 | 28.27 | 0.32 | 5.71 | 0.08 | 15.31 | 3.51 | 0.04 | 1.32 | 0.01 |
| KJiq$_a$ | 3321246C | NE/4 SW/4 | 24 | 33N | 21E | 57.83 | 18.21 | 0.91 | 6.58 | 0.11 | 6.70 | 3.45 | 1.23 | 4.70 | 0.29 |
| KJiq$_a$ | 33212555 | NE/4 SW/4 | 25 | 33N | 21E | 61.52 | 16.46 | 0.74 | 5.87 | 0.10 | 5.87 | 3.36 | 1.82 | 4.06 | 0.22 |
| KJiq$_f$ | MK870744 | SW/4 SE/4 | 35 | 34N | 22E | 59.51 | 17.43 | 0.86 | 6.30 | 0.11 | 6.21 | 3.53 | 1.89 | 3.92 | 0.24 |
| KJiq$_f$ | MK870745 | NE/4 NE/4 | 34 | 34N | 22E | 60.69 | 17.33 | 0.77 | 5.83 | 0.10 | 6.02 | 3.13 | 2.07 | 3.84 | 0.23 |
| KJiq$_f$ | MK870746 | SE/4 SE/4 | 27 | 34N | 22E | 56.27 | 18.38 | 0.84 | 6.97 | 0.12 | 7.50 | 4.30 | 1.50 | 3.84 | 0.29 |
| KJiq$_f$ | 3322222G | NE/4 NE/4 | 22 | 33N | 22E | 54.94 | 17.99 | 0.90 | 9.06 | 0.18 | 8.95 | 4.23 | 0.47 | 3.12 | 0.15 |
| KJiq$_f$ | 3322221F | SE/4 NE/4 | 22 | 33N | 22E | 54.53 | 17.99 | 0.62 | 8.26 | 0.16 | 9.87 | 5.56 | 0.35 | 2.61 | 0.05 |
| KJit$_f$ | 3322238E | SW/4 NW/4 | 23 | 33N | 22E | 75.23 | 13.73 | 0.25 | 1.69 | 0.05 | 2.42 | 0.48 | 1.69 | 4.43 | 0.04 |
| KJvs$_n$ | HS0715873 | SW/4 NE/4 | 21 | 33N | 21E | 57.67 | 17.17 | 0.87 | 8.82 | 0.16 | 7.78 | 3.28 | 0.14 | 3.95 | 0.16 |
| KJvs$_n$ | BP0717871 | SE/4 SE/4 | 12 | 33N | 21E | 50.42 | 20.15 | 0.94 | 9.69 | 0.21 | 8.39 | 5.20 | 1.09 | 3.73 | 0.17 |
| KJvs$_n$ | BP0717875 | SW/4 SW/4 | 20 | 32N | 21E | 55.02 | 19.48 | 0.92 | 8.06 | 0.20 | 9.82 | 3.05 | 0.16 | 3.08 | 0.22 |
| KJvs$_n$ | BP0717874 | SE/4 SE/4 | 9 | 32N | 21E | 53.55 | 19.33 | 0.75 | 7.73 | 0.14 | 9.86 | 3.05 | 0.03 | 5.47 | 0.09 |
| KJvs$_n$ | 0P36510 | ---- NW/4 | 14 | 32N | 20E | 63.73 | 15.65 | 0.96 | 5.37 | 0.08 | 4.22 | 3.33 | 1.29 | 5.10 | 0.26 |
| KJvs$_n$ | 0P43201 | NE/4 NE/4 | 14 | 32N | 20E | 58.92 | 15.77 | 0.96 | 6.52 | 0.09 | 6.37 | 4.74 | 1.94 | 4.39 | 0.31 |
| KJvs$_n$ | 0P4410 | NE/4 SE/4 | 3 | 32N | 20E | 59.02 | 16.79 | 1.04 | 6.56 | 0.11 | 4.70 | 5.00 | 1.92 | 4.55 | 0.33 |
| KJvs$_n$ | 0P46201 | SE/4 SE/4 | 3 | 32N | 20E | 56.01 | 17.51 | 1.24 | 7.51 | 0.12 | 8.35 | 3.26 | 1.68 | 4.02 | 0.31 |
| **KJvs$_n$ | HS0717875 | NW/4 NE/4 | 1 | 32N | 20E | 58.01 | 16.33 | 1.04 | 7.90 | 0.14 | 6.04 | 4.72 | 1.47 | 4.09 | 0.27 |
| Kog$_{br}$ | RPG | ---- ---- |  | 33N | 18E | 68.59 | 16.38 | 0.34 | 2.42 | 0.05 | 3.41 | 1.14 | 2.55 | 5.00 | 0.12 |
| **KJvs$_n$ | 33225CTRNW4 | NE/4 NW/4 | 5 | 33N | 22E | 53.00 | 21.00 | 0.84 | 7.08 | 0.21 | 9.38 | 3.35 | 0.63 | 4.41 | 0.11 |
| KJvs$_n$ | 322241D | NE/4 SE/4 | 4 | 33N | 22E | 49.96 | 19.68 | 0.81 | 9.93 | 0.20 | 10.03 | 6.36 | 0.08 | 2.83 | 0.12 |
| PAit$_o$ | 0P47801 | ---- ---- |  | 33N | 20E | 65.97 | 17.56 | 0.59 | 3.36 | 0.06 | 4.17 | 1.04 | 1.91 | 5.14 | 0.20 |
| PAit$_o$ | 0P35610 | ---- ---- |  | 32N | 20E | 67.64 | 17.40 | 0.54 | 2.32 | 0.03 | 3.65 | 0.63 | 2.00 | 5.60 | 0.19 |
| PAit$_o$ | OPSLAB | ---- ---- |  | 32N | 19E | 67.45 | 17.62 | 0.41 | 2.54 | 0.05 | 4.38 | 0.66 | 1.63 | 5.12 | 0.14 |
| PAog$_j$ | LE | ---- ---- |  | 32N | 19E | 74.10 | 15.09 | 0.15 | 0.92 | 0.02 | 1.86 | 0.12 | 2.80 | 4.91 | 0.03 |
| PAog$_o$ | 0P49401 | ---- ---- |  | 32N | 20E | 64.69 | 18.46 | 0.54 | 3.45 | 0.05 | 5.06 | 1.00 | 1.34 | 5.22 | 0.19 |
| PAog$_w$ | WCG | ---- ---- |  | 33N | 19E | 71.42 | 15.97 | 0.28 | 1.50 | 0.03 | 2.61 | 0.51 | 2.11 | 5.50 | 0.08 |
| pKhm$_t$ | 0P44003 | ---- ---- |  | 33N | 19E | 49.97 | 15.29 | 0.91 | 8.88 | 0.18 | 10.13 | 11.62 | 0.57 | 2.31 | 0.12 |
| pKhm$_t$ | 0P44701 | ---- ---- |  | 33N | 19E | 48.84 | 16.51 | 2.72 | 11.67 | 0.21 | 6.39 | 9.18 | 1.17 | 2.92 | 0.38 |
| pKhm$_t$ | 0P50901 | ---- ---- |  | 33N | 19E | 50.78 | 14.48 | 1.34 | 10.58 | 0.21 | 11.56 | 7.96 | 0.24 | 2.77 | 0.09 |
| pKhm$_t$ | 0P48402 | ---- ---- |  | 33N | 19E | 48.79 | 16.29 | 2.72 | 9.98 | 0.18 | 9.00 | 7.67 | 0.94 | 3.80 | 0.64 |
| pTgn | 3321247G | NW/4 NW/4 | 24 | 33N | 21E | 76.50 | 13.62 | 0.24 | 1.57 | 0.03 | 2.21 | 0.38 | 0.35 | 5.04 | 0.04 |
| tz | 0P5210 | ---- ---- |  | 32N | 20E | 54.41 | 14.71 | 1.39 | 13.08 | 0.18 | 7.42 | 4.82 | 0.44 | 3.41 | 0.14 |
| tz | 0P43401 | SE/4 SW/4 | 31 | 32N | 21E | 54.35 | 14.03 | 1.86 | 10.79 | 0.19 | 9.53 | 5.43 | 0.39 | 3.24 | 0.19 |
| tz | 0P5010 | ---- ---- |  | 32N | 20E | 60.74 | 15.12 | 0.99 | 9.28 | 0.18 | 6.90 | 2.42 | 0.23 | 3.97 | 0.16 |
| tz | 0P4710 | ---- ---- |  | 32N | 20E | 57.30 | 15.00 | 1.14 | 12.43 | 0.16 | 6.57 | 4.51 | 0.15 | 2.60 | 0.13 |
| tz | 0P43701 | ---- ---- |  | 31N | 21E | 50.96 | 15.58 | 1.62 | 11.37 | 0.19 | 10.62 | 6.09 | 0.40 | 3.02 | 0.16 |

**Table 2.** Trace element geochemical analyses for units occurring on the east half of the Twisp 1:100,000-scale quadrangle. Analyses by XRF, Department of Geology, Washington State University. **Indicates that unit area is too small to be shown on map.

| Unit | Sample | Subsection | Sec | Twp | Rge | Ni | Cr | Sc | V | Ba | Rb | Sr | Zr | Y | Nb | Ga | Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KJigb$_f$ | FCC2 | N1/2 SW/4 | 10 | 33N | 22E | 15 | 45 | 28 | 276 | 101 | 9 | 552 | 35 | 5 | 1.9 | 17 | 36 | 84 |
| KJigb$_f$ | FCC1 | NE/4 SE/4 | 10 | 33N | 22E | 8 | 7 | 31 | 191 | 10 | 2 | 560 | 33 | 4 | 0.8 | 20 | 41 | 49 |
| KJiq$_a$ | 3321246C | NE/4 SW/4 | 24 | 33N | 21E | 27 | 41 | 19 | 175 | 600 | 16 | 945 | 167 | 16 | 5.8 | 19 | 179 | 83 |
| KJiq$_a$ | 33212555 | NE/4 SW/4 | 25 | 33N | 21E | 36 | 48 | 21 | 148 | 581 | 27 | 682 | 101 | 19 | 4.0 | 16 | 231 | 73 |
| KJiq$_f$ | MK870744 | SW/4 SE/4 | 35 | 34N | 22E | 33 | 46 | 22 | 163 | 804 | 38 | 681 | 127 | 17 | 7.2 | 18 | 63 | 71 |
| KJiq$_f$ | MK870745 | NE/4 NE/4 | 34 | 34N | 32E | 31 | 38 | 20 | 136 | 787 | 37 | 684 | 166 | 15 | 5.4 | 15 | 74 | 71 |
| KJiq$_f$ | MK870746 | SE/4 SE/4 | 27 | 34N | 22E | 43 | 72 | 21 | 190 | 616 | 25 | 893 | 98 | 14 | 5.1 | 22 | 85 | 79 |
| KJiq$_f$ | 3322222G | NE/4 NE/4 | 22 | 33N | 22E | 4 | 19 | 35 | 267 | 162 | 9 | 441 | 59 | 17 | 2.7 | 17 | 79 | 77 |
| KJiq$_f$ | 3322221F | SE/4 NE/4 | 22 | 33N | 22E | 16 | 70 | 32 | 239 | 144 | 6 | 403 | 53 | 12 | 1.5 | 16 | 126 | 84 |
| KJit$_f$ | 3322238E | SW/4 NW/4 | 23 | 33N | 22E | 11 | 0 | 9 | 15 | 716 | 24 | 190 | 95 | 12 | 2.4 | 15 | 21 | 39 |
| KJvs$_n$ | HS0715873 | SW/4 NE/4 | 21 | 33N | 21E | 6 | 17 | 29 | 277 | 25 | 4 | 303 | 56 | 19 | 2.1 | 20 | 43 | 105 |
| KJvs$_n$ | BP0717871 | SE/4 SE/4 | 12 | 33N | 21E | 13 | 39 | 36 | 295 | 432 | 20 | 1170 | 80 | 16 | 2.6 | 17 | 121 | 97 |
| KJvs$_n$ | BP0717875 | SW/4 SW/4 | 20 | 32N | 21E | 7 | 8 | 30 | 209 | 139 | 2 | 2049 | 121 | 22 | 2.8 | 20 | 126 | 116 |
| KJvs$_n$ | BP0717874 | SE/4 SE/4 | 9 | 32N | 21E | 11 | 25 | 30 | 291 | 0 | 0 | 95 | 35 | 13 | 1.9 | 16 | 110 | 74 |
| KJvs$_n$ | OP36510 | ---- NW/4 | 14 | 32N | 20E | 71 | 191 | 15 | 213 | 646 | 34 | 586 | 156 | 17 | 13.0 | 17 | 55 | 77 |
| KJvs$_n$ | OP43201 | NE/4 NE/4 | 14 | 32N | 20E | 41 | 101 | 18 | 141 | 839 | 47 | 1162 | 163 | 17 | 12.3 | 17 | 49 | 89 |
| KJvs$_n$ | OP4410 | NE/4 SE/4 | 3 | 32N | 20E | 50 | 123 | 15 | 159 | 1193 | 43 | 952 | 162 | 17 | 12.7 | 18 | 62 | 119 |
| KJvs$_n$ | OP46201 | SE/4 SE/4 | 3 | 32N | 20E | 12 | 26 | 26 | 256 | 530 | 33 | 811 | 136 | 18 | 8.3 | 22 | 144 | 131 |
| **KJvs$_n$ | HS0717875 | NW/4 NE/4 | 1 | 32N | 20E | 21 | 85 | 20 | 196 | 557 | 42 | 693 | 109 | 18 | 5.5 | 17 | 51 | 97 |
| Kog$_{br}$ | RPG | ---- ---- |  | 33N | 18E | 19 | 11 | 6 | 61 | 954 | 51 | 819 | 111 | 7 | 4.7 | 18 | 8 | 49 |
| **KJvs$_n$ | 33225CTRNW4 | NE/4 NW/4 | 5 | 33N | 22E | 9 | 63 | 37 | 310 | 161 | 8 | 336 | 44 | 16 | 2.5 | 17 | 84 | 85 |
| KJvs$_n$ | 322241D | NE/4 SE/4 | 4 | 33N | 22E | 32 | 73 | 38 | 293 | 79 | 1 | 475 | 46 | 14 | 0.0 | 18 | 115 | 92 |
| PAit$_o$ | OP47801 | ---- ---- |  | 33N | 20E | 10 | 1 | 8 | 82 | 630 | 45 | 882 | 144 | 10 | 5.3 | 23 | 15 | 111 |
| PAit$_o$ | OP35610 | ---- ---- |  | 32N | 20E | 10 | 0 | 3 | 45 | 750 | 39 | 1073 | 141 | 6 | 6.3 | 20 | 17 | 102 |
| PAit$_o$ | OPSLAB | ---- ---- |  | 32N | 19E | 8 | 0 | 11 | 41 | 601 | 36 | 777 | 117 | 8 | 5.2 | 19 | 30 | 86 |
| PAog$_j$ | LE | ---- ---- |  | 32N | 19E | 9 | 0 | 6 | 0 | 1459 | 62 | 703 | 92 | 4 | 5.0 | 20 | 11 | 58 |
| PAog$_o$ | OP49401 | ---- ---- |  | 32N | 20E | 9 | 0 | 12 | 55 | 632 | 30 | 889 | 145 | 7 | 5.4 | 23 | 19 | 115 |
| PAog$_w$ | WCG | ---- ---- |  | 33N | 19E | 13 | 2 | 6 | 25 | 724 | 38 | 739 | 114 | 6 | 3.2 | 20 | 13 | 56 |
| pKhm$_t$ | OP44003 | ---- ---- |  | 33N | 19E | 178 | 682 | 45 | 291 | 255 | 14 | 434 | 76 | 16 | 3.3 | 14 | 76 | 93 |
| pKhm$_t$ | OP44701 | ---- ---- |  | 33N | 19E | 52 | 136 | 29 | 255 | 211 | 19 | 330 | 194 | 27 | 44.2 | 19 | 70 | 114 |
| pKhm$_t$ | OP50901 | ---- ---- |  | 33N | 19E | 87 | 263 | 42 | 293 | 0 | 3 | 167 | 82 | 29 | 2.8 | 19 | 132 | 158 |
| pKhm$_t$ | OP48402 | ---- ---- |  | 33N | 19E | 95 | 160 | 26 | 195 | 386 | 19 | 662 | 196 | 25 | 50.2 | 20 | 63 | 92 |
| pTgn | 3321247G | NW/4 NW/4 | 24 | 33N | 21E | 10 | 0 | 9 | 0 | 178 | 5 | 252 | 98 | 20 | 3.6 | 11 | 20 | 22 |
| tz | OP5210 | ---- ---- |  | 32N | 20E | 11 | 48 | 37 | 506 | 82 | 7 | 197 | 71 | 24 | 3.7 | 21 | 259 | 139 |
| tz | OP43401 | SE/4 SW/4 | 31 | 32N | 21E | 63 | 114 | 41 | 340 | 124 | 6 | 262 | 119 | 27 | 10.4 | 18 | 119 | 87 |
| tz | OP5010 | ---- ---- |  | 32N | 20E | 6 | 20 | 31 | 253 | 34 | 4 | 159 | 58 | 26 | 0.0 | 18 | 66 | 109 |
| tz | OP4710 | ---- ---- |  | 32N | 20E | 9 | 20 | 33 | 457 | 33 | 3 | 203 | 67 | 23 | 1.8 | 17 | 153 | 118 |
| tz | OP43701 | ---- ---- |  | 31N | 21E | 64 | 106 | 41 | 361 | 154 | 8 | 301 | 104 | 26 | 9.2 | 19 | 138 | 96 |

**Table 3.** K-Ar age estimates for units occurring on the east half of the Twisp 1:100,000-scale quadrangle.

| UNIT NAME | UNIT SYMBOL | SAMPLE NUMBER | ROCK TYPE | NORTH LATITUDE | WEST LONGITUDE | MATERIAL DATED | AGE (Ma) | S.D. (Ma) | $K_2O$ (wt. %) | RAD. AR (moles/gm) | PERCENT RAD. AR ($x10^{-10}$) | REF. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alder Creek stock | $KJiq_a$ | TW-30 | quartz diorite | 48° 20′ 31″ | 120° 09′ 23″ | hb | 137.3 | 1.1 | 0.722 | 1.4831 | 61.7 | 1 |
| Alder Creek stock | $KJiq_a$ | 33212555 | quartz diorite | 48° 19′ 50″ | 120° 09′ 18″ | hb | 139 | 6 | 0.691 | 1.730 | 69.1 | 2 |
| Black Peak batholith | --- | PM26a | quartz diorite | 48° 28′ 00″ | 120° 34′ 00″ | hb | 88.4* | 2.7 | 0.873 | 1.17 | 61 | 6 |
| Black Peak batholith | --- | --- | quartz diorite | 48° 28′ | 120° 34′ | b | 73.2 | 2 | --- | --- | --- | 8 |
| Black Peak batholith | --- | PM22 | quartz diorite | 48° 28′ 00″ | 120° 34′ 00″ | b | 73.0** | 2 | --- | --- | --- | 6 |
| Black Peak batholith | $Kog_{br}$ | RM-84-MB | weakly foliated granodiorite | 48° 30′ 25″ | 120° 43′ 48″ | b | 71.8<br>72.0 | 1.8<br>1.8 | 9.14<br>9.10 | 9.6229<br>9.6463 | 86.2<br>90.8 | 1 |
| Black Peak batholith | $Kog_{br}$ | RM-84-MB | weakly foliated granodiorite | 48° 30′ 25″ | 120° 43′ 48″ | hb | 98.5 | 2.5 | 0.700<br>0.706 | 1.0242 | 35.6 | 1 |
| Black Peak batholith | --- | --- | --- | --- | --- | --- | 87.0 | 2.5 | --- | --- | --- | 3 |
| Carlton stocks | $Kiq_c$ | --- | quartz diorite | 47° 12′ 20″ | 120° 07′ 14″ | hb | 129.6 | 1.1 | --- | --- | --- | 5 |
| Chelan Complex of H & M* | $Kog_c$ | RWT 84-79 | tonalite | 47° 57′ 42″ | 120° 01′ 36″ | b | 74.3 | 0.6 | 9.23 | 10.1 | 89.1 | 4 |
| Chelan Complex of H & M* | $Kog_c$ | RWT 183-77 | tonalite | 47° 46′ 54″ | 120° 01′ 36″ | b<br>hb | 58.4<br>63.9 | 0.6<br>1.5 | 7.85<br>1.037 | 6.60<br>0.0966 | 87.6<br>75.7 | 4<br>4 |
| Copper Mtn. batholith | $Eigd_c$ | OP-3B | biotite granodiorite | 48° 07′ 07″ | 120° 12′ 53″ | b | 47.7 | 1.2 | 7.84<br>7.89 | 5.4764 | 62.4 | 1 |
| Copper Mtn. batholith | $Eigd_c$ | --- | --- | --- | --- | --- | 48.1 | 1.7 | --- | --- | --- | 3 |
| Copper Mtn. batholith | $Eigd_c$ | RWT 40-79 | granodiorite-quartz monzonite | 48° 01′ 24″ | 120° 11′ 30″ | b | 48.1 | 5.4 | 9.14 | 6 | 17.4 | 4 |
| Duncan Hill pluton | $Eiq_d$ | C-541-1 | quartz diorite | 47° 50′ 00″ | 120° 21′ 06″ | b | 46.2 | 1.4 | 4.875 | 3.365 | 80 | 9 |
| Duncan Hill pluton | $Eiq_d$ | C-685-1 | quartz diorite | 47° 56′ 18″ | 120° 31′ 12″ | hb | 44.9 | 1.8 | 0.667 | 0.448 | 67 | 9 |
| Foggy Dew fault zone | fz | OP-52-10 | amphibolite in fault zone | 48° 13.32′ | 120° 16.19′ | hb | 55.8 | 3.6 | 0.288 | 0.2823 | 20.9 | 2 |
| Frazer Creek complex | $KJiq_f$ | MK870746 | tonalite | 48° 24′ 43″ | 120° 03′ 34″ | hb<br>b | 139<br>109 | 6<br>4 | 0.646<br>7.721 | 1.615<br>15.10 | 70.2<br>78.4 | 2<br>2 |

**Table 3.** K-Ar age estimates for units occurring on the east half of the Twisp 1:100,000-scale quadrangle (continued).

| UNIT NAME | UNIT SYMBOL | SAMPLE NUMBER | ROCK TYPE | NORTH LATITUDE | WEST LONGITUDE | MATERIAL DATED | AGE (Ma) | S.D. (Ma) | $K_2O$ (wt. %) | RAD. AR (moles/gm) | PERCENT RAD. AR (x$10^{-10}$) | REF. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frazer Creek complex | KJiq$_f$ | T-1 | foliated quartz diorite | 48° 24′ 21″ | 120° 03′ 31″ | hb | 130.1 | 3.3 | 1.119<br>1.124 | 2.1783 | 63.1 | 1 |
| | | | foliated quartz diorite | 48° 24′ 21″ | 120° 03′ 31″ | b<br>b | 107.6<br>103.7 | 2.7<br>2.6 | 9.36<br>9.32 | 0.1435<br>0.1491 | 87.7<br>58.5 | 1<br>1 |
| Frazer Creek complex | KJiq$_f$ | 3322221F | diorite | 48° 20′ 52″ | 120° 03′ 29″ | hb | 13.9 | 9 | 9.22<br>9.24 | 10.10 | 89.1 | 2 |
| Hungry Mtn. (stock of) | Eiq$_h$ | --- | quartz diorite-diorite | 47° 08′ 33″ | 120° 10′ 14″ | hb | 44.5 | 0.9 | --- | --- | --- | 5 |
| Leecher Metamorphics | pKhm$_l$ | TE-1 | amphibolite | 48° 15′ 17″ | 120° 05′ 38″ | hb | 114.6 | 2.9 | 0.292<br>0.290 | 49.5590 | 62.5 | 10 |
| Methow Gneiss | pKog$_m$ | Met-4 | biotite trondhjemite | 48° 09′ 02″ | 120° 03′ 16″ | b | 61.7 | 1.5 | 5.04<br>5.09 | 4.5755 | 66.1 | 10 |
| Newby Group | KJvs$_n$ | TW-38 | basaltic andesite | 48° 21′ 45″ | 120° 07′ 59″ | wr | 81.3 | 2.0 | 0.227<br>0.240<br>0.228<br>0.230 | 27.6707<br>--- | 27.8<br>--- | 10<br>10 |
| Newby Group (flow?)** | --- | DM-25 | basaltic andesite | 48° 31′ 30″ | 120° 10′ 39″ | wr | 90.4 | 2.3 | 0.334<br>0.324 | 43.9060 | 46.7 | 10 |
| Newby Group (dike in)** | KJm$_n$ | HP-44 | basaltic andesite | 48° 18′ 26″ | 120° 15′ 23″ | wr | 49.0 | 1.2 | 0.878<br>0.874<br>0.894<br>0.878 | 63.0619 | 58.8 | 10 |
| Summit Creek pluton | KJog$_s$ | LL-1 | gneissic biotite trondhjemite | 48° 16′ 47″<br>48° 16′ 47″ | 119° 59′ 07″<br>119° 59′ 07″ | b<br>b | 100.6<br>100.0 | 2.5<br>2.5 | 9.27<br>9.16 | 0.1373<br>0.1364 | 94.6<br>93.7 | 10<br>10 |
| Texas Creek stock | Kigd$_t$ | TE-3 | tonalite | 48° 15′ 44″ | 120° 03′ 22″ | b<br>hb | 91.9<br>114.3 | 1.2<br>1.0 | ---<br>--- | ---<br>--- | ---<br>--- | 10<br>10 |
| Texas Creek stock (dike in)** | Kigd$_t$ | Met-2 | monzogranite | 48° 13′ 28″ | 120° 03′ 51″ | b<br>b | 87.5<br>88.8 | 2.2<br>2.2 | 1.92<br>8.06 | 0.1047<br>0.1032 | 88.4<br>90.9 | 10<br>10 |
| Twisp Valley Schist | pKhm$_t$ | --- | amphibolite | 48° 16.11′ | 120° 27.66′ | hb | 54.0 | 0.7 | --- | --- | --- | 7 |

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AGES:

\# Recalculated age of 90.6 +/- 2.4 Ma (Hoppe, 1984)
\## Recalculated age of 74.9 +/- 2 Ma (Hoppe, 1984)

MATERIALS DATED:

b biotite
hb hornblende
wr whole rock

UNIT NAMES:

* Chelan complex of Hopson & Mattinson (1971)
** Unit too small to be shown on map

**Table 4.** Uranium-lead age estimates for units occurring on the east half of the Twisp 1:100,000-scale quadrangle.

| | | | | | | Model Age (Ma) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE NO. | UNIT NAME | ROCK TYPE | NORTH LATITUDE | WEST LONGITUDE | MATERIAL | Pb 206/U 238 | Pb 207/U 235 | Pb 207/Pb 206 | Pb 208/Th 232 | REFER. |
| OPF | Oval Peak batholith | foliated tonolite | -------- | --------- | zircon | 61.1 +/- 2 | 61.4 +/- 2 | 72.4 | --- | 1 |
| OPF | Oval Peak batholith | foliated tonolite | -------- | --------- | zircon | 61.4 +/- 2 | 61.6 +/- 2 | 71.2 | --- | 1 |
| OPD | Oval Peak batholith | directionless tonolite | -------- | --------- | zircon | 60.6 +/- 2 | 61.7 +/- 2 | 103.8 | --- | 1 |
| CAS-1e | Lake Juanita leucogneiss | trondhjemitic gneiss | -------- | --------- | zircon | 58.2 +/- 2 | 58.9 +/- 2 | 89.7 | --- | 1 |
| CAS-1e | Lake Juanita leucogneiss | trondhjemitic gneiss | -------- | --------- | zircon | 59.2 +/- 2 | 59.4 +/- 2 | 68.1 | --- | 1 |
| MY-1 | Foggy Dew fault zone | mylonitic gneiss | -------- | --------- | zircon | 49.4 +/- 2 | 50.4 +/- 2 | 99.8 | --- | 1 |
| WJH 80-13 | Black Peak batholith | quartz diorite | 48° 30.2' | 120° 42.6' | zircon | 90.3 +/- 1.4 | 91.1 +/- 1.8 | 112.3 +/- 13 | --- | 2 |
| WJH 80-13 | Black Peak batholith | quartz diorite | 48° 30.2' | 120° 42.6' | sphene | 90.8 +/- 1.8 | ------- | ------- | --- | 2 |
| WJH 80-13 | Black Peak batholith | quartz diorite | 48° 30.2' | 120° 42.6' | zircon | 89.9 +/- 1.4 | 90.6 +/- 1.8 | 108.0 +/- 28 | --- | 2 |
| WJH 80-13 | Black Peak batholith | quartz diorite | 48° 30.2' | 120° 42.6' | sphene | 88.7 +/- 1.8 | ------- | ------- | --- | 2 |
| JM 68-1 | Chelan Complex | hornblende-biotite trondhjemitic gneiss | 47° 51'39" | 120° 09'21" | zircon | 132 | ------- | ------- | --- | 3 |
| JM 68-1 | Chelan Complex | hornblende-biotite trondhjemitic gneiss | 47° 51'39" | 120° 09'21" | zircon | --------- | ------- | 183 +/- 10 | --- | 3 |
| JM 68-1 | Chelan Complex | hornblende-biotite trondhjemitic gneiss | 47° 51'39" | 120° 09'21" | zircon | 111 | ------- | ------- | --- | 3 |
| RWT-183-77 | Chelan Complex of H & M* | tonolite | 47° 46.9' | 120° 01.6' | zircon | 77.1 | 77.3 | 84.6 | 77.2 | 4 |
| RWT-183-77 | Chelan Complex of H & M* | tonolite | 47° 46.9' | 120° 01.6' | zircon | 78.7 | 78.8 | 80.5 | 77.1 | 4 |
| RWT 221-80 | Duncan Hill pluton | gneissic tonolite | 48° 06.5' | 120° 41.4' | zircon | 46.4 | 46.5 | 49.7 | 45.3 | 4 |
| RWT 221-80 | Duncan Hill pluton | gneissic tonolite | 48° 06.5' | 120° 41.4' | zircon | 45.8 | 45.8 | 47.8 | 47.1 | 4 |
| JM 69-10 | Skagit Gneiss | garnet-amphibole-biotite gneiss | 48° 41'26" | 121° 13'41" | apatite | 46 | ------ | ------- | --- | 4 |
| JM 69-12 | Skagit Gneiss | biotite trondhjemite pegmatite | 48° 42'25" | 120° 10'15" | zircon | 90 | ------ | ------- | --- | 3 |
| JM 69-10 | Skagit Gneiss | garnet-amphibole-biotite gneiss | 48° 41'26" | 121° 13'41" | zircon | 98 | 112 | 428 +/- 10 | --- | 3 |
| JM 69-12 | Skagit Gneiss | biotite trondhjemite pegmatite | 48° 42'25" | 120° 10'15" | zircon | 57 | ------ | ------- | --- | 3 |
| JM 68-16 | Skagit Gneiss | gneissic biotite-hornblende quartz diorite | 48° 42'30" | 121° 05'35" | zircon | 66 | 67 | 79 +/- 10 | --- | 3 |

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* Chelan Complex of Hopson and Mattinson (1971)

Table 5. Rb-Sr age estimates for units occurring on the east half of the Twisp 1:100,000-scale quadrangle.

| SAMPLE NUMBER | UNIT NAME | ROCK TYPE | NORTH LATITUDE | WEST LONGITUDE | MATERIAL DATED | AGE | REFERENCE |
|---|---|---|---|---|---|---|---|
| OK-3 | Summit Frazer gneiss | trondjhemite | 48°27' | 119°55' | whole rock/biotite | 104.2 +/- 0.5 Ma | Menzer, 1970 |
| OK-6 | Summit Frazer gneiss | trondjhemite | 48°22' | 119°55' | whole rock/biotite | 104.2 +/- 0.5 Ma | Menzer, 1970 |

Table 6. Fission track age estimates for units occurring on the east half of the Twisp 1:100,000-scale quadrangle.

| SAMPLE NO. | UNIT NAME | ROCK TYPE | NORTH LATITUDE | WEST LONGITUDE | MATERIAL DATED | AGE | REFERENCE |
|---|---|---|---|---|---|---|---|
| OK-3 | Summit-Frazer gneiss | trondjhemite | 48°27' | 119°55' | apatite | 76 +/- 8 Ma | Menzer, 1970 |
| OK-6 | Summit-Frazer gneiss | trondjhemite | 48°22' | 119°55' | sphene<br>apatite | 90 +/- 9 Ma<br>92 +/- 9 Ma | Menzer, 1970 |
| RWT 183-77 | Chelan complex | mafic tonalite | 47°46.9' | 120°01.6' | apatite | 54.7 +/- 1.6 Ma | Tabor and others, 1987 |
| ---- | Noname stock | biotite-hornblende granodiorite | --- | --- | zircon<br>sphene | 55.5 +/- 5 Ma<br>53.6 +/- 5 Ma | Buddington, 1986 |

Table 7. Lead-alpha age estimates for units occurring on the east half of the Twisp 1:100,000-scale quadrangle.

| SAMPLE NUMBER | UNIT NAME | ROCK TYPE | NORTH LATITUDE | WEST LONGITUDE | MATERIAL DATED | AGE | REFERENCE |
|---|---|---|---|---|---|---|---|
| OK-3 | Summit-Frazer gneiss | trondjhemite | 48°27' | 119°55' | zircon | 90 +/- 10 Ma | Menzer, 1970 |
| TLW 252 | Duncan Hill pluton | quartz diorite - granodiorite | 48°00' | 120°38.1' | zircon | 40 +/- 10 Ma | Engels and others, 1976 |

Geologic map of the East Half of the Twisp 1:100,000 Quadrangle, Washington Division of Geology and Earth Resources Open File Report 90-9.

ERRATUM

The polygon labeled "$Kvs_b$" in Section 25, T.21E., R.33N. should be "$KJvs_n$".

April 9, 1990