

DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Preliminary geologic map of the Sauk River
30 by 60 minute quadrangle, Washington

by

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Open-File Map 88-692

This report is preliminary and has not been reviewed for conformity with Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsements by the USGS.

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Map A.

1. Booth (in press)
2. Brown and others (1982, Fig. 2)
3. Crowder and others (1966)
4. Tabor (1961, Pl. XXIV)
5. Tabor and others (1982b)
6. J.A. Vance (unpublished field maps 1959-1985)

Map B.

1. Baum (1968, Pl. I)
2. Beach (1962, map 4)
3. Bechtel, Inc. (1979, Appendix H, Sheet I)
4. Book (1977)
5. Brown and others (1987)
6. Bryant (1955, Pl. XLVIII)
7. Danner (1957, Pl. XII)
8. Danner (1966, p. 290, 302, 312, 318, 326, 333)
9. Dotter (1977)
10. Dungan (1974, Pl. 3)
11. A. B. Ford, H. W. Nelson, R. A. Sonnevill, R. A. Loney, Carl Huie, R. A. Haugerud, and S. L. Garwin (unpublished U. S. Geological Survey geologic map)
12. Franklin (1974, Pl. I)
13. Grant (1966)
14. Heath (1971, Pl. I)
15. Jenne (1978, Pl. I)
16. Jones (1959, Pl. II)
17. Milnes (1976, Pl. I)
18. Robertson (1981, Pl. I)
19. Silverberg (1985, Pl. I)
20. Vance (1957, Pl. I)
21. Wiebe (1963, Pl. I)
22. Reller (1986, Pl. I)
23. Tabor and Crowder (1969, Pl. I)
24. D. F. Crowder (unpublished U.S. Geological Survey field maps, 1963)

Map C.

2. Carithers and Guard (1945, Pl. I)
3. Cruver (1981)
4. Ford (1959, Pl. 5)
5. Ford (1983)
6. Grant (1969, Figs. 3, 22, 24)
7. Grant (1982)
8. Heller (1978)
9. McCleary and others (1978, Fig. 13)
10. Miers (1970, Pl. I)
11. Misch (1977, Figs. 1, 2, 3)
12. Morrison (1977)
13. Russel (1900, Pl. IX)
14. Spurr (1901)
15. Vance and others (1980, Fig. 3)
16. Wilson (1978)

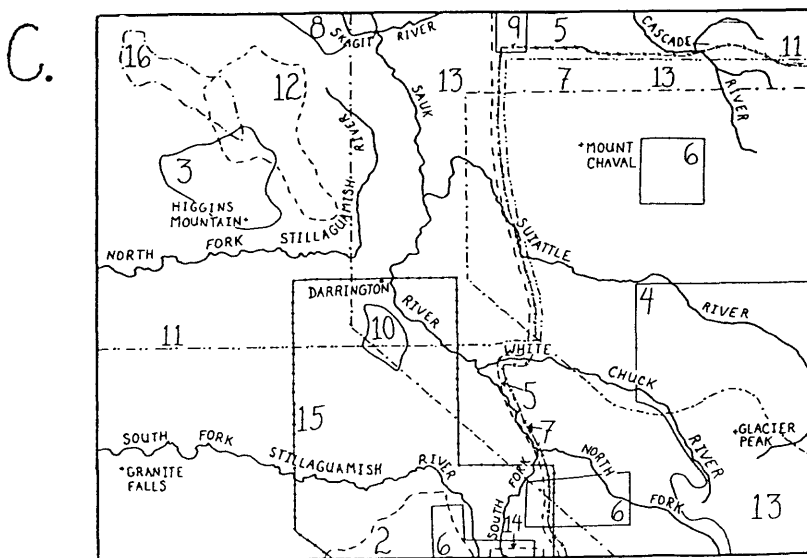
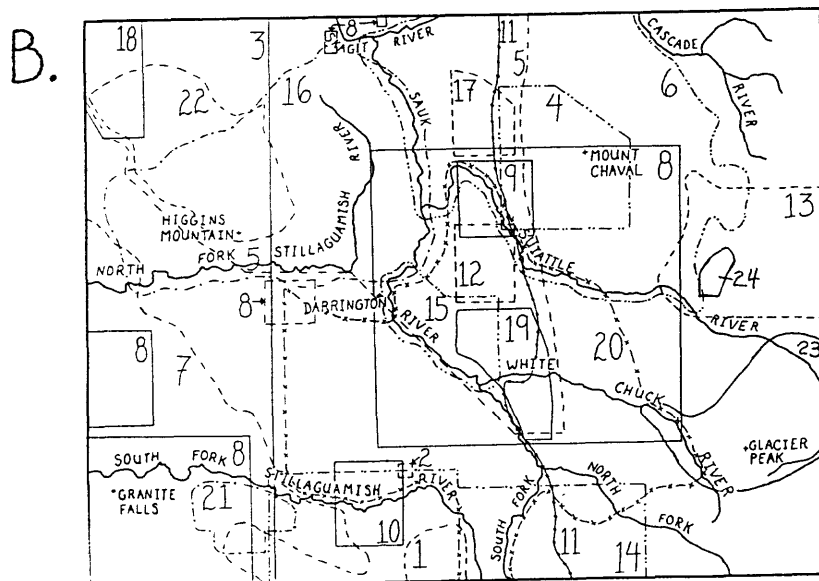
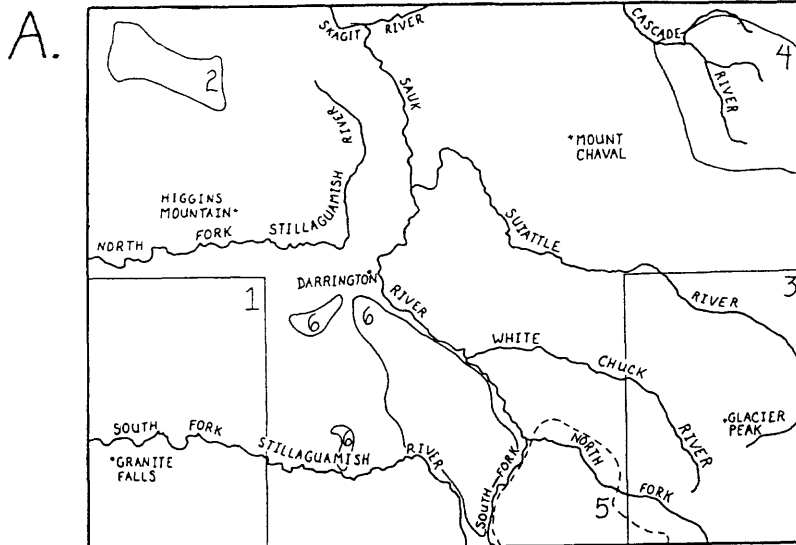


Figure 1. Previous geologic studies within the Sauk River quadrangle. A. Much data used, with little to modest modification; B. Some data used; C. Consulted extensively but data not used directly on map

INTRODUCTION

When I. C. Russell (1900) visited Cascade Pass in 1898, he began a geologic exploration which could blossom only after three-quarters of a century of growing geologic theory. The region encompassed by the Sauk River quadrangle is so structurally complex that even when Peter Misch (1952) and his students began their monumental studies of the North Cascades in 1948, the available geologic tools and theories were barely adequate to start deciphering the history. Subsequently Bryant (1955) Danner (1957), Vance (1957), Jones (1959), and Ford (1959) sketched the fundamental outlines of the geology of the Sauk River quadrangle. Their studies and those of the many workers who have followed have contributed to this map and are shown in Figure 1.

Our work in this quadrangle began in 1978 and has continued through 1985. It is part of a major U. S. Geological Survey goal to compile and map the entire Concrete 1x2-degree quadrangle at 1:100,000 scale.

Our field work was greatly facilitated by the assistance of Steven L. Garwin, Patrick Goldstrand, Ralph A. Sonnevill, Kathleen Ort, Vicky Pease, Carolyn Ortenburger, Fred Zankowsky and the late Carl Huie. We thank Michael Swanson, Fred Zankowsky, and especially Carolyn Ortenburger for office and laboratory services. Paleontologists who have helped immensely by identifying deformed and commonly metamorphosed (and usually uninspiring) fossils are Charles Blome, Anita Harris, David L. Jones, J. W. Miller, and Kate Schindler. Chuck Blome has been particularly helpful (see table 1). We thank John Whetten and Bob Zartman and John Stacey and his staff for unpublished U-Pb isotopic analyses (cited in table 2). Dennis Sorg provided clean mineral separates for K-Ar dates, Carolyn Ortenburger and Michael Ort extracted and analyzed most of the argon. P. Klock, S. Neil, T. Frigs, L. Espos, S. MacPherson, and M. Taylor analyzed the potassium.

We have had fruitful discussions on the geology of the area and the North Cascades in general with Ned Brown, Greg Reller, the late Peter Misch, Dave Silverberg, Ralph Haugerud, and John Whetten.

Most of our helicopter support was in the capable hands of Anthony Reese. We also thank the late Jack Johnson for his flying skill. U. S. Forest Service personnel at Darrington and Verlot have been helpful in many ways. We especially thank Howard Barstow, Janet DeRoco, and Fred Schaub.

Kathleen Duggan digitized the field map with the aid of computer program GS-MAP, and the accompanying map is mostly computer drawn.

GENERAL GEOLOGY

The Straight Creek fault almost bisects the Sauk River quadrangle. This major north-south structure is considered to have had about 100 km of right-lateral strike-slip offset during the late Cretaceous and early Tertiary time (Misch, 1977a; Vance and Miller, 1981; Monger in Price and others, 1985, p. 3-48). Within the Sauk River quadrangle, the Straight Creek fault mostly separates low grade rocks on the west from medium- to high-grade metamorphic rocks on the east (Fig. 2). In places the fault consists of several strands that bound unfaulted slivers of unmetamorphosed Tertiary sandstone. On the

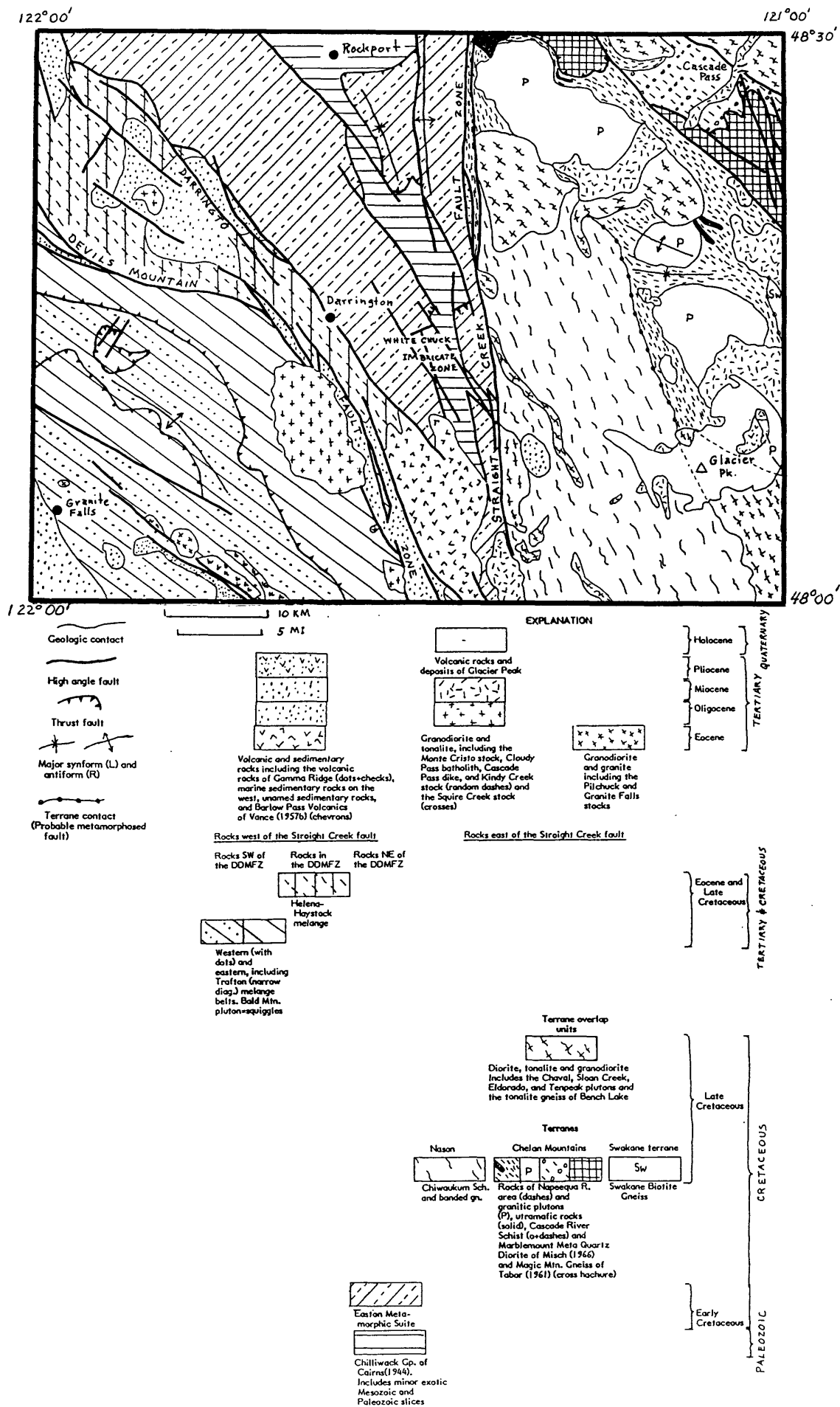


Figure 2. Generalized geologic map of the Sauk River quadrangle.

west side of the Straight Creek fault, a considerable number of north to north-northwest trending faults within the lower grade rocks may be subsidiary or sympathetic faults to the Straight Creek fault.

PreCenozoic rocks

Rocks East of the Straight Creek Fault

The rocks east of the Straight Creek fault are interpreted here as tectono-stratigraphic terranes based on their overall distinctive lithologies and possible different ages and structural histories (Tabor and others, 1987a,b,) although they all have been thoroughly metamorphosed in the Late Cretaceous. Three major terranes crop out east of the fault in the quadrangle: the Swakane, the Chelan Mountains, and the Nason.

The Swakane Biotite Gneiss is the sole component of the **Swakane terrane**. It is a probable metamorphosed sandstone or dacitic volcanic accumulation, notable for its uniformity in structure and lithology. Most of the Swakane is exposed southeast of the Sauk River quadrangle, where its protolith and age have been studied and debated by Mattinson (1972), Cater (1982, p. 5-6), and (Tabor and others (1987b)). Its protolith age is probably Precambrian, as indicated by the U-Th-Pb analysis of zircons (Mattinson, 1972, p. 3773; Tabor and others, 1987a, p. 8-9) and Rb-Sr studies (R. J. Fleck, written communication to A. B. Ford, 1987).

Overlying the Swakane terrane, and in probable thrust contact as revealed southeast of the Sauk River quadrangle (Tabor and others, 1987a, b), are the rocks of the Napeequa River area. Formerly we (Tabor and others, 1987a, b) included the rocks of the Napeequa River area in the Mad River terrane. New stratigraphic evidence north of the Sauk River quadrangle suggests that the Napeequa rocks may be in stratigraphic contact with metaconglomerates in the Cascade River Schist of Misch, (1966). Because the Cascade River Schist is an integral part of the Chelan Mountains terrane, the Napeequa rocks cannot be in a separate terrane. The **Chelan Mountains terrane** includes the rocks of the Napeequa River area, metaplutonic rocks intrusive into them, the metaplutonic rocks of the Marblemount-Dumbell-Entiat belt, and the Cascade River Schist of Misch (1966), restricted here to the mostly metaclastic part.

The rocks of the Napeequa River area are predominantly micaceous quartzites, fine-grained hornblende schist, and amphibolites derived from a protolith of oceanic chert and basalt. Minor marble and small bodies of meta-ultramafic rock are also characteristic. These rocks have been intruded by large, metamorphosed granitic to granodioritic plutons that may be Paleozoic or older in age based on a U-Th-Pb analysis of zircons from one such pluton south of the quadrangle (Tabor and others, 1987 a, b).

The Cascade River Schist (restricted) appears to have been a thick sequence of clastic rocks with minor volcanic rocks. It is now mostly plagioclase-rich mica schist, metaconglomerate, and amphibolitic schist. Minor constituents are siliceous schists (metatuff), marble, and rare meta-ultramafic rocks. The Marblemount Meta-Quartz Diorite of Misch (1966) is late Triassic in age based on U-Pb analyses of zircons (Mattinson, 1972, p. 3778). It appears to be overlain unconformably by the Cascade River Schist which contains metaconglomerate apparently derived from the Marblemount. The

contact between the oceanic rocks of the Napeequa unit with the locally coarse metaclastic rocks of the Cascade River Schist might have been along a fault or along an unconformity, since obscured by faulting, folding, and metamorphism, but the unconformity above the Marblemount suggests that the protolith clastics of the Cascade River Schist may have been laid down on both the Marblemount and the Napeequa protoliths.

Zircons from a dacitic metatuff, collected by Jeff Cary in the Cascade River Schist just above the Marblemount, yield Late Triassic ages (Table 1, no. 66). The succession of units suggest deposition in a forearc or intra-arc basin wherein intrusion was followed by rapid uplift of arc plutons and further deposition of arc volcanic rocks. Both the pluton and overlying deposits were metamorphosed in the Late Cretaceous.

The **Nason terrane** is composed predominantly of the Chiwaukum Schist, a metapelite, with some metasandstone and metabasite, characterized by aluminum silicate minerals and a banded gneiss derived from the schist. The protolith age of the Chiwaukum is uncertain although it appears to be pre-Late Jurassic. Some workers have argued from Rb-Sr data that its age is Triassic (Gabites, 1985, p. 68; Evans and Berti, 1986, p. 697-698; Magloughin, 1986, p. 264).

Apparently all the terranes had been assembled by the Late Cretaceous when they were intruded by deep-seated, synmetamorphic, mostly tonalite to granodiorite plutons. These terrane overlap plutons characteristically have both igneous and metamorphic features and generally yield U-Th-Pb ages of about 90 m.y. Some of the overlap plutons (such as the Tenpeak) have probable igneous epidote suggesting intrusion at depths greater than 18 km (Zen and Hammarstrom, 1984). During the Late Cretaceous metamorphism, thorough recrystallization and injection of tonalitic materials transformed parts of the Chiwaukum Schist and the rocks of Napeequa River area into banded gneiss and relatively homogeneous paragneiss. We consider these gneisses to be terrane overlap units as well because they developed their dominant characteristics during the Late Cretaceous metamorphism.

The contact between the Nason and Chelan Mountains terranes is marked by a gradual lithologic change from dominantly mica schist to micaceous quartzites and fine-grained amphibolite plus a scattering of small meta-ultramafic bodies in the Chelan Mountains terrane along the transition zone. We consider the contact to be a metamorphosed fault.

Although in the the Sauk River quadrangle the dominant metamorphism appears to be Late Cretaceous, just to the north, the oceanic rocks of the Napeequa River area are a significant constituent of the Skagit Gneiss of Misch (1966), which, in its core area was intruded by 60 and 75 Ma-orthogneisses and was still being metamorphosed in the Middle Eocene (about 45 Ma) (Babcock and others, 1985; Haugerud and others, 1988; Tabor and others in press b). Zircon from the Hidden Lake Peak stock yields crystallization ages of 75 Ma. The stock is undeformed but has been recrystallized, probably reflecting the ongoing heating event to the north.

Rocks west of the Straight Creek fault

The several major supracrustal units in the quadrangle west of the fault have been referred to the **Northwest Cascades System (NWCS)** by Brown (1987, 1988), following the structural framework established by Misch (1966). In the Sauk River quadrangle the NWCS is characterized by rocks of oceanic origin that have been metamorphosed at low temperatures (T) and at pressures (P) ranging from low to high. The structural complexity of the NWCS has led Brown (1987, p. 201) to aptly characterize it as a regional melange.

A major zone of disruption and faulting, here called the Darrington-Devils Mountain fault zone (DDMFZ) separates two distinct assemblages. Northeast of the DDMFZ, the Paleozoic Chilliwack Group of Cairnes (1944), with infaulted blocks of metasedimentary and meta-igneous rocks, is at least locally thrust over by the Easton Metamorphic Suite composed of the high P/T Darrington Phyllite and Shuksan Greenschist. The thrust may be the regional Shuksan thrust, mostly mapped to the north of the quadrangle (Misch, 1966, p. 120-123; Brown and others, 1987), but in the Sauk River quadrangle most contacts between the Chilliwack and the Easton are high-angle faults which some workers interpret to be the Shuksan-thrust (see Silverberg, 1985 for further discussion of the faults).

The Chilliwack Group is composed of marine sedimentary rocks and mafic to intermediate volcanic rocks and widespread but minor marble. Locally Chilliwack rocks are strongly foliate, mostly with a low dip. Chilliwack Group rocks probably were deposited in an arc setting in the Late Paleozoic (Blackwell, 1983; Brown, 1987). The Shuksan Greenschist is a fine-grained but well recrystallized metamorphic rock, commonly with blue amphiboles. Its oceanic basalt protolith formed in the Middle to Late Jurassic and it was metamorphosed in the early Cretaceous (Brown, 1987).

Associated with the Chilliwack, especially at major tectonic contacts, are slices of exotic rocks. The most prominent are the Yellow Aster Complex of Misch (1966) composed of probable Precambrian gneisses metamorphosed in the Silurian (Mattinson, 1972, p. 3775-3776) and Paleozoic diorite and gabbro. Another exotic component is the Vedder Complex of Armstrong and others (1983) composed of siliceous amphibolite and other schists yielding Paleozoic metamorphic ages. A small amount of metachert and greenstone of the Mesozoic and Paleozoic(?) Elbow Lake Formation of Brown and others (1987) crops out along faults on the valley walls above the White Chuck River, and in the White Chuck imbricate zone northwest of White Chuck Mountain (fossil locality 36f).

Following the lead of Tabor and others (in press b) we restrict the NWCS in the Sauk River quadrangle to the Chilliwack, Easton, and exotic slices described above.

Southwest of the DDMFZ, the **western and eastern melange belts** of oceanic rocks are characterized by extreme disruption on an outcrop scale and low P-T metamorphic assemblages. The western melange belt is mostly clastic, characterized by commonly thick-bedded volcanic subquartzose sandstone. A regional antiform exposes a pelitic facies, characterized by pervasive phyllitic cleavage. The eastern melange belt is locally less penetratively deformed and is characterized by mafic volcanic rocks, chert, and ultramafic

rocks. The eastern melange belt and a probable correlative, the highly mixed Trafton melange of Whetten and others (1988), appear to be structurally high and folded over the regional antiform expressed in the western melange belt. We consider the eastern melange belt and Trafton melange to be in fault contact with the underlying western melange belt, although the disruption between the two units along this inferred fault is no more severe than that within the melanges themselves (Tabor and Booth, 1985). In the western melange belt fossil ages are Late Jurassic and Early Cretaceous except for marble which is Permian (Table 1; Frizzell and others, 1987, p. 135) and may be olistostromal. Meta-igneous blocks in the Eastern melange belt are Late Triassic (Whetten and others, 1980; Frizzell and others, 1987), whereas fossils range from Late Triassic to Late(?) Jurassic. Fossils in the Trafton melange range from Mississippian to Early Jurassic and a metatonalite block is at least as old as Pennsylvanian.

The age of melange formation for the eastern and western belts and the Trafton melange can only be restricted to a time span between the youngest component of the melange and the oldest overlying unit. For simplicity and lacking evidence to the contrary, we have assumed here that all the melanges south of the DDMFZ formed at about the same time, that is between mid-Cretaceous and Eocene. The younger limiting age is based on post-deformation intrusion of the early Eocene Pilchuck stock.

Within the DDMFZ, the **Helena-Haystack melange** is composed of a variety of lithologies in a serpentinite matrix (Vance and others, 1980). Components of the eastern melange belt and the Easton Metamorphic Suite are represented in the Helena-Haystack melange as well as foliated silicic volcanic rocks, hornblende tonalite, and fine-grained schistose amphibolite, rock types not present in the adjoining units.

A hornblende tonalite block has a probable crystallization age of 150 Ma (Late Jurassic) as revealed by a U-Pb age of zircon (Table 1, no. 77), whereas a metarhyolite block has a metamorphic age of about 90 Ma (Late Cretaceous) as shown by a K-Ar muscovite age (Table 1, no. 79) and a two point Rb-Sr "isochron". Clearly rocks of great diversity in age and origin have been mixed in Late Cretaceous and/or early Tertiary time.

The conditions of low-grade metamorphism appear to differ between rocks north of the DDMFZ and rocks to the south. North of the DDMFZ rocks are characterized by development of minerals representative of high P/T, specifically blue amphibole and lawsonite in the Easton Metamorphic Suite and lawsonite and aragonite in the Chilliwack (Brown and others, 1981). South of the DDMZ blue amphiboles have not been found. Aragonite and possible lawsonite occur in phyllitic rocks of the western melange belt and in the eastern melange belt, but only in small amounts north of the South Fork of the Stillaguamish River. The melange belts to the south contain only prehnite and pumpellyite (Tabor and others, in press).

Many rocks within the DDMFZ were also metamorphosed at high P/T. Brown and others, (1987, p. 173-174) and Reller (1987, p. 26-31) consider meta-volcanic rocks in the Helena-Haystack melange comprising Big and Little Deer Peaks, to have been metamorphosed at about the same P but at slightly lower T than rocks in the Easton Metamorphic Suite.

Tertiary and Quaternary Rocks and Deposits

The Mount Pilchuck and Granite Falls stocks and associated small bodies intruded and thermally metamorphosed rocks of the western melange belt in Early Eocene time. At the same time the rhyolitic ash flow tuffs of Hansen Lake erupted. The similarity in age and the occurrence of garnet in both intrusive and extrusive rocks suggests that the rhyolite was an eruptive phase of the granite of the Pilchuck stock (Wiebe, 1963, p. 36-39).

A widespread eruptive event produced the middle Eocene Barlow Pass Volcanics of Vance (1957b), the correlative volcanic rocks in the Naches Formation to the south of the quadrangle, and in the Puget Group to the southwest. Within the thick pile of predominantly basalt, basaltic andesite, and rhyolite of the Barlow Pass are interbeds of fluvialite feldspathic sandstone and conglomerate, which in many areas dominate the section.

Along much of the DDMFZ, the Barlow Pass overlies the Helena-Haystack melange. The Tertiary rocks are locally highly faulted, and locally have been incorporated in the melange. Locally sheet-like fault slivers of serpentinite from the underlying melange have been emplaced into the sandstone facies of the unit and recrystallized as metaperidotite (Vance and Dungan, 1977). Clasts in Tertiary conglomerates are highly stretched, roughly horizontally, parallel to the faults, suggesting strike-slip movement in post-Middle Eocene time. The Barlow Pass erupted in a time of regional extension (Ewing, 1980; Heller and others, 1987) and probable strike-slip faulting along the DDMFZ. Waning strike-slip movement along the Straight Creek Fault may have occurred during this time as well, but large displacement is precluded by the occurrence of Barlow Pass rocks on both sides of the fault south of the Sauk River quadrangle (Tabor and others, in press a).

With establishment of the Cascade Arc along what is now the north-trending backbone of the Cascade Range (Vance and others, 1986), a series of intrusive events followed the eruption of Barlow Pass volcanics. Stocks at Vesper Peak, Squire Creek, and Granite Lakes are the northern outliers of the 34 Ma (early Oligocene) Mount Index batholith exposed south of the quadrangle. Magmas of the Index intrusive episode appear to have come up along the southwest side of the northwest-trending DDMFZ. The plutons cut the fault zone and are not displaced by it.

In the latest Oligocene (about 25 Ma) small satellitic stocks and plugs (including the Monte Cristo and Dead Duck stocks) of the Grotto batholith (itself exposed south of the quadrangle) invaded the north-trending Straight Creek fault zone. About 22 to 23 Ma in Miocene time, the Cloudy Pass batholith and satellitic bodies apparently invaded northeast-trending structures in the higher grade metamorphic rocks east of the Straight Creek fault. The even more strongly northeast-oriented Cascade Pass dike and Mount Buckindy pluton were emplaced at 18 and 15 Ma, respectively.

Late Neogene volcanic activity is recorded in the area first by the volcanic rocks of Gamma Ridge. Their occurrence near Glacier Peak suggests an early expression of the Quaternary volcanism that built Glacier Peak volcano. A major eruption of Glacier Peak 11,250 years ago mantled much of the country east of the quadrangle with dacitic pumice. Other eruptions have been discussed in detail by Beget (1981); their deposits form extensive terraces and fills in the valleys of the Suiattle, White Chuck, Sauk, and

North Fork of the Stilliguamish Rivers. Alluvium enriched in presumed Glacier Peak ash has been identified as far west as Whidby Island, 40 km west of the quadrangle and over 100 km west of Glacier Peak (D. P. Dethier, written communication, 1985).

Pleistocene Glacial Deposits

Glaciations in the Sauk River Quadrangle are represented by deposits of both alpine and ice-sheet glaciers. Valley-bottom and valley-wall deposits in the upland trunk drainages (such as Downey Creek, Sulphur Creek, Illabot Creek, and Clear Creek) include till and outwash from glaciers that originated at the drainage headwalls. The majority of these deposits probably date from the Evans Creek stade of the Fraser glaciation (Armstrong and others, 1965), about 20,000 yr B.P. Additional deposits have been derived from lesser expansions of these same glaciers in latest Pleistocene and Holocene time.

In the west half of the quadrangle, deposits derived from the Puget lobe of the Cordilleran ice sheet fill many of the lower valleys and mantle the upland surfaces. Virtually all deposits date from the Vashon stade of the Fraser glaciation culminating about 15,000 yr B.P. (Booth, 1987). Ice tongues from Puget lobe probably advanced up each of the major river valleys into areas previously occupied by downvalley-advancing alpine ice. In general the surface altitude of the ice sheet increased to the north, reflecting the major source area in British Columbia (Booth, 1986). In the northeastern part of the quadrangle, the projected high altitude of the ice-sheet surface indicates that the Cascade glaciers in the headwaters of each drainage probably merged with the Puget lobe, creating a near-continuous ice cover across this part of the Cascade Range. Most of these upvalley deposits lack good exposure or diagnostic non-local clast types and so mappable deposits of the ice sheet are found only west of the Sauk River.

DESCRIPTION OF MAP UNITS

QUATERNARY DEPOSITS

Non-Glacial Deposits

- Q1 LANDSLIDE DEPOSITS (HOLOCENE)--Diamictons composed of angular clasts of bedrock and surficial deposits derived from upslope. Commonly shown without letter symbol; arrows denote downslope direction of movement. Include both the transported material and unstable scarp area if present
- Q1i INCIPIENT BLOCKSLIDES (HOLOCENE) - Large unrotated masses of bedrock crevassed or otherwise deformed as a result of slight movement toward nearby free face. Recognized primarily from air photos. Crevassed arrow symbol shows direction of movement
- Qmw MASS-WASTAGE DEPOSITS (HOLOCENE AND PLEISTOCENE)--Colluvium, soil, or landslide debris with indistinct morphology, mapped where sufficiently continuous and thick to obscure underlying material. Unit is gradational with units Qf and Q1

- Qt TALUS DEPOSITS (HOLOCENE)--Non-sorted angular boulder gravel to boulder diamicton. At lower altitudes gradational with Qf. At higher altitudes includes small rock-avalanche deposits as well as some Holocene moraines, rock glaciers, and protalus rampart deposits that lack characteristic morphology. Surfaces generally unvegetated
- Qf ALLUVIAL-FAN DEPOSITS (HOLOCENE)--Poorly sorted cobble to boulder gravel, deposited either as a discrete lobe at the intersection of a steep stream with a valley floor of lower gradient or as a broad apron on steep sideslopes
- Qb BOG DEPOSITS (HOLOCENE)--Peat and alluvium. Poorly drained and intermittently wet. Grades into unit Qyal
- Qyal YOUNGER ALLUVIUM (HOLOCENE)--Moderately sorted deposits of cobble gravel to pebbly sand along rivers and streams. Generally unvegetated surfaces; gradational with both units Qf and Ob
- Qoal OLDER ALLUVIUM (HOLOCENE AND PLEISTOCENE)--Similar to unit Qyal, but standing above modern floodplain level and generally separated from it by a distinct topographic scarp. Age of deposits presumed younger than that of unit Qvr but relations are ambiguous in some localities
- Qa ALLUVIUM AND MASS-WASTAGE DEPOSITS, UNDIFFERENTIATED (HOLOCENE AND PLEISTOCENE)--Includes deposits of units Qf, Qyal, Qmw, Qvt, Qvr, intermixed on the sides and floors of upland stream valleys. Similar to unit Qag in heterogeneity but occurring where deposits of alpine glaciers have been later obscured or are absent

Glacial Deposits

- Qag ALPINE GLACIAL DEPOSITS (PLEISTOCENE AND HOLOCENE)--Ranges from boulder till in uplands and upvalley to gravel or sand outwash on broad valley floors. On valley sides and uplands includes areas veneered with drift but also includes bedrock, alluvial fans, colluvium, or talus deposits. On valley floors also includes small fans, bogs, and modern stream alluvium. Areas of thin, sparse drift not distinguished from bedrock. Includes indistinct moraines near the outlets of Heather Lake and Lake Twenty-two
- DEPOSITS OF THE VASHON STAGE OF FRASER GLACIATION OF ARMSTRONG AND OTHERS (1965) (PLEISTOCENE)--Divided into:
- Qvr Recessional outwash deposits--Stratified sand and gravel, moderately to well-sorted, and well-bedded silty sand to silty clay. This deposit formed predominantly in outwash plain and valley train environments in the lowland areas. Locally it is subdivided into:

- Qvrs Stillaguamish sand member--Deposits of the recessional outwash (Minard, 1985 a, b)
- Qvi Ice-contact deposits--Similar in texture to unit Qvr, but containing collapse features, abrupt grain-size changes, or till lenses that indicate deposition near stagnant or active ice
- Qvt Till--Mainly compact diamicton with subangular to rounded clasts, glacially transported and deposited. In ice-marginal areas or where covered by a thin layer of recessional outwash, contact with units Qvi or Qvr is gradational. Mapped areas also include deposits of units Qf, Qmw, and Qyal too small or too poorly exposed to show at map scale
- Qva Advance outwash deposits--Well-bedded gravelly sand, fine-grained sand, and bedded silt, generally firm and unoxidized; deposited by proglacial streams and in proglacial lakes

Non-Glacial and Glacial Deposits

- Qtb TRANSITIONAL BEDS (PLEISTOCENE)--Pre-Vashon deposits of laminated clayey silt to clay; rare dropstones present
- Qpf NON-GLACIAL AND GLACIAL SEDIMENTARY DEPOSITS OF PRE-FRASER GLACIATION AGE (PLEISTOCENE)--Moderately to deeply weathered, moderately sorted sand and gravel. Weathering rinds 1-3 mm thick on fine-grained volcanic clasts. Exposed only in the western part of the quadrangle along the northern and southern boundaries

Volcanic Rocks and Deposits

GLACIER PEAK AND ASSOCIATED VOLCANIC ROCKS AND DEPOSITS (PLEISTOCENE AND HOLOCENE); divided into:

- Qlh Laharic Deposits--Boulder diamicton to well-sorted sand and gravel with characteristic clasts of pumice and volcanic rocks from Glacier Peak; found along the Suiattle, White Chuck, Sauk, and North Fork of the Stillaguamish Rivers. Includes deposits of unit Qyal where the alluvium is too narrow to easily distinguish at map scale. Stratigraphy and general distribution first delineated by Beget (1981); additional localities provided by D.P Dethier (written communication 1985)
- Qsf Deposits of the Suiattle Fill--Well-bedded assemblage of lahars, pyroclastic flows, air-fall ash, alluvium, and rare lava flows. Deposit grades downvalley into Qlh. Described in detail by Ford (1959, p. 273-284), Tabor and Crowder (1969, p. 36-40), and more recently by Beget (1981, p. 96-132; 1982, p. 47-48) who brackets the age of deposit between 6,700 and 3,400 years and possibly equivalent to the upper part of the White Chuck fill (Kennedy Creek assemblage) at 5,500 to 5,100 years old. Includes some younger volcanic deposits

- Qwf Deposits of the White Chuck Fill--Well-bedded assemblage of
Qdt lahars, pyroclastic flow deposits, alluvium, and reworked ash and silt. Parts of this unit become Qlh downvalley. Includes Crystal Creek mudflow, White Chuck assemblage, and Kennedy Creek assemblage of Beget (1982, p.22-38), who describes these deposits in detail. Beget (1982, p.24-34) reports bracketing ages between 11,670 and 5,100 years for these deposits. May also include some younger deposits. An indurated, cliff-forming dacitic vitric tuff, Qdt, (Ford, 1959, p. 292-295; Tabor and Crowder, 1969, p. 43-44; Beget, 1982, p. 29-30) crops out in the upper part of the fill
- Qgdu Dacite, undifferentiated--Clinopyroxene-hypersthene dacite. In flows and volcanic rubble on Glacier Peak volcano. Extensive descriptions of Glacier Peak rocks in Ford (1959, p. 250-271) and Tabor and Crowder (1969, p. 24-36), who indicated that all the flows of Glacier Peak are probably less than 700,000 years old but might extend to 900,000 years old based on lack of magnetic reversals in the rocks. Locally mapped as:
- Qgy Younger flows--clinopyroxene-hypersthene dacite in valley-side-clinging and valley bottom flows
- Qgo Older flows--clinopyroxene-hypersthene dacite in highly eroded ridge-capping flows
- Qgdd Dacite of Disappointment Peak--Oxyhornblende-hypersthene dacite in massive, partly eroded dome
- Qcc CINDER CONES (HOLOCENE)--The White Chuck Cinder Cone is composed of basalt lapilli and minor bombs with a few interbedded olivine basalt flows. Eroded cone is at least 11,250 years old (Beget, 1981), but younger than the alpine glaciation of about 20,000 years b.p. The cinder cone remnant southwest of Indian Head Peak is mostly composed of well-stratified tuff and breccia. Its age may be about the same as the White Chuck Cinder Cone (Tabor and Crowder, 1969, p. 47)
- Qaf ANDESITE FLOW (HOLOCENE OR PLEISTOCENE)--Eroded remnant of columnar jointed olivine andesite flow at the mouth of Lightning Creek. Other than being post-major alpine glaciation (ca 20,000 y. BP) age is unknown. For further descriptions see Tabor and Crowder (1969, p. 47-48)

TERTIARY BEDROCK

- VOLCANIC ROCKS OF GAMMA RIDGE (PLIOCENE), divided into:
- Tgre Conglomerate--White to dirty gray tuffaceous conglomerate. Poorly bedded, composed of cobbles of granitoid rock, quartzite, schist, and light-colored dike rocks in a fine-grained matrix of volcanic subquartzose sandstone that is much altered to greenish-yellow chlorite (?). Locally composed entirely of andesite cobbles and may include earliest detritus from Glacier Peak volcano. This and other descriptions of the volcanic rocks of Gamma Ridge adapted from Crowder and others (1966) and Tabor and Crowder (1969, p. 19-23)

Tgrv Volcanic rocks--Altered tuff, volcanic breccia, volcanic sandstone, welded tuff, and minor flows of basalt. Variegated red, brown, green, and white; bedding obscure; altered to carbonate, sericite, clays, and chlorite; siliceous kaolinite common near Gamma Peak; glassy rocks commonly spherulitic; common veins of zeolite, carbonate, and quartz. Before alteration, composition ranged from rhyolite to basalt. For further descriptions and chemical analyses see Tabor and Crowder (1969, p. 19-23, 30). A fission track age of zircon separated from an ashflow tuff is about 2 m.y. (Table 2, no. 2)

Tgrf Fows of altered andesite and dacite--Red to black andesite and dacite, plagioclase phyric, trachytic; much altered to calcite, chlorite, and zeolites

COOL GLACIER STOCK (PLIOCENE), includes:

Tcg Granodiorite--Pyroxene-biotite hornblende granodiorite and quartz monzodiorite. Medium grained, hypidiomorphic granular. Concordant biotite and hornblende ages of about 4 m.y. (Table 2, no. 1) suggest that this stock represents the magma chamber that fed the lavas of the Gamma Ridge unit. Chemical and modal data are in Tabor and Crowder (1969, p. 14) and Ford and others (1988, p. 117)

Tcgb Breccia--Clasts of Tenpeak pluton in a highly ground up and hydrothermally altered matrix of commuted tonalite and altered volcanic material and some glass (Tabor and Crowder, 1969, p. 16)

Tdp DACITE PLUGS (PLIOCENE)--Gray porphyritic biotite-hornblende-hypersthene dacite with locally resorbed quartz phenocrysts. Locally well-developed columnar jointing. Includes dacite breccia northwest of Glacier Peak. Locally includes andesite. A hypabyssal intrusive and extrusive complex of similar rock exposed at Cady Ridge south of the quadrangle has a K-Ar hornblende age of about 5 m.y. (Tabor and others, in press a)

MOUNT BUCKINDY PLUTON (MIOCENE), divided into:

Tmt Tonalite and granodiorite--Mostly porphyritic biotite-hornblende tonalite to hornblende tonalite porphyry. Rock is quartz phyric with hypidiomorphic granular groundmass, but heterogeneous in grain size and texture. A number of K-Ar ages from hornblende and biotite pairs are concordant at about 14 Ma. One pair is slightly discordant at 16 and 15 Ma, respectively (Table 2, nos. 3-6)

Tmb Breccia--Clasts of tonalite in a vuggy quartz and iron oxide (magnetite?) matrix

CASCADE PASS DIKE (MIOCENE), divided into:

Tct Tonalite--Medium-grained hornblende-biotite tonalite, hypidiomorphic granular with small glomeroporphyrocrysts of mafic minerals. Massive and coarsely jointed, with local areas

of disseminated sulfide minerals. The dike has finer-grained, porphyritic, chilled margins; contact lit-par-lit complexes are common, and alteration is pervasive locally. Tabor (1963) presents arguments for shallow intrusion and gives more detailed descriptions. A number of samples of hornblende and biotite yield K-Ar ages ranging from 16 to 19 m.y. (Table 2, nos. 7-9). Concordant pairs suggest that the age of this shallow pluton is about 18 m.y.

Tcb Breccia--Rotated fragments of altered hornblende schist with minor quartz and calcite or aplitic matrix grading downward into swarms of schist inclusions in a miarolitic tonalite matrix

CLOUDY PASS BATHOLITH AND ASSOCIATED ROCKS (MIOCENE), divided into:

Tcpl Light-colored granite and granodiorite--Hornblende-biotite granite and granodiorite, white to pink, medium-grained subhedral plagioclase in a finer grained matrix of xenomorphic granular to granophyric quartz and orthoclase; CI=5-15, massive, jointed, inclusions rare. Sharp contact with country rocks on west, grades into Tcpl on east. Descriptions for units of the Cloudy Pass batholith adapted from Crowder and others (1966). Further descriptions and discussion of the batholith's chemistry and intrusive history are in Ford (1959, p. 182-248), Grant (1966, p. 207-245) and Tabor and Crowder (1969, p. 3-18). See also Cater (1969), and for modal and O¹⁸ data Ford and others (1988, p. 36-38) and White and others (1988, p. 20)

Tcpd Dark colored granodiorite, tonalite, gabbro, and quartz gabbro--Light- to dark-gray, medium-grained hornblende-biotite granodiorite, gabbro, tonalite and quartz gabbro, hypidomorphic granular. CI=10-30. Massive, well-jointed, inclusions rare; locally altered and cataclastic, grades into Tcpl in smaller bodies commonly contains pyroxene and locally abundant mafic inclusions. Varied in texture and composition, locally porphyritic. South of Lake Byrne forms a complex of dikes, sills, and irregular small masses. At South Cascade Glacier, quartz with necklace inclusions suggests early-formed quartz phenocrysts. Just east of the quadrangle two biotites from the pluton and one from adjacent hornfels yield K-Ar ages of about 23, 23, and 21 m.y., respectively (Tabor and Crowder, 1969, p. 3; ages corrected for new constants). Hornblende and biotite ages from the stock at the South Cascade Glacier are slightly discordant at about 21 and 23 m.y., respectively, and a pair from the stock on Sitkum Creek is concordant at 20 m.y. (Table 2, nos. 10, 11)

Tcpu Undifferentiated granodiorite, tonalite, and gabbro

Tcpb Breccia, intrusive--Chips and large blocks of schist, gneiss, and aphanite in a matrix of dacite which is commonly highly cataclastic; dark aphanite fragments and dacitic matrix commonly trachytic; locally recrystallized by thermal

- metamorphism. See Tabor and Crowder (1969, p. 15-17) for further description
- Tepc Concentration of light-colored dikes and irregular bodies--White, variably fine- to coarse-grained xenomorphic or hydior-morphic granular tonalite to granite alaskite in densely clustered dikes, sills, and irregular bodies, generally making up 80% or more of bedrock. Locally weakly to strongly foliated. Contacts sharp. Rocks rich in K-feldspar appear to be related to the batholith but many light-colored rocks may be older, associates of the metamorphic country rock (Tabor and Crowder, 1969, p. 10-12)
- Tdm DOWNEY MOUNTAIN STOCK--Hornblende-biotite tonalite, locally granodiorite. Similar to Tcpc. Some modal and O^{18} data in Ford and others (1988, p. 117) and White and others (1988, p. 32)
- GROTTO BATHOLITH (MIOCENE AND OLIGOCENE), divided into--
- Tgm Monte Cristo stock--Hornblende-biotite granodiorite and tonalite. Locally contains augite and hypersthene. Commonly somewhat altered to chlorite, epidote, and sphene. K-Ar ages of hornblende and biotite are concordant at about 24 m.y. (Table 2, nos. 12, 13)
- Tgd Dead Duck pluton--Hornblende-biotite tonalite and granodiorite, with minor augite and hypersthene. Two hornblende-biotite pairs yield concordant K-Ar ages of about 27 and 25 m.y., respectively (Table 2, nos. 14, 15). We do not know why the concordant ages of the separate pairs are different, but the younger pair is in the appropriate age range for the lithologically similar Grotto and Snoqualmie batholiths exposed mostly to the south of the quadrangle
- Tgs Shake Creek stock--Biotite-hornblende tonalite, fine grained, highly altered. Isotopic age has not been determined; the Shake Creek stock could have Squire Creek stock (Index batholith) affinity
- Trb BRECCIA OF ROUND LAKE (MIOCENE)--Predominantly andesite to dacite breccia forming massive cliffs, locally weakly bedded. Rocks are plagioclase phyric but phenocrysts are highly altered and mafic minerals are replaced by chlorite. (See Vance, 1957, p. 288-290). Two chemical analyses are in Ort and others (1983). Volcanic breccia grades downward into talus breccia composed of underlying metamorphic rocks, locally in a tuff matrix. Includes some probable hypabyssal holocrystalline pyroxene andesite porphyry. The breccia is much like the breccia of Kyes Peak (Tabor and others, in press a) exposed south of the quadrangle. The Kyes Peak breccia appears to post date the latest Oligocene Grotto batholith whereas the breccia of Round Lake is thermally metamorphosed by the Dead Duck pluton (a Grotto batholith satellite).

SQUIRE CREEK STOCK AND RELATED INTRUSIVE ROCKS (OLIGOCENE),
divided into:

- Tst Tonalite--Predominantly uniform hornblende-biotite tonalite and granodiorite, medium-grained and hypidiomorphic granular. Locally rich in small hornblende diorite inclusions. CI=12-18 as reported in Vance (1957, p. 241-274) who also describes the pluton in detail. Locally in interior, pluton is fine-grained and with lower CI. The stock has a 1-2 km wide thermal aureole. A hornblende and biotite pair from the Squire Creek stock yield a concordant K-Ar age of about 35 m.y. (Yeats and Engels, 1971, p. D36), and zircon gives a U-Pb age of about 35 m.y. (Table 2; nos. 18, 19). The ages of the Squire Creek stock and associated plutons are appropriate for the Index batholith to the south, well dated at about 34 Ma. (Yeats and Engels, 1971); Tabor and others, in press a)
- Tsbt Biotite tonalite--On Vesper peak mostly medium-grained hypidiomorphic inequigranular; rarely hornblende-biotite tonalite with rare hypersthene. CI=9-28, mostly about 12-20 (Baum, 1968, p. 20). Baum (1968, p. 49-65) and Griffis (1977, p. 118-206) describe sulphide mineralization in the Sunrise breccia pipe and elsewhere associated with the stock. Griffis (op cit, p. 96) cites a 32.7 ± 2 m.y. whole rock K-Ar age obtained from a chip sample along the northern margin of the pluton
- Tshg Hornblende quartz diorite--At Granite Lakes the rock is a porphyritic hornblende quartz diorite with euhedral, highly corroded, pale brown hornblende phenocrysts. Dikes of similar but more porphyritic rock are common in the Mount Higgins area. The stock at Granite Lakes yields poorly reproducible K-Ar hornblende ages of about 37 m.y. (Table 2, nos. 20, 21)
- Tus UNNAMED SANDSTONE (OLIGOCENE)--Moderately to deeply weathered, sandy pebble conglomerate to very-fine-grained sandstone. Coarse beds contain a high percentage of quartzose pebbles; finer beds contain considerable mica and lignite. Deeply weathered exposures usually can be distinguished from old glacial outwash by manganese staining on joint planes, quartzose or pebble-rich lithology, and presence of organic matter.

These rocks appear to be continuous with shallow marine rocks of Oligocene age to the southwest, where Minard, (1981) considers them to be correlative with the Blakeley Formation and reports that they unconformably overlies volcanic rocks that are probably continuous with the volcanic rocks of Mount Persis. Along the South Fork of the Stillaguamish on the west edge of the quadrangle, Danner (1957, p. 492-499) described outcrops which he called the Oligocene Riverside Formation. Whetten and others (1988) referred these same rocks to the Bulson Creek unit of Lovseth (1975; see also Marcus 1980, 1981)

BARLOW PASS VOLCANICS OF VANCE (1957b) (LATE EOCENE AND OLIGOCENE),
divided into:

- Tbd Dacite porphyry--Gray dacite and andesite porphyry with abundant plagioclase and rare quartz phenocrysts highly altered to epidote, chlorite, sericite, albite, and carbonate. At the northwest base of Sheep Mountain, rocks are a mixture of holocrystalline hornblende tonalite grading into dacite. Area mapped as Tbd is a large arcuate mass of porphyry ("Sauk ring dike") which includes swarms of dikes with less than 10% Tbv country rock. Smaller, more widely spaced dikes are abundant in the Twin Peaks-Mount Forgotten area. At Sheep Mountain a poorly reproducible K-Ar hornblende age from a tonalite is 37 ± 9 m.y. (Tabor and others in press a). A hornblende dacite porphyry dike cutting eruptive rocks of the Barlow Pass northeast of Twin Peaks has a hornblende with a K-Ar age of about 40 m.y. (Table 2, no. 29,) and a FT zircon age of 32 m.y. Although most of Tbd looks like andesite, chemical analyses show clearly that two samples from the upper Sauk River are dacites (Ort and others, 1983). As the dacite porphyry clearly intrudes Barlow Pass Volcanics, it may be a late phase of the volcanic rocks or entirely unrelated
- Tbv Volcanic rocks--Basalt, rhyolite, and subordinate andesite in flows, breccia, and tuff interbedded with tuffaceous to feldspathic sandstone, conglomerate, and minor argillite. Basalt in the upper part of the section forms dark brown columnar flows. Basaltic andesite occurring lower in the section is generally dark-green to gray, aphyric, massive, and dense. Rhyolite occurs as thick flows, typically light-green to white with flow laminations commonly spherulitic. Volcanic rocks are mostly highly altered to a dense mat of chlorite, epidote, calcite, and sericite; porphyritic and trachytoid textures are relict. Bedding in volcanic rocks is obscure except in some water-laid tuffs. Further descriptions are in Vance (1957a, p. 275-286) and Heath (1971, p. 116-118)
- Tbg Gabbro--Medium-grained, ophitic with plagioclase and clinopyroxene. Intrusive into Barlow Pass volcanic rocks but affinity uncertain
- Tbb Basalt--Clinopyroxene-plagioclase microphyric basalt; in part amygdaloidal. Cliff-forming columnar flows up to several tens of meters thick
- Tbr Rhyolite flows and rhyolite ash flow tuff--Commonly dark-colored, green or black, weathering to light green, gray, white or orange with sparse microphenocrysts of plagioclase and quartz. Commonly laminated and spherulitic, devitrified or highly altered to montmorillonoids. Chemically rocks are high-silica rhyolites (Ort and others, 1983).

A number of fission track ages obtained from zircons from rhyolite tuff in the Barlow Pass Volcanics range from about 35 to 46 m.y. (Table 2, nos. 23-28). The youngest ages from the Dickerman Peak area are probably partially reset by the nearby Squire Creek stock; many of the rocks

are incipiently statically metamorphosed. The ages in the range 42-46 m.y. are in keeping with the proposed correlation of the Barlow Pass with the middle and late Eocene and Oligocene(?) Naches Formation (Tabor and others, 1984; Tabor and others, in press a)

Tbs Sandstone--Mostly feldspathic subquartzose sandstone and pebble conglomerate with minor interbeds of argillite and siltstone, rarer tuffaceous sandstone, and tuff. Micaceous sandstone common. Well bedded fossil leaves common. In the area northwest of Darrington, bentonite interbeds are present (Cruver, 1981, p. 29), and many sandstone beds are composed of quartz framework grains totally supported in a matrix rich in montmorillonoids probably derived from volcanic glass. Within 1 to 2 km of the Squire Creek stock and related plutons, sandstone and argillite are hornfelsic. Within the Darrington-Devils Mountain fault zone, conglomerate clasts are highly stretched. South of the South Fork of the Stillaguamish, volcanic interbeds are lacking and correlation of these sandstones with the Barlow Pass is uncertain (cf Tabor and others, in press a)

Tbsv Sandstone with conspicuous interbeds of basalt and rhyolite.

Tuv UNNAMED VOLCANIC ROCKS (AGE UNCERTAIN)--Altered mafic tuff and breccia and siliceous tuff. Northwest of Lake Bosworth rocks are highly altered to epidote and smectites. Includes Danner's (1957, p. 483-484) Pilchuck Bend Formation, exposed west of Granite Falls. Rocks are possibly correlative with the late Eocene volcanic rocks of Mount Persis (Tabor and others, 1982a) exposed about 20 km to the southeast.

Tgf GRANITE FALLS STOCK AND ASSOCIATED PLUTONS (EOCENE)--Biotite hornblende granodiorite, mostly fine-grained hypidiomorphic granular, slightly porphyritic. Locally contain hypersthene. Commonly highly altered. Country rock strongly thermally metamorphosed. At Iron Mountain quarry east of Granite Falls, western melange belt rocks (TKws) are recrystallized and locally permeated with tourmaline (elbaite) suggesting an intrusion is not far below the surface. A K-Ar analysis of hornblende from the Granite Falls stock indicates a probable minimum age of about 44 m.y. (Table 2, no. 22).

PILCHUCK STOCK (EOCENE), divided into:

Tpg Granite and granodiorite--Mostly fine-grained slightly porphyritic, hypidiomorphic granular biotite granite with resorbed quartz phenocrysts. CI=4-8, locally with up to 40% K-feldspar, mostly perthite (Wiebe, 1963, p. 21). Wiebe (op cit, p. 24-31) describes accessory cordierite and one occurrence of garnet. Zircon and tourmaline (elbaite) are also common accessories. Rock is massive, has chilled margins and has thermally metamorphosed the country rock in an aureole up to 1 km wide or slightly greater (Wiebe, 1964). Roughly concordant K-Ar ages on

biotite and muscovite are 49 m.y. (Table 2, no. 32). Wiebe (1963, pl. 1) reports an older granite in the southern part of the stock which may be Bald Mountain pluton (bmg)

- Tpd Dike swarm--Concentration of granite and granite porphyry dikes comprising up to 50 percent of TKwg rock ground. May include numerous dikes and sills of the Bald Mountain pluton
- Thr RHYOLITE OF HANSEN LAKE(EOCENE)--Dark colored glassy to devitrified biotite rhyolite and rhyolite ash-flow tuff. Commonly perlitic, contains sanidine, plagioclase quartz and garnet phenocrysts. Poorly exposed near Hansen Lake and to the west where the unit includes quartz and clinopyroxene-bearing mafic tuff. Danner (1957, p. 484-490) and Wiebe (1963, p. 16-19) describe the rhyolite and associated sandstone and conglomerate in greater detail. Biotite yields a K-Ar age of about 53 m.y.; sanidine gives a minimum age of about 46 m.y., and a fission track age of zircon is about 34 m.y. (Table 2, nos. 33, 34). This discordant array of ages is not promising but as suggested by Wiebe (1963, p. 36-39; 1968, p. 691), the Pilchuck Stock may represent the same magma that erupted as the rhyolite of Hanson Lake
- Tfs FELDSPATHIC SANDSTONE AND CONGLOMERATE(EOCENE)--Dark-gray to green, locally red to purple, medium- to coarse-grained feldspathic sandstone, pebble- to boulder-conglomerate and minor thin-bedded black argillite. Most coarse clasts are graywacke and greenstone. Contains no clasts of rhyolite or granite of the Bald Mountain pluton or Pilchuck stock (Booth, in press)
- Tss SANDSTONE--Feldspathic sandstone and pebble conglomerate associated with the Straight Creek fault. Mostly highly sheared and locally altered. Possibly correlative with the early Eocene Swauk Formation exposed about 60 km to the south east of the Straight Creek fault (Tabor and others, in press a) or the Eocene Chuckanut Formation exposed about 50 km to the northwest.

PRETERTIARY BEDROCK

ROCKS WEST OF THE STRAIGHT CREEK FAULT

Rocks within the Darrington-Devils Mountain Fault Zone (DDMFZ)

HELENA-HAYSTACK MELANGE-- (Late Cretaceous to Eocene) The Helena-Haystack melange is named for exposures on Helena Ridge south of Darrington and along the slopes above lower Deer Creek where rocks are continuous with the Haystack terrane or melange of Whetten and others (1980; 1988) west of the quadrangle. The unit consists of a wide variety of rock blocks in a serpentinite matrix and is mostly bounded by

high angle faults, many of which cut Middle Eocene sandstone and volcanic rocks. Many of the blocks are of rock types found in the eastern melange belt which borders the unit on the south and the Easton Metamorphic Suite which borders the unit on the north, but other blocks are of lithologies occurring only in the Helena-Haystack melange. Blocks range from a few centimeters across to greater than 8 km across. We infer metagabbro on Jumbo Mountain to be a single block at least 10 km long. Many blocks are rounded or ellipsoid in map pattern, based on topographic expression, but contacts are seldom exposed. The serpentinite matrix is very poorly exposed and locally the extent of melange may only be surmised by a subdued topography pimpled by steep-sided hillocks of resistant rock. Vance and others (1980, p. 364-365) describe the melange on Helena Ridge, and Jones (1959, p. 111, 131-140) provides some descriptions of its rocks in the Deer Creek area. As mapped includes:

TKhm

Peridotite, metaserpentinite, and serpentinite--Peridotite and rare metadunite are orange and black weathering resistant rocks occurring mostly as steeply dipping tectonic lenses and sheets in Tertiary sandstone and isolated blocks in serpentinite. Tectonically emplaced metaserpentinite (peridotite) "dikes" on Jumbo Mountain and on Devils Thumb have formed by dehydration of serpentinite (Vance and Dungan, 1977). Some relict pyroxene in serpentinite above Swede Heaven suggests original cumulus textures. Serpentinite is generally flakey, gray to green in rare outcrops. On Helena Ridge serpentinite is lizardite and chrysotile (Vance and Dungan, 1977, p. 1498). In the Iron Mountain-Gee Point area, Brown and others (1982, p. 1089) describe serpentinites composed of antigorite, commonly with well-defined foliation and relict aluminous chromite, rimmed by Fe-chromite suggesting an alpine peridotite protolith.

On Helena Ridge, unit includes small slivers of volcanic rock and sandstone of the middle Eocene Barlow Pass Volcanics, probably infaulted along the high angle faults of the DDMFZ.

X and/or dashed line=poor and/or layer too small to show at map scale

TKhg

Greenstone, foliated greenstone, and greenschist--Greenstone includes basalt with relict clinopyroxene and plagioclase to well-recrystallized actinolitic greenstone, and greenschist, commonly with pumpellyite, prehnite, lawsonite(?), stilpnomelane, and locally with aragonite in veins. Cruver (1983, p. 23) reports lawsonite in metagraywacke associated with greenstone of the Haystack unit on strike to the northwest. Outcrops are commonly massive, but on Big and Little Deer Creek, probable bedding is revealed by broad color bands and contrasting joint patterns when viewed from afar. See Cruver (1983)

and Reller (1986) for detailed petrography and chemistry. Includes minor schistose dacite metaporphry, graywacke, and argillite

- TKhmg Metagabbro and metadiabase--Medium-grained uralitic metagabbro, rarely with relict brown hornblende and saussuritic plagioclase, and very rare relict clinopyroxene. Partially to completely altered to actinolite and pumpellyite with pseudomorphous ophitic or subophitic textures. Commonly cut by mylonitic to cataclastic microshears. Commonly weathers out of serpentinite matrix as steep-sided hillocks
- TKhs Sedimentary rocks--Chert, graywacke, phyllitic argillite, and semischist. Black chert east of lower Deer Creek has Mesozoic, possibly Triassic radiolarians (Table 1, no. 31f)
- TKhf Foliated metavolcanic rock--Silicic metaporphry and micaceous quartz-feldspar schist, commonly with relict plagioclase phenoclasts. Foliated light-colored greenstone and greenstone. On Helena ridge includes considerable foliated greenstone, some with relict pillows. Northwest of Darrington includes considerable metabasalt with relict plagioclase and clinopyroxene in an altered felty or trachytic matrix. On Helena Ridge a metarhyolite yields a K-Ar muscovite age of 89.7 m.y. (Table 2, no. 79) and a 2 point Rb-Sr whole rock isochron suggests a 93 ± 7 m.y. metamorphic age (R. L. Armstrong, written communication to J. A. Vance, 1983)
- TKha Amphibolite--Fine-grained amphibolite with well-crystallized green hornblende and plagioclase, partially altered to chlorite, epidote, and pumpellyite(?). K-Ar age of hornblende is about 141 m.y. (Table 2, no. 78) a probable minimum age of metamorphism
- TKht Tonalite--Medium-grained hypidiomorphic hornblende tonalite altered to chlorite, prehnite, epidote, and pumpellyite(?). Rock is locally gneissic and cataclastic, interlayered with amphibolite at the southern contact. No evidence of intrusion into ultramafic rock at northern contact. The crystallization age is Late Jurassic (150 Ma based on a U-Pb analysis of zircon (Table 2, no. 77)
- (Kes), Blocks in the melange of units adjoining the Helena-Haystack
(Ked), melange.
(Tkegg),
etc.

Rocks southwest of the Darrington-Devils Mountain fault zones

BALD MOUNTAIN PLUTON (AGE UNCERTAIN), as mapped includes:

- bmg Granodiorite and granite--Medium- to coarse-grained hypidiomorphic biotite granodiorite and granite, in part gneissic near the margins. Locally with coarse(1-2 cm) crystals of K-feldspar, accessory cordierite, mostly altered to pinite, and rare garnet. Rock is locally cataclastic.

Clinopyroxene rimmed with hornblende; intergranular graphic intergrowths of quartz and K-feldspar.

U-Th-Pb ages obtained from zircons from the Bald Mountain pluton indicate that it crystallized or recrystallized about 50-55 Ma, but the much older $^{207}\text{Pb}/^{206}\text{Pb}$ ages of about 119 and 126 m.y. of coarse- and fine-grained fractions (Tabor and others, in press a) indicate either an older Pb component inherited from older detrital zircons picked up in the magma, presumably from the surrounding Mesozoic rocks, or indicate that the pluton originally was much older and has been partially recrystallized by the intrusion of the nearby Mount Pilchuck stock. For a further discussion of the enigmatic age see (Tabor and others, in press a)

bms Sill complex--Multiple sills of granodiorite in hornfelsic argillite and graywacke. Sills, ranging from a few meters to hundreds of meters thick, comprise from 10 to 90% of the rock

WESTERN MELANGE BELT (MID-CRETACEOUS TO PALEOCENE)--The western melange belt is distinguished from the eastern melange belt and the Trafton melange by the dominance of clastic components, chiefly graywacke and argillite or semischist and phyllite. The eastern melange and Trafton are largely greenstone and chert. Frizzell and others (1987) describe the melange belts south of the quadrangle and discuss their origin and emplacement. As mapped the western melange belt is divided into:

TKwg Graywacke and argillite--Mostly pervasively foliated gray to black lithofeldspathic and volcanolithic subquartzose sandstone and semischist. Fine- to medium-grained, locally abundant cobble conglomerate. Commonly interbedded with argillite or phyllite. Locally well-developed rhythmite. Where foliation is less well developed, sedimentary features are locally well preserved, including graded beds and load casts. Although many sandstones of the unit south of the quadrangle contain up to 20% K-feldspar (Tabor and others, 1982 a; Jett, 1986) no samples from this quadrangle contain significant K-feldspar. Metamorphic minerals, which locally replace matrix and framework grains and also occur in veins, are carbonate, prehnite, pumpellyite(?) chlorite, and sericite. Unit includes rare greenstone derived from mafic volcanic breccia, tuff, and flows. Also includes locally abundant chert.

Melange exposed along the Stillaguamish River east of Granite Falls is composed of lenticular and locally necked blocks of sandstone, greenstone, limestone, and rare metatonalite in a massive argillite matrix. It resembles Cowan's (1985, p. 454-456) type II melange evolved from submarine landslides. From studies south of the quadrangle, Jett (1986) and Jett and Heller (1987) concluded that the unit formed in an accretionary wedge.

Sparse fossils in the western melange belt including radiolarians in chert and megafossils in argillite indicate that with the exception of limestone, most components and the matrix are Late Jurassic to Early Cretaceous in age (Table 1, nos. 1f-5f; 8f,9f. Frizzell and others, 1987, p. 135). However, limestone blocks are Permian, and a few chert blocks are Early Jurassic (Table 2, nos. 10f, 11f). The melange is intruded by the middle Eocene Mount Pilchuck stock suggesting that assembly (or deformation) was mid-Cretaceous or younger but definitely completed by middle Eocene

- TKwp Phyllite--Gray, brown to black phyllite, less abundant semischist, locally abundant chert and rare greenstone. Includes subordinate thin beds of recrystallized sandstone and semischist and rare stretched-pebble conglomerate. Phyllite is strongly foliated, locally with well-developed pencil structures and rarer crinkle lineation. Metamorphic minerals are sericite, carbonate, chlorite, prehnite, and pumpellyite(?). Metasandstone commonly forms small boundins up to a few meters long
- TKwmv Mafic volcanic rock--Greenstone and sheared greenstone including diabase and gabbro. Poorly exposed south of the Pilchuck River
- TKwm Marble and limestone--Mostly coarsely crystalline dark-gray to white marble in small to moderate-sized pods. Mostly massive but locally bedded with bioclastic layers. Fusulinids in outcrops east and southeast of Granite Falls are Late Permian (Table 1, nos. 6f, 7f) and Middle Permian (12f) in age. Star-pod too small to show at map scale
- TKwmg Metagabbro and metadiorite--Massive to foliated fine-to medium-grained metagabbro and diorite. Outcrops sheared on all scales. In massive rocks, euhedral, mottled, locally crushed plagioclase, intergranular to euhedral uralitized clinopyroxene and opaque minerals common. Metamorphic minerals are uralite, chlorite, sphene, and carbonate. U-Th-Pb ages of zircons from gabbro blocks south of the quadrangle are mostly Late Jurassic (Frizzell and others, 1987; Tabor and others in press a)
- TKwu Ultramafic rock--Serpentinized peridotite and dunite. Mostly recrystallized by nearby plutons, locally with enstatite and talc
- TKt TRAFTON MELANGE (MID-CRETACEOUS TO PALEOCENE)--Predominantly greenstone and banded chert with subordinate graywacke and argillite. Commonly highly sheared and mixed on all scales. Greenstone has relict plagioclase and clinopyroxene but is now mostly chlorite, carbonate, and brownish pumpellyite (?); some rocks with veins of green pumpellyite. Chert is red and black, locally highly recrystallized. Includes some diabase. Argillite locally phyllitic. Originally called the Trafton Sequence by Danner (1966, p. 363), the Trafton melange is continuous with rocks to the west mapped as Trafton terrane by Dethier and others (1980) and Whetten and others (1988)

who report radiolarian ages of chert ranging from Mississippian to Middle Jurassic. Within the quadrangle, cherts yield radiolarian ages ranging from Triassic to Jurassic (Table 1, nos. 13f-16f, 20f, 21f), but one may be Paleozoic (17f). Locally the Trafton is mapped as:

- TKtm Marble and limestone--Similar to TKwm. Highly fossiliferous bioclastic limestone at the abandoned Morcrop quarry on the north side of Porter Creek yields Late Middle Permian fusulinids (Table 1, no. 19f)
- TKtg Metagranodiorite--Medium-grained, hypidiomorphic hornblende-biotite metagranodiorite partially recrystallized to albite, chlorite, prehnite, and pumpellyite. A discordant U-Th-Pb age is about 320 m.y. (Early Permian) (Table 2, no. 80)

EASTERN MELANGE BELT (MID-CRETACEOUS TO PALEOCENE)--The eastern melange belt displays many of the same lithologies and the same degree of disruption as the western melange belt, but in the Whitehorse Mountain area has three units that may be more or less stratigraphically intact. The youngest is a Middle to Late Jurassic argillite unit which presumably overlies the Late Triassic volcanic rocks of Whitehorse Mountain. The volcanic rocks in turn overlie a Late Triassic chert belt although we have not found undisrupted contacts with top indicators. As mapped, the eastern melange belt is divided into:

- TKeg Greenstone with graywacke and foliated graywacke, argillite and phyllitic argillite, chert and marble--Highly sheared and disrupted greenstone comprises from 20 to 50% of melange and contains relict clinopyroxene, some titaniferous, and plagioclase in an altered matrix of chlorite, carbonate, pumpellyite, and locally lawsonite(?). Rare deformed pillows. Locally prehnite in veins. Volcanic sub-quartzose sandstone similar to sandstone in TKwg. Deformed and/or recrystallized radiolarians from chert in this unit are Jurassic (Table 1, no. 23f)
- TKea Argillite--Black, locally foliate argillite with limey concretions. Poorly exposed south of the town of Whitehorse. Locally cut by deformed and brecciated metadacite dikes. Radiolarians from a concretion are Middle to Late Jurassic in age (Table 1, no. 30f)
- TKev Volcanic rocks of Whitehorse Mountain--Plagioclase phyric pyroxene andesite and basaltic andesite ranging to dacite. Includes minor diabase and gabbro. Most rocks slightly metamorphosed and contain chlorite, pumpellyite and prehnite. Forms massive cliffs. Amygdaloidal flow tops, breccia, tuff, and thin local sedimentary interbeds. For further descriptions see Vance (1957, p. 218) and Vance and others (1980, p. 367). Major element chemical analyses are in Ort and Tabor (1985) and some trace element data in Vance and others (1980, p. 377). Locally mapped as:

- Tkevm Marble--Mostly coarsely crystalline gray to white marble, locally with chorite. Danner (1966, p. 326-329) describes the deposits south of Whitehorse and reports undiagnostic crinoid and coral remains in float specimens. A limestone pod on Whitehorse Mountain yields Late Triassic conodonts (Table 1, no. 29f)
- TKec Chert--Mostly white-weathering, red or black ribbon chert and metachert ranging from 20 to 80% of unit. Uniformly banded to complexly disrupted. Some chert as thin laminae in cherty argillite. Subordinate to abundant greenstone, graywacke, and argillite. Vance (1957a, p. 221-222) reports considerable argillite and sandstone and several conglomerate beds on the west side of Three Fingers. Radiolarians from TKec are Late Triassic and possibly Jurassic (Table 1, nos. 25f-28f)
- TKem Marble--Gray coarsely crystalline; mostly in small pods. Star= pod too small to show at map scale
- TKegg Gabbro--On the South Fork of the Stillaguamish River gabbro, layered gabbro, and interlayered cumulate ultramafic rock (wehrlite) (Dungan, 1974). Includes some metatonalite and gneissic amphibolite. The large gabbro body (TKegg) mapped within the Helena-Haystack melange south of Darrington is medium grained and massive but laced with swarms of diabase dikes (Vance and others, 1980, p. 365). The gabbros are generally partially altered to albite, actinolite, epidote, and chlorite. A small unmapped block of well-recrystallized fine-grained schistose amphibolite on Wiley Ridge yields a K-Ar hornblende age of about 121.4 ± 4.2 m.y. (Table 2, no. 81A), probably a minimum age for the metamorphism
- TKeu Ultramafic rock--Serpentinite, metaperidoite, and metaclino-pyroxenite. Dungan (1974, p. 48-53, 94) describes some ultramafic blocks with primary cumulus textures and others as harzburgite and dunite tectonite. Metamorphic minerals, mostly confined to rocks north of the South Fork of the Stillaguamish River are tremolite, talc, and olivine. Dungan (op. cit) and Vance and Dungan (1977) give mineral analyses and parageneses. Vance and others (1980, p. 362-367) describe these rocks and, based on regional considerations, suggest that they are Jurassic in age. They consider the ultramafic rocks and associated gabbro (TKegg) to be part of a metamorphosed and dis-membered ophiolite complex imbricated in the oceanic and volcanic rocks of the eastern melange along Tertiary high-angle faults

Rocks northeast of the Darrington-Devils Mountain fault zones

EASTON METAMORPHIC SUITE (EARLY CRETACEOUS), as mapped divided into:

- Kes Shuksan Greenschist--Predominantly fine-grained greenschist actinolite-bearing greenschist, and/or blueschist. Locally includes quartzitic greenschist, iron- and manganese-rich quartzite (metachert), greenstone, and

graphitic phyllite. Rare relict clinopyroxene in some greenschist. Common also is leucogreenschist, generally with lawsonite, and characterized by a mosaic of albite porphyroblasts that have mineral inclusions aligned in the foliation. The schists are commonly conspicuously layered on a centimeter scale and foliation and layering are tightly folded on an outcrop scale. Locally interlayered with Kedb and Keds.

Excellent descriptions are in Haugerud and others (1981); for a good summary see Brown (1986). Dungan and others (1983) discuss the chemistry, petrogenesis, and MORB protolith. Brown and others (1982, p. 1095) and Brown (1986, p. 146) suggest the protolith age of the Easton Metamorphic Suite is Jurassic and the metamorphic age is Early Cretaceous.

- Ked Darrington Phyllite--Predominantly black, highly fissile sericite-graphite-albite-quartz phyllite, typically with abundant quartz veinlets; commonly complexly folded. Most phyllite has a strong crinkle lineation well foliated metasandstone locally. The Darrington and Shuksan are locally interlayered but recent workers consider the Shuksan protolith of ocean floor basalt to have originally underlain the Darrington protolith of marine sediments (see Brown 1986, p. 145)
- Keds Darrington Phyllite, silver--Predominantly fine-grained muscovite-rich phyllite or schist, commonly with lawsonite, locally with graphite and garnet. Some rocks with albite porphyroblasts. Dazzling bright in sunlight. Locally interlayered with greenschist
- Kem Mixed Shuksan Greenschist and Darrington Phyllite--Interlayered greenschist and black phyllite on a 1-10 m scale. Locally mapped as:
- Kems Mixed Shuksan Greenschist and silver-colored Darrington phyllite (Keds)
- Keu Ultramafic rock--mostly serpentinite
- Keg Garnet amphibolite--Zone of garnet amphibolite and muscovite-quartz schist, barroisite schist, hornblende-garnet rocks, and rare eclogite in Shuksan Greenschist. Most of these rocks are coarser grained than typical Shuksan. The garnet amphibolite is overprinted by blueschist facies metamorphism (Brown and others, 1982). Includes minor ultramafic rocks.
- MzPz METAMORPHIC ROCKS (MESOZOIC AND PALEOZOIC)--Metagabbro, metadiorite, metatonalite, silicic gneiss, fine-grained epidote amphibolite gneiss, micaceous quartzite, and amphibole schist. Rocks highly variable, commonly mylonitic and/or cataclastic.

On south side of White Chuck River, Silverberg (1985, p. 118-120) describes steeply imbricated slices of metaigneous rock, including metagabbro to leucotrandjhemite, metachert and associated metabasalt, and

quartzitic schist and associated siliceous amphibole schist. He (op cit. p. 13-14) correlates the metaigneous rocks with the Yellow Aster Complex of Misch (1966, p. 104) exposed in the type area 88 km to the north but also occurring in isolated fault-bounded slivers associated with Chilliwack Group rocks throughout the intervening terrain (cf Brown and others, 1987). The Yellow Aster Complex has been interpreted to be a Precambrian to lower Paleozoic basement complex that was metamorphosed in the Silurian (Mattinson, 1972, p. 3775-3776; Brown, 1988).

Silverberg (op cit, p. 38-39) correlates the metachert and metabasalt with the Elbow Lake Formation of Brown (1987) and Brown and others (1987). The Elbow Lake is a disrupted oceanic assemblage of uncertain, but possible Permian and/or Jurassic age. It is exposed in semicontinuous fault-bounded belts north of the quadrangle. A mapped sliver of metachert, which is probably Elbow Lake, in the White Chuck imbricate zone (see Figure 2) at the head of Decline Creek contains Mesozoic, probably Late Triassic or Early Jurassic radiolarians (Table 1, no. 37f)

Silverberg (1985, p. 29) correlates the schistose rocks with the Vedder Complex of Armstrong and others (1983) exposed on Vedder Mountain, B. C., about 105 km north of the quadrangle, but also occurring in fault-bounded slivers and blocks in the intervening area, commonly associated with the Elbow Lake Formation in fault zones (Brown and others, 1987). The Vedder Complex is considered to have a late Paleozoic metamorphic age (Armstrong and others, 1983, p. 456-457). Muscovite and blue amphibole from three schistose rock samples south of the White Chuck River yielded K-Ar ages of about 267, 249, 238, and 214 ma, (Table 2, no. 83) confirming the correlation with the Vedder Complex.

Barroisite schist, a common constituent of the Vedder Complex elsewhere, crops out in upper Decline Creek. The schist is highly cataclastic, and we presume the contacts are faulted. The greenish blue amphibole is rimmed by crossite.

Brown and others (1987) correlate metagabbro, meta-diorite, silicic garnet gneiss, and tonalite gneiss on Prairie Mountain with the Yellow Aster Complex of Misch (1966). These rocks are locally highly cataclastic and locally gneissic but commonly original igneous textures are well preserved. Mafic minerals are altered to actinolite, albite, epidote, chlorite; pumpellyite and lawsonite are common. Franklin (1971, p. 13-35) and Vance and others (1980, p. 363-364) further describe these rocks. Zircon from a hornblende tonalite in this complex yields slightly discordant U-Th-Pb ages of about 370-400 m.y. (Early Devonian) and hornblende has a K-Ar age of

about 406 m.y. (Table 2, no. 84)

Metagneous rocks predominate in outlying outcrops of MzPz southeast of Prairie Mountain and south of Rockport

- MzPzu ULTRAMAFIC ROCK (PALEOZOIC AND MESOZOIC) -- usually associated with faults. X=pod or sliver to small to show at map scale
- CHILLIWACK GROUP OF CAIRNES (1944) AND ASSOCIATED ROCKS (SILURIAN, DEVONIAN, AND PENNSYLVANIAN)--Outcrops of metagraywacke, argillite, phyllite, and greenstone with minor marble north of the Skagit River are continuous with rocks mapped as Chilliwack Group by Misch (1966, 1979). On Prairie Mountain similar rocks appear to be correlative with the Chilliwack, but are structurally complex and locally imbricated with a wide variety of other units ranging from Early Devonian silicic gneiss of the Yellow Aster Complex to probable Triassic chert. Dotter (1977) considered these rock a melange. Although penetrative deformation is well developed locally the dominant character is one of stratigraphic coherence. How much of the lithologic mixing is due to a regional penetrative tectonism or high- and/or low-angle faulting is not clear. Smith (1985) and Brown (1987) discuss the origin of structure in the Chilliwack Group. As mapped divided into:
- Pzcs Sedimentary rocks--Well-bedded gray to brown and black argillite and volcanic subquartzose sandstone with minor pebble conglomerate and rare chert. Includes some volcanic rocks locally. Graded beds, scour structures, and load casts locally prominent; some rhythmite. Locally sandstone beds strongly disrupted in argillite matrix. Rocks grade rapidly from little deformed to phyllitic with a pronounced foliation generally subparallel to bedding. Descriptions in Vance (1957, p. 200-206), Franklin (1974, p. 60-66), Dotter (1977, p. 28-30) and Silverberg (1985, p. 21-26). Franklin (1974, p. 69) and Christenson (1981, p. 125-151) suggest that the Chilliwack Group sedimentary rocks are deep-water fan deposits and that they and the associated volcanic rocks were derived from an island arc. Most workers consider the stratigraphic age of the Chilliwack to be Late Paleozoic as indicated by fossils in clastic rocks and marble beds. The metamorphic age is probably mid-Cretaceous, although some recrystallization continued into the Late Cretaceous (Smith 1985, p. 131-134; Brown, 1987)
- Pzcv Volcanic and metavolcanic rocks--Mostly greenstone with subordinate meta-andesite and rare metadacite or meta-rhyolite. Breccia and tuff predominate. Mafic metavolcanic rocks commonly with relict plagioclase and clinopyroxene in a chlorite-epidote matrix, commonly with carbonate. Plagioclase is mostly recrystallized as albite. Christenson (1981, p. 71-74, Appendix A and Plate 1B) reports lawsonite and aragonite from greenstone just north of the quadrangle. Chemical analyses of Chilliwack

volcanic rocks and discussion of their origin are in Christenson (1981) and Blackwell (1983)

Pzcm Marble--Mostly gray to black, commonly coarsely crystalline marble in small isolated pods and blocks; commonly argillaceous. Brachiopods from deposits just north of Rockport range in age from Silurian to Devonian and partially recrystallized marble on Conn Creek with crinoid stems yields Late Mississippian to Pennsylvanian conodonts (Table 1, nos. 35f, 36f)

ROCKS EAST OF THE STRAIGHT CREEK FAULT

Terrane overlap units

Terrane overlap units east of the Straight Creek fault are mostly Upper Cretaceous, deep-seated, symmetamorphic plutons. They are characterized by both igneous intrusive and metamorphic features, lack thermal aureoles, and are generally elongate parallel to the metamorphic grain.

The banded gneiss units and tonalite gneiss of Bench Lake are an exception in that their igneous features are strongly overprinted by metamorphic crystallization, but their close association with light-colored tonalite and pegmatite sills and dikes, and overall migmatitic aspect suggests they are closely related to the major Late Cretaceous to early Tertiary metamorphism recorded elsewhere in the North Cascades (Mattinson, 1972, p. 3778; Tabor and others, 1987b).

For consistency the banded gneiss of Nason terrane, although intimately associated with the Chiwaukum Schist and elsewhere described with it (c.f. Tabor and others, 1987 a, b) is included with overlap units here. For similar reasons, the tonalite gneiss of Bench Lake in the Chelan Mountains terrane is also included here.

Kh1 HIDDEN LAKE PEAK STOCK (LATE CRETACEOUS) Biotite metatonalite.
Hypidiomorphic granular with plagioclase mostly filled with well-crystallized epidote and muscovite; some crushed grain margins have recrystallized and quartz is sutured. Some K-feldspar is microcline. Rock is massive and sharply intrusive. A U-Pb age of zircon is 75 m.y. (Late Cretaceous) (Table 2, no. 54) a probable magmatic crystallization age. Two samples yield K-Ar biotite ages of about 38 and 46 m.y. (Table 2, nos. 55, 56) which are probably cooling ages and a minimum for metamorphism. Ford and others (1988, p. 116-117) report modal analyses and White and others (1988, p. 32) give O^{18} data. Misch (1966, p. 141) describes the Hidden Lake stock as a forceful intrusion into the Cascade River Schist, but its age, texture, and little deformation suggest late metamorphic intrusion

CHAVAL PLUTON (LATE CRETACEOUS), divided into:

Kch Biotite-hornblende quartz diorite--Mostly medium-grained biotite-hornblende quartz diorite, locally diorite or tonalite, with clinopyroxene and hypersthene locally and accessory iron-titanium oxide, allanite, zircon, and apatite.

Textures are mostly subidioblastic with little or no relict igneous texture except for rare euhedral oscillatory-zoned plagioclase. Margins of the main pluton are gneissic and minerals are mylonitized and recrystallized. Flaser gneiss common. Metamorphic minerals are epidote, blue-green hornblende (commonly with cores of brown igneous(?) hornblende, biotite, and garnet. Some euhedrally zoned epidote. Descriptions modified from Boak (1977, p. 32-55). Ford and others (1988, p. 86-88) report extensive modal data and White and others (1988, p. 26) give O^{18} data

Kchm Mafic hornblende diorite, quartz diorite, and mafic amphibolite. Heterogeneous, layered with zones of Kch and country rocks. Commonly rich in pegmatite and light-colored tonalite in sharply bounded dikes or irregular bodies with swirled, gradational contacts

Kchs Sills and dikes of mafic diorite, quartz diorite, and amphibolite in Chiwaukum Schist--sharply banded, tabular bodies of mafic rock, similar to Kchm

Ksc SLOAN CREEK PLUTONS (LATE CRETACEOUS)--Biotite-hornblende tonalite gneiss, flaser gneiss, and local gneissic tonalite; medium grained, homogeneous, crystalloblastic gneissose to strongly flaseroid; locally strongly mylonitic. $CI=0-37$, but for most rocks $CI=20-30$ (Ford and others, 1988, p. 71). Locally contains garnet. Plagioclase normally zoned or unzoned and strongly stress twinned but with relict patchy zoning and faint oscillatory zoning and synneusis twins (Heath, 1971, p. 62). Retrogressive alteration is pronounced but somewhat sporadic; epidote minerals and sericite commonly fill plagioclase cores; mafic minerals are altered to chlorite, sphene, and prehnite. Includes some interlayered flaser gneiss and banded gneiss (Kbg). See Heath (1971; p. 57-59) for modes and further description. Ford and others (1988, p. 18-27, 69-71) and White and others (1988, p. 24) report modes, O^{18} values, and some chemical data. Zircons yield concordant U-TH-Pb ages of about 90 m.y. (Table 1, nos. 62, 63) Hornblende yields similar or somewhat younger K-Ar ages, and biotite ages reflect cooling at about 75 m.y. A zircon fission track age of 59 m.y. may reflect Eocene uplift

ELDORADO PLUTON (LATE CRETACEOUS), divided into:

Ke Biotite-hornblende quartz monzodiorite gneiss--Medium-grained subidioblastic to idioblastic sodic plagioclase with matrix of crystalloblastic to cataclastic quartz, K-feldspar, hornblende, biotite, and epidote; accessory sphene, apatite, zircon, and opaque oxides; commonly well-aligned prismatic aggregates of hornblende and biotite, but in many rocks mafic minerals are aligned in a streaky planar fabric. Gradational over several 100 meters into Kef. Modal data, some chemical data, and O^{18} values are in Ford and others (1988, p. 18-27, 106-108, and White and others 1988 (p. 30). U-Pb isotope ages of zircon from the

Eldorado are remarkably concordant at 88 and 90 m.y. (Mattinson, 1972, p. 3778, and Table 1, no. 64) A K-Ar hornblende age of 43 ± 1.5 m.y. (Engels and others, 1976), reflects the cooling age or the early Tertiary metamorphism associated with rocks to the north of the quadrangle (Babcock and others, 1985)

Kef Flaser gneiss--Fine- to medium-grained biotite-hornblende meta-granodiorite and meta-quartz monzodiorite flaser gneiss, with mosaic sodic plagioclase patches and rare simple crystals set in mylonitic fabric of finer grained quartz, plagioclase, and mafic minerals. See Tabor (1961, p. 145-150) for further description

TENPEAK PLUTON (LATE CRETACEOUS), divided into:

Ktc Contact zone--Dark-colored biotite-hornblende tonalite and tonalite gneiss, hornblende diorite, and hornblendite, locally with garnet; layers of garnet-hornblende-biotite schist increase to west

Ktd Dark-colored tonalite and tonalite gneiss--Medium-grained biotite-hornblende diorite and tonalite. Xenoblastic to granoblastic with rare broken faintly oscillatory zoned sodic andesine, commonly in a dark mesh of hornblende and biotite. CI=20-50. Rich in mafic lenses and streaks and hornblendite inclusions. Grades into Ktl. This description and others of the Tenpeak adapted from Crowder and others (1966). For additional description see Ford (1959, p. 149-171) and, for modes, some chemical data, and oxygen isotope data, Ford and others (1988, p. 18-27, 72-76) and White and others (1988, p. 25)

Ktl Light-colored tonalite and tonalite gneiss--Medium-grained hornblende-biotite tonalite and tonalite gneiss. Xenoblastic to hypidiomorphic, commonly with aligned euhedral hornblende prisms, locally up to 1 cm long. CI=15-20, locally up to 40. Subhedral epidote and pseudomymekitic epidote common. Allanite and garnets occur on western margin. Hornblende commonly zoned from brownish green to bluish green on rims. Sodic andesine crystals commonly broken and with faint euhedral oscillatory zoning. K-Ar ages of biotite and hornblende are 77.3 ± 2.4 and 92.8 ± 3.1 m.y., respectively (Engels and others, 1976). Zircons yield concordant U-Pb ages of 90 m.y. (R. A. Haugerud and T. Stern, written, commun., 1987). The Late Cretaceous ages probably represent the synmetamorphic intrusive age of the plutons (Tabor and others, 1987)

Kti Interlayered light- and dark-colored biotite-hornblende diorite gneiss, tonalite gneiss and flaser gneiss. Includes subordinate hornblende schist

Ktf Flaser gneiss--Medium-grained hornblende and/or biotite tonalite flaser gneiss, xenoblastic, porphyroblastic, mylonitic. CI=20-40

Kbtg TONALITE GNEISS OF BENCH LAKE (LATE CRETACEOUS)--Mostly light-colored fine-grained heterogeneous biotite tonalite gneiss, locally with hornblende. CI=3-19, mostly about 9-12.

Layers and pods of finer grained biotite gneiss, garnet biotite-hornblende schist, and amphibolite locally making up 5-10% of rock. Mafic schlieren may be swirled. Cut by light-colored tonalite, pegmatite and aplite dikes. Contact with Kbbg is gradational. Descriptions in Tabor (1961, p. 130-137) and Grant (1966, p. 162-172). Ford and others (1988, p. 18-27, 60-62) and White and others (1988 p. 23) report some chemical data, modes, and O^{18} values. No radiometric ages available for this unit but based on its apparent development from the banded tonalite gneiss which is similar to banded gneisses elsewhere in the North Cascades (in specific the banded gneisses of the Nason terrane), we assume that it formed during the Late Cretaceous metamorphism dated elsewhere (see Matthinson 1972; Tabor and others, 1987a). Includes also:

Kbbg Banded tonalite gneiss--Strongly layered fine-grained biotite hornblende gneiss and light-colored biotite tonalite to granodiorite gneiss commonly containing garnet and thin and thick layers and pods of rocks of the Napeequa River area (Kn), especially hornblende schist and schistose hornblendite as well as some ultramafic rocks (Knu). Layers pinch and swell. Rocks are cut by many irregular pegmatite and aplite dikes and have a migmatitic aspect. 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 igneous origin. Descriptions are in Tabor (1961, p. 130-137) and Grant (1966, p. 162-172)

Kbg BANDED GNEISS (LATE CRETACEOUS)--In south mostly heterogeneous light-colored tonalite to granodiorite gneiss interlayered with mica schist and amphibolite similar to the Chiwaukum Schist. Predominantly crystalloblastic. Most common is medium-grained biotite gneiss with a slightly porphyroblastic appearance due to anastomosing mica layers surrounding larger plagioclase crystals or aggregate grains. Contacts between gneiss and schist are both sharp and gradational along and across strike. Grades northward into more uniform, mostly medium-grained garnet-biotite-quartz-oligoclase (or andesine) gneiss which is difficult to distinguish from Chiwaukum Schist. Rare rounded relict kyanite and sillimanite occur within sericite knots.

Cross-cutting sills, dikes, and irregular bodies of light-colored fine-grained to pegmatitic tonalite and gneiss are also abundant. Locally migmatitic. Most of unit has 50% or more light-colored gneiss. Descriptions are in Vance (1957a, p. 65-95) and Crowder and others (1966)

md METADIORITE (AGE UNCERTAIN)--At Hardtack Lake, fine- to medium-grained hornblende and biotite hornblende metadiorite and diorite gneiss with CI=20-30. Xenoblastic to granoblastic

with epidote-filled andesine, epidote, allanite, and garnet. May be a terrane overlap unit, possibly related to the Tenpeak pluton. Description adapted from Crowder and others (1966)

- fc FOAM CREEK STOCK (AGE UNCERTAIN)--Medium-grained biotite metagranodiorite with distinctive decussate biotite books. CI=10-15, rarely 25 (Ford and others 1988, p. 17). Hypidiomorphic granular with faint relict oscillatory zoned oligoclase-andesine. Commonly retrogressively altered. Margins are highly gneissic. Of several mica ages by the K-Ar method (Table 1, nos. 52, 53), the oldest, a muscovite age of about 78 m.y. (Engels and others, 1976) probably is a minimum for metamorphism. For descriptions see Crowder and others (1966), and for some chemical and O^{18} data, see White and others (1988, p. 31)

Nason Terrane

- Kc CHIWAUKUM SCHIST (CRETACEOUS), divided into
Biotite schist and amphibolite--Mostly fine- to medium-grained, well laminated graphitic garnet-biotite-quartz-oligoclase (or andesine) schist, locally with cordierite, andalusite, staurolite, or kyanite and rarely with sillimanite. Abundant schistose amphibolite, fine-grained hornblende gneiss, hornblende biotite schist, and less common calc-silicate schist and marble. Cut by dikes and sills of light-colored biotite tonalite and pegmatite. Unit in the Cadet Creek area described in detail by Heath (1971, p. 12-55), and west of Glacier Peak by Ford (1959, p. 27-111) and Crowder and others (1966). Grades into unit Kbg. The age of the Chiwaukum protolith is not well constrained. Based on Rb-Sr studies, other workers have assigned it to the Triassic (Evans and Beri 1986; p. 697-698; Magloughlin 1986, p. 264) and more recently the Devonian (Magloughlin, 1988). Based on its correlation with the Tonga Formation of Yeats (1958) and other correlations (Tabor and others 1987a, press), we conservatively suggest it is pre-Late Jurassic in age. Lines showing limits of metamorphic index mineral occurrences are tentative, drawn from sparsely scattered data. Staurolite is present east of the eastern kyanite line and west of the western kyanite line. Kc and Kbg in the area northeast of Sloan Peak, north of the North Fork of the Sauk River, south of the Suttle River and west of about 121° 15' lack Al-silicate minerals but appear to be the right bulk composition for them
- Kcm Marble--Thin-to-thick-coarsely crystalline white-to-gray-marble layers, commonly with thin schist interbeds and associated calc-silicate schist. Star = outcrop too small to show at map scale
- Kca Amphibolite and hornblende schist--Black to light green, fine- to medium-grained garnet-hornblende-quartz-plagioclase schist, gneiss, and amphibolite. Lepidoblastic to grano-

felsic, rarely garbenschiefer, with pods or layers rich in biotite, clinopyroxene, and/or epidote. Chemical analyses of amphibolite from the Chiwaukum are available in Ort and Tabor (1985)

Kcgg Garnet-graphite-mica schist--Predominantly very fine-grained
garnet-graphite-biotite-oligoclase (or andesine)-quartz
schist with kyanite and (or) staurolite

Kcu Ultramafic rock

Chelan Mountains Terrane

The Chelan Mountains terrane is predominantly composed of the rocks of the Napeequa River area and intruding metaigneous granodiorite plutons, the Marblemount Meta-Quartz Diorite of Misch (1966) and the Cascade River Schist. In previous reports Tabor and others (1987a,b) included the rocks of the Napeequa River area and associated metaigneous rocks in the Mad River terrane. Typical oceanic lithologies of the Napeequa River rocks occur also in the Cascade River Schist as originally defined by Misch (1966). The metachert and metamafic rocks of the Napeequa River area are interlayered with metaconglomerate of the Cascade River Schist, north of the Sauk River quadrangle. The contrast in depositional facies suggests that the original contact may have been an unconformity or a fault which was subsequently complexly faulted or folded. The metaclastic rocks also unconformably overlie the Marblemount Meta-Quartz Diorite of Misch (1966) We restrict the Cascade River Schist of Misch (1966) to the predominantly metaclastic rocks of the Cascade River area and include the metachert and metamafic rocks (amphibolite) in the rocks of the Napeequa River area.

The protolithic oceanic sedimentary and volcanic rocks of the Napeequa River area were intruded by a number of large granodioritic plutons that are now metamorphosed. One of these plutons exposed about 60 km southeast of the quadrangle yields discordant zircon U-Th-Pb ages suggesting a Paleozoic or older crystallization age (Tabor and others, 1987 a, b, 1988). Similar characteristics suggest that the other granodiorite plutons in the terrane may be as old, and hence are integral parts of the Chelan Mountains terrane. The plutons assigned to this group, with the exception of the Jordan Lakes pluton, have few relict igneous structures and textures, commonly bear muscovite, and have higher (10) ¹⁸O values (White and others, 1986) than the younger, tonalitic, mostly Late Cretaceous, synmetamorphic plutons that are common to all the terranes. Because these probable older plutons are superficially similar to the Late Cretaceous plutons, at least one, the Sulphur Mountain, has been previously considered to be Late Cretaceous (Tabor and others, 1987b). Some of the granodioritic plutons yield discordant K-Ar ages that suggest a minimum Late Cretaceous metamorphic age. Definite age assignment of the protoliths awaits completion of further isotopic studies.

Kcl CYCLONE LAKE PLUTON--Light-colored, fine- to medium-grained,
muscovite-biotite metagranodiorite (meta-alaskite).
Subhedral sodic plagioclase with relict euhedral oscillatory zoning in a matrix of quartz and microcline, locally blastomylonitic along foliation planes with sparse muscovite and biotite. Common myrmekite. Minor clinozoisite with rare allanite cores. C.I. = 3-7 (Ford and others, 1988, p. 53). Faintly gneissic in outcrop. Rock becomes coarser grained and more gneissic towards

margins where it grades abruptly into the Jordan Lake pluton. K-Ar ages from 3 hornblende-biotite pairs are mostly discordant but suggest a minimum metamorphic or cooling age of about 58 m.y. (Table 2, nos. 39-42). Bryant (1955) p. 177-206) describes rocks of the Cyclone Lake and Jordan Lake plutons. White and others (1988, p. 22) report O^{18} and some chemical data

Kj1 JORDAN LAKES PLUTON--Medium-grained hornblende-biotite tonalite and granodiorite. Hypidiomorphic granular with euhedral to subhedral plagioclase with relict euhedral oscillatory zoning and locally filled with clinozoisite and muscovite and in a mesostasis of microcline or perthite. Myrmekite common. CI=5-21, generally 10-17 (Ford and others, 1988, p. 60). Discordant K-Ar ages of hornblende and biotite pairs suggest a minimum cooling or metamorphic age of about 74 m.y. White and others (1988, p. 24) report O^{18} and some chemical data

Kdc DOWNEY CREEK PLUTON--Mostly light-colored muscovite-biotite metagranodiorite and granodiorite gneiss, locally tonalite. CI=3-6 (Ford and others, 1988, p. 59) Crystalloblastic to porphyroblastic with insets of larger plagioclase in granofelsic, foliated matrix of quartz, oligoclase, K-feldspar including microcline, micas, garnet, epidote, and sphene. Ellipsoidal quartz mosaic aggregates suggest former quartz phenocrysts in some rocks. Some plagioclase with faint relict euhedral oscillatory zoning. Modal data and some chemical and O^{18} data in Ford and others (1988, p. 18-27, 57-59) and White and others (1988, p. 22)

Occurs mostly as sills and irregular masses in rocks of the Napeequa River area (Kn) with intrusive contacts and metaporphry apophyses. Schist inclusions in the pluton range from 10-70%. Includes small lenses in Milk Creek and along Canyon Creek that have similar petrographic features

SUPHUR MOUNTAIN PLUTON consists of:

Ksm Metagranodiorite and metatonalite--Medium-grained hornblende-biotite metagranodiorite and metatonalite characterized by large clinopyroxene prisms up to 8 cm long and quartz-augen up to 1.4 cm across with accessory clinozoisite. Textures are xenoblastic to hypidiomorphic. Sphene and rare garnet and allanite. Calcic oligoclase commonly has faint euhedral oscillatory zoning but is also highly filled with epidote. CI=5-19, mostly about 10-13. Hornblende yields K-Ar ages of about 60, 63, and 72 m.y. (Table 2, nos. 42-46). The oldest hornblende age is probably a minimum age of metamorphism. Descriptions in Ford (1959, p. 112-134) and Crowder and others, (1966). Modes, some chemical data, and oxygen isotopic values are in Ford and others (1988, p. 18-27, 63-65) and White and

- others (1988, p. 23)
- Ksmf Flaser Gneiss--On east, medium-grained hornblende-biotite tonalite flaser gneiss with layers and inclusions of clinopyroxene-hornblende schist, hornblende gneiss, biotite gneiss, and quartzite. On west, hornblende-biotite metatonalite and tonalite flaser gneiss with layers of hornblendite and hornblende schist (Crowder and others, 1966)
- Kgp GRASSY POINT STOCK--Light-colored, medium- to coarse-grained biotite metatonalite to metagranodiorite with CI=5-50. Mostly uniform granitoid rock with gneissic margins and rare rhythmic mafic layering. Hypidomorphic granular with highly strained crystals and strong cataclasis. Rare relict euhedral oscillatory zoned oligoclase-andesine. For further description see Crowder and others (1966), and for modal, some chemical and O¹⁸ data see Ford and others (1988, p. 116, 148) and White and others (1988, p. 32)
- ROCKS OF THE NAPEEQUA RIVER AREA, consist of:
- Kn Hornblende schist and mica-quartz schist--Predominantly fine-grained hornblende schist, amphibolite, hornblende-mica schist, mica-quartz schist, garnet-biotite schist and minor hornblende-zoisite schist, hornblende garbenschiefer, calc-silicate schist, marble, and ultramafic rock. In the Cascade River area and in the Straight Creek Fault zone, phyllitic muscovite-chlorite-quartz schist predominates.
- Rocks are mostly white, tan, brown to black, locally greenish with conspicuous compositional banding. Fine lamellar foliation, locally blastomylonitic. Evenly spaced quartz-rich layers, 1-10 cm thick, in mica-quartz schist suggest relict chert bedding, especially prominent north of Illabot Creek and locally along Downey Creek. On outcrop scale the schist is isoclinally folded, commonly crenulated or contorted; small crinkle folds on prominent s-surfaces. Detailed descriptions of rocks of the Napeequa River area are in Bryant (1955, p. 32, 56-76), Tabor (1961, p. 117-120), Cater and Crowder (1967), Crowder and others (1967), and Grant (1966, p. 115-135). Chemical analyses of Napeequa rocks are in Ort and Tabor (1985).
- The probable age of the protolith is Paleozoic or older and the probable age of metamorphism is Late Cretaceous to Lower Eocene based on isotopic studies described in Tabor and others (1987 a, b)
- KnM Marble--Coarsely crystalline, white marble grading into calcareous schist and locally calc-silicate schist
- Knu Ultramafic rock--Thick, large layers along Downey Creek are mostly metadunite (Grant, 1966, p. 110). Other bodies are serpentized metadunite and metaperidotite. Rocks are dark green to black on fresh surfaces, weathering rusty orange to brown with relics of olivine in a felted mat of

antigorite, talc, and tremolite (Crowder and others, 1966). The large body on Jordan Creek is mostly serpentized peridotite (Bryant, 1955, p. 51-53). Many small pods of talc-tremolite schist are unmapped

CASCADE RIVER SCHIST OF MISCH (1966), divided into:

Kcr Mica schist and amphibolite--Mostly fine-grained highly fissile green, brown, and black micaceous schist ranging from phyllitic sericite-quartz schist to granoblastic biotite- and muscovite-biotite-quartz-albite (or oligoclase) schist and fine-grained paragneiss. Many rocks have garnet and blue-green tourmaline. Hornblende-biotite-andesine schist, garbenschiefer, and fine-grained amphibolite common. Calcareous mica schist locally. Hornblende is commonly blue-green. Most descriptions abstracted from Tabor (1961, p. 81-115)

Metaconglomerate in the Cascade River schist indicates that its protolith unconformably overlay the protolith of the Late Triassic Marblemount Meta-Quartz Diorite. U-Pb ages of zircon recovered from a fine-grained silicic mica schist (metarhyolite) stratigraphically above the metaconglomerate are about 220 m.y., also Late Triassic

On Spider Mountain includes phyllitic quartz-rich schist, calcareous mica schist, grading to impure marble, and silicic metaporphyry

Kerc Metaconglomerate--gray to dark-green rocks ranging from boulder conglomerate with weak foliation to highly schistose rocks in which pebble clasts are so highly attenuated that they are only visible on surfaces cut perpendicular to fabric lineation. Identifiable protoliths of clasts are quartzite and volcanic and granitoid rocks. Unmapped granule conglomerate rich in granitoid and metaquartzite clasts occurs elsewhere in the Cascade River Schist south of the North Fork of the Cascade River

Kcrm Marble--Coarsely crystalline gray to white marble with many impurities of quartz, plagioclase, and mica. Grades into calcareous mica schist. Star = outcrop too small to show at map scale

Kmm MAGIC MOUNTAIN GNEISS OF TABOR (1961, 1962) (LATE CRETACEOUS)--Light-colored chlorite-muscovite-epidote-plagioclase gneiss or flaser gneiss interlayered with chlorite-epidote-quartz-albite schist, locally with garnet and hornblende. Plagioclase, strikingly filled with epidote, is mostly albite but ranges to oligoclase; epidote is strongly zoned, mostly to iron-rich rims; chlorite is typically Mg-rich. The gneiss layers range from flaseroid with epidote-filled plagioclase insets in a blastomylonitic quartz matrix to strongly layered quartz and albite rocks with numerous stringers of epidote and chlorite. Gneiss layers and greenschist layers are mostly clearly

separated, but gradations occur. Scale of layering ranges from 5 cm to 6 m, but near the contact with the Cascade River Schist greenschist layers increase in thickness and may be up to 60 m thick. Locally the contact is marked by a monolithologic breccia of equidimensional light-colored gneiss clasts, commonly augen-shaped and up to 10 cm across in a greenschist matrix. Greenschist of supra-crustal origin may be included along this contact. Descriptions abstracted from Tabor (1961, p. 38-72) who proposed that the gneiss was derived from the Marblemount Meta-Quartz Diorite by thrusting into greenschist facies conditions above the Cascade River Schist of Misch (1966). Zircon yields discordant U-Pb ages of about 195-210 m.y. suggesting that the protolith was indeed Triassic (Table 1, no. 69). A K-Ar hornblende age of about 117 m.y. (Table 2, no. 68) is old for the accepted age of metamorphism of about 90 m.y.; it may reflect partial degassing of original igneous hornblende in the Marblemount or excess argon during metamorphism of the Magic Mountain Gneiss. For modal, chemical, and oxygen isotope data, see Ford and others (1988, p. 18-27; 100-102) and White and others (1988, p. 29)

MARBLEMOUNT META-QUARTZ DIORITE OF MISCH (1966) (LATE CRETACEOUS),
divided into:

Kmqd

Meta-quartz diorite--Hornblende meta-quartz diorite, metatonalite and gneiss; minor metadiorite, hornblendite, and schistose hornblendite. Light-colored metatonalite dikes. Most common rock has CI=16-54 (Ford and others, 1988, p. 96). West of the Entait fault and in the South Fork of the Cascade River area, the rock is medium grained, pale green, containing numerous anastomosing shears rich in chlorite, epidote, and actinolitic hornblende, and varies from massive with relict hypidiomorphic granular texture to highly foliate and mylonitic. Sodic plagioclase commonly unzoned, complexly twinned and filled with epidote and or white mica.

East of the Cascade River South Fork, rocks are progressively more recrystallized to the southeast with pronounced metamorphic segregation, well-recrystallized blue-green hornblende, and locally biotite. Roughly concordant U-Pb ages on zircons from the Marblemount north of the quadrangle indicate an intrusive age of about 220 m.y. (Mattinson, 1972, p. 3777-3778). A muscovite K-Ar age of about 95 m.y. (Table 2, no. 67) may reflect the age of metamorphism. For further description see Bryant (1955, p. 34-49), Tabor (1961, p. 14-37), and for modes, some chemical data, and oxygen isotope values, Ford and others (1988, p. 18-27, 94-96) and White and others (1988, p. 28)

- Kmqf Flaser gneiss--Dark-colored epidote-chlorite-muscovite-quartz-plagioclase flaser gneiss. Subhedral to subidioblastic sodic plagioclase in a foliate matrix, locally with biotite.
- KmqS Schistose meta-quartz diorite and chlorite schist

Swakane terrane

- Ksg SWAKANE BIOTITE GNEISS (LATE CRETACEOUS)--Biotite-quartz-oligoclase gneiss, medium grained, locally with garnet. Generally granofelsic to schistose but remarkably uniform and unlayered. Foliation folded on a small scale and swirled locally. Rare layers of hornblende schist. Cut by numerous sills and dikes of light-colored tonalite and tonalite gneiss. For further description see Waters (1932), Crowder (1959, p. 833-835), and Crowder and others (1966), and Tabor and others, (1987b).

The protolith age of the Swakane is uncertain depending in part whether the gneiss is interpreted to be a metamorphosed sandstone or pyroclastic dacite. Zircons yield Early Proterozoic ages (Mattinson, 1972, p. 377; Tabor and others, 1987 a, b) but Rb-Sr isochrons suggest a Late preCambrian depositional age (R. J. Fleck and A. B. Ford in Tabor and others 1987b)

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TABLE 1. Fossils and fossil localities in the Sauk River Quadrangle

Map number	Sample number	Location		Description	Age	Reference
		Latitude	Longitude			
Western Melange belt						
1f.	VP 39-84	48°14.7'	121°54.2'	Radiolarians in chert	Late Jurassic	C.D. Blome (written comm., 1985)
2f.	RWT 5-83	48°02.5'	121°50.7'	Pelecypod in concretion in argillite	Late Jurassic	J.W. Miller (written comm., 1984)
3f.	KO 83-47	48°02.9'	121°39.9'	Radiolarians in chert	Mesozoic	C.D. Blome (written comm., 1984)
4f.	KO 83-52	48°02.6'	121°39.6'	Radiolarians in chert	Mesozoic	C.D. Blome (written comm., 1984)
5f.	RWT 19-83	48°05.4'	121°49.4'	Radiolarians in chert and argillite	Mesozoic	C.D. Blome (written comm., 1984)
6f.	---	48°07.0'	121°55.7'	Fusulinids in limestone	Late Permian	Danner (1966, p. 318-322)
7f.	---	48°06.1'	121°54.4'	Fusulinids in limestone	Late Permian	Danner (1966, p. 322-323)
8f.	WA 134	48°08.3'	121°57.8'	Pelecypods in limestone	Latest Jurassic	Danner (1957, p. 411)
9f.	KO 83-64	48°09.1'	121°56.0'	Radiolarians in chert	Late Jurassic	C.D. Blome (written comm., 1984)
10f.	RWT 436-84	48°12.3'	121°47.3'	Radiolarians in chert	Mesozoic, ?Early to Middle Jurassic	C.D. Blome (written comm., 1984)
11f.	FMZ 41-83	48°04.7'	121°51.7'	Radiolarians in chert	Early Jurassic	C.D. Blome (written comm., 1984)
12f.	---	48°02.7'	121°48.9'	Fusulinids in limestone	Middle Permian	Danner (1966, p. 324-325) and Wiebe (1963, p. 6)
Trafton Melange						
13f.	RWT 438-84	48°12.3'	121°48.0'	Radiolarians in chert	Early Jurassic or earliest Middle Jurassic	C.D. Blome (written comm., 1986)
14f.	FMZ 75-83	48°08.2'	121°51.9'	Radiolarians in chert	Early Jurassic	C.D. Blome (written comm., 1984)
15f.	KO 83-72	48°09.1'	121°54.2'	Radiolarians in chert	Mesozoic, ?Jurassic	C.D. Blome (written comm., 1984)
16f.	RWT 427-84	48°13.3'	121°53.6'	Radiolarians in chert	Mesozoic, ?Late Triassic	C.D. Blome (written comm., 1986)
17f.	RWT 116-83	48°12.3'	121°53.9'	Radiolarians in chert	?Paleozoic	C.D. Blome (written comm., 1984)
18f.	---	48°10.5'	121°57.0'	Fusulinids in limestone	Late Permian	Danner (1966, p. 315-317)
19f.	---	48°12.0'	121°59.6'	Fusulinids in limestone	Late Middle Permian	Danner (1966, p. 311-315)
20f.	JTW 77-15A, B	48°11.9'	121°59.6'	Radiolarians	Triassic	D.L. Jones and J.T. Whetten (written comm., 1985)
	JTW 77-26	48°11.9'	121°59.6'	Radiolarians in chert	Triassic	
21f.	JTW 77-10	48°11.7'	121°55.4'	Radiolarians in chert	Mesozoic	D.L. Jones and J.T. Whetten (written comm., 1985)
Eastern Melange belt						
23f.	RWT 39-84	48°14.0'	121°44.3'	Radiolarians in chert	Jurassic	C.D. Blome (written comm., 1986)
24f.	RWT 92-83	48°05.0'	121°40.4'	Radiolarians in chert	Mesozoic	C.D. Blome (written comm., 1984)
Eastern melange belt: chert-rich unit						
25f.	RWT 326-84	48°15.4'	121°45.8'	Radiolarians in chert	Mesozoic, ?Triassic	C.D. Blome (written comm., 1986)
26f.	RWT 327-84	48°15.4'	121°46.0'	Radiolarians in chert	Late Triassic	C.D. Blome (written comm., 1985)
27f.	RWT 153-84	48°14.3'	121°43.9'	Radiolarians in chert	Mesozoic	C.D. Blome (written comm., 1985)
28f.	RWT 154-84	48°14.3'	121°43.8'	Radiolarians in sheared chert	Mesozoic, ?Jurassic	C.D. Blome (written comm., 1985)
Eastern melange belt: Whitehorse unit						
29f.	RWT 155-84	48°13.9'	121°43.1'	Conodonts in marble	Late Triassic	K.S. Schindler and A.G. Harris (written comm., 1985)
Eastern melange belt: argillite unit						
30f.	RWT 42-84	48°15.5'	121°43.1'	Radiolarians in concretion in black argillite	Middle to Late Jurassic	C.D. Blome (written comm., 1985)
Helena-Haystack melange						
31f.	RWT 216-83	48°20.0'	121°53.2'	Radiolarians in chert	Mesozoic, ?Triassic	C.D. Blome (written comm., 1984)
32f.	RWT 460-85	48°23.1'	121°59.9'	Ostracods	Indeterminate	C.D. Blome (written comm., 1986)
Chilliwack Group of Cairnes (1944) and associated rocks						
33f.	---	48°30.0'	121°35.6'	Brachiopods in argillaceous limestone	?Silurian to Devonian	Danner (1966, p. 289-294)
35f.	RWT 143-84	48°13.4'	121°27.9'	Conodonts in foliated marble	Late Mississippian to earliest Pennsylvanian	K.S. Schindler and A.G. Harris (written comm., 1985)
36f.	RWT 135-84	48°13.5'	121°26.9'	Radiolarians in sheared chert	Mesozoic, probably Late Triassic or Early Jurassic	C.D. Blome (written comm., 1986)

Table 2. Summary of fission track and isotope analyses of rocks in the Sauk River Quadrangle [all fission track ages calculated with $F=7.03 \times 10^{-17} \text{ yr}^{-1}$; all USGS K/Ar ages calculated on the basis of 1976 IUGS decay and abundance constants. K/Ar ages from Yeats and Engels, 1971, Engels and others, 1976, and Vance and others, 1980, corrected by use of table in Dalrymple, 1979. Errors on single new K/Ar ages of this report and Tabor and others, (1982) based on an empirical function relating the coefficient of variation in the age to percent radiogenic argon (Tabor and others, 1985). Uranium-thorium-lead isotope ages reported in the following order: $^{206}\text{Pb}/^{238}\text{U}$; $^{207}\text{Pb}/^{235}\text{U}$; $^{207}\text{Pb}/^{206}\text{Pb}$; $^{208}\text{Pb}/^{232}\text{Th}$. Two data sets are reported, each preceded by the approximate mesh size in parentheses. Constants: $^{238}\text{U} = 1.55125 \times 10^{-10} \text{ yr}^{-1}$; $^{235}\text{U} = 9.8485 \times 10^{-10} \text{ yr}^{-1}$; $^{232}\text{Th} = 4.9475 \times 10^{-11}$; $^{238}\text{U}/^{235}\text{U} = 137.88$. Isotopic composition of common lead assumed to be $^{204}\text{Pb}/^{206}\text{Pb} = 207\text{Pb}/^{206}\text{Pb} = 208\text{Pb}/^{206}\text{Pb} = 1:18.40:60:38.20$. nn = no sample number available. Map numbers in parentheses are not on this map]

Map No.	Sample Number	Method	Materials	Location Lat N Long W	Unit	Age (m.y.)	Map Unit or comment	Reference
1.	81F345A	K/Ar K/Ar	Hornblende Biotite	48°06.4' 121°04.6'	Cool Glacier stock	3.9±0.3 3.7±0.1		R.J. Fleck (written commun. to A.B. Ford 1987)
2.	JV218	FT	Zircon	48°09.0' 121°03.7'	Gamma Ridge volcanics	2.3±0.4		This paper
3.	80G2189	K/Ar	Hornblende	48°23.9' 121°11.4'	Mount Buckindy pluton	16.0±0.2		R.J. Fleck (written commun. to A.B. Ford, 1987)
4.	80L198	K/Ar	Biotite	48°23.7' 121°16.5'	Do.	15.0±0.1 14.4±0.2		Do.
5.	818-5C	K/Ar	Hornblende	48°23.2' 121°17.2'	Do.	14.5±0.1 14.5±0.2		Do.
6.	82T2A	K/Ar	Biotite	48°21.4' 121°13.4'	Do.	13.8±0.1 14.0±0.9	Dike	Do.
7.	PM 23	K/Ar	Hornblende	48°28' 121°04'	Cascade Pass dike	14.4±0.3 18.6±1		Engels and others (1976)
8.	RWT-479-67	K/Ar	Biotite	48°28.6' 121°03.9'	Do.	18.5±1.5 18.8±1.0		
9.	827-5A	K/Ar	Hornblende	48°28.7' 121°04.0'	Do.	16.1±0.1 17.9±0.1		R.J. Fleck (written commun. to A.B. Ford, 1987)
10.	818-5F	K/Ar	Biotite	48°21.9' 121°03.9'	Cloudy Pass batholith	21.3±1.3 23.3±0.2	South Cascade Glacier stock	Do.
11.	81F307A	K/Ar	Hornblende	48°06.6' 120°09.3'	Do.	20.1±2.1 20.8±1.1	Sitkum Creek stock	Do.
12.	JTW 79-219	K/Ar	Biotite	48°00.0' 121°22.0'	Grotto batholith	24.1±0.3	Monte Cristo stock	Tabor and others (1982)
13.	RWT-13-68	K/Ar	Hornblende	48°02.4' 121°22.6'	Do.	24.5±1.0 24.8±1.1		Yeats and Engels (1971, p. D36)
14.	R-159	K/Ar	Biotite	48°10.3' 121°22.0'	Do.	28.5±1.0 27.2±0.5	Dead Duck pluton	This paper
15.	827-6G	K/Ar	Hornblende	48°09.2' 121°21.9'	Do.	25.0±0.3 25.7±0.2	Do.	R.J. Fleck (written commun. to A.B. Ford, 1987)
(16)	nn	K/Ar	Whole rock		Vesper Peak stock	32.7±2	Composite chip sample	Griffis (1977, p. 96)
(17)	nn	K/Ar	Whole rock		Do.	28.2±1	Mineralized tonalite clast in Sunrise brx.	T. Gates (in Griffis, 1977, p. 203)
18.	RWT-48-84 (JV-317)	U/Pb K/Ar	Zircon Hornblende	48°09.6' 121°37.0'	Squire Creek (coarse) pluton (fine)	35.7;36.0;----;---- 35.0;35.3;----;----		Vance and others (1986) and N. Walker (written comm., 1985)
		K/Ar	Hornblende			42.1±3.5	Age too old; hbl. contaminated by mafic inclusions	This paper
19.	PM 32	K/Ar FT	Biotite Zircon	48°10.2' 121°35.5'	Do.	33.4±0.4 33.6±3.4		Yeats and Engels (1971, p. D36)
20.	JV-289	K/Ar	Hornblende	48°21.8' 121°51.5'	Granite Lakes pluton	35.1±1.8 35.1±1.4		This paper
21.	DB-98-85	K/Ar	Biotite	48°21.6' 121°51.3'	Do.	38.5±7.0 36.7±4.0		Do.
22.	RWT-12-68	K/Ar	Hornblende	48°06.2' 121°57.5'	Granite Falls stock	44.4±1.4		Yeats and Engels (1971, p. D36)
23.	RWT-15-84	FT	Zircon	48°18.4' 121°58.1'	Barlow Pass volcanics	45.7±4.6		Do.
24.	JV-229	FT	Zircon	48°09.8' 121°30.3'	Do.	43.9±4.4		Do.
25.	JV-1357	FT	Zircon	48°04.1' 121°29.3'	Do.	35.8±3.6	Probably reset by Squire Creek pluton	Do.
26.	JV-43	FT	Zircon	48°03.3' 121°28.8'	Do.	33.0±3.3		Do.
27.	JV-167	FT	Zircon	48°22' 121°47'	Do.	44.5±4.5	Bentonite bed in sandstone	Cruver (1981, p. 38)
28.	JV-48	FT	Zircon	48°21.5' 121°45.3'	Do.	42.1±4.2		This paper
29.	RWT-373-85	K/Ar	Hornblende	48°04.9' 121°25.8'	Do.	40.5±5.4	Sauk Ring dike	Do.
30.	JH 80-66A	K/Ar	Zircon	48°02.5' 121°25.9'	Do.	32.3±5	Do.	Do.
31.	27	K/Ar	Hornblende	48°02.5' 121°25.9'	Basalt dike?	36.8±9.2 46±8		Tabor and others (1982) Bechtel, Inc. (1979, Appendix F)
32.	RWT-20-68	K/Ar	Whole Rock	48°24.6' 121°46.7'				Yeats and Engels (1971, p. D36)
33.	FMZ-22-83	K/Ar	Biotite Muscovite Sanidine	48°03.7' 121°48.2' 48°03.4' 121°51.1'	Mount Pilchuck stock Hansen Lake rhyolite	48.8±1.4 49.2±1.7 45.7±0.8	Probably a minimum age Geochron age	This paper
34.	JV-53	K/Ar	Biotite	48°03.4' 121°51.0'	Do.	52.8±2.0		R.L. Gresens, (written comm., 1978)
		FT	Zircon			33.6±3.4		C.W. Naeser (written comm., 1977)
35.	26	K/Ar	Hornblende	48°22.5' 121°51.3'	"Dioritic stock" intruding Tbs	53±8	Suspect age	Bechtel, Inc. (1979, Appendix F)
36.	80L38A	K/Ar K/Ar	Biotite Muscovite	48°24.5' 121°18.3'	Cyclone Lake pluton	26.8±0.1 57.9±0.3		R.J. Fleck (written commun. to A.B. Ford, 1987)
37.	818-5E	K/Ar	Biotite	48°25.0' 121°17.0'	Do.	28.7±0.1 57.3±0.3		Do.
38.	818-50	K/Ar	Muscovite Biotite	48°23.4' 121°17.4'	Do.	14.3±0.1	Reset by Buckindy pluton	Do.
39.	RWT 185-86	K/Ar	Biotite	48°25.4' 121°14.7'	Do.	55.5±1.6 58.8±0.9		This paper
40.	80N330	K/Ar	Muscovite Hornblende	48°22.1' 121°10.0'	Tonalite of Bench Lake	58.9±0.3 51.9±0.3		Do.
41.	818-5G	K/Ar	Biotite	48°21.5' 121°10.4'	Do.	64.2±1.2 44.7±0.8		Do.
42.	DFC-285-62	K/Ar	Hornblende	48°14.8' 121°06.8'	Sulphur Mountain pluton	72.2±2.1 59.2±1.7		Engels and others (1976)
43.	80R117A	K/Ar	Biotite	48°14.1' 121°07.7'	Do.	57.5±0.3		R.J. Fleck (written commun. to A.B. Ford, 1987)
44.	80R118B	K/Ar	Pyroxene	48°14.8' 121°07.5'	Do.	286.0±4.3		Do.
45.	818-6A	K/Ar	Hornblende	48°15.3' 121°02.8'	Do.	63.2±1.1 26.1±0.5		Do.
46.	818-6B	K/Ar	Biotite Hornblende Biotite	48°14.3' 121°06.8'	Do.	59.5±0.5 54.2±0.4		Do.

47.	RWT-29-86	K/Ar	Biotite	48°29.4'	121°20.9'	Jordan Lakes Pluton	57.6±1.2		Do.
48.	81F109A	K/Ar	Hornblende	48°27.1'	121°19.0'	Do.	73.7±0.5		Do.
		K/Ar	Biotite				58.9±0.3		
49.	827-6A	K/Ar	Biotite	48°26.6'	121°19.6'	Do.	61.1±0.3		Do.
50.	827-6B	K/Ar	Biotite	48°27.8'	121°21.4'	Do.	61.4±0.3		Do.
51.	RWT-413-85	K/Ar	Biotite	48°10.4'	121°19.5'	Chiwaukum schist	75.7±1.5		This paper
52.	DFC-86-60	K/Ar	Biotite	48°02.7'	121°06.5'	Foam Creek stock	71.2±2.1		Engels and others (1976)
		K/Ar	Muscovite				77.6±2.1		
53.	RWT-211-62	K/Ar	Biotite	48°03.4'	121°07.4'	Do.	29.0±0.8	Partially reset by Cloudy Pass batholith	Do.
54.	RH86-B127A	U/Pb	Zircon	48°30.6'	121°12.3'	Hidden Lake (-60+140)75;75;80;----		Just north of quad	J.S. Stacey (written comm., 1987)
55.	827-6D	K/Ar	Biotite	48°30.0'	121°12.0'	Peak stock(-140)	73;73;79;----		R.J. Fleck (written commun. to A.B. Ford, 1987)
56.	827-6E	K/Ar	Biotite	48°29.6'	121°10.9'	Do.	37.6±0.3		
						Do.	46.4±0.3		
57.	80N41A	K/Ar	Hornblende	48°20.5'	121°22.0'	Chaval pluton	78.9±0.5		Do.
58.	80S36A	K/Ar	Hornblende	48°20.8'	121°18.1'	Do.	81.7±0.4		Do.
59.	818-5A	K/Ar	Hornblende	48°20.3'	121°18.4'	Do.	72.3±3.1		Do.
		K/Ar	Biotite				54.4±1.3		
60.	818-5B	K/Ar	Hornblende	48°22.3'	121°19.6'	Do.	63.8±0.7		Do.
61.	DFC-60-62	K/Ar	Hornblende	48°02.9'	121°01.6'	Tenpeak pluton	84.5±2.5	Tonalite gneiss	Engels and others (1976)
		K/Ar	Biotite				67.7±2.0		
		K/Ar	Muscovite				71.2±2.1		
(62)	JV-529	U/Pb	Zircon	48°09'	121°17'	Sloan Creek (-100+170)90.0;90.6;106.0;----			N. Walker written comm., 1981
		K/Ar	Hornblende				77.1±8.9		This paper
		K/Ar	Biotite				78.4±1.2		
		FT	Zircon				58.6±5.9		
63.	JTW 79-200	U/Th/Pb	Zircon	48°02.4'	121°20.3'	Do.	(-100+150)89.7;89.8;91.2;89.8		Tabor and others (1982a; in press, a)
		K/Ar	Hornblende				(-200+250)89.4;89.5;93.1;88.2		
		K/Ar	Biotite				89.9±2.1		
							75.3±1.0		
(64)	RWT-204-86	U/Pb	Zircon	48°31.1'	121°08.5'	Eldorado Pluton (-60+140)88;88;102;----		Just north of quad	J.S. Stacey (written comm., 1988)
						(-140+200)88;89;99;----			
(65)	RWT-42-85	K/Ar	Muscovite	48°32.1'	121°18.2'	Cascade River schist	45.8±0.8	Marblemount meta-quartz diorite clast in metacongl.	This paper
(66)	118-15G	U/Pb	Zircon	48°32.6'	121°19.7'	Do.	(-150)219;221;240;----	Metatuff	J.S. Stacey (written comm., 1987)
(67)	RWT-39-85	K/Ar	Muscovite	48°31.1'	121°21.8'	Marblemount Meta Quartz Diorite	94.0±1.5		This paper
68.	RT-58-63	K/Ar	Hornblende	48°24.9'	121°05.3'	Magic Mountain Gneiss of Tabor (1961)	117.4±3.5		Do.
69.	RWT-176-86	U/Pb	Zircon	48°27.1'	121°03.2'	Do.	(-150+250)195;197;223;----		J.S. Stacey (written comm., 1987)
						(-250)206;209;240;----			
70.	PM2a	K/Ar	Muscovite	48°28'	121°56'	Easton Metamorphic Suite	150±5		Armstrong and Misch, (1987, p. 94)
71.	38S	K/Ar	Muscovite	48°24.8'	121°47.4'	Do.	128±4	Graphitic qtz-alb-musc schist	Brown and others (1982, p. 1095)
72.	67-53	K/Ar	Hornblende	48°26.1'	121°50.8'	Do.	148±5	Epidote amphibolite	Do.
73.	67-45B	K/Ar	Muscovite	48°26.1'	121°50.7'	Do.	164±6	Do.	Do.
74.	RF-75120	K/Ar	Crossite	48°25.8'	121°45.3'	Do.	104.5±7		Armstrong and Misch, (1987, p. 94)
75.	RF-75098	K/Ar	Whole Rock	48°12.9'	121°23.5'	Do.	97.2±2		
76.	81F192A	K/Ar	Blue Amph.	48°13.2'	121°23.5'	Do.	110.9±1.3	Minimum metamorphic age	R.J. Fleck (written comm., to A.B. Ford, 1987)
77.	JV-243	U/Pb	Zircon	48°09.5'	121°32.1'	Helena- (coarse)146.7;147.1;155;----		Tonalite block	N. Walker (written comm., 1985)
		K/Ar	Hornblende			Haystack (fine)148.7;149.0;155;----			This paper
		FT	Zircon			melange	128.6±6.0		
							137±14		
78.	JV-MC (RF-75096)	K/Ar	Hornblende	48°10.2'	121°32.0'	Do.	141±6	Amphibolite block	Vance and others, (1980, p. 365) Armstrong and Misch (1987, p. 94)
79.	JV-236	U/Pb	Sphene	48°11.4'	121°33.4'	Do.	36.5	Meta-rhyolite block	N. Walker (written comm., 1985)
		K/Ar	Muscovite				89.7±3.1		R.L. Armstrong (written comm., 1984)
		FT	Sphene				37.3±3.7	Hydrothermal?	This paper
80.	3a	K/Ar	Plagioclase	48°20.5'	121°59.3'	Do.	133±10	Metagabbro block	Bechtel, Inc. (1979, Appendix F)
	3b	K/Ar	Pyroxene	Do.	Do.	Do.	164±24		
(81)	nn	U/Pb	Zircon	48°23.9'	121°51.5'	Do.	168	Metadacite block	N. Walker in Brown and others, 1987)
81A	RWT 263-83	K/Ar	Hornblende	48°05.7'	121°40.4'	Eastern melange belt	121.4 4.2	Amphibolite block	This paper
82.	JTW 76-204	U/Th/Pb	Zircon	48°11.5'	121°56.3'	Trafton (-50+100)296;299;327;350		Tonalite block	R.E. Zartman (written comm., 1983)
						melange (-200+270)295;297;317;304			
83.	RWT-51-84	K/Ar	Blue amphib.	48°10.2'	121°25.3'	Metamorphic Rocks	214.4±15.6	Crystalline blocks assoc.	This paper
		K/Ar	Muscovite				266.9±3.0		Do.
	RWT-52-84	K/Ar	Muscovite	Do.	Do.	Do.	249.4±2.7	with Chilli- wack Group of	Do.
	RWT-53-84	K/Ar	Muscovite	Do.	Do.	Do.	238.1±2.8		Do.
84.	JV-PM	U/Th/Pb	Zircon	48°16.8'	121°27.6'	Do.	(-100+150)370;374;398;402	Cairnes (1944)	R.E. Zartman (written comm., 1983)
							(-200+250)366;371;402;399		R.B. Forbes (written comm., 1980)
		K/Ar	Hornblende				406±17	Geochron age	Vance and others (1980, p. 364)
		FT	Zircon				178±18		

EXPLANATION OF SYMBOLS

	Contact--Dotted where concealed; shown with unsupported hachures where units are gradational or location is very approximate
	High-angle fault--Dashed where inferred; dotted where concealed. Bar and ball on downthrown side
	Thrust fault--Dashed where inferred; dotted where concealed. Sawteeth on upper plate
	Major folds--Dotted where concealed. Arrows along axial trace show direction of plunge
	Antiform
	Synform
	Small plunging fold in bedded rocks and in foliation
	Horizontal fold
	Strike and dip of bedding--ball on end of strike line indicates top in direction of number
	Inclined
	Overturned
	Vertical
	Strike and dip of foliation in igneous and metamorphic rocks
	Inclined
	Variable
	Vertical
	Bearing and plunge of lineation--May be combined with other symbols
	Inclined
	Horizontal
	Zone of sheared rock
	Landslide--Arrow shows direction of movement
	Incipient landslide--Arrows show direction of movement
	Dated sample locality--See Table 2
	Fossil locality--See Table 1
	Limits of common occurrence of metamorphic index mineral (letter on mineral side of limit): K=kyanite; B=biotite; S=sillimanite
	Area of well-developed foliation in rocks of eastern and western melange belts. Limits are very approximate and particularly obscure where rocks are thermally metamorphosed by Tertiary plutons
	River-cut terrace boundary--Hachures on eroded scarp. Shown northwest of Oso only.

CORRELATION OF MAP UNITS

Note: For melange and metamorphic units, positions of boxes with solid boundaries indicate age of assemblage or metamorphism, respectively; boxes with dashed boundaries indicate age of protolith.

