NATURAL RESOURCES

Geologic Map of the West Half of the Twisp 1:100,000 Quadrangle, Washington

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geochronology by W. McClelland

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 95-3
July 1995

Partially supported by
U.S. Geological Survey
State Map Grant
1434-94-A-1258

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

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

compiled by
Joe D. Dragovich and David K. Norman

INTRODUCTION AND METHODS

This report provides a geologic compilation map of the west half of the Twisp 1:100,000-scale quadrangle (herein referred to as the Twisp quadrangle or study area). The Twisp quadrangle is one of nineteen 1:100,000-scale quadrangles that cover the northwest quadrant of Washington State (Fig. 1). Geologic maps of some of these quadrangles are currently being compiled by geologists at the Washington Division of Geology and Earth Resources (DGER) and will be the principle data sources for the 1:250,000-scale geologic map of northwestern Washington. Ten of these quadrangles will be released as DGER open-file reports; the remainder have been or are being published by the U.S. Geological Survey (USGS). Quadrangles adjacent to the Twisp quadrangle are the Chelan (Tabor and others, 1987a), Robinson Mtn. (R. Haugerud, USGS, and others, currently unpublished; Stoffel and McGroder, 1990), and Sauk River (Tabor and others, 1988). Recent mapping by Tabor and others (1994) in the Mt. Baker quadrangle directly northwest of the study area is an important comparative study. Bunning (1990) compiled the geology of the eastern half of the Twisp 1:100,000-scale quadrangle (Fig. 1).

Literature review and preliminary compilation of the DGER geologic maps began in 1991 for the northwest quadrant. The map was 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. From 1992 to 1995 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 the (now defunct) DGER student mapping program. Additionally, the U.S. Geological Survey STATEMAP Program (National Geologic Mapping Act) supported field and office activities in the western half of the Twisp and in the Bellingham and Roche Harbor 1:100,000-scale maps (Fig. 1). To further improve geologic interpretations, DGER and STATEMAP funds were used to obtain radiometric ages and whole-rock geochemical data.

The areas covered by the map sources used for this compilation are outlined in Figure 2. Much of the northern half of the Twisp quadrangle was mapped during the 1960s by University of Washington students (J. Adams, R. Tabor, W. Libby, and A. Grant) under the tutelage of the late Peter Misch, whose pioneering work in the North Cascades provided the backbone for later studies. In the southern half of the Twisp quadrangle the USGS mapped the Lucerne (Cater and Wright, 1967) and Holden (Cater and Crowder, 1967) 1:62,500-scale quadrangles. During the 1980s and 1990s R. B. Miller (San Jose State University) mapped the Twisp River-Chelan Mountains divide area. These studies provide almost complete coverage for the present Twisp compilation. Several studies of smaller areas in the quadrangle (shown and listed in Fig. 2) provided additional information. Areas remapped or field verified by the authors are shown in Figure 3.

This report consists of a geologic map of the western half of the Twisp 1:100,000-scale quadrangle and accompanying text with descriptions of map units and tables of whole-rock geochemistry and radiometric ages (sampling locations shown on Fig. 4). Formal, informal, and unnamed geologic units are 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 *protolith* age, lower-case letters indicate lithology; and subscripts identify named units. For example, the Tenpeak pluton, a Late Cretaceous (K) dominantly tonalitic orthogneiss (og), is shown with the symbol Kog_t.

Age assignments of geologic units were made following the flow chart in Figure 5. 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; Aguirre and Pasini, 1985).

Plutonic rock names were assigned from results of modal analyses (provided by other studies) and using the International Union of Geological Sciences rock classification (Streckeisen, 1973). For some geologic units, our rock names differ from those given by previous authors,

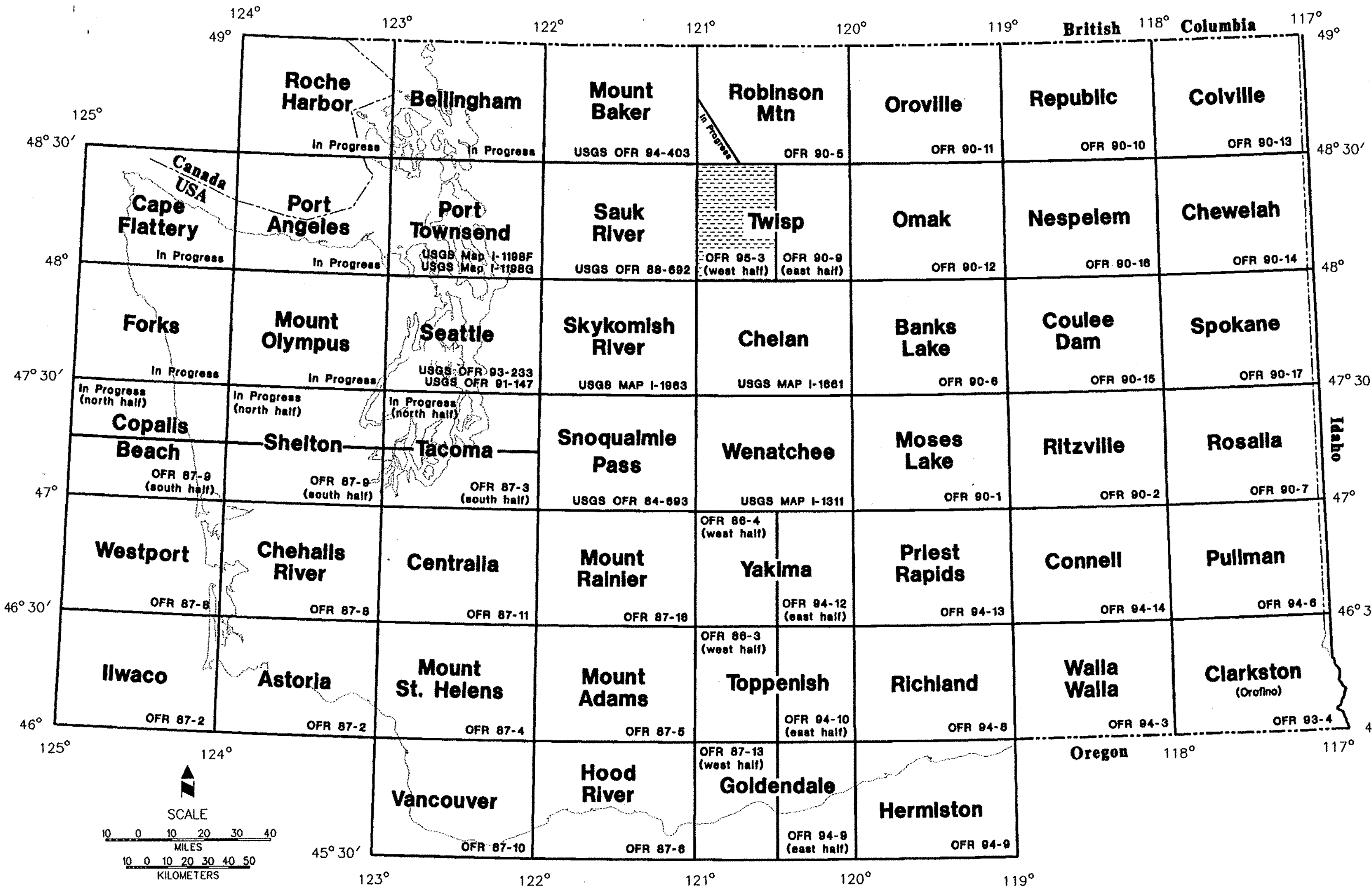

Figure 1. 1:100,000-scale quadrangles in Washington State. Reports published by the U.S. Geological Survey are preceded by USGS; I-, Miscellaneous Field Investigations; OFR, open-file reports. OFR numbers with no other designation are reports published by the Washington Department of Natural Resources, Division of Geology and Earth Resources.

owing to the compilation of data from two or more sources as well as the use of different pre-Streckeisen (1973) classifications. For example, the hornblende-"quartz diorite" augen gneiss of the Dumbell Mountain plutons of Cater and Crowder (1967) and Cater (1982, p. 17) is tonalite according to the nomenclature of Streckeisen (1973). Volcanic rock names were assigned using whole-rock geochemistry and the total alkali-silica diagram (Zanettin, 1984). The term "high-grade metamorphic rocks" refers 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 in sedimentary, volcanic, or intrusive rock units.

Rocks of plutonic parentage were separated into plutonic igneous rocks or high-grade metamorphic rocks on the basis of the degree of fabric development and metamorphism; that is, plutonic bodies described as gneissose were assigned to the metamorphic category. This division is somewhat arbitrary because (1) all Late Cretaceous and older igneous bodies within the Crystalline Core (CC) of the North Cascades (Fig. 6) are thought to have been metamorphosed during the mid- to Late Cretaceous and locally the early Tertiary (Mattinson, 1970, 1972; Miller and others, 1993a; Brown and Walker, 1993; Haugerud and others, 1991); (2) not all mid- to Late Cretaceous and early Tertiary plutons intruded during this time were penetratively deformed and rendered gneissose or strongly foliated (strain was partitioned); and (3) a consensus among previous workers regarding the terms "orthogneiss", "metaplutonic", and "strong fabric development" is generally lacking.

Results of geochemical analyses are given in Appendix 1, and K-Ar, U-Pb, Rb-Sr, fission-track, Pb-Pb and Pb-α analyses are given in Appendix 2. Many of the protolith age assignments are based on the data provided in Appendix 2 . U-Pb age data from this study are given in Appendix 3.

Aerial Photograph Interpretation

The compilation and field mapping were supplemented by aerial photograph (AP) interpretation of the entire western half of the quadrangle using color 1:24,000-scale and black and white 1:14,000-scale APs. APs aided in mapping (1) many of the surficial deposits (e.g., glacial deposits and landslides), (2) some bedrock contacts, and (3) some faults. AP mapping of many of the surficial deposits over the western two-thirds of the study area was supplemented by a previous compilation by R. W. Tabor (USGS, written commun., 1994; see also Fig. 2).

Many of the faults previously mapped in the Lucerne and Holden 15-minute quadrangles (Cater and Wright, 1967; Cater and Crowder, 1967, respectively) were easily recognized on the APs and provided baseline information regarding the geomorphology of faulted areas in regions outside these well-mapped domains. Several new faults were mapped during this study. Many of these faults are northeast to east trending. (See Geologic Setting.) These linear features are recognized as easily eroded zones adjacent to jointed and, in some places, sheared rocks. Because of the increased erodibilty and dominance of high-angle faults in the region, these zones are linear and typically are occupied by drainages. These drainages are periodically scoured and cleaned by debris flows and other shallow landslides that originate in the fault-weakened rocks. Commonly these lineaments cross one or more ridges, and some parallel ridges, where they capture tributaries. Some of the faults we located using APs offset bedrock contacts and coincide with anomalously oriented foliations (as mapped by previous workers in the adjacent rocks).

Acknowledgments

Special thanks go to the U.S.Geological Survey STATEMAP Program for financial support (grant No.1434-94-A-1258). Thanks to Pat Pringle (DGER) and Bob Miller (San Jose State University) for mapping with us in the field; to Miller, Ralph Haugerud (USGS), and Rowland Tabor (USGS) for many stimulating Twisp quadrangle discussions; to Jim Whipple and Mike Zientek of the USGS for providing and barging a truck up to Stehekin for our field use; and to Phil Campbell and his associates of the North Cascades National Park (Lake Chelan National Recreation Area) at Stehekin for friendly logistical support. Thanks also to Brian Kriens (California State Univ., Dominguez Hills), Hugh Hurlow (Univ. of Washington), Ralph Dawes (formerly Univ. of Washington), Miller, and Haugerud for early reviews of the map. Very helpful unpublished mapping was provided by Linda Nicholson and Miller of San Jose State University, Art Ford and Tabor of the USGS, and John Riedel of the U.S. Forest Service. Troy Rasbury (New York State University, Stony Brook) provided preliminary geochronologic data and stimulating discussions. Thanks to Kitty Reed for editing the map and manuscript, Eric Schuster for a map edit, Hank Schasse and Josh Logan for a text edit, Connie Manson and Rebecca Christie for assistance with references, Heidi Thomsen for clerical support, and Keith Ikerd and Carl Harris for cartographic support on the figures, correlation diagram, and explanation. We are grateful to Tabor and Ford of the USGS and John Simmons of the USFS (Wenatchee National Forest) for providing aerial photographs.

GEOLOGIC SETTING

The west half of the Twisp 1:100,000-scale quadrangle (hereafter the Twisp quadrangle or study area) contains two distinct geologic provinces, referred herein as the Skagit Crystalline Core (CC) and the Methow basin (Fig. 6). These provinces are separated along the Late Cretaceous to Eocene Ross Lake Fault Zone (RLFZ). In

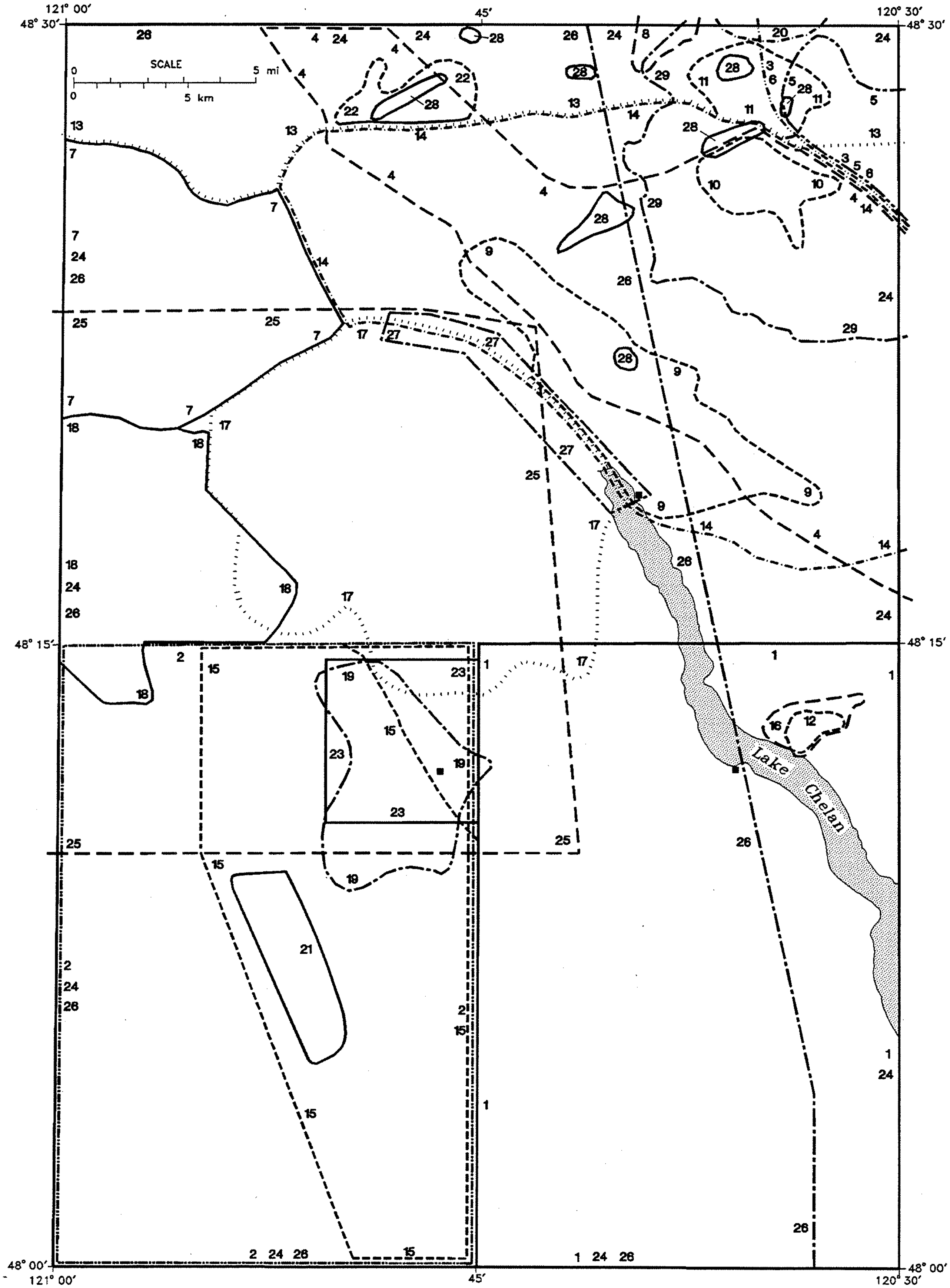
121° 00′
45′
120° 30′
48° 30′
48° 15′
48° 00′
SCALE
0
5 mi
0
5 km
Lake Chelan

Figure 2. (Facing page) Sources of geologic map data, west half of the Twisp 1:100,000-scale quadrangle.

1. Cater and Wright, 1967, 1:62,500
2. Cater and Crowder, 1967, 1:62,500
3. McGroder and others, 1990; Waitt, 1972, 1:100,000
4. Miller, 1987, 1:100,000, 1:24,000
5. DiLeonardo, 1990, 1:100,000
6. Barksdale, 1975, 1:125,000
7. Tabor, 1961, 1:100,000
8. V. F. Hollister*, 1:24,000
9. Nicholson, 1991, 1:24,000
10. V. F. Hollister*, 1:24,000
11. V. F. Hollister*, 1:24,000
12. V. F. Hollister*, 1:24,000
13. Misch, 1966, 1:250,000
14. Adams, 1961, 1:50,000
15. Crowder, 1959, 1:62,500
16. Webb, 1957, 1:24,000**
17. Libby, 1964, 1:24,000**
18. Grant, 1966, 1:50,000**
19. DuBois, 1953, 1:24,000**
20. Stull, 1969, 1:100,000**
21. Morrison, 1954, 1:100,000**
22. Hoppe, 1984, 1:24,000
23. Hurban, 1991, 1:24,000
24. R. W. Tabor (U.S. Geological Survey [USGS], preliminary compilation of the Twisp 1:100,000 quadrangle, written commun., 1994), 1:100,000
25. A. B. Ford (USGS, unpub. mapping, written commun., 1994), 1:100,000
26. R. W. Tabor (USGS, unpub. surficial geologic mapping using aerial photographs, written commun., 1994), 1:100,000
27. J. Riedel (U.S. Forest Service, unpub. surficial geologic mapping of the lower Stehekin valley, written commun., 1994), 1:24,000
28. R. B. Miller (San Jose State University, unpub. geologic mapping, written commun., 1994), 1:24,000
29. Grant, 1982, 1:100,000

* mineral exploration studies; archived at DGER

** scale approximate

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the Twisp quadrangle the RLFZ includes the Twisp Valley and North Creek faults and the Gabriel Peak Tectonic Belt (GPTB)(Plate 1). Strain was transferred to the GPTB portion of the RLFZ in the Late Cretaceous(?) to Eocene, after intrusion of the Black Peak batholith (90 Ma); transfer of strain is evidenced by transtensional ductile fabrics in the Paleocene Oval Peak batholith (65 Ma)(Miller and Bowring, 1990).

Cretaceous to Tertiary Orogeny

Generally, the CC consists of a heterogenous assemblage of complexly deformed, medium- to high-grade greenstone, ultramafite, phyllite, schist, gneiss, and igneous rock of several geologic ages. The common element linking the diverse rock packages in the CC is a mid- to Late Cretaceous to Tertiary orogenic event. Orogeny is characterized by Barrovian metamorphism, tectonism of several deformational episodes, and pre-, syn-, and late-orogenic calc-alkaline plutonism. U-Pb ages of syn- to post-metamorphic plutons indicate that metamorphism took place from approximately 95 to 45 Ma (Mattinson, 1972; Haugerud and others, 1991; Miller and others, 1993a), locally extending into the Eocene (Haugerud and others, 1991). Metamorphism is dominantly characterized by amphibolite-facies conditions, culminating in high temperatures and pressures (700°C and 8-9 kb; e.g., Whitney, 1992a) in and around the highest grade, migmatitic portions of the Skagit Gneiss.

Metamorphic grade in the CC generally increases to the southeast, as evidenced by the increasing recrystallization and development of migmatites in the "Marblemount metaplutonic belt" (Fig. 6B, unit 3b). The gradient is part of a regional increase in this belt from the chlorite zone in the Cascade River area to the sillimanite-kyanite zones of the amphibolite facies in the Twisp quadrangle (Misch, 1966; Dragovich and others, 1989; Brown and others, 1994)(see Cascade River, west side of Fig. 6B). This thermal gradient is also characterized by increasing metamorphic pressures, from about 3 kb in the Cascade River area to 9 kb in the quadrangle. Metamorphic grade also increases from greenschist to amphibolite facies in a northeasterly direction over a few kilometers from the Cascade River area to the region occupied by the Skagit Gneiss (e.g., Dragovich, 1989; Whitney, 1992a; Brown and others, 1994).

The loading mechanism that produced the high-grade metamorphism in the CC is controversial. Brown and Walker (1993) and Miller and others (1993a), using geochronology, timing of metamorphic index minerals (e.g., andalusite replaced by kyanite), and metamorphic patterns and field relations, contend that the mid-Cretaceous plutons intruded to shallow levels (3-5 kb) and were loaded by voluminous later Cretaceous and locally early Tertiary plutons invading the CC[1]. Conversely, McGroder (1991, 1989) and Whitney and McGroder (1989), on the basis of their observations in the Methow basin of field relations and high-pressure metamorphism and their regional palinspastic reconstructions, contend that the CC was loaded by thrust sheets mapped in the adjacent Northwest Cas-

1 The deep-seated, syn-metamorphic, commonly recrystallized nature of Late Cretaceous and some early Tertiary plutons appears to contradict observations made by Cater (1982) that the plutonic fabrics are largely unrecrystallized and that pluton fabrics can be largely attributed to protoclasis (deformation during pluton emplacement).

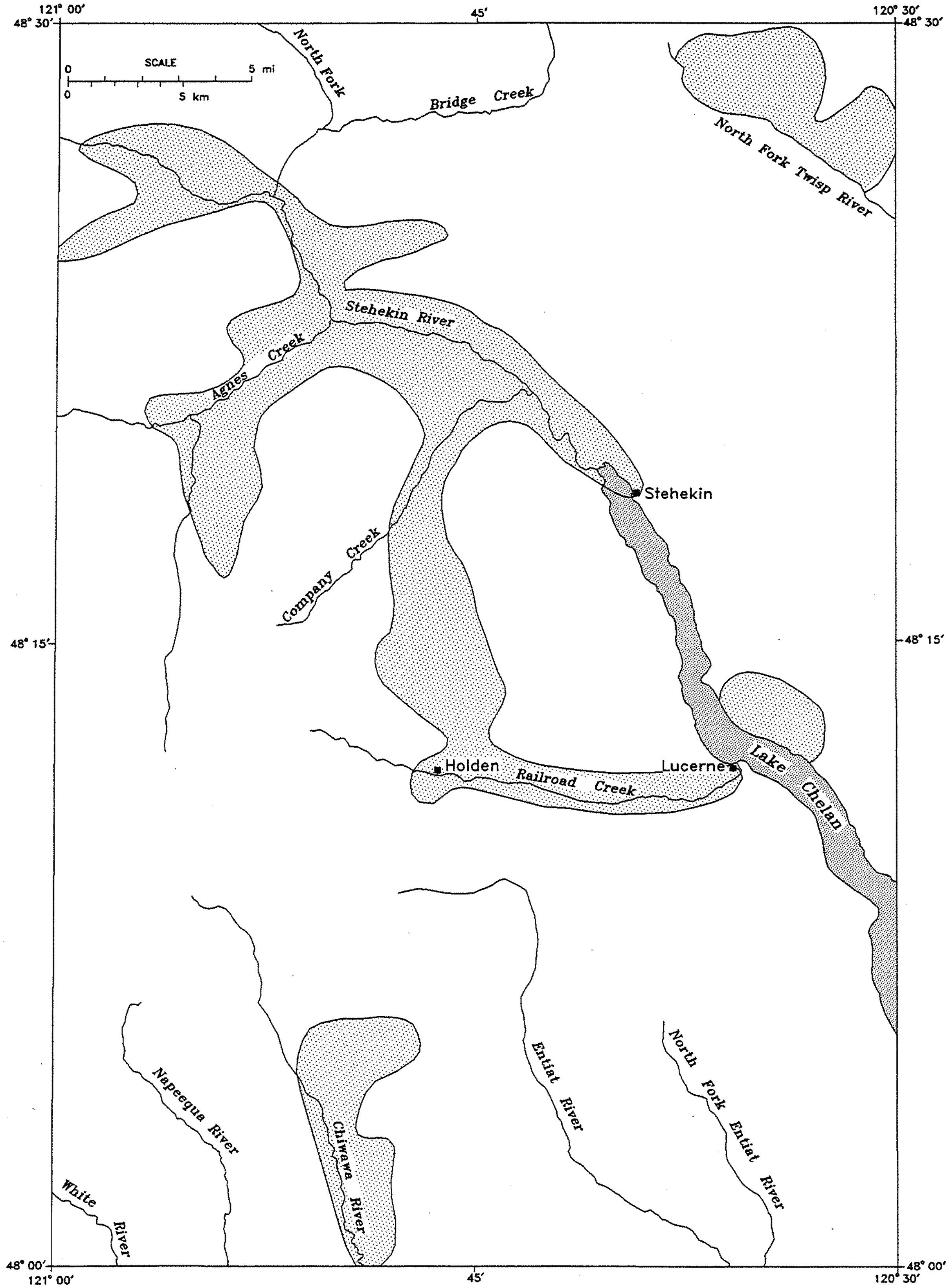


Figure 3. Areas (shaded) in the west half of the Twisp quadrangle that were remapped by the authors.

cade System and Methow terrane (also see Brandon and Cowan, 1985; Brandon and others, 1988; McGroder and Miller, 1989).

The CC is divided along the Entiat fault into the (1) Wenatchee block (Fig. 6A) where radiometric cooling ages marking the approximate cessation of metamorphism are largely mid- to Late Cretaceous, and (2)

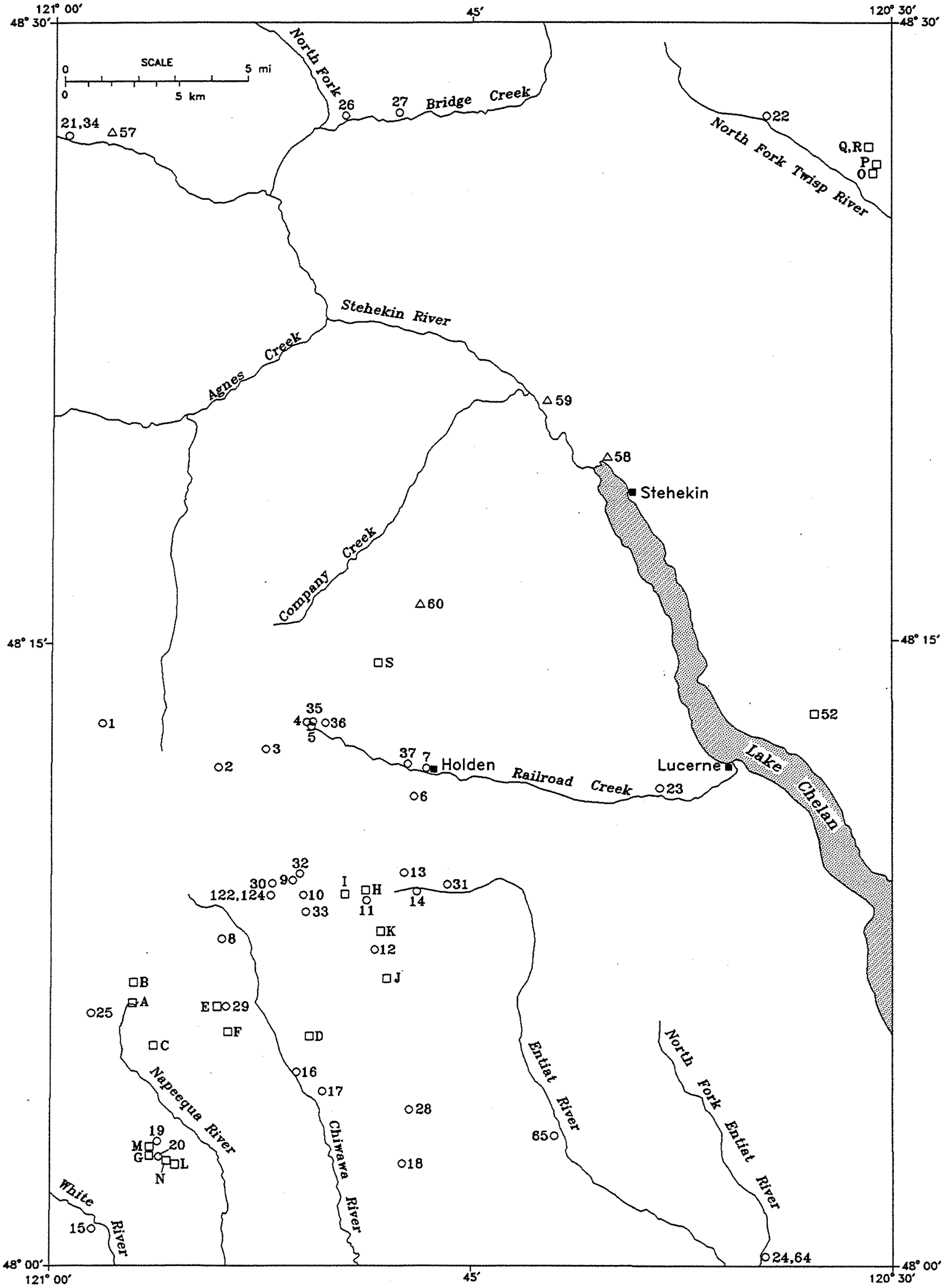


Figure 4. Locations of many of the geochronologic and geochemical data cited in the appendices. (See Appendices 1 [letters] and 2 [numbers] for data associated with locations). Some geochronologic data provided in Appendix 2 were not located by the previous workers and are thus not shown on this map or are from adjacent areas. Squares, geochemical analyses (Appendix 1); circles, geochronologic data (Appendix 2); triangles, geochronologic data, this study (Appendix 3).

PROTOLITH AGE KNOWN? — NO → **AGE OF METAMORPHISM, DEFORMATION, INTRUSION, OR ONLAP KNOWN?** — NO → **Assign "best guess" age.**

PROTOLITH AGE KNOWN? — **YES** →

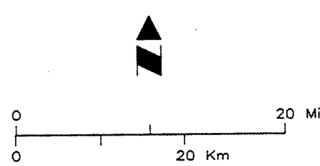
Assign protolith age based on:
(1) radiometric age data,
(2) paleontologic evidence, or
(3) stratigraphic position.

AGE OF METAMORPHISM, DEFORMATION, INTRUSION, OR ONLAP KNOWN? — **YES** →

Assign best estimate of protolith age as "pre" age of:
(1) oldest known metamorphism or deformation,
(2) oldest known intrusion by intrusive igneous rocks, or
(3) onlap of unmetamorphosed sedimentary rocks,
WHICHEVER IS OLDEST.

Figure 5. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age may be assigned by correlation with other geologic units. The unit description includes information on how the unit's age was determined.

Figure 6. (Facing page) A, location of the major faults surrounding the Crystalline Core (CC) and the Chelan and Wenatchee blocks of the CC. (Blocks are defined by uplift ages; see Fig. 7.)Box, western half of the Twisp 1:100,000-scale quadrangle. **B,** major rock units in the Chelan block (see A) of the CC (modified from Haugerud and others, 1991)(This schematic differs slightly from our compilation, Plate 1.) . Note the location of Marblemount (city) and the Cascade River area (mentioned in the text). Recent work in this area has direct bearing on understanding the geologic history of the study area; see, for example, Brown and others (1991). See Eocene strata (in A) fpr unit 10 locations.. C, Major tectonostratigraphic terranes in the CC. Box, western half of the Twisp 1:100,000-scale quadrangle.



GEOLOGIC UNITS

13 Volcanic rocks of the Cascade arc (Neogene)

12 Plutons of the Cascade arc (Miocene to early Oligocene)

11 Middle Eocene plutons

10 Eocene continental strata—Mostly arkosic sandstones and siltstones; includes some volcanic rocks

Rocks of earliest Tertiary and Late Cretaceous orogeny

9 Earliest Tertiary and latest Cretaceous plutons (75–50 Ma)

8 Mid-Cretaceous plutons (100–85 Ma)

7 Plutons of unknown age – May be pre-Cretaceous in part

6 Skagit Gneiss Complex (Early Tertiary and Late Cretaceous) – Locally, divided into:

6a Mostly orthogneiss – Locally, divided into orthogneiss of Custer Ridge and orthogneiss of The Needles

6b Banded gneiss – Paragneiss and abundant sills of orthogneiss. Supracrustal component is mostly strata of Chelan Mountains terrane

6c Other rocks – Massive pegmatite north of the Eldorado orthogneiss. Complex of gabbro, troctolite, and norite at Skymo Lake

5 Chelan complex (1971) (Late Cretaceous?) Migmatitic gneiss;c – supracrustal component is mostly strata of Chelan Mountains terrane

Rocks of Pre-Late Cretaceous terranes

4 Swakane Biotite Gneiss – Protolith is Precambrian

3 Chelan Mountains terrane – Locally, divided into:

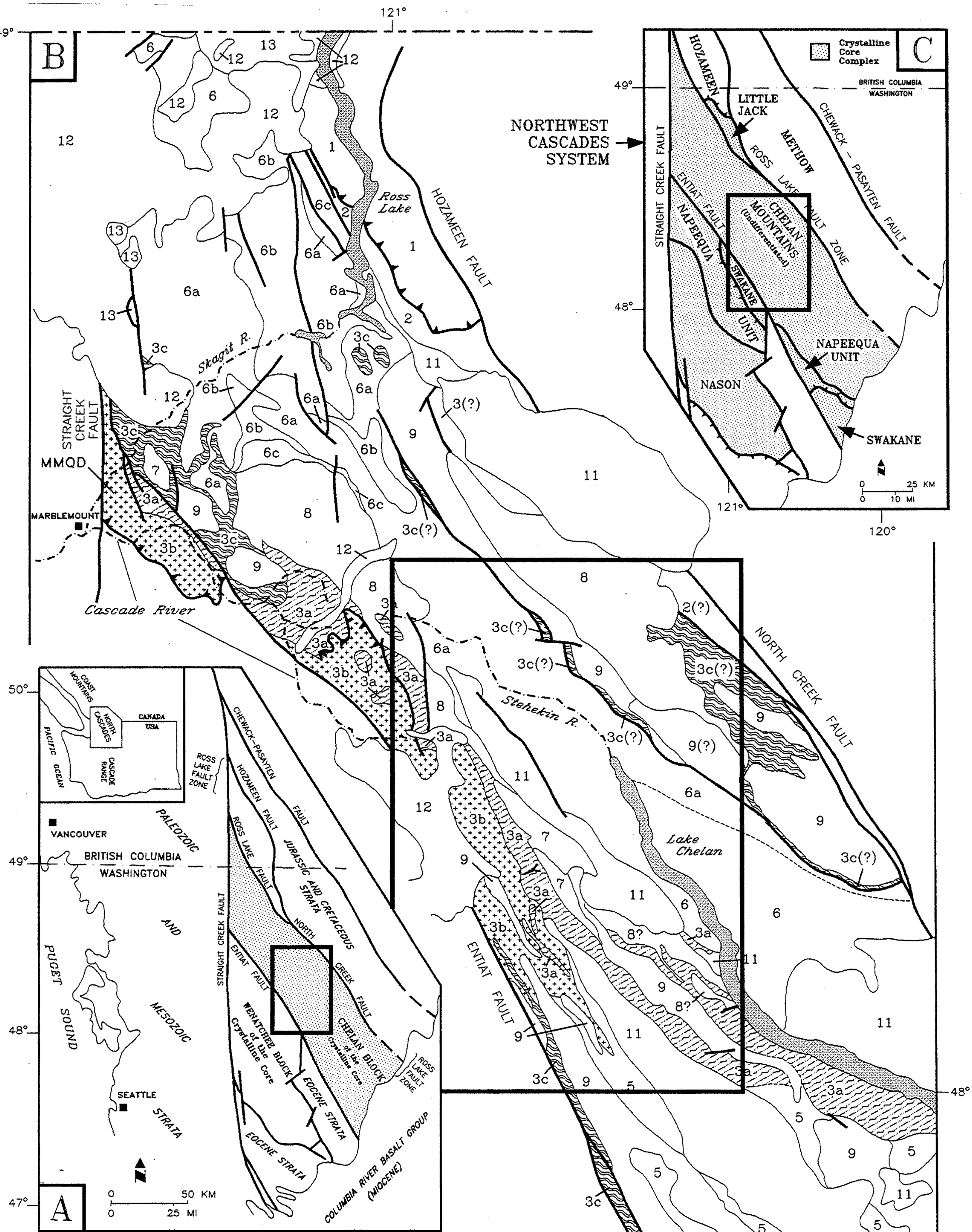
3a Cascade River unit (Late Triassic, in part) – Metamorphosed arkose, conglomerate, and pelite and associated metavolcanic rocks

3b Marblemount plutons (Late Triassic) – Quartz diorite to tonalite and derivative gneisses.

3c Napeequa unit (Permian to Triassic, in part) – Metamorphosed oceanic strata

2 Little Jack terrane (age unknown) – Metapelite and metasandstone with minor marble, meta-ribbon chert, and ultramafic rock

1 Hozameen Group (Mississippian to Jurassic) – Mostly basaltic greenstones, ribbon chert, and argillite


B
A
C
Crystalline Core Complex
NORTHWEST CASCADES SYSTEM
HOZAMEEN
LITTLE JACK
METHOW
ROSS LAKE FAULT ZONE
CHEWACK - PASAYTEN FAULT
STRAIGHT CREEK FAULT
ENTIAT FAULT
NAPEEQUA
CHELAN MOUNTAINS (Undifferentiated)
SWAKANE
UNIT
NAPEEQUA UNIT
NASON
SWAKANE
BRITISH COLUMBIA
WASHINGTON
Ross Lake
HOZAMEEN FAULT
Skagit R.
STRAIGHT CREEK FAULT
MMQD
MARBLEMOUNT
Cascade River
Stehekin R.
NORTH CREEK FAULT
Lake Chelan
ENTIAT FAULT
COAST MOUNTAINS
NORTH CASCADES
CANADA
USA
PACIFIC OCEAN
CASCADE RANGE
ROSS LAKE FAULT ZONE
VANCOUVER
PALEOZOIC AND MESOZOIC STRATA
PUGET SOUND
SEATTLE
CHEWACK-PASAYTEN FAULT
HOZAMEEN FAULT
ROSS LAKE FAULT
JURASSIC AND CRETACEOUS STRATA
NORTH CREEK FAULT
WENATCHEE BLOCK of the Crystalline Core
CHELAN BLOCK of the Crystalline Core
EOCENE STRATA
COLUMBIA RIVER BASALT GROUP (MIOCENE)
0 50 KM
0 25 MI
0 25 KM
0 10 MI
49°
48°
47°
50°
123°
122°
121°
120°
120° 30′

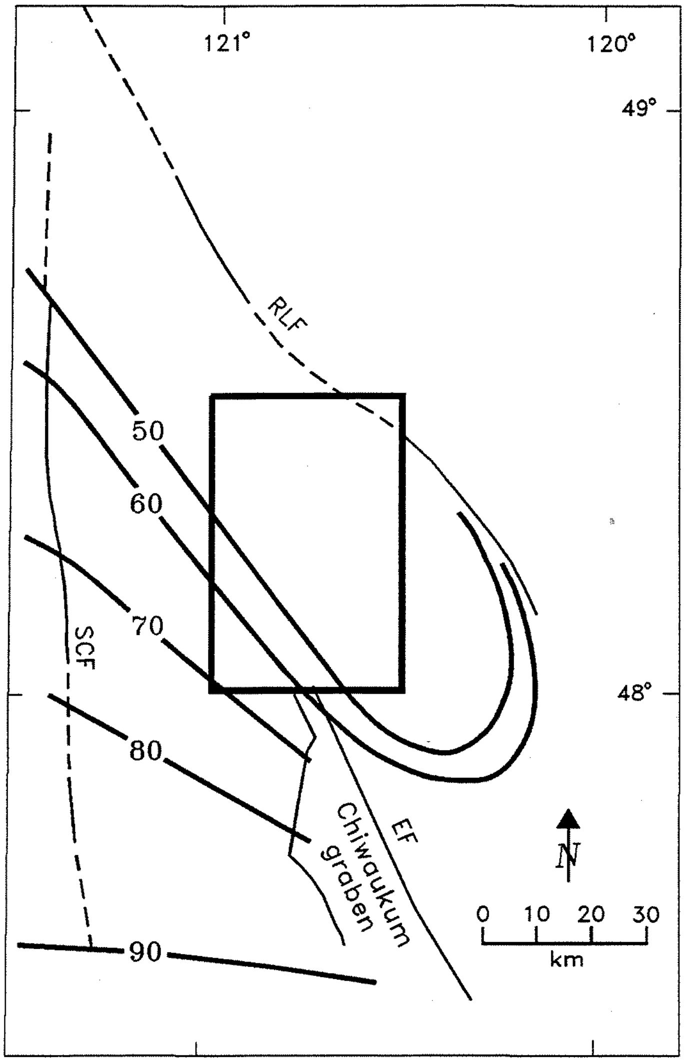


Figure 7. Contoured biotite K-Ar cooling ages (Ma) in the Crystalline Core (modified from Brown and Talbot, 1989). Box, study area; SCF, Straight Creek fault; RLF, Ross Lake fault; EF, Entiat fault. The Wenatchee block of the Crystalline Core (CC, Fig. 6) was uplifted largely in the mid- to Late Cretaceous, indicating metamorphism and uplift in rapid succession. The Chelan block of the CC (Fig. 6) was uplifted largely in the Eocene, indicating a more prolonged metamorphic and ductile deformational episode. For example, see Haugerud and others (1991).

the Chelan block, where uplift cooling ages are largely Eocene (Haugerud and others, 1991; Brown and Talbot, 1989; Figure 7, below; Appendix 2).

Several generations of Cretaceous to Tertiary ductile and largely Tertiary brittle deformations are recognized in the CC. Even though deformation is diachronous and complex, a simplified deformational sequence can be generalized as follows. The earliest recognized deformation (D1) in the CC is apparently a moderate-strain flattening fabric. D1 is found in isolated domains (not overprinted by later ductile fabrics) and is probably related to pure shear or contraction during CC metamorphism (e.g., Dragovich, 1989; Hurban, 1991; McShane, 1991, 1992). The most widely recognized deformation (D2) in the CC is recorded in the rocks as subhorizontal northwest-trending stretching lineations along steep mylonitic foliations, many of which are associated with right-lateral kinematic indicators (e.g., Brown and Talbot, 1989). D2 is locally transpressional, resulting in localized northeast-directed reverse-slip contractional mylonitic zones (Hurlow, 1992, 1991; Dawes, 1993a). In the Chelan Mountains area (Fig. 6C), D2 conjugate foliations trend *northeast*, are shallow dipping and accommodate strain along the en-echelon northwest-trending Ross Lake and Gabriel Peak D2 shear zones (Miller and Bowring, 1990). D2 is syn- to late metamorphic and lasted from about the mid- to Late Cretaceous to (locally) the Tertiary. For example, in the Chelan block (Fig. 6A), where the rocks were buried longer, Haugerud and others (1991) define a north-northwest-trending, approximately 8-km-wide zone of D2 mylonites affecting the Tertiary-Cretaceous Skagit Gneiss, Eocene (43 Ma) granitic dikes, and the Eocene Duncan Hill and Railroad Creek plutons. Preliminary U-Pb Eocene ages of the Skagit orthogneiss (this study) suggest that ductile deformation may have been more widespread than described by Haugerud and others (1991). Elsewhere in the Chelan block of the CC (Fig. 6A), brittle deformation (D3) commenced as rocks were uplifted and cooled in the Tertiary. In the Wenatchee block, southwest of the Entiat fault (Fig. 6A), Late Cretaceous uplift ages and development of D2 metamorphic fabrics in the mid-Cretaceous (Brown and Talbot, 1989; Walker and Brown, 1991) indicate a less protracted metamorphic history. Both dextral strike-slip and dip-slip offset along the Straight Creek, Leavenworth, and Entiat faults and other northwest-trending faults in the Eocene record the passage of the CC into a brittle regime; filling of the Chiwaukum graben with the Eocene Chumstick Formation records denudation of the CC and opening of pull-apart basins adjacent to the CC. Northwest-trending open to tight folding of the layered metamorphic rocks in the CC and formation of northeast-trending brittle faults with small but significant left-lateral offset (conjugate to the northwest-trending right-lateral faults) record the onset of brittle wrench tectonics in the CC (Dragovich and others, unpub. data), akin to (1) *ductile* wrench style (step-over) structures in the Chelan divide area (Miller, 1994), and (2) brittle wrench tectonics in strike-slip regimes elsewhere (e.g., Aydin and Nur, 1985; Wilcox and others, 1973). Large folds of the rocks of the Napeequa River area (east of the Chiwawa River; Plate 1) (1) fold D2 fabrics, (2) are late to probably post-metamorphic in age, and (3) may be related to transpression during D3 faulting.

Plutonism in the CC can generally be divided into Triassic, mid-Cretaceous, Late Cretaceous to Paleocene, and Eocene and younger episodes on the basis of depth of emplacement and other characteristics (e.g., Mattinson, 1972; Miller and others, 1989; Haugerud and others, 1991). Triassic plutons of the Marblemount belt and the related Cascade River unit volcanic arc material (Fig. 6B) were probably accreted to North America prior to CC metamorphism. Mid-Cretaceous to locally Tertiary plutons are syn- to late-metamorphic in age. (See Dawes, 1991a, b, c, 1993a, b, for the petrogenesis of Cretaceous plutons in the southern part of the study area.) Eocene to Miocene plutons in the CC record (1) a transition from localized D2 ductile deformation to widespread D3 brittle deformation and (2) cessation of localized Chelan block metamorphism. The directionless Miocene Cloudy Pass pluton and Eocene Golden Horn batholith were intruded to shallow (epizonal) levels and cross-cut the Entiat and Ross Lake faults, respectively. CC Miocene intrusive rocks are the roots of the first Cascade arc volcanoes and record establishment of a new plutonic regime across the North Cascades.

Terranes and Depositional Environments

The country-rock protoliths of the CC have been divided into tectonostratigraphic terranes by Tabor and others (1987b, 1989; Fig. 6C). These terranes contain distinct country-rock protolith assemblages of presumably similar age and depositional environment. In the study area the CC is represented by the Chelan Mountains (CMt) and Swakane terranes (Fig. 6C). The most extensive of these terranes is the Chelan Mountains terrane, which has been subdivided into the Cascade River unit (CRu) and Napeequa unit (Nu). The CRu protoliths consist of arc-affinity clastics, including a distinctive granitoid clast conglomerate, basic, intermediate, to felsic volcanic rocks, and rare pelites, carbonates, marls, marbles, and volcanogenic massive sulfide deposits (Dragovich and Derkey, 1994)(Fig. 6B, C). The oceanic Napeequa unit consists of quartz mica schist and impure quartzite and fine-grained amphibolite, reflecting its chert- and basalt-rich protoliths, respectively. It also includes greenschist, quartz-rich phyllite, very rare aluminous and amphibole-bearing mica schist, metagabbro, and marble (Cater and Crowder, 1967; Misch, 1966; Tabor, 1961; Fugro Northwest, Inc., 1979; Tabor and others, 1987b). Ultramafic pods and lenses, probably representing tectonically dismembered peridotitic mantle material, are scattered throughout the Napeequa unit. Metabasite geochemistry indicates MORB or oceanic island basalt protoliths (Miller and others, 1993b; Babcock and Misch, 1988).

The tabulation below lists the once-disparate and geographically localized supracrustal rock packages included in the CRu and Nu of the CMt. Northwest of the study area the Cascade River Schist is divided into both the Nu and CRu. The southwestmost part of the younger rocks of the Holden area is included in the Nu.

Supracrustal arc protolith packages included in the Cascade River unit

- Cascade River Schist
- Holden Assemblage
- younger gneissic rocks of the Holden area
- Spider Mountain Schist

Supracrustal oceanic-crust protolith rock packages included in the Napeequa unit

- Twisp Valley Schist
- Rainbow Lake Schist
- rocks of the Napeequa River area

Despite intense deformation, the intimate layering and lack of repetition of rock types (and locally metasedimentary fining trends) suggest that the CRu is largely a single depositional sequence proximal to a volcanic arc (Dragovich, 1989; Cary, 1990; Dragovich and Derkey, 1994; Miller and others, 1994). In the Cascade River region to the northwest of the study area (Fig. 6B), the 220 Ma Marblemount Meta-Quartz Diorite (MMQD) of Misch (1966) has about the same age as a metatuff bed in the adjacent CRu (Cary, 1990; Dragovich and others, 1989). This relation, along with interpreted intrusive relations, suggest the MMQD is the coeval sub-arc plutonic complex of the supra-arc sediments and volcanic materials of the CRu (Dragovich and others, 1989; Cary, 1990). Alternatively, Tabor and others (1987b) suggest that the MMQD-CRu contact is unconformable and represents intrusion, uplift, and deposition of arc-affinity materials in rapid succession on the MMQD basement. In the study area the Dumbell Mountain plutons correlate with the MMQD (Mattinson, 1972) and together largely form the 220 Ma Marblemount plutonic belt (Fig. 6B). The Dumbell Mountain plutons are adjacent to the CRu (Tabor and others, 1989; Miller and others, 1994) and appear to be intrusive into the CRu (Cater, 1982). Miller and others (1994) concur with this observation and note that xenoliths of amphibolite exceeding 2 m in diameter occur in these plutons and that stringers of Dumbell Mountain plutons intrude the amphibolitic wall rock.

The CRu and Nu were juxtaposed prior to metamorphism. The CRu volcanic arc was either (1) formed unconformably on the oceanic Nu (Tabor and others, 1989) or (2) overthrust by the Nu (Dragovich and others, 1989; Brown and others, 1994), or (3) perhaps both (Dragovich and Derkey, 1994). Contact relations between the CRu and Nu have yet to be clearly defined. However, along the east edge of the Coast Mountains (in British Columbia) Upper Triassic CRu-like Cadwallader Group conglomerates are in fault contact with the Nu-like Bridge River Complex (Rusmore and Woodsworth, 1991; Rusmore and others, 1988; Tabor and others, 1989), suggesting, at least locally, faulted contacts between the CRu and Nu in the CC.

The Virginian Ridge Formation of the Methow terrane in the northeast corner of the Twisp quadrangle is composed of argillite, sandstone, and chert-pebble conglomerate. Paleocurrent measurements indicate a western source, presumably the Permian (or older) to Jurassic Hozameen Group (Tennyson and Cole, 1978; Trexler, 1985) or possibly the Nu of the Chelan Mountains terrane, which is lithologically similar to the Hozameen Group. Trexler (1985) described and named the Slate Peak Member of the Virginian Ridge Formation; it is composed mostly of argillite with minor sandstone and chert-pebble conglomerate, which he inferred to be shallow-marine and deltaic deposits. He also named the overlying Devils Pass Member, with abundant chert-pebble conglomerate, which he inferred to be alluvial fan and delta deposits. In early Late Cretaceous time supracrustal rocks must have emerged along the Ross Lake Fault Zone (RLFZ) and Hozameen fault, the fault motion elevating chert-rich source areas such as the Hozameen Group or the CC (Nu) above base level. Erosion of these rocks produced the chert-rich detritus in the Methow section (e.g., Tennyson and Cole, 1978), possibly in a pull-apart basin setting involving the RLFZ (Trexler and Bourgeois, 1981 (Fig. 6).

The nature of the "contact" between the CC and the Methow across the RLFZ is controversial. There are two prevalent hypotheses: (1) Kriens and Wernicke (1990) suggest there is little offset along the RLFZ and that the Methow-CC transition represents a largely intact crustal section from the subarc plutonic welt of the CC to backarc Methow basin (they correlate many of the CC supracrustal protoliths with unmetamorphosed Methow rocks), and (2) Haugerud (1985) and Miller and others (1994) indicate that significant offset exists along the terrane-bounding RLFZ. This fault system underwent pre-90 Ma slip of unknown sense (Misch, 1966; Miller, 1994), latest Cretaceous and Paleocene dextral strike slip and reverse slip (Miller and Bowring, 1990), and Eocene dextral-normal slip (east-side-down)(Haugerud, 1985; Miller and Bowring, 1990; Coleman and Parrish, 1991).

Cabin Creek Fault System, Eocene Ductile Deformation, and the Thrust Contact of the Eldorado Orthogneiss

We herein informally name the north-trending Cabin Creek fault system (Plate 1) evident on aerial photographs and observed in the field in the northern half of the study area. This fault system is an extension of faults mapped by Cater and Crowder (1967) in the Holden quadrangle east of Phelps Creek, along Big Creek and Holden Creek, and perhaps as far south as Rock Creek. These faults have (1) apparent right-lateral displacement of a few kilometers, and (2) probable, but an unknown amount of, dip-slip displacement. These fault(s) are en echelon with, and may be splays of, the Eocene Entiat fault. For example, Cater (1982) describes the westernmost mass of the Seven Fingered Jack pluton on the ridge east of Phelps Creek as "strongly cataclastically sheared *Entiat fault dislocation zone* [emphasis added]." In the northern end of the study area, the fault is projected along Cabin Creek, turns northwest around the Agnes Creek-Stehekin River juncture and continues (1) directly northeast of the Stehekin River, and(or) (2) joins the prominent cataclastic shear zone along the northeast side of the Railroad Creek pluton. In the northwest corner of the study area these faults appear to be kinematically tied to prominent faults observed along Park Creek, which join north-northwest-trending faults mapped along Thunder Creek in the Robinson Mtn. quadrangle (R. A. Haugerud, USGS, written and oral commun., 1994). In the Mount Baker quadrangle (Tabor and others, 1994), north-northeast-trending faults around Diablo Lake may be kinematically linked to the Thunder Creek–Cabin Creek faults.

The Cabin Creek faults are roughly spatially coincident with the middle Eocene, north-northwest-trending ductile deformation zone of Haugerud and others (1991); perhaps (1) uplift and cooler crustal conditions led to the commencement of brittle conditions and faulting in this zone, and/or (2) faults locally mark the western boundary of this ductile deformation zone, and later dip-slip along these faults juxtaposed deeper middle Eocene ductile shear zones on the east against cooler rocks unaffected by this deformation on the west. A preliminary U-Pb age of about 54 Ma for a ductilely nondeformed massive leucodike west of the Cabin Creek fault (see below; site 57, Fig. 4; Appendix 3) suggests that Eocene ductile deformation occurred east of the leucodike and supports (2) above. (See Haugerud and others, 1991, and Babcock and Misch, 1988, for a description of similar *ductilely deformed* 43 Ma leucodikes in the Skagit Gneiss.) Furthermore, preliminary U-Pb dates of about 50 Ma for the ductilely deformed Skagit Gneiss (see Stehekin orthogneiss of Nicholson, below; sites 58 and 59, Fig. 4) suggest that the Eocene ductile deformation may be extended farther northeast, probably involving most of the rocks between the Cabin Creek fault system and the RLFZ; major ductile deformation occurred along the RLFZ, including the Gabriel Peak Tectonic Belt, in the mid-Eocene. (See Miller and Bowring, 1990; R. B. Miller, San Jose State Univ., oral commun., 1995.)

Our mapping indicates that the Eldorado Orthogneiss is thrust over the Skagit Gneiss in the northwest corner of the study area. (See site 57, Fig. 4, and Appendix 3; Plate 1. Also see Misch, 1966, for a discussion of thrusting of the Eldorado Orthogneiss over the Skagit Gneiss, and McShane, 1992, for a discussion of Skagit Gneiss-Eldorado Orthogneiss mid-Cretaceous intrusive contacts to the northwest of the study area.) Post early-Eocene thrusting of the Eldorado Orthogneiss over the Skagit Gneiss is suggested by our preliminary age of 54 Ma for a leucodike (Appendix 3) intruding the Skagit Gneiss but cut by thrust-parallel cataclastic fabrics directly below the thrust contact. The thrust apparently merges with, or is offset by, the high-angle Cabin Creek fault(s) along Park Creek. Merging of the thrust and high-angle Cabin Creek fault(s) may indicate strike-slip duplexing or a low-angle step-over fault in the Cabin Creek fault system (e.g., Aydin and Nur, 1985; Wilcox and others, 1973).

DESCRIPTION OF MAP UNITS

Sedimentary and Volcanic Rocks and Deposits

Quaternary sedimentary deposits

Nonglacial deposits

Qls_i Incipient landslide (Holocene)—Large mass of bedrock extensively crevassed as a result of slight movement toward nearby free faces.

Qls_a Rock avalanche deposits (Holocene and Pleistocene)—Unstratified, unconsolidated, very poorly sorted deposits containing angular boulders, cobbles, and/or gravel; may include a sand, silt, and/or clay matrix; found below rocky cliffs where translational slab failures or rockfall topples (Varnes, 1958, 1978) are common.

Qls Mass-wasting deposits (Holocene and Pleistocene)—Unstratified, unconsolidated diamicton and very poorly sorted deposits of angular boulders, cobbles, and/or gravel in a sand, silt, and/or clay matrix largely originating as deep-seated failures (slump-earthflow, debris slump, rock slump; Varnes, 1958, 1978).

Qls_m Mass-wasting deposits, undivided (Holocene and Pleistocene)—Unstratified, unconsolidated landslide deposits that may include deposits of units Qta, Qaf, and/or Qls, as well as localized glacial deposits; generally occur on mid- to lower-slopes as mixtures of glacial and mass-wasting deposits.

Qta, t Talus deposits (Holocene and Pleistocene)—Unstratified and unconsolidated bouldery gravel to gravelly boulder diamicton formed below rocky escarpments. At higher altitudes the unit includes moraines, rock glaciers, and protalus ramparts. (Single letter label is applied to very small polygons.)

Qa Quaternary alluvium, undivided (Holocene and Pleistocene)—Stratified, unconsolidated deposits consisting of rounded boulders, gravel, sand, and (or) silt and clay on modern alluvial plains; locally contains glacial and mass-wasting deposits.

Qoa Older alluvium and alluvial terrace deposits (Holocene and Pleistocene)—Stratified, unconsolidated deposits consisting of rounded gravel, sand, silt and clay forming erosional or constructive (overbank) terraces bordering the wider river valleys.

Qaf, af Alluvial fan deposits (Holocene and Pleistocene)—Unconsolidated diamicton (boulders, gravel, sand, silt, and clay) locally modified or sorted by alluvial processes and originating as periodic debris flow-debris avalanches or debris slides (Varnes, 1958, 1978) during intense or long-lived saturating precipitation events. (These debris flows or avalanches may transform to hyperconcentrated floods in transit.) (Double letter label is applied to very small polygons.)

Glacial deposits

Qad Alpine glacial drift, undivided (Holocene and Pleistocene)—Unstratified, unconsolidated diamicton, largely consisting of loose, commonly rounded boulders, gravel, and sand with some silt and clay deposited largely during ablation of alpine glaciers during the last Fraser glaciation. (At higher elevations this unit may include Holocene glacial re-advance deposits). The unit locally contains till, thinly laminated clay, silt, and sand of glaciolacustrine origin, and poorly stratified to moderately stratified outwash clay, silt, and gravel. The unit blankets many valley floors and lower valley walls. (See Waitt, 1972, for a discussion of Methow Valley–Twisp River area glaciation.)

Pyroclastic deposits

Qvp$_g$ Dacite pumice of the Glacier Peak volcano (Pleistocene)—Yellow, white, and gray pumice lapilli consisting of rare crystals of green hornblende, hypersthene, plagioclase, and opaque minerals in a vesicular, clear glass matrix. Deposits are a few feet thick, locally thicker, and sorted and crossbedded where reworked by streams (Crowder and others, 1966). The pumice is associated with a major Glacier Peak eruption 11,250 years ago (Crowder and others, 1966).

Tertiary sedimentary rocks

Ec2 Chumstick Formation (middle Eocene)—White to gray micaceous feldspathic sandstone with varied but lesser amounts of interbedded pebbly sandstone, conglomerate, minor shale, and rare siliceous tuff; sandstones generally massive with local crossbeds. Coal a few inches thick is rare (Cater and Crowder, 1967; Gresens and others, 1981a,b; Gresens, 1982a, b; Whetten and Laravie, 1976). Formation is a maximum of about 11 km thick (Evans, 1994).

The Chumstick Formation of dominantly fluvial origin crops out in the Chiwaukum graben, which is bounded to the east by the Entiat fault and to the west by the Leavenworth fault (Plate 1). The northernmost portion of the graben extends into the southwestern portion of the study area; the Chumstick occurs along Giant Creek in the Chiwawa drainage, and a small body is found on the ridge east of Trinity.

Zircon fission-track ages from tuffs and detrital clasts are about 45 Ma and range from 56 to 41 Ma (Tabor and others, 1982; Gresens and others, 1981a,b; Gresens, 1982a,b; Evans, 1988; McClincy, 1986)(Appendix 2). Palynomorphs indicate a late Eocene age (Newman, 1971, p. 397-398; 1975, p. 158). (See Evans, 1994, for a current synopsis of geologic age and setting.)

Mesozoic sedimentary rocks

Km2,
Kcg2 Virginian Ridge Formation, Pasayten Group (Cretaceous)—Black mudstone, siltstone, and lenticular to tabular beds of chert-lithic sandstone and chert-pebble conglomerate; minor lithofeldspathic sandstone near the top of the unit. The formation has been subdivided into two informal map units: Km2 which contains less than 40 percent conglomerate beds, and Kcg2, which contains more than 40 percent conglomerate beds (McGroder and others, 1990). Black mudstone and siltstone are the dominant lithologies in the Virginian Ridge Formation; they commonly display graded beds, ripple cross-laminations, convolute bedding, and plant fossils along partings. The fine-grained rocks are interbedded with, and commonly grade into, dark-gray, thin-bedded, fine- to medium-grained sandstone that is composed of subrounded to subangular grains of chert, plagioclase, quartz, and volcanic and sedimentary rocks. The chert-pebble conglomerates are composed of subrounded to subangular pebbles and cobbles of gray to black chert and subordinate sedimentary rocks in a sandy matrix of chert, quartzite, altered mafic volcanic rocks, feldspar, and quartz grains. Conglomerate beds are as much as 6 m thick (Barksdale, 1948, 1975; Pitard, 1958; Mauer, 1958; Tennyson, 1974; Tennyson and Cole, 1978; McGroder and others, 1990).

The Virginian Ridge Formation reaches a maximum thickness of more than 4,000 m near Cady Point to the north of this map area in the Robinson Mtn. quadrangle. It thins to the east as it interfingers with the Winthrop Sandstone in the Methow Valley (Barksdale, 1975).

Eastward-thinning and -fining trends, paleocurrent data, and the presence of chert pebbles probably derived from the Hozameen Group indicate ta western source for the clastics. Sedimentary structures suggest deposition in a fan delta or deltaic environment (Tennyson and Cole, 1978; Trexler, 1985).

Marine pelecypods, gastropods, and belemnites indicate a mid-to Late Cretaceous (Albian to Cenomanian) age (Barksdale, 1975; Trexler, 1985; M. F. McGroder and others, written commun. to Bonnie Bunning, 1989). However, a Late Cretaceous (Cenomanian-Coniacian) age for the Pasayten Group seems most likely (Miller and others, 1994) on the basis of (1) the time needed to develop a basin-wide unconformity that separates Pasayten Group rocks from underlying middle Albian and younger strata and (2) a probable Turonian fauna (W. P. Elder, USGS, written commun., 1993, to Miller and others, 1994) collected from the Pasayten Group. The unit cannot be younger than the overlying 87 Ma Midnight Peak Formation or the 88 Ma Fawn Peak or Pasayten plutons that intrude the Midnight Peak Formation (see Miller and others, 1994).

Low-Grade Metamorphic Rocks

KJmv$_n$ North Creek Volcanics (Cretaceous-Jurassic?)—Altered green andesitic breccias and massive flows and tuffs with minor arkosic to lithic sandstones and thinly interbedded minor siltstone, shale, and conglomerate. Breccias and flows contain hornblende (plagioclase phenocrysts locally present), but primary mineralogy has been largely 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. The volcanic and volcaniclastic rocks are interbedded with siltstone and shale (Miller and others, 1994; McGroder and others, 1990; Misch, 1966; DiLeonardo, 1990, 1991). Geochemical analyses of metavolcanic rocks (this study; Appendix 2) suggest a volcanic arc setting for the North Creek Volcanics.

In the study area, DiLeonardo (1990, 1991) divided this apparently homoclinally northeast-dipping unit into three informal members: (1) an upper member—andesitic tuff and volcanic lithic wackes; (2) a middle member—tuff breccia (flow breccia) and coarse-grained, matrix-supported breccia (lahars) in which crystal tuffs are locally abundant; these strata are interbedded with black shales; and (3) a lower member—crystal and lithic tuffs interbedded with porphyritic hornblende andesite (greenstone).

The North Creek Volcanics, which crop out east of the old mining town of Gilbert, are bounded by the Twisp River Fault Zone and the North Creek fault.

The age of the North Creek Volcanics is problematic. They are intruded by the Black Peak batholith (90 Ma). No fossil or radiometric age has been determined. The unit is given a Cretaceous and Jurassic age on the basis of Barksdale's (1975) and Kriens and Wernicke's (1990) correlations of the unit with the Methow terrane Newby Group, DiLeonardo's (1991) correlation of the unit with the Methow terrane Midnight Peak Formation (volcanic member), and its broad similarity with Cretaceous and Jurassic Methow terrane rocks (Miller and others, 1994). A pre-Cretaceous age assignment for this unit by Bunning (1990) seems untenable in light of recent correlations.

Intrusive Igneous Rocks

Petrographic and chemical data for intrusive rocks (including orthogneiss, below) by Ford and others (1988a) document the distinctly subalkalic and calcalkalic nature of both the plutonic and orthogneiss bodies in the Glacier Peak Wilderness (GPW). (See Ford and others, 1988b, and White and others, 1988, for magnetic susceptibility, density, and oxygen isotope data for rocks in the GPW.)

The term trondhjemite has been inconsistently applied to intrusive igneous and orthogneiss rock units in the study area. Trondhjemite is a quartz-plagioclase rock of low color index, essentially a leucocratic tonalite (>0.5 wt percent K_2O). For example, Miller (1987) applied the term to many of the orthogneiss bodies northeast of the Skagit Gneiss. Cater (1982) and Ford and others (1988a) applied the term tonalite to many of the plutonic bodies outside of Miller's study areas. Some of the rocks described as tonalitic in the study area are trondhjemites using the above definition. This distinction is important because Dawes (1991b), using geochemical analyses (major, trace, and rare earth elements and new Sr data combined with isotopic data available at the time), showed that Cretaceous plutons in the study area fall into two distinct groups: (1) a relatively silicic, largely *trondhjemitic* to granodioritic suite, and (2) a mafic to intermediate, predominantly *tonalitic* suite. The more silicic suite originated primarily as lower crustal melts of amphibolitic metagraywacke and (or) metavolcanic rocks, leaving a garnet-rich residuum, whereas the mafic to intermediate suite contains gabbroic to quartz dioritic rocks that probably originated as subduction-related, mantle-derived basaltic magmas (Dawes, 1991b).

Tertiary intrusive igneous rocks

Dikes, undivided (Miocene to Eocene)—Chiefly dark-colored aphanitic dacite, rhyodacite, spessartite, hornblende-quartz diabase or pawdite, porphyritic diabase, augite minette, and kersantite. Light-colored nonporphyritic granitoid dikes consist of biotite-quartz granite and granodiorite, hornblende-biotite granodiorite and quartz diorite, and minor alaskite. Most dikes are less than 50 m thick and are typically only meters thick, but a few dikes exceed 60 m thick (Cater, 1982).

Dikes occur sporadically throughout the study area; only a few representative dikes are shown from the many mapped in the Holden and Lucerne quadrangles (Cater and Crowder, 1967; Cater and Wright, 1967).

Although of diverse origins, most dikes appear to be Eocene to possibly Miocene in age. Radiometric ages from the Chelan quadrangle to the south indicate an Eocene age for much of the dike intrusion (Tabor and others, 1987a; Appendix 2). Dikes locally cross-cut Eocene rocks and are younger than metamorphism, which waned in the latest Cretaceous to Eocene in the study area. Some dikes are genetically related to nearby Eocene intrusive bodies. Few dikes cut the Miocene Cloudy Pass pluton; however, some diking may be attributed to Cloudy Pass plutonism (Cater, 1982). Dikes are commonly parallel to and intrude northeast-trending faults that are locally conjugate to the Eocene Entiat fault and similar northwest-trending faults in the area, suggesting an Eocene age of diking (Dragovich and others, unpub. data).

Tib Basaltic plugs and dikes at Chiwawa River and intrusive breccia at Klone Creek (Tertiary)—At Chiwawa River black aphanitic basaltic plugs and dikes containing bytownite phenocrysts in an intergranular groundmass with accessory magnetite, chlorophaeite, and apatite (Cater and Crowder, 1967); intrusive breccia at Klone Creek consisting of large and small blocks and lenses of various kinds of gneiss in a matrix of medium-grained hornblende-biotite granodiorite of uncertain affinities (Cater and Wright, 1967).

The age is uncertain, although dikes at Chiwawa River probably intrude the Eocene Chumstick Formation (Cater and Crowder, 1967) and appear to be related to other hypabyssal intrusive rocks assigned to the Eocene and Miocene.

$Migd_c$, Mig_c Cloudy Pass labradorite granodiorite (Miocene)—Light- to dark-gray labradorite tonalite to labradorite granodiorite (unit $Migd_c$) and labradorite granite (unit Mig_c). Average modal composition is granodiorite with local quartz diorite. The rocks are medium grained, hypidiomorphic granular, and massive, and, except locally, have few inclusions. Late orthoclase (1-30 percent) is interstitial or replaces other minerals (Cater, 1982; Sans, 1983; Ford and others, 1988a).

The pluton is discordant and contains a variety of subvolcanic features, including miarolitic cavities and a complex of chilled border rocks along its northeast contact. However, contacts are generally sharp, and host rocks are thermally metamorphosed but not commonly deformed or brecciated. The contact between the granodiorite and tonalite (unit $Migd_c$) and the granite (unit Mig_c) is gradational in most places. However, on the north flank of North Star Mountain, the tonalite/granite contact is a marble-cake mixture of the two rock types (Cater and Wright, 1967; Cater, 1982).

Cloudy Pass batholith and its satellitic intrusive breccias, plugs, and stocks are the youngest of the major intrusions in the study area (early Miocene). The batholith is being deroofed, and about 80 km^2 of it are either exposed or covered by thin surficial debris in the northern parts of the Glacier Peak and Holden quadrangles. Parts of the mass lie under a fairly thin cover of metamorphic roof rocks in the northwestern part of the quadrangle (see unit Mix, below). Northwest-trending satellitic plugs and intrusive breccias suggest that the pluton resides at shallow depths and may floor much of the country rock between Phelps Ridge and Agnes Creek (Cater, 1982). The part of the batholith in the Glacier Peak quadrangle has been described in detail by Tabor and Crowder (1969) and that part in the Holden quadrangle by Cater (1969). Grant (1966; 1969, p. 30-40), Tabor (1963), and Libby (1964) reported on the part cropping out north of these two quadrangles; Ford and others (1988a) provide additional petrographic data.

A Miocene age is indicated by three biotite K-Ar determinations (H. H. Thomas and others, USGS) that yielded ages of 20 ± 2 Ma, 22 ± 2.2 Ma, and 22.8 ± 0.9 Ma; two Pb-α zircon determinations (T. W. Stern, USGS) yielded ages of 20 ± 20 Ma and 30 ± 20 Ma (Tabor and Crowder, 1969).

$Mian_c$, $Mida_c$, $Mida_{c2}$ Cloudy Pass Pluton chilled border rocks (Miocene)—Intermixed labradorite-bytownite andesite and dacite porphyry or andesite porphyry (unit $Mian_c$), dacite porphyry or intrusive breccia (unit $Mida_c$), and dacite and labradorite-bytownite andesite porphyry breccia (unit $Mida_{c2}$). (See Cater and Wright, 1967, and Cater, 1982, for further petrologic descriptions.)

Chilled porphyritic rocks occur at many places along the contacts of the Cloudy Pass batholith. Near Hart Lake a chilled complex consisting of separately injected, contrasting layers of porphyry having a total thickness of more than 1 km borders the northeast side of the batholith (Cater, 1969, p. 8-17). Oldest is an outer layer of dacite porphyry that to the north of the complex grades directly into the core of the batholith and to the south of Hart Lake diverges from the batholith as a prong. Next oldest is an inner layer of dacite and labradorite-bytownite andesite, and, between these layers, is a still younger layer of autobreccia of a composition similar to that of the inner layer. The middle layer consists of dacite andesite autobreccia and resembles a volcanic flow breccia. Its contact with the inner layer is gradational, but the contact with the outer layer is intrusive. This intrusive contact is evident only at higher altitudes where the outer layer had solidified before intrusion of the middle layer. At lower altitudes near Hart Lake, the contact with the outer layer is partly gradational and partly mixed, as though the outer layer were still plastic when the middle layer was injected (Cater, 1982).

These rocks were formed during the rise and emplacement of the Cloudy Pass pluton and are thus Miocene in age (see above).

Mian$_{c}$ Intermixed labradorite-bytownite andesite and dacite porphyry of the Cloudy Pass pluton (Miocene)—Dark-gray to black intricately mixed dacite porphyry and lesser amounts of labradorite-bytownite andesite porphyry. The dacite is petrologically similar to the dacite of the outer layer (unit Mida$_{c}$). The andesite contains phenocrysts of labradorite-bytownite and hornblende in a groundmass of andesine, hornblende, biotite, and sparse quartz (Cater and Crowder, 1967).

Contacts between the two rock types of this unit are difficult to recognize in the field. Contacts with the adjoining units are mostly sharp at higher elevations and gradational at lower elevations (Cater and Crowder, 1967).

Mida$_{c}$,

Dacite porphyry or intrusive breccia of the Cloudy Pass pluton (Miocene)—Light to dark greenish-gray dacite porphyry with closely packed phenocrysts of sodic labradorite, quartz, hornblende, and sparse augite in an aphanitic green groundmass of andesine, quartz, hornblende, biotite, and some orthoclase; locally trachytic. Within the pluton, the unit consists of pipes and angular to rounded fragments of labradorite and granodiorite and porphyritic rocks of the Cloudy Pass in a matrix of light-colored granite and dark-colored tonalite. Elsewhere, irregular pipes and dikes of coarsely to finely comminuted angular fragments of igneous and metamorphic rocks occur in a matrix of porphyry or a fine-grained matrix of chlorite, biotite, sericite, quartz, orthoclase, and tourmaline. Rocks in breccias cutting metamorphic rocks commonly show various degrees of alteration, and some contain considerable amounts of sulfides (pyrite and pyrrhotite, and locally, minor chalcopyrite and sphalerite). Contacts with unit Migd$_{c}$ are generally gradational. Contacts with unit Mida$_{c}$ are a "marble cake mixture" at lower elevations and sharp at higher elevations (Cater and Crowder, 1967; Cater, 1982).

Mida$_{c2}$ Dacite and labradorite-bytownite andesite porphyry breccia of the Cloudy Pass pluton (Miocene)—Fragments of unit Mida$_{c}$ and Mian$_{c}$ in a matrix of the same rock types. This unit is texturally indistinguishable from a volcanic flow breccia. These rocks differ from the adjacent layered dacite and andesite porphyries near Hart Lake by their higher degree of alteration; fracture surfaces are coated with pyrite and pyrrhotite with chalcopyrite; alteration intensity increases at higher levels. Contacts grade from a "marble cake mixture" at low elevations to sharp at high elevations (Cater and Crowder, 1967; Cater, 1982).

Mix Porphyries and breccias of Lyall Ridge (Miocene?)—Breccias, porphyries, and aphanitic igneous rocks; breccias locally interlayered with porphyries and aphanites. Breccia fragments include porphyry, aphanitic igneous rock, and the host-rock Cascade River unit schists. Breccia composes 1-50 percent of the outcrop area. The matrix is in part finely crystalline and in part cryptocrystalline with flow layering (vitrophyre?)(Libby, 1964). Libby (1964) suggested the unit was subaerially deposited or possibly was akin to Cloudy Pass pluton contact-complex porphyries and breccias described by Grant (1966, 1969) or Cater (1960) elsewhere. Aerial photograph interpretation of the area by the authors shows that the Cloudy Pass pluton extends up the south side of Lyall Ridge and underlies unit Mix, suggesting that it is a Cloudy Pass pluton chilled border complex similar to the border complex at Hart Lake (see above).

Eit$_{c}$ Quartz diorite and tonalite of the Copper Peak and Holden Lake plutons (Eocene)—Dark gray (Color Index [CI] 40-50), medium-grained, massive, hypidiomorphic to panidiomorphic granular quartz diorite to tonalite, with lesser quartz gabbro. Minerals include plagioclase (labradorite), hornblende, and quartz. Some hornblende has augite cores; magnetite commonly makes up 5 percent of the rock, and apatite and titanite are accessory. The parallel orientation of labradorite suggests plutonic flow alignment. The Holden Lake pluton has low silicon content and high ferromagnesian mafic mineral content and has some tholeiite chemical characteristics (Ford and others, 1988a; Cater and Crowder, 1967; Cater, 1982).

The unit forms numerous dikes and elongate masses about 2.5 km east of Holden Lake. The largest intrusions have a width of about 1.5 km and are at least 2 km long. We used aerial photos (utilizing the distinct color contrast with adjacent rocks) to map the pluton's extent north of the Holden 15-minute quadrangle. The Copper Peak pluton crops out on the north side of Copper Peak and is a little more than 1.5 km long and about 0.5 km wide, although dikes of the rock are widespread as much as 1.5 km farther west (Cater, 1982).

Contacts are typically sharp, except where locally sharp contacts give way to spectacular contact complexes (See unit Eit_{cc}.)

These plutons are cut by the late Eocene Duncan Hill pluton and are thus older. But, because the satellitic dikes cut mineralized rock associated with the Duncan Hill pluton, the unit is assigned a late Eocene age (Cater, 1982).

Eit Hornblende biotite tonalite near Holden (Eocene?)—Gray (CI 12-20), hypidiomorphic tonalite ranging from very fine grained to fine- and medium-grained; locally slightly to distinctly porphyritic; consisting of 50-60 percent plagioclase (andesine to labradorite), 20-30 percent quartz, 7-15 percent biotite, 0-8 percent hornblende, and generally less than 1 percent potassium feldspar. Accessory minerals include titanite, allanite, and apatite. Associated but later dikes and small masses of lesser granodiorite and granite locally intruded the tonalite while the tonalite was still molten. Most of the bodies are dikes a few meters to a few tens of meters thick (Cater and Wright, 1967; Cater, 1982).

Two large bodies are mapped near Holden. Contacts are sharp or gradational through a few centimeters. Variations occur at the Riddle Peaks pluton (units $pTgb_r$ and $pTgb_{rl}$) where the contact is highly irregular and contains many inclusions of hornblende gabbro. Where later granodiorite and granite intruded the host tonalite, the contacts are complex and irregular.

The unit intrudes the Late Cretaceous Cardinal Peak pluton and is cross-cut by Tertiary dikes, most importantly dikes associated with the Eocene Railroad Creek pluton. A pervasive flow fabric is defined by aligned biotite flakes, plagioclase laths and hornblende (Cater, 1982); however, the fabric attributed by Cater (1982) to magmatic flow is, at least locally, tectonic (e.g., descriptions by Cater of sutured quartz in the groundmass of this unit is suggestive of a mylonitic fabric). This unit and units Eigd and Eiq_d (below) apparently display an overprinting solid-state fabric attributed by Haugerud and others (1991) to middle Eocene deformation.

Eigd Biotite granodiorite and granite near Holden (Eocene)—White to light-gray (CI 6-12) hypidiomorphic granodiorite and granodiorite. Plagioclase is predominantly andesine (An_{55} in the core to An_{15} near the rims); titanite, allanite, zircon, and apatite are accessory minerals, and secondary minerals are characteristic muscovite (matrix and replacing plagioclase), chlorite, epidote, and pyrite (Cater and Wright, 1967; Cater, 1982).

These rocks are largely coextensive with unit Eit, but unlike Eit, they occur as far south as Fern Lake. The largest outcrops are east of Wilson Creek.

The granodiorite and granite intrude unit Eit and older plutons, producing both irregular contacts with the host rocks and a spectacular array of dikes of various sizes, especially where the unit intrudes the Cardinal Peak pluton (units Kit_{cp} and Kiq_{cp}). The contacts are sharp at map scale (Cater and Wright, 1967; Cater, 1982). Most rocks have a pronounced mylonitic foliation defined by aligned biotite, sutured quartz lenticular aggregates, and abraded and aligned feldspars that parallel the regional trend in the country-rock; fabric was attributed by Cater (1982) to protoclasis but is probably tectonic. (See Haugerud and others, 1991, for the extent of middle Eocene ductile deformation.)

The unit intrudes, commonly is spatially associated with, and is probably a later phase of unit Eit. The unit also intrudes unit Eiq_d (below). It appears to have been molten locally when the granodiorite and granites were emplaced, and thus it may be more evolved phases of the same magmatic source (Cater, 1982). The granodiorite and granite petrographically resemble unit Eit except for the higher (commonly perthitic) potassium feldspar (orthoclase) content.

Eiq$_{d}$ Duncan Hill pluton (Eocene)—Light-gray to gray (CI 7-25), hypidiomorphic, medium-grained, massive to gneissic tonalite, granodiorite, quartz diorite, monzodiorite and rare granite. Tonalite and quartz diorite give way to granodiorite south of Snow Brushy Creek. (See Hopson and others, 1970, Dellinger and Hopson, 1986, and Calvert, 1994, for tilted diapir origin of compositional and textural heterogeneity.) Hornblendite inclusions are rare. The unit consists of oligoclase or andesine, quartz, orthoclase or perthite, conspicuous books of biotite and, locally, hornblende. Hornblende is minor relative to biotite, increases in the tonalite, and is absent in granite. Potassium feldspar is late and mostly replaces plagioclase; accessory minerals include magnetite, ilmenite, titanite, apatite, allanite (characteristic), zircon, and rare xenotime (Libby, 1964; Cater and Crowder, 1967; Cater, 1982; Ford and others, 1988a).

The large (260 km^2) Duncan Hill pluton is about 23 km long, extending from Buckskin Mountain in the Holden quadrangle into the Chelan 1:100,000 quadrangle (Figs. 1, 6B). It is tadpole shaped and tapers from a maximum width of about 9.6 km in the Chelan quadrangle to about 1 km at its "tail" on Buckskin Mountain (Cater, 1982).

Largely ductilely sheared north of Snow Brushy Creek, the unit is characterized by a slightly gneissic texture and by a fine-grained biotite-rich groundmass with attenuated quartz lenses that wrap around porphyroclasts of andesine. (See Haugerud and others, 1991, for the extent of middle Eocene ductile deformation.) The gneissic foliation increases toward the contacts.

Contacts are sharp or gradational or form contact complexes. (See unit Eit$_{dc}$.) However, away from the complexes, the contacts are fairly sharp; hornfels or migmatites are only a few meters thick and have minimal effects on the host rocks (Cater, 1982).

Numerous K-Ar and Pb-alpha analyses indicate an Eocene age (43 to 49 Ma)(Appendix 2). This conclusion is also confirmed by a 47 Ma U-Pb zircon age from the Chelan quadrangle (Tabor and others, 1987a)(Appendix 2). Biotite Ar-Ar ages (Calvert, 1994) range from 46 Ma at the southeast end of the pluton to 44 Ma at the northwest end of the pluton.

Eigd$_{rc}$ Railroad Creek pluton (Eocene)—White to light-gray hypidiomorphic granodiorite (CI 3-15) to granite (CI 3-5)(locally xenomorphic) with minor tonalite; grades to granodiorite and tonalite (CI 7-14) with lesser quartz diorite (CI 12-17) and granite north of the Lucerne quadrangle (See Hopson and others, 1970, Dellinger and Hopson, 1986, and Calvert, 1994, for tilted diapir origin of compositional and textural heterogeneity.) This unit contains various amounts of plagioclase (typically oligoclase to andesine) quartz, orthoclase (or rarely microcline), biotite, hornblende, with rare muscovite, and allanite and accessory titanite (locally absent), apatite, and zircon. Rocks are typically fresh; however, alteration products may include chlorite, sericite, epidote-clinozoisite, and pyrite (common in granite). Biotite is ubiquitous and typically abundant, whereas hornblende exceeds 1-2 percent only in rocks near contacts (Libby, 1964; Cater and Crowder, 1967; Cater, 1982; Ford and others, 1988a).

The pluton occupies the northwest part of the Lucerne 1:62,500 quadrangle, extending northwest into the northwest quadrant of the Twisp 1:100,000 quadrangle (see Libby, 1964; Ford and others, 1988a). Similar rocks believed to connect with the pluton under Bearcat Ridge crop out between Bear Creek and Lake Chelan; smaller masses crop out west of Mirror Lake and on the ridge north of the head of Little Creek. (See Eigd$_{rc}$ dike symbols.) Satellitic dikes and small irregular masses are widely scattered over much of the northern part of the Lucerne quadrangle (Cater, 1982).

The white granite is conspicuous in outcrop and typically grades into granodiorite or tonalite or, in a few places, intrudes these rocks. The pluton parallels the regional structural grain of the host rocks, but typically contacts cross-cut foliations at various angles, as is typical for most Tertiary plutons in the region. The pluton widens at depth; the southwest contact dips outward, whereas the northeast contact is vertical and dips more steeply than the enclosing gneisses. Contacts are commonly sharp, and intrusion does not appear to have affected the adjacent rocks; however, in many places the hosts rocks are interlayered and cut by granodiorite dikes (Cater, 1982). Libby (1964) showed the northwestern contact of the pluton as cataclastically sheared and faulted against the adjacent country rock.

The pluton is cut by probable Eocene to Miocene dikes and intrudes Late Cretaceous plutons. Hornblende and biotite K-Ar ages are Eocene, 42.6 ± 2.0 and 43.7 ± 0.3 Ma respectively (unpublished USGS data referenced in Cater, 1982)(Appendix 2).

Eig_r Rampart Mountain pluton (Eocene)—Light-gray (CI 10-15), medium-grained, hypidiomorphic biotite granodiorite to dominantly granite; massive to slightly foliated; consists of nearly equal amounts of oligoclase and quartz and various amounts of potassium feldspar. Biotite (5-12 percent) and muscovite (1-4 percent) occur with accessory titanite, apatite, allanite, and magnetite; epidote, sericite, and muscovite replace both biotite and oligoclase, particularly the more calcic cores of the oligoclase. Chlorite and magnetite are alteration products of biotite (Cater, 1982).

The Rampart Mountain pluton crops out between Rampart Mountain and Larch Lakes and is about 3 km long and about 1 km wide.

The pluton is concordant with enclosing rocks. Contacts are sharp but irregular; locally stoped blocks of host rocks are numerous, and granite dikes project short distances into the host rocks (Cater, 1982).

The unit intrudes the Eocene (Paleocene?) to Cretaceous Larch Lakes pluton and the Late Cretaceous Entiat pluton and is intruded by probable Miocene to Eocene dikes and is thus assigned an Eocene age.

Eig_g Golden Horn batholith (Eocene)—Directionless, pinkish-gray, distinctive golden orange weathering, fine- to coarse-grained, leucocratic granite with crystal-lined miarolitic cavities up to several meters in diameter. The granite in the southern half of the batholith (northeast corner of the study area) is composed of more than 60 percent potassium feldspar, approximately 30 percent quartz, less than 5 percent albite, and less than 5 percent arfvedsonite (sodic amphibole) and annite (iron-rich biotite)(Stull, 1969; Boggs, 1984; Barksdale, 1975).

The Golden Horn batholith is a large intrusion whose southernmost tip crops out in the northeast corner of the study area. The batholith intrudes the North Creek fault. K-Ar hornblende ages of 47.8 ± 5 Ma and 46.7 ± 1.9 Ma, and K-Ar biotite ages of 48 ± 2 Ma, 46.9 ± 0.4 Ma, and 46.6 ± 1.4 Ma are reported from the batholith (Misch, 1963, 1964; Tabor and others, 1968; Engels and others, 1976; Davis and Stull, 1984). The ages suggest that magmatic crystallization occurred approximately 47 Ma.

$Eida_{gm}$,
$Eian_{gm}$ Old Gib volcanic complex (Eocene)—Pelean spine (unit $Eida_{gm}$) and associated dacite to andesite porphyry (unit $Eian_{gm}$). The unit is found along the eastern edge of the Holden quadrangle. The Old Gib volcanic complex appears to be controlled by the Entiat fault, possibly during formation of the Chiwaukum graben and extension (dip-slip) of the graben-bounding Entiat fault (Cater and Crowder, 1967; Cater, 1982).

K-Ar analysis of the andesite porphyry (by J. Engels) indicates the complex is 44 Ma.

$Eida_{gm}$ Dacite volcanic neck on Old Gib Mountain (Eocene)—Locally vesicular; contacts fluted and striated (Cater, 1960).

$Eian_{gm}$ Labradorite andesite porphyry on and near Old Gib Mountain (Eocene)—Dark greenish-gray, conspicuously porphyritic dacites and labradorite andesites; contains phenocrysts of labradorite or calcic andesine, quartz, hornblende, biotite, and pseudomorphic nontronitic material embedded in a greenish, fine-grained but holocrystalline groundmass (Cater, 1982).

$Eigd_l$ Larch Lakes pluton (Eocene to Paleocene?)—Light-gray (CI 8-15), hypidiomorphic, locally medium-grained and commonly fine-grained, homogeneous, massive granodiorite, tonalite, and granite, consisting of varied proportions of oligoclase or andesine, quartz, potassium feldspar (perthitic microcline or rarely orthoclase) and biotite. Accessory minerals include titanite, apatite, and opaque minerals. In fresh hand specimen, these rocks typically contain trace amounts of chlorite, sericite, and clinozoisite-epidote as secondary replacement products. Parallelism of andesine laths in some rocks suggests a flow foliation in this generally massive to slightly foliated and lineated rock (Cater, 1982). However, a solid-state fabric is also evident (R. B. Miller, San Jose State Univ., oral commun., 1995).

The pluton crops out in the south-central part of the study area around Larch Lakes cirque and on the ridge to the west.

Contacts are sharp and discordant to the fabric in the host rocks.

The pluton intrudes the Cretaceous Entiat pluton (unit Kit_e) and is intruded by late Eocene dikes and the probably Eocene Rampart Mountain pluton (unit Eig_r) (Cater, 1982). Preliminary unpublished U-Pb data suggest a Paleocene age (R. B. Miller, San Jose State Univ., oral commun., 1995).

PAito Oval Peak pluton (Paleocene)—Light-colored biotite tonalite that grades locally into biotite trondhjemite. Aplite and pegmatite dikes, commonly garnet bearing, occur throughout the unit. This unit contains plagioclase (average An_{30}), quartz, biotite, epidote, microcline, titanite, and trace amounts of apatite. A foliated margin rims the massive core of the pluton (Adams, 1961; Libby, 1964; Miller, 1987; Miller and Bowring, 1990).

This is a batholith-scale body bordering the northeast part of the study area southwest of the Twisp River.

The presence of magmatic epidote suggests crystallization under pressures exceeding 6 kb (Zen and Hammarstrom, 1984). Emplacement pressures of 5-7 kb are indicated by hornblende geobarometers from the pluton (Miller and Bowring, 1990). Moderate to high pressures from latest Cretaceous and Paleocene plutons in the Crystalline Core (CC) and lower pressures (about 3 kb) for many of the mid-Cretaceous plutons suggest loading of the CC, possibly by plutons, after mid-Cretaceous plutonism (e.g., Miller and others, 1993a).

Miller and Bowring (1990) report a U-Pb age of about 65 Ma, consistent with a U-Pb titanite age of 65.3 Ma reported by Miller and Walker (1987) and slightly different from the preliminary age of 61 Ma reported by Miller and others (1989) on the basis of slightly discordant data.

Tertiary to Mesozoic intrusive igneous rocks

TKit Intrusive tonalitic rock intruding the Virginian Ridge Formation in the northeast corner of the study area. The unit is younger than the Late Cretaceous Virginian Ridge Formation. (This unit was mapped but not described by McGroder and others, 1990.)

TKigs Sisters Creek pluton (Tertiary-Cretaceous)—Light-colored biotite quartz monzonite to granite orthogneiss; contains 20-25 percent quartz, 30-35 percent plagioclase, 30-35 percent perthitic K-feldspar, 3-7 percent muscovite, and minor amounts of myrmekite, garnet, biotite, apatite, sericite, calcite, and chlorite (Tabor, 1961).

Two small bodies occur around the headwaters of Sisters Creek in the northwest part of the study area.

On the basis of its well-defined metamorphic fabric, the unit is probably a pre- to syn-metamorphic pluton of mid- to Late Cretaceous or earliest Tertiary age.

Mesozoic intrusive igneous rocks

Penetrative fabric development in many Mesozoic intrusive igneous rocks and orthogneisses (described below) was attributed by Cater (1982) to protoclasis (shearing during magma emplacement) but probably is best attributed to subsolidus deformation (e.g., Haugerud and others, 1991; Walker and Brown, 1991).

Kit Leucocratic tonalite (trondhjemite) and granodiorite (Tertiary? to Cretaceous)—White (CI 1-5), fine-to medium-grained, rarely pegmatitic, tonalite-trondhjemite. The unit chiefly consists of oligoclase and quartz; potassium feldspar is rare, but locally the concentration warrants a granodiorite classification. The main accessory is biotite; other accessory minerals include apatite, titanite, opaque minerals, and muscovite. Chlorite and epidote replace biotite, and sericite replaces oligoclase (Cater and Wright, 1967; Cater, 1982).

This unit occurs as irregular masses and dikes, locally as the migmatizing agent of the host rocks. The only large, mappable body occurs south of Pomas Creek, which is just west of the junction of Ice Creek and the Entiat River. Otherwise, this material forms the migmatitic leucosome observed in many of the rock units of the region. (See Cater and Wright, 1967, and Cater and Crowder, 1967, for extent and density of migmatization in the southern half of the study area. Some of the more extensively migmatized rock units in the area, all described below, are the Dumbell Mountain plutons, Entiat pluton, Swakane Biotite Gneiss, and Skagit Gneiss.)

The age is problematic. Leucosome formation affected Late Cretaceous plutons and predates the largely unaffected Eocene plutons. Mattinson (1972, p. 3778-3779) obtained ages that ranged from 60 to 90 Ma for zircons from pegmatitic leucosomes in the Swakane Gneiss along the Columbia River, the Skagit gneiss, and from the Dumbell Mountain plutons. Similarly, Hurlow (1992) obtained two discordant U-Pb ages of about 70 Ma from coarse-grained tonalitic and pegmatitic granite dikes of this unit. However, migmatization may be diachronous across the region, the result of metamorphic, metasomatic, and igneous injection mechanisms. For a discussion of the origin of migmatites in the Skagit Gneiss, see Yardley (1978), Misch (1968), Babcock and Misch (1988), Whitney and Evans (1988), Whitney (1992b), and in the Chelan Complex to the south of the study area, see Hopson and Mattinson (1994).

Kit$_s$, Kit$_e$ Kid$_e$, Kit$_{ep}$ Entiat and Seven Fingered Jack plutons (Cretaceous)—Units include the Entiat pluton tonalite (unit Kit$_e$), diorite-gabbro (unit Kid$_e$), and the tonalitic orthogneiss (unit Kit$_{ep}$). Also includes Seven Fingered Jack pluton biotite-hornblende tonalite (unit Kit$_s$) and a contact complex (unit Kit$_{pc}$) (Cater and Wright, 1967; Cater and Crowder, 1967.)

The Seven Fingered Jack and Entiat plutons make up a group of intrusive bodies cropping out from the vicinity of Hart Lake south-southeastward across the Holden and Lucerne quadrangles and into the Chelan quadrangle (Fig. 1).

Seven Fingered Jack plutons contacts are mostly sharp, but locally they are faulted or gradational through a distance of a few meters. The Entiat pluton is characterized by sharp to gradational contacts or is bordered by contact complexes. (See below.)

The Seven Fingered Jack and Entiat plutons intrude the Triassic Dumbell Mountain plutons and are intruded by probable Eocene dikes. Several K-Ar and U-Pb ages, mostly from the Chelan quadrangle (Tabor and others, 1987a), indicate uplift in the Eocene and a crystallization age of about 75 Ma for these plutonic bodies (Appendix 2).

Kit$_s$ Seven Fingered Jack pluton (Cretaceous)—Light to dark greenish-gray, medium-grained, hypidiomorphic to xenoblastic, massive to gneissic biotite-hornblende tonalite (CI 10-35) to quartz diorite (CI 20-40), consisting of andesine, quartz, and hornblende, and in most rocks, small amounts of biotite. Titanite, opaque minerals, apatite, and rare zircon are accessory minerals. Secondary products include small amounts of clinozoisite-epidote, chlorite, and sericite. Gneissic varieties show protomylonitic hypidiomorphic granular texture (Cater and Crowder, 1967; Cater, 1982; Ford and others, 1988a).

The westernmost dike-like mass paralleling the Entiat fault is largely gneissic. This gneissic layering is dominantly defined by parallel, pencil-shaped mafic streaks and schlieren. Locally, the large mass between Hart Lake and Ice Lakes consists of layers (0.3 m thick) of gneissic quartz diorite alternating with nongneissic rock (Cater, 1982).

Kit$_e$ Entiat pluton (Cretaceous)—Gray to dark-gray (CI 20-30), medium- to coarse-grained, hypidiomorphic to xenomorphic, and locally gneissic to mylonitic hornblende-biotite tonalite containing hornblende and biotite (commonly aligned). Quartz and accessory potassium feldspars are interstitial or concentrated along zones of cataclasis. Coarse titanite is common.

Local gneissic layering is defined by alignment of crystals, mylonitic fabric, or parallel mafic streaks. Rocks are petrographically similar to the biotite-hornblende tonalites of the Seven Fingered Jack plutons except that biotite predominates over hornblende and plagioclase is more sodic and commonly contains small amounts of potassium feldspar, in some rocks enough to classify the rocks as a granodiorite (Cater, 1982). The elongate body west and southwest of Rampart Mountain and along the southwestern part of the Entiat pluton is a more gneissic tonalite; light-colored segregation pods, mafic streaks, and elongate amphibolite pods near contacts define the layering. Foliation is pervasive, highly swirled, but not strongly accentuated (Cater, 1982).

Kid$_e$ Hornblende diorite and gabbro of the Entiat pluton (Cretaceous)—Gray and dark-gray, varies from hypidiomorphic diorite to ophitic to panidiomorphic to xenomorphic greenish-black gabbro (CI 25-50). Diorite is medium grained and mostly massive, but some has a slight foliation. The varied gabbro is slightly pegmatitic to fine grained. Hornblende and plagioclase are the major constituent minerals; some rocks contain considerable biotite and even a few percent quartz. Plagioclase in diorite is calcic andesine and in gabbro is sodic labradorite. Orthoclase is sparse, and titanite, apatite, muscovite, and magnetite are accessory minerals. Epidote, chlorite, and sericite are secondary minerals. Both metamorphic foliation and cataclasis are prevalent. The various rock types are intergradational and locally stirred together in mixtures that look like marble cake (Cater and Wright, 1967; Cater, 1982).

Kit$_{ep}$ Hornblende tonalitic orthogneiss of the Entiat pluton (Cretaceous)—Light- to greenish-gray (CI 10-35), medium-grained, hypidiomorphic to xenoblastic, locally cataclastic hornblende tonalitic orthogneiss consisting of oligoclase or andesine, quartz, hornblende and biotite (typically accessory), with localized muscovite; accessory minerals include magnetite, titanite, and apatite; secondary minerals are chlorite and epidote-clinozoisite. Light-colored segregation dikes and pods common, and dark lenticular segregations consist of mostly biotite. The unit contains numerous amphibolite inclusions.

Kit_{cp}, Kiq_{cp} Cardinal Peak pluton (Cretaceous)—Includes a main tonalitic phase, a quartz dioritic to dioritic border phase and a contact complex along the northwest end of the pluton (see unit Kit_{pc})(Cater and Wright, 1967; Cater and Crowder, 1967).

The pluton extends about 30 km from the northeast corner of the Holden quadrangle southeastward across the Lucerne quadrangle. Mapping by Dragovich and R. B. Miller suggests that the pluton terminates under Lake Chelan or may extend across the lake in the eastern half of the Twisp quadrangle and northeastern part of the Chelan quadrangle (Fig. 1).

A Late Cretaceous intrusive age (Appendix 2) is indicated by a U-Pb age on zircon of about 75 Ma obtained by R. Zartman (USGS, cited in Miller and others, 1989) and mildly discordant ages of 73-79 Ma, which intercept concordia at 72.5 (Haugerud and others, 1991).

Kit_{cp} Cardinal Peak pluton (Cretaceous)— Dark-gray (CI 15-30), medium-grained, massive or foliated hornblende-biotite tonalite at the northwest end of the main pluton in the valley of Tenmile Creek. South of Railroad Creek, tonalite is lighter gray and coarser grained and has localized flaser appearance; locally contains enough orthoclase to constitute granodiorite. Tonalite contains andesine, quartz, and biotite; only the northwest end of the pluton contains more than a trace of hornblende. Accessory minerals in all rocks of this unit include apatite, opaque minerals, and titanite; rarely allanite and clinopyroxene are present. Small amounts of chlorite, sericite, and clinozoisite-epidote are common replacement products (Cater, 1982).

Kiq_{cp} Cardinal Peak pluton border phase (Cretaceous)—Gray to dark-gray, fine- to medium-grained, hypidiomorphic, commonly massive to gneissic calcic hornblende diorite and quartz diorite. The unit contains andesine, hornblende, biotite, and some quartz. Accessory minerals include orthoclase, titanite, apatite, and opaque minerals, and secondary minerals are chlorite and epidote (Cater, 1982).

$Kigd_{hp}$, $Kigd_{bp}$ High Pass and Buck Peak plutons (Cretaceous)—Light- to medium-gray (CI 5-20), medium-grained (varied), hypidiomorphic to xenoblastic granodiorite, with lesser amounts of tonalite (trondhjemite) and granite. The plutons consists of oligoclase, quartz, biotite, and potassium feldspar. Accessory minerals include opaque minerals, apatite, zircon, and considerable coarse-grained titanite. Clinozoisite-epidote and sericite are ubiquitous, and chlorite is less common. Hornblende and garnet occur along contacts, probably resulting from assimilation of the host rock. The unit is locally gneissic or foliated (Cater and Crowder, 1967; Cater, 1982; Ford and others, 1988a).

The separate plutonic bodies of this intrusion underlie an area of approximately 20 km^2 in the west-central part of the Holden quadrangle.

The contacts vary from mostly pegmatite-rich lit-par-lit zones measuring a few to hundreds of meters wide to conformable or locally discordant sharp contacts. The High Pass pluton intrudes the crest of folded rocks of the Napeequa River area and, on Chiwawa Ridge, appears to have distorted the synform (folded rocks of the Napeequa River area) (Cater, 1982). These structural-intrusive relations suggest intrusion was post-folding. However, the folding is apparently late to post-metamorphic (folds the regional foliation) and thus may be Tertiary (or post-metamorphic) in age; these relations suggest that intrusion of the Cretaceous High Pass and Buck Peak plutons occurred prior to folding.

The plutons intrude the Late Cretaceous (about 96 Ma; Walker and Brown, 1991) Sulphur Mountain pluton (Cater, 1982) and are older than the K-Ar cooling ages on biotite (54-59 Ma) and hornblende (59-72 Ma). The crystallization age of the pluton is about 84 ± 1 Ma based on four concordant U-Pb zircon ages obtained by Hurlow (1992).

$pTgb_r$,
$pTgb_{rl}$ Riddle Peaks pluton (pre-Tertiary)—Gray to black (CI 13-100), medium- to coarse-grained hornblendite, gabbro (unit $pTgb_r$), and white, hornblende-bearing, medium- to-coarse-grained anorthosite; locally contains quartz gabbro. The largely layered gabbro (unit $pTgb_{rl}$) consists of various proportions of bytownite (with some labradorite rims) and hornblende and lesser but still considerable quantities of magnetite; accessories include titanite, apatite, interstitial pyrite, and rare biotite, and pyroxene (rare). Secondary minerals include chlorite replacing hornblende and sausserite and sericite replacing bytownite. Scattered thin veins of epidote, prehnite, and orthoclase (rare) cut the rock. Cater (1982) compared the unit to the Stillwater Complex mafic layered intrusion (Cater, 1982; Ford and others, 1988a).

Unit $pTgb_{rl}$ is strongly layered and exposed between Ninemile and Tenmile Creeks. Locally, unit $pTgb_{rl}$ is only vaguely layered or consists of nearly massive, mesocratic hornblende gabbro. Some gravity-stratified layers resemble graded beds. (See Cater, 1982, p. 41-46, for additional information about petrology and field relations.)

The contact between the relatively massive and layered hornblende gabbro is gradational in most places; layering becomes evident over a distance of meters (Cater, 1982).

The pluton may not be much older than the Cardinal Peak pluton, which intrudes this mafic unit (Cater, 1982). Also, the pluton appears to have been recrystallized during the mid- to Late Cretaceous metamorphism affecting the Crystalline Core and thus is pre-Tertiary, but is probably mid-Cretaceous (see below).

The mafic Riddle Peaks pluton is compositionally anomalous in the Crystalline Core. Dawes (1993a, b) indicates that the best petrogenetic model that accounts for both the occurrence of mafic intrusive masses and apparently contemporaneous Late Cretaceous tonalites-trondhjemites and granodiorites in the study area is that intermediate, enclave-bearing tonalites are hybrids created by mixing of modified, mantle-derived mafic magmas (e.g., mafic enclaves in intermediate intrusives and larger, syn-plutonic mafic intrusives such as the Riddle Peaks pluton) with lower crustal melt represented by felsic trondhjemites and granodiorites.

Kit_{cm} Clark Mountain pluton (Cretaceous?)—Gray (CI 15-30), medium-grained, hypidiomorphic homogenous-appearing tonalite and granodiorite. Aplite dikes are locally abundant near contacts. The unit consists of 45-55 percent plagioclase (albite to oligoclase), 20-26 percent quartz, 13-16 percent biotite, 0.2-10 percent potassium feldspar (orthoclase and microcline), and 0-2.5 percent hornblende. Accessory titanite occurs in amounts as high as 1.6 percent; apatite, magnetite, and zircon are plentiful. Secondary replacement minerals include clinozoisite-epidote, chlorite, and sericite. Secondary minerals are invariably present, but only clinozoisite-epidote exceeds 1 percent. Potassium feldspar is late and possibly metasomatic. A faint lineation is ubiquitous, and a foliation is locally present (Cater and Crowder, 1967; Cater, 1982; Ford and others, 1988a).

The unit consists of four small stocks (2 km^2) that occur near Clark Mountain in the southeastern part of the Holden quadrangle.

Contacts are typically sharp, although locally zones several tens of meters wide of interlayered intrusive rock and schist or gneiss occur locally. Rarely do the wall rocks show megascopically discernible contact effects; even marble is virtually unmodified.

Engels (Engels and others, 1976) obtained K-Ar ages of about 57 Ma from biotite and 59 Ma from muscovite. The unit is assigned a Late Cretaceous crystallization age based on its textural and compositional similarity to other Late Cretaceous rocks in the study area.

Mixed Igneous and Metamorphic Rocks of Plutonic Complexes

Tertiary to Mesozoic contact complexes

A few of the Cretaceous and Tertiary plutons in the area possess contact complexes consisting of heterogeneous mixtures of coarse hornblendite, gabbro, diorite, and tonalite, as well as inclusions in various stages of digestion and incorporation (Cater, 1982). The cores of the plutons cut the complexes, but generally the complexes seem not to have solidified before they were invaded by the cores. The diorite to tonalite in the complexes are sufficiently similar in composition to the core rocks to have been derived directly from them, but this relation cannot be true for the ubiquitous hornblende gabbro to coarse-grained, generally pegmatitic hornblendite, the rocks most characteristic of these complexes. The unhomogenized marble-cake mixture of gabbros and siliceous igneous rocks would suggest such mixtures are not far traveled, and the presence of both calcic and sodic plagioclase in homogenized hybrid rock indicates that their disequilibrium in the mixed magma before solidifying could not have been prolonged (Cater, 1982, p. 90-91).

Eit_{dc} Contact complex of the Duncan Hill pluton (Eocene)—Xenomorphic or hypidiomorphic hornblendite, hornblende gabbro, diorite, quartz diorite, tonalite, granodiorite, dikes of various compositions, and inclusions of host metamorphic rocks. Hornblende gabbro and quartz diorite-tonalite are most abundant. Uncontaminated hornblende gabbro consists of roughly equal proportions of plagioclase (labradorite to bytownite) and hornblende; accessory minerals include opaque minerals and apatite; secondary minerals include sausserite in plagioclase and chlorite. Hornblendite is coarse grained (grains as much as 3 cm or more long). Host schist and gneiss inclusions consist of unaltered xenoliths to vague schlieren. The hypidiomorphic, mylonitic, or foliated rocks in the contact complexes are mineralogically similar to, but distinct from, the core rock (see unit Eiq_d for a description) and consist of andesine, quartz (as much as 25 percent), biotite, and, in some rocks, hornblende as major minerals. Accessory minerals include opaque minerals, titanite, apatite, and a little allanite (Cater, 1982, p. 61-67).

The complex is discordant along the northwest side of the pluton (Cater, 1982). Much of the complex, particularly the more felsic rock varieties, shows pronounced ductile deformation, suggesting to Haugerud and others (1991) that an Eocene ductile shear zone (about 8 km wide) that is evident in the Skagit Gorge type section of the Skagit Gneiss extends southward into the Lucerne quadrangle. (See Geologic Setting.)

The intrusive complex is probably slightly younger than the 43 to 49 Ma Duncan Hill pluton main mass because core granodiorite, tonalite, and quartz diorite appear as inclusions in the complexes (Cater, 1982).

Eit_{cc} Contact complex of the Holden Lake pluton (Eocene)—Along the west side of the Holden Lake pluton, hornblendite, gabbro, diorite, quartz-bearing rocks, partly assimilated Dumbell Mountain gneisses, and all possible gradations among all these rock types are stirred together in chaotic jumbles. (See Cater, 1982, p. 81, for further information.)

Kit_{ec} Contact complex of the Entiat pluton and Seven Fingered Jack plutons (Cretaceous)—Hornblende schist and gneiss inclusions, very coarse grained hornblendite (hornblende crystals as much as 15 cm long), swarms of dikes and irregular mixed masses of fine-grained, locally porphyritic to pegmatitic hornblende-tonalite similar to the core rocks, as well as quartz diorite, diorite, and gabbros (Cater, 1982).

The rocks are approximately coeval with the core rocks of the Entiat and Seven Fingered Jack plutons (about 75 Ma) because the core rocks intrude the complexes, but locally rocks of the contact complex cut core rocks, and some gabbros are chilled against the more felsic, cooler core rocks (Cater, 1982).

Kit_{pc} Contact complex of the Cardinal Peak pluton (Cretaceous)—Medium- to coarse-grained hornblendite and hornblende diorite and gabbro that range from fine-grained to coarsely pegmatitic with hornblende crystals as much as 5 cm long. The hornblendite may be digested amphibolite or hornblende schist country rock or, less likely, inclusions of the Riddle Peaks pluton (unit $pTgb_r$)(Cater, 1982).

The complex is cut by dikes of the core rocks; contacts are sharp or gradational. Metamorphic host rocks typically grade into rocks of the contact complex through an increase in the amount of included igneous material; however, some contacts are sharp. Hornblendite contacts are both gradational or sharp into gabbro (Cater, 1982).

Kog_{tc} Contact complex of the Tenpeak-White Mountains pluton (units Kog_t and Kog_{tf})(Cretaceous)—Gabbro, locally pegmatitic diorite, hornblendite, quartz diorite to tonalite, and inclusions of metamorphic rock. Hornblendite and pegmatitic rocks contain crystals as much as 5 cm long. The complex is confined to the northwest end of the pluton where the tonalitic main body sharply cuts the contact complex locally, but elsewhere the intermingling suggests that the main intrusion intruded into a still-molten complex. Locally, highly irregular inclusions of the contact complex occur in the tonalite host rock (Cater, 1982).

Tertiary to Mesozoic plutonic complex

TKmi_s Skagit Gneiss (Tertiary-Cretaceous)—Undivided heterogeneous tonalitic, trondhjemitic, granodioritic, and quartz dioritic orthogneiss with pods and rafts of minor biotite schist, quartzite, amphibolite, calc-silicate rock, and rare marble; pegmatite containing very coarse grained quartz and minor plagioclase. Locally, extensive lit-par-lit intrusion of orthogneiss into minor paragneiss and development of pegmatitic leucosomes in both orthogneiss and paragneiss contribute to an overall migmatitic aspect (Tabor and others, 1989). In the Skagit Gorge type section (Misch, 1987; Tabor and others, 1994; Haugerud and others, 1991) more than half the Skagit Gneiss is orthogneiss. In the Lake Chelan area, abundant orthogneiss contains minor biotite and hornblende schist and paragneiss, amphibolite, marble, calc-silicate rock, and ultramafite (Tabor and others, 1989).

Northeast of the Railroad Creek pluton and southwest or west of the Stehekin River, the unit is composed of gray (CI 2-20), heterogeneous, granodiorite, tonalite, trondhjemite quartz diorite orthogneiss (locally migmatitic, massive or mylonitic) with paragneiss septa; orthogneiss contains quartz (7-25 percent), oligoclase to andesine (30-74 percent), potassium feldspar (0-45 percent), biotite (1-18 percent), hornblende (0-10 percent), and accessory apatite, epidote, titanite, zircon, opaque minerals, muscovite and secondary chlorite; the north end of this belt is richer in hornblende (Tabor, 1961; Libby, 1964; Ford and others, 1988a). In the Chelan divide region, the Skagit Gneiss is predominantly weakly deformed trondhjemitic orthogneiss with numerous bodies of massive and foliated tonalite and granodiorite (Miller, 1987). Directly east of the study area, Wade (1988) described the Skagit Gneiss as quartz diorite, granodiorite, and quartz monzonite orthogneisses and biotite schist metamorphosed to amphibolite facies. The orthogneisses are generally medium grained, consisting of plagioclase, quartz, and potassium feldspar and minor biotite, chlorite, hornblende, and accessory epidote/clinozoisite and apatite. Adams (1961), around McGregor Mountain, described granodiorite, tonalite, and quartz diorite gneiss and granofels containing plagioclase (An_{15}-An_{40})(39-64 percent), quartz (6-35 percent), K-feldspar (0-22 percent), biotite (1-22 percent) and hornblende (0-18 percent); accessories include titanite (0-1 percent), magnetite, apatite, zircon, orthite, muscovite and garnet. Adams (1961) divided the Skagit Gneiss into three northwest-trending gneiss belts, the central belt containing hornblende and the adjacent belts only containing biotite. (Adams' mapping was extensively modified by later workers.) Miller and others (1994) indicate that the Skagit Gneiss rocks involved in the Gabriel Peak Tectonic Zone (see Plate 1) and for at least several kilometers southwest contain leucogranodiorite to hornblende quartz diorite (e.g., Lake Juanita leucogneiss, below) and in general are more felsic than tonalitic orthogneisses that are dominant elsewhere in the Crystalline Core. Locally, orthogneisses are sheet-like bodies, and individual sheets commonly range from 1 to 10 m in thickness (Miller, 1992). The widespread sheeting imparts a distinctly heterogenous appearance to the rocks; mafic sheets are typically intruded by more felsic varieties (Miller and others, 1994).

See Tertiary and Mesozoic orthogneiss (below) for subdivided Skagit orthogneiss bodies in the Twisp quadrangle. In the map area, the unit includes the Lake Juanita leucogneiss of Miller (1987)(see below), subdivided Skagit orthogneiss bodies of Nicholson (1991)(see below), the Skagit Gneiss of Libby (1964), Adams (1961), Webb (1957), Tabor (1961), and Wade (1988). The Skagit Gneiss along its type section to the northwest of the study area along U.S. Highway 20 was originally mapped and named by Misch (1956, 1966). This unit continues northward into Canada, where many investigators have noted the similarities of the Skagit Gneiss to the Custer Granite Gneiss of Daly and Custer Gneiss mapped by McTaggart and Thompson (1967) near the Canadian Border. The probably incorrect correlation of the Swakane Gneiss with the Skagit Gneiss by Cater (1982) is discussed by Miller and others (1994).

Numerous xenoliths and rafts of biotite schist occur along the southern margin of the Skagit Gneiss. According to Hopkins (1987) and Wade (1988), 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. Quartzite occurs in minor amounts, most commonly as well-foliated micaceous quartzite containing either biotite or muscovite.

The paragneiss and metasedimentary and metavolcanic rafts and pods are lithologically similar to the lithologies of both the oceanic Napeequa and volcanic arc Cascade River units, respectively, of the Chelan Mountains terrane (described below) and probably are migmatized and heavily intruded equivalents of those units. Quartzite (metachert), amphibolite (metabasalt), metacarbonate (metamarl and metalimestone) and ultramafite ("metamantle") appear to correlate with other Permian-Triassic Napeequa unit lithologies in the region (see below). However, Miller and others (1994) correlate paragneiss rafts along the southwestern part of the belt (especially near Domke Mountain in the eastern part of the study area) with the Triassic Cascade River unit.

Rasbury and Walker (1992) analyzed single zircons from a garnet-biotite paragneiss yielding a nearly concordant 0.14 Ga age; Sm-Nd depleted mantle model ages from three other Skagit paragneiss samples are

0.45, 0.39, and 1.09 Ga, suggesting a mixture of Proterozoic and Phanerozoic zircons in the Skagit paragneiss protolith. A nearly concordant U-Pb zircon age of 136 Ma suggests the paragneiss protolith is latest Jurassic to earliest Cretaceous (Napeequa unit?), assuming a detrital origin for the zircon (T. Rasbury, Univ. of New York, Stony Brook, oral commun., 1995). Older zircons in the Skagit paragneiss may be detrital and indicative of Precambrian source areas adjacent to the paragneiss protoliths (e.g., Mattinson, 1972; T. Rasbury, Univ. of New York, Stony Brook, oral commun., 1995).

Libby (1964) noted that the heterogeneous granodiorite to trondhjemite and quartz diorite are cut by abundant syn- and post-kinematic dikes and irregular coarse-grained intrusive bodies. He and other early workers interpreted the Skagit Gneiss in this area as derived from sedimentary and volcanic rocks by granitization and migmatization. More recently workers have described synneusis and other possible relict igneous textures, in addition to microgranitoid enclaves, which suggest that the unit formed through anatexis and/or intrusion. Several workers (in their studies to the north along the Skagit type section along U.S. Highway 20), using petrologic and mass-balance arguments, suggest that the migmatization of the Skagit Gneiss is the result of metamorphic differentiation, and (or) metasomatism, and they delegate anatexis to a secondary role. (See Kit references, p. 21, pertaining to the origin of the Skagit Gneiss migmatites.)

Skagit orthogneisses are a complex of rock types that is poorly mapped and poorly dated. The ages reported by Haugerud and others (1991) for the Skagit Gneiss to the north and those in Mattinson (1972) support a latest Cretaceous to earliest Tertiary history (about 87-68 Ma) of protracted intrusion and metamorphism (Appendix 2). Three U-Pb ages in the study area suggest that intrusion of the Skagit orthogneiss protolith may have extended into the Eocene, particularly along the northeastern part of the belt. A tonalitic orthogneiss along Bridge Creek (site 2, Fig. 4; Appendix 2) yields U-Pb zircon ages of 50.2 Ma and 49.4 Ma for coarse and fine fractions, respectively. These ages are in good agreement with calculated $^{206}Pb/^{238}U$ ages from two titanite separates (47.3 and 48.9 Ma) and a well-defined 50 Ma Rb-Sr isochron (Hoppe, 1984). Like the orthogneisses we dated (below), the Bridge Creek orthogneiss experienced moderate ductile deformation and displays relict igneous textures suggestive of only moderate metamorphic recrystallization. P. Misch (pers. commun. to Hoppe, 1980) interpreted the Bridge Creek orthogneiss as late-metamorphic intrusive, which invaded the Skagit core during the waning of the period of metamorphism. The large spread between zircon $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages for the Bridge Creek orthogneiss is interpreted by Hoppe (1984) as indicating incorporation of an older zircon component during intrusion of this unit. Two samples of the Stehekin (tonalitic) orthogneiss (see unit TKog$_s$ below; sites 58 and 59, Fig. 4) yield preliminary discordant U-Pb zircon ages of 49 and 50.5 Ma, similar to the Bridge Creek orthogneiss to the north of these samples (Appendix 3). Other similarities between the approximately 50 Ma Bridge Creek and Stehekin orthogneiss include (1) only mild ductile deformation, (2) retention of relict intrusive textures, and (3) the occurrence of both units along the northeastern portion of the Skagit Gneiss belt adjacent to the Gabriel Peak Tectonic Zone. The existence of penetrative ductile fabric in these rocks suggests that the Eocene ductile deformation of Haugerud and others (1991) affects this portion of the Skagit Gneiss. (See Geologic Setting, p. 3.)

High-grade Metamorphic Rocks

High-grade metamorphic rocks include amphibolite-facies metasedimentary and metavolcanic units as well as plutonic rocks described solely as orthogneiss. This usage is not intended to imply that these orthogneiss units have attained a higher metamorphic grade than Cretaceous-Eocene plutonic rocks described above. Development of a gneissose fabric, while aided by elevated temperatures and directed pressures, may only be the result of locally more intense deformation. Loading and consequent high-pressure metamorphism of the CC (Fig. 6A) is thought to have occurred in the latest Cretaceous and locally the earliest Tertiary *after* emplacement of mid-Cretaceous plutons. (See Geologic Setting.)

Tertiary orthogneiss

PAog$_w$ War Creek orthogneiss (Paleocene to Cretaceous?)—Medium-grained, leucocratic to trondhjemitic orthogneiss consisting of quartz, plagioclase, biotite, and titanite. Small but distinct differences in composition and grain size in the unit suggest that it represents several metamorphosed plutons. The unit 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. The unit was first named and mapped by Adams (1961) and further described and mapped by Miller (1987) and Miller and Bowring (1990).

The War Creek orthogneiss together with the Mount Benzarino orthogneiss (unit PAKog$_b$) form the northeastern side of the Gabriel Peak Tectonic Belt (Plate 1), a zone of strongly deformed and, in part, mylonitic rocks that extends for at least 35 km northwest from the western edge of the map area. The zone is the westernmost part of the Ross Lake Fault Zone (Miller, 1987).

The War Creek orthogneiss intrudes and contains large inclusions and screens of the 90 Ma Reynolds Peak phase of the Black Peak batholith (unit Kog_{br}). The gneiss is distinguished from the Reynolds Peak phase by its lack of hornblende, lower color index, and smaller grain size.

The War Creek orthogneiss intrudes and is younger than the 90 Ma Black Peak batholith. According to R. B. Miller (San Jose State Univ., written commun. to B. Bunning, 1988), ductile deformation in the Ross Lake Fault Zone took place between 65 and 45 Ma. The War Creek orthogneiss may have been a Late Cretaceous pluton, but it was deformed sometime between 65 and 45 Ma. Because of these relations, the War Creek orthogneiss was assigned a Paleocene age by Bunning (1990). However, a recent preliminary U-Pb titanite age of 85-87 Ma suggests the pluton may by Cretaceous (R. B. Miller, San Jose State Univ., oral commun., 1995).

Tertiary to Mesozoic orthogneisses

Skagit Orthogneiss Complex[1] (Tertiary—Cretaceous) divided into:

$PAog_j$ Lake Juanita leucogneiss (Paleocene)—Trondhjemitic and leucogranodioritic orthogneiss. Most of the unit is lineated, but it displays only a weak foliation (although it is strongly foliated east of the study area); in the Gabriel Peak tectonic belt (Plate 1), the leucogneiss is well foliated and in places mylonitic. Coarse-grained igneous textures are generally preserved in the leucogneiss. Solid state foliation is defined by fine- to medium-grained aggregates of biotite and muscovite, elongate quartz and recrystallized quartz lenses, and bands of recrystallized mosaic of quartz, plagioclase, and myrmekite. Plagioclase occurs as both large relict grains and as fine- to medium-grained mosaics with quartz. Perthitic orthoclase and quartz are commonly interstitial. 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, quartzitic schist, and amphibolite, possibly correlative with the Twisp Valley Schist, are locally present (Miller, 1987; Miller and Bowring, 1990).

The unit has been partially subdivided by Nicholson (1991) into the Boulder Creek gneiss, the Purple Creek orthogneiss, and the McGregor Mountain migmatitic orthogneiss (below). The northern part of the leucogneiss is in contact with and similar to the Boulder Creek gneiss. The contact between the two is drawn somewhat arbitrarily as a fault that accompanies a change in foliation intensity and orientation. The Lake Juanita leucogneiss and Boulder Creek orthogneiss are gradational with the Purple Creek orthogneiss to the southwest over a narrow but complex zone of mylonites, numerous small gneissic bodies of heterogenous composition (including one of the flecked gneiss), and younger brittle faults. Foliation within the Boulder Creek gneiss and the Purple Creek orthogneiss strikes northeast, discordant with the northwest-striking foliation of the leucogneiss and the Rainbow Lake Schist. In addition, the Lake Juanita leucogneiss is distinguished from the Boulder Creek and Purple Creek orthogneisses because it lacks hornblende, titanite, and inclusions or bodies of flecked gneiss (Adams, 1961). The leucogneiss is also distinguished from the Purple Creek, Stehekin, and Rainbow Mountain gneisses by a significantly lower color index and coarser grain size (Nicholson, 1991).

The Lake Juanita leucogneiss is cut by numerous (Eocene?) dikes of different compositions. Pegmatites and other silicic dikes are common, but dioritic dikes are more abundant (Nicholson, 1991). The northeastern part of the unit is deformed by the Gabriel Peak tectonic belt of the Ross Lake Fault Zone. (See Geologic History.) The unit intrudes both the Tuckaway Lake gneiss and the Battle Mountain gneiss of Miller (1987); two fractions of leucogneiss yield an internally concordant U-Pb zircon age of 60 Ma (Miller and Bowring, 1990) (Appendix 2). (See Skagit Gneiss, above; Appendix 3.)

[1] The Skagit Gneiss (formal name) is informally termed the Skagit orthogneiss complex to emphasize the dominance of metamorphosed intrusive bodies over paragneiss (e.g., Haurgerud and others, 1991) and the lithologic complexity of included units.

TKog$_b$, TKog$_p$, TKog$_s$, TKog$_r$, TKog$_m$ Nicholson (1991) subdivided the Skagit Gneiss (unit TKmi$_s$) around McGregor Mountain, including part of the Lake Juanita orthogneiss, into several orthogneiss bodies including the Boulder Creek, Purple Creek, Stehekin, Rainbow Mountain, and McGregor Mountain orthogneisses using field and petrologic characteristics (Plate 1). (Unit Rog$_j$, also a subdivision of the Skagit Gneiss, is described above.) All these units are assigned a Late Cretaceous to Tertiary age based on the dating of orthogneiss bodies elsewhere in the Skagit Gneiss. However, two discordant preliminary U-Pb dates (this study) suggest an Eocene intrusive age of about 50 Ma for the Stehekin orthogneiss and possibly the Rainbow Mountain orthogneiss (below; sites 58 and 59; site 59 may be part of Nicholson's [1991] Rainbow Mountain orthogneiss) (Appendix 3). (See Skagit Gneiss, above.)

TKog$_b$ Boulder Creek orthogneiss (Tertiary-Cretaceous)—Leucogranodioritic to trondhjemitic(?) biotite gneisses. Locally this unit contains small (~1 mm) pink garnets and abundant muscovite near its intrusive(?) but tectonically modified contact with Rainbow Lake Schist (Nicholson, 1991).

The unit has a gradational contact to the southwest with the Purple Creek orthogneiss (below) and is distinguished from the Purple Creek orthogneiss by the smaller grain size, lower color index, and the presence of hornblende and titanite in the latter. Farther north, the Boulder Creek orthogneiss is in gradational contact with the McGregor Mountain migmatitic orthogneiss. This unit is similar to, and gradational with, the Lake Juanita leucogneiss, and distinguished from it by a better developed foliation and a slightly higher percentage of biotite. The contact between the Boulder Creek orthogneiss and the Rainbow Lake Schist is characterized by a transition zone (1-500 m wide) containing parallel layers and lenses of each unit. Some of contacts between individual layers of schist and gneiss are sharp, others are gradational. Some of the leucocratic layers may be quartzite (Nicholson, 1991).

Foliation in most of the Boulder Creek orthogneiss strikes northeast, perpendicular to its northwest-striking contact with the Rainbow Lake Schist and the foliation in the schist and the Lake Juanita leucogneiss. However, thin sheets of the Boulder Creek orthogneiss(?) that intruded(?) into and deformed with the schist exhibit a northwest-striking foliation. Locally, near Rainbow Lake, the Boulder Creek orthogneiss and the schist have a concordant east-northeast-striking foliation. The change from the northwest-striking foliation of the Lake Juanita leucogneiss to the northeast-striking foliation of the Boulder Creek orthogneiss is gradual. To the southwest, away from this contact, the foliation in the Boulder Creek orthogneiss, as well as in the Purple Creek, Stehekin, and Rainbow Mountain orthogneisses, is consistently northeast striking (Nicholson, 1991).

Between Rainbow Lake and Bench Creek there are numerous east-northeast-trending faults on the ridge extending southeast from Bowan Mountain. These faults offset the northwest-striking contact between the Boulder Creek orthogneiss and the Rainbow Lake schist exposed along the southwest slope of this ridge. Locally, this contact and the northeast-striking foliation in the orthogneiss are sharply discordant. Although they seem to occur together, it is not yet clear if the cross faults are related to local truncation of the northeast-striking foliation of the orthogneiss. Conversely, the Gabriel Peak Orthogneiss (now informally the Mount Benzarino orthogneiss), which is in sharp contact with the schist to the northeast, has consistently concordant foliation with the schist (Nicholson, 1991) and parallel to the Gabriel Peak Tectonic Belt.

TKog$_p$ Purple Creek orthogneiss (Tertiary-Cretaceous)—Heterogeneous titanite-bearing tonalitic biotite-hornblende orthogneiss. Small bodies of nonfoliated diorite occur in the unit (Nicholson, 1991).

The unit is distinguished from the Lake Juanita leucogneiss and the Boulder Creek and the Stehekin orthogneisses by the presence of hornblende and, in most places, titanite; inclusions of various compositions, including leucogneiss, are common and oriented parallel to the foliation. Contacts between the Purple Creek orthogneiss and the other orthogneisses are gradational and defined on the basis of the presence of hornblende in addition to biotite, which is invariably present in this unit. Northeast-striking foliation is moderately developed throughout the unit (Nicholson, 1991).

TKog$_s$ Stehekin orthogneiss (Tertiary-Cretaceous)—Fine- to medium-grained tonalitic to granodioritic biotite orthogneiss (Nicholson, 1991).

The Stehekin orthogneiss is in gradational contact with both the Purple Creek orthogneiss to the northeast and the Rainbow Mountain orthogneiss to the northwest. It is distinguished from these by its lack of hornblende and titanite. A northeast-plunging, subhorizontal stretching lineation is generally better developed than foliation. North-northeast-striking foliation is poorly to moderately developed throughout the unit. Bodies of flecked gneiss of Adams (1961) occur within the Stehekin orthogneiss (Nicholson, 1991). An Eocene age (about 50 Ma, above) combined with northeast-directed ductile fabrics (shallow lineation and moderate to steep foliations) suggest northeast-directed shear possibly related to Eocene ductile deformation in the Gabriel Peak Tectonic Belt to the east (Miller and Bowring, 1990) and (or) an extension of ductile deformation suggested by Haugerud and others (1991) to the west. (See Geologic Setting.)

$TKog_r$ Rainbow Mountain orthogneiss (Tertiary-Cretaceous)—Fine- to medium-grained granodioritic hornblende-biotite orthogneisses (Nicholson, 1991).

This unit is distinguished from the Stehekin orthogneiss to the southeast by the presence of minor amounts of hornblende and titanite. To the north it is in gradational contact with the Purple Creek orthogneiss and the McGregor Mountain migmatitic orthogneiss. The Rainbow Mountain orthogneiss contains less hornblende than the Purple Creek orthogneiss and is more homogeneous than the McGregor Mountain migmatitic orthogneiss. Poorly to moderately well developed foliation strikes northeast and dips steeply to the northwest or southeast, except near the Stehekin River, where a northwest-striking foliation was measured (Nicholson, 1991).

$TKog_m$ McGregor Mountain migmatitic orthogneiss (Tertiary-Cretaceous)—Heterogeneous unit dominated by hornblende granodioritic and trondhjemitic orthogneisses. This unit contains abundant inclusions of various compositions; in general the inclusions are oriented parallel to the foliation of the unit (Nicholson, 1991).

The gradational contact between this unit and the Boulder Creek orthogneiss south of Rainbow Lake is a zone of banded and migmatitic orthogneisses of various compositions; the unit is distinguished from the Boulder Creek orthogneiss by the presence of hornblende and titanite and, in general, a finer grain size. The Rainbow Mountain orthogneiss has considerably less hornblende and is more homogeneous than the migmatite. A northeast-striking foliation is moderately well developed (Nicholson, 1991).

$PaKog_b$ Mount Benzarino orthogneiss (Paleocene-Cretaceous—Moderately foliated and lineated to mylonitic tonalite; generally fine-to medium-grained. The metamorphic assemblage consists of hornblende, plagioclase (albite to oligoclase), biotite, epidote, quartz, and titanite (Miller, 1987).

The unit is present along the west side of the Black Peak batholith (unit Kog_b) and grades eastward into weakly deformed Black Peak rocks; it is interpreted to be the deformed margin of the batholith (Misch, 1977; Hoppe, 1984; Miller, 1987). There are some compositional differences, however, within rocks mapped as this unit, and it is possible that the protolith for this unit also includes small pluton(s) younger than the Black Peak batholith. The southern "tail" of the orthogneiss is distinguished from the War Creek orthogneiss by the generally weaker foliation and lower mafic mineral content (Miller, 1987).

U-Pb analysis of zircon and titanite and a poorly defined Rb-Sr isochron age yield an apparent age of about 68 Ma; calculated $^{206}Pb/^{238}U$ ages are 68.2 Ma for zircon, and 64.6 and 61.0 Ma for titanite (Hoppe, 1984). This unit was mapped as the Gabriel Peak orthogneiss by Miller (1987) and the western deformed margin of the Black Peak batholith (e.g., Miller and Bowring, 1990), but here it is included in the informally designated Mount Benzarino orthogneiss unit due to (1) general uncertainty pertaining to the extent and nature of the Gabriel Peak orthogneiss (R. W. Tabor, USGS, written commun., 1994), (2) local compositional differences between the Black Peak batholith and rocks previously mapped as Gabriel Peak orthogneiss, and (3) Hoppe's (1984) latest Cretaceous ages. R. B. Miller considered Hoppe's (1984) sample site for the 68 Ma age to reside within the Skagit Gneiss west of the Gabriel Peak Tectonic Belt (oral commun., 1995). However, examination of our compilation and Hoppe's sample site map suggests that the sample dates the Mount Benzarino orthogneiss directly east of the Gabriel Peak Tectonic Belt (the Mount Benzarino orthogneiss as designated herein).

Mesozoic orthogneisses

Kog_l Leroy Creek pluton (Cretaceous)—Light-colored (CI 5-20), hypidiomorphic, xenomorphic mylonitic to locally cataclastic, fine- to medium-grained gneissic biotite tonalite; darker where contaminated. The unit consists of oligoclase, quartz, biotite, minor epidote, sericite, chlorite, and accessory potassium feldspar, opaque minerals, titanite, muscovite, and apatite. The northern part of the pluton contains garnets as much as 1 cm across, as well as significant hornblende and andesine. Most of the epidote is secondary, but some primary magmatic epidote suggests that this pluton was emplaced at depths greater than 6 kb (Zen and Hammarstrom, 1984). Numerous country-rock inclusions are present. Structurally, the unit varies from nearly nonfoliated to extremely schistose, with a characteristically swirled foliation (Cater, 1982). The mylonitic fabric was attributed by Cater (1982) to semi-solid deformation associated with pluton emplacement; however, the fabric appears to be due to solid state deformation during the Eocene (e.g., Haugerud and others, 1991).

The pluton is about 10 km long and 2 km wide and extends along the west side of the Entiat Mountains from upper Rock Creek to upper Phelps Creek.

Contacts are fairly sharp. The long sides of the pluton contain lit-par-lit injection zones, whereas the north end of the pluton terminates in a migmatite zone a few meters thick.

The pluton intrudes the Triassic Dumbell Mountain plutons and is in turn intruded by the 75 Ma Seven Fingered Jack plutons; hence the ages of 45 and 54 Ma determined on mica (Engels and others, 1976) are much too young and indicate heating by later intrusions (Cater, 1982) or are cooling ages. The unit is assigned a latest Cretaceous age based on the above intrusive relations and its similarities with other nearby Cretaceous plutonic bodies, including the occurrence of primary magmatic epidote (suggestive of depths of emplacement equivalent to those indicative of pressures greater than 6 kb), which is regionally common in latest Cretaceous plutons.

Kog_{sm} Sulphur Mountain pluton (Cretaceous)—Light-to medium-gray (CI 5-19), xenomorphic, hypidiomorphic to mylonitic, medium-grained hornblende-biotite granodiorite and tonalite gneiss; mostly augen gneiss containing conspicuous eyes of quartz, oligoclase, microcline, and biotite. The unit also contains locally minor hornblende and minor pyroxene. Accessory minerals commonly include titanite (1 percent) and coarse-grained euhedral clinozoisite; apatite is rare. Secondary minerals are chlorite, sericite, and fine-grained epidote (Ford, 1959, p. 112-134; Crowder and others, 1966; Cater, 1982; Ford and others, 1988a).

A small lobe of the Sulphur Mountain pluton extends into the western edge of the Holden quadrangle, but the pluton underlies a considerable part of the adjacent Glacier Peak quadrangle (Cater, 1982).

The unit has varied contacts, sharp in some places, gradational across a few meters in others, and in still others consisting of lit-par-lit zones of granodiorite and schist or gneiss (Cater, 1982). Unreconciled differences remain concerning the nature of the fabric in the pluton. Cater (1982) describes abundant (solid state?) augen gneiss in the unit, whereas Walker and Brown (1991) suggest that the pluton contains little solid state deformation, and dikes originating from the pluton cross-cut regional fabrics in the host rocks along the west side of the pluton.

The pluton is intruded by the Miocene Cloudy Pass pluton. K-Ar hornblende ages are 70 Ma (Engels and others, 1976) and about 60, 63, and 72 Ma (Tabor and others, 1988). The oldest hornblende age is probably a minimum age of metamorphism. Walker and Brown (1991) obtained concordant U/Pb zircon ages of 96 Ma on two fractions from the pluton, indicating a mid-Cretaceous intrusive age.

Kog_b, Kog_{br},
Kog_{bm} Black Peak batholith (Cretaceous)—Divided into three units by Miller (1987) partially based on previous work of Adams (1961): a main tonalite phase (unit Kog_b), tonalitic orthogneiss (Reynolds Creek phase) (unit Kog_{br}), and dioritic (mafic phase) orthogneiss (unit Kog_{bm}).

The Paleocene War Creek orthogneiss intrudes, and contains inclusions and screens of, the Reynolds Peak phase, which is about the same age as the main phase (Miller, 1987). The main tonalite yielded a 90 Ma K-Ar hornblende age near Roads End campground (Misch, 1964), a 90 Ma zircon (U-Pb) age along U.S. Highway 20 north of the study area (Hoppe, 1984), and a 88-91 Ma (U-Pb) zircon age in the mylonitic margin of the Black Peak batholith near Rainbow Lake. Other ages include (1) a K-Ar hornblende age of 98 Ma (V. R. Todd, USGS, written commun., 1986, to M. F. McGroder *in* McGroder and others, 1990), and (2) K-Ar ages of 88 Ma (hornblende) and 73 Ma (biotite) (Engels and others, 1976). (See discussion of the age of the adjacent Mount Benzarino orthogneiss.) From these relations, the batholith is given a Cretaceous age. Adams (1961) originally mapped the mafic border phase and thought it had formed by metasomatic transformation of the tonalitic phase of the batholith. Field relations suggest, however, that the tonalite *intrudes* the dioritic gneiss and is slightly younger (Miller, 1987).

Kog_b Black Peak batholith (main phase)(Cretaceous)—Directionless, weakly foliated, dominantly tonalite; consists of hornblende, biotite, plagioclase (An_{25}-An_{35}), quartz, and accessory titanite, apatite, and magnetite; pyroxene rare. Epidote is common along fractures. The unit underlies much of the northeast corner of the study area (Adams, 1961; Miller, 1987).

The weak fabric in parts of the pluton probably represent an igneous flow foliation. The unit is directionless elsewhere. Ductile shear zones (a few meters wide) cut the directionless rocks in numerous places, but are less abundant than in the Reynolds Creek phase of this pluton (Miller, 1987).

Kog_{br} Black Peak batholith (Reynolds Peak phase)(Cretaceous)—Tonalitic orthogneiss; dominantly consisting of biotite, plagioclase, quartz, epidote, and titanite; hornblende present locally; epidote replacing plagioclase. The unit is characterized by a moderately developed tectonic foliation and forms the southernmost portion of the Black Peak batholith (Miller, 1987).

The Reynolds Peak phase is distinguished from the weakly foliated to directionless main phase by its stronger fabric and slightly higher mafic mineral content. The Reynolds Peak phase is coarser grained and darker than the War Creek orthogneiss, and it commonly contains hornblende, in contrast to the latter unit (Miller, 1987).

Kog_{bm} Black Peak batholith (mafic phase)(Cretaceous)—Dark, typically well-foliated, granoblastic, porphyroblastic to hypidiomorphic dioritic orthogneiss; locally directionless, the unit consists of plagioclase (An_{25}-An_{40}), biotite and hornblende; locally it contains lesser amounts of pyroxene and epidote with accessory titanite, quartz (10 percent), magnetite, apatite, zircon, and orthite.

The unit occurs on the east side of the Black Peak batholith between Tony basin and Williams Butte (Miller, 1987; Adams, 1961).

Kog_t, Kog_{tf} Tenpeak and White Mountains plutons (Cretaceous)—Divided into tonalite to tonalite orthogneiss (Kog_t) and flaser orthogneiss (Kog_{tf}) units. A 0.5-km-wide interlayered zone mapped by Cater and Crowder (1967) intervenes between units Kog_t and Kog_{tf}; this zone is mapped as part of unit Kog_t on Plate 1. The zone contains interlayered Kog_t and Kog_{tf}, biotite-hornblende diorite gneiss, and thin sheets of hornblende schist, quartzite, and ultramafite. Contacts between layers are sharp or gradational; dark-colored biotite-hornblende diorite and tonalite gneiss are layered on a scale of centimeters to many meters (Cater and Crowder, 1967; Cater, 1982).

Both plutonic bodies occur in the southwest corner of the study area and over large parts of adjacent quadrangles; flaser orthogneiss borders the entire northeastern margin of the pluton. The White Mountains pluton intrusive eastern body in the Twisp quadrangle forms a thick sill-like mass extending from the south-central part of the Holden quadrangle southward about 8 km; about 3 km of this is south of the study area, and this part of the pluton has been studied by Van Diver (1967); the White Mountains and Tenpeak plutons probably connect at depth (Cater, 1982).

The probable occurrence of magmatic epidote in this pluton (Zen and Hammarstrom, 1984) suggests syn-metamorphic crystallization at pressures greater than 6 kb (Tabor and others, 1987a).The occurrence of magmatic epidote suggestive of crystallization at great depth is anomalous for a mid-Cretaceous pluton in the Crystalline Core. Typical mid-Cretaceous plutons (e.g., Black Peak batholith, Eldorado Orthogneiss, or Mount Stuart batholith) show evidence for relatively shallow depths of emplacement followed by later Cretaceous and (locally) Tertiary loading. (See Geologic Setting.)

K-Ar ages of biotite and hornblende are 77.3 ± 2.4 Ma and 92.8 ± 3.1 Ma, respectively (Engels and others, 1976). Concordant U-Pb zircon ages of 90 Ma (R. A. Haugerud and T. Stern, USGS, written commun. to Tabor and others, 1988) and internally concordant U-Pb zircon ages of 91 and 92 Ma (Walker and Brown, 1991) probably represent the syn-metamorphic intrusive age of the plutons; fabric and age constraints indicate that deformation and metamorphism in this area began by 92 Ma and waned between 91 and 85 Ma (Walker and Brown, 1991).

Kog$_t$ Tenpeak and White Mountains plutons (Cretaceous)—Gray to dark-gray (CI 15-40), medium-grained, xenoblastic to hypidiomorphic, slightly foliated and distinctly lineated hornblende-biotite tonalite to tonalitic orthogneiss with rare diorite containing crystals of hornblende as much as 1 cm long and coarse-grained biotite flakes. Small amounts of granodiorite occur in the White Mountains pluton. Rhombs of titanite as much as 0.6 cm long and reddish amber crystals of garnet nearly 1 cm across are locally common in the Tenpeak pluton. Near contacts, undigested xenoliths and schlieren increase in abundance (Cater, 1982; Ford and others, 1988a).

Kog$_{tf}$ Tenpeak pluton flaser orthogneiss—Gray (CI 20-30), fine-to medium-grained, xenoblastic to porphyroclastic biotite and/or hornblende tonalitic flaser orthogneiss; porphyroclasts of oligoclase-andesine enveloped by folia of biotite. Coarse crystals of titanite are common, but garnet is rare (Cater, 1982; Tabor and others, 1988).

The contacts of the flaser orthogneiss with the country rock to the northeast range from sharp to gradational and strictly conformable to foliation trends. Gradational zones are narrow and consist commonly of lit-par-lit injections of the unit into the country rock. The southeast contact with the interlayered zone is gradational (Cater, 1982).

Kog$_e$, Kog$_{ef}$ Eldorado Orthogneiss and flaser orthogneiss (Cretaceous)—Includes a western lineated belt and an eastern, largely mylonitic belt of flaser (augen) orthogneisses (e.g., Tabor, 1961).

A thin septum of the pluton projects southeastward from the main pluton (A. B. Ford, USGS, unpub. mapping, written commun., 1994; our mapping to south of Devore Peak (Plate 1). Libby (1964) described, but did not map, occurrences of quartz diorite (pre-Streckeisen [1973] classification scheme) in the Cascade River Schist, supporting Ford's mapping of the southwestward-projected Eldorado septa.

The pluton intruded to relatively shallow levels (3 kb, or less than about 10 km) and was subsequently deeply buried (see Geologic Setting)(McShane, 19901 1992; Brown and others, 1994; Miller and others, 1993a). Locally the Eldorado Orthogneiss is in thrust contact with the Skagit Gneiss. (See Cabin Creek fault system, Eocene ductile deformation, and the thrust contact of the Eldorado Orthogneiss, p. 12). Kog$_e$ grades over several hundred meters into Kog$_{ef}$.

U-Pb isotope ages of zircon from the Eldorado unit are remarkably concordant at 88 and 90 Ma (Mattinson, 1972). A K-Ar hornblende age of 43 ± 1.5 Ma (Engels and others, 1976) is a cooling age (Babcock and others, 1985). The similar ages and composition of the Eldorado and Bearcat Ridge pluton (unit Kogbp) (e.g., Miller and others, 1993a) and the occurrence of Eldorado septa on strike to the north-northwest of the Bearcat Ridge pluton (Plate 1) suggest that these plutons are related.

Kog$_e$ Eldorado Orthogneiss (Cretaceous)—Light- to medium-gray to green (CI 20-30), medium-to-coarse grained, subidioblastic to idioblastic, biotite-hornblende granodiorite and meta-quartz monzodiorite; consists of albite-andesine plagioclase insets in a matrix of crystalloblastic to cataclastic quartz, potassium feldspar; also includes hornblende, biotite, and epidote. Hornblende and biotite commonly form well-aligned prismatic aggregates or a streaky planar fabric. Accessory minerals include titanite, apatite, zircon, and opaque minerals, and secondary minerals are commonly chlorite, sericite, calcite, prehnite, and zeolites (Tabor, 1961, p. 145; Ford and others, 1988a, p. 18-27, 106-108; White and others, 1988, p. 30).

Kog$_{ef}$ Eldorado flaser orthogneiss (Cretaceous)—Fine- to medium-grained biotite-hornblende granodiorite and quartz monzodiorite flaser orthogneiss (see Kog$_e$); consists of sodic plagioclase crystals in a mylonitic fabric of finer grained quartz, plagioclase, biotite, hornblende, and potassium feldspar, with lesser epidote, titanite, apatite, tourmaline, allanite, opaque minerals, and rutile (Tabor, 1961, p. 149).

Kog$_{bp}$ Bearcat Ridge pluton (Cretaceous)—Light- to dark-gray (CI 15-35), granoblastic, hypidiomorphic, and mylonitic granodiorite orthogneiss and flaser orthogneiss, with lesser tonalite, quartz diorite, and monzodiorite flaser orthogneiss; medium-grained, proto-augen orthogneisses containing abraded, aligned, and fractured plagioclase porphyroclasts in a sutured matrix of quartz, biotite, and orthoclase, and accessory magnetite and ilmenite. Hornblende, where present, is subordinate to biotite. Hornblende-bearing rocks contain considerable ilmenite and coarse titanite (about 1 mm long) and relatively more calcic plagioclase (An_{33}), whereas the hornblende-free rocks contain no ilmenite, minor titanite, and less calcic plagioclase (An_{20}). Muscovite and epidote are locally present, and chlorite commonly replaces mafic minerals. Light-colored gneisses form lenses and layers that are rarely more than several centimeters thick. All rocks are affected by shearing to various degrees. Flaser orthogneiss is more common in the southwestern bodies (Cater and Wright, 1967; Cater, 1982).

The Bearcat Ridge pluton, represented by two plutonic bodies in the study area, crops out in the Lucerne quadrangle between Lake Chelan and Railroad Creek.

Contacts are either sharp or gradational through a zone only a few centimeters thick.

Cater and Wright (1967) correlate the Bearcat Ridge pluton with the Triassic (Mattinson, 1972) Dumbell Mountain plutons. However, a U-Pb age of 89 Ma (S. A. Bowring, unpub. data, *in* Miller and others, 1993a) indicates a Cretaceous age, so these intrusive bodies are possibly coeval with the Eldorado plutonic belt to the northwest (e.g., Miller and others, 1993a).

Kog_{bl} Banded gneiss of Bench Lake (Late Cretaceous)—Strongly layered, fine-grained biotite hornblende tonalitic to granodioritic gneiss with minor quartz diorite gneiss and light-colored biotite tonalitic to granodioritic gneiss commonly containing garnet and thin to thick layers and pods of rocks of the Napeequa River area (units with symbol starting ₧Phm_n, p. 38), especially hornblende schist and schistose hornblendite as well as some ultramafic rocks. These rocks are cut by many irregular pegmatite and aplite dikes, lending a migmatitic aspect to the rocks. Gneiss layers are crystalloblastic gneissose to granoblastic with heterogeneous grain size; some biotite gneiss layers have subidioblastic to porphyroblastic plagioclase with faint relict euhedral zoning, suggesting an igneous origin (Tabor, 1961, p. 130; Grant, 1966, p. 162; Tabor and others, 1988; Ford and others, 1988a).

This unit is confined to a small area on the western edge of the study area, adjacent to the Entiat fault, but it has a large outcrop area in the adjacent Sauk River 1:100,000 quadrangle (Tabor and others, 1988).

The Cretaceous age is based on (1) similarities with banded gneiss in the Chiwaukum Schist, which contains tonalitic gneiss that yields an age of 89 Ma using discordia treatment of the data (Walker and Brown, 1991); and (2) the mid- to Late Cretaceous age of syn-metamorphic intrusion and uplift ages in the Wenatchee block of the Crystalline Core (Figs. 6 and 7, and see Geologic Setting).

Ѣog, Ѣog_a, Ѣog_d, Ѣiq_m, Ѣog_{mm} Metamorphic rocks and orthogneisses of the Marblemount plutonic belt (Triassic)—Metaplutonic rocks and orthogneisses of dominantly tonalitic to quartz dioritic composition. The rocks crop out in a belt that extends southwest from near Marblemount to the Lucerne quadrangle (Fig. 6B; unit 3b). This group of units includes the Marblemount Meta-Quartz Diorite, Magic Mountain gneiss, the Dumbell Mountain plutons, LeConte gneiss, and probably the orthogneiss of the Needles[1]. The orthogneiss of the Needles and LeConte gneiss occur along strike west and northwest, respectively, of the Twisp quadrangle. This belt has been spatially and temporally related to the Cascade River unit of the Chelan Mountains terrane and appears to represent a Triassic sub-volcanic plutonic mass coeval with or closely related to a supra-volcanic arc metavolcanic and metasedimentary sequence termed the Cascade River unit (see Geologic Setting) (Misch, 1966; Tabor, 1961; Cater and Crowder, 1967; Cater and Wright, 1967; Grant, 1966; Mattinson, 1972; Tabor and others, 1987b, 1989).

Generally, metamorphic grade in the Chelan Mountains terrane increases gradually to the southeast (parallel to the Marblemount belt) and more abruptly to the northeast from the Cascade River area, near Marblemount (Fig. 6B). The nonmigmatitic Marblemount Meta-Quartz Diorite near Marblemount is metamorphosed to the chlorite zone of the greenschist facies and is associated with medium-grade schist. Metamorphic grade increases along strike where the migmatitic Dumbell Mountain plutons and correlatives are recrystallized to the amphibolite facies and associated with high-grade schist and gneiss.

The intrusive age of the Marblemount belt is Triassic (about 220 Ma) based upon several roughly concordant results of U-Pb analyses (Appendix 2)(Mattinson, 1970, 1972). Hurlow (1991) also obtained a slightly discordant age of about 218 Ma for the Dumbell Mountain pluton. A K-Ar age of about 95 Ma reflects the

[1] Recent U/Pb dating of the orthogneiss of the Needles by Haugerud and others (1991) (orthogneiss along the western Skagit Gneiss belt) suggests this meta-intrusive may belong to the Marblemount plutonic belt (Fig. 6B).

age of metamorphism or cooling of the Marblemount belt where it occurs in the Wenatchee block of the CC (Figs. 6 and 7). The Magic Mountain gneiss yields discordant zircon U-Pb ages of about 195-210 Ma, suggesting that the protolith was also Triassic and part of the Marblemount belt.

TRog, TRoga, TRogd Dumbell Mountain plutons (Triassic)—The Dumbell Mountain plutons have been divided into three rock units in the Holden and Lucerne 15-minute quadrangles and the area mapped by Libby (1964). Units include hornblende tonalite orthogneiss (TRog); hornblende quartz diorite augen orthogneiss (TRoga), and gneissic hornblende-quartz diorite (TRogd). These units are similar chemically (i.e., low K_2O) and mineralogically except that the plagioclase in tonalite orthogneiss and augen orthogneiss is An_{38}-An_{50} and in the gneissic quartz diorite is An_{30}-An_{50}. The units may represent different original plutons. The major differences between the bodies are mostly a function of deformation (the nature of the gneissic foliation; its degree of segregation, and persistence or prevalence of swirling) (Cater and Crowder, 1967; Cater and Wright, 1967; Cater, 1982).

Contacts between the plutons and the metamorphic country rocks are varied, sharp in some places, gradational in others, but more commonly characterized by lit-par-lit interlayering of intrusives and country rock. Sheets and screens of country-rock schist and gneiss are common in the plutons, particularly unit TRoga between Railroad and Ice Creeks. Notably, a screen of hornblende schist and gneiss about 8 km long separates the quartz diorite augen orthogneiss from the gneissic hornblende quartz diorite (Cater, 1982).

TRog Hornblende tonalite orthogneiss of the Dumbell Mountain plutons—Greenish to dark greenish-gray (CI 10-45), medium-grained, granoblastic, hypidiomorphic, and xenomorphic, locally mylonitic (recrystallization during synmetamorphic ductile shear less pronounced in this unit than in the other Dumbell rocks), hornblende tonalite gneiss with minor quartz diorite; largely plagioclase (An_{38}-An_{50}), hornblende, and quartz, and commonly lesser biotite. Accessory minerals include magnetite, titanite, and apatite. Rare potassium feldspar occurs as veinlets or in the matrix. Secondary minerals include chlorite, clinozoisite-epidote, and sericite (Cater, 1982; Ford and others, 1988a).

TRoga Hornblende tonalite and quartz diorite augen orthogneiss of the Dumbell Mountain plutons (Triassic)—Greenish to dark greenish-gray (CI 10-30), fine-grained, porphyroblastic-granoblastic, locally mylonitic hornblende quartz diorite augen orthogneiss. Mineralogically this unit is very similar to unit TRog (Cater, 1982); however, these rocks are generally more siliceous and show a moderate to strong shear fabric. Inclusions of hornblendite and other country rocks are numerous. Unlike the tonalitic orthogneiss, the foliation of the augen orthogneiss is commonly swirled (Cater, 1982; Ford and others, 1988a).

TRogd Gneissic hornblende-quartz diorite and tonalite of the Dumbell Mountain plutons (Triassic)—Greenish-gray to dark greenish-gray (CI 25-35), fine- to medium-grained, granoblastic, xenomorphic to hypidiomorphic (in massive rocks), locally mylonitic gneissic hornblende-quartz diorite; mineralogically very similar to the other plutons except that plagioclase can be as sodic as An_{30}. Swirled foliations are common (Cater, 1982; Ford and others, 1988a).

TRiqm Marblemount Meta-Quartz Diorite (Triassic)[1]—Green to gray (CI 16-54), relict hypidiomorphic granular to highly mylonitic, quartz diorite, tonalite (both locally gneissic); minor diorite, hornblendite, and schistose hornblendite. Light-colored metatonalite dikes are present. The unit contains plagioclase, hornblende, epidote, biotite; accessory minerals include titanite, apatite, potassium-feldspar, clinozoisite, actinolitic hornblende, magnetite, calcite, and rutile with secondary chlorite, sericite and pyrite. Sodic plagioclase is commonly unzoned, complexly twinned, and filled with epidote and/or sercite (Cater, 1982; Misch, 1966; Grant, 1966; Bryant, 1955, p. 34; Tabor, 1961, p. 14; Ford and others, 1988a; White and others, 1988, p. 28).

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[1] The Marblemount Meta-Quartz Diorite is an integral part of the Marblemount belt and thus, although generally of lower grade than the remainder of the belt, is included with correlative Triassic metaplutonic rocks of gneissic texture.

Units TRogmm (below) and TRiqm are thrust over the Cascade River unit (below) south of the West Fork Agnes Creek (see Grant, 1966; Dougan, 1993).

TRogmm Magic Mountain orthogneiss (Triassic)—Light-colored chlorite-muscovite-epidote-plagioclase (tonalitic, trondhjemitic to alaskitic) gneiss or flaser orthogneiss containing albite to oligoclase filled with epidote, zoned epidote, and chlorite. The orthogneiss is interlayered with chlorite-epidote-quartz-albite schist, which locally contains garnet and hornblende. The gneiss layers range from flaseroid with plagioclase insets in a blastomylonitic quartz matrix to strongly layered quartz and albite rocks with numerous stringers of epidote and chlorite. Contacts between gneiss and schist layers are sharp, but locally gradational. Scale of layering ranges from 5 cm to 6 m, but near the contact with the Cascade River Schist (now Cascade River unit TRhmcc), greenschist layers are as much as 60 m thick (Tabor, 1961; Grant, 1966; Ford and others, 1988a; White and others, 1988, p. 29).

Layered High-grade Metamorphic Rocks

These supracrustal high-grade rocks include metasedimentary and metavolcanic rocks of the Cascade River (CRu) and Napeequa (Nu) units of the Chelan Mountains terrane (CMt), which consist of volcanic arc and oceanic protoliths, respectively (Tabor and others, 1987b, 1989; Babcock and Misch, 1988). (See Geologic Setting.) These units contain distinct protolith packages and, in the case of the Cascade River unit (CRu), Triassic depositional ages, and they provide for regional correlations formerly disparate and geographically localized rock packages. (For example, rocks of the Napeequa River area, Twisp Valley Schist, parts of the Cascade River Schist, and others previous geographically localized units are included in the regional Napeequa unit of the Chelan Mountains terrane. See tabulation on p. 11.)

Mesozoic layered metamorphic rocks

TRhmcc, TRhmcs, TRhmc, TRhmch, TRhmcg, TRhmcb,

Cascade River unit (CRu) of the Chelan Mountains terrane (CMt) (Triassic)—Schist, gneiss, and amphibolite of volcanic arc origin. (See Geologic Setting.) In the northwest quadrant of the study area, these rocks include the Cascade River Schist (TRhmcc unit) of Grant (1966), Libby (1964), and Tabor (1961), and the Spider Mountain Schist (unit TRhmcs) of Tabor (1961)(Fig. 2). The undivided Cascade River Schist was named by Misch (1952, 1966) and later divided by Dragovich (1989), Cary (1990), McShane (1992), and Dougan (1993) in the Cascade River drainage (Fig. 6B) northwest of the Twisp 1:100,000 quadrangle. In the southern part of the study area are the younger gneissic rocks of the Holden area of Cater and Crowder (1967) and Cater and Wright (1967)(units TRhmc, TRhmch, TRhmcb, TRhmcg, marble; informally renamed the Holden assemblage by Miller and others, 1994). These rocks are also correlative with the CRu (Tabor, 1987b, 1989; Miller and others, 1994). The Twentyfive Mile Creek unit (Tabor and others, 1987a) and parts of the migmatitic Chelan Complex (Hopson and Mattinson, 1994) may be southwestern continuations of units of the CRu. Bunning (1990) included the Twenty-five Mile Creek units (TMCu) in the Nu unit of the CMt; however, Miller and others (1994) recently correlated the TMCu with the CRu.

The CRu appears to have an age of about 220 Ma, based on a recent U-Pb analysis of zircons (dated by J. S. Stacey, USGS, *in* Cary, 1990) obtained from a CRu metadacite collected and described by Cary (1990) in the Cascade River drainage. (See Geologic Setting.) Mattinson estimated a crystallization age of about 265 ± 15 Ma for zircons in the leucogneiss unit (unit TRhmcg, below). If the leucogneiss is metamorphosed quartz keratophyre, as suggested by C. A. Hopson (*in* Mattinson, 1972), then the protolith age for part of the sequence may be Permian. The age is compatible with the locally intrusive nature of the 220 Ma Marblemount plutons (TRog, TRoga) into the CRu, suggesting the CRu is Late Triassic or older. However, the zircon age is based on discordant U-Pb analyses of a single fraction; at least some (all?) of these zircons may be detrital, and thus the Permian age is speculative (Miller and others, 1994).

TRhmcc Undivided Cascade River unit schists, gneisses and amphibolites (Triassic)—Amphibolite, hornblende-quartz-plagioclase schist, mica-bearing quartzofeldspathic schist, clinopyroxene-bearing quartzofeldspathic schist and their granofelsic equivalents with minor marble and metaconglomerate locally. The clinopyroxene-bearing rocks are restricted to the northeastern part of the belt in Libby's (1964) study area north of the Lucerne 15-minute quadrangle (Fig. 2). Libby mapped these rocks as the Cascade River Schist. All these rock types have counterparts along strike to the southeast in the Holden and Lucerne quadrangles where they have been included in separate units. The undivided CRu west and northwest of Libby's study area (Fig. 2; Plate 1) as mapped by Grant (1966) and Tabor (1961). These rocks consist of mica schist and amphibolite and minor metaconglomerate and marble. The schists and amphibolites are mostly fine-grained, highly fissile, green, brown, and black micaceous rocks ranging from phyllitic sericite-quartz schist to granoblastic biotite- and muscovite-biotite-quartz-albite (or oligoclase) schist and fine-grained paragneiss. Many of the rocks contain garnet and blue-green tourmaline. Hornblende-biotite-andesine schist displays garbenschiefer texture. Fine-grained amphibolite is common. Calcareous mica schist occurs locally.

The composition and mutual interlayering of the amphibolite, schist, metaconglomerate, and marble indicate derivation from several interbedded supracrustal rock types. The amphibolite and hornblende-quartz-plagioclase schist were derived from intermediate to mafic flows, tuff, and volcanic graywackes. Most of the quartzofeldspathic rocks were originally arkosic; however, rocks locally contain relict porphyritic and synneusis textures, which indicate derivation from a porphyry, probably of dacitic composition (Libby, 1964). These lithologies represent the arc-type protoliths of the CRu and are very similar to CRu lithologies in the Cascade River drainage to the northwest (Dragovich and others, 1989; Brown and others, 1994).

TRhmcs Spider Mountain Schist (Triassic)—Phyllitic quartz-rich schist and calcareous mica schist (grading into impure marble), and silicic metaporphyry. Included marbles are coarsely crystalline and gray to white and contain many impurities of quartz, plagioclase, and mica (Tabor, 1961).

TRhmc Heterogeneous gneiss, schist, and quartzite of the younger gneissic rocks of the Holden area (Triassic)—Interlayered, light and dark, fine-grained hornblende, hornblende-biotite, and biotite gneiss and schist, epidote-garnet gneiss, calcareous gneiss, graphitic schist, micaceous quartzite (probably metafelsic volcanic rocks), and thinly laminated quartzite; scattered layers of siliceous pebble conglomerate; isoclinally folded with bedding apparent locally.

Miller and others (1994) combine units TRhmc and TRhmch because the units are not lithologically distinct. Hornblende gneiss, amphibolite, and hornblende-biotite schist and gneiss dominate, but biotite schist, biotite gneiss, and calc-silicate (diopside-biotite-quartz) schist are also abundant. Layers of marble, calcareous gneiss, and quartzite are widespread, but they make up less than 5 percent of the unit. Rare constituents are pelitic schist, granitoid gneiss, hornblendite, and metaconglomerate with granitoid and quartz pebbles in a biotite-hornblende gneiss matrix. Amphibolites and hornblende-biotite gneisses probably were basalt or basaltic andesite originally. Calc-silicate gneisses and schists probably have a range of protoliths (they consist of diopside, quartz, tremolite, plagioclase, titanite, epidote-clinozoisite, biotite, grossularite, and calcite) and probably represent calcareous siltstone and mudstone (marl protolith; e.g., Dragovich, 1989) interbedded with tuffaceous and siliciclastic rocks. Hornblende-biotite gneisses are probably metatonalites intruded into the supracrustal rocks before or during metamorphism (Miller and others, 1994).

TRhmch Hornblende schist and gneiss of the younger gneissic rocks of the Holden area (Triassic)—Black, fine-grained schist and dark-green to black, fine- to medium-grained gneiss with conspicuous light and dark laminae less than 1 mm thick and interlayers of biotite schist and gneiss. A hornblende lineation is common (Cater and Crowder, 1967; Cater and Wright, 1967).

TRhmcg Biotite (leuco)gneiss of the younger gneissic rocks of the Holden area (Triassic)—White to light-gray, fine- to medium-grained, well-foliated gneiss (locally interlayered with centimeter- to meter-thick amphibolites) with lenses of quartz as much as 1 mm thick. The unit contains abundant quartz (about 60 percent), plagioclase (about 30 percent), and biotite (about 10 percent); accessory minerals include garnet, titanite, epidote/clinozoisite, and white mica. A lineation is defined by sparse streaks of biotite. Hornblende schist and gneiss layers are common to the east and sparse in the western part of the unit (Cater and Crowder, 1967; Cater and Wright, 1967; Miller and others, 1994).

Three analyzed samples of leucogneiss (R. B. Miller, San Jose State Univ., unpub. data; this study, sample DNR-94-18M, Appendix 2) contain 77-78 percent SiO_2. The medium grain size and homogeneity of the rock are compatible with a volcanic rhyolite protolith (C. A. Hopson, *in* Mattinson, 1972). Interlayering of amphibolites (basalt or basaltic andesite) with metarhyolite suggests an original bimodal volcanic suite (Miller and others, 1994); this association is also described elsewhere in the CRu (Libby, 1964; Dragovich, 1989; Cary, 1990). The syndepositional (Triassic) volcanogenic massive sulfide deposit of the Holden mine occurs in or adjacent to this unit (Dragovich and Derkey, 1994).

TRhmcb Clinopyroxene-biotite-quartz schist of the younger gneissic rocks of the Holden area (Triassic)—Light-gray to black, with sulfide-induced rusty red-weathering stain, very fine grained schist with finely disseminated pyrrhotite. Flame structures and graded bedding are visible locally (Cater and Crowder, 1967; Cater and Wright, 1967).

Marble within units of the younger rocks of the Holden area(Triassic)—White, fine- to medium-grained and sugary marble beds. The unit crops out along the northernmost part of the Holden quadrangle (Cater and Crowder, 1967) and may be correlative with two mapped marble beds described by Libby (1964) in the undivided Cascade River Schist on strike directly to the north of the Holden quadrangle. Fairly pure marbles reach approximately 20 m in thickness. Many of the marbles mapped by Cater and Crowder (1967) and Cater and Wright (1967) are actually calc-silicate rocks and not pure marbles (Miller and others, 1994).

Mesozoic to Paleozoic layered metamorphic rocks

TRPhmnr TRPhmnt, TRPhmnh, TRPhmnb, TRPhmnq,

Napeequa unit of the Chelan Mountains terrane (Triassic to Permian)—Schist, gneiss, amphibolite, metagabbro, and ultramafite. (See Geologic Setting.) This oceanic unit of the Chelan Mountains terrane includes the Rainbow Lake Schist (unit TRPhmnr), Twisp Valley Schist (unit TRPhmnt) originally mapped by Adams (1961), and rocks of the Napeequa River area originally mapped by Cater and Crowder (1967) and Cater and Wright (1967)(Tabor and others, 1987b, 1989; Miller and others, 1993b, 1994). The rocks of the Napeequa River area have been subdivided, whereas the Rainbow Lake Schist (TRPhmnr) and Twisp Valley Schist (TRPhmnt) remain largely undivided. (See Miller and others, 1993b, and Dragovich, unpub. data, for general map subdivisions of the Twisp Valley Schist.)

The age of the Napeequa unit is problematic due to the paucity of datable materials. Tabor and others (1987a) indicate that isotopic ages reflect mostly metamorphism and uplift and infer a Paleozoic or older protolith age for the Napeequa rocks on the basis of an old zircon component in the orthogneiss to the south of the study area. Recent discordant Rb-Sr data from the rocks of the Napeequa River area suggest a Jurassic age for the Nu (Magloughlin, 1995). The Napeequa unit may be the metamorphosed equivalent of the older part of the Hozameen Group (Misch, 1966; Tabor and others, 1989); more specifically, the Twisp Valley Schist may be correlative with the Triassic upper chert-rich section (refer to Ray, 1986) of the Hozameen Group (Miller, 1987; Miller and others, 1993b). The Hozameen Group and its correlative, the Bridge River Complex of the eastern Coast Mountains of British Columbia, are offset by the Straight Creek fault (Fig. 6) and form a Mississippian to Middle Jurassic terrane of greenstone and chert, with lesser amounts of limestone, argillite, gabbro, volcaniclastic sandstone, and serpentinite (McTaggart and Thompson, 1967; Haugerud, 1985; Ray, 1986; Potter and others, 1986; Cordey and Schiarizza, 1993).

TRPhmnr Rainbow Lake Schist, undivided (Triassic-Permian)—Biotite schist and quartzite (metachert), less common amphibolite, marble, and calc-silicate, and rare metaperidotite. The most distinctive rock type is a staurolite-garnet-biotite schist. Sillimanite-bearing staurolite schist occurs locally near Rainbow Lake. Leucocratic sills and pegmatites intrude the schist; some of them have been folded with the schists (Miller, 1987). Tight folds of foliation are common. An axial-planar foliation is well developed, and a mineral lineation commonly parallels fold axes (Miller, 1987).

TRPhmnt Twisp Valley Schist, undivided[1] (Triassic-Permian)—Siliceous schist and impure quartzite (metachert) that grade into phyllite, with some amphibolite and greenschist, marble, calc-silicate, and minor metaperidotite. Siliceous rocks locally grade into pelitic graphitic phyllite and mica schist that have rhythmically bedded metasandstone and metasiltstone interlayers. The

[1] "Unidivided" here indicates that the rock unit could be subdivided into its constituent lithologies (e.g., metachert, metagabbro, etc.).

marbles and metaperidotites occur as lenses that are elongate parallel to foliation and range from less than 1 m to about 50 m in thickness. The interleaving of metaperidotites and supracrustal rocks suggests that significant tectonic mixing predated the complicated folding and metamorphic history of the unit (Miller, 1987; Miller and others, 1993b).

Metamorphism reached greenschist and amphibolite facies. Andalusite porphyroblasts occur in several biotite schists near Scaffold Peak; andalusite has been partially replaced by sillimanite and muscovite, which also define the foliation that wraps around the andalusite porphyroblasts (Miller, 1987; Miller and others, 1993b).

Foliation is prominent throughout the unit. The first foliation (S1) is typically tightly to isoclinally folded (F2), and an axial-planar foliation (S2) is the dominant fabric element in the Twisp Valley Schist. Open to tight folds (F3) of S2 are common and generally have wavelengths ranging from less than 0.5 m to 3 m, but locally reaching at least 30 m. F3 folds are typically noncylindrical and have axes that curve significantly. The refolding of F2 structures apparently accounts for the highly varied orientation of F3 axes. A mineral lineation is commonly parallel to F2 axes and is folded by F3 (Miller, 1987; Miller and others, 1993b).

TRPhmnh, TRPhmnb, TRPhmnq,

Rocks of the Napeequa River area, divided, crop out in a belt along the western part of the Holden 15-minute quadrangle in the southwestern quadrant of the study area. Rocks of the Napeequa area are probably juxtaposed against the Swakane Gneiss along a thrust fault west of the Chiwawa River (see Tabor and others, 1987a).

TRPhmnh Hornblende schist and gneiss (amphibolite) and biotite-hornblende schist of the rocks of the Napeequa River area (Triassic-Permian)—Black, fine-grained, hornblende schist and biotite-hornblende schist; dark-green to black, fine-to medium-grained hornblende gneiss containing light- and dark-colored laminae less than 1 mm thick; also containing mica-quartz schists and micaceous quartzites a few centimeters to tens of meters thick that are very similar to unit TRPhmnq. Pervasive crenulation lineations parallel the commonly observed hornblende mineral lineations (Cater and Crowder, 1967). Included in this unit are mica-quartz augen gneiss of the rocks of the Napeequa River area; Cater and Crowder (1967) describe this unit as gneiss with insets of quartz and plagioclase and relict granitoid pebbles. (Granitoid pebbles are probably largely sheared porphyritic dikes; R. A. Haugerud, USGS, 1994, oral commun.).

TRPhmnb Calcite-biotite-quartz schist and gneiss of the rocks of the Napeequa River area (Triassic-Permian)—Dark-brown to black, rusty stained, very fine to fine-grained schists and gneisses, with as much as 5 percent graphite in localized layers several meters thick; epidote and aligned hornblende crystals locally abundant; light- and dark-colored layers and lenses are typically 1 mm thick. The unit also includes a few layers of hornblende schist up to several meters thick. Crenulation lineations are common (Cater and Crowder, 1967).

TRPhmnq Mica-quartz schist and micaceous quartzite of the rocks of the Napeequa River area (Triassic-Permian)—Bluish-gray, weathering to yellow and red, very fine to fine-grained impure quartzites (metachert). Thin mica-rich laminae separate layers of quartz 2-5 mm thick that pinch and swell; as much as 5 percent graphite is present in some layers. The unit also contains a few layers of hornblende schist as much as several meters thick. Crenulation lineation and numerous small-scale chevron folds are characteristic (Cater and Crowder, 1967).

Marble within units of the rocks of the Napeequa River area (Triassic-Permian)—White to gray, fine-to medium-grained marble with graphite dust around siliceous fragments locally (Cater and Crowder, 1967).

* Ultramafite within units of the rocks of the Napeequa River area (Triassic-Permian)—Light- to dark-green, fine-grained, fibrous to well-foliated pods and layers of

serpentinite and talc-rich rock near Boulder Pass. Also includes hornblendite and hornblende peridotite on Buckskin Mountain. The symbol shows the location of some of the ultramafites (but the bodies are too small to map at this scale). Contacts are highly sheared. Ultramafites are probably tectonically placed slivers of mantle-derived rock (Cater and Crowder, 1967).

Precambrian layered metamorphic rocks

p€gns, p€ams Swakane Biotite Gneiss (Precambrian)—Homogeneous, light-brown to brownish-gray, fine- to medium-grained, strongly foliated gneiss (unit p€gns), locally including thin layers of hornblende schist and gneiss, some of which are mappable (unit p€ams), and rare thin layers of quartzitic rock (unmappable at this scale). The gneisses commonly contain clinozoisite-epidote; kyanite occurs sparsely on Phelps Ridge but is rare elsewhere. Garnet is common in many places. Biotite streaks define a foliation. Lenses and pods of quartz and irregular masses of leucosome tonalite (unit Kit) are notably abundant in some places and common elsewhere (Waters, 1932; Cater, 1982; Sawyko, 1994).

The protolith of this unit is problematic. Except for the isolated original amphibolite (metavolcanic flows) and quartz-epidote-rich layers (metasedimentary layers), no textural or structural features remain to constrain its protolith. Some of the amphibolite layers can be traced for kilometers and represent an original compositional layering or bedding. Waters (1932, p. 616) thought the gneiss was likely derived from mostly arkosic material; later (*in* Mattinson, 1972, p. 3773) he considered a volcanic derivation more likely because accumulation of a nearly uniform pile of arkose many thousands of meters thick and of wide areal extent seemed unlikely. The gneiss chemically approximates a dacite (Cater 1982) and was probably derived from a huge, fairly silicic pile of dacitic volcanic rocks (Cater, 1982). Modal analyses by Ford and others (1988a) show that the plutonic equivalent would be a tonalite.

The Swakane Biotite Gneiss has been warped into steep sided, generally open folds having steep axial planes. The foliation is commonly uniform for considerable distances, but locally attitudes of the foliation are irregular, particularly adjacent to intrusive bodies (Cater, 1982).

$^{207}Pb/^{206}Pb$ ages from three large multigrain zircon fractions reported by Mattinson (1972) from the Swakane gneiss are Precambrian (1,304, 1,398, and 1,486 Ma; corrected by Tabor and others (1987a) for revised decay constants). Tabor and others (1978a) also reported Precambrian $^{207}Pb/^{206}Pb$ ages of two multigrain zircon fractions from an amphibolite layer within the Swakane gneiss of 1,427 and 1,464 Ma. A minimum protolith age of 690 Ma (R. J. Fleck and A. B. Ford, USGS, written commun., to R. W. Tabor and others, 1987a) was obtained using numerous Rb-Sr whole rock samples. T. Rasbury and N. W. Walker (1992; written commun., 1994) isolated rounded, subrounded, and euhedral zircons; three of the four analyzed grains define a well-correlated discordia array that intercepts concordia at 1,400 Ma, whereas the fourth grain has a 1,600 Pb-Pb age; Sm-Nd depleted mantle model ages of two samples are 1,180 and 1,270 Ma, respectively. Rasbury and Walker (written commun., 1994) interpret the unit to be an approximately 1,400 Ma meta-igneous unit with two zircon populations. One population represents the primary crystallization age of about 1,400 Ma; the other is Mesozoic and is probably the result of Late Cretaceous metamorphic zircon overgrowth.

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Appendix 1. Geochemical analyses.

See Figure 4 for sample locations. na, not analyzed; nd, not detected; ppm, parts per million. Fe expressed as total FeO. Analyses O through S done at the Western Washington University geochemical loaboratory. See also Cater (1982).

Map loc.	Sample no.	Unit	Location (N. Lat.; W. Long.)	Reference
A	RD90-27	High Pass pluton	48° 06.35' 120° 57.08'	Dawes, 1991a
B	RD90-29	High Pass pluton	48° 06.83' 120° 57.03'	Dawes, 1991a
C	RD90-28	High Pass pluton	48° 05.8' 120° 56.26'	Dawes, 1991a
D	RD90-22	High Pass pluton	48° 05.63' 120° 54.33'	Dawes, 1991a
E	RD90-20	High Pass pluton	48° 06.33' 120° 54.00'	Dawes, 1991a
F	RD90-23	Napeequa unit	48° 05.70' 120° 53.65'	Dawes, 1991a
G	RD88-53	Clark Mtn. pluton	48° 02.57' 120° 56.18'	Dawes, 1991a
H	RD89-37	Entiat pluton	48° 09.03' 120° 48'.78	Dawes, 1991a
I	RD89-26	Entiat pluton	48° 09.00' 120° 49.82'	Dawes, 1991a
J	RD90-12	Entiat pluton	48°06.98' 120 °48.02'	Dawes, 1991a
K	RD90-16	Entiat pluton	48° 08.08' 120° 48.13'	Dawes, 1991a
L	RD88-54	Clark Mtn. pluton	48° 02.33' 120° 55.52'	Dawes, 1991a
M	RD89-2	Clark Mtn. pluton	48° 02.65' 120° 55.85'	Dawes, 1991a
N	RD89-4	Clark Mtn. pluton	48° 02.65' 120° 55.85'	Dawes, 1991a
O	DNR 94 29A	North Creek Volcanics	See Fig. 4	this study
P	DNR 94 29B	North Creek Volcanics	See Fig. 4	this study
Q	DNR 94 29D	North Creek Volcanics	See Fig. 4	this study
R	DNR 94 29D2	North Creek Volcanics	See Fig. 4	this study
S	DNR 94 18M	Cascade River unit	See Fig. 4	this study
T	Tenpeak pluton 1	Tenpeak pluton	composite sample (see Cater, 1982)	Cater, 1982
U	White Mtns. pluton 2	White Mtns. pluton	composite sample (see Cater, 1982)	Cater, 1982
V	High Pass pluton 1	High Pass pluton	composite sample (see Cater, 1982)	Cater, 1982
W	Riddle Peaks pluton 1	Riddle Peaks pluton	composite sample (see Cater, 1982)	Cater, 1982
X	Cardinal Peak pluton 1	Cardinal Peak pluton	composite sample (see Cater, 1982)	Cater, 1982
Y	Cardinal Peak pluton 2	Cardinal Peak pluton	composite sample (see Cater, 1982)	Cater, 1982
Z	Clark Mtn. pluton 1	Clark Mtn. pluton	composite sample (see Cater, 1982)	Cater, 1982
AA	Duncan Hill pluton 1	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AB	Duncan Hill pluton 2	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AC	Duncan Hill pluton 3	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AD	Duncan Hill pluton 4	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AE	Duncan Hill pluton 5	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AF	Duncan Hill pluton 6	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AG	Duncan Hill pluton 7	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AH	Duncan Hill pluton 8	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AI	Duncan Hill pluton 9	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AJ	Duncan Hill pluton 10	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AK	Duncan Hill pluton 11	Duncan Hill pluton	see Cater, 1982	Cater, 1982
AL	Larch Lakes pluton 1	Larch Lakes pluton	composite sample (see Cater, 1982)	Cater, 1982
AM	Rampart Mtn. pluton 1	Rampart Mtn. pluton	composite sample (see Cater, 1982)	Cater, 1982
AN	Old Gib volcanic neck 1	Old Gib volcanic neck	composite sample (see Cater, 1982)	Cater, 1982
AO	Eocene tonalite 1	Eocene tonalite	composite sample (see Cater, 1982)	Cater, 1982
AP	Railroad Creek pluton 1	Railroad Creek pluton	composite sample (see Cater, 1982)	Cater, 1982
AQ	Copper Peak /Holden Lake pluton 1	Copper Peak /Holden Lake pluton	composite sample (see Cater, 1982)	Cater, 1982
AR	Eocene granodiorite 1	Eocene granodiorite	composite sample (see Cater, 1982)	Cater, 1982

na = not analyzed

nd = not detected

Appendix 1, Geochemical analyses (continued)

Map	Major elements (weight percent)										Trace elements (ppm)							
loc.	SiO2	Al2O3	TiO2	FeO*	MnO	CaO	MgO	K2O	Na2O	P2O5	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr
A	69.08	17.39	0.308	1.86	0.024	3.81	0.44	1.88	5.12	0.086	7	0	4	14	1005	43	957+	173
B	71.81	15.76	0.257	1.53	0.024	2.51	0.4	2.71	4.92	0.07	9	3	5	0	1640	52	955+	158
C	71.11	16.41	0.242	1.48	0.024	3.34	0.31	2.2	4.81	0.069	5	4	3	3	1160	47	842+	154
D	69.2	16.98	0.288	2.05	0.047	3.86	0.47	1.87	5.13	0.094	6	5	0	4	823	42	792+	155
E	71.57	16.02	0.287	1.38	0.016	2.72	0.26	3.08	4.58	0.078	9	2	0	0	1819	60	603	120
F	57.76	17.43	0.956	8.19	0.167	7.82	3.58	0.14	3.73	0.197	0	17	27	207	5	2	210	75
G	64.14	0.87	17.02	4.67	0.07	1.55	4.75	4.31	2.09	0.35	18	20	6.4	51	919	na	804	149
H	55.19	18.88	1.004	7.97	0.152	7.94	3.89	1	3.74	0.239	0	9	22	263	354	20	580	92
I	50.55	11.63	1.184	11.53	0.189	8.26	13.5	1.16	1.88	0.095	29	265	40	291	204	23	255	64
J	56.11	16.01	0.0959	7.53	0.151	8.36	5.74	0.99	3.97	0.183	12	200	29	177	324	18	483	104
K	54.59	13.21	1.183	10.06	0.174	9.08	8.71	0.86	2.04	0.101	5	368	42	301	263	15	301	92
L	61.12	17.05	0.859	6	0.012	6.19	2.84	1.69	3.86	0.286	5	34	15	99	733	41	577	150
M	63.87	17.41	0.786	4.34	0.064	5.07	1.72	1.9	4.59	0.263	4	9	8	55	843	47	843+	183
N	67.38	16.98	0.693	3.39	0.04	4.23	0.84	1.22	4.99	0.224	5	0	2	8	907	37	841+	179
O	63.39	18.3	0.673	4.91	0.124	3.87	2.12	1.64	4.72	0.26	27	49	13	108	750	42	558	164
P	50.85	14.89	1.041	9.32	0.155	11.38	9.32	0.86	2.02	0.142	85	376	46	356	249	13	350	72
Q	67.02	45.4	0.963	4.31	0.095	0.76	3.26	0.84	7.08	0.279	83	177	10	110	313	21	143	137
R	51.6	17.17	1.286	8.81	0.176	8.42	7.89	1.39	2.89	0.376	144	400	25	216	857	34	818	159
S	76.16	13.12	0.172	2.33	0.011	1.53	0.2	0.09	6.35	0.034	9	4	12	14	37	2	98	97
T	62.3	16.89	0.74	5.1	0.11	5.92	2.36	1.39	3.75	0.23	7	30	15	150	700	na	1500	150
U	59.67	16.34	0.92	6.26	0.13	6.11	3.61	1.67	3.43	0.27	15	70	15	150	700	na	700	150
V	70.43	16.07	0.33	1.87	0.03	3.24	0.65	1.77	4.67	0.09	1.5	1.5	na	15	1500	na	1500	150
W	45.08	22.06	1.31	8.82	0.1	11.67	5.43	0.23	2.85	0.16	15	7	30	300	na	na	1000	20
X	66.09	16.5	na	3.47	0.06	4.1	0.96	1.61	4.36	na	20	50	10	100	1000	na	1500	70
Y	65.3	18.5	na	3.82	0.09	5	0.93	1.17	4.55	na	nd	7	15	100	700	na	1000	50
Z	66.26	16.09	0.74	3.81	0.06	4.3	1.53	1.93	4.01	0.21	3	15	7	70	700	na	1500	150
AA	60.7	17.4	0.95	6.31	nd	5.7	2.23	1.5	4.13	0.39	7	30	15	100	700	na	700	150
AB	63	15.9	1.03	5.92	0.15	5.5	2.47	2	3.57	0.41	7	30	15	100	700	na	500	150
AC	63	17.3	nd	5.21	0.36	5.2	1.6	2.13	3.56	nd	20	50	20	150	1500	na	700	70
AD	66.4	16	0.64	3.83	nd	3.6	1.33	2.8	3.73	0.24	na	15	15	70	1500	na	500	150
AE	68.3	15.5	0.44	2.63	nd	3.6	1.13	2.6	3.9	0.17	na	30	15	70	700	na	500	30
AF	70	16.4	nd	3.02	0.06	3.6	0.81	2.4	3.86	nd	na	15	7	70	1000	na	500	70
AG	72	14.4	0.42	2.46	0.08	2.6	0.97	3.3	3.67	0.14	10	30	20	150	1000	na	700	70
AH	73.9	13.9	0.12	1.51	0.02	0.9	0.16	5.3	3.83	0.08	na	15	7	30	1000	na	300	150
AI	74.2	13.2	0.12	1.83	0.05	0.7	0.09	5.6	3.43	0.08	na	10	50	10	700	na	70	150
AJ	75.4	13.1	0.07	1.34	nd	0.6	0.11	5.7	3.3	0.08	na	5	5	na	1000	na	70	70
AK	74.2	12.8	0.06	1.04	nd	0.8	0.08	5.5	3.5	0.08	na	7	na	na	500	na	70	70
AL	69.5	16.7	na	2.64	0.06	3	0.63	3.01	3.96	na	na	15	10	70	1000	na	700	70
AM	73.2	15.4	na	2.33	0.06	2.3	0.53	3.01	3.81	na	na	10	7	70	1000	na	500	70
AN	64.46	16.15	0.38	4.18	0.1	3.93	1.75	1.52	3.82	0.13	3	3	15	70	700	na	700	70
AO	66.5	14.4	na	7.95	0.08	3.92	2.16	1.41	3.39	na	10	30	20	150	500	na	700	100
AP	70.1	15.6	na	2.57	0.05	3.1	0.66	2.5	3.91	na	10	20	10	100	1000	na	500	150
AQ-	53.26	18.91	2.31	6.93	0.12	8.95	4.01	0.66	2.95	0.69	15	50	30	200	500	na	700	50
ĀR	74.5	15.6	na	1.66	0.04	2	0.32	3.26	3.74	na	7	7	5	30	700	na	300	na

(Appendix 1. Geochemical analyses (continued)

Map loc.	Trace elements (ppm) Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
A	4	10	22	3	90	7	22	33	4
B	5	6.2	24	2	89	8	14	44	2
C	4	9.2	21	4	76	8	23	33	2
D	5	12.3	23	2	92	10	11	39	1
E	4	9.3	20	10	66	9	19	0	2
F	20	4.4	18	20	83	0	0	2	1
G	10	26	na	13	112	na	25	48.7	na
H	18	6.8	18	0	92	5	11	27	2
I	15	4.9	13	0	120+	0	8	18	0
J	21	6.2	15	5	93	4	17	28	1
K	24	6.4	18	17	108	2	4	23	2
L	17	11.5	20	0	93	3	18	21	3
M	10	13.9	22	5	105	7	21	60	3
N	7	15.3	24	5	119+	13	27	65	6
O	24	10.3	16	33	83	8	15	54	5
P	19	1.3	14	56	68	0	16	12	1
Q	12	9	15	6	82	9	28	51	5
R	20	12.6	22	81	100	9	23	39	7
S	27	1.5	12	7	1	0	5	35	1
T	15	na	15	15	na	na	na	na	na
U	15	na	15	15	na	na	na	na	na
V	na	na	15	3	na	na	na	na	na
W	20	na	30	30	na	na	na	na	na
X	10	na	50	100	na	na	na	na	na
Y	15	na	30	100	na	na	na	na	na
Z	7	na	15	7	na	na	30	na	na
AA	15	10	30	7	na	70	na	na	na
AB	15	10	30	20	na	na	50	na	na
AC	15	na	20	30	na	na	na	na	na
AD	15	10	20	10	150	20	70	na	na
AE	15	na	15	7	500	150	na	na	na
AF	10	10	15	5	300	70	na	na	na
AG	15	na	20	10	na	na	na	na	na
AH	15	10	20	7	na	70	na	na	na
AI	30	na	30	3	na	20	100	200	na
AJ	15	na	20	na	na	20	na	na	na
AK	10	na	20	1	na	15	na	na	na
AL	15	na	20	3	na	na	na	na	na
AM	10	na	20	10	na	na	na	na	na
AN	15	na	7	na	na	na	na	na	na
AO	20	na	20	15	na	na	na	na	na
AP	15	na	30	5	na	na	na	na	na
AQ	30	na	20	50	na	na	na	na	na
AR	10	na	15	3	70	na	na	na	na

Appendix 2. Geochronologic data for samples in and adjacent to the study area.

See Figure 4 for sample locations in the study area. Ages from adjacent areas (e.g, Chelan and Sauk River 1:100,000 quadrangles, Tabor and others, 1987a and 1988, respectively) are not located on Figure 4. In addition, locations for some dated samples from the Twisp study area were not specified by previous authors. NM, nonmagnetic fraction; M, magnetic fraction; NMA, nonmagnetic abraded fraction; FDFZ, Foggy Dew Fault Zone.

Numbered comments below are keyed to numbers in the last column in the data entries.

(1) Borealis Ridge
(2) Borealis Ridge
(3) Garnet amphibolite in the Swakane Biotite Gneiss
(4) Garnet amphibolite in the Swakane Biotite Gneiss
(5) Garnet amphibolite in the Swakane Biotite Gneiss
(6) Garnet amphibolite in the Swakane Biotite Gneiss
(7) Garnet amphibolite in the Swakane Biotite Gneiss
(8) Garnet amphibolite in the Swakane Biotite Gneiss
(9) Garnet amphibolite in the Swakane Biotite Gneiss
(10) Garnet amphibolite in the Swakane Biotite Gneiss
(11) Foggy Dew Fault Zone (FDFZ)
(12) Foggy Dew Fault Zone (FDFZ)
(13) Foggy Dew Fault Zone (FDFZ)
(14) Foggy Dew Fault Zone (FDFZ)
(15) Foggy Dew Fault Zone (FDFZ)
(16) Foggy Dew Fault Zone (FDFZ)
(17) Borealis Ridge
(18) Lower age is interpreted by Hurlow as the intrusive age of the dike. The systematics are intrepreted to reflect mixing of magmatic zircon with an inherited population of Precambrian zircons possibly derived from the Swakane Gneiss.
(19) Crystallization age of the dike is intrepreted by Hurlow to be 70.7. The sample probably contains inherited Precambrian zircons possibly from the Swakane Gneiss.
(20) Location in Mattinson, 1970 is wrong. Engels and others, 1976 location is correct.Primary crystallization
(21) Location in Mattinson, 1970 is wrong. Engels and others, 1976 location is correct.Primary crystallization
(22) primary crystallization
(23) primary crystallization
(24) primary crystallization
(25) primary crystallization
(26) primary crystallization
(27) metamorphic event ?
(28) primary crystallization
(29) primary crystallization
(30) primary crystallization
(31) Concordia; primary crystallization
(32) Borealis Ridge
(33) Borealis Ridge
(34) Borealis Ridge
(35) Borealis Ridge
(36) Borealis Ridge
(37) Thermally metamophosed by Cloudy Pass batholith
(38) rounded detrital (?) zircon
(39) location uncertain
(40) cuts Chelan complex
(41) Corbaley Canyon swarm
(42) Corbaley Canyon swarm
(43) metamorphic event ?
(44) Thermally metamophosed by Cloudy Pass batholith
(45) Old Gib volcano
(46) Altered biotite; associated with the Old Gib volcano
(47) Trinity mine
(48) Sitkum Creek stock
(49) South Cascade Glacier stock
(50) South Cascade Glacier stock
(51) Sitkum Creek stock
(52) detrital grains
(53) detrital grains
(54) detrital grains
(55) detrital grains
(56) detrital grains
(57) detrital grains
(58) detrital grains
(59) detrital grains
(60) detrital grains
(61) detrital grains
(62) detrital grains
(63) Eagle Creek tuff
(64) unnamed
(65) Eagle Creek tuff
(66) Eagle Creek tuff
(67) tuff
(68) tuff
(69) detrital grains
(70) zeolite tuff
(71) zeolite tuff
(72) zeolite tuff
(73) detrital grains
(74) detrital grains

Loc. no.	Sample no.	Rock type	Formation	Location
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
94	VF 80-179	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
94	VF 80-179	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
94	VF 80-179	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
94	VF 80-179	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
98	OP-F d-2	tonalite	Oval Peak batholith foliated margin	48° 12.76' 120° 17.87'
98	OP-F d-2	tonalite	Oval Peak batholith foliated margin	48° 12.76' 120° 17.87'
97	OP-D d-2(#2)	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
98	OP-F d-2	tonalite	Oval Peak batholith foliated margin	48° 12.76' 120° 17.87'
99	OP-F nml	tonalite	Oval Peak batholith foliated margin	48° 12.76' 120° 17.87'
100	CAS-LE d-2	leucogneiss	Lake Juanita leucogneiss	48° 16.38' 120° 28.79'
99	OP-F nml	tonalite	Oval Peak batholith foliated margin	48° 12.76' 120° 17.87'
99	OP-F nml	tonalite	Oval Peak batholith foliated margin	48° 12.76' 120° 17.87'
97	OP-D d-2(#2)	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
96	OP-D d-1	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
96	OP-D d-1	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
95	VF 81-1091	banded gneiss - light-colored tonalite unit	light-colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
96	OP-D d-1	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
96	OP-D d-2	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
97	OP-D d-2(#2)	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
96	OP-D d-2	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
96	OP-D d-2	tonalite	Oval Peak batholith nonfoliated	48° 17.97' 120° 27.19'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
88	RWT 203-80	metagabbro	Mad River terrane	47° 56.3' 120° 49.9'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'

Loc. no.	Dating method	Material	Age (Ma)	Reference
95	Pb206/U238	zircon	76.4 (-250+325 mesh)	Tabor and others, 1987a
95	Pb 207/U235	zircon	76.9 (-250+325 mesh)	Tabor and others, 1987a
95	Pb206/Pb207	zircon	127.0 (-150+200 mesh)	Tabor and others, 1987a
95	Pb208/Th232	zircon	75.1 (-150+200 mesh)	Tabor and others, 1987a
95	Pb206/U238	zircon	73.5 (-400 mesh)	Tabor and others, 1987a
95	Pb 207/U235	zircon	73.6 (-400 mesh)	Tabor and others, 1987a
95	Pb206/Pb207	zircon	92.3 (-250+325 mesh)	Tabor and others, 1987a
95	Pb208/Th232	zircon	71.3 (-250+325 mesh)	Tabor and others, 1987a
95	Pb 207/U235	zircon	78.5 (-150+200 mesh)	Tabor and others, 1987a
88	Pb208/Th232	zircon	47.4 (-400 mesh)	Tabor and others, 1987a
94	Pb206/U238	zircon	77.2 (-150+250 mesh)	Tabor and others, 1987a
88	Pb 207/U235	zircon	52.4 (-400 mesh)	Tabor and others, 1987a
88	Pb206/Pb207	zircon	99.8 (-400 mesh)	Tabor and others, 1987a
94	Pb208/Th232	zircon	90.9 (-150+250 mesh)	Tabor and others, 1987a
95	Pb206/U238	zircon	75.9 (-150+200 mesh)	Tabor and others, 1987a
94	Pb 207/U235	zircon	78.5 (-150+250 mesh)	Tabor and others, 1987a
94	Pb206/Pb207	zircon	104.2 (-150+250 mesh)	Tabor and others, 1987a
95	Pb206/Pb207	zircon	75.5 (-400 mesh)	Tabor and others, 1987a
98	Pb 207/U235	zircon	61.6 ± 0.3	Miller and Bowring, 1990
98	Pb206/Pb207	zircon	72.1 ± 5	Miller and Bowring, 1990
97	Pb206/Pb207	zircon	77.6 ±7	Miller and Bowring, 1990
98	Pb206/U238	zircon	61.41 ± 0.3	Miller and Bowring, 1990
99	Pb206/Pb207	zircon	138.5 ± 13	Miller and Bowring, 1990
100	Pb206/U238	zircon	59.9 ± 0.3	Miller and Bowring, 1990
99	Pb206/U238	zircon	60.8 ±0.3	Miller and Bowring, 1990
99	Pb 207/U235	zircon	62.8 ±0.5	Miller and Bowring, 1990
97	Pb 207/U235	zircon	64.5 ±0.4	Miller and Bowring, 1990
96	Pb 207/U235	zircon	65.6 ±0.3	Miller and Bowring, 1990
96	Pb206/Pb207	zircon	78.0 ±6	Miller and Bowring, 1990
95	Pb208/Th232	zircon	71.3 (-400 mesh)	Tabor and others, 1987a
96	Pb206/U238	zircon	65.2 ±0.3	Miller and Bowring, 1990
96	Pb206/Pb207	zircon	103.9 ±11	Miller and Bowring, 1990
97	Pb206/U238	zircon	64.1 ±0.3	Miller and Bowring, 1990
96	Pb206/U238	zircon	61.3 ±0.3	Miller and Bowring, 1990
96	Pb 207/U235	zircon	62.4 ±0.4	Miller and Bowring, 1990
78	Pb 207/U235	zircon	76.0 (-100 + 150 mesh)	Tabor and others, 1987a
78	Pb206/Pb207	zircon	178.2 (-100 + 150 mesh)	Tabor and others, 1987a
77	Pb208/Th232	zircon	77.2 (-200 + 250 mesh)	Tabor and others, 1987a
78	Pb206/U238	zircon	72.8 (-100 + 150 mesh)	Tabor and others, 1987a
78	Pb 207/U235	zircon	79.7 (-200 + 250 mesh)	Tabor and others, 1987a
78	Pb206/Pb207	zircon	259.7 (-200 + 250 mesh)	Tabor and others, 1987a
78	Pb208/Th232	zircon	72.0 (-100 + 150 mesh)	Tabor and others, 1987a
78	Pb206/U238	zircon	73.8 (-200 + 250 mesh)	Tabor and others, 1987a
77	Pb206/Pb207	zircon	84.6 (-200 + 250 mesh)	Tabor and others, 1987a
77	Pb206/U238	zircon	76.5 (-100 + 150 mesh)	Tabor and others, 1987a
77	Pb 207/U235	zircon	77.1 (-100 + 150 mesh)	Tabor and others, 1987a
65	Pb206/Pb207	zircon	49.7 (-250 +325 mesh)	Tabor and others, 1987a (1)
65	Pb208/Th232	zircon	45.3 (-250 +325 mesh)	Tabor and others, 1987a (2)
77	Pb206/U238	zircon	77.1 (-200 + 250 mesh)	Tabor and others, 1987a
77	Pb 207/U235	zircon	77.3 (-200 + 250 mesh)	Tabor and others, 1987a
77	Pb206/Pb207	zircon	96.6 (-100 + 150 mesh)	Tabor and others, 1987a
77	Pb208/Th232	zircon	84.2 (-100 + 150 mesh)	Tabor and others, 1987a
78	Pb208/Th232	zircon	79.1 (-200 + 250 mesh)	Tabor and others, 1987a
88	Pb208/Th232	zircon	45.1 (-150 +200 mesh)	Tabor and others, 1987a
88	Pb206/U238	zircon	50.1 (-250+325 mesh)	Tabor and others, 1987a
88	Pb 207/U235	zircon	53.0 (-150 +200 mesh)	Tabor and others, 1987a
88	Pb206/Pb207	zircon	91.4 (-150 +200 mesh)	Tabor and others, 1987a
88	Pb208/Th232	zircon	48.9 (-250+325 mesh)	Tabor and others, 1987a
88	Pb206/U238	zircon	51.4 (-400 mesh)	Tabor and others, 1987a
88	Pb 207/U235	zircon	50.9 (-250+325 mesh)	Tabor and others, 1987a
88	Pb206/Pb207	zircon	88.4 (-250+325 mesh)	Tabor and others, 1987a
88	Pb206/U238	zircon	52.1 (-150 +200 mesh)	Tabor and others, 1987a
87	Pb206/Pb207	zircon	1427.0 (+250 mesh)	Tabor and others, 1987a (3)
87	Pb208/Th232	zircon	344.3 (+250 mesh)	Tabor and others, 1987a (4)
87	Pb206/U238	zircon	312.8 (+250 mesh)	Tabor and others, 1987a (5)
87	Pb 207/U235	zircon	488.3 (+250 mesh)	Tabor and others, 1987a (6)
87	Pb206/Pb207	zircon	1464.5 (-250 mesh)	Tabor and others, 1987a (7)
87	Pb208/Th232	zircon	329.1 (-250 mesh)	Tabor and others, 1987a (8)
87	Pb206/U238	zircon	315.6 (-250 mesh)	Tabor and others, 1987a (9)

Loc. no.	Sample no.	Rock type	Formation	Location
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
100	CAS-LE d-2	leucogneiss	Lake Juanita leucogneiss	48° 16.38' 120° 28.79'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
121	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
121	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
121	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
120			Tenpeak pluton, east	
120			Tenpeak pluton, east	
119			Tenpeak pluton, northwest	
119			Tenpeak pluton, northwest	
120			Tenpeak pluton, east	
120			Tenpeak pluton, east	
120			Tenpeak pluton, east	
120			Tenpeak pluton, east	
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
124	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
124	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
125	SK 91-49	gneiss	Skagit Gneiss	48° 43.58' 121 03.15'
125	SK 91-49	gneiss	Skagit Gneiss	48° 43.58' 121 03.15'
124	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
125	SK 91-49	gneiss	Skagit Gneiss	48° 43.58' 121 03.15'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
122	SW 91-78	gneiss	Swakane Gneiss	48° 08.63' 120° 52.28'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
123	SW 91-42	gneiss	Swakane Gneiss	47° 08.63' 120° 16.96'
104	BMG d-1	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
104	BMG d-1	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
103	MY -1 nm10	mylonitic gneiss	Foggy Dew Fault Zone tonalitic mylonite	48° 13.12' 120° 15.77'
104	BMG d-1	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
105	BMG nm4	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
105	BMG nm4(#2)	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
105	BMG nm4	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
105	BMG nm4	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
103	MY -1 nm10	mylonitic gneiss	FDFZ tonalitic mylonite	48° 13.12' 120° 15.77'
101	CAS-LE nml	leucogneiss	Lake Juanita leucogneiss	48° 16.38' 120° 28.79'
101	CAS-LE nml	leucogneiss	Lake Juanita leucogneiss	48° 16.38' 120° 28.79'
100	CAS-LE d-2	leucogneiss	Lake Juanita leucogneiss	48° 16.38' 120° 28.79'
101	CAS-LE nml	leucogneiss	Lake Juanita leucogneiss	48° 16.38' 120° 28.79'
102	MY-1 nml	mylonitic gneiss	FDFZ tonalitic mylonite	48° 13.12' 120° 15.77'
103	MY -1 nm10	mylonitic gneiss	FDFZ tonalitic mylonite	48° 13.12' 120° 15.77'
102	MY-1 nml	mylonitic gneiss	FDFZ tonalitic mylonite	48° 13.12' 120° 15.77'
102	MY-1 nml	mylonitic gneiss	FDFZ tonalitic mylonite	48° 13.12' 120° 15.77'
105	BMG nm4(#2)	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
118			Sulphur Mountain pluton	
118			Sulphur Mountain pluton	
118			Sulphur Mountain pluton	
118			Sulphur Mountain pluton	
119			Tenpeak pluton, northwest	
119			Tenpeak pluton, northwest	
119			Tenpeak pluton, northwest	
119			Tenpeak pluton, northwest	
118			Sulphur Mountain pluton	
117			banded gneiss	
117			banded gneiss	
105	BMG nm4(#2)	gneiss	Battle Mountain gneiss	48° 16.23' 120° 27.81'
117			banded gneiss	
117			banded gneiss	

Loc. no.	Dating method	Material	Age (Ma)	Reference
87	Pb 207/U235	zircon	499.5 (-250 mesh)	Tabor and others, 1987a (10)
100	Pb 207/U235	zircon	60.3 ±0.3	Miller and Bowring, 1990
122	Pb206/U238	zircon	1,165 ± 2	Rasbury and Walker, 1992
122	Pb 207/U235	zircon	1,236 ± 2	Rasbury and Walker, 1992
121	Pb 207/U235	zircon	1,195 ± 3	Rasbury and Walker, 1992
121	Pb206/Pb207	zircon	1,360 ± 4	Rasbury and Walker, 1992
122	Pb 207/U235	zircon	1,306 ± 4	Rasbury and Walker, 1992
122	Pb206/Pb207	zircon	1,380 ± 6	Rasbury and Walker, 1992
122	Pb206/Pb207	zircon	1,361 ± 4	Rasbury and Walker, 1992
122	Pb206/U238	zircon	1,261 ± 4	Rasbury and Walker, 1992
121	Pb206/U238	zircon	1,106 ± 5	Rasbury and Walker, 1992
120	Pb206/U238	zircon	90.9 ± 0.4 (nm,0.5deg, +100μm)	Walker and Brown, 1991
120	Pb 207/U235	zircon	90.8 ± 0.6 (nm,0.5deg, + 100μm)	Walker and Brown, 1991
119	Pb 207/U235	zircon	92.4 ± 0.4 (nm, 3 deg, -64 +40μm)	Walker and Brown, 1991
119	Pb206/Pb207	zircon	97 ± 5 (nm, 3 deg, -64 +40μm)	Walker and Brown, 1991
120	Pb 207/U235	zircon	90.9 ± 0.4 (nm,0.5deg, - 100μm)	Walker and Brown, 1991
120	Pb206/Pb207	zircon	94 ± 5 (nm,0.5deg, - 100μm)	Walker and Brown, 1991
120	Pb206/Pb207	zircon	90 ± 8 (nm,0.5deg, + 100μm)	Walker and Brown, 1991
120	Pb206/U238	zircon	90.8 ± 0.3 (nm,0.5deg, - 100μm)	Walker and Brown, 1991
122	Pb206/U238	zircon	1,207 ± 3	Rasbury and Walker, 1992
124	Pb206/U238	zircon	318 ±1	Rasbury and Walker, 1992
124	Pb 207/U235	zircon	504 ±4	Rasbury and Walker, 1992
123	Pb 207/U235	zircon	499 ± 2	Rasbury and Walker, 1992
123	Pb206/Pb207	zircon	1,230 ±4	Rasbury and Walker, 1992
125	Pb 207/U235	zircon	132 ± 3	Rasbury and Walker, 1992
125	Pb206/Pb207	zircon	136 ± 70	Rasbury and Walker, 1992
124	Pb206/Pb207	zircon	1,427 ±20	Rasbury and Walker, 1992
125	Pb206/U238	zircon	131 ± 2	Rasbury and Walker, 1992
123	Pb206/U238	zircon	355 ± 2	Rasbury and Walker, 1992
123	Pb206/U238	zircon	503 ±1	Rasbury and Walker, 1992
123	Pb 207/U235	zircon	638 ±4	Rasbury and Walker, 1992
122	Pb 207/U235	zircon	1,360 ±3	Rasbury and Walker, 1992
122	Pb206/Pb207	zircon	1,610 ±3	Rasbury and Walker, 1992
123	Pb 207/U235	zircon	400 ± 1	Rasbury and Walker, 1992
123	Pb206/Pb207	zircon	1,119 ±6	Rasbury and Walker, 1992
123	Pb206/Pb207	zircon	1,153 ± 4	Rasbury and Walker, 1992
123	Pb206/U238	zircon	287 ± 1	Rasbury and Walker, 1992
104	Pb 207/U235	zircon	87.9 ± 0.5	Miller and Bowring, 1990
104	Pb206/Pb207	zircon	109.4 ± 9	Miller and Bowring, 1990
103	Pb206/Pb207	zircon	254.5 ± 3	Miller and Bowring, 1990 (11)
104	Pb206/U238	zircon	87.1 ± 0.4	Miller and Bowring, 1990
105	Pb206/Pb207	zircon	83.2 ± 10	Miller and Bowring, 1990
105	Pb206/U238	zircon	86.8 ± 0.4	Miller and Bowring, 1990
105	Pb206/U238	zircon	87.3 ± 0.4	Miller and Bowring, 1990
105	Pb 207/U235	zircon	87.1 ± 0.5	Miller and Bowring, 1990
103	Pb 207/U235	zircon	72.0 ± 0.3	Miller and Bowring, 1990 (12)
101	Pb 207/U235	zircon	59.0 ± 0.4	Miller and Bowring, 1990
101	Pb206/Pb207	zircon	91.7 ± 9	Miller and Bowring, 1990
100	Pb206/Pb207	zircon	75.8 ±3	Miller and Bowring, 1990
101	Pb206/U238	zircon	58.2 ± 0.3	Miller and Bowring, 1990
102	Pb206/Pb207	zircon	95.6 ± 25	Miller and Bowring, 1990 (13)
103	Pb206/U238	zircon	66.6 ± 0.3	Miller and Bowring, 1990 (14)
102	Pb206/U238	zircon	49.3 ±0.2	Miller and Bowring, 1990 (15)
102	Pb 207/U235	zircon	50.3 ± 0.6	Miller and Bowring, 1990 (16)
105	Pb 207/U235	zircon	87.5 ± 0.5	Miller and Bowring, 1990
118	Pb 207/U235	zircon	96.0 ± 0.8 (nm, 2deg, -75 +64μm)	Walker and Brown, 1991
118	Pb206/Pb207	zircon	104 ± 10 (nm, 2deg, -75 +64μm)	Walker and Brown, 1991
118	Pb206/Pb207	zircon	96 ± 8 (nm, 2deg, -100 +75μm)	Walker and Brown, 1991
118	Pb206/U238	zircon	95.9 ± 0.5 (nm, 2deg, -75 +64μm)	Walker and Brown, 1991
119	Pb206/Pb207	zircon	103 ± 5 (nm, 3deg, -100 +64 μm)	Walker and Brown, 1991
119	Pb206/U238	zircon	92.2 ± 0.3 (nm, 3 deg, -64 +40μm)	Walker and Brown, 1991
119	Pb206/U238	zircon	92.1 ± 0.3 (nm, 3deg, -100 +64 μm)	Walker and Brown, 1991
119	Pb 207/U235	zircon	92.4± 0.4 (nm, 3deg, -100 +64 μm)	Walker and Brown, 1991
118	Pb 207/U235	zircon	96.3 ± 0.7 (nm, 2deg, -100 +75μm)	Walker and Brown, 1991
117	Pb 207/U235	zircon	97.2 ±0.6 (nm, 1deg, +250μm)	Walker and Brown, 1991
117	Pb206/Pb207	zircon	147 ± 5 (nm, 1deg, +250μm)	Walker and Brown, 1991
105	Pb206/Pb207	zircon	105.8 ± 6	Miller and Bowring, 1990
117	Pb206/U238	zircon	95.7 ± 0.3 (nm, 1deg, +250μm)	Walker and Brown, 1991
117	Pb206/Pb207	zircon	102 ± 9 (nm, 1deg, -100 +75μm)	Walker and Brown, 1991

Loc. no.	Sample no.	Rock type	Formation	Location
118			Sulphur Mountain pluton	
117			banded gneiss	
117			banded gneiss	
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
40	RWT 179-86	orthogneiss at Newhalem	Skagit Gneiss complex	
40	RWT 179-86	orthogneiss at Newhalem	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
40	RWT 179-86	orthogneiss at Newhalem	Skagit Gneiss complex	
40	RWT 179-86	orthogneiss at Newhalem	Skagit Gneiss complex	
41	RWT 211-86	orthogneiss of The Needle	Skagit Gneiss complex	
40	RWT 179-86	orthogneiss at Newhalem	Skagit Gneiss complex	
40	RWT 179-86	orthogneiss at Newhalem	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
39	RH83-H77	lineated granite	Skagit Gneiss complex	
43	RWT 204-86		Eldorado Orthogneiss	
43	RWT 204-86		Eldorado Orthogneiss	
42	RWT 97-86	orthogneiss at Newhalem Creek	Skagit Gneiss complex	
43	RWT 204-86		Eldorado Orthogneiss	
43	RWT 204-86		Eldorado Orthogneiss	
44	RWT 224-80	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	RWT 224-80	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
43	RWT 204-86		Eldorado Orthogneiss	
43	RWT 204-86		Eldorado Orthogneiss	
42	RWT 97-86	orthogneiss at Newhalem Creek	Skagit Gneiss complex	
41	RWT 211-86	orthogneiss of The Needle	Skagit Gneiss complex	
41	RWT 211-86	orthogneiss of The Needle	Skagit Gneiss complex	
41	RWT 211-86	orthogneiss of The Needle	Skagit Gneiss complex	
41	RWT 211-86	orthogneiss of The Needle	Skagit Gneiss complex	
41	RWT 211-86	orthogneiss of The Needle	Skagit Gneiss complex	
42	RWT 97-86	orthogneiss at Newhalem Creek	Skagit Gneiss complex	
42	RWT 97-86	orthogneiss at Newhalem Creek	Skagit Gneiss complex	
42	RWT 97-86	orthogneiss at Newhalem Creek	Skagit Gneiss complex	
42	RWT 97-86	orthogneiss at Newhalem Creek	Skagit Gneiss complex	
30	H-128	post-tectontic pegmatite granite dike		48° 9.6' 120° 52.6'
30	H-129	foliated granodiorite dike		48° 9.6' 120° 52.6'
28	H-17	mylonitic biotite-honblende quartz diorite	Entiat Pluton or Dumbell Mountain pluton	48° 6.8' 120° 49.02'
29	CLM-7	foliated biotite granodiorite	High Pass pluton	48° 6.8' 120° 53.96'
31	JM 67-1	hornblende biotite quartz diorite augen gneiss	Dumbell Mountain pluton	48° 09.6' 120° 47.7'
32	JM 68-10	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 09.4' 120° 51.2'
32	JM 68-10	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 09.4' 120° 51.2'
31	JM 67-1	hornblende biotite quartz diorite augen gneiss	Dumbell Mountain pluton	48° 09.6' 120° 47.7'
32	JM 68-10	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 09.4' 120° 51.2'
27	WJH 80-5	orthogneiss	Gabriel Peak orthogneiss	48° 27.7' 120° 47.5'
5	107	quartz diorite gneiss	Dumbell pluton	48° 13.0' 120° 50.6'
7	115	bitotite granofels	younger gneiss of Holden area	48° 12.1' 120° 46.4'
4	106	quartz diorite gneiss	Dumbell pluton	48° 13.3' 120° 50.7'
5	107	quartz diorite gneiss	Dumbell pluton	48° 13.0' 120° 50.6'
10	109	quartz diorite gneiss	Dumbell pluton	48° 08.6' 120° 50.9'
25	E-1a-4a		High Pass pluton	48° 6.17' 120° 53.96'
26	WJH 80-15	orthogneiss	Bridge Creek orthogneiss	48° 27.5' 120° 48.8'
13	110	quartz diorite gneiss	Dumbell pluton	48° 09.6' 120° 47.7'
13	110	quartz diorite gneiss	Dumbell pluton	48° 09.6' 120° 47.7'
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	

Loc. no.	Dating method	Material	Age (Ma)	Reference
118	Pb206/U238	zircon	96.3 ± 0.4 (nm, 2deg, -100 +75µm)	Walker and Brown, 1991
117	Pb206/U238	zircon	91.5 ± 0.4 (nm, 1deg, -100 +75µm)	Walker and Brown, 1991
117	Pb 207/U235	zircon	92.2 ± 0.5 (nm, 1deg, -100 +75µm)	Walker and Brown, 1991
65	Pb 207/U235	zircon	46.5 (-250 +325 mesh)	Tabor and others, 1987a (17)
40	Pb 206/U238	zircon	64.8 ± 0.1 (-102+63µ NM)	Haugerud and others, 1991
40	Pb 207/U235	zircon	65.0 ± 0.3 (-102+63µ NM)	Haugerud and others, 1991
39	Pb 206/Pb 207	zircon	45.3 ± 0.4	Haugerud and others, 1991
39	Pb 206/Pb 207	zircon	51.5 ± 1.4	Haugerud and others, 1991
40	Pb 206/Pb 207	zircon	74 ± 11 (-102+63µ NM)	Haugerud and others, 1991
40	Pb 206/Pb 207	zircon	84 ± 13 (-63µ)	Haugerud and others, 1991
41	Pb 206/U238	zircon	16.9 ± 0.2 (-102 +63µ)	Haugerud and others, 1991
40	Pb 206/U238	zircon	63.3 ±0.2 (-63µ)	Haugerud and others, 1991
40	Pb 207/U235	zircon	63.9 ± 0.4 (-63µ)	Haugerud and others, 1991
39	Pb 206/U238	zircon	45.1 ± 0.4	Haugerud and others, 1991
38	Pb 206/Pb 207	zircon	73 ± 28 (-74 + 44µ NM)	Haugerud and others, 1991
39	Pb 206/U238	zircon	43.9 ± 0.3	Haugerud and others, 1991
38	Pb 206/U 238	zircon	60.4 ± 0.4 (-74 + 44µ NM)	Haugerud and others, 1991
38	Pb 207/U 235	zircon	60.7 ± 0.9 (-74 + 44µ NM)	Haugerud and others, 1991
39	Pb 207/U 235	zircon	43.6 ± 0.7	Haugerud and others, 1991
39	Pb 207/U235	zircon	45.9 ± 0.4	Haugerud and others, 1991
39	Pb 206/Pb 207	zircon	-11 ± 9	Haugerud and others, 1991
39	Pb 206/Pb 207	zircon	25 ± 33	Haugerud and others, 1991
39	Pb 206/U238	zircon	46.9 ± 0.3	Haugerud and others, 1991
43	Pb 207/U235	zircon	88.2 ± 0.3 (60/140 mesh)	Haugerud and others, 1991
43	Pb 206/Pb 207	zircon	102 ± 6 (60/140 mesh)	Haugerud and others, 1991
42	Pb 206/Pb 207	zircon	61 ± 11 (-63µ)	Haugerud and others, 1991
43	Pb 206/U238	zircon	87.7 ± 0.1 (60/140 mesh)	Haugerud and others, 1991
43	Pb 206/U238	zircon	88.3 ± 0.1 (140/200 mesh)	Haugerud and others, 1991
44	Pb 206/U238	zircon	74.2± 0.3 (60/150 mesh)	Haugerud and others, 1991
44	Pb 207/U235	zircon	76.5 ± 0.4 (60/150 mesh)	Haugerud and others, 1991
43	Pb 207/U235	zircon	88.7 ± 0.3 (140/200 mesh)	Haugerud and others, 1991
43	Pb 206/Pb 207	zircon	99 ± 0.4 (140/200 mesh)	Haugerud and others, 1991
42	Pb 207/U235	zircon	72.1 ± 0.4 (-63µ)	Haugerud and others, 1991
41	Pb 206/U238	zircon	112.9 ± 0.2 (-63µ)	Haugerud and others, 1991
41	Pb 207/U235	zircon	117.7 ± 0.3 (-63µ)	Haugerud and others, 1991
41	Pb 207/U235	zircon	122.0 ± 0.7 (-102 +63µ)	Haugerud and others, 1991
41	Pb 206/Pb 207	zircon	221 ± 13 (-102 +63µ)	Haugerud and others, 1991
41	Pb 206/Pb 207	zircon	242 ± 6 (-63µ)	Haugerud and others, 1991
42	Pb 206/Pb 207	zircon	92 ± 4 (+102µ)	Haugerud and others, 1991
42	Pb 206/U238	zircon	72.5 ± 0.1 (-63µ)	Haugerud and others, 1991
42	Pb 206/U238	zircon	74.1 ± 0.1 (+102 µ)	Haugerud and others, 1991
42	Pb 207/U235	zircon	74.7 ± 0.3 (+102 µ)	Haugerud and others, 1991
30	U-Pb	zircon	67.4± 1.2	Hurlow, 1992 (18)
30	U-Pb	zircon	70.1 ± 1.5	Hurlow, 1992 (19)
28	U-Pb	zircon	216.5 ± 1.5	Hurlow, 1992
29	U-Pb	zircon	84 ± 1	Hurlow, 1992
31	Pb-Pb	zircon	233 ± 10 coarse	Mattinson, 1970; Engels and others, 1976 (20)
32	Pb-Pb	zircon	215 ± 15 medium	Mattinson, 1970; Engels and others, 1976
32	Pb-Pb	zircon	278 ± 15 fine	Mattinson, 1970; Engels and others, 1976
31	Pb-Pb	zircon	243 ±10 fine	Mattinson, 1970; Engels and others, 1976 (21)
32	Pb-Pb	zircon	221 ± 35 coarse	Mattinson, 1970; Engels and others, 1976
27	U-Pb	zircon	68	Hoppe, 1984
5	U-Pb	zircon	216 ± 10	Engels and others, 1976
7	Pb-Pb	zircon	235 ± 10	Engels and others, 1976 (22)
4	U-Pb	zircon	215 ± 10	Engels and others, 1976 (23)
5	U-Pb	zircon	230 ± 5	Engels and others, 1976
10	U-Pb	zircon	89	Mattinson, 1972; Engels and others, 1976
25	U-Pb	zircon	85 ± 1	Hurlow, 1991 (written communication)
26	U-Pb	zircon	50	Hoppe, 1984
13	Pb-Pb	zircon	233 ± 10	Mattinson, 1972; Engels and others, 1976
13	Pb-Pb	zircon	243 ± 10	Mattinson, 1972; Engels and others, 1976
38	Pb207/Pb206	zircon	36 ± 19 (-210 + 149µ M)	Haugerud and others, 1991
38	Pb 206/U 238	zircon	62.9 ± 0.4 (-149 + 74µ NM)	Haugerud and others, 1991
38	Pb206/U238	zircon	63.1 ± 0.7 (-210 + 149µ M)	Haugerud and others, 1991
38	Pb207/U235	zircon	62.5 ± 0.8 (-210 + 149µ M)	Haugerud and others, 1991
38	Pb 207/U 235	zircon	63.4 ± 0.5 (-149 + 74µ NM)	Haugerud and others, 1991
38	Pb 207/U 235	zircon	64.4 ±1.5 (-74 +44µ M)	Haugerud and others, 1991
38	Pb 206/Pb 207	zircon	150 ± 51 (-74 +44µ M)	Haugerud and others, 1991
38	Pb 206/Pb 207	zircon	82 ± 7 (-149 + 74µ NM)	Haugerud and others, 1991

Loc. no.	Sample no.	Rock type	Formation	Location
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
34	JM 68-12	biotite-hornblende granodiorite gneiss	Eldorado orthogneiss	48° 27.2' 120° 59.8'
35	JM 68-13	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 13.3' 120° 50.7'
33	JM 68-11	trondhjemite pegmatite	Dumbell Mountain pluton	48° 08.6' 120° 50.9'
34	JM 68-12	biotite-hornblende granodiorite gneiss	Eldorado orthogneiss	48° 27.2' 120° 59.8'
36	JM 68-14	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 13.0' 120° 50.6'
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
38	RH83-H76b	orthogneiss of Custer Ridge	Skagit Gneiss complex	
36	JM 68-14	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 13.0' 120° 50.6'
37	JM 68-15	biotite quartz oligoclase granofels	younger gneiss of Holden area	48° 12.1' 120° 46.4'
44	82-S11A	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	82-S11A	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	82-S11A	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	82-S11A	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	82-S11A	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
65	RWT 221-80		Duncan Hill pluton	48° 06.5' 120° 41.4'
44	82-S11A	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	RWT 224-80	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	RWT 224-80	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	RWT 224-80	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
44	RWT 224-80	intrudes schists of the Chelan Mountains terrane	Cardinal Peak pluton	
64	TLW 252		Duncan Hill pluton	48° 00.6' 120° 34.4'
1	102	biotite gneiss	Swakane Biotite Gneiss	48° 12.8' 120° 58.2'
7	116	quartz diorite	Cardinal Peak pluton	48° 12.1' 120° 45.9'
14	111	gneissic quartz diortite	Dumbell pluton	48° 09.2' 120° 46.8'
24	135	granodiorite	Duncan Hill pluton	48° 00.6' 120° 34.4'
8	120	biotite gneiss	Swakane Biotite Gneiss	48° 07.9' 120°54.0'
3	104	granodiorite	Cloudy Pass pluton	48° 12.6' 120° 52.5'
2	103	granodiorite	Cloudy Pass pluton	48° 11.9' 120° 53.9'
2	103	granodiorite	Cloudy Pass pluton	48° 11.9' 120° 53.9'
3	105	granodiorite	Cloudy Pass pluton	48° 12.5 120° 52.8'
3	105	quartz diortie	Cloudy Pass pluton	
70	RWT 455-78	granite porphyry dike swarm	dike	47° 53.5' 120° 34.7'
71	RWT 40-79		Cooper Mountain pluton	48° 01.4' 120° 11.5'
22	141	quartz diorite	Black Peak batholith	48° 28' 120° 34'
69	RWT 32-79	granite porphyry dike swarm	dike	47° 59.6' 120° 09.9'
23	139	quartz monzonite	Railroad Creek pluton	48° 11.4' 120° 38.6'
23	139	quartz monzonite	Railroad Creek pluton	48° 11.4' 120° 38.6'
69	RWT 32-79	granite porphyry dike swarm	dike	47° 59.6' 120° 09.9'
72	RWT 91-79	dike	dike	47° 56.7' 119° 59.9'
115	818-6A		Sulphur Mountain pluton	48° 15.3' 121 02.8'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
116	818-6B		Sulphur Mountain pluton	48° 14.3' 121 06.8'
116	818-6B		Sulphur Mountain pluton	48° 14.3' 121 06.8'
74	C101	hornblende gabbro dike	dike	47° 38.2' 120° 10.2'
73	KA-4	porphyritic dacite dike	dike	47° 38.1' 120° 10.6'
32	JM 68-10	hornblende quartz diorite gneiss	Dumbell Mountain pluton	48° 09.4' 120° 51.2'
77	RWT 151-79	massive tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
22	140	quartz diorite	Black Peak batholith	48° 28' 120° 34'
66	FWC 252 B		Duncan Hill pluton	47° 56.7' 120° 31.2'
66	FWC 252 B		Duncan Hill pluton	47° 56.7' 120° 31.2'
11	112	quartz diorite gneiss	Leroy Creek pluton	48° 08.6' 120° 49.2'
12	113	quartz diorite gneiss	Leroy Creek pluton	48° 07.4' 120° 48.6'
12	113	quartz diorite gneiss	Leroy Creek pluton	48° 07.4' 120° 48.6'
2	103	granodiorite	Cloudy Pass pluton	48° 11.9' 120° 53.9'
1	102	biotite gneiss	Swakane Biotite Gneiss	48° 12.8' 120° 58.2'
3	104	granodiorite	Cloudy Pass pluton	48° 12.6' 120° 52.5'
6	114	gangue	Leroy Creek pluton	48° 11.2' 120° 46.9'
66	FWC 252 B		Duncan Hill pluton	47° 56.7' 120° 31.2'
67	C-685-1		Duncan Hill pluton	47° 56.3 120° 31.2'
19	100	granodiorite	Clark Mountain stock	48° 02.8' 120° 56.2'
18	119	andesite porphyry		48° 02.9' 120° 47.4'
19	100	granodiorite	Clark Mountain stock	48° 02.8' 120° 56.2'
21	47	granodiorite	Eldorado Orthogneiss	48° 27.2' 120° 59.8'

Loc. no.	Dating method	Material	Age (Ma)	Reference
38	Pb 206/U 238	zircon	62.1 ± 0.5 (-74 +44μ M)	Haugerud and others, 1991
38	Pb207/Pb206	zircon	49 ± 25 (-210 + 149 μ NMA)	Haugerud and others, 1991
34	Pb-Pb	zircon	110 ± 10 fine	Mattinson, 1970; Engels and others, 1976 (25)
35	U-Pb	zircon	215 ± 10	Mattinson, 1970; Engels and others, 1976 (26)
33	U-Pb	zircon	89	Mattinson, 1970; Engels and others, 1976 (27)
34	Pb-Pb	zircon	92 ± 15 coarse	Mattinson, 1970; Engels and others, 1976 (28)
36	U-Pb	zircon	230 ± 15 coarse	Mattinson, 1970; Engels and others, 1976 (29)
38	Pb206/U238	zircon	64.4 ± 0.5 (-210 + 149μ NMA)	Haugerud and others, 1991
38	Pb207/U235	zircon	64.0 ± 0.8 (-210 + 149 μ NMA)	Haugerud and others, 1991
36	U-Pb	zircon	216 ± 10 fine	Mattinson, 1970; Engels and others, 1976 (30)
37	Pb-Pb	zircon	235 ± 10	Mattinson, 1970; Engels and others, 1976 (31)
44	Pb 207/U235	zircon	74.0 ± 0.4 (-150 mesh)	Haugerud and others, 1991
44	Pb 206/Pb 207	zircon	106 ± 12 (-150 mesh)	Haugerud and others, 1991
44	Pb 206/U238	zircon	73.1 ± 0.4 (-150 mesh)	Haugerud and others, 1991
44	Pb 207/U235	zircon	78.9 ± 0.4 (60/150 mesh)	Haugerud and others, 1991
44	Pb 206/Pb 207	zircon	198 ± 9 (60/150 mesh)	Haugerud and others, 1991
65	Pb 207/U235	zircon	45.8 (-150+200 mesh)	Tabor and others, 1987a (32)
65	Pb206/Pb207	zircon	47.8 (-150+200 mesh)	Tabor and others, 1987a (33)
65	Pb 206/U238	zircon	45.8 (-150+200 mesh)	Tabor and others, 1987a (34)
65	Pb 206/U238	zircon	46.4 (-250 +325 mesh)	Tabor and others, 1987a (35)
65	Pb208/Th232	zircon	47.1 (-150+200 mesh)	Tabor and others, 1987a (36)
44	Pb 206/U238	zircon	75.0 ± 0.3 (60/150 mesh)	Haugerud and others, 1991
44	Pb 206/U238	zircon	73.8 ± 0.3 (-150 mesh)	Haugerud and others, 1991
44	Pb 206/Pb 207	zircon	151 ± 7 (60/150 mesh)	Haugerud and others, 1991
44	Pb 206/Pb 207	zircon	137 ± 3 (-150 mesh)	Haugerud and others, 1991
44	Pb 207/U235	zircon	75.7 ± 0.3 (-150 mesh)	Haugerud and others, 1991
64	Pb-alpha	zircon	40.0 ± 10.0	Tabor and others, 1987a; Engels and others, 1976
1	Pb-alpha	zircon	320 ± 40	Engels and others, 1976 (37)
7	Pb-alpha	zircon	126 ± 13	Engels and others, 1976
14	Pb-alpha	zircon	107 suspect age	Jaffe and others, 1959; Engels and others, 1976
24	Pb-alpha	zircon	40 ± 10	Engels and others, 1976
8	Pb-alpha	zircon	300 ± 40	Engels and others, 1976 (38)
3	Pb-alpha	zircon	30 ± 20	Engels and others, 1976
2	Pb-alpha	zircon	20 ± 20	Engels and others, 1976
2	Pb-alpha	zircon	30 ± 20	Engels and others, 1976
3	Pb-alpha	zircon	111± 11 suspect age	Engels and others, 1976
3	Pb-alpha	zircon	134 ± 13 suspect age	Engels and others, 1976 (39)
70	K-Ar	biotite	47.0 ± 0.7	Tabor and others, 1987a
71	K-Ar	biotite	48.1 ± 4.5	Tabor and others, 1987a
22	K-Ar	biotite	73 ± 2	Misch, 1963; Engels and others, 1976
69	K-Ar	biotite	46.9 ± 0.6	Tabor and others, 1987a
23	K-Ar	hornblende	42.6 ± 2	Engels and others, 1976
23	K-Ar	biotite	43.7 ± 1.3	Engels and others, 1976
69	K-Ar	hornblende	44.2 ± 2.0	Tabor and others, 1987a
72	K-Ar	hornblende	48.1 ± 1.3	Tabor and others, 1987a (40)
115	K-Ar	biotite	26.1 ± 0.5	Tabor and others, 1988
77	K-Ar	biotite	60.3 ± 0.8	Tabor and others, 1987a
116	K-Ar	biotite	54.2 ± 0.4	Tabor and others, 1988
116	K-Ar	hornblende	59.5 ± 0.5	Tabor and others, 1988
74	K-Ar	hornblende	48.4 ±2.2	Tabor and others, 1987a (41)
73	K-Ar	biotite	47.8 ±1.9	Tabor and others, 1987a (42)
32	K-Ar	hornblende	88.3 ± 3.3	Mattinson, 1970; Engels and others, 1976 (43)
77	K-Ar	hornblende	73.2 ± 1.5	Tabor and others, 1987a
22	K-Ar	hornblende	88.4 ± 2.7	Misch, 1963; Engels and others, 1976
66	K-Ar	biotite	43.0 ± 2.2	Cater and Crowder, 1967
66	K-Ar	hornblende	48.3 ± 0.5	Cater and Crowder, 1967
11	K-Ar	biotite	45.1 ± 2.6	Engels and others, 1976
12	K-Ar	muscovite	54.8 ± 1.5	Engels and others, 1976
12	K -Ar	biotite	45.2 ± 1.5	Engels and others, 1976
2	K-Ar	biotite	21.1 ± 2.2	Engels and others, 1976
1	K-Ar	biotite	20.4 ± 2.0	Engels and others, 1976 (44)
3	K-Ar	biotite	22.5 ± 2.0	Engels and others, 1976
6	K-Ar	phlogopite	44.1 ± 3.0	Engels and others, 1976
66	K-Ar	hornblende	48.3 ± 4.5	Cater and Crowder, 1967
67	K-Ar	hornblende	44.9 ± 1.8	Cater and Crowder, 1967
19	K-Ar	biotite	57.1 ± 2.3	Cater and Crowder, 1967; Engels and others, 1976
18	K-Ar	biotite	43.9 ± 1.5	Cater and Crowder, 1967; Engels and others, 1976 (45)
19	K-Ar	muscovite	59.2 ± 2.4	Cater and Crowder, 1967; Engels and others, 1976
21	K-Ar	hornblende	41.9 ± 1.5	Engels and others, 1976

Loc. no.	Sample no.	Rock type	Formation	Location
20	101	biotite quartz schist	rocks of Napeequa River area	48° 02.6' 120° 55.8'
15	99	gneissic quartz diortite	Ten Peak pluton	48° 01.2 ' 120° 58.6'
68	C-541-1		Duncan Hill pluton	47° 54.0 120° 21.1'
15	99	gneissic quartz diortite	Ten Peak pluton	48° 01.2 ' 120° 58.6'
17	118	dacite		48° 04.2' 120° 50.5'
16	117	granodiorite		48° 04.5' 120° 51.1'
115	818-6A		Sulphur Mountain pluton	48° 15.3' 121 02.8'
89	RWT 9-81	amphibolite layer	heterogeneous schist and gneiss unit	47° 44.2' 120° 27.9'
108	827-5A		Cascade Pass dike	48° 28.7' 121 04.0'
108	827-5A		Cascade Pass dike	48° 28.7' 121 04.0'
92	RWT 201-80	zoisite amphibolite	rocks of the Napeequa River area	47° 56.3' 120° 49.8'
91	RWT 8-81	amphibolite layer	heterogeneous schist and gneiss unit	47° 44.2' 120° 26.1'
90	RWT 39-80	amphibolite layer	heterogeneous schist and gneiss unit	47° 43.9' 120° 29.1'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
87	RWT 3-81		Swakane Biotite Gneiss	47° 36.5' 120° 14.5'
107		amphibolite from envelope of Twisp Valley Schist	Twisp Valley Schist	48° 16.11' 120° 27.66'
106		mylonitic amphibolite from the Foggy Dew Fault Zone	FDFZ	48° 13.32' 120° 16.19'
45	75-207		dike cutting Chumstick Fm.	47° 38.9' 120° 36.8'
94	VF 80-179	banded gneiss - light-colored tonalite unit	light colored gneiss of Wenatchee Ridge	47° 38.9' 120° 13.9'
93	RWT 201-80	zoisite amphibolite	rocks of the Napeequa River area	47° 56.3' 120° 49.8'
112	80N33D		tonalite of Bench Lake	48° 22.1' 121 10.0'
114	80R118B		Sulphur Mountain pluton	48° 14.8' 121 07.5'
113	818-5G		tonalite of Bench Lake	48° 21.5' 121 10.4'
113	818-5G		tonalite of Bench Lake	48° 21.5' 121 10.4'
110	81F307A		Cascade Pass batholith	48° 06.6' 120° 09.3'
109	818-5F		Cascade Pass batholith	48° 21.9' 121 03.9'
109	818-5F		Cascade Pass batholith	48° 21.9' 121 03.9'
111	27	basalt dike		48° 24.6' 121 46.7'
112	80N33D		tonalite of Bench Lake	48° 22.1' 121 10.0'
110	81F307A		Cascade Pass batholith	48° 06.6' 120° 09.3'
51	78-232		Chumstick Formation	47° 34.9 '120° 37.0'
52	78-228		Chumstick Formation	47° 30.1' 120° 26.0'
51	78-232		Chumstick Formation	47° 34.9 '120° 37.0'
52	78-228		Chumstick Formation	47° 30.1' 120° 26.0'
84	78-247		Swakane Biotite Gneiss	47° 33.7' 120° 19.4'
85	78-225		Swakane Biotite Gneiss	47° 31.9' 120° 27.1'
86	78-234		Swakane Biotite Gneiss	47° 39.2' 120° 33.9'
47	78-227		Chumstick Formation	47° 32.4' 120° 26.7'
47	78-227		Chumstick Formation	47° 32.4' 120° 26.7'
46	78-226		Chumstick Formation	47° 33.9' 120° 25.3'
48	78-235		Chumstick Formation	47° 39.4' 120° 31.0'
50	78-237		Chumstick Formation	47° 49.9' 120° 46.7'
49	78-236		Chumstick Formation	47° 44.9' 120° 38.4'
49	78-236		Chumstick Formation	47° 44.9' 120° 38.4'
60	75-x	tuff in Chumstick Formation	Chumstick Formation	47° 40.1' 120° 34.0'
61	75-191	tuff in Chumstick Formation	Chumstick Formation	47° 40.8' 120° 36.0'
78	RWT 123-79	flaser gneiss	Entiat pluton	47° 38.6' 120° 09.7'
58	75-200	tuff in Chumstick Formation	Chumstick Formation	47° 38.5' 120° 32.5'
59	75-124C	tuff in Chumstick Formation	Chumstick Formation	47° 40.7' 120° 34.8'
75	78-249	gneissic tonalite	Entiat pluton	47° 42.5' 120° 13.0'
63	76-67	tuff in Chumstick Formation	Chumstick Formation	47° 30.4' 120° 29.0'
62	75-215	tuff in Chumstick Formation	Chumstick Formation	47° 41.5' 120° 36.1'
77	RWT 151-79	gneissic tonalite	Entiat pluton	47° 48°.2' 120° 26.2'
75	78-249	gneissic tonalite	Entiat pluton	47° 42.5' 120° 13.0'
76	78-241	gneissic tonalite	Entiat pluton	47° 58.8' 120° 42.6'
80	78-244		Swakane Biotite Gneiss	47° 38.4' 120° 26.6'
79	78-243		Swakane Biotite Gneiss	47° 39.0' 120° 27.0'
81	78-246		Swakane Biotite Gneiss	47° 35.4' 120° 22.7'
83	78-248		Swakane Biotite Gneiss	47° 32.7' 120° 17.4'
82	78-245		Swakane Biotite Gneiss	47° 36.0' 120° 24.8'
53	78-233		Chumstick Formation	47° 39.1' 120° 34.2'
56	75-209	tuff in Chumstick Formation	Chumstick Formation	47° 38.2' 120° 36.2'
57	75-202	tuff in Chumstick Formation	Chumstick Formation	47° 37.2' 120° 35.2'
55	75-211	tuff in Chumstick Formation	Chumstick Formation	47° 40.4' 120° 36.6'
54	78-242		Chumstick Formation	47° 50.6' 120° 39.9'
54	78-242		Chumstick Formation	47° 50.6' 120° 39.9'

Loc. no.	Dating method	Material	Age (Ma)	Reference
20	K-Ar	biotite	56.2 ± 2.2	Cater and Crowder, 1967; Engels and others, 1976
15	K-Ar	muscovite	70.4 ± 3.4	Engels and others, 1976
68	K-Ar	biotite	46.2 ± 1.4	Cater and Crowder, 1967
15	K-Ar	biotite	70.1 ± 2.2	Engels and others, 1976
17	K-Ar	biotite	26.2 ± 4.5	Engels and others, 1976 (46)
16	K-Ar	sericite	24.5 ± 0.7	Engels and others, 1976 (47)
115	K-Ar	hornblende	63.2 ± 1.1	Tabor and others, 1988
89	K-Ar	hornblende	67.1 ± 3.0	Tabor and others, 1987a
108	K-Ar	biotite	17.9 ± 0.1	Tabor and others, 1988
108	K-Ar	hornblende	16.1 ± 0.1	Tabor and others, 1988
92	K-Ar	muscovite	52.4 ± 0.9	Tabor and others, 1987a
91	K-Ar	hornblende	71.5 ± 1.4	Tabor and others, 1987a
90	K-Ar	hornblende	63.0 ± 3.5	Tabor and others, 1987a
78	K-Ar	hornblende	60.0 ±1.2	Tabor and others, 1987a
78	K-Ar	biotite	56.2 ± 0.8	Tabor and others, 1987a
87	K-Ar	hornblende	50.8 ± 1.5	Tabor and others, 1987a
107	K-Ar	hornblende	54.0 ± 0.7	Miller and Bowring, 1990
106	K-Ar	hornblende	55.8 ± 3.6	Miller and Bowring, 1990
45	K-Ar	hornblende	41.5 ± 2.6	Tabor and others, 1987a
94	K-Ar	biotite	53.2 ± 1.0	Tabor and others, 1987a
93	K-Ar	hornblende	54.9 ± 4.0	Tabor and others, 1987a
112	K-Ar	biotite	51.9 ± 0.3	Tabor and others, 1988
114	K-Ar	pyroxene	286.0 ± 4.3	Tabor and others, 1988
113	K-Ar	biotite	44.7 ± 0.8	Tabor and others, 1988
113	K-Ar	hornblende	64.2 ± 1.2	Tabor and others, 1988
110	K-Ar	hornblende	20.1 ± 2.1	Tabor and others, 1988 (48)
109	K-Ar	biotite	23.3 ± 0.2	Tabor and others, 1988 (49)
109	K-Ar	hornblende	21.3 ± 1.3	Tabor and others, 1988 (50)
111	K-Ar	whole rock	46 ± 8	Tabor and others, 1988
112	K-Ar	hornblende	58.9 ± 0.3	Tabor and others, 1988
110	K-Ar	biotite	20.8 ± 1.1	Tabor and others, 1988 (51)
51	fission track	zircon	50.2 ± 2.4	Tabor and others, 1987a (52)
52	fission track	zircon	50.6 ± 2.2	Tabor and others, 1987a (53)
51	fission track	apatite	29.0 ± 4.8	Tabor and others, 1987a (54)
52	fission track	apatite	38.8 ± 6.3	Tabor and others, 1987a (55)
84	fission track	zircon	44.8 ± 2.3	Tabor and others, 1987a
85	fission track	zircon	46.4 ± 3.0	Tabor and others, 1987a
86	fission track	zircon	52.9 ± 2.4	Tabor and others, 1987a
47	fission track	apatite	32.1 ± 5.1	Tabor and others, 1987a (56)
47	fission track	zircon	45.4 ± 2.0	Tabor and others, 1987a (57)
46	fission track	apatite	38.3 ± 6.7	Tabor and others, 1987a (58)
48	fission track	zircon	46.6 ± 2.4	Tabor and others, 1987a (59)
50	fission track	apatite	47.7 ± 7.7	Tabor and others, 1987a (60)
49	fission track	apatite	34.7 ± 6.1	Tabor and others, 1987a (61)
49	fission track	zircon	47.5 ± 2.3	Tabor and others, 1987a (62)
60	fission track	zircon	46.2 ± 1.8	Tabor and others, 1987a (63)
61	fission track	zircon	46.4 ± 1.9	Tabor and others, 1987a (64)
78	fission track	apatite	50.4 ±1.2	Tabor and others, 1987a
58	fission track	zircon	42.7 ± 1.5	Tabor and others, 1987a (65)
59	fission track	zircon	46.1 ± 1.9	Tabor and others, 1987a (66)
75	fission track	zircon	57.6 ±4.1	Tabor and others, 1987a
63	fission track	zircon	44.4 ± 2.6	Tabor and others, 1987a (67)
62	fission track	zircon	42.7 ±3.7	Tabor and others, 1987a (68)
77	fission track	apatite	48.1 ± 1.2	Tabor and others, 1987a
75	fission track	apatite	50.2 ±7.7	Tabor and others, 1987a
76	fission track	zircon	32.8 ± 1.8	Tabor and others, 1987a
80	fission track	zircon	37.8 ±2.0	Tabor and others, 1987a
79	fission track	zircon	36.6 ± 2.3	Tabor and others, 1987a
81	fission track	zircon	40.5 ±2.1	Tabor and others, 1987a
83	fission track	zircon	43.9 ± 2.5	Tabor and others, 1987a
82	fission track	zircon	42.3 ± 8.2	Tabor and others, 1987a
53	fission track	zircon	56.6 ± 5.2	Tabor and others, 1987a (69)
56	fission track	zircon	42.7 ± 5.1	Tabor and others, 1987a (70)
57	fission track	zircon	48.8 ± 7.2	Tabor and others, 1987a (71)
55	fission track	zircon	41.9 ± 6.8	Tabor and others, 1987a (72)
54	fission track	zircon	66.4 ± 3.9	Tabor and others, 1987a (73)
54	fission track	apatite	43.9 ± 7.4	Tabor and others, 1987a (74)

APPENDIX 3. Preliminary U-Pb Ages (this study)

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Three fractions from each of the three samples were analyzed using an ion counter for the 204 beam. All of the fractions will be reanalyzed. (*All results should be quoted as preliminary.*)

SAMPLE 94-28A3: Leucodike in the Skagit Gneiss from 5 m below the Skagit Gneiss thrust contact with the Eldorado Orthogneiss (Site 57 in Fig. 4). (See the thrust contact of the Eldorado Orthogneiss, p.12.)

All fractions are strongly discordant and define a linear array with upper and lower intercepts of 1830±340 Ma and 54±7 Ma. The lower intercept is interpreted as a crystallization age. The large uncertainty is due to the slight dispersion in the data and low number of points. Additional data will likely tighten up the lower intercept.

SAMPLE 94-28C: Skagit orthogneiss (Site 59 in Fig. 4). (See Stehekin orthogneiss.)

All fractions are discordant and define a linear array with upper and lower intercepts of 1250±35 Ma and 49±1 Ma. Fractions "a" and "b" are essentially identical, with the effect that the regression is essentially a 2-point line. Thus the small uncertainty is likely an artifact and will expand somewhat with additional analyses.

SAMPLE 94-28D: Skagit orthogneiss (Site 58 in Fig. 4). (See Stehekin orthogneiss.)

All fractions are discordant and define a linear array with upper and lower intercepts of 1960±485 Ma and 50.5±1 Ma. Again, fractions "a" and "b" are essentially identical, with the effect that the regression is essentially a 2-point line. The small uncertainty will likely expand somewhat with additional analyses, unless I can refine it with a few concordant fractions.

SUMMARY COMMENTS

The systematics of all these samples are probably complex and need to be resolved before definitive final age assignments can be made. *Age assignments are preliminary.* Sample site #60 (Fig. 4) shows the location of an Eldorado Orthogneiss sample (geochronology in progress).

U-Pb isotopic data and apparent ages

	Fraction[a]	Wt (mg)	Concentration[b]		Isotopic composition[c]			Apparent ages (Ma)[d]			Th-corrected ages (Ma)[e]	
			U	Pb*	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{206}Pb*/^{238}U$	$^{207}Pb*/^{235}U$	$^{207}Pb*/^{206}Pb*$	$^{206}Pb*/^{238}U$	$^{207}Pb*/^{206}Pb*$
Sample DNR 94-28A3 - Leucodike in Skagit Gneiss												
a	63-80	0.1	618	7.2	2502±22	12.808	9.751	86.1	127.9±0.3	997	86.2±0.2	995±3
b	80-100A	0.3	682	5.6	1329±8	15.088	10.575	60.8	70.9±0.2	425	60.9±0.1	422±5
c	100-350A	0.3	411	3.7	2210±30	14.978	15.205	67.3	84.8±0.3	612	67.4±0.1	609±6
Sample DNR 94-28C - Skagit orthogneiss												
a	45-63	0.4	542	3.9	3008±28	18.361	15.512	52.8	55.6±0.2	176	52.9±0.1	172±4
b	63-100	0.2	539	3.8	2674±25	18.336	12.272	51.9	54.1±0.2	150	52.0±0.1	147±5
c	63-100A	0.3	573	4.6	2618±25	17.009	12.671	59.1	66.3±0.2	338	59.1±0.1	335±6
Sample DNR 94-28D - Skagit orthogneiss												
a	63-80	0.4	396	2.8	2773±26	18.442	8.518	51.7	53.8±0.2	145	51.8±0.1	141±8
b	80-100	0.5	281	2.0	2438±22	18.236	9.263	52.1	54.0±0.3	139	52.1±0.1	135±11
c	100-350A	0.4	237	1.6	2490±22	18.813	7.242	50.8	51.0±0.3	62	50.9±0.1	58±11

[a] a, b, and c designate conventional fractions; a designates conventional fractions abraded to 30 to 60% of original mass. Conventional fractions were washed in warm 3N HNO_3 and 3N HCL for 15 minutes each, spiked with ^{205}Pb-^{235}U tracer, and dissolved in a 50% HF>>14N HNO_3 solution within 3 ml Savillex[Tm] capsules placed in 45 ml TFE Teflon[Tm] line Parr acid digestion bomb, a process which is similar to the procedure outlined by Parrish (1987). Following evaporation and dissolution in HCL, Pb and U for all fractions were separated following techniques modified from Krogh (1973). Pb and U were combined and loaded with H_3PO_4 and silica gel onto singledegassed Re filaments. Isotopic compositions of Pb and U were determined through static collection on a Finnigan-MAT 261 multicollector mass spectrometer utilizing an ion counter for collection of the ^{204}Pb beam. Zircon fractions are nonmagnetic on Frantz magnetic separator at 1.8 amps, 15° forward slope, and side slope of 1°.

[b] Pb* is radiogenic Pb expressed as ppm. U is expressed as ppm.

[c] Reported ratios corrected for fractionation (0.125±0.038%/AMU) and spike Pb. Ratios used in age calculation were adjusted for 6 to 10 pg of blank Pb with isotopic composition of $^{206}Pb/^{204}Pb = 18.6$, $^{207}Pb/^{204}Pb = 15.5$, and $^{208}Pb/^{204}Pb = 38.4$, 2 pg of blank U, 0.25±0.049%/AMU fractionation for UO_2, and initial common Pb with isotopic composition approximated from Stacey and Kramers (1975) with an assigned uncertainty of 0.1 to initial $^{207}Pb/^{204}Pb$ ratio.

[d] Uncertainties reported as 2 sigma. Error assignment for individual analyses follows Mattinson (1987) and is consistent with Ludwig (1991). An uncertainty of 0.2% is assigned to the $^{206}Pb/^{238}U$ ratio based on our estimated reproducibility unless this value is exceeded by analytical uncertainties. Calculated uncertainty in the $^{207}Pb/^{206}Pb$ ratio incorporates uncertainty due to measured $^{204}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios, initial $^{207}Pb/^{204}Pb$ ratio, and composition and amount of blank. Linear regression of discordant data utilized Ludwig (1992). Decay constants used: ^{238}U=9.845 E-10. $^{238}U/^{235}U = 137.88$.

[e] 75%±25% efficiency in ^{230}Th exclusion during zircon crystallization is assumed and $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$ ratios have been adjusted accordingly. Age assignments presented are derived from the Th-corrected ratios.

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