GEOLOGIC MAP OF THE SAUK RIVER 30- BY 60-MINUTE QUADRANGLE, WASHINGTON

By

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But lower, in every dip and valley, the forest is dense, of trees crowded and hugely grown, impassable with undergrowth as toughly woven as a fisherman's net. Here and there, unnoticed until you stumble across them, are crags and bouldered screes of rock thickly clothed with thorn and creeper, invisible and deadly as a wolf trap.[1]

The Hollow Hills by Mary Stewart, 1973

INTRODUCTION AND ACKNOWLEDGMENTS

When Russell (1900) visited Cascade Pass in 1898, he began a geologic exploration which would 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 when 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), Jones (1959), Vance (1957a), Ford (1959), and Tabor (1961) 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 (sheet 2).

Most U.S. Geological Survey (USGS) work in the Sauk River quadrangle began in 1978 and has continued through 1992. It is part of a major USGS project to compile and map the Concrete 1° by 2° quadrangle at 1:100,000 scale. J.A. Vance mapped many areas throughout the quadrangle during the years 1951-1985. A.B. Ford and colleagues (fig. 1, sheet 2) contributed mapping in much of the Glacier Peak Wilderness area during studies in 1980-1982 mandated by the Wilderness Act. D.B. Booth mapped during the years of 1978-1986, and R.W. Tabor mapped during the years of 1978-1991. R.A. Haugerud contributed mapping and considerable geologic insight. Responsibility for the bedrock mapping and compilation rests with Tabor, Booth, and Vance. Responsibility for mapping the unconsolidated deposits resides with Booth.

Our field work was greatly facilitated by the assistance of Kris Alvarez, Steven L. Garwin, Patrick Goldstrand, Kathleen Ort, Vicky Pease, Carolyn Ortenburger, Ron A. Sonnevil, Fred Zankowsky, and the late Carl Huie. We thank Michael Swanson, Fred Zankowsky, and especially Carolyn Ortenburger for office and laboratory services. R.W. Tabor prepared the digital version of this map with considerable help from Kris Alvarez, Kathleen Duggan, Tracy Felger, Eric Lehmer, Paddy McCarthy, Geoffry Phelps, Kea Umstadt, Carl Wentworth, and Karen Wheeler.

Paleontologists who helped immensely by identifying deformed, commonly recrystallized, and usually uninspiring fossils are Charles Blome, William Elder, Anita Harris, David L. Jones, Jack W. Miller, and Kate Schindler. Chuck Blome has been particularly helpful (see table 1).

We thank John Whetten, Bob Zartman, and John Stacey and his staff for unpublished U-Pb isotopic analyses (cited in table 2). Robert Fleck has generously shared unpublished Rb-Sr and K-Ar data with us. Dennis Sorg provided clean mineral separates for K-Ar ages (cited in table 3): 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 (table 3). All new fission-track ages were determined by Joseph Vance (table 4).

We have had fruitful discussions on the geology of the area and the North Cascades in general with Ned Brown, Bernie Dougan, Bob Miller, the late Peter Misch, Greg Reller, Dave Silverberg, and John Whetten. Dave Harwood, Ralph Haugerud, and Ned Brown critically reviewed the manuscript and map. We are particularly indebted to Ralph for sharing his ideas on the origin of the onlap plutons of the granodioritic group.

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.

Time scales used in this discussion and for the Correlation of Map Units (sheet 1) are those of Berggen and others (1985) and Cowie and Bassett (1989). Igneous rock terminology is that of Streckeisen (1973, 1979).

[1] Used by permission from Harper Collins Publishers (Stewart, 1973)

GENERAL GEOLOGY

The north-south-trending Straight Creek Fault roughly bisects the Sauk River quadrangle and defines the fundamental geologic framework of the area (fig. 2, sheet 1). The fault is considered to have had about 100 km of right-lateral strike-slip offset during Late Cretaceous and early Tertiary time (Misch, 1977a; Vance and Miller, 1981; Monger in Price and others, 1985), but estimates of offset range from about 70 to 180 km and the timing of movement is controversial (Vance, 1985; Vance and Miller, 1992; Tabor, 1994). Within the Sauk River quadrangle, the Straight Creek Fault mostly separates low-grade metamorphic rocks on the west from medium- to high-grade metamorphic rocks on the east. In places, the fault consists of several strands that bound infaulted slivers of unmetamorphosed Tertiary sandstone. On the west side of the fault, a swarm of north- to north-northwest-trending faults within the lower grade rocks may be subsidiary or sympathetic to the Straight Creek Fault.

ROCKS EAST OF THE STRAIGHT CREEK FAULT

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; Tabor and others, 1989; Tabor and Haugerud, 1999) although they all were thoroughly metamorphosed in the Late Cretaceous and early Tertiary. In the Sauk River quadrangle, three major terranes crop out east of the fault: the Swakane terrane, the Chelan Mountains terrane, and the Nason terrane.

The Swakane Biotite Gneiss is the sole component of the Swakane terrane. It is probably a metamorphosed sandstone or dacitic volcanic accumulation, notable for its uniformity in structure and lithology. Isotopic and geochemical studies have indicated its derivation from either a Precambrian dacitic volcanic accumulation (Mattinson, 1972; Cater, 1982; Tabor and others, 1987a, b) or a younger detrital rock derived from Early Proterozoic and younger source terranes (Waters, 1932; Cater, 1982; Rasbury and Walker, 1992).

Overlying the Swakane terrane, and in probable thrust contact with it, as revealed southeast of the Sauk River quadrangle (Tabor and others, 1987a, b), is the herein-named Napeequa Schist of the Chelan Mountains terrane. Formerly we (Tabor and others, 1987a, b) included the rocks making up the Napeequa Schist in the now-abandoned Mad River terrane. New mapping north of the Sauk River quadrangle suggests that although the Napeequa Schist is generally distinct from other rocks of the Chelan Mountains terrane, namely the herein-restricted Cascade River Schist, it has been thoroughly imbricated or interfolded with them and may not be clearly mappable as a separate terrane unit. We now consider the Napeequa Schist to be a part of the Chelan Mountains terrane. The Chelan Mountains terrane also includes the metaplutonic rocks of the Marblemount-Dumbell belt and the Cascade River Schist.

Most rocks of the Napeequa Schist are micaceous quartzites, fine-grained hornblende schist, and amphibolite derived from a protolith of oceanic chert and basalt. Minor marble and small bodies of meta-ultramafic rocks are also characteristic. Mica schist and hornblende-mica schist probably derived from shale and sandstone are common but not unique to the unit. These rocks have been intruded by large, metamorphosed, granitic to granodioritic plutons that yield discordant U-Th-Pb ages suggesting both Late Cretaceous crystallization and contamination by older crustal rocks.

The Cascade River Schist (herein restricted) originally appears to have been a thick sequence of arc-derived clastic rocks with minor arc volcanic rocks. It is now mostly plagioclase-rich mica schist, metaconglomerate, and amphibolitic schist. Minor constituents are silicic schists (metatuff), marble, and amphibolite. Zircons from a dacitic metatuff yield a Late Triassic U-Pb age (see also Cary, 1990).

The Marblemount pluton (equivalent to the Marblemount meta-quartz diorite of Misch, 1966) is also Late Triassic in age based on U-Pb analyses of zircons (Mattinson, 1972). Although the exact nature of the contact between the Marblemount pluton and the Cascade River Schist is enigmatic, the contemporaneity of the plutonic rocks and the overlying metavolcanic rocks suggests deposition of the protolith of the Cascade River Schist 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 and early Tertiary.

The Nason terrane is composed predominantly of the Chiwaukum Schist, a metapelite, characterized by aluminum silicate minerals, as well as some metasandstone and metabasite. The protolith of the Chiwaukum Schist was predominantly marine clastic materials with minor oceanic basalts, perhaps deposited in a distal arc setting (Magloughlin, 1993). Part of the terrane is underlain by the Nason Ridge Migmatitic Gneiss (named herein) derived from the Chiwaukum Schist by more advanced recrystallization and probable igneous injection. The protolith age of the Chiwaukum is uncertain, but it appears to be pre-Late Jurassic. Some workers have argued on the basis of Rb-Sr data that its age is Triassic (Gabites, 1985; Evans and Berti, 1986; Magloughlin, 1986).

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 interpret the contact to be a metamorphosed fault. The elongate, Late Cretaceous Tenpeak pluton has intruded along part of the contact.

The Napeequa Schist overlies the Swakane Biotite Gneiss along a folded thrust fault (Tabor and others, 1987a, p. 117), and it may also overlie the Chiwaukum Schist as explained below. Thus the Chelan Mountains terrane may have been thrust over both the Swakane and Nason terranes prior to Late Cretaceous metamorphism. We do not know if this thrusting was prior to or after accretion to North America.

Apparently all the terranes had been assembled by the Late Cretaceous when they were intruded by deep-seated, synmetamorphic, mostly tonalite to granodiorite plutons. The largest of these include the Chaval, Tenpeak, Eldorado, Sloan Creek, Hidden Lake, Bench Lake, Sulphur Mountain, Jordan Lakes, and Cyclone Lake plutons. These terrane-overlap or stitching plutons characteristically have both igneous and metamorphic features and most yield U-Th-Pb ages of about 94–89 Ma. Some of the stitching plutons (such as the Tenpeak, Chaval, and Sulphur Mountain) have igneous epidote suggesting their intrusion at depths greater than 25 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 Napeequa Schist into relatively homogeneous paragneiss and banded gneiss. We consider these gneisses to be terrane stitching units as well because they developed their dominant characteristics during Late Cretaceous metamorphism.

Although in 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 Complex (equivalent to the Skagit Gneiss of Misch, 1966), which, in its core area, was intruded by 60- and 75-Ma orthogneisses and was still being dynamically metamorphosed in the middle Eocene (about 45 Ma) (Babcock and others, 1985; Haugerud and others, 1991). The 75-Ma Hidden Lake pluton appears to lie on the edge of this Tertiary (Skagit) metamorphism because, although it has been metamorphically recrystallized, it is undeformed, whereas just to the north, the 75-Ma Marble Creek pluton is strongly deformed, presumably reflecting the Skagit metamorphic event (Haugerud and others, 1991).

ROCKS WEST OF THE STRAIGHT CREEK FAULT

West of the Straight Creek Fault, a belt of serpentinite mélange, the Helena-Haystack mélange, and a coincident zone of major disruption and faulting, the Darrington-Devils Mountain Fault Zone, separate two distinct assemblages, or superterranes: the Northwest Cascade System and the western and eastern mélange belts (Tabor and others, 1989; Tabor, 1994). Major supracrustal units in the Sauk River quadrangle west of the Straight Creek Fault have been referred to as the Northwest Cascades System by Brown (1987) and Brown and others (1987), following the structural framework established by Misch (1966). The Northwest Cascades System is characterized by rocks of oceanic and arc origin that have been metamorphosed at low temperatures (T) and at pressures (P) ranging from low to high. The structural complexity of the Northwest Cascades System has led Brown (1987) to characterize it as a regional mélange. Following the lead of Tabor and others (1989), we restrict the Northwest Cascades System in the Sauk River quadrangle to the units northeast of the Darrington-Devils Mountain Fault Zone.

North of the Sauk River quadrangle, the following units of the Northwest Cascades System are exposed in a well-developed regional thrust stratigraphy from structurally highest to lowest (Misch, 1966; Brown and others, 1987; Tabor, 1994; Tabor and others, in press): the Easton Metamorphic Suite, the Bell Pass mélange, the Chilliwack Group of Cairnes (1944) and the Cultus Formation of Daly (1912), and the Nooksack Group and Wells Creek Volcanics of Misch (1966).

In the Sauk River quadrangle, the Nooksack Group, Wells Creek Volcanics, and Cultus Formation are not exposed and only scraps of the Bell Pass mélange crop out.

The Paleozoic Chilliwack Group of Cairnes (1944) is composed of marine sedimentary rocks, mafic to intermediate volcanic rocks, and widespread but minor limestone and marble. Locally Chilliwack rocks are strongly foliate, mostly with a low dip. Chilliwack strata probably were deposited in an arc setting in the late Paleozoic (Blackwell, 1983; Brown, 1987). The Easton Metamorphic Suite comprises the Shuksan Greenschist and Darrington Phyllite. The Shuksan Greenschist is a fine-grained but well-recrystallized metamorphic rock, commonly containing sodic amphiboles. Its oceanic basalt protolith formed in the Middle and Late Jurassic and it was metamorphosed in the Early Cretaceous (Brown, 1987). The Shuksan protolith was overlain by oceanic shale and sandstone, protoliths of the Darrington Phyllite. Most of the Darrington is graphitic quartz-albite-sericite phyllite, but locally it is well-recrystallized, fine-grained muscovite schist, commonly with albite porphyroblasts and well-developed lawsonite.

The Bell Pass mélange consists of various tectonic slices of crystalline schist, gneiss, and meta-igneous rocks in a disrupted phyllite and semischist matrix. Much of the disrupted clastic matrix appears to be derived from the Elbow Lake Formation of Brown and others (1987), which north of the quadrangle, characteristically contains chert and Ti-rich metabasalt (Brown and others, 1987; Sevigny and Brown, 1989). In the Sauk River quadrangle, small slices of probable Bell Pass mélange are commonly associated with high-angle faults. These fault slices rarely contain chert and Ti-rich greenstone, but are associated with a variety of metamorphic and meta-igneous rocks. The most prominent slices in the mélange are the Yellow Aster Complex of Misch (1966) composed of tonalitic to granitic gneisses that yield Proterozoic zircon ages (Mattinson, 1972, p. 3775–3776). Other exotic slices are the Vedder Complex of Armstrong and others (1983) composed of quartzose amphibolite and other schists yielding late Paleozoic metamorphic ages.

Misch (1966) considered the deformed rocks of the Bell Pass mélange and the exotic blocks to be a thick imbricate zone beneath the Shuksan Thrust Fault, a regional overthrust which separates the Easton Metamorphic Suite from the

Chilliwack Group. Except for the low-angle fault on Suiattle and Prairie Mountains (see below), most contacts between the Chilliwack Group, Easton Metamorphic Suite, and Bell Pass mélange in the Sauk River quadrangle are high-angle faults that some workers have interpreted to be the Shuksan Thrust Fault (see Silverberg, 1985, for further discussion of the faults).

Southwest of the Helena-Haystack mélange and the Darrington-Devils Mountain Fault Zone, the western and eastern mélange belts contain rocks of probable submarine fan and deep oceanic origin that are characterized by extreme disruption on an outcrop scale and low P and T metamorphic mineral assemblages. The western mélange 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 mélange belt is locally less penetratively deformed and is characterized by mafic volcanic rocks, chert, and ultramafic rocks. The Trafton terrane appears to be structurally high and folded over the regional antiform expressed in the western mélange belt. We consider the eastern mélange belt and Trafton terrane to be in fault contact with the underlying western mélange belt, although the disruption between the two units along this inferred fault is no more severe than that within the mélange or the Trafton units themselves (Tabor and Booth, 1985). In the western mélange belt, fossil ages are Late Jurassic and Early Cretaceous except for limestone which is Permian and may be olistostromal. Meta-igneous blocks in the eastern mélange belt are Late Triassic in age, whereas fossils range in age from Late Triassic to Late(?) Jurassic. Fossils in the Trafton terrane range from Mississippian to Early Jurassic in age, and a metatonalite block is at least as old as Pennsylvanian (table1; Frizzell and others, 1987, p. 135; Whetten and others, 1980b).

Within the Darrington-Devils Mountain Fault Zone, the Helena-Haystack mélange is composed of a variety of lithologies in a serpentinite matrix (Vance and others, 1980). Components of the eastern mélange belt and the Easton Metamorphic Suite are represented in the Helena-Haystack mélange as well as foliated silicic volcanic rocks, hornblende tonalite, and fine-grained schistose amphibolite, rock types not commonly 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, whereas a metarhyolite block has a metamorphic age of about 90 Ma (Late Cretaceous) as shown by a K-Ar muscovite age and a two point Rb-Sr isochron. Clearly, rocks of great diversity in age and origin have been mixed together in the mélange in Late Cretaceous and (or) early Tertiary time (Tabor, 1994).

The conditions of low-grade metamorphism differ between rocks north of the Helena-Haystack mélange and coincident Darrington-Devils Mountain Fault Zone and rocks to the south. To the north 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 Group (Brown and others, 1981). South of the Darrington-Devils Mountain Fault Zone, blue amphiboles have not been found in the western and eastern mélange belts, but prehnite and pumpellyite are common, and, although aragonite is present in veins, lawsonite has not been positively identified (Tabor, 1994).

Many rocks within the Darrington-Devils Mountain Fault Zone, that is in the Helena-Haystack mélange, were also metamorphosed at high P/T. Brown and others (1987) and (Reller, 1986) considered metavolcanic rocks in the Helena-Haystack mélange underlying 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.

The Helena-Haystack mélange may have formed in Late Cretaceous to middle Eocene time when the western and eastern mélange belts were obducted onto the Northwest Cascades System (Tabor, 1994).

TERTIARY AND QUATERNARY ROCKS AND DEPOSITS

The Mount Pilchuck (named for Pilchuck Mountain) and Granite Falls stocks and associated small bodies intruded and thermally metamorphosed rocks of the western mélange belt in the early middle Eocene. At the same time the rhyolite of Hanson 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 Mount Pilchuck stock (Wiebe, 1963 p. 36–39). The nearby Bald Mountain pluton appears to be older than the Mount Pilchuck stock based on its sill-like shape and strongly deformed margins, but it yields discordant U-Th-Pb ages that suggest a middle Eocene age. The Bald Mountain pluton contains garnet and cordierite and shows some of the same S-type characteristics as the Mount Pilchuck stock. The chemical features and the older Pb component may reflect contamination by underlying continental basement, such as the Swakane Biotite Gneiss (Haugerud and others, 1994, p. 2E19–20).

A widespread eruptive event produced the middle and late Eocene Barlow Pass Volcanics of Vance (1957a, b). Within the thick pile of predominantly basalt, basaltic andesite, and rhyolite of the Barlow Pass are interbeds of fluviatile feldspathic sandstone and conglomerate, which in many areas dominate the section.

Along much of the Darrington-Devils Mountain Fault Zone, the Barlow Pass Volcanics overlie the Helena-Haystack mélange. The Tertiary rocks are locally highly faulted, and locally have been incorporated into the mélange. Locally, sheet-like fault slivers of serpentinite from the underlying mélange have been implaced into the sandstone facies of the unit and recrystallized as metaperidotite (Vance and Dungan, 1977). Clasts in Tertiary conglomerates are highly stretched, roughly horizontal, and parallel to the faults, suggesting strike-slip movement along the Darrington-Devils Mountain Fault Zone in post-late middle Eocene time. The Barlow Pass Volcanics erupted in a time of regional extension (Ewing, 1980; Heller and others, 1987) and probable strike-slip faulting. Waning strike-slip movement along the Straight Creek Fault may have occurred during this time as well, but large displacement in post-Barlow Pass time is precluded by the presence of the Barlow Pass Volcanics on both sides of the fault south of the Sauk River quadrangle (Tabor and others, 1993).

With establishment of the Cascade arc in the early Oligocene along what is now the north-trending backbone of the Cascade Range, a series of intrusive events followed the eruption of the Barlow Pass Volcanics (Vance and others, 1986). 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 Sauk River quadrangle. Magmas of the Index family (Tabor and others, 1989) appear to have come up along the southwest side of the northwest-trending Darrington-Devils Mountain Fault Zone. The plutons cut the fault zone and are not displaced by it.

In the latest Oligocene (about 25 Ma), small outlying satellitic stocks and plugs (including the Monte Cristo stock and Dead Duck pluton) of the Grotto batholith (a plutonic body of the Snoqualmie family), exposed south of the Sauk River quadrangle, invaded the north-trending Straight Creek Fault Zone. About 22 to 23 Ma, in Miocene time, the Cloudy Pass batholith and satellitic bodies of the Cascade Pass family apparently invaded northeast-trending structures in the higher grade metamorphic rocks east of the Straight Creek Fault. The northeast-trending Cascade Pass dike and Mount Buckindy pluton were emplaced at 18 and 15–16 Ma, respectively.

The Cool Glacier stock, a small tonalite body, intruded at about 4 Ma, and the associated volcanic rocks of Gamma Ridge erupted at around 1.8 Ma. These late Pliocene magmas were precursors to the Quaternary volcanism that built Glacier Peak volcano at the same eruptive center. A major eruption of Glacier Peak 11,250 years ago mantled much of the country east of the Sauk River quadrangle with dacitic pumice. Deposits of other eruptions (Beget, 1981), form extensive terraces and fills in the valleys of the Suiattle, White Chuck, Sauk, and North Fork of the Stillaguamish Rivers. Very thick lahars from Glacier Peak have been identified in the vicinity of La Conner, about 72 miles northwest of the volcano. These deposits buried the lower Skagit River delta about 5,000 years ago (Dragovich and others, 2000b). Alluvium enriched in ash presumably derived from Glacier Peak has been identified as far west as Whidbey Island, 40 km west of the quadrangle and over 100 km west of Glacier Peak (D.P. Dethier, written commun., 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 [18; number in brackets indicates position on location map, fig. 3]) include till and outwash from alpine glaciers that originated at the drainage headwalls. Most 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 Sauk River 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 at about 15,000 yr B.P. (Booth, 1987). Ice tongues from the 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, so mappable deposits of the ice sheet are found only west of the Sauk River.

DESCRIPTION OF BEDROCK UNITS
by R.W. Tabor and J.A. Vance

BEDROCK EAST OF THE STRAIGHT CREEK FAULT

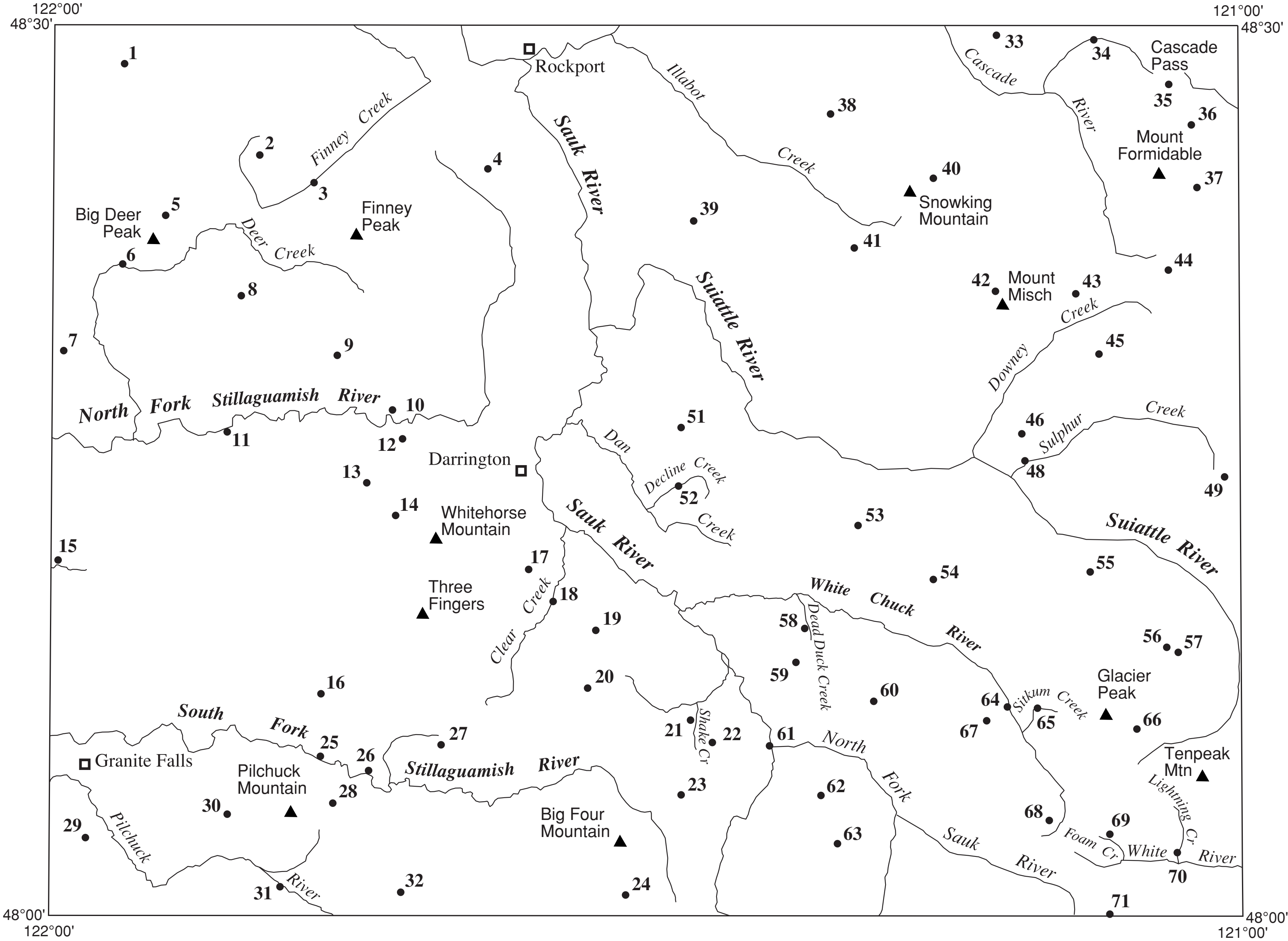
The north-trending Straight Creek Fault separating pre-Tertiary rocks of strongly contrasting metamorphic grade in northwestern Washington is one of the region's major terrane boundaries and a principal component of the Late Cretaceous and early Eocene deformational events (fig. 2). In post-middle Eocene time, the crystalline core of the North Cascades was up-arched and upfaulted east of the Straight Creek Fault, exposing rocks of upper amphibolite facies (Haugerud and others, 1991). West of the fault, most rocks are greenschist facies or of lesser metamorphic grade.

Swakane terrane

Swakane Biotite Gneiss

The Swakane terrane, exposed mostly east and southeast of the Sauk River quadrangle, is underlain by the Swakane

Figure 3. Generalized geographic map of the Sauk River quadrangle, Washington. Number indicates locality of obscure place or place name referred to in text.



Biotite Gneiss. The gneiss was probably derived from dacitic volcanic rocks or possibly clastic sedimentary rocks (Waters, 1932; Mattinson, 1972, p. 3733; Tabor and others, 1987b, p. 115–116). The Swakane locally contains kyanite and its mineralogy indicates amphibolite facies metamorphism; Sawyko and Evans (1994) describe the metamorphic conditions of the Swakane for an area southeast of the Sauk River quadrangle. Evidence to the southeast indicates that the Swakane Biotite Gneiss was probably in thrust contact with rocks of the Chelan Mountains terrane prior to Late Cretaceous metamorphism (Tabor and others, 1987b, p. 117), but in Sauk River quadrangle the contact is apparently high-angle and obscured by the development of migmatite in rocks of both terranes. Mattinson (1972, p. 3733) and Tabor and others (1987b, p. 115–116) have discussed the probably Precambrian protolith age of the Swakane Biotite Gneiss, but recent U-Pb and Sm-Nd analyses of zircon (Rasbury and Walker, 1992; Troy Rasbury, written commun., 1993) indicate that the gneiss may have been derived from sedimentary rocks as young as Mesozoic, but rich in Early Proterozoic clastic zircons. For further description, see Waters (1932), Crowder (1959, p. 833–835), Crowder and others (1966), and Tabor and others (1987a, p. 8–9; 1987b, p. 115–116).

Isotopic characteristics of some granodioritic stitching plutons intrusive into the Napeequa Schist suggest magma contamination by a source rich in Precambrian detritus or by a Precambrian terrane, such as the Swakane terrane, which may underlie much of the Chelan Mountains terrane (see discussion of terrane stitching plutons below).

Chelan Mountains terrane

The major units of the Chelan Mountains terrane are rocks of the Napeequa River area, herein named the Napeequa Schist, the herein-restricted Cascade River Schist, and the metaplutonic rocks of the Marblemount-Dumbell belt.

Tabor and others (1987b, p. 117–118) originally proposed that the major supracrustal component of the Chelan Mountains terrane was the Cascade River Schist of Misch (1966, p. 112–114). Our more recent mapping (Tabor and others, 1988, 1989) and the work of Dragovich (1989), Dragovich and others (1989), and Cary (1990) indicates that the Cascade River Schist contains two distinct lithofacies: one consisting predominantly of metaclastic rocks including coarse metaconglomerate and metavolcanic rocks ranging in composition from rhyolite to basalt (Dragovich, 1989, p. 15–30) and a second consisting predominantly of oceanic rocks: metachert, metamafic rocks, scattered ultramafic rocks, and lesser metapelite. This latter oceanic facies is lithologically identical to many of the rocks of the Napeequa River area (Cater and Crowder, 1967) that we formerly included in the Mad River terrane (Tabor and others, 1987a, b). Because the clastic and oceanic facies appear to have been interlayered prior to metamorphism, and although the exact nature of their original contact—unconformity or fault—is unknown, we now include both lithic units in the Chelan Mountains terrane and here abandon the name "Mad River terrane". We herein restrict the Cascade River Schist to its predominantly clastic and arc-volcanic rock facies and include the oceanic facies in the Napeequa Schist. Future study may warrant placing the Cascade River Schist and Napeequa Schist in separate terranes. See, for instance, discussion in Miller and others (1994a, p. 87–88).

Tabor and others (1987a, p. 10–11) describe an area south of the Sauk River quadrangle where a zone of mylonitic rocks and imbrication suggests a major tectonic contact between the Chelan Mountains and Nason terranes (see also, Magloughlin, 1989). In the quadrangle, the contact between typical medium-grained biotite schist of the Chiwaukum Schist in the Nason terrane and the fine-grained micaceous quartz schist and amphibolite of the Napeequa Schist is marked mainly by a belt of meta-ultramafic rocks, all mapped as part of the Napeequa Schist. If this is indeed a major tectonic boundary, metamorphism has thoroughly masked it except for the incorporated mantle material.

Along the Cascade River, the metamorphic grade of rocks in the Chelan Mountains terrane increases irregularly from northwest to southeast and also from southwest to northeast (Dragovich, 1989, p. 79–84; McShane and Brown, 1991; Brown and others, 1994). This belt of low-grade rocks, located between higher grade schists to the southwest and the Skagit Gneiss Complex to the northeast, has been described by Misch (in Tabor, 1961, p. 7) as a low-grade embayment into the higher grade core of the North Cascades. Included in the embayment are parts of the Marblemount pluton, the Magic Mountain Gneiss, the Cascade River Schist, and the Napeequa Schist.

Just north of the Sauk River quadrangle, the Entiat Fault separates greenschist-facies rocks metamorphosed at about 3–5 kb pressures on the southwest from lower amphibolite-grade rocks metamorphosed at 8–10 kb on the northeast (Dragovich, 1989, p. 80–81). Within the quadrangle, rocks grade from greenschist and lower amphibolite facies in the southeast-trending, low-grade embayment to upper amphibolite facies to the southwest, northeast, and southeast, although superimposed static recrystallization near the Cascade Pass dike and its apophyses obscures the regional grade within a few kilometers of the pluton. Mineral isograds shown on the map are derived from Dougan (1993, fig. 40) and Brown and others (1994).

Farther southeast, beyond the Sauk River quadrangle, deep-seated partial melting has transformed the schists and metaplutonic rocks into migmatite and tonalite plutons of the Chelan Complex of Hopson and Mattinson (1971). The anatectic origin of the plutons and migmatites to the southeast from the Marblemount-Dumbell belt was proposed by Mattinson (1972, p. 3778), challenged by Cater (1982, p. 24), reaffirmed by Tabor and others (1987a, p. 4–8), and modified by Hopson and Mattinson (1990; 1994). For further discussion of the metamorphism, see Age of metamorphism below.

Napeequa Schist

Fine-grained micaceous quartz schist, garnet-mica-quartz-plagioclase schist, hornblende-mica schist, hornblende schist, and amphibolite are the characteristic rocks of the herein-named Napeequa Schist. In addition, in its type area of the Napeequa River valley, just east of the Sauk River quadrangle, the unit contains small masses of metamorphosed igneous rocks including granitoid stocks and porphyritic dikes ranging from tonalite to granodiorite in composition, as well as marble and scattered small to large masses of metaultramafic rocks. Except for the ultramafic rocks, the igneous components are less conspicuous in the Sauk River quadrangle. The predominance of quartzitic rocks, presumably metamorphosed chert, and amphibolite, presumably metabasaltic rocks, and scattered ultramafic rocks indicates that the Napeequa Schist has an oceanic origin. The Twisp Valley Schist of Adams (1964), cropping out about 50 km east of the Sauk River quadrangle, is a likely correlative of the Napeequa Schist (Tabor and others, 1989, p. 8; Miller and others, 1993, p. 1312–1313), and the rocks forming both units have been correlated with the late Paleozoic and early Mesozoic, oceanic Hozomeen Group of Cairnes (1944) and (or) the Bridge River Complex (Misch, 1966, p. 116–117; Tabor and others, 1989, p. 8; Miller and others, 1993, p. 1312–1313), which crops out east of the metamorphic crystalline core of the North Cascades. On the basis of chemistry, Miller and others (1993, p. 1310–1312) consider the Twisp Valley Schist to contain both ocean-island basalts and mid-ocean ridge basalts.

Detailed descriptions of the rocks that form the Napeequa Schist are in Bryant (1955, p. 32, 56–76), Tabor (1961, p. 117–120), Cater and Crowder (1967), Crowder and others (1966), Grant (1966, p. 115–135), and Dragovich (1989, p. 30–38). Chemical analyses of Napeequa rocks are in Ort and Tabor (1985), Babcock and Misch (1989), and Dragovich (1989, p. 160–162). Magloughlin (1993, p. 229–234, 300–301) provides some Rb-Sr data and discussion of trace element chemistry.

Cater and Crowder (1967) first mapped rocks forming the Napeequa Schist, referring to them as the rocks of the Napeequa River area. We propose the name “Napeequa Schist” for the schistose, mostly supracrustal rocks of the Napeequa River area including small bodies of metamorphosed igneous rocks. We correlate the Napeequa Schist with rocks of similar lithology along strike in the Glacier Peak 15' quadrangle (Crowder and others, 1966) as well as with rocks east of the Entiat Fault (south of the Sauk River quadrangle) called the heterogeneous schist and gneiss unit by Tabor and others (1987a), some rocks to the north included in the Green Mountain isochemical rocks of Grant (1966, p. 115–135) and Tabor (1961, p. 115–120), and with rocks southwest of the Entiat Fault referred to as the White Chuck unit by Bryant (1955, p. 21–33) and with the oceanic facies in the Cascade River Schist (Misch, 1966; see also, Tabor, 1961). In its type area along the upper Napeequa River (at and in the vicinity of lat 48°2.5' N., long 120°53' W., Clark Mountain 7.5' quadrangle), for which the unit is named, the Napeequa Schist consists of relatively persistent compositional units ranging from hornblende schist and gneiss to micaceous quartzite, exposed mostly in the west limb of a large synform. Similar regular compositional layering parallel to foliation is characteristic of the unit, forming regional fold structures in the Downey Creek area of this map (see also, Grant, 1966, pl. II). On an outcrop scale, well-developed foliation of the Napeequa Schist is typically highly folded. Metacherts and banded amphibolitic gneiss are commonly contorted. Dragovich (1989, p. 86–136) describes multiple deformation just north of the Sauk River quadrangle.

The rocks of the Napeequa Schist are for the most part of the upper amphibolite facies. Few rocks have aluminum-silicate minerals, although rare staurolite occurs on Illabot Creek, kyanite occurs near Totem Pass [49], and according to Bryant (1955, p. 107–108) sillimanite occurs at the head of Buck Creek. The scarcity of aluminum-silicate minerals is probably a function of bulk composition rather than of metamorphic grade. Many rocks in the zone near the Jordan Lakes pluton and especially in the main belt of the Napeequa between the Jordan Lakes pluton and the Marblemount pluton are blastomylonites.

The protolith age of the Napeequa Schist is not well constrained. Based on discordant U-Th-Pb ages of zircons from a granodioritic orthogneiss, which is assumed to have intruded the Napeequa and is exposed in the Entiat Mountains southeast of the Sauk River quadrangle, Tabor and others (1987a, p. 11–12) proposed the original depositional age of the protolith sediments and volcanic materials to be Paleozoic or older. More recent zircon dating of similar granodioritic orthogneisses, which we now interpret to be Late Cretaceous in age, indicates that the older Pb-Pb ages may be from xenocrystic zircons (see discussion of terrane stitching units below).

Although the contact between the Marblemount pluton and the Napeequa Schist is tectonic, the common occurrence of metamorphosed plutonic rocks (albeit of unknown age) in the Napeequa elsewhere (Tabor and others, 1987a) indicates that the Marblemount pluton may also have been intrusive into the Napeequa Schist, suggesting that the Napeequa Schist is at least pre-Late Triassic in age. Tabor and others (1989, p. 7) proposed that the rocks forming the protolith of the Napeequa Schist were older than the Cascade River Schist (see below), and we tentatively assign a pre-Late Triassic age to the Napeequa protolith. The metamorphic age of the Napeequa Schist is discussed below.

In a contrasting view, on the basis of very limited Rb-Sr isotopic studies, Magloughlin (1993, p. 231–234) suggested that the protolith age of the rocks forming the Napeequa Schist is younger than the Cascade River Schist, possibly middle Mesozoic.

North of the Sauk River quadrangle, Dragovich and others (1989) and Dragovich (1989, p. 135–136) interpreted the rocks forming the Napeequa Schist to overlie the Cascade River Schist in an overturned north-plunging syncline. Major evidence for the syncline is relict graded beds in coarse metaclastic rocks of the Cascade River Schist in the east upright limb of the fold. Because the oceanic origin of the Napeequa Schist suggests that its protolith could not have been deposited on the coarse clastic rocks of the Cascade River Schist, Dragovich (1989, p. 136) and Dragovich and Derky (1994) suggested that the Napeequa Schist was thrust over the Cascade River Schist before folding. Intercalation of Napeequa and Cascade River lithologies, especially well exposed just north of the quadrangle (Tabor and others, in press) might be due to premetamorphic folding or fault imbrication.

Based on the southward plunge of the folded Magic Mountain Gneiss (fig. 2), we interpret the Napeequa Schist to be exposed in a southeast-plunging antiform. That the Napeequa appears to be stratigraphically older than the Cascade River Schist supports this interpretation as does the relative uplift of the northeast side of the Entiat Fault, which would have brought up the antiformal core. Local isoclinal folding in the Cascade River Schist may account for the inconsistency of a single top direction with the antiform interpretation.

However, we believe that the Napeequa Schist to the southwest of the Entiat Fault, in the Wenatchee block (fig. 2), may be exposed around the flanks of a northwest-plunging antiform as explained below.

We tentatively include schistose rocks exposed along Illabot Creek in the Napeequa Schist because of their abundant quartz-rich schists and scattered ultramafic pods, as well as their apparent continuity with typical metachert of the Napeequa unit on the north border of the Sauk River quadrangle. Mica schist in the Illabot Creek area, however, is locally lithologically similar to the Chiwaukum Schist, complete with staurolite, making the Napeequa correlation somewhat uncertain.

The identification of rocks exposed adjacent to and east of the Straight Creek Fault is important to the major structural interpretation of the area. The rocks north of the Illabot Creek area which are exposed between strands of the Straight Creek Fault are almost certainly the Napeequa Schist based on the abundant, included metachert; these fault-bounded rocks continue south where they appear to be an infaulted sliver of the Napeequa Schist between blocks of the Chiwaukum Schist. The general pattern of low-grade rocks west of the Straight Creek Fault and higher grade rocks to the east suggests that more recent fault movement is overall up to the east (see Misch, 1966; Haugerud and others, 1991, p. 1306). That slivers between strands of the major fault may be down-faulted is suggested also by slivers of Tertiary sandstone along the fault, caught between major blocks of metamorphosed rocks. Thus the downfaulted sliver of the Napeequa Schist suggests that the Napeequa must have structurally overlain the Chiwaukum Schist, that is, the Chelan Mountains terrane overlay the Nason terrane. A hint of this major structure is afforded by the consistent northeast dip of foliation and compositional layering in the area of the tectonic contact in the Chelan quadrangle (to the southeast; Tabor and others, 1987a) where the Napeequa flanks the northeast limb of a regional antiform developed in the Chiwaukum Schist. Viewed in this way, the fault-bounded, northwest-trending salient (fig. 2) of higher grade rocks between low-grade rocks of the Cascade River Schist on the east and rocks of the Easton Metamorphic Suite on the west is a structurally uplifted and faulted regional antiform, plunging northwest. The eroded core of this antiform exposes several large Late Cretaceous plutons. Brown and others (1994) show a decrease in metamorphic and igneous pressures northwestward along the axis of this antiform which would be expected from the northwest plunge of the structure (see discussion of the Jordan Lakes and Cyclone Lake plutons).

Marblemount pluton

The Marblemount meta-quartz diorite was named by Misch (1966; see also, 1952, p. 4) for outcrops in the vicinity of Marblemount on the Skagit River (north of the Sauk River quadrangle). The major protolith rock type is quartz diorite, but the original lithologies within the metaplutonic belt range from gabbro and locally hornblendite to tonalite (Tabor 1961, p. 14; Ford and others, 1988, p. 95; Cary, 1990, p. 16). Metamorphosed pegmatite and aplite are also present. Rocks now range from massive to schistose and contain chlorite, epidote, quartz, and albite on the northwest with increasing amounts of hornblende, local biotite, and more calcic plagioclase to the southeast. Greenschist and hornblende-bearing greenschist zones and layers are common.

The Marblemount pluton was traced southeast by Bryant (1955, plate XLVIII), by Tabor (1961, plate l; 1962), who called it the Le Conte Gneiss, and by Grant (1966, plate II). Southeast of the south fork of Agnes Creek (southeast of the Sauk River quadrangle), Grant (1966, plate II) and Ford and others (1988, p. 94) mapped meta-quartz diorite, which they considered to be the Marblemount pluton and which is essentially continuous with the Dumbell Mountain plutons of Cater and Crowder (1967). The Dumbell Mountain plutons are mostly tonalite and quartz diorite and are described in detail by Dubois (1954, p. 156–168), Crowder (1959, p. 838–852), and Cater (1982, p. 8–18). Chemical analyses of the pluton are shown in table 5. For modes, additional chemical data, and oxygen isotope values of the Marblemount pluton, see Ford and others (1988, p. 18–27, 94–96), White and others (1988, p. 28), and Cary (1990, p. 41–42).

Misch (1966, p. 105; 1963, p. 1736–1737) considered the Marblemount pluton to be an anticlinal uplift of basement rocks, a basement equivalent of the pre-Devonian Yellow Aster Complex of Misch (1966) exposed in the less metamorphosed rocks west of the Straight Creek Fault. Boulders of meta-quartz diorite and metatonalite in the Cascade River Schist (Tabor, 196l, p. 91; Misch, 1963, 1966) appear

Table 5. *Chemical composition of rocks from the Marblemount pluton and Magic Mountain Gneiss in the Sauk River quadrangle, Washington*

[Samples analyzed by X-ray flourescence supplemented by methods described in Shapiro and Brannock (1962). Analysts: Paul Elmore, Sam Botts, Gillison Chloe, Lowell Aris, and N. Smith. Abbreviations: LOI, loss on ignition]

	Marblemount pluton		Magic Mountain Gneiss				
	Gabbro		Light-colored gneiss			Green-colored schist	
Sample No.	RT 187-57	RT 222-60	RT 85a-57	RT 57-63	RT 90A-57	RT 162-57	RT 170b-57
Map No.	1c	2c	3c	4c	5c	6c	7c
SiO_2	50.20	49.20	74.20	72.90	75.40	55.60	39.00
TiO_2	0.89	1.00	0.25	0.19	0.12	0.66	1.30
Al_2O_3	21.00	18.00	13.00	13.20	12.90	17.40	19.00
FeO	5.40	7.50	1.40	1.00	0.76	3.80	6.10
Fe_2O_3	2.30	2.60	1.80	2.40	1.60	4.20	6.40
MnO	0.13	0.16	0.10	0.08	0.05	0.12	0.08
MgO	4.20	6.40	1.00	1.10	0.92	4.50	5.70
CaO	10.10	10.70	3.20	2.50	1.40	7.60	13.70
Na_2O	3.50	2.80	3.70	4.60	4.60	3.80	4.10
K_2O	0.34	0.45	0.57	1.00	1.10	0.31	0.04
H_2O+	2.10	0.88	0.50	0.82	0.40	1.80	3.40
H_2O-	0.29	0.12	0.22	0.13	0.15	0.16	0.21
P_2O_5	0.19	0.15	0.05	0.03	0.02	0.08	0.71
CO_2	0.12	< 0.05	< 0.05	< 0.05	0.55	< 0.05	0.11
LOI	-- --	-- --	-- --	-- --	-- --	-- --	-- --
Total	99.00	100.00	100.00	100.00	100.00	100.00	100.00

to confirm that the Marblemount pluton is basement to the Cascade River Schist, but concordant U-Pb ages of zircons (Mattinson, 1972, p. 3777) from the Marblemount indicate a Late Triassic crystallization age of 220 Ma—too young for the unit to be included in the Yellow Aster Complex and essentially the same age as metatuffs in the Cascade River Schist (see below). We, along with Cary (1990, p. 88), note that metaconglomerate has not been found adjacent to the pluton. The flaseroid margin of the pluton adjacent to the Napeequa Schist was highly deformed during metamorphism, and the trace of the contact suggests that the pluton has been thrust over the Napeequa Schist.

The contact of the Marblemount pluton with the Cascade River Schist is enigmatic. We have mapped a wide flaser gneiss zone that suggests strong deformation of the pluton along the contact (see also, Dragovich, 1989, p. 54). Just north of the Sauk River quadrangle, E.H. Brown (in Fugro-Northwest, 1979, p. 13–14) suggested that the contact was originally intrusive, and Cary (1990, p. 87) considers the contact gradational from coarse-grained metaplutonic rocks through hypabyssal dikes to surficial volcanic rocks. An origin as a root pluton to a rapidly depositing, uplifting, and eroding volcanic arc might satisfy all the observations (Tabor and others, 1989, p. 8). The Cascade River Schist represents the arc volcanic rocks and eroded debris.

Metamorphic muscovite from a light-colored metatonalite sill or dike in the Marblemount pluton just north of the Sauk River quadrangle yields a K-Ar age of about 94 Ma (Tabor and others, 1988; 1994) which probably represents the age of metamorphism (see below: Age of metamorphism).

Magic Mountain Gneiss

A strongly layered rock unit, the Magic Mountain Gneiss, structurally overlies the Cascade River Schist and is composed of light-colored chlorite-muscovite-epidote-quartz plagioclase gneiss and flaser gneiss, mafic greenschist, and chlorite schist. The unit was named by Tabor (1962; see also Tabor, 1958, p. 33; 1961, p. 38; Keroher, 1970, p. 457). We here adopt the Magic Mountain Gneiss which is named for Magic Mountain [36], located south of Cascade Pass (in the vicinity of lat 48°27' N. and long 121°02' W., Cascade Pass 7.5' quadrangle) and designate this feature as its principal reference locality. The gneiss is overlain by fine-grained schist, called the Spider Mountain [37] Schist (Tabor, 1961, 1962), which we here include in the Cascade River Schist.

The protolith age of the Magic Mountain Gneiss is Late Triassic, based on a discordant U-Pb age of zircon of about 195–210 Ma (table 2, No. 76). The metamorphic age of the Magic Mountain Gneiss is presumably Late Cretaceous to middle Eocene (see discussion of Age of metamorphism below). A K-Ar hornblende age of about 117 Ma (table 2, No. 75) is old even for the Late Cretaceous (94- to 85-Ma) metamorphism that probably first effected these rocks; the age may reflect partial degassing of original igneous hornblende in the Marblemount pluton during metamorphism.

The Magic Mountain Gneiss has many features, such as mylonitic to blastomylonitic textures, relict garnet and hornblende, decalcified plagioclase filled with epidote, and local relict phacoids of deformed hypidiomorphic granular tonalite, that suggest derivation from fine- to medium-grained metamorphic and (or) igneous rocks.

On the east margin of the Sauk River quadrangle, the gneiss grades into meta-quartz diorite of the Marblemount pluton. Tabor (1961, p. 38–72) described the rocks of the Magic Mountain Gneiss in detail and concluded that it was a diaphthorite, derived from the igneous rocks of the Marblemount pluton (equivalent to his Le Conte Gneiss) as it was thrust over the Cascade River Schist during greenschist-facies metamorphism.

An alternate hypothesis for the formation of the Magic Mountain Gneiss has been proposed by Dougan and Brown (1991) and Dougan (1993) who suggest that the gneiss is a lit-par-lit complex of sills derived from the Marblemount pluton and intrusive into the protolithic volcanic rocks of the Cascade River Schist. They argue that lack of ductile fabrics at the contact between the Cascade River Schist and the gneiss, similarity between greenschist layers in the gneiss and greenschist in the Cascade River Schist, and similarity in the contact between the gneiss and the schist and the analogous contact between the Marblemount pluton and the schist in other areas support the sill interpretation. The gneiss is on top of the Cascade River Schist because it has been folded in a northeast-verging nappe.

The gneiss layers are unlike the Marblemount pluton which is chemically gabbroic in composition (table 5). The light-colored gneiss layers (table 5, Nos. 3, 4, and 5) are normative tonalites (Streckeisen, 1973), but are higher in silica and lower in potassium than most silicic igneous rocks (Nockolds, 1954). The Marblemount is cut by some silicic dikes which are petrographically similar to the light-colored gneiss in the Magic Mountain unit, but no chemical analyses of them are available. The metamorphosed dikes and the light-colored gneiss layers in the Magic Mountain Gneiss could have had plagioclase pegmatite protoliths.

Tabor (1960, p. 2079; 1961, p. 191–197) argued that the Magic Mountain Gneiss and Cascade River Schist were folded into steep-limbed southeast-plunging folds. The map pattern could also be produced by a southeast-dipping, roughly planar thrust contact, and although the available structure data overall are only weakly supportive of a folded contact, the steep dips in the units along the northwest-striking contacts suggest some post-emplacement folding. Structural and contact data as shown on this map are based on the data in Tabor (1961, plate 1) replotted on modern 1:24,000-scale topographic maps from original locations on aerial photographs, as well as newer USGS mapping.

For further description and a lengthy discussion of the origin of the Magic Mountain Gneiss, see Dougan (1993), and for more modal, chemical, and oxygen isotope data, see Ford and others (1988, p. 18–27, 100–102) and White and others (1988, p. 29).

Cascade River Schist

Within the Sauk River quadrangle, the Cascade River Schist consists of a heterogeneous assemblage of mostly fine-grained mica-quartz-plagioclase schist, biotite paragneiss, hornblende-biotite schist, calcareous mica schist, meta-conglomerate, and rare amphibolite, hornblende schist, and marble. Included in the Cascade River Schist on this map is the Spider Mountain Schist of Tabor (1961, p. 106–115; 1962), probably correlative with but separated from the main outcrop belt of the Cascade River Schist by the Magic Mountain Gneiss. All of these schists are characterized by a low degree of metamorphic recrystallization, especially to the northwest where relict sedimentary grains are common in metasandstones. For descriptions and some chemical analyses, see Tabor (1961, p. 81–109), Ort and Tabor (1985), Babcock and Misch (1988, p. 221–223), Dragovich (1989, p.15–27, 39–49), and Cary (1990, p. 28–59).

Misch (1952, p. 7) first described the schists along the Cascade River and only formally referred to them as the Cascade River Schist when he included the unit in his Skagit Metamorphic Suite (Misch, 1966, p. 103). We here adopt the Cascade River Schist for the predominantly metasedimentary and metavolcanic rocks and their on-strike continuations exposed along the Cascade River, for which the unit is named, east of the Marblemount pluton. The principal reference locality of the unit is here designated as the main valley walls of the North, South, and Middle Forks of the Cascade River, at and in the vicinity of lat 48°27' N. and long 121°05' W., Cascade Pass 7.5' quadrangle.

Rocks of this general character have been mapped discontinuously southeast (Tabor, 1961, plate 1; Grant, 1966, plate II) as far as Holden (about 9 km east of the Sauk River quadrangle). In the Holden area, they have been referred to as the younger gneissic rocks of the Holden area (Cater and Crowder, 1967; Cater and Wright, 1967; Cater, 1982, p. 6–7). Miller and others (1994a) and Dragovich and Derky (1994) favor correlation of the Holden rocks with the Cascade River Schist, but point out differences that suggest the Holden rocks may be a different unit altogether. Dragovich and Derky

(1994, p. 34) consider a massive sulphide deposit at Holden to be Late Triassic based on a lead isotope signature similar to other Cordilleran massive sulphide deposits of Late Triassic age, thus supporting the correlation with the Cascade River Schist. However, Mattinson (1972, p. 3773) reported discordant U-Pb isotope ratios of zircon from biotite-granofels in the Holden rocks that give an upper concordia intercept of 265±15 Ma (Permian) if the lower intercept is assumed to be 90–60 Ma, the likely age for the metamorphism. C.A. Hopson (as reported in Mattinson, 1972, p. 3773) interprets the granofels near Holden to be a metamorphosed keratophyre and thus the Permian age is believed to represent the depositional age. This age is too old for the Late Triassic protolith of the Cascade River Schist, and Miller and others (1994a, p. 87) suggested that the zircon might be detrital. Possibly, the biotite granofels represents the Napeequa Schist, imbricated in the Cascade River Schist.

Tabor and others (1987a, b) correlated the amphibolite and schist of Twentyfive Mile Creek near Lake Chelan (50 km southeast of the Sauk River quadrangle) with the younger gneissic rocks of the Holden area and the Cascade River Schist of Misch (1966), but most of the rocks in the Chelan area are amphibolite and micaceous quartzite suggesting that they belong to the oceanic facies of the Chelan Mountains terrane and should be correlated with the Napeequa Schist.

Misch (1966, 1979), Bryant (1955), and Tabor (1961, 1962) included rocks exposed southwest of the Marblemount pluton in their Cascade River Schist; however, we exclude these rocks from the (here-redefined) Cascade River Schist and include them in the Napeequa Schist.

We have discussed previously the contact of the Cascade River Schist and the problematic unconformity with the adjacent Marblemount pluton. Just north of the Sauk River quadrangle, silicic mica schist (metarhyolite) about 500 m stratigraphically above the Marblemount contact (Cary, 1990) and structurally overlain by metaconglomerate contains zircons which yield concordant 220-Ma ages (Tabor and others, 1988; 1994). The protolith age of the Cascade River Schist is Late Triassic. The age of metamorphism in the Cascade River Schist has not been definitively determined, but we assume that it began in the Late Cretaceous and for parts of the unit continued into the middle Eocene. Rubidium-strontium studies in the Cascade River Schist do not provide a unique depositional age for the unit, but strongly indicate its Mesozoic and early Tertiary metamorphism (Babcock and others, 1985).

On the east, the Cascade River Schist is in tectonic contact with the Eldorado Orthogneiss, a Late Cretaceous syntectonic pluton which at one time probably intruded the schist (McShane and Brown, 1991; McShane, 1992). East of the Sauk River quadrangle, the schist and strongly deformed Eldorado pluton are complexly interlayered suggesting either original lit-par-lit intrusion or intense tectonic imbrication (Tabor, 1961, p. 145–152). The intrusion of the unit by the 90-Ma Eldorado pluton was followed by higher pressure metamorphism (McShane, 1992, p. 57–61; Brown and Walker, 1993, p. 494), which to the north at least, continued into the middle Eocene (Haugerud and others, 1991; and see below).

Nason terrane

The Chiwaukum Schist underlies much of the Nason terrane, especially south of the Sauk River quadrangle (Tabor and others, 1993). In the quadrangle, much of the terrane is migmatitic gneiss (herein named the Nason Ridge Migmatitic Gneiss) derived from the schist by more thorough or intense metamorphism and probably by the addition of Late Cretaceous synkinematic to post-kinematic sills and dikes (Tabor and others, 1987a). The probable premetamorphic fault contact of the Nason terrane with the Chelan Mountains terrane is described above.

Chiwaukum Schist

Within the Sauk River quadrangle, the Chiwaukum Schist includes rocks mapped by Vance (1957a, p. 65–94) as the heterogeneous gneiss unit, by Bryant (1955, p. 76–138) and Ford (1959, p. 27–111) as the Green Mountain unit, by Crowder and others (1966) as the central schist belt, and by Heath (1971, p. 12–26) as the Cadet Creek unit. The Chiwaukum Schist includes a locally mappable, fine-grained, black, garnet-mica schist subunit (Crowder and others, 1966), small lenses of hornblende schist and amphibolite, and marble. The protolith of the Chiwaukum Schist was predominantly pelitic rocks, and, based on the chemical characteristics of the schist and interbedded amphibolite, it was probably deposited in a distal submarine fan setting associated with an oceanic arc (Magloughlin, 1993, p. 174–179). Chemical and isotopic analyses of amphibolite from the Chiwaukum Schist are available in Ort and Tabor (1985) and Magloughlin (1993, p. 133–189, 242–247).

Intimately associated with the Chiwaukum Schist is the Nason Ridge Migmatitic Gneiss (described with the stitching units below), which to the south is readily recognized by the abundance of biotite tonalitic gneiss layers in mica schist and amphibolite (Tabor and others, 1993). The biotite tonalitic gneiss becomes the predominant constituent to the northwest and the distinct layering, except for light-colored pegmatite and aplite, is less pronounced northwest of the White Chuck River. In this latter area the uniformity of the biotite tonalitic gneiss, in spite of its coarser grain size, makes it difficult to distinguish from much of the Chiwaukum Schist to the east. In the area north of Meadow Mountain [54], the contact is gradational and difficult to define over several kilometers across strike.

The kyanite isograd on the east side of the outcrop belt of the Chiwaukum Schist is taken mostly from Crowder and others (1966). The isograd is well constrained by our reconnaissance mapping north of Downey Creek. South of the Sauk

River quadrangle, kyanite and staurolite are common in the same rocks, but most of the rocks within this eastern kyanite zone lack staurolite in this quadrangle. The eastern sillimanite isograd is projected north into the Sauk River quadrangle from the south (Tabor and others, 1993) and constrained by only two occurrences near the head of Sloan Creek. Aluminum silicate minerals are scarce within the mapped exposures of the Nason Ridge Migmatitic Gneiss, but Vance (1957a, p. 119) reports three occurrences of relict kyanite and one of staurolite in the area of Circle Peak [53] and south of it. The significance of the kyanite distribution on the east side of the belt, however, is not clear judging from thermobarometry, which indicates that the metamorphic pressure increased from the central axis of the unit to the northeast (Brown and Walker, 1993, fig. 11).

Aluminum-silicate mineral isograds in the Chiwaukum Schist of the Sloan Peak [63] area on the west side of the unit are based on data in Heath (1971, p. 26–35 and plate I). Heath interpreted the unusual distribution of the aluminum silicates to be the result of post-metamorphic thrusting and depth-controlled oxygen fugacity. As demonstrated in the Chiwaukum Schist and associated gneiss to the south where the kyanite isograd parallels the development of the Nason Ridge Migmatitic Gneiss, the increase in metamorphic grade in the Sloan Peak area appears to be roughly parallel to the contact of the Nason Ridge and (or) the synkinematic Sloan Creek plutons (see below). The isograd configuration south of Sloan Peak may be due to a northwest-plunging regional antiform. As noted by Heath (1971, p. 71–72), the foliation in the schists and gneisses support the fold interpretation as do the outcrop patterns of the sill-like bodies of the Sloan Creek plutons. Most of the west limb of this fold is cut off by the Straight Creek Fault. The occurrence of sillimanite physically above kyanite and staurolite on the ridge south of Sloan Peak may be because a major Sloan Creek sill once extended above the ridge, continuous with the erosional remnant that now makes up Sloan Peak. Heath (1971, p. 32) reported statically formed andalusite partially replaced by sillimanite adjacent to the Sloan Creek plutons. Similar sillimanite replacement of andalusite has been reported by Berti (1983) and Evans and Berti (1986) south of the quadrangle. McShane and Brown (1991) describe andalusite replaced by kyanite in the Cascade Pass area. Berti (1983) and Evans and Berti (1986) suggested that the region underwent Buchan metamorphism at low confining pressures (2–3 Kb) followed by high-pressure Barrovian metamorphism (6–7 Kb) because of burial by a thrust plate or plates. McShane and Brown (1991) and Brown and Walker (1993) suggested that growth of kyanite and sillimanite associated with Late Cretaceous plutons was facilitated by magmatic loading, which fits the relations at Sloan Peak. For a more thorough discussion of this metamorphic history, see below.

On the basis of correlations described in Tabor and others (1993, p. 13–14), the protolith age of the Chiwaukum Schist is pre-Late Jurassic. On the basis of correlation with the Settler Schist in British Columbia, offset across the Straight Creek Fault (Misch, 1977a; Vance and Miller, 1981), and poorly defined whole-rock Rb-Sr isochrons, Gabites (1985) and Magloughlin (1986, p. 264) considered the age of the Chiwaukum protolith to be Triassic. In a later study, Magloughlin (1993, p. 212–225) examined new chemical and isotopic analyses of the Chiwaukum Schist and concluded that, based on the Rb-Sr and Nd data, the source terrane for the clastic protolith of the Chiwaukum Schist and its correlatives was most likely late Paleozoic or early Mesozoic rocks, although rocks of an early Paleozoic age could not be entirely excluded. Based on a number of structural and petrologic arguments, Monger (1990) correlated the Chiwaukum Schist with the Darrington Phyllite and Shuksan Greenschist of Misch's (1966) Shuksan Metamorphic Suite which we call the Easton Metamorphic Suite. The Easton Metamorphic Suite has a Middle Jurassic protolith age (see below). Tabor and others (1993, p. 13), Duggan (1992), Magloughlin (1993, p. 174–178), and Duggan and Brown (1994) correlated the Chiwaukum Schist with the Tonga Formation of Yeats (1958b), a less-metamorphosed pelitic schist exposed south of the Sauk River quadrangle. Giving some credence to Monger's correlation, earlier workers (Misch, 1966, p. 111–112; Yeats, 1958a, p. 40–41; R.S. Yeats in Yeats and others, 1977, p. 267–269; Tabor and others, 1987b, p. 112–113) correlated the Tonga with the Darrington Phyllite. As indicated by Tabor and others (1993, p. 13) and overall isotopic and petrologic evidence, discussed in detail by Duggan and Brown (1994), the correlation of the Tonga with the Chiwaukum seems valid, but not the correlation of the Tonga and the Chiwaukum with the Darrington Phyllite. For now, we can only restrict the protolith age of the Chiwaukum to the pre-Late Jurassic. We discuss the metamorphic age of the Chiwaukum Schist below in the section on Age of metamorphism.

Terrane stitching units

During Late Cretaceous metamorphism, all the terranes east of the Straight Creek Fault in the North Cascades were invaded by large, deep-seated, synmetamorphic plutons. On the basis of general lithology, for the most part both modal and normative, and $\delta^{18}O$ values, we divide these plutons into: (1) a tonalitic group and (2) a granodioritic group. Most of the plutons here included in the tonalitic group are characterized by both igneous and metamorphic features, lack static thermal aureoles, and are generally elongate parallel to the metamorphic grain. They crop out across the North Cascades in several different terranes. Most of the granodioritic plutons of the second group intrude the Napeequa Schist. The granodioritic plutons commonly contain muscovite and have fewer relict textures and structures revealing their probable igneous origin, and those for which data is available have higher $\delta^{18}O$ values (more than 10; White and others, 1988) than the tonalitic group. Plutons of this group also tend to contain zircons with discordant ages suggesting inherited lead. An exception to this grouping is the Eldorado pluton which is a monzodiorite modally and a granodiorite chemically, but has $\delta^{18}O$ values less than 10, an isotope characteristic of the tonalitic group.

Dawes (1993, p. 104; 1996) studied the chemistry of several stitching plutons in the Sauk River quadrangle and concluded that the Tenpeak and Chaval plutons of the tonalitic group were derived from "mantle-derived, subduction-related basaltic magmas" formed at the base of and in the lower and middle crust. He feels that the Sulphur Mountain, Bench Lake, and Downey Creek plutons of the granodioritic group, on the other hand, are composed of lower crustal melt derived from "plagioclase- and lithic-rich graywacke" sandstones or altered basalts or both. He notes (p. 106) their similarity to Archean plutons of the craton, but considered their common chemical signature to be process related. In contrast, we suggest that magmas of the granodioritic group may have assimilated material from ancient rocks underlying the Chelan Mountains terrane, presumably the Swakane terrane (see below).

We also include in the terrane stitching units the Nason Ridge Migmatitic Gneiss of the Nason terrane and the tonalitic gneiss of Bench Lake and associated banded tonalitic gneiss in the Chelan Mountains terrane because they appear to be products of the Late Cretaceous metamorphism, but they are not as conspicuously igneous in origin as the major tonalitic and granodioritic plutons.

Plutons of the granodioritic group

Several plutons in the granodioritic group yield discordant U-Pb ages and have higher $\delta^{18}O$ values than most of the tonalitic plutons described below. Except for the Foam Creek stock, the plutons of this group all intrude the Napeequa Schist. In an earlier report, Tabor and others (1988) did not consider the granodioritic bodies to be overlap or stitching units because of their unique lithology and their similarity to a granodiorite pluton in the Entiat Mountains (southeast of the Sauk River quadrangle) that also displays highly discordant U-Pb isotope ages (Tabor and others, 1987a, p. 11). At that time we interpreted the discordance to reflect Paleozoic or older cognate zircons. More recently obtained U-Pb ages from the granodioritic group in the Sauk River quadrangle indicate that most, if not all, of the plutons are Late Cretaceous in age (Brown and Walker, 1993). With the help of some insightful suggestions by Ralph Haugerud, we now interpret the zircons that yield highly discordant ages in the granodioritic plutons to be partially inherited from an older source, namely the Swakane terrane, known to structurally underlie the Napeequa Schist in the Entiat Mountains. The Swakane terrane also occurs along the southeast margin of the Napeequa Schist southeast of, and at the east margin of, the Sauk River quadrangle where it crops out along the projected axis of a major antiform. To the north, the Swakane terrane is cut out by the Entiat Fault.

Foam Creek stock

A small elongate pluton of biotite metagranodiorite on Foam Creek [69] is strongly gneissic on its margins. Its overall uniformity with coarse-grained, but thin biotite books in a decussate texture and faint relict oscillatory zoning in plagioclase suggests metamorphism of an igneous rock. Metaporphyry dikes of similar aspect crop out in the adjacent schist. Potassium-argon ages range from 29 to 78 Ma (table 2, Nos. 57, 58); the oldest age, a muscovite age, probably represents a minimum age of metamorphism, and we assume that the stock is one of the Late Cretaceous stitching plutons. For further descriptions of the Foam Creek stock, see Ford (1959) and Crowder and others (1966).

Sulphur Mountain pluton

A large pluton of granitoid igneous rocks on Sulphur Mountain was first described by Ford (1957; 1959, p. 112–148). It is distinct from other plutons in the Sauk River quadrangle in having conspicuous pyroxene prisms up to several centimeters long and small quartz augen.

Viewed as a whole, the pluton is tear-drop shaped and mostly concordant to foliation and compositional layering in the surrounding Napeequa Schist. The body has gneissic margins and a strongly flaseroid contact zone where highly strained metatonalite of the pluton is interlayered with the country rock (Crowder and others, 1966).

Although most of the textures in the rocks are metamorphic, the uniform composition, evidence of intrusion (Grant, 1966, p. 83), and relict igneous textures, including relict euhedral oscillatory zoning in plagioclase, indicate an igneous protolith for the pluton. Subhedral and pseudomyrmekitic clinozoisite of probable igneous origin indicate intrusion at depths greater than 25 km (more than 8 Kb) (Zen and Hammarstrom, 1984). Aluminum in hornblende thermobarometry indicates similar depths (Brown and Walker, 1993, fig. 11; Dawes, 1993, fig. 2–10).

Uranium-lead ages of zircons are 93–94 Ma; K-Ar ages of biotite and hornblende range from about 55 to 72 Ma (table 2, Nos. 44–49). Hornblende is consistently older than biotite and the ages probably reflect cooling. The Sulphur Mountain pluton has been described in detail by Ford (1957; 1959, p. 112–124), Grant (1966, p. 87–108), Crowder and others (1966), and Cater (1982, p. 35–37). Ford and others (1988, p. 18–27, 63–65), White and others (1988, p. 23), and Dawes (1993) report modes, oxygen isotope values, and some mineralogical and chemical data.

Downey Creek sill complex

A swarm of thick, light-colored, gneissic granodiorite sills permeates the Napeequa Schist in the Downey Creek area. Some intrusions of the light-colored metagranodiorite may be dikes or irregular masses. The metagranodiorite has predominantly metamorphic fabrics, but its contacts appear to be intrusive with some small, well-defined, metaporphyry dikes extending into the surrounding schist. Layers of schist, coplanar with regional structure, are common throughout the mapped body and make up from 10 to 70 percent of the rock mass. The contacts of the sill complex are drawn where the amount of light-colored gneiss is greater than 30 percent of the terrane, as estimated in close and distant views of outcrops. The metagranodiorite of the sill complex is not cut by as many sharply bounded pegmatite and aplite dikes as the migmatitic banded gneiss to the east and as the tonalitic gneiss of Bench Lake [43, fig. 3].

Grant (1966, p. 176–188) included much of the metagranodiorite of the Downey Creek sill complex in his Bachelor Ridge [45] unit (not named on the Sauk River quadrangle) which he ascribed to metasomatic origin. Ford and others (1988, p. 57–59) called the mass the Downey Creek pluton and suggested that it was intrusive. Much of our mapped contact has been drawn from their work.

On the basis of chemical and lithologic similarities, Dawes (1993, p. 24) suggested that the Downey Creek sill complex and the tonalitic gneiss of Bench Lake were derived from the same magma. The light-colored rocks that make up the metagranodiorite of the Downey Creek sill complex are indeed similar in outcrop appearance to the tonalitic gneiss of Bench Lake and its banded tonalitic gneiss subunit (described below), but differ in containing muscovite, more K-feldspar, and less hornblende. Grant (1966, plate II) included tonalitic rocks in his Bachelor Ridge unit and it may well be that the Downey Creek sill complex as mapped includes considerable metatonalite sills and dikes akin to the tonalitic gneiss of Bench Lake. Ford and others (1988, p. 18–27, 57–59), White and others (1988, p. 22), and Dawes (1993) report mineralogical, modal, and some chemical and $\delta^{18}O$ data.

Judging from relict igneous textures, relict euhedral oscillatory zoning in plagioclase, and evidence of intrusive contact, the metagranodiorite of the Downey Creek sill complex appears to be metamorphosed igneous intrusive material. The high amount of K-feldspar helps distinguish this sill complex from light-colored tonalitic rocks associated with the Late Cretaceous metamorphism elsewhere in the North Cascades. The High Pass and Buck Creek plutons, in the Holden quadrangle (Cater and Crowder, 1967) to the east, are similar metagranodiorite, in part sill-like bodies, but Cater (1982, p. 37–40) ascribes their deformational textures to protoclasis.

The lack of contact metamorphism and high degree of metamorphic recrystallization in the metagranodiorite suggests that it is a pre- or early-synmetamorphic intrusion. Its age is otherwise unknown.

Jordan Lakes and Cyclone Lake plutons

The Jordan Lakes [38] pluton is predominantly hornblende-biotite tonalite and granodiorite. The rock is light-colored and coarsely jointed. The pluton has a sharp contact against the Napeequa Schist, but the foliation in the schist wraps around the north end of the body where its contact cuts northeast across the regional structural grain. The grade and recrystallization of the Napeequa Schist increases abruptly near the margin of the pluton. The upgrading is most obvious on the north where chlorite schists develop biotite and hornblende near the contact.

Zircons from the Jordan Lakes pluton yield U-Pb and Pb-Pb ages of about 74 and 90 Ma, respectively. Hornblende yields a 74-Ma age, but K-Ar biotite ages of the pluton range from about 58–61 Ma (table 2, Nos. 50–54). Walker and Brown (1991, p. 716) favor an intrusive age of about 73–74 Ma, which is consistent with the hornblende age and shallow depth of intrusion (see below). The pluton cooled rapidly, although biotite lost argon during cooling.

Alaskite of the Cyclone Lake [40] pluton is distinct from tonalite and granodiorite of the Jordan Lakes pluton, but a gradational contact between the plutons suggests that they are related. The Cyclone Lake pluton is slightly gneissic; thin zones of blastomylonite and aligned mica define the foliation. The pluton becomes less gneissic and gradually coarser grained at its contact with the more mafic tonalite and granodiorite of the Jordan Lakes pluton. An increase in biotite, decrease or disappearance of muscovite, and appearance of hornblende define the contact of the Jordan Lakes body. There is no sign of intrusion or thermal effects at the contact. No chemical data are available to argue a common magma, but the contact indicates that the bodies were in thermal equilibrium and probably are the same age.

Muscovite and biotite from the Cyclone Lake pluton yield considerably younger K-Ar ages (about 57 and 27–28 Ma, respectively; table 2, Nos. 38–41) than the hornblende and biotite in the contemporaneous Jordan Lakes pluton. These younger cooling ages reflect the greater depth of intrusion for the exposed part of the Cyclone Lake pluton as revealed by paleobarometry discussed below.

The Jordan Lakes pluton crystallized at pressures of less than 2 Kb although the metamorphic pressures in nearby country rock are 4–6 Kb, indicating intrusion after peak metamorphism and after uplift began (Fluke, 1992, p. 53; Brown and others, 1994). Brown and others (1994) indicate a rapid increase in paleobarometric pressures from the northwest Jordan Lakes pluton to the southeast across the Cyclone Lakes pluton to between 6 and 7 Kb. The northwest decrease in paleopressures supports the idea of a northwest structural plunge (see section on the structure in the Napeequa Schist).

The Miocene Kindy Creek stock intrudes the south side of the Cyclone Lake pluton. Nowhere is the Cyclone Lake body in contact with supracrustal rocks, although we assume that it intruded them. Bryant (1955, p. 177–206) and Fluke (1992, p. 31–33) describe rocks of the Cyclone Lake and Jordan Lakes plutons. Some chemical and isotopic data are available in Ford and others (1988, p. 53, 60) and White and others (1988, p. 22, 24).

Hidden Lake stock

On the north border of the Sauk River quadrangle, uniform light-colored massive metatonalite makes up the bold cliffs of Hidden Lake Peaks [33] above Hidden Lake. The stock is modally a tonalite, but chemically it is a granodiorite (Ford and others, 1988, p. 26). The Hidden Lake stock (sometimes called the Hidden Lake Peaks stock) is podlike in outcrop pattern with foliation in the intruded schists deflected around the pluton. The biotite metatonalite of the stock has been partially deformed and recrystallized without development of foliation except on the sharply crosscutting north contact (Dragovich, 1989, p. 124) of the body, and locally along the west margin. Dragovich (1989, p. 124) reports a slight thermal aureole in the adjoining schist.

Two size fractions of zircons from the metatonalite yield essentially concordant 73- to 75-Ma ages (Haugerud and others, 1991) indicating a crystallization age of Late Cretaceous. Two samples have biotite K-Ar cooling ages of 38 and 46 Ma (Haugerud and others, 1991). Lack of deformation in the stock in contrast to strong deformation in similar-aged plutons just to the north suggest that the stock was little affected by the Eocene deformation documented in rocks to the north (Tabor and others, 1989, p. 42; Dragovich, 1989, p. 123–128), but clearly it has been recrystallized. Brown and others (1994, fig 8; E.B. Brown, written commun., 1995) indicate the pluton crystallized at about 4 Kb in contrast to paleometamorphic pressures of 6–9 Kb in the country rock adjoining it. Like the Jordan Lakes pluton, the Hidden Lake stock intruded late in the Cretaceous part of the metamorphic cycle, probably as uplift was underway. Haugerud and others (1991) and Brown and others (1994) discuss the ages and deformation in detail. Ford and others (1988, p. 116–117) report modal analyses, and White and others (1988, p. 32) give $\delta^{18}O$ data.

Eldorado Orthogneiss

Massive to gneissic metamorphosed quartz monzodiorite, granodiorite, and tonalite, named the Eldorado Orthogneiss by Misch (1966), are exposed in the northeast corner of the Sauk River quadrangle and make up part of a large elongate pluton extending about 42 km to the northwest and southeast. Within the quadrangle, much of the exposed rocks are strongly flaseroid with anastomosing mafic layers and augen of filled plagioclase or quartz, plagioclase, and K-feldspar. The less-foliated gneiss has a strong hornblende lineation.

Contacts of the Eldorado Orthogneiss with the Cascade River Schist are not well exposed in the Sauk River quadrangle, but to the east, highly strained flaser gneiss of the Eldorado is interlayered with schist and amphibolite suggesting either an original lit-par-lit complex or tectonic imbrication (Tabor, 1961, p. 104, 145–146). McShane and Brown (1991) and McShane (1992, p. 8–14) found intrusive contacts north of the quadrangle.

Misch (1966, p. 105) first described the Eldorado Orthogneiss and considered it to be basement to his Cascade River Schist, structurally similar to his Marblemount metaquartz diorite and, as such, part of his pre-Devonian Yellow Aster Complex exposed to the west. Concordant U-Pb isotope ages of zircon of about 88 to 92 Ma from hornblende gneiss collected just east and north of the quadrangle (Mattinson, 1972, p. 3778; Haugerud and others, 1991) indicate that the Eldorado is one of the Late Cretaceous suites of synkinematic plutons. We include the Eldorado Orthogneiss in the granodioritic group because of its greater K-feldspar content (Ford and others, 1988, p. 22, 25–26). Paleobarometry of hornblende in the Eldorado Orthogneiss and lack of igneous epidote suggest that it was crystallized at only 3.7–5 Kb, a strong contrast to the nearby Cascade River Schist with crystallization pressures of 6.5–7.5 Kb (Dragovich, 1989, p. 78; Brown and others, 1994). Babcock and Misch (1988, p. 21) proposed that the pluton was thrust over the Skagit Gneiss and Cascade River Schist, but Tabor and others (1989, p. 40) suggested that the pluton had been faulted down into the Cascade River Schist from a higher structural level. McShane and Brown (1991) and McShane (1992) concluded that the pluton was intrusive into the Cascade River Schist prior to magmatic loading which produced higher pressure metamorphism in the schist.

Descriptions of the Eldorado Orthogneiss are in Tabor (1961, p. 145–151), Tabor and others, (1989, p. 40), and McShane (1992). Ford and others (1988, p. 18–27, 106–108) and White and others (1988, p. 30) report modes, oxygen isotope values, and some chemical data.

Plutons of the tonalitic group

Metadiorite

A small elongate pluton of biotite-hornblende metadiorite west of Lake Byrne [67] contains epidote-filled andesine and has xenoblastic to granoblastic texture suggesting that it has been metamorphosed. Its mafic composition is very similar to the mafic phases of the Tenpeak pluton, and we suggest that it may be a satellitic stock of that body. Alternatively it may be related to the Sloan Creek plutons. For further description see Crowder and others (1966).

Grassy Point stock

A small stock of biotite metatonalite on Grassy Point [55] has gneissic margins and locally developed mafic layering. The contacts with surrounding schist appear to be abrupt. Textures are crystalloblastic, but the compositional uniformity and faint relict euhedral oscillatory zoning in plagioclase indicate that the stock is composed of metamorphosed igneous rocks. For further description, see Crowder and others (1966). Ford and others (1988, p. 18–27) and White and others (1988, p. 32) report modes, oxygen isotopic values, and some chemical data.

Chaval pluton

Relatively mafic biotite-hornblende quartz diorite and local diorite make up the Chaval pluton, named for Mount Chaval [41] above Illabot Creek (Bryant, 1955, p. 147). Much of the quartz diorite is massive, but near its borders the rock is gneissic. Near the margins, the pluton is rich in streaked-out mafic inclusions, schlieren, and thin mafic layers, all parallel to the gneissic foliation. Black hornblendic rocks studded with white plagioclase characterize the south and east margins of the pluton. These mafic rocks occur in dike swarms in the surrounding schist and within the pluton as swarms of elongate inclusions. The mafic border complex is also rich in light-colored tonalite and pegmatite dikes, some of which are highly foliated and mixed with the dark rocks of the pluton.

Clinopyroxene and hypersthene occur in rocks ranging from tonalite to diorite. Both Bryant (1955, p. 157) and Boak (1977, p. 32–33) felt that the mafic pyroxene diorite core of the pluton showed little evidence of metamorphism. Stronger metamorphism is demonstrated in the gneissic marginal rocks by growth of metamorphic minerals and recrystallization of broken and strained primary igneous crystals. The textures and the lack of a contact aureole led Boak (1977, p. 69–72) to conclude that the Chaval pluton was a late-kinematic intrusion. Bittenbender and Walker (1990) and Bittenbender (1991, p. 42–47) ascribe most of the foliation in the pluton to igneous flow and observed that the pluton and its dikes crosscut earlier foliation in adjacent schist. They discounted the textural evidence of metamorphism in the margins of the pluton and, because they obtained U-Pb zircon ages from the pluton and its dikes of about 92 to 94 Ma (table 2, Nos. 65–67), they suggested that the regional metamorphism occurred before 93–94 Ma.

For further description see Boak (1977) and Bittenbender (1991). Ford and others (1988, p. 86–89), White and others (1988, p. 26), and Dawes (1993) report some chemical and isotopic data.

Tenpeak pluton

The Tenpeak pluton is a composite body of light- and dark-colored hornblende-biotite tonalite, tonalitic gneiss, and flaser gneiss. This sill-like body underlies the volcanic rocks of Glacier Peak and extends southeast about 10 km beyond the Sauk River quadrangle. For about 31 km, the elongate Tenpeak pluton follows the contact between the Chelan Mountains and Nason terranes, suggesting control of its emplacement by that major structural boundary.

The pluton displays a combination of igneous and metamorphic textures and structures indicating deep-seated intrusion during regional metamorphism, and indeed, based on the contained igneous epidote, Zen and Hammarstrom (1984, p. 515) suggested its intrusion at a depth of more than 25 km (8 Kb). Paleobarometry based on hornblende compositions confirmed substantial depth (Dawes, 1993, fig. 2–10; Brown and Walker, 1993, fig. 11). K-Ar and Ar-Ar hornblende ages, as well as U-Pb zircon ages, of about 90 Ma confirm that the pluton belongs to the Late Cretaceous suite (Engels and others, 1976; Haugerud, 1987; Walker and Brown, 1991). Haugerud (1987) suggested that the Ar-Ar ages and conventional K-Ar ages in the Tenpeak body and surrounding rocks reflect slow cooling and that the Wenatchee structural block, situated between the Straight Creek and Entiat Faults, has been tilted as much as 15° up to the northeast.

Descriptions of the Tenpeak pluton are in Ford (1959, p. 149–169), Crowder and others (1966), and Cater (1982, p. 33–34). See also Debari and others (1996). Cater ascribes the deformational features of the pluton to protoclasis during intrusion, not metamorphism. For a discussion, see Tabor and others (1987a, p. 16–17). Ford and others (1988, p. 18–27), White and others (1988 p. 25), and Dawes (1993) report mineralogical data, modes, oxygen isotope values, and some chemical data.

Sloan Creek plutons

Several large sill-like bodies of uniform biotite-hornblende tonalitic gneiss form the resistant summits of Sloan and Bedal Peaks [63, 62] and Pugh Mountain [59], as well as surrounding ridges. Originally referred to as the hornblende gneiss unit by Vance (1957a, p. 161–162), this distinctive rock unit was called the Sloan Peak Orthogneiss by Heath (1971, p. 55–56; 1972). The name “Sloan Peak” is preempted, however, so we will refer to the bodies as the Sloan Creek plutons, a name used by Crowder and others (1966) for these same rocks.

The well-foliated, light-colored gneiss has predominantly metamorphic texture and minerals, but relict euhedral oscillatory zoning and synneusis twins (Heath, 1971, p. 62) in subhedral plagioclase crystals, uniform composition, and recrystallized mylonitic textures indicate that the original rock was igneous. Layers of hornblende tonalite flaser gneiss are common in schist and banded gneiss near the plutons. Heath (1971, p. 56–57) believed that the main tonalitic gneiss contacts on Bedal and Sloan Peaks were synmetamorphic thrust faults. Mylonitic textures are strongly developed in both schist and gneiss at some contacts, but elsewhere, such as on the south ridge of Sloan Peak, the tonalitic gneiss is intrusive into schist. Zones of high strain are common at the contacts of and within the more massive rocks of the Late Cretaceous plutons throughout the Nason and Chelan Mountains terranes.

The overall configuration and orientation of foliation in the Sloan Creek plutons and adjacent schist indicate that the sill-like bodies may be part of a northwest-plunging antiform (see discussion of Chiwaukum Schist).

Hornblende and biotite from tonalitic gneiss yield K-Ar ages of about 75–78 Ma (table 2, Nos. 70, 72). U-Th-Pb isotope ages of zircons from the same samples and others are concordant at about 90 Ma (table 2, Nos. 70, 72, 73, 74) which we interpret to be the crystallization age.

For further descriptions of the Sloan Creek plutons, see Vance (1957a, p. 161–178), Crowder and others (1966), Heath (1971, p. 55-65), and Longtine (1991, p.14–21). Ford and others (1988, p. 18–27, 69–71) and White and others (1988, p. 24) report modes, oxygen isotope values, and some chemical data.

Nason Ridge Migmatitic Gneiss

Intimately associated with the Chiwaukum Schist and making up a large part of the Nason terrane is layered gneiss made up of light-colored biotite tonalitic gneiss layers, biotite schist, and amphibolite cut by numerous sills and dikes of pegmatite and aplite. We have earlier referred to this gneiss as the banded gneiss (Tabor and others, 1982a, b; 1987a, b; 1988; 1993), but here formally name these rocks the Nason Ridge Migmatitic Gneiss. We here designate exposures on Nason Ridge, for which the unit is named (at and in the vicinity of lat 47°47' N. and long 121°01' W., Labyrinth Mtn. 7.5' quadrangle, about 25 km southeast of the Sauk River quadrangle) as the type locality. The metamorphic age of the Nason Ridge Migmatitic Gneiss is Late Cretaceous.

Tabor and others (1987a, p. 15 and cross sections) suggested that the formation of the gneiss was related to the underlying Mount Stuart batholith. On the basis of a late high-pressure metamorphic overprint of kyanite-replacing contact andalusite, presumably formed by the intrusion of the Mount Stuart batholith, and comparison with similar history of the Scuzzy batholith in British Columbia, Brown and Walker (1993; see also Haugerud and others, 1994, p. 2E24) suggested that the migmatitic gneiss formed at the margin of an overlying mushroom-shaped pluton like the Scuzzy batholith, since eroded off.

Although most light-colored gneiss layers in the Nason Ridge Migmatitic Gneiss can be seen to be intrusive, some layers may have formed by the metasomatic addition of plagioclase feldspar to the Chiwaukum Schist. Vance (1957a, p. 65–95, 102–124) and Crowder and others (1966) describe structures and textures in the gneiss. The most convincing evidence for the replacement derivation of some gneiss layers from the Chiwaukum Schist are widely scattered, small, rounded, relict kyanite crystals in porphyroblastic plagioclase layers in the gneiss. Walker and Brown (1991) interpret discordant ages of zircon from a leucosome (table 2, No. 56), which they interpret to be of igneous origin, to indicate primary crystallization at 89 Ma. Magloughlin (1993, p. 235–243) reports Rb-Sr analyses from metasomatic rocks associated with ultramafic rocks and a late-intrusive leucosome in the gneiss south of the Sauk River quadrangle. Isochrons yield ages of 79.5±0.2 Ma and 86.2±0.5 Ma, respectively. Magloughlin (1993), after some discussion of the validity of these ages, concluded that they represent cooling ages. They are minimum ages for metamorphism (see below).

For further description see Vance (1957a, p. 101–161), Crowder and others (1966), and Longtine (1991, p. 30–60). Maglouglin (l994, p. 2B7–2B13) presents a complete and detailed analysis of a typical outcrop of the Nason Ridge Migmatitic Gneiss.

Tonalitic gneiss of Bench Lake (including banded tonalitic gneiss)

In the area of the South Cascade Glacier [44] south to upper Sulphur Creek, the Napeequa Schist is interlayered with light-colored tonalite to granodiorite gneiss and cut by numerous light-colored tonalitic aplite and pegmatite dikes. Schist may constitute 10–70 percent of the rock, which in many areas is migmatitic. The contact with the Napeequa Schist, as mapped, is gradational, marked by an increasing abundance of light-colored sills and dikes. The contact with the tonalitic gneiss of Bench Lake [43] is also gradual, marked by a decrease in the amount of schist and amphibolite, as well as an increase in the grain size of the gneissic component until the overall aspect of the terrane is granitoid.

Tabor (1961, p. 120–128, 133–137), Grant (1966, p. 162–176), and Fluke (1992, p. 28–31) describe these rocks in more detail. Tabor (1961) and Grant (1966) concluded that much of the light-colored material is of replacement origin. However, the similarity of many of the tonalitic gneiss layers to the tonalitic gneiss of Bench Lake and the gradational contact suggests that much of the rock may be metamorphosed igneous material. Dawes (1993, p. 24) considered the tonalitic gneiss of Bench Lake and the Downey Creek sill complex to be the same rocks.

Although massive and uniform-looking from a distance, the tonalitic gneiss of Bench Lake is relatively heterogeneous on outcrop scale compared to other metamorphosed plutons in the North Cascades. Concentrations of mafic material in lenses, layers, and faint schlieren are common. Foliation is swirled and complex. Microscopic features, such as late K-feldspar and quartz replacing plagioclase and mafic minerals, led Tabor (1961, p. 134–136) and Grant (1966, p. 158–172) to consider most of the more uniform rock to be a product of feldspathization processes, but scattered, faintly preserved, euhedral oscillatory zoning in plagioclase and relict hypidiomorphic texture in an otherwise crystalloblastic gneissose fabric indicates an igneous protolith. Probable igneous epidote (Fluke, 1992, p. 30–31) indicates crystallization at more than 25 km depth (8 Kb) (Zen and Hammarstrom, 1984). The unit is more thoroughly metamorphosed than other terrane stitching plutons, and the textures described above suggest considerable intergranular transfer of components.

Because the tonalitic gneiss of Bench Lake and banded tonalitic gneiss appear to crosscut the contact between the Chelan Mountains and Nason terranes, we include them in the terrane stitching units. The rocks are similar to the more homogeneous gneiss layers in the Nason Ridge Migmatitic Gneiss associated with the Chiwaukum Schist which also were produced during Late Cretaceous metamorphism. The unit differs from the Late Cretaceous synmetamorphic plutons in the map area by its lack of clear-cut intrusive features and relict porphyritic phases. These rocks have not been dated, but they probably formed during the Late Cretaceous metamorphic event which occurred about 94 to 85 Ma, as documented in the Napeequa Schist and elsewhere in the North Cascades in general (see below).

Age of metamorphism

The metamorphic and plutonic rocks of the North Cascades core in the Sauk River quadrangle crop out in two structural-metamorphic blocks, the Chelan block, located northeast of the Entiat Fault, and the Wenatchee block, to the southwest (fig. 2) (Haugerud and others, 1991). Rocks in the Wenatchee block were mostly metamorphosed in the Late Cretaceous, whereas rocks in at least the northern part of the Chelan block were probably metamorphosed in the Late Cretaceous, but continued recrystallizing until or were metamorphosed again in the middle Eocene (Haugerud and others, 1991; Tabor and others, 1993). Hopson and Mattinson (1994) describe an Early Cretaceous metamorphic event in the Chelan area of the Chelan block some 65 km east-southeast of the Sauk River quadrangle. Much of the evidence for the ages of metamorphism comes from the ages of the synkinematic or metamorphosed terrane stitching plutons that have been dated by the U-Pb method.

In the Wenatchee block, Late Cretaceous metamorphism is well defined. Walker and Brown (1991) determined that the Chaval pluton crystallized at 93–94 Ma, after the regional metamorphism in the local area, although our data (see above) indicates that the pluton was metamorphosed along its margins. Other U-Pb ages from synkinematic plutons located farther south, such as metatonalite in the Nason Ridge Migmatitic Gneiss, Sloan Creek plutons, and Mount Stuart batholith (about 15 km south of the Sauk River quadrangle) (Tabor and others, 1987a, p. 15, 1993, table 2; Walker and Brown, 1991, p. 492–493) and in correlatable terranes in Canada, coupled with K-Ar cooling ages, suggest that the metamorphism occurred from about 96 to 85 Ma. The 94-Ma age of metamorphic muscovite from the Marblemount pluton confirms that metamorphism began during intrusion of the Late Cretaceous magmas. The unmetamorphosed Jordan Lakes pluton, which crystallized at about 73–74 Ma and yields a K-Ar hornblende cooling age of 74 Ma, provides a younger age limit. Metamorphism in the Wenatchee block ranged in age from about 96 to 85 Ma, perhaps with considerable local variation. Miller and others (2000) have presented a thorough summary of some of the stitching plutons described here and of the Cretaceous metamorphism in the North Cascades in general based on considerable new data acquired since this map was prepared. We recommend their paper to the interested reader.

In the northern part of the Chelan block, the age of the oldest metamorphism is not well defined. Based on relations of deepseated deformed plutons north of the Sauk River quadrangle, Haugerud and others (1991) concluded that metamorphism began prior to 73 Ma. McShane and Brown (1991) and McShane (1992) concluded that andalusite-bearing rocks in the Cascade River Schist were upgraded to kyanite grade following the shallow intrusion of the Eldorado pluton at 90 Ma. Whether the andalusite was present in regionally metamorphosed schists or produced by thermal metamorphism in sedimentary rocks surrounding the pluton is not clear. Fifty kilometers or more to the east, Miller and others (1993, p. 1320) consider the metamorphism of the Twisp Valley Schist to have culminated at about 91–88 Ma and at about 68–60 Ma. Some 75 km to the southeast in the Chelan area, rocks of the Chelan block were recrystallized during deepseated metamorphism and plutonism occurring from 120 to about 70 Ma (Mattinson, 1972, p. 3778; Tabor and others, 1987a, p. 8; Hopson and Mattinson, 1990). For rocks in the southern part of the Chelan block, Miller and others (1994b) describe the extended Late Cretaceous to middle Eocene metamorphism.

Younger (Eocene) metamorphism is mostly evident north of the Sauk River quadrangle where 45-Ma granitic sills in the Skagit Gneiss Complex are strongly deformed (Haugerud and others, 1991). In the Sauk River quadrangle, deformation of the 90-Ma Eldorado pluton may reflect this event, but deformation could also be older. A boulder of the Marblemount pluton from a Tertiary conglomerate sliver in the Straight Creek Fault Zone north of the quadrangle contains zircons which yielded a 45-Ma fission-track age (Tabor and others, in press) suggesting that some rocks of the Marblemount pluton were metamorphosed in the middle Eocene event as well as during the earlier event.

Miller and others (1994b) consider the Entiat Fault to sharply delimit the two domains of metamorphism expressed in the Chelan and Wenatchee blocks. We cannot be sure that, in the Sauk River quadrangle, the area metamorphosed only in the Late Cretaceous and the area with evidence of the middle Eocene metamorphism are sharply separated by the Entiat Fault. Available ages and the lack of deformation in the Hidden Lake stock—probably on the edge of the region that was strongly deformed and recrystallized by the middle Eocene event (Haugerud and others, 1991)—support the separation. Lacking more precise data and for the sake of simplification, we have assigned a Cretaceous metamorphic age to all the rock units of the Chelan Mountains terrane in the Wenatchee block southeast of the Entiat Fault and a Cretaceous and Tertiary metamorphic age to all rock units northeast of the Entiat Fault, in the Chelan block. Some parts of the units northeast of the Entiat Fault may not have experienced the early Eocene metamorphic event.

Deformation associated with younger metamorphism ended by 34 Ma when the region was intruded by Cascade magmatic arc-root plutons which are unmetamorphosed.

BEDROCK WEST OF THE STRAIGHT CREEK FAULT, NORTHEAST OF THE DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Northwest Cascades System

Within the Sauk River quadrangle, the Easton Metamorphic Suite, the Chilliwack Group of Cairnes (1944), and rocks correlated with the Bell Pass mélange (Haugerud and others, 1992; Tabor and others, in press) constitute the Northwest Cascades System and underlie most of that terrane northeast of the Helena-Haystack mélange and the Darrington-Devils Mountain Fault Zone. North of the quadrangle, these rocks and others crop out in a complex stack of thrust plates (Misch, 1966; Brown and others, 1987; Brown, 1987; see also, Haugerud and others, 1992) whose structural stratigraphy is more or less consistent over a wide area. In the Sauk River quadrangle, the structural stratigraphy is obscured by numerous high-angle faults; units of the Northwest Cascades System are mostly bounded by high-angle faults.

Interpretation of the structure in the areas underlain by rocks of the Northwest Cascades System is complicated by the difficulty in distinguishing phyllitic rocks of the Easton Metamorphic Suite, Chilliwack Group, and Bell Pass mélange from each other, as well as in distinguishing metagabbro and metadiabase blocks in the Bell Pass mélange from late Paleozoic and (or) Mesozoic mafic igneous rocks which may have been intrusive into other units. Previous workers (Brown and others, 1987; Jenne, 1978; Franklin, 1974; Vance, 1957a) have interpreted sparse outcrops in many different ways, especially on the west side of Prairie Mountain [51].

Chilliwack Group of Cairnes (1944)

Outcrops of metagraywacke, argillite, phyllite, and greenstone with minor marble exposed north of the Skagit River are continuous with rocks mapped as the Chilliwack Group by Misch (1966, 1979). On Prairie Mountain, similar rocks, including late Paleozoic marble (table 1, No. 35f), appear to be correlative with the Chilliwack, but their intimate association with exotic crystalline rocks, especially the pre-Devonian silicic gneiss of the Yellow Aster Complex and mafic igneous rocks of unknown age, moved Dotter (1977) to consider all the rocks on Prairie Mountain to be a mélange. In overall aspect Chilliwack Group rocks are unmetamorphosed, although they actually reveal considerable but variable low-grade recrystallization on close examination. Although penetrative deformation in these rocks is well developed locally, the dominant character is one of stratigraphic coherence. How much of the lithologic mixing of the rocks in this general area is due to a regional penetrative tectonism or high- and (or) low-angle faulting is not clear.

The volcanic rocks are mostly basalt with subordinate andesite and rare dacite or rhyolite. Breccia and tuff predominate. Christenson (1981, p. 71–74, Appendix A and Plate 1B) reports lawsonite and aragonite from greenstone just north of the Sauk River quadrangle. Chemical and some isotopic analyses of volcanic rocks of the Chilliwack Group are in Christenson (1981, p. 172–179), Blackwell (1983, p. 209–217), and Sevigny and Brown (1989, p. 394).

Franklin (1974, p. 69), Monger (1977, p. 1851), and Christenson (1981, p. 125–151) suggest that the clastic sedimentary rocks of the Chilliwack Group represent deep-water fan deposits and that they and the associated volcanic rocks were derived from an island arc. Brachiopods from rocks just north of Rockport have been assigned a Silurian to Devonian age (table 1, No. 33f). Most workers consider the stratigraphic age of the Chilliwack Group to be late Paleozoic as indicated by fossils in its clastic rocks and limestone beds. The age of the metamorphism which affected the group is presumably mid-Cretaceous, although some recrystallization continued into the Late Cretaceous (Smith 1985, p. 131–134; Brown, 1987, p. 209). Vance (1957a, p. 200–206), Franklin (1974, p. 60–66), and Dotter (1977, p. 28–30) describe the Chilliwack rocks in the Sauk River quadrangle. Smith (1988) and Brown (1987) discuss the origin of structure in the Chilliwack Group.

Bell Pass mélange

Misch (1966) considered the rocks that make up the Early Cretaceous Easton Metamorphic Suite to be thrust over the late Paleozoic Chilliwack Group along the Shuksan Thrust Fault, a regional structure, thought by some workers (Brandon and others, 1988; McGroder, 1991) to extend as far west as the San Juan Islands. More recent mapping by E.H. Brown and his students shows that in most areas the mostly early Mesozoic Elbow Lake Formation of Brown and others (1987), included in the Chilliwack Group by earlier workers (Misch, 1966, p. 116, 1979; Vance, 1957a, p. 200–210; Rady, 1980, p. 86–88), crops out between the Chilliwack Group and the structurally overlying Easton Metamorphic Suite. The Elbow Lake Formation is mostly phyllite and metasandstone (semischist) with characteristic and locally predominating banded radiolarian chert and titanium-rich greenstone. The formation is commonly highly disrupted on an outcrop scale and is the principal component of the Bell Pass mélange. The Bell Pass mélange also contains exotic clasts: gneiss belonging to the Yellow Aster Complex of Misch (1966), metamorphosed mafic igneous rocks, and siliceous schists with blue amphibole of the Vedder Complex of Armstrong and others (1983). Ultramafic rocks are scattered and locally abundant. The Yellow Aster Complex has been interpreted to be a Precambrian to early Paleozoic basement complex with associated Paleozoic mafic intrusive rocks that were metamorphosed in the Silurian (Mattinson, 1972, p. 3775–3776; Brown, 1987, p. 201–202). The Vedder Complex was metamorphosed in the Permian. Misch (1966, p. 123–124) ascribed the extreme deformation of the rocks in the Bell

Pass mélange to an imbricate zone beneath the Shuksan Thrust Fault.

A thrust contact between the Easton Metamorphic Suite and the Bell Pass mélange is well exposed on the south side of Suiattle Mountain where 50 m or more of ductilely deformed rocks underlie brecciated phyllite and greenschist. In earlier papers Tabor and others (1988; 1989, p. 50) considered all the footwall rocks to be the Chilliwack Group, but a relatively thin layer of strongly deformed rocks with exotic igneous rocks and ultramafic pods is part of the Bell Pass mélange (although the mélange is too thin to be shown on the map here). We infer that this same layer of the Bell Pass mélange is exposed on the north ridge of Prairie Mountain where diverse and strongly mylonitic igneous and sedimentary rocks cap the ridge in two places; presumably, most of the mélange and all of the Easton Metamorphic Suite have been eroded from this area. We consider small pods of serpentinite along inferred faults cutting mostly Chilliwack rocks on Prairie Mountain to be slivers of the Bell Pass mélange.

We infer also that the thrust contact exposed on Suiattle Mountain continues along the valley bottom of the Sauk and Skagit Rivers where it has been depicted by Vance (1957a), Huntting and others (1961), and Brown and others (1987). This thrust, considering its probable regional extent and low dip, is probably the Shuksan Thrust Fault. Within the Sauk River quadrangle, most other contacts between the Chilliwack Group and the Easton Metamorphic Suite are high-angle faults with narrow shear zones lacking mylonite. Some of these high-angle faults were interpreted in earlier studies (Vance, 1957a, Pl. 1; Franklin, 1974, Pl. 1; Milnes, 1976, Pl. 1) to be the folded Shuksan Thrust Fault. A wide zone of mylonites and brittle shears on the east side of Prairie Mountain and associated metagabbro and metadiorite making up the summit of Prairie Mountain suggest another remnant of the Shuksan Thrust Fault and underlying mélange, complexly deformed by a younger, north-south trending, high-angle fault system (see Brown and others, 1987, for an alternative interpretation).

On the south side of the White Chuck River, Silverberg (1985, p. 118–120) described steeply imbricated slices of meta-igneous rocks, including metagabbro and leucotrondhjemite, metachert and associated metabasalt, and quartzitic schist and associated siliceous amphibole schist. He (1985, p. 13–14) correlated the coarse-grained meta-igneous rocks with the Yellow Aster Complex of Misch (1966).

Silverberg (1985, p. 29) correlated the schistose rocks with the Vedder Complex of Armstrong and others (1983) exposed on Vedder Mountain, British Columbia, about 105 km north of the Sauk River quadrangle. The Vedder has a late Paleozoic metamorphic age (Armstrong and others, 1983, p. 456–457). Muscovite and blue amphibole from three schistose rock samples from exposures south of the White Chuck River yielded K-Ar ages of about 267, 249, 238, and 214 Ma, (table 2, No. 93), confirming the correlation with the Vedder Complex. With reservations, Silverberg (1985, p. 54) correlated the metabasalt and metachert with the Elbow Lake Formation of Brown and others (1987).

Brown and others (1987) correlate metagabbro, metadiorite, silicic garnet-bearing gneiss, and tonalitic gneiss on Prairie Mountain with the Yellow Aster Complex. These rocks are locally highly cataclastic and locally gneissic, but commonly original igneous textures are well preserved. The steeply faulted contact of these rocks with the Chilliwack Group is well exposed on the south ridge of Prairie Mountain. Many of the meta-igneous rocks in the igneous complex at Prairie Mountain are very similar to rocks mapped as Paleozoic and Mesozoic metagabbro (MzPzg). Franklin (1974, p. 13–35) and Vance and others (1980, p. 363–364) further describe these rocks. Zircon from a hornblende tonalite in this igneous complex yields slightly discordant U-Th-Pb ages of about 370–400 Ma (Early Devonian) and hornblende has a K-Ar age of about 406 Ma (table 2, No. 94).

Slate of Rinker Ridge [4]

A belt of metaclastic rocks, characteristically less metamorphosed than the Darrington Phyllite that flanks it, extends northwestward from Prairie Mountain to north of the Skagit River (north of the Sauk River quadrangle). Previous workers (for instance, Brown and others, 1987; Tabor and others, 1988) correlated rocks of this belt with the Darrington Phyllite, but the slate of Rinker Ridge is consistently less metamorphosed and richer in metasandstone. The unit comprises slate and thin-bedded sandstone; locally, rhythmites are common. Rare outcrops of greenstone can generally be identified as dikes. Significant differences between the slate of Rinker Ridge and the Darrington Phyllite are listed in table 6.

Although overall most of the criteria listed in table 6 characterize the phyllite or slate, respectively, in some places along the margins of the mapped slate, and locally within it, the rocks match criteria of both lists. This uncertainty and the reconnaissance nature of our mapping have contributed to the linear contacts shown on the geologic map, but the overall distribution of the rock types suggests a linear belt, and locally we observed highly brecciated phyllite and slate along the west contact north of Finney Creek [3] suggesting that the slate is bounded by high-angle faults.

We have no age control on the slate of Rinker Ridge. Its lithology, degree of deformation, and structural setting make it a candidate for correlation with several units, specifically:

1. Darrington Phyllite. The slate of Rinker Ridge could be a lower grade correlative of the Darrington Phyllite. The abruptness of the contact between the two units in many places suggests that the slate of Rinker Ridge does not simply grade into the Darrington Phyllite but rather that the transitional zone between the two units has been cut out by post-metamorphism faulting.

2. Chilliwack Group of Cairnes (1944). The slate of Rinker Ridge is on strike with and not easily distinguished from rocks assigned to the Chilliwack Group (slaty argillite, foliated sandstone, minor metavolcanic rocks and limestone) cropping out south of Decline Creek [52]. This assemblage is typical of the Chilliwack Group, and the limestones contain Late Mississippian to earliest Pennsylvanian fossils (table 1, No. 35f). Although Decline Creek may well follow a fault separating the slate of Rinker Ridge from the Chilliwack rocks, the similarity of the clastic rocks and the degree of deformation in the Chilliwack and the Rinker Ridge units suggests that the slate of Rinker Ridge may be a clastic facies of the Chilliwack, albeit more pelitic than that found elsewhere in that unit. If so, it has been faulted up from a structural position underlying the Easton Metamorphic Suite.
3. Semischist of Mount Josephine. Another candidate postulated as a correlative of the slate of Rinker Ridge is the semischist of Mount Josephine, exposed in the Mount Baker quadrangle to the north (Tabor and others, in press). The age of the Mount Josephine unit is also unknown, but its rocks have been correlated with the Darrington Phyllite (Misch, 1966; Brown and others, 1987). The Mount Josephine unit commonly contains considerable metasandstone. The degree of metamorphism in the Mount Josephine unit commonly appears to be intermediate between those of the slate of Rinker Ridge and the Darrington Phyllite.

The most compelling arguments are those suggesting that the slate of Rinker Ridge is correlative with the Chilliwack Group, and tentatively we here assign it as part of that unit. We have no direct evidence for the metamorphic age of the slate of Rinker Ridge, but if it was metamorphosed with the rest of the Chilliwack Group, its metamorphic age is mid-Cretaceous.

Easton Metamorphic Suite

In an earlier paper (Tabor and others, 1993. p. 6), we revised the Easton Schist as the Easton Metamorphic Suite, and the Easton Metamorphic Suite as used here indicates the same rocks referred to as the Shuksan Metamorphic Suite of Misch (1966) and (or) the Shuksan Suite of Brown (1986) by many workers. The Shuksan Greenschist and Darrington Phyllite make up the Easton Metamorphic Suite.

Much has been written about the Shuksan Greenschist, beginning with the pioneering work of Misch (1959, 1966) and Vance (1957a, p. 12–60). Brown (1974), Morrison (1977), Haugerud (1980), Haugerud and others (1981), Street-Martin (1981), Brown and others (1982), and Dungan and others (1983) describe the Easton Metamorphic Suite in greater detail than we can here. Brown (1986) has written an excellent summary.

The Shuksan Greenschist is predominantly well recrystallized but fine-grained epidote-chlorite-quartz albite schist. Both the Shuksan Greenschist and Darrington Phyllite are characterized by well-developed blueschist mineralogy, including the high-pressure, low-temperature minerals crossite, lawsonite, and aragonite. Haugerud and others (1981, p. 380) and Brown (1986, p. 151) indicate that the Easton crystallized at T = 330° C to 400° C and at P = 7–9 Kb.

The lithology of the Darrington Phyllite is remarkably monotonous. Locally it contains rare metasandstone layers, but otherwise it is notable only for its quartz segregations and their complex ptigmatic folding. See the description of the slate of Rinker Ridge for more on the Darrington Phyllite. We have herein mapped a coarser grained, muscovite-rich variety as the so-called silver-colored phyllite because of its shiny dazzle in the sun. Some of the silver-colored phyllite is similar to muscovite-lawsonite-albite schist associated with rocks of the Gee Point-Iron Mountain area described below.

Chemistry and relict textures indicate that the Shuksan Greenschist was derived from ocean-floor basalt (MORB) (Dungan and others, 1983). Misch (1966, p. 109) thought that the protolith basalt of the Shuksan stratigraphically overlay the protolith sediments of the Darrington Phyllite, but Haugerud and others (1981, p. 377) and Brown (1986, p. 145) consider the Darrington to have stratigraphically overlain the Shuksan. On a small scale, the two units are interlayered, although the expected sequence on the ocean floor would be sediments over basalt; Morrison (1977, p. 66–67) and Dungan and others (1983, p. 132) suggest that thin ferruginous chert

Table 6. *Characteristics of Darrington Phyllite and slate of Rinker Ridge*

DARRINGTON PHYLLITE	SLATE OF RINKER RIDGE
1. Multiple deformation; commonly with highly crinkled foliation	1. Mostly poorly developed slaty cleavage; commonly pencil slate; some fine crenulations on foliation
2. Many quartz segregations: lenses and veins	2. Some quartz, but generally in coarser veins
3. Clearly recrystallized with new sericite (muscovite) as viewed under the hand-lens	3. Little recrystallization viewed in hand specimens. Black and dull on most fresh surfaces
4. Very little metasandstone in most outcrops	4. Greater than 10 percent sandstone in most outcrops
5. Bedding not generally recognizable; no other sedimentary structures	5. Bedding prominent and commonly at angle to slaty cleavage. Some graded bedding

beds between greenschist and phyllite represent submarine hot-spring deposits on freshly erupted ocean-floor basalt. Misch (1966, p. 109–112), Brown (1974), Haugerud and others (1981), and Dungan and others (1983) have discussed the petrology of the Easton Metamorphic Suite.

Armstrong (1980) and Brown and others (1982, p. 1095) proposed that the protolith age of the Easton rocks is Jurassic, possibly Late Jurassic, although more recently a $^{206}Pb/^{238}U$ zircon age of 163 Ma from a metadiorite body enclosed within rocks correlated with the Easton Metamorphic Suite indicates a Middle Jurassic protolith age (Brown, 1986, p. 146; Gallagher and others, 1988, p. 1420). The Easton was metamorphosed at about 130 Ma (Brown and others, 1982). A discordant U-Th-Pb age of zircon from blueschist considered to be correlative with the Shuksan Greenschist, 26 km south of the Sauk River quadrangle, suggests Precambrian detrital zircon (Tabor and others, 1993, p. 13).

In the Gee Point-Iron Mountain area [1, 2], epidote amphibolite, Na-amphibole schist, quartz-muscovite schist, hornblende-garnet rocks, and rare eclogite crop out in the Shuksan Greenschist. Most of these schists are considerably coarser grained than schist typical of the Shuksan. The coarser grained rocks are especially abundant as blocks in the serpentinite matrix of the Helena-Haystack mélange near Iron Mountain, but they also occur as scarce isolated masses along with rare serpentinite in the Shuksan exposed to the northeast. Many of the hornblende-bearing, coarser grained rocks have an overprint of blueschist metamorphism (Brown and others, 1982). Minerals from the coarser grained rocks yield K-Ar and Rb-Sr ages of 144–160 Ma, older than the 130-Ma age accepted for the metamorphism of the Easton Metamorphic Suite. Brown and others (1982) suggest that amphibolite and barroisite schists were thermally metamorphosed when the original protolith basalt and oceanic sediments were overthrust by hot mantle rocks in a subduction zone prior to the blueschist metamorphism which recrystallized the Easton in general. The ultramafic rocks of this Jurassic event were subsequently incorporated into the serpentinite matrix of the Helena-Haystack mélange.

Gabbroic intrusions

Medium-grained metagabbro and (or) metadiabase occur in large and small irregular bodies enclosed within rocks of the Chilliwack Group and as unmapped dikes intrusive into the Easton Metamorphic Suite and slate of Rinker Ridge. The bodies enclosed within the Chilliwack have been included as part of the Yellow Aster Complex of Misch (1966) by earlier workers, but in this report, we have mapped metadiabase and metagabbro that are not clearly associated with Yellow Aster-type gneiss or are strongly mylonitic or blastomylonitic as Paleozoic and Mesozoic gabbroic intrusions. We have not found intrusive contacts between these mafic igneous rocks and the Chilliwack rocks, although metadiabase appears to intrude Yellow Aster tonalite northeast of Rinker Ridge. Sevigny (1983, p.19, 36–38) and Sevigny and Brown (1989) describe mafic igneous intrusions cutting Yellow Aster gneiss in the type area of the complex, about 55 km north of the Sauk River quadrangle. Based on chemical data, Sevigny and Brown (1989) showed that mafic igneous rocks intruding gneissic (byag) rocks of the Yellow Aster Complex of Misch (1966) differ from basalt of the Chilliwack Group. We do not have chemical data for gabbroic intrusions in the Sauk River quadrangle. Much of the rock shown on the map as non-gneissic rocks (byan) of the Yellow Aster Complex, such as metagabbro and metadiorite on Prairie Mountain, could be younger intrusive material. Jenne (1978, p. 54–58) describes metagabbro and metadiabase in the vicinity of Prairie Mountain.

BEDROCK WEST OF THE STRAIGHT CREEK FAULT, IN THE DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Helena-Haystack mélange

The Helena-Haystack mélange is best exposed on Helena Ridge [19], an area first described by Vance (1957a, p. 193–198) and later by Vance and others (1980, p. 364–365). On Helena Ridge, blocks of various lithologies including gabbro, graywacke, chert, and greenstone of the eastern mélange belt, the Darrington Phyllite, schistose metavolcanic rocks, fine-grained schistose amphibolite, and biotite-hornblende tonalite are embedded in serpentinite matrix. Northwest of Helena Ridge, much of Jumbo Mountain [17] is metagabbro, but on the mountain, slivers of peridotite have been faulted into feldspathic sandstone of the middle and late Eocene Barlow Pass Volcanics of Vance (1957a, b) suggesting that the Jumbo Mountain rocks are a huge block in the serpentinite-matrix mélange. Most clasts are of rocks exposed to either side of the mélange in the Northwest Cascades System or the western and eastern mélange belts, but others are exotic as described below.

The Helena Ridge area is separated from the Deer Creek exposures by the wide valley of the North Fork of the Stillaguamish River, and the continuity of the mélange is further obscured by overlying sandstone and volcanic rocks of the Barlow Pass Volcanics.

In the vicinity of Deer Creek, the easily eroded serpentinite matrix is poorly exposed, but ridges are studded with steep-walled hillocks of greenstone, metagabbro, and metadiabase; more rarely, the Darrington Phyllite and schistose metavolcanic rocks crop out. West of the Sauk River quadrangle, the mélange is continuous with the Haystack terrane or thrust plate of Whetten and others (1980b). Immediately west of Deer Creek, the serpentinite matrix is clearly present, but farther to the west serpentinite has not been widely mapped (Whetten and others, 1979, 1980a,b, 1988; Dethier and Whetten, 1980; Dethier and others, 1980) as it tends to be poorly exposed, but its abundance has been demonstrated in bore holes (Bechtel Inc., 1979).

About 70 km southeast of Helena Ridge, the Helena-Haystack mélange is exposed in the Manastash Ridge area, separated from the Helena Ridge outcrops by right-lateral faulting on the Darrington-Devils Mountain Fault Zone and (or) the Straight Creek Fault. Much of the intervening area is intruded by Tertiary plutons (see Vance, 1985; Tabor and others, 1989, p. 10–14; Tabor and others, 1993; Tabor, 1994).

Metaserpentinite in "dikes" (dike-like outcrops) on Jumbo Mountain northwest of Helena Ridge appears to have had a unique, albeit somewhat controversial, history. The "dikes" are ultramafic fault slivers emplaced into Eocene sandstone of the Barlow Pass Volcanics. Miers (1970) and Vance and Dungan (1977) describe deserpentinization during a pre-Eocene or early Eocene event, prior to tectonic emplacement of the ultramafic rocks as "dikes". Healed mylonitic foliation in the ultramafic slivers is parallel to the long axes of the slivers and preferred orientation directions of a- and c-crystallographic axes of olivine lie in the foliation (Miers, 1970). Locally the sandstone also is well-recrystallized cataclasite and (or) mylonite. Both the ultramafic rocks and the surrounding sandstone are hornfelsic.

The clear parallelism of the healed foliation to the tectonic margins of the bodies in the Eocene sandstone suggests strongly that deserpentinization occurred after the bodies were emplaced as slivers. The ultramafic material appears to have been faulted into the Tertiary sandstone as serpentinite, then dehydrated by thermal metamorphism associated with the nearby Oligocene (35 Ma) Squire Creek stock. However, the occurrence of these same high-temperature peridotite tectonites outside the immediate thermal aureole (such as on the south end of the Devils Thumb [20]) led Miers (1970) and Vance and Dungan (1977) to not consider the Squire Creek stock responsible for the recrystallization in the dikes. Clearly the existence of a pre-middle Eocene metamorphic event in the ultramafic matrix of the Helena-Haystack mélange would greatly alter the history of formation of the mélange as presented by Tabor (1994) and summarized here below. More detailed mapping of the thermal aureole around the Squire Creek stock is needed.

Although most blocks in the mélange can be identified as pieces of surrounding terranes, including a block of black chert just east of lower Deer Creek that contains Mesozoic, possibly Triassic, radiolarians (table 1, No. 31f), some blocks are of unusual lithologies. Schistose metavolcanic rocks in the mélange range in composition from mostly dacite or rhyolite to basalt. Most rocks are phyllitic metaporphyries composed of subhedral to rounded plagioclase and quartz phenoclasts in an anastomosing matrix of chlorite, epidote, sericite, quartz, and plagioclase. Some are fine-grained mica schist with relict porphyroclasts of plagioclase. In outcrops, most of the schistose metavolcanic rocks are distinguished from other components of the mélange by their light-green color, well-developed foliation, and phyllitic aspect.

Very large masses of crudely bedded greenstone, metadiabase, local silicic metavolcanic rocks, and rare metasedimentary rocks make up Big and Little Deer Peaks [5], near Deer Creek. Some workers (Misch, 1966; Bechtel Inc., 1979) have included these rocks in the Chilliwack Group, but they differ from it in metamorphic grade (Reller, 1986, p. 31) and mostly lack other Chilliwack lithologies, such as marble. A Middle Jurassic age (168 Ma) of zircon (Brown and others, 1987, p. 3) from metadacite indicates that the Big and Little Deer Peaks rocks are too young to be the Chilliwack. Based on chemical data obtained by Reller (1986, p. 34–49), Brown and others (1987) considered the Big and Little Deer Peaks rocks to be a Northwest Cascades System thrust plate of unknown affinity emplaced on rocks of the Easton Metamorphic Suite.

On Helena Ridge, a mica schist (metarhyolite) is Late Cretaceous, a metamorphic age based on an 89.7-Ma K-Ar analysis of muscovite (table 2, No. 87). This age is confirmed by a two-point (whole rock and muscovite) Rb-Sr-isochron age of 93±7 Ma (R.L. Armstrong, written commun., 1982, to J.A. Vance). Considering the overall grade of the schistose metavolcanic blocks in the mélange and the lack of metamorphism of this degree in the adjacent matrix, the mica schist must have been metamorphosed before its incorporation into the mélange; the mid-Cretaceous age is therefore a maximum for mélange formation.

The schistose metavolcanic rocks of dacitic to rhyolitic composition in the mélange are distinct from most nearby rocks in the Northwest Cascades System and western and eastern mélange belts, although schistose metadacite porphyry dikes crop out in the eastern mélange belt southwest of Darrington and in the western mélange belt elsewhere (see for instance, Miller, 1989, p. 1302). The Middle Jurassic Wells Creek Volcanics of Misch (1966) are of the right age and composition but are less deformed than the schistose metavolcanic rocks, and the nearest exposure is 24 km to the north in the Baker Lake area (north of the Sauk River quadrangle; Tabor and others, in press). In northwestern Washington about 60 km northwest of Helena Ridge, schistose rhyolitic to dacitic metavolcanic rocks appear to be associated with rocks correlated with the Easton Metamorphic Suite. Gallagher and others (1988) suggest that these rocks are remnants of a volcanic arc associated with the protolithic oceanic basalt of the Easton. If the schistose metavolcanic rocks in the mélange are fragments of the Easton Metamorphic Suite, the timing of their metamorphism is enigmatic because the Easton was metamorphosed in the Early Cretaceous.

A large block of hornblende tonalite and fine-grained amphibolite, about 2.5 km long, on Helena Ridge is another component exotic to the surrounding units in the Helena Ridge area. On Helena Ridge, the hornblende tonalite is medium grained and massive to weakly gneissic with hypidiomorphic texture. Poor exposures on Helena Ridge reveal that the fine-grained amphibolite is interlayered with gneissic tonalite. The contact is sharp, but there is little other evidence of intrusion. Concordant U-Pb ages of zircon from the tonalite (table 2, No. 85) are about 150 Ma, and a conventional K-Ar age analysis of hornblende from the amphibolite is 141 Ma (table 2, No. 86), which is probably a minimum age.

Most of the ultramafic rocks of the Helena-Haystack mélange may correlate with the ophiolitic Fidalgo Complex of Brown and others (1979), as earlier suggested by Whetten and others (1980b) and more recently discussed by Tabor (1994, p. 228).

Vance (1985) and Vance and Miller (1992) correlated the rocks of the Helena-Haystack mélange with similar rocks in the Manastash Ridge area, about 70 km to the southeast, and suggested that the rocks had been offset dextrally about 80 km across the Straight Creek Fault. Tabor (1994) agreed with this correlation, but argued as well that the tonalite and amphibolite block on Helena Ridge could have been offset along faults in the Darrington-Devils Mountain Fault Zone from similar rocks on the east side of the Darrington-Devils Mountain Fault Zone in the Manastash Ridge area. He suggested that the Helena-Haystack mélange formed at the sole thrust when the western and eastern mélange belts were emplaced across the Northwest Cascades System and probably across the Straight Creek Fault between 90 Ma and about 40 Ma. See Tabor (1994) for further discussion of correlations and origin of the mélange.

BEDROCK WEST OF THE STRAIGHT CREEK FAULT, SOUTHWEST OF THE DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Western and eastern mélange belts and Trafton mélange

Southwest of the Northwest Cascades System, the western and eastern mélange belts of marine rocks are characterized by extreme disruption on an outcrop scale and low-P and low-T metamorphic mineral assemblages. The western mélange belt is mostly clastic, characterized by commonly well bedded volcanic subquartzose sandstone; mafic volcanic rocks and chert, although locally abundant, are minor overall. A regional antiform (cross sections A–A' and B–B') exposes a pelitic facies, characterized by pervasive phyllitic cleavage. The eastern mélange belt is locally less penetratively deformed and is characterized by mafic volcanic rocks, chert, and ultramafic rocks. In both belts, the matrix is generally scaly argillite or phyllite. The eastern mélange belt and a probable correlative mélange, the highly mixed Trafton terrane of Whetten and others (1988), appear to be structurally high and exposed over the pelitic facies of the regional antiform. We consider the eastern mélange belt and Trafton terrane to be in fault contact with the underlying western mélange belt, although the disruption between the two units along this inferred fault is no more severe than that within the mélanges themselves (Tabor and Booth, 1985). The mélange belts south of the Sauk River quadrangle and historic views of their correlations have been described by Frizzell and others (1987), Tabor and others (1993, p. 7–10), and Tabor (1994).

The western and eastern mélange belts contain considerable pumpellyite locally; prehnite is common. Some thin-sections of samples contain clear untwinned carbonate which might be aragonite. Tabor and others (1988) noted questionable very fine grained lawsonite in these rocks, but more thorough examination indicates that lawsonite is not present (M.T. Brandon in Tabor, 1994). These rocks have not reached the high pressures evident in units of the Northwest Cascades System.

The western mélange belt is predominantly thin bedded to medium bedded, lithofeldspathic to volcanolithic, subquartzose, foliated sandstone and semischist, locally with abundant phyllite. The unit contains minor chert, metagabbro, and diabase and very rare limestone (or marble) and ultramafic rocks. South of the Sauk River quadrangle, the western mélange belt includes some meta-mafic volcanic rocks (Tabor and others, 1993). We mapped the contact between the heterogeneous Trafton terrane and the eastern mélange belt where metavolcanic rocks, chert, and ultramafic rocks become the dominant lithologies. Although many sandstones of the western mélange belt exposed south of the quadrangle contain up to 20 percent K-feldspar (Jett and Heller, 1988; Tabor and others, 1993, p. 8), none of our samples from the western mélange belt of this quadrangle contain significant K-feldspar.

Three outcrops of metagabbro near Granite Falls resemble the more abundant metagabbro in the western mélange belt south of the quadrangle where U-Th-Pb ages of zircon from associated metatonalite of about 150-160 Ma indicate a Late Jurassic crystallization age (Frizzell and others, 1987, p. 139–140; Tabor and others, 1993, p. 9, table 2).

Ultramafic rocks are rare throughout the western mélange belt as a whole, but three pods in the Sauk River quadrangle are aligned along the northwest structural grain in the Granite Falls area.

Sparse fossils in the western mélange belt, including radiolarians in chert and megafossils in argillite, indicate that, with the exception of limestone, most of its components and its matrix are Mesozoic (Late Jurassic to earliest Cretaceous) in age (table 1, Nos. 1f–5f, 8f, 9f; Frizzell and others, 1987, p. 135). The limestone blocks are Permian in age, and a few chert blocks are Early Jurassic (table1, Nos. 10f, 11f). The linearity of limestone outcrops east of Granite Falls, also parallel to the regional structural grain, suggest that the limestone originally had stratigraphic continuity prior to strong deformation. Because the limestone ages are older than the host clastic rocks, we assume that the limestones were emplaced as olistostromes, perhaps along one stratigraphic horizon.

The regional development of penetrative foliation, especially in the phyllitic rocks of the western mélange belt, suggests that tectonism was important in mélange formation, but in exposures along the Stillaguamish River east of Granite Falls the mélange is composed of lenticular and locally necked blocks of sandstone, greenstone, limestone, and rare metatonalite in a massive argillite matrix resembling Cowan's type II mélange evolved from submarine landslides (Cowan, 1985, p. 454–456). From studies south of the Sauk River quadrangle, Jett (1986, p. 39–52) and Jett and Heller (1988) concluded that the unit formed in an accretionary wedge.

The Trafton terrane is characterized by a complex mixture of mafic metavolcanic rocks, chert, limestone, metagabbro, and metatonalite. Rocks originally called the Trafton sequence by Danner (1966, p. 363) have been mapped just west of the Sauk River quadrangle and were referred to as the 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 interlayered in rocks continuous with the Trafton terrane yield radiolarian ages mostly ranging from Triassic to Jurassic (table 1, Nos. 13f–16f, 20f, 21f), but one age may be Paleozoic (17f). Highly fossiliferous bioclastic limestone at the abandoned Morcrop quarry on the north side of Porter Creek [15] yields Permian fusulinids (table 1, No. 19f). Permian faunas in the limestones of the Trafton terrane and the western mélange belt have long been recognized as Tethyan and thus exotic to North America (Danner, 1966, 1977). This fauna contrasts with the Paleozoic fauna in the Chilliwack Group of Cairnes (1944) of the Northwest Cascades System. Metatonalite blocks are at least as old as Pennsylvanian (320 Ma) (table 2, No. 92).

The eastern mélange belt displays many of the same lithologies and the same degree of disruption as the western mélange belt, but it is predominantly greenstone and chert and contains numerous pods of ultramafic rocks and gabbro. The eastern mélange belt differs little from the Trafton terrane. Although disruption is common on an outcrop scale, in the Whitehorse Mountain area, the eastern mélange belt consists of three units that appear to be more or less stratigraphically intact. The youngest (1) is a Middle to Late Jurassic argillite unit (table 1, No. 30f) which overlies (2) the Late Triassic volcanic rocks of Whitehorse Mountain. Locally, a volcanic-clast conglomerate crops out in the argillite unit at the contact with the volcanic rocks. The volcanic rocks, in turn, appear to overlie (3) a Late Triassic chert-rich unit, although we have not found undisrupted contacts with top indicators. An ultramafic pod enclosed within the volcanic rocks of Whitehorse Mountain suggests that the unit may be more disrupted than it appears, at least near the contacts.

A zone rich in pods of highly deformed metatonalite and metagabbro trends from Mount Bullon northwestward to the northwest ridge of Whitehorse Mountain. The overall disruption of rocks in this zone does not seem greater than elsewhere in the eastern mélange belt, but the alignment of the tectonized igneous bodies suggests a significant fault.

The volcanic rocks of Whitehorse Mountain are mostly flows of vesicular, plagioclase-phyric, pyroxene andesite and basaltic andesite without pillows. For further descriptions, see Vance (1957a, p. 218) and Vance and others (1980, p. 367). Ort and Tabor (1985) report major element chemical analyses, and Vance and others (1980, p. 377) give some trace element data.

Thin, local, sedimentary interbeds are present including a belt of limestone lenses on the northwest ridge of Whitehorse Mountain. Danner (1966, p. 326–329) reports non-diagnostic crinoid and coral remains in float specimens. A small limestone pod enclosed within the volcanic rocks contains Late Triassic conodonts (table 1, No. 29f). Radiolarians from the chert-rich unit adjoining the volcanic rocks of Whitehorse Mountain on the southwest are Late Triassic and possibly Jurassic in age (table 1, Nos. 25f–28f).

Deformed and (or) recrystallized radiolarians from chert in the main body of the eastern mélange belt are Jurassic in age (table 1, No. 23f). A small unmapped block of well-recrystallized fine-grained schistose amphibolite on Wiley Ridge [27] yields a K-Ar hornblende age of about 121.4±4.2 Ma (table 2, No. 90), probably a minimum age for metamorphism of this block. Zircon from a metatonalite block in the French Creek Shear Zone on the west side of Whitehorse Ridge yielded a fission-track age of about 127 Ma (table 2, No. 91).

On the South Fork of the Stillaguamish River, gabbro, layered gabbro, and interlayered cumulate ultramafic rocks (wehrlite) have been described by Dungan (1974). The 10-km-long gabbro body (TKeg) on Jumbo Mountain, within the Helena-Haystack mélange south of Darrington, is medium grained and massive, but laced with swarms of diabase dikes (Vance and others, 1980, p. 365).

Ultramafic rocks, including serpentinite, metaperidotite, and metaclinopyroxenite, are characteristically scattered throughout the eastern mélange belt. 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 (1974) 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 (TKeg) to be part of a metamorphosed and dismembered ophiolite complex imbricated in the oceanic and volcanic rocks of the eastern mélange belt along Tertiary high-angle faults. We consider this imbrication within the mélange to be mostly due to mélange mixing, probably a combination of olistostromal and tectonic processes, but additional displacement by high-angle faulting is also likely.

Bald Mountain pluton

Biotite granodiorite exposed on the south margin of the Sauk River quadrangle on Bald Mountain [32] is medium grained to coarse grained and bears trace amounts of cordierite, garnet, and rare andalusite. The pluton is clearly an S-type or peraluminous granitoid (Campbell, 1991, p. 93–94) and is of unusual composition for northwest Washington. Minerals are conspicuously altered in the granodiorite, and locally biotite has recrystallized in directionless aggregates suggesting thermal metamorphism. The pluton itself has a pronounced thermal aureole, producing cordierite hornfels in adjacent argillite.

The pluton forms elongate masses parallel to the regional structure and sills of granodiorite make a lit-par-lit complex southeast of the Mount Pilchuck stock. A discontinuous selvage of ultramafic rocks crops out along the northeast margin of the easternmost body. Dungan (1974, p. 41–42) described this selvage and inclusions in the pluton as high-grade peridotite hornfels, predominantly olivine and minor enstatite. Within the selvage, a tectonically(?) layered fabric is recrystallized as olivine replaced by enstatite and both replaced by felty tremolite and talc. The earlier fabric parallels the strong mylonitic fabric in the margin of the pluton, but a similar fabric is rotated in large inclusions within the pluton.

Dungan (1974, p. 32–33) and Tabor and others (1982a, 1993) interpreted the northeast margin of the pluton as a fault, but the foliation in the ultramafic rocks appears to be relict after structures formed prior to intrusion of the Bald Mountain pluton. The pluton may well have intruded along a preexisting fault in the western mélange belt. The pluton is faulted and strongly cataclastic on the south side along the major northwest-trending Pilchuck River Fault. Southeast of Pilchuck Mountain, shattered coarse-grained granitoid rocks, which we presume to be the Bald Mountain pluton, are strongly recrystallized by the Mount Pilchuck stock.

Dungan (1974, p. 31–34) correlated the Bald Mountain pluton with the nearby 49-Ma Mount Pilchuck stock (see description below), which overall is compositionally similar (Campbell, 1991, p. 59–66). Like the Bald Mountain pluton, the Mount Pilchuck stock also contains cordierite (Wiebe, 1963, p. 20). However, the stock is circular in shape, strongly discordant, fine grained, and nonfoliate. U-Th-Pb ages obtained from zircons from the Bald Mountain pluton suggest that they crystallized or recrystallized at about 55–50 Ma, but the much older $^{207}Pb/^{206}Pb$ ages of about 120 Ma either indicate a Pb component that reflects xenocrystic zircons picked up in the magma, presumably from the surrounding Mesozoic rocks, or indicate that the pluton is in fact much older and has been recrystallized by the intrusion of the Mount Pilchuck stock (Tabor and others, 1993, p. 11). Although the similarity in composition argues that the Mount Pilchuck stock and Bald Mountain pluton are comagmatic and the same age, the field relations contrast in their textures, contacts, and shapes, which indicate that the pluton is older than the stock. For further discussion, see Haugerud and others (1994, p. 2E19–20).

The Bald Mountain pluton is clearly truncated by the northwest-trending Pilchuck River Fault. We think that the probably younger Mount Pilchuck stock cuts at least one strand of this fault, although Wiebe (1963, plate 1) shows the fault cutting the stock.

Of particular interest is where the magma for these peraluminous or S-type plutons was generated, because the composition suggests a component of old continental material in the original melt(s). This shared underlying basement may account for the similarity in composition of the Mount Pilchuck stock and the Bald Mountain pluton even if they are of different ages. Although no Rb-Sr isotope data are available for the Bald Mountain pluton, the high $^{87}Sr/^{86}Sr$ initial ratio of 0.7067±0.0010 for the Mount Pilchuck stock (R.L. Armstrong, written commun., 1989; Campbell, 1991, p. 66) supports the existence of an old continental basement. The nearest possible Precambrian terrane with a $^{87}Sr/^{86}Sr$ ratio that is greater than 0.704 is the Swakane terrane, exposed 56 km to the northeast (Armstrong and others, 1977, fig. 10; Robert Fleck, written commun., 1989). Numerous Tertiary tonalite plutons physically between the Swakane terrane and the Mount Pilchuck and Bald Mountain bodies have initial $^{87}Sr/^{86}Sr$ ratios less than 0.706 (Robert Fleck, written commun., 1989) suggesting that the underlying basement in the Bald Mountain area is an isolated terrane sliver.

QUATERNARY AND TERTIARY ROCKS

Sandstone associated with the Straight Creek Fault

Small patches of feldspathic subquartzose sandstone and pebble conglomerate crop out between strands of the Straight Creek Fault or presumed faults nearby. These rocks are similar to Eocene feldspathic sandstones elsewhere in, and peripheral to, the Straight Creek Fault Zone. Observed bedding dips moderately, and the northernmost occurrence in the Sauk River quadrangle appears to be synclinal; the bounding faults are inferred from the outcrop pattern.

The age of these deposits is not certain, but about 60 km to the south, feldspathic sandstone units east of the Straight Creek Fault are the early and middle Eocene Swauk Formation and the middle and late Eocene Roslyn Formation (Tabor and others, 1984; Tabor and others, 2000). Sandstone and conglomerate also occur in isolated patches along the Straight Creek Fault extending into Canada, where a conglomerate in the Fraser River Fault Zone near Hope, British Columbia, has been dated as early Eocene on the basis of pollen (Glenn Rouse to Ralph Haugerud, written commun., 1989). The sandstone and conglomerate in the Sauk River quadrangle appear to have been deposited on rocks of the Northwest Cascades System; hence they are on the predominantly downthrown side of the Straight Creek Fault. Fission-track ages of about 45 Ma, from meta-quartz diorite clasts of the Triassic Marblemount pluton in conglomerate along the Straight Creek Fault north of the quadrangle (Tabor and others, in press), indicate that some of the faulted slivers of sandstone are late middle Eocene or younger in age, assuming that the zircon ages were reset prior to incorporation of the clasts in the conglomerate.

Feldspathic sandstone and conglomerate

On the south side of Bald Mountain, well-indurated fluviatile feldspathic sandstone and conglomerate with shaley beds and locally with leaf fossils are preserved in a down-faulted block along the south side of the Pilchuck River Fault. Clasts as large as boulder size are mostly feldspathic subquartzose sandstone and greenstone, apparently derived from the underlying western mélange belt. Danner (1957, p. 489–490) describes questionable evidence of a conglomerate interbed in the rhyolite of Hanson Lake [30] (see below), but neither he, nor Wiebe (1963, p. 14), nor we found clasts of the rhyolite or of the nearby and distinctive granodiorite of the Mount Pilchuck stock or Bald Mountain pluton in the conglomerate. For this reason, Danner's conglomerate notwithstanding, we assume that the sandstone and conglomerate are at least slightly older than the early middle Eocene rhyolite of Hanson Lake and probably were deposited at a much higher structural level than the Mount Pilchuck stock of the same age and the questionably older Bald Mountain pluton. Neither the sandstone and conglomerate nor the underlying mélange south of the Pilchuck River Fault show thermal metamorphism common in rocks surrounding the Mount Pilchuck stock and Bald Mountain pluton northeast of the fault (Wiebe, 1963, p. 41). They may correlate with the oldest part of the early and middle Eocene Swauk Formation (about 50 Ma), exposed about 55 km to the southeast, or with the lowest part of the Chuckanut Formation exposed about 45 km to the northwest.

Rhyolite of Hanson Lake

Danner (1957, p. 484–492) included rhyolite cropping out north of the Pilchuck River in what he referred to as the Hanson Mountain Group. He and Wiebe (1963, p. 16–19) describe these unusual garnet-bearing rhyolite flows and tuffs. Campbell (1991, p. 114–116) gives major and trace element data. Wiebe (1963, p. 36–39; 1968, p. 691) thought that the rhyolite was genetically related to the Mount Pilchuck stock based on the petrologic similarity and especially on the garnets common in both the intrusive and extrusive rocks.

We consider the rhyolite of Hanson Lake to be younger than nearby sandstone and conglomerate based on evidence described above. Biotite separated from the rhyolite yields a K-Ar age of about 53 Ma, and sanidine gives a minimum age of about 46 Ma. A suspect fission-track age of zircon is about 38 Ma (table 2, Nos. 35, 36). This discordant array of ages is not promising, but combined with the evidence that the Mount Pilchuck stock may represent the same magma that erupted as the rhyolite of Hanson Lake, the age may be about 49 Ma (see below).

We tentatively include as part of the rhyolite of Hanson Lake poorly exposed, highly altered, mafic to silicic volcanic rocks north of Bosworth Lake [29] and silicic tuff along the Pilchuck River west of Granite Falls. Danner (1957, p. 483–484) described the latter rocks as his Pilchuck Bend Formation and correlated them with the Snohomish andesite unit of McKnight and Ward (1925), exposed about 30 km to the south, which we now include in the presumed middle Eocene volcanic rocks of Mount Persis (Tabor and others, 1993, p. 19).

Mount Pilchuck stock

Biotite granite of the Mount Pilchuck stock holds up bold crags of Pilchuck Mountain at the east margin of the Puget Lowland. The stock is strongly discordant, permeated the host rocks with dikes, and developed a thermal aureole up to 1–2 km wide. The stock carries accessory cordierite and rare garnet (Wiebe, 1963, p. 24–31), and the occurrence of these minerals and the stock's composition led Dungan (1974, p. 31–34) to correlate the stock with the granitic Bald Mountain pluton. We discussed the merits of this correlation in the previous description of the Bald Mountain pluton.

Wiebe (1963, plate 1) shows the northern trace of the Pilchuck River Fault cutting the stock, a relation that we could not verify. He also mapped what he termed "older granites" on the south side of the stock which might be granodiorite of the Bald Mountain pluton, but which we could not find in our reconnaissance. Concordant K-Ar ages of biotite and muscovite are 49 Ma; a fission-track age on zircon is about 45 Ma (table 2, Nos. 33, 34). A three-point strontium isochron with an initial $^{87}Sr/^{86}Sr$ value of 0.7067±0.0010 indicates a crystallization age of 44.3±8 Ma (R.L. Armstrong, written commun., 1989; Campbell, 1991, p. 66); we discuss the significance of this high initial value and the unusual S-type composition in the section on the Bald Mountain pluton.

Granite Falls stock and associated plutons

Like the town of Granite Falls, the Granite Falls stock is named for the nearby falls on the South Fork of the Stillaguamish River. The fine-grained biotite-hornblende granodiorite lacks peraluminous indicator minerals like the nearby Mount Pilchuck stock and Bald Mountain pluton and is chemically metaluminous (Campbell, 1991, p. 59–66). The stock yields a minimum K-Ar age of about 44 Ma (table 2, No. 23)from hornblende, which suggests that it is related to the Mount Pilchuck igneous episode. Thermal metamorphism is notable around the stock at distances of 2 km or more from the exposed contact, suggesting a low-dipping contact or a swarm of such bodies in the area. The stock contains a distinctive blue-green tourmaline (elbaite), which is also present in the Mount Pilchuck stock and is prevalent in the thermal aureole, particularly notable in hornfelsed mafic tuffs and graywacke at the large quarry at Iron Mountain near Granite Falls.

Barlow Pass Volcanics of Vance (1957a, b)

Spurr (1901, p. 791–796) called volcanic rocks exposed just south of the Sauk River quadrangle, in the Monte Cristo area, the “earlier andesites”. These rocks have been mapped continuously to the north where Vance (1957a, p. 275–287; 1957b) described them as the Barlow Pass Volcanics. Although in its type area the unit is predominantly volcanic rocks ranging from basalt to rhyolite in composition, feldspathic sandstone interbeds are common and are the dominant lithology in some areas. The unit takes its name from Barlow Pass, where basalts and andesites are part of a nearby well-exposed section on Dickerman Mountain [23]. Vance (1957a) described the type area of the Barlow Pass where he estimated a minimum thickness of 1,200 m for the unit. Presumably the unit rests unconformably on a variety of older rocks but principally on the highly deformed and metamorphosed Helena-Haystack mélange and locally on rocks of the Northwest Cascades System and the western and eastern mélange belts. In the Monte Cristo area, the Barlow Pass Volcanics unit is overlain unconformably by the Miocene breccia of Kyes Peak (Tabor and others, 1982a, b; 1993, p. 22). Most observed contacts of the Barlow Pass Volcanics in the Sauk River quadrangle are faults.

Vance (1957a, p. 232) and Ristow (1992, p. 3; Evans and Ristow, 1994) considered steeply dipping sandstone beds in the western part of the Barlow Pass outcrop belt to be the early and middle Eocene Swauk Formation (or the correlative Chuckanut Formation). Vance (1957a) described a faulted contact between these undated beds and the gently dipping Barlow Pass Volcanics to the east but felt that the difference in degree of deformation was strong circumstantial evidence for an unconformity. Minor mafic and rhyolitic volcanic beds in the sandstone fault sliver east of Devils Thumb [20] suggest that these steeply dipping rocks are also the Barlow Pass unit and that their contrast in deformation is related to faulting along the Darrington-Devils Mountain Fault Zone. A similar contrast in deformation between well-correlated beds can be seen some 90 km southward along this same belt between the gently folded middle and late Eocene Roslyn Formation in the Teanaway block of Tabor and others (1984) and the highly folded middle Eocene to early Oligocene(?) Naches Formation in the westward-situated Manastash block. Clearly the difference in deformation may be a function of proximity to active structures and (or) a difference in mechanical properties and may not indicate a difference in age.

The volcanic rocks form characteristic massive cliffs. Locally minor sandstone, conglomerate, and argillite form interbeds. Distinctive conglomerate, consisting of clasts derived from the Darrington Phyllite, crops out as interbeds low in the section in the Mount Forgotten area [22] of the volcanic belt. Our field impression of the composition of the volcanic rocks is that of a bimodal suite, a preponderance of rhyolite and basalt and basaltic andesite with subordinate andesites and dacites. Available chemical data suggests that most of the silicic rocks are dacite with subordinate rhyolite (Ort and others, 1983; Videgar, 1975, p. 18–28). Basalt in the upper part of the section in the Dickerman Mountain area forms dark-brown, cliff-forming, columnar flows, tens of meters thick. Mafic volcanic rocks are locally highly altered.

In the type area of the Barlow Pass Volcanics of Vance (1957a, b), rhyolite flows and minor rhyolite ash-flow tuff are chemically high-silica rhyolites (Ort and others, 1983). Silicic ash-flow tuffs are the dominant volcanic rocks in the unit northwest of Darrington. Further descriptions are in Vance (1957a, p. 275–286) and Heath (1971, p. 116–118).

The sandstone is mostly feldspathic subquartzose sandstone and pebble conglomerate with interbeds of argillite and siltstone, rarer tuffaceous sandstone, and tuff. Evans and Ristow (1994) describe the lithology and sedimentology of these rocks in great detail. South of Barlow Pass, volcanic interbeds are rare and correlation of these sandstones with the Barlow Pass Volcanics is uncertain (see Tabor and others, 1993, p. 19). Conglomerate clasts in the Barlow Pass Volcanics within the Darrington-Devils Mountain Fault Zone south of Darrington are highly stretched subhorizontally and parallel to the north-south faults of the Darrington-Devils Mountain Fault Zone (Tabor, 1994).

A number of fission-track ages obtained from zircons from rhyolite tuff in the Barlow Pass Volcanics range from about 35 to 46 Ma (table 2, Nos. 24– 29). Four fission-track ages in the range of 44-46 Ma are late middle Eocene. A 40±5-Ma dacite dike on Mount Forgotten [22] (table 2, No. 30) intrudes the Barlow Pass Volcanics near the top of their presently exposed strata, suggesting that the unit is no younger than latest Eocene. A 35-Ma age (table 2, No. 26) from the Dickerman Mountain area was probably reset by the nearby Shake Creek stock, a probable outlier of the Squire Creek stock; many of the rocks in this area are incipiently statically metamorphosed. A second 35-Ma age (table 2, No. 29) from upper Deer Creek is less easily explained, although a subsurface pluton of Squire Creek-age could have reset the age. In earlier reports we (Vance, 1957a, p. 287; Tabor and others, 1984; Tabor and others, 1993, p. 18) correlated the Barlow Pass Volcanics with the Naches Formation of middle and late Eocene and early Oligocene(?) age. The Barlow Pass unit is only correlative with part of the Naches Formation and its age should be revised to middle and late Eocene.

Sandstone and rhyolite in isolated outcrops north of the North Fork of the Stillaguamish River, in the upper Deer Creek area [6], west of Lake Cavanaugh [7], and west of the Sauk River quadrangle have been previously correlated with the Chuckanut Formation (Whetten and others, 1988; Evans and Ristow, 1994). Near Bellingham, about 40 km northwest of the quadrangle, the lower member of the Chuckanut contains a rhyolite ash bed with 49-Ma zircons dated by fission-track analysis. The dated strata appear to be in about the middle part of the total Chuckanut section, which led Johnson (1984) to consider the upper part of the unit to extend into the late Eocene, although no volcanic interbeds have been found for dating in the upper part of the section. J.A. Vance has recently recounted zircons from the same ash bed and obtained an age of 57 Ma which corresponds to the age of the major detrital zircon population in the sandstone of the Chuckanut Formation, indicating that the age of the younger Chuckanut strata may not be as young as envisioned by Johnson (1984) and hence may not be as young as the Barlow Pass Volcanics.

Whetten and others (1988) report rhyolite fission-track ages ranging from about 38 to 44 Ma from rhyolite masses associated with sandstone exposed west of Lake Cavanaugh which are appropriate for their assignment to the Barlow Pass Volcanics. Whetten and others (1988) refer to these bodies as dikes, but most exposures are too poor to rule out their being interbeds (J.T. Whetten, oral commun., 1994). A few older ages suggest that early middle Eocene rocks equivalent to the dated middle part of the Chuckanut Formation may also be present, but these ages are questionable. Whetten and others (1988) report a zircon fission-track age of 52.7±2.5 Ma from a rhyolite interbed(?) west of Lake Cavanaugh. This age was obtained from a wide spread of counts (34 to 60 Ma on individual zircons; C.W. Naeser, oral commun., 1990). Recalculated with modern statistics, the age becomes 52.6 ± 4.8 Ma, which within the error almost overlaps the oldest part of the Barlow Pass Volcanics. Bechtel Inc. (1979) obtained early middle Eocene K-Ar ages on whole rock samples of dikes presumably intruding the sedimentary rocks. Whole rock ages commonly are too young due to argon loss during alteration, but they can also be too old due to contamination by old xenoliths. An early Eocene diorite(?) stock identified by Bechtel, Inc. (1979) as cutting sandstone in the Deer Creek area appears to be the same rock as the stock at Granite Lakes. We think that the stock is Oligocene in age based on our determinations, but the hornblende we dated did not yield consistent results. Bechtel, Inc. (1979) cites a large (15 percent) error on their hornblende age confirming our doubts.

Evans and Ristow (1994) correlated interbedded sandstone and tuff in the Deer Creek area and south of Darrington with the Chuckanut Formation on the basis of sedimentological characteristics and observed unconformities between the volcanic rocks and the fluviatile sandstone. We think that the isotopic ages and the association of fluviatile feldspathic sandstone with the main mass of the Barlow Pass Volcanics is convincing evidence that the sandstone strata in the area here discussed is a facies of the Barlow Pass Volcanics, although the section may well contain minor unconformities. We have previously explained a major discordance between Barlow Pass volcanic rocks and sedimentary strata in the Darrington-Devils Mountain Fault Zone.

Future work may indicate that the late middle Eocene feldspathic sandstone associated with the Barlow Pass Volcanics is indeed equivalent to the upper part of the Chuckanut Formation and that the rocks comprising the Barlow Pass Volcanics and the sandstone interbeds should be reassigned as a formal member of the Chuckanut. For now and for the purposes of this map, we consider these rocks to be part of the Barlow Pass Volcanics of Vance (1957a, b).

Far to the southwest, the middle and late Eocene Puget Group and Cowlitz Formation also partially correlate with the Barlow Pass-Naches rocks and reveal widespread fluvial sedimentation locally punctuated or interrupted by volcanism. The conventional interpretation indicates that the region was undergoing extension in the Eocene associated with strike-slip faulting (Ewing, 1980; Heller and others, 1987; Johnson, 1985).

Unnamed sandstone

Moderately to deeply weathered conglomerate and very fine grained sandstone crop out in the Puget Lowland along the southwest margin of the Sauk River quadrangle. Deeply weathered exposures usually can be distinguished from old glacial outwash by manganese staining on joint planes, quartzose or pebble-rich lithology, and the presence of organic matter.

These rocks appear to be continuous with shallow-marine rocks of Oligocene age to the southwest, which Minard (1981) considers to be similar to the Blakeley Formation (Weaver, 1912) and which unconformably overlie Tertiary volcanic rocks that are probably continuous with the volcanic rocks of Mount Persis. We include in the unnamed sandstone unit outcrops along the South Fork of the Stillaguamish River on the west edge of the quadrangle; Danner (1957, p. 492–499) referred these rocks to his Oligocene Riverside unit. Whetten and others (1988) referred these same rocks to the Bulson Creek unit of Lovseth (1975) (see also, Marcus, 1980, 1981).

ROCKS AND DEPOSITS OF THE CASCADEMAGMATIC ARC

The Cascade magmatic arc began erupting at about 36 Ma (Oligocene) (Vance and others, 1986, 1987) and continues today. Most of the arc rocks in the Sauk River quadrangle are arc root plutons (see Tabor and Haugerud, 1999, p. 38–41). Tabor and others (1989) divided root plutons in the North Cascades into three families, the Index family with crystallization ages of about 34 Ma, the Snoqualmie family with ages of about 25–30 Ma, and the Cascade Pass family with ages ranging from about 20 to 3 Ma. Index and Snoqualmie family plutons tend to be aligned along north-northwest- or north-trending structures, such as the Straight Creek Fault. Cascade Pass family plutons are commonly oriented northeast-southwest. Exceptions to this grouping are some plutons of Snoqualmie family age in the Chilliwack composite batholith exposed north of the quadrangle which have strong northeast trends (Tabor and others, in press).

Sauk ring dike

A dense swarm of dacite porphyry dikes crops out along the east side of the main mass of the Barlow Pass Volcanics of Vance (1957a, b). The area mapped as underlain by unit Tsrd contains a large arcuate mass of porphyry, but also includes swarms of dikes with less than 10 percent country rock. Smaller, more widely spaced dikes are abundant in the Twin Peaks-Mount Forgotten area [22]. Although most of the dacite dikes look like andesite in outcrop, chemical analyses show clearly that they are dacites (Ort and others, 1983). The association and proximity of these volcanic rocks to the Barlow Pass Volcanics suggest that they may represent the youngest episode of that volcanic event, but the ages of the dikes do not support such a direct association. At Sheep Mountain, a poorly reproducible K-Ar hornblende age from a tonalite is 37±9 Ma (Tabor and others, 1993). A hornblende dacite porphyry dike cutting eruptive rocks of the Barlow Pass northeast of Twin Peaks has hornblende with a K-Ar age of about 40 Ma (table 2, No. 30) and a fission-track zircon age of 32 Ma. This range of ages indicates several possible source plutons, including the Squire Creek stock (34 Ma). The arcuate configuration of the rocks centered on the Shake Creek stock, which, although not directly dated, has reset zircons in its aureole to 35 Ma, suggests an incipient resurgent dome and cauldron subsidence related to the Index family of arc root plutons (see below).

Intrusive rocks of the Index family

Squire Creek stock and related intrusive rocks

The Squire Creek stock and several smaller bodies form a northwest-trending string of tonalite and granodiorite plutons anchored at its south end by the Oligocene Index batholith exposed south of the Sauk River quadrangle (Tabor and others, 1993). The Index batholith is of appropriate age and location to be a root pluton of the Cascade volcanic arc which began erupting at about 36 Ma (Vance and others, 1986). This retinue of plutons appears to have intruded along the west edge of the northwest-curving Darrington-Devils Mountain Fault Zone.

The Squire Creek stock is the largest of these plutons. Vance (1957a, p. 241–274) has described the uniform medium-grained hornblende-biotite tonalite and granodiorite in some detail. The stock has a 1- to 2-km-wide thermal aureole. The Vesper Peak [24] stock is mostly medium-grained biotite tonalite and, less typically, hornblende-biotite tonalite with rare hypersthene. Baum (1968, p. 49–65) has described the Vesper Peak stock, as well as the sulfide mineralization that is associated with the stock (see also, Griffis, 1977, p. 118–206). At Granite Lake [8], the rock is a porphyritic hornblende quartz diorite with euhedral, highly corroded, pale-brown, hornblende phenocrysts. Dikes of similar, but more porphyritic diorite are common in the Mount Higgins area [9].

A hornblende-biotite pair from the Squire Creek stock yields a concordant K-Ar age of about 35 Ma (Yeats and Engels, 1971, p. D36), and zircon gives a U-Pb age of about 35 Ma (table 2, Nos. 19, 20). Griffis (1977, p. 96) cites a whole rock K-Ar age of 32.7±2 Ma obtained from a chip sample along the north margin of the Vesper Peak stock. The stock at Granite Lake yields poorly reproducible K-Ar hornblende ages of about 37 Ma and a zircon fission-track age of about 30 Ma (table 2, Nos. 21, 22). A small stock in Shake Creek [21], exposed only along its roof, has not been directly dated, but a reset zircon fission-track age from the nearby Barlow Pass Volcanics of about 35 Ma (table 2, No. 26) suggests that it too is a satellite of the Squire Creek stock.

The ages of the Squire Creek stock and its associated plutons are appropriate for the Index batholith to the south, which is well dated at about 34 Ma (Yeats and Engels, 1971; Vance and others, 1986; Tabor and others, 1993, p. 20).

Intrusive rocks of the Snoqualmie family

Grotto batholith

The Oligocene Monte Cristo stock appears to be a satellite of the larger Grotto batholith exposed south of the Sauk River quadrangle, which in turn is the northern continuation of the Snoqualmie batholith (Tabor and others, 1993, p. 21–22). A small stock on Dead Duck Creek [58] to the northeast of the Monte Cristo stock is made of the same hornblende-biotite granodiorite and tonalite, locally with augite and hypersthene.

K-Ar ages of hornblende and biotite from the Monte Cristo stock are concordant at about 24 Ma (table 2, Nos. 13, 14). Two hornblende-biotite pairs from the Dead Duck pluton yield concordant K-Ar ages of about 27 and 25 Ma, respectively, and zircon yields a fission-track age of 26 Ma (table 2, Nos. 15, 16). We do not know why the concordant K-Ar ages of the separate pairs are different, but the younger pair is in the appropriate age range for the Grotto batholith.

Tabor and others (1989, p. 17) included the Grotto batholith and related plutons in the Snoqualmie family of shallow arc-root plutons, characterized by ages of about 25–30 Ma and commonly aligned along north-south structures such as the Straight Creek Fault.

Intrusive rocks of the Cascade Pass family

Cloudy Pass batholith and associated rocks

The Cloudy Pass batholith is mostly exposed east and north of the Sauk River quadrangle. Because of breccia pipes, explosion breccias, and related mineralization associated with the batholith, Cater (1960, 1969), Grant (1969, p. 27–28), and Tabor and Crowder (1969) examined it in much detail for evidence of its role as a direct source of Cascade arc volcanic rocks. Tabor and others (1989, p. 17) grouped the batholith and its associated stocks in the Cascade Pass family of North Cascades plutons, but, in fact, the ages and structural alignments of the bodies suggest that both the

Snoqualmie and Cascade Pass families are represented by these rocks.

Just east of the Sauk River quadrangle, two biotite samples from the main body of the Cloudy Pass batholith and one from adjacent hornfels yield K-Ar ages of about 23, 23, and 21 Ma, respectively (Tabor and Crowder, 1969, p. 3; ages corrected for new constants). Hornblende and biotite ages from the stock at the South Cascade Glacier [44] are slightly discordant at about 21 and 23 Ma, respectively. These ages fall between the age ranges for the Cascade Pass and Snoqualmie families as defined by Tabor and others (1989), but they may be minimum ages judging from the discordance. The main body of the Cloudy Pass batholith and the South Cascade Glacier stock display a distinct north-northwesterly trend (Tabor and Crowder, 1969, fig. 12) which is appropriate for the Snoqualmie family.

The K-Ar ages of biotite and hornblende from the stock on Sitkum Creek [65] are concordant at 20 Ma (table 2, No. 12). This stock and a retinue of small stocks trend southwest from the main body of the Cloudy Pass batholith and are roughly aligned with a 20-Ma stock in upper Silver Creek, southwest of the Monte Cristo area (and south of the quadrangle; see Tabor and others, 1982a, b; 1993). This is an alignment typical of the Cascade Pass family. Grant (1969) described the northeast-trending structures that have controlled the plutons and mineralization.

Two phases of the Cloudy Pass batholith are exposed in the Sauk River quadrangle: light-colored granite and granodiorite and darker colored granodiorite, tonalite, gabbro, and quartz gabbro that grade into the lighter colored rocks to the west. Descriptions and discussion of the batholith's chemistry and intrusive history are in Ford (1959, p. 182–248), Grant (1966, p. 207–245; 1969, p. 30–34), Tabor and Crowder (1969, p. 3–18), and Cater (1969). Further modal and $\delta^{18}O$ data are found in Ford and others (1988, p. 36–38) and White and others (1988, p. 20).

Downey Mountain stock

A small hornblende tonalite stock on Downey Mountain [46] was first noted by Grant (1966, p. 191–192, plate II). Its contacts are not well exposed, but the composition and texture of the stock suggest that it is a satellite of the Cloudy Pass batholith. Some modal and $\delta^{18}O$ data are available in Ford and others (1988, p. 117) and White and others (1988, p. 32).

Cascade Pass dike

The large northeast-trending tonalite dike that goes through Cascade Pass [35] was noted early in geologic exploration of the North Cascades (Russell, 1900). The dike is about 1 km wide and 16.5 km long. Tabor (1963) described the Cascade Pass dike; an explosion breccia associated with the stock suggests the stock intruded at only a few kilometers in depth. A number of samples of hornblende and biotite yield K-Ar ages ranging from 16 to 19 Ma (table 2, Nos. 8–10). Concordant pairs suggest that the age of this pluton is about 18 Ma. Ford and others (1988, p. 32–34) and White and others (1988, p. 19) report modes, chemical data, and oxygen isotope data for the Cascade Pass dike.

Mount Buckindy pluton

Tonalite and granodiorite of the Mount Buckindy [42] pluton were first described by Bryant (1955, p. 215–235). The pluton intrudes a suite of Late Cretaceous granodiorite bodies, making identification of its contact difficult, and which led Bryant (1955) and Grant (1969, p. 69–71) to suggest that the Mount Buckindy rocks were generated by partial melting during the Late Cretaceous metamorphism. Associated with the Mount Buckindy body are breccias similar to those found with other relatively shallow plutons of the Cascade Pass family. A number of K-Ar ages from hornblende and biotite pairs are concordant at 16 and 15 Ma, respectively (table 2, Nos. 4–7).

The northeast-elongate orientation of the Mount Buckindy pluton on trend with the Cascade Pass dike and their similar lithology suggest that they are comagmatic although the Mount Buckindy pluton is about 2–3 m.y. younger.

Ford and others (1988, p. 29–31) and White and others (1988, p. 19) report modes, chemical data, and oxygen isotope data for the Mount Buckindy pluton.

Dacite plugs and dikes

Small plugs of biotite-hornblende-hypersthene dacite crop out along the southeast margin of the Sauk River quadrangle. A hypabyssal intrusive and extrusive complex of similar rocks exposed at Cady Ridge south of the quadrangle has a K-Ar hornblende age of about 5 Ma (Tabor and others, 1993, p. 23–24).

Cool Glacier stock

The small stock of pyroxene-biotite hornblende granodiorite and quartz monzodiorite below the Cool Glacier [66] at the head of the Suiattle River is one of the youngest plutons in the Sauk River quadrangle. Crowder and others (1966) and Tabor and Crowder (1969, p. 6–7) thought that the pluton was satellitic to the Cloudy Pass batholith, but new concordant hornblende and biotite K-Ar ages at about 4 Ma (table 2, No. 3) indicate that it is much younger. A nearby highly altered breccia is similar to explosion breccias associated with the Cloudy Pass batholith and other plutons of the Cascade Pass family. The pluton is older than the nearby volcanic rocks of Gamma Ridge, but it may represent an early phase of the Gamma Ridge magmatic event (see below). Chemical, isotopic, and modal data are in Tabor and Crowder (1969, p. 14), Ford and others (1988, p. 117), and White and others (1988, p. 33).

Breccia of Round Lake

At Round Lake [60], andesite to dacite breccia forms massive cliffs. Rocks are plagioclase-phyric, but phenocrysts are highly altered and mafic minerals are replaced by chlorite (see Vance, 1957a, p. 288–291). Two chemical analyses are in Ort and others (1983). Bedding in the breccia is rarely observable, and the lack of bedding led Vance (1957a, p. 288–291) to consider the breccia to be a volcanic neck. Locally, however, the volcanic breccia grades downward into tuffaceous talus breccia composed of underlying metamorphic rocks, a stratigraphy proving subaerial deposition of these rocks. Contact configuration suggests their deposition on terrain with considerable topographic relief. The breccia of Round Lake is much like the breccia of Kyes Peak (Tabor and others, 1993, p. 22–23) exposed south of the Sauk River quadrangle, but the breccia of Kyes Peak appears to postdate the Oligocene Grotto batholith, whereas the breccia of Round Lake is thermally metamorphosed by the Oligocene (about 26 Ma) Dead Duck pluton, presumably a satellite body of the Grotto.

Volcanic rocks of Gamma Ridge

Altered and much eroded volcanic rocks crop out beneath the Holocene eruptive materials of Glacier Peak volcano. Crowder and others (1966) and Tabor and Crowder (1969, p. 19–22) described the volcanic rocks of Gamma Ridge [57] and thought that their age was Miocene to Pliocene. New fission-track ages of 1.6 Ma and 2 Ma (table 2, Nos. 1, 2) place these rocks clearly in the late Pliocene. Flows, breccias, and tuffs, including significant silicic ash-flow tuffs, are present. Based on petrographic and chemical analyses, the rocks are mostly dacite and rhyolite with lesser amounts of andesite and basalt. The Gamma Ridge volcanic rocks are analogous to the Pliocene volcanic rocks filling Kulshan caldera (Hildreth, 1996), also overlain by a Holocene volcano—Mount Baker—and located about 30 km north of the Sauk River quadrangle. The volcanic rocks of Gamma Ridge probably had the same origin.

The volcanic rocks are overlain by tuffaceous conglomerate, rich in cobbles of granitoid rocks, quartzite, schist, and light-colored dike rocks. Locally, the conglomerate is composed entirely of andesite cobbles which may include the earliest detritus from Glacier Peak volcano.

Tabor and Crowder (1969, p. 55–57) discuss the drainage diversions caused by the eruption of the volcanic rocks of Gamma Ridge and the succeeding Glacier Peak volcano.

Rocks of Glacier Peak volcano and associated volcanic rocks and deposits

I.C. Russell (1900) visited Glacier Peak volcano in 1899, but little geologic work was done until Ford (1959, p. 250–331) described its abundant dacite lavas and breccias, determined the basic history of the volcano, and recognized the huge vocaniclastic debris fans that flank the mountain. An oxyhornblende dacite dome forms the subsidiary Disappointment Peak on the southwest flank of the volcano, and local centers erupted basalt nearby. Tabor and Crowder (1969) described the volcano and associated deposits, concluding that most of the eruptive products on the peak itself are younger than 700,000 yr B.P. based on the lack of magnetic reversals recorded in them. Recently completed high precision K-Ar ages suggest that the present cone began to form about 600,000 yr B.P. and that its lavas are mostly Pleistocene in age (Tom Sisson and Marvin Lanphere, written commun., 2000). Beget (1981, 1982) determined that the youngest deposits, especially the debris fans, are about 12,000 to 3,500 years old. Porter (1976) portrayed the extent and thickness of late Pleistocene tephra fans from Glacier Peak, and Beget (1982) inferred that the youngest tephra erupted between the late 17th and the latest 19th Centuries. Three hot springs—Kennedy Hot Springs [64], Sulphur Hot Springs [48], and Gamma Hot Springs [56]—bubble on the flanks of the volcano.

Two basaltic cinder cones (Qcc) have erupted near Glacier Peak: the White Chuck Cinder Cone [68] located southwest of the peak and the Indian Pass Cinder Cone [71], south of the peak on the south edge of the Sauk River quadrangle. The White Chuck Cinder Cone, consisting of basalt lapilli, minor bombs, and a few interbedded olivine basalt flows, is at least 11,250 years old (Beget, 1981), but it is younger than the alpine glaciation of about 20,000 yr B.P. The cinder cone remnant near Indian Pass is mostly composed of well-stratified tuff and breccia. Its age may be about the same as that of the White Chuck Cinder Cone (Tabor and Crowder, 1969, p. 47).

The olivine andesite flow at the mouth of Lightning Creek [70] clearly postdates major alpine glaciation (about 20,000 yr B.P.), but otherwise its age is unknown. For further descriptions, see Tabor and Crowder (1969, p. 47–48).

The lahars, pyroclastic flow deposits, alluvium, and reworked ash and silt making up the White Chuck fill on the west side of Glacier Peak include the informally named Crystal Creek mudflow, White Chuck assemblage, and Kennedy Creek [64] assemblage of Beget (1982, p. 22–38), who describes these materials in detail. He reports bracketing ages between 11,670 and 5,100 yr B.P. for these deposits. An indurated, cliff-forming dacitic vitric ash-flow tuff (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 White Chuck fill.

The immense debris fan on the east side of Glacier Peak, the Suiattle fill, is a well-bedded assemblage of lahars, pyroclastic flows, air-fall ash, alluvium, and rare lava flows. Ford (1959, p. 273–284), Tabor and Crowder (1969, p. 36–40), and more recently Beget (1981, p. 96–132; 1982, p. 47–48) describe the fill in detail, and he brackets its age at between 6,700 and 3,400 yr B.P., possibly equivalent to that of the upper part (Kennedy Creek assemblage) of the White Chuck fill at 5,500 to 5,100 years old.

Laharic deposits of boulder diamicton to well-sorted sand and gravel, containing characteristic clasts of pumice and volcanic rocks from Glacier Peak, mantle river bottoms and terraces along the Suiattle, White Chuck, Sauk, and North Fork of the Stillaguamish Rivers. The stratigraphy and general distribution of these deposits were first delineated by Beget (1981). We thank D.P. Dethier (written commun., 1985) for indicating additional locations of these deposits far to the west. Recent mapping has shown a probable lahar of the Kennedy Creek assemblage up to 60 ft thick in the vicinity of La Connor (about 85 miles downriver from the peak). This catastrophic deposit yields radiocarbon ages of about 5,000 yr B.P. (Dragovich and others, 2000a, b).

Loose pumice deposits form significant cover on slopes of Glacier Peak and nearby ridges. These deposits represent a number of tephra eruptions from Glacier Peak and probably minor amounts of ash from Mount Mazama in Oregon and Mount St. Helens in southern Washington. Both airfall pumice and reworked tephra may be present in the deposits as mapped. Beget (1981, 1982) recognized at least seven tephra eruptions ranging in age from about 12,500 yr B.P. to less than 316 yr B.P. He and Porter (1976) portray the distribution and thickness of three tephra eruptions, which were distributed mostly to the east and southeast of the volcano.

DESCRIPTION OF THE UNCONSOLIDATED DEPOSITS

by D.B. Booth

PLEISTOCENE GLACIATIONS

Introduction

The landscape of the Sauk River quadrangle has been fundamentally shaped by Pleistocene glaciers and their deposits. Glaciated U-shaped valleys are common throughout the east two-thirds of the quadrangle. The lower valleys of the Sauk and Stillaguamish Rivers reflect the action of both ice and water. The southwest corner of the quadrangle includes the edge of the Puget Lowland, a product of tectonic subsidence and glacial erosion throughout the Quaternary.

Source areas of ice

Throughout the multiple glaciations of the region, ice has originated from two discrete source areas. The first area encompasses the ridge tops and cirques of the Sauk River quadrangle itself. This alpine source of glacial ice is weakly echoed by the modern distribution of permanent snow fields and cirque glaciers. Climatic depression of the regional snowline elevation has allowed this ice to grow a number of times during the Quaternary; these high glaciers expanded, coalesced, and extended well down the trunk valleys of the Cascade Range. The stratigraphy of these alpine deposits has been best defined in the Mount Rainier area, 130 km south of the Sauk River quadrangle, where Crandell (1963) identified several such ice advances. Relative glacial extent and weathering characteristics have allowed us to correlate equivalent deposits located immediately south of this quadrangle (Porter, 1964; Booth, 1990; Tabor and others, 1993). In the Sauk River quadrangle, we distinguish deposits only of the latest major alpine advance, the Evans Creek stade of the Fraser glaciation of Armstrong and others (1965), culminating at about 20,000 yr B.P. Deposits of earlier glaciations are undoubtedly present, but we did not recognize them during our field work here. Deposits of later alpine glacial advances, some probably as recent as the 18th century, are evident as numerous unvegetated high-elevation moraines but are too small to show at this map scale.

The second source area of glacial ice for the quadrangle lay to the north and west, in the Coast Ranges of British Columbia. From this region, mountain ice caps grew to form the Cordilleran ice sheet, which has expanded several times throughout the Quaternary to cover the Fraser and Puget Lowland to the north and west of the quadrangle and the north part of the Columbia Plateau southeast of the quadrangle. At least six major Cordilleran ice-sheet advances are recognized in Washington State (Crandell and Mullineaux, 1958; Easterbrook and others, 1967); the latest advance, named the Vashon stade of the Fraser glaciation by Armstrong and others (1965), reached its maximum at about 15,000 yr B.P. and deposited virtually all of the ice-sheet sediments recognized in the quadrangle.

Cary and Carlston (1937) and Mackin (1941) first recognized the asynchronous behavior of the Canadian and alpine glacial advances south of the Sauk River quadrangle where they documented ice-free conditions in once-glaciated alpine valleys during the Cordilleran ice advance. Radiocarbon dating has established the 5,000-year interval now generally recognized to separate these two Fraser-age ice maxima (Booth, 1987). Alpine glaciers probably readvanced during the Vashon stade, albeit not as far as their maximum during the Evans Creek stade, a concept first proposed by Porter (1964). One of the few examples of continental till overlying alpine till is exposed in the Sauk River quadrangle about 2.5 km east-southeast of Verlot [25]. Although too small to show at map scale, alpine till is separated from overlying continental till by 1 m of fluvial sand, demonstrating both the stratigraphic relation between the tills and the ice-free interval between glacial episodes in this valley.

In the Skykomish River quadrangle to the south, tongues of Puget lobe ice advanced several kilometers up each alpine valley, an insufficient distance to meet downvalley-flowing alpine glaciers. Farther north, however, two factors brought ice from these two systems closer together: the gentle northward rise of the ice-sheet upper surface, reflecting the source area in British Columbia (Booth, 1986), and the northward descent of the regional snowline for alpine glaciers, reflecting the climatic effects of increasing latitude. In the northern part of the Sauk River quadrangle, these two factors probably allowed convergence of upvalley-flowing continental ice and downvalley-flowing alpine ice during the Vashon stade. A near-continuous blanket of ice thus covered the northeastern part of the map area, broken by numerous nunataks that projected above the ice surface. This blanket was fed by both steep local cirque glaciers and the main, but more distant, Puget lobe. The effects of multiple source areas and complex bed topography inhibit a proper reconstruction of the ice surface in this area. The locally opposing slopes of converging ice from these two sources also reduced the amount of glacial scour and its products that might otherwise provide diagnostic indication of ice limits. Evidence of directional glacial erosion and ice-transported erratics is rare.

Vashon stade of the Fraser glaciation of Armstrong and others (1965)

Although alpine glaciers eroded individual valleys throughout the east two-thirds of the Sauk River quadrangle, erosional effects and deposits of the continental ice sheet dominate the landscape on the west. Thick Vashon-age deposits flank the Sauk River below Darrington and as far upstream as Bedal [61]; they also choke the main valleys of the South and North Forks of the Stillaguamish River. From a line running between about Lake Cavanaugh [7] and Bald Mountain [32], on the west and south borders of the quadrangle respectively, deposits of the Cordilleran ice sheet lap up onto the bedrock of the Cascade Range. Southwest of this line, Cordilleran ice deposits thicken and finally bury almost entirely the older rocks, marking the east edge of the Puget Lowland province of western Washington. See Booth (1989) for greater detail in this western area.

Because of steep, irregular topography and complicated interactions between alpine and continental ice, the Vashon-age ice limit is not well expressed in the Sauk River quadrangle. However, several localities provide good limiting data, particularly along the western edge of the Cascade Range in the western third of the quadrangle and farther east up a few of the alpine river valleys. Ice-flow indicators are also rather sparse, but those observed show southeastward flow along the western map boundary, eastward flow up the North Fork of the Stillaguamish valley below Darrington, and southward flow up the Sauk River valley north of Darrington. Based on the distribution of erratics, the Vashon-age Puget lobe ice limit lay above 1,100-m elevation on the southwest face of Pilchuck Mountain, above 1,050 m along the main ridge of Green Mountain [16], between 1,100 and 1,200 m on the west slopes of Meadow Mountain [54], and above 1,200 m just west of Finney Peak. Jones (1959, p. 166) also reports erratics to 1,200 m on Little Deer Peak [5]. A good ice limit at 1,050 m is also suggested by erratic distribution along the French Creek valley, leading up to the southwest side of Whitehorse Ridge [13] and at 1,250 m on the northeast side of Whitehorse Ridge north of Lone Tree Pass [14]. Farther east, erratics constrain the ice limit to about 1,350 m on the southwest ridge of Prairie Mountain [51] and above Lake Tupso [39], south of Illabot Peaks. The eastern limits of valley-bottom erratics were identified in the White Chuck River valley by Vance (1957a) and Beget (1981). Beget (1981, p. 43) suggested that a Vashon ice tongue extended to about the confluence of Sitkum Creek and the White Chuck River. Coincident expansions of glaciers on Glacier Peak, however, are likely to have resulted in a confluent ice mass this far upvalley.

The most voluminous deposition of glacial sediments in the Sauk River quadrangle occurred during the recession of the Puget lobe during the Vashon stade. In the valleys of the North and South Forks of the Stillaguamish River, tongues of ice receded progressively, leaving valley-filling deposits of fluvial (ice-proximal) and lacustrine (distal) sediments in their wakes. The ice thinned as it retreated, allowing drainage from the upper valley to flow either above or beneath the ice at successively lower elevations. Thus the valley fills lie at successively lower elevations to the west, with the higher upvalley segments now sharply incised by later Quaternary recessional and Holocene river erosion. Some of the largest landslides in the quadrangle are developed along these incised terraces, particularly at Rowan [11] on the North Fork of the Stillaguamish River and west of Wiley Creek [26] on the South Fork Stillaguamish River. Once out of the confining alpine valleys, recessional drainage was directed first southeast, then south, and finally west as the Puget lobe thinned and retreated (Booth, 1989).

Drainage derangement

The Sauk River north of Darrington is unique in that it beheads a major west-trending spur of the Cascade Range and so links two major river valleys, the Skagit and the lower North Fork of the Stillaguamish Rivers, along a valley conspicuously athwart the regional drainage pattern. For most of the Vashon stade (and preceding Cordilleran ice advances), first subglacial and then proglacial meltwater from the upper Skagit River basin would have drained south along this channel, because the ice sheet thinned to the south. A plug of Vashon-age sediments, with an upper surface above 300-m elevation, blocked the Skagit valley just west of its confluence with the Sauk River (Heller, 1978; Tabor and others, in press; see also Tabor and Haugerud, 1999, p. 50–51) and so maintained this diversion throughout ice occupation and well into the recessional history of the area. All of the upper Skagit River, the Suiattle River, and the Sauk River drained out the valley of the North Fork of the Stillaguamish River. Ice-contact and recessional outwash sediments, lying as high as 200-m elevation, were deposited in the connecting channel (between Rockport and Darrington) during this time.

The Skagit valley plug was eventually breached just north of the Sauk River quadrangle near the town of Concrete, probably incised by the Baker River and other local flows draining over the top of the sediments, together with piping on the steep downvalley face by emergent groundwater once the ice tongue had retreated farther west. Even after the Skagit valley plug had been breached, the Sauk River may not have drained out the lower Skagit valley. Indeed, the gradient downstream of the Suiattle River mouth had been established to the south by recessional meltwater. This flow direction would have persisted until otherwise disrupted. The lower valley of the North Fork of the Stillaguamish River shows the effects of an extensive history of such a drainage pattern, with a broad valley carved through bedrock walls now several kilometers apart. The modern North Fork of the Stillaguamish River, by contrast, is clearly an underfit channel in this valley.

The agent of post-glacial diversion of both the Sauk and Suiattle Rivers was volcanic eruptions of Glacier Peak (Vance, 1957a). Lahars and lahar-derived fluvial sediments choke the mouth of the Suiattle River, form the drainage divide at Darrington (and underlie the town itself), and fill much of the lower North Fork Stillaguamish valley. Drainage of the Sauk River is thus a function of local deposition of sediments where the valley widens at Darrington, with the local alluvial-fan topography determining whether the Sauk River will flow west towards the Stillaguamish or north towards the Skagit River. Both the North Fork of the Stillaguamish River and the lower Sauk River have nearly identical gradients, suggesting that the Sauk had established the gradients in both valleys by successive occupations during the Holocene.

The Suiattle River has also been influenced by laharic deposition at its mouth, but changes to the flow direction of the Sauk River, into which it flows, have been more important. When the Sauk River was diverted from Darrington to Rockport in late Pleistocene (Vashon stade) or early Holocene time, the base level of the Suiattle dropped significantly—from 150-m elevation, 12 km distant at its confluence with the Sauk River at Darrington, to 60 m at its confluence with the Skagit River at Rockport (via the now north-flowing Sauk). In response to this lower base level, and thus significantly steeper gradient, the Suiattle has degraded up to 50 m in its lower valley. The highest laharic surface we recognize at the mouth of the Suiattle River is at 160-m elevation, barely sufficient to exceed the present valley divide at Darrington, over 10 km distant. Even a new lahar filling the Suiattle River valley would be unlikely to divert the Sauk River (and Suiattle River) back to the North Fork of the Stillaguamish River. The westward diversion of the Sauk River is quite plausible in a future major eruption of Glacier Peak or even by normal alluviation of the Sauk River fan. Southward diversion of the Suiattle River, however, is likely to require another glaciation.

QUATERNARY (INCLUDING HOLOCENE) DEPOSITS

Early glacial and non-glacial deposits

Unconsolidated deposits that predate the Vashon stade are rare in the Sauk River quadrangle and commonly of uncertain origin. Sedimentary deposits that predate the Fraser glaciation are recognized only along the south map boundary, but crop out much more extensively farther south (Booth, 1990). These deposits are distinguished from younger Quaternary sediments by degree of oxidation, weathering-rind thickness on gravel clasts, and stratigraphic position.

A younger episode of deposition is reflected by the transitional beds, relatively unoxidized compact silt and clay, which are exposed mainly in the valley of Pilchuck River [31]. They are correlative with the Lawton Clay Member of the Vashon Drift (Mullineaux and others, 1965), with the transitional beds of Minard (1983), and in part with the Pilchuck Clay Member of the Vashon Drift (Newcomb, 1952), although apparently he also included lacustrine sediments lying stratigraphically above Vashon till in the Pilchuck.

The transitional beds are so named because lacustrine sediments from local preglacial lowland lakes typically cannot be distinguished unequivocally from sediments deposited in more widespread lakes that were subsequently impounded by the advancing ice sheet.

Glacial deposits

Alpine glacial deposits are mapped up most of the valleys in the east two-thirds of the Sauk River quadrangle, reflecting occupation by ice originating from peaks and cirques in the local area. During the time of maximum alpine-ice advance, about 20,000 yr B.P., the regional snowline lay about 900 m below its present elevation (Porter, 1977). Similar glaciers probably formed during earlier glaciations, but we could not discriminate any such deposits at map scale. We distinguish alpine glacial deposits from those of the Cordilleran ice sheet on the basis of clast lithology, because the alpine deposits typically contain no clasts foreign to the up-glacier basin.

Deposits of Fraser glaciation of Armstrong and others (1965)

Advance outwash deposits mark the advance of the ice sheet into the Puget Lowland and comprise the sand and gravel transported by glacial outwash streams. In the Sauk River quadrangle, advance outwash deposits are exposed near the south map boundary, along the North Fork of the Stillaguamish River, and along the Skagit River. Except for the Skagit River exposures, the deposits are thin and outcrops are very sparse. To the south (Booth, 1990) and west (Pessl and others, 1987), however, the deposits rapidly thicken to over 100 m and probably underlie much of the central Puget Lowland (Booth and Goldstein, 1994). These deposits correspond to the Esperance Sand Member of the Vashon Drift (Mullineaux and others, 1965).

Till is a compact, matrix-supported diamicton that forms a patchy cover over much of the west one-third of the Sauk

River quadrangle. The thickness of the till is generally only a few meters, but it can range from a discontinuous veneer to several tens of meters. Commonly the uppermost meter is looser and more oxidized than the compact till below, probably a result of Holocene weathering. Weathering rinds on fine-grained rocks are much thinner than 1 mm, and oxidation extends less than a meter into the deposit. The mapped distribution of this deposit includes only those areas where the underlying bedrock is completely obscured; elsewhere within the ice-sheet limits, till is discontinuously exposed but not mapped.

Recessional outwash deposits are exposed throughout the western part of the Sauk River quadrangle, primarily filling channels that conveyed meltwater from the retreating ice sheet between protruding bedrock uplands. Recessional outwash deposits also form terraces that line the valleys of the South and North Forks of the Stillaguamish River, the Sauk River, and the Skagit River. These deposits essentially fill the valleys of the Pilchuck River [31], Deer Creek [6], and upper Finney Creek [3]. At the head ends of some of these valleys, outwash probably was deposited immediately adjacent to melting ice tongues; such ice-contact deposits are particularly prominent in the valleys of the Pilchuck River and the South Fork of the Stillaguamish River.

Late in the ice-recessional history of the Sauk River quadrangle, drainage patterns more closely approximating the modern configuration of rivers in the quadrangle were established. During this time, the Stillaguamish Sand Member of the recessional outwash deposits of the Vashon Drift (see also, Minard, 1985a, b) was deposited to form the broad valley flats north and west of Granite Falls.

Non-glacial deposits

A variety of nonglacial materials, deposited after the retreat of the Cordilleran ice sheet, fills the river valleys and mantles many of the hillsides of the Sauk River quadrangle. Because most of the recessional river channels were graded to the level of ice-dammed lakes, the modern rivers, graded to sea level, have entrenched the recessional deposits. Where the resulting excavation has been extensive, wide surfaces underlain by valley-bottom alluvium (Qoal, Qyal) are particularly prominent, such as along the Skagit and Sauk Rivers and along the lower North Fork of the Stillaguamish River. Elsewhere, recessional outwash still chokes most of the bedrock valleys, except where laharic deposits from Glacier Peak have been deposited, particularly north and west of Darrington (see descriptions of rocks of Glacier Peak volcano and associated volcanic rocks and deposits).

In the process of valley excavation by Holocene river erosion, numerous landslide deposits (Ql) have formed as the eroded face of the recessional outwash deposits collapsed onto the expanding floodplain below. These deposits are particularly common along both sides of the lower North Fork of the Stillaguamish River. They are also prominent in the advance outwash deposits present along the Skagit River valley near Rockport. Landslides are also common on glacially steepened slopes, particularly those underlain by the Darrington Phyllite. In some places, such as north of Darrington, we also have recognized incipient blockslides (Qbi) where widespread, systematic cracking and pull-apart features in the phyllite suggest deep-seated creep failure of the rocks.

DESCRIPTION OF MAP UNITS

[Unit symbols in parentheses on map indicate mélange blocks]

NON-GLACIAL DEPOSITS

Ql **Landslide deposits (Holocene)**—Diamictons composed of angular clasts of bedrock and surficial deposits derived from upslope. Arrows denote downslope direction of movement. Unit includes both transported material and unstable scarp area if present

Qbi **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. Arrows show 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 Ql

Qt **Talus deposits (Holocene)**—Non-sorted angular boulder gravel to boulder diamicton. At lower elevations gradational with unit Qf. At higher elevations 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. Grade 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 units Qf and Qb

Qoal **Older alluvium (Holocene and Pleistocene)**—Deposits 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, undivided (Holocene and Pleistocene)**—Undivided deposits composed of units Qf, Qyal, Qmw, Qvt, and 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 (Holocene and Pleistocene)**—Deposits ranging 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. Include indistinct moraines near outlets of Heather Lake and Lake Twentytwo [28; number in brackets indicates position on location map, fig. 3]. Miller (1969) has described neoglacial moraines below South Cascade and Le Conte Glaciers

Deposits of the Fraser glaciation of Armstrong and others (1965)

Vashon Drift (Pleistocene)—Divided into:

Qvr **Recessional outwash deposits**—Stratified sand and gravel, moderately sorted to well sorted and well-bedded silty sand to silty clay. This deposit formed predominantly in outwash-plain and valley-train environments in lowland areas. Locally includes:

Qvrs **Stillaguamish Sand Member**

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 area also includes deposits of units Qf, Qmw, and Qyal that are poorly exposed or too small to show at this 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

EARLY GLACIAL AND NON-GLACIAL DEPOSITS

Qtb **Transitional beds (Pleistocene)**—Laminated clayey silt to clay that either pre-date or were formed during the early part of the Vashon stade; 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 Sauk River quadrangle along north and south boundaries

ROCKS AND DEPOSITS OF THE CASCADE MAGMATIC ARC

Rocks of Glacier Peak volcano and associated volcanic rocks and deposits (Holocene and Pleistocene)—Divided into:

Qglh **Laharic deposits (Holocene and Pleistocene)**—Boulder diamicton to well-sorted sand and gravel with characteristic clasts of pumice and volcanic rocks from Glacier Peak; found along Suiattle, White Chuck, Sauk, and North Fork of the Stillaguamish Rivers. Include deposits of unit Qyal where alluvium is too narrow to easily distinguish at this map scale

Qgp **Pumice deposits (Holocene)**—Mostly unconsolidated dacitic ash and pumice clast deposits as thick as 3 m

Qgwf **Deposits of the White Chuck fill (Holocene and Pleistocene)**—Well-bedded assemblage of lahars, pyroclastic flow deposits, alluvium, and reworked ash and silt. Parts of unit grade into unit Qglh downvalley. May also include some younger deposits. Includes:

Qgwt **Dacitic vitric tuff**—An indurated, cliff-forming tuff crops out in upper part of White Chuck fill. The tuff is depicted on the map as forming a cap on the fill, but in reality, the tuff is overlain by at least one lahar (Beget, 1981, p. 59)

Qgsf **Deposits of the Suiattle fill (Holocene)**— Well-bedded assemblage of lahars, pyroclastic flows, air-fall ash, alluvium, and rare lava flows. Deposit grades downvalley into unit Qglh

Qgd **Dacite (Pleistocene)**—Mostly clinopyroxene-hypersthene dacite. Forms flows and volcanic rubble on Glacier Peak volcano

Qgdp **Dacite of Disappointment Peak (Holocene and(or)Pleistocene)**—Oxyhornblende-hypersthene dacite forming massive, partly eroded dome

Qcc **Cinder cones (Holocene)**—White Chuck Cinder Cone [68] consisting of basalt lapilli and minor bombs with a few interbedded olivine basalt flows. Cinder cone remnant [71] just north of Indian Pass (just south of Sauk River quadrangle) is mostly composed of well-stratified tuff and breccia

Qaf **Andesite flow (Holocene and (or) Pleistocene)**—Eroded remnant of columnar-jointed olivine andesite flow at mouth of Lightning Creek [70]

Volcanic rocks of Gamma Ridge (Pliocene)—Divided into:

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 minerals, sericite, clays, and chlorite; siliceous kaolinite common near Gamma Peak; glassy rocks commonly spherulitic; common veins of zeolites, carbonate minerals, and quartz. Before alteration, composition ranged from rhyolite to basalt

Tgrc **Conglomerate**—White to dirty-gray tuffaceous conglomerate. Poorly bedded, composed of cobbles of granitoid rocks, quartzite, schist, and light-colored holocrystalline volcanic rocks in a fine-grained matrix of volcanic subquartzose sandstone that is much altered to greenish-yellow chlorite(?). Locally composed entirely of andesite cobbles

Tgrf **Altered andesite and dacite flows**—Red to black andesite and dacite, plagioclase-phyric, trachytic; much altered to calcite, chlorite, and zeolites

Intrusive rocks of the Cascade Pass family

Cool Glacier stock (Pliocene)—Divided into:

Tcgg **Granodiorite**—Pyroxene-biotite-hornblende granodiorite and quartz monzodiorite. Medium grained, hypidiomorphic granular

Tcgb **Breccia**—Clasts derived from Tenpeak pluton in a hydrothermally altered matrix of highly comminuted tonalite and altered volcanic material and some glass

Tdp **Dacite plugs and dikes (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

Mount Buckindy pluton (Miocene)—Divided into:

Tmbt **Tonalite and granodiorite**—Mostly porphyritic biotite-hornblende tonalite to hornblende tonalite porphyry. Rocks are quartz-phyric with hypidiomorphic granular groundmass, but heterogeneous in grain size and texture

Tmbb **Breccia**—Clasts of tonalite in a vuggy quartz and iron oxide (magnetite?) matrix

Cascade Pass dike (Miocene)—Divided into:

Tdt **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 fine-grained, porphyritic, chilled margins; contact lit-par-lit complexes are common, and alteration is pervasive locally

Tdbx **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; color index (CI)=5–15, massive, jointed, inclusions rare. Sharp contact with country rocks on west, grades into unit Tcpd on east

Tcpd **Dark-colored granodiorite, tonalite, gabbro, and quartz gabbro**—Light- to dark-gray, medium-grained hornblende-biotite granodiorite, gabbro, tonalite, and quartz gabbro, hypidio-morphic granular. CI=10–30. Massive, well-jointed, inclusions rare; locally altered and cataclastic, grades into unit Tcpl and in smaller bodies commonly contains pyroxene and locally abundant mafic inclusions. Varied in texture and composition, locally porphyritic. South of Lake Byrne [67] forms a complex of dikes, sills, and irregular small masses. At South Cascade Glacier, quartz with necklace inclusions suggests early-formed quartz phenocrysts

Tcpu **Granodiorite, tonalite, and gabbro, undivided**

Tcpb **Intrusive breccia**—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

Tcpc **Clustered light-colored dikes and irregular intrusive bodies**—White, variably fine grained to coarse grained xenomorphic or hypidio-morphic granular tonalite to granite alaskite in densely clustered dikes, sills, and irregular bodies, generally making up 80 percent or more of bedrock. Locally weakly to strongly foliated. Contacts of individual bodies are sharp. Contact of mapped concentration is gradational. 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

Tdm **Downey Mountain stock (Miocene)**—Hornblende-biotite tonalite, locally granodiorite. Similar to unit Tcpd

Intrusive rocks of the Snoqualmie family

Grotto batholith (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

Tgd **Dead Duck pluton**—Hornblende-biotite tonalite and granodiorite, with minor augite and hypersthene

Intrusive rocks of the Index family

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 (1957a, p. 241–274). Locally in interior, pluton is fine-grained and with lower CI

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)

Tsh **Hornblende quartz diorite**—At Granite Lake [8] the rocks are a porphyritic hornblende-clinopyroxene quartz diorite with euhedral, highly corroded, pale-brown hornblende phenocrysts. Dikes of a similar but more porphyritic rock-type are common in the Mount Higgins area [9]

Tsst **Tonalite of the Shake Creek stock**—Biotite-hornblende tonalite, fine grained, highly altered

Tsrd **Sauk ring dike (Oligocene and (or) middle Eocene)**—Gray dacite and andesite porphyry with abundant plagioclase and rare quartz phenocrysts; highly altered to epidote, chlorite, sericite, albite, and carbonate minerals. At northwest base of Sheep Mountain, rocks are a mixture of holocrystalline hornblende tonalite, dacite, and porphyry, as well as gradational types in between

SEDIMENTARY AND IGNEOUS ROCKS

Trl **Breccia of Round Lake (Oligocene)**—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. Includes some probable hypabyssal holocrystalline pyroxene andesite porphyry

Tus **Unnamed sandstone (Oligocene)**—Moderately weathered 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

Barlow Pass Volcanics of Vance (1957a, b) (late and middle Eocene)—Divided into:

Tbv **Volcanic rocks**—Basaltic andesite, basalt and rhyolite 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 section is generally dark green to gray, aphyric, massive, and dense. Rhyolite occurs as thick flows, typically weathering 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

Tbg **Gabbro**—Medium-grained, ophitic with plagioclase and clinopyroxene. Intrusive into volcanic rocks (Tbv), 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 montmorillinite minerals

Tbs **Sandstone**—Mostly feldspathic subquartzose sandstone and pebble conglomerate with minor interbeds of argillite and siltstone, rarer tuffaceous sandstone, and tuff. Detrital mica and fossil leaves common. Well bedded. In the area northwest of Darrington, bentonite interbeds are present (Kinder-Cruver, 1981, p. 29), and many sandstone beds are composed of quartz framework grains totally supported in a matrix rich in montmorillinite minerals 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

Tbsv **Sandstone and volcanic rocks**—Sandstone with conspicuous interbeds of basalt and rhyolite

Tgf **Granite Falls stock and associated plutons (middle Eocene)**—Biotite hornblende granodiorite, mostly fine grained hypidiomorphic granular, slightly porphyritic. Locally contains hypersthene and small amounts of elbaite (tourmaline). Commonly highly altered. Country rock strongly thermally metamorphosed

Mount Pilchuck stock (middle 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 as much as 40 percent K-feldspar, mostly perthite (Wiebe, 1963, p. 21). Wiebe (1963, 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

Tpd **Dike swarm**—Concentration of granite and granite porphyry dikes making up as much as 50 percent of unit TKwg rock ground (horizontal black line overlay). May include numerous dikes and sills associated with the Bald Mountain pluton (bms)

Thl **Rhyolite of Hanson Lake (middle Eocene)**—Dark-colored, glassy to devitrified biotite rhyolite ash-flow tuff. Commonly perlitic, contains sanidine, plagioclase, quartz, and garnet phenocrysts. Poorly exposed near Hanson Lake [30] and to the west where the unit includes quartz- and clinopyroxene-bearing mafic tuff. Northwest of Bosworth Lake [29], mafic tuff and breccia are highly altered to epidote and smectites

Tfs **Feldspathic sandstone and conglomerate (middle 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

Tss **Sandstone associated with the Straight Creek Fault (middle and (or) early Eocene)**—Feldspathic sandstone and pebble conglomerate. Mostly highly sheared and locally altered

ROCKS WEST OF THE STRAIGHT CREEK FAULT

Rocks in the Darrington-Devils Mountain Fault Zone

Helena-Haystack mélange (middle Eocene to Late Cretaceous)—Divided into:

TKhm **Peridotite and serpentinite matrix**—Metamorphic peridotite and rare metamorphic dunite are orange- and black-weathering resistant rocks occurring mostly as steeply dipping tectonic lenses and sheets in Tertiary sandstone and as isolated blocks in serpentinite. Some relict pyroxene in serpentinite above Swede Heaven [10] suggests original cumulus textures. Serpentinite is generally flaky, gray to green in rare outcrops. On Helena Ridge, serpentinite is lizardite and chrysotile (Vance and Dungan, l977, p. 1498). In the Iron Mountain-Gee Point area [1, 2], Brown and others (1982, p. 1089) describe serpentinite composed of antigorite, commonly with well-defined foliation, and relict aluminous chromite, rimmed by Fe-chromite suggesting an alpine peridotite protolith

TKhg **Greenstone, foliated greenstone, and green–schist**—Greenstone including basalt with relict clinopyroxene and plagioclase to well-recrystallized actinolitic greenstone and greenschist, commonly with pumpellyite, prehnite, stilpnomelane, and locally with aragonite in veins. Cruver (1983, p. 23) reports lawsonite in metagraywacke associated with greenstone of his Haystack Mountain unit on strike to the northwest. Outcrops are commonly massive, but on Big and Little Deer Peaks, 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. Include minor schistose dacite metaporphyry, graywacke, and argillite

TKhd **Diabase and gabbro**—Uralitic metadiabase and 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 steepsided hillocks

TKhs **Sedimentary rocks**—Chert, graywacke, phyllitic argillite, and semischist

TKhf **Foliated metavolcanic rocks**—Silicic metaporphyry 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

TKha **Amphibolite**—Fine-grained amphibolite with well-crystallized green hornblende and plagioclase, partially altered to chlorite, epidote, and pumpellyite(?)

TKht **Tonalite**—Medium-grained hypidiomorphic hornblende tonalite altered to chlorite, prehnite, epidote, and pumpellyite(?). Rocks are locally gneissic and cataclastic, interlayered with amphibolite (TKha) at north contact of tonalite

Rocks southwest of the Darrington-Devils Mountain Fault Zone

Bald Mountain pluton (age uncertain)—Divided into:

bmg **Granodiorite and granite**—Medium- to coarse-grained hypidiomorphic biotite granodiorite and granite, in part gneissic near 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

bms **Sill complex**—Multiple sills of granodiorite in hornfelsic argillite and graywacke. Sills, ranging from a few meters to hundreds of meters thick, make up from 10 to 90 percent of this rock unit

Rocks of the western mélange belt (middle Eocene to Late Cretaceous)—Divided into:

TKws **Semischist, slate, and phyllite**—Mostly pervasively foliated gray to black lithofeldspathic and volcanolithic subquartzose sandstone and semischist. Locally abundant fine- to medium-cobble conglomerate. Commonly interbedded with argillite or phyllite. Locally well developed rhythmite. Where foliation is less well developed, sedimentary features, including graded beds and load casts, are locally well preserved. Metamorphic minerals, which locally replace matrix and framework grains and also occur in veins, are carbonate minerals, prehnite, pumpellyite, chlorite, and sericite. Unit includes rare greenstone derived from mafic volcanic breccia, tuff, and flows. Also includes locally abundant chert

TKwph **Phyllite**—Gray and 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. Locally with well-developed pencil structures and rarer crinkle lineation. Metamorphic minerals are sericite, carbonate minerals, chlorite, prehnite, and pumpellyite(?). Metasandstone commonly forms small boudins as long as a few meters

TKwv **Volcanic rocks**—Greenstone and sheared greenstone including diabase and gabbro. Poorly exposed south of the Pilchuck River [31]

TKwm **Marble and limestone**—Mostly coarsely crystalline, dark-gray to white marble in small to moderate-size pods. Mostly massive but locally bedded with bioclastic layers. Cyan diamond indicates outcrop of carbonate rocks too small to show at this map scale

TKwg **Gabbro and diorite**—Massive to foliated, fine- to medium-grained metagabbro and metadiorite. Outcrops sheared on all scales. In massive rocks, euhedral, mottled, locally crushed plagioclase, intergranular to euhedral uralitized clinopyroxene and opaque minerals are common. Metamorphic minerals are albite(?), uralite, chlorite, sphene, and carbonate minerals

TKwu **Ultramafic rocks**—Serpentinized peridotite and dunite. Nearby Tertiary plutons have recrystallized ultramafic rocks to higher grade assemblages, locally with enstatite and talc. Asterisk (shown on map explanation) indicates outcrop of ultramafic rocks too small to show at this map scale

TKt **Trafton terrane of Whetten and others (1988) (middle Eocene to Late Cretaceous)**—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 minerals, and brownish pumpellyite(?); some rocks with veins of green pumpellyite. Chert is red and black, locally highly recrystallized. Minor diabase. Argillite locally phyllitic. Locally includes:

TKtm **Marble and limestone**—Similar to unit TKwm. Locally highly fossiliferous bioclastic limestone such as at the abandoned Morcrop quarry on the north side of Porter Creek [15]. Cyan diamond indicates outcrop of carbonate rocks, which is too small to show at this map scale

TKtg **Metagranodiorite**—Medium-grained, hypidiomorphic hornblende-biotite metagranodiorite partially recrystallized to albite, chlorite, prehnite, and pumpellyite

Rocks of the eastern mélange belt (middle Eocene to Late Cretaceous)—Divided into:

TKev **Mafic metavolcanic rocks with mostly subordinate graywacke and foliated graywacke, argillite and phyllitic argillite, chert, and marble**—Highly sheared and disrupted greenstone makes up from 20 to 50 percent of mélange and contains relict clinopyroxene (some titaniferous) and plagioclase in an altered matrix of chlorite, carbonate minerals, and pumpellyite. Rare deformed pillows. Locally prehnite in veins. Volcanic subquartzose sandstone similar to sandstone in unit TKwg. Unit symbol in parenthesis (TKev) on map indicates block or inferred block in Helena-Haystack mélange

TKea **Argillite**—Black, locally foliate argillite with limey concretions. Poorly exposed south of the town of White Horse [12]. Locally cut by deformed and brecciated metadacite dikes

TKew **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 local thin sedimentary interbeds

TKec **Chert**—Mostly white-weathering, red or black ribbon chert and metachert making up to 20 to 80 percent of unit. Uniformly banded to complexly disrupted. Some chert as thin laminae in cherty argillite. Locally 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

TKem **Marble**—Gray to white, locally with chlorite; coarsely crystalline. Danner (1966, p. 326–329) describes the deposits south of White Horse; mostly in small pods. Cyan diamond indicates outcrop of carbonate rocks, which is too small to show at this map scale

TKegb **Gabbro**—On the South Fork of the Stillaguamish River, unit consists of gabbro, layered gabbro, and interlayered cumulate ultramafic rocks (wehrlite) (Dungan, 1974, p. 46–53). Includes some metatonalite and gneissic amphibolite. The large gabbro body mapped within the Helena-Haystack mélange south of Darrington is medium grained and massive but laced with swarms of diabase dikes (Vance and others, 1980, p. 365). Gabbros are generally partially altered to albite, actinolite, epidote, and chlorite. Unit symbol in parenthesis (TKegb) on map indicates block or inferred block in Helena-Haystack mélange

TKet **Zone of tectonized meta-igneous pods**—Disrupted argillite, chert, and greenstone with abundant pods of tectonized metatonalite and metagabbro

TKeu **Ultramafic rocks**—Serpentinite, metaperidotite, and metaclinopyroxenite. 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. Asterisk (shown on map explanation) indicates outcrop of ultramafic rocks too small to show at this map scale

Rocks northeast of the Darrington-Devils Mountain Fault Zone

Northwest Cascades System

MzPzg **Gabbroic intrusions (Mesozoic and Paleozoic)**—Mostly metagabbro and metadiabase. Fine- to medium-grained, granular or ophitic saussuritized plagioclase in fibrous matrix of green amphibole, chlorite, and epidote minerals. Grains are crushed, locally microbrecciated. Includes cataclastic tonalite northeast of Rockport

Easton Metamorphic Suite—Divided into:

Kes **Shuksan Greenschist (Early Cretaceous)**—Predominantly fine-grained greenschist, sodic 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 pumpellyite, characterized by a mosaic of albite porphyroblasts that have mineral inclusions aligned in the foliation. Common are epidote clots or balls, generally less than 1mm in diameter, and probably derived from vesicle fillings in the protolith basalt (Misch 1965; Haugerud, 1980, p. 39–44). Schists are commonly conspicuously layered on centimeter scale, and foliation and layering are tightly folded on outcrop scale. Locally interlayered with units Ked and Keds. Unit symbol in parenthesis (Kes) on map indicates block or inferred block in Helena-Haystack mélange

Keg **Garnet amphibolite (Early Cretaceous)**—Garnet amphibolite and muscovite-quartz schist, barroisite schist, hornblende-garnet rocks, and rare eclogite commonly surrounded by greenschist. Most of these rocks are coarser grained than typical Shuksan lithologies. The garnet amphibolite is overprinted by blueschist facies metamorphism (Brown and others, 1982). Includes minor ultramafic rocks. Unit symbol in parenthesis (Keg) on map indicates block or inferred block in Helena-Haystack mélange

Ked **Darrington Phyllite (Early Cretaceous)**—Predominantly black, highly fissile sericite-graphite-albite-quartz phyllite, typically with abundant quartz veinlets; commonly complexly folded. Most phyllite has a strong crinkle lineation. Some well-foliated meta-sandstone. Locally interlayered with unit Kes. Includes:

Keds **Silver-colored phyllite**—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 unit Kes. Unit symbol in parenthesis (Keds) on map indicates block or inferred block in Helena-Haystack mélange

Kem **Mixed greenschist and phyllite (Early Cretaceous)**—Interlayered greenschist and black phyllite on a 1- to 10-m scale. Locally includes:

Kems **Mixed greenschist and silver-colored phyllite**

Keu **Ultramafic rocks (Early Cretaceous)**—Mostly serpentinite. Occurs in unit Keds and near faulted contacts with unit TKhm. Asterisk (shown on map explanation) indicates outcrop of ultramafic rocks too small to show at this map scale

Krs **Slate of Rinker Ridge (Cretaceous)**—Predominantly gray to brown, little-recrystallized slate and phyllite with local foliated sandstone and semischist

KJb **Bell Pass mélange (Early Cretaceous and Late Jurassic)**—Metagabbro, metadiorite, metatonalite, silicic gneiss, fine-grained epidote amphibolite gneiss, micaceous quartzite, amphibole schist, and ultramafic rocks. Lesser amounts of phyllitic argillite, cherty phyllite, chert, graywacke, semischist, metavolcanic rocks, and marble. Rocks highly variable, commonly mylonitic and (or) cataclastic. Locally includes:

Yellow Aster Complex of Misch (1966)—Medium- to coarse-grained silicic and feldspathic gneisses and associated weakly deformed plutonic rocks. See text for discussion of age. Divided into:

byan **Non-gneissic rocks**—Mostly metagabbro, metadiabase, and metatonalite with minor gneissic igneous rocks

byag **Gneissic rocks**—Siliceous gneiss, pyroxene gneiss, and associated metagabbro, metadiabase, and metatonalite. Includes areas lacking siliceous gneiss but including metaigneous rocks with strongly mylonitic quartz bands

bm **Marble**—Coarsley crystalline marble exposed on Prairie Mountain too small to show at this map scale. Shown as cyan diamond

bu **Ultramafic rocks**—Commonly serpentinite; occurs along faults in the Prairie Mountain area. Asterisk (shown on map explanation) indicates outcrop of ultramafic rocks, which is too small to show at this map scale

bc **Chert**—Ribbon chert in large block north of White Chuck River

bv **Vedder Complex of Armstrong and others (1983)**—Amphibolite, blueschist, micaceous quartzite, and mica-quartz schist. See text for discussion of age. Black square indicates outcrop of unit, which is too small to show at this map scale

Chilliwack Group of Cairnes (1944) (Permian to Devonian)—Divided into:

PDcs **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

PDcv **Volcanic and metavolcanic rocks**—Mostly greenstone, with subordinate meta-andesite and rare metadacite or metarhyolite. Breccia and tuff predominate. Mafic metavolcanic rocks commonly with relict plagioclase and clinopyroxene in a chlorite-epidote matrix, commonly with carbonate minerals. Plagioclase mostly recrystallized as albite. Includes some gabbro and diabase

PDcl **Limestone and marble**—Mostly coarsely crystalline, gray to black. Carbonate rocks in small isolated pods and blocks; locally fossiliferous. Cyan diamond indicates outcrop of carbonate rocks too small to show at this map scale

ROCKS EAST OF THE STRAIGHT CREEK FAULT

Stitching units

Plutons of the tonalitic group

Kbl **Tonalitic gneiss of Bench Lake (Late Cretaceous)**—Mostly light colored, fine grained heterogeneous biotite tonalitic gneiss, locally with hornblende. Subhedral clinozoisite associated with mafic minerals. 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 percent of rock. Mafic schlieren may be swirled. Cut by light-colored tonalite, pegmatite, and aplite dikes. Contact with unit Kblg is gradational. Includes:

Kblg **Banded tonalitic gneiss**—Strongly layered fine-grained biotite-hornblende gneiss and light-colored biotite tonalite to granodioritic gneiss. As mapped, commonly contains garnet and thin and thick layers and pods of Napeequa Schist (Kns), 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 an igneous origin

Kng **Nason Ridge Migmatitic Gneiss (Late Cretaceous)**—In south, mostly heterogeneous light-colored tonalite to granodioritic gneiss interlayered with mica schist and amphibolite similar to the Chiwaukum Schist and some ultramafic rock (Ksc). Predominantly crystalloblastic. Most common lithology 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. Cross-cutting sills, dikes, and irregular bodies of light-colored, fine-grained to pegmatitic tonalite and gneiss are also abundant in migmatitic phases. Most of unit has 50 percent or more light-colored gneiss. 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

Ksc **Sloan Creek plutons (Late Cretaceous)**—Biotite-hornblende tonalitic gneiss, flaser gneiss, and local gneissic metatonalite; 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. As mapped, includes some interlayered flaser gneiss and Nason Ridge Migmatitic Gneiss (Kng) and rare ultramafic rock (Kcu)

Tenpeak pluton (Late Cretaceous)—Divided into:

Ktc **Contact zone**—Dark-colored biotite-hornblende metatonalite and tonalitic gneiss, hornblende diorite, and hornblendite, locally with garnet; layers of garnet-hornblende-biotite schist increase to west. Pods of hornblendite and ultramafic rocks (R.A. Haugerud, written commun., 1993) suggest that much of the country rock in this zone may be the Napeequa Schist. This description and others of the Tenpeak pluton adapted from Crowder and others (1966)

Ktd **Dark-colored metatonalite and tonalitic gneiss**—Medium-grained biotite-hornblende metadiorite and metatonalite. 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 unit Kti

Ktm **Metatonalite and tonalitic gneiss**—Light-colored medium-grained hornblende-biotite tonalite and tonalitic gneiss. Xenoblastic to hypidiomorphic, commonly with aligned euhedral hornblende prisms, locally as long as 1 cm. CI=15–20, locally as much as 40. Subhedral epidote and pseudomyrmekitic epidote common. Allanite and garnet occur on west margin of unit. Hornblende commonly zoned from brownish green to bluish green on rims. Sodic andesine crystals commonly broken and with faint euhedral oscillatory zoning

Kti **Interlayered rocks**—Light- and dark-colored biotite-hornblende dioritic gneiss, tonalitic gneiss, and flaser gneiss, and subordinate hornblende schist. Contains rare ultramafic pods (Knu)

Ktf **Flaser gneiss**—Medium-grained hornblende and (or) biotite tonalite flaser gneiss; textures are xenoblastic, porphyroclastic, and mylonitic. CI=20–40

Chaval pluton (Late Cretaceous)—Divided into:

Kchb **Biotite-hornblende quartz diorite and 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 igneous but near the margins become subidioblastic with little or no relict igneous texture except for rare euhedral oscillatory-zoned plagioclase. Margins of 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)

Kchm **Mafic hornblende metadiorite, meta-quartz diorite, and mafic amphibolite**—Heterogeneous, layered rocks with zones of unit Kchb 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**—Sills and dikes composed of mafic metadiorite and meta-quartz diorite intrusive into the Chiwaukum Schist. Many layers of amphibolite. Sharply banded, tabular bodies of mafic rocks, similar to unit Kchm

Kgp **Grassy Point stock (Late Cretaceous)**—Light-colored, medium- to coarse-grained biotite metatonalite to rare metagranodiorite with CI=5–50. Mostly uniform granitoid rocks with gneissic margins and rare rhythmic mafic layering. Hypidiomorphic granular with highly strained crystals and strong cataclasis. Rare relict euhedral oscillatory zoned oligoclase-andesine

Kdm **Metadiorite (Late Cretaceous)**—West of Lake Byrne [67] fine- to medium-grained hornblende and biotite-hornblende metadiorite and dioritic gneiss with CI=20–30. Xenoblastic to granoblastic with epidote-filled andesine, epidote, allanite, and garnet. Description adapted from Crowder and others (1966)

Plutons of the granodioritic group

Eldorado Orthogneiss (middle Eocene to Late Cretaceous)—Divided into:

TKeb **Biotite-hornblende quartz monzodioritic 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 hundred meters into unit TKef. Rock is granodiorite chemically, but $\delta^{18}O$ is less than 10, a characteristic of the tonalitic group (Ford and others, 1988, p. 26; White and others, 1988, p. 30)

TKef **Flaser gneiss**—Fine- to medium-grained biotite-hornblende metagranodiorite and meta-quartz monzodiorite flaser gneiss, with mosaic sodic plagioclase patches and rare simple crystals set in a finer grained mylonitic matrix of quartz, plagioclase, and mafic minerals

TKhl **Hidden Lake stock (middle Eocene to Late Cretaceous)**—Biotite metatonalite, based on modes, but rocks are granodiorite based on CIPW norms and $\delta^{18}O$ values greater than 10 (Ford and others, 1988, p. 26; White and others, 1988, p. 30). Relict hypidiomorphic granular texture 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. Rocks are massive and sharply intrusive

Kcl **Cyclone Lake pluton (Late Cretaceous)**—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 subhedral clinozoisite with rare allanite cores associated with micas. CI=3–7 (Ford and others, 1988, p. 53). Faintly gneissic in outcrop. Rocks become coarser grained and more gneissic towards north margin of pluton where they grade abruptly into the Jordan Lakes pluton

Kjl **Jordan Lakes pluton (Late Cretaceous)**—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

Kdc **Downey Creek sill complex (Late Cretaceous)**—Mostly light colored muscovite-biotite metagranodiorite and granodioritic gneiss, locally metatonalite. 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, mica, garnet, epidote, and sphene. Ellipsoidal quartz mosaic aggregates suggest former quartz phenocrysts in some rocks. Some plagioclase with faint relict euhedral oscillatory zoning. Occurs mostly as sills and irregular masses in the Napeequa Schist (Kns) with intrusive contacts and metaporphyry apophyses. Schist inclusions in the pluton range from 10-70 percent. Includes small lenses in Milk Creek, along Canyon Creek, and a large sill in upper Sulphur Creek that have similar petrographic features

Sulphur Mountain pluton (Late Cretaceous)—Divided into:

Ksmm **Metagranodiorite and metatonalite**—Medium-grained hornblende-biotite metagranodiorite and metatonalite characterized by large clinopyroxene prisms as long as 8 cm and quartz augen as large as 1.4 cm with accessory subhedral 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

Ksmf **Flaser gneiss**—On east side of pluton, flaser gneiss consists of medium-grained hornblende-biotite tonalite flaser gneiss with layers and inclusions of clinopyroxene-hornblende schist, hornblende gneiss, biotite gneiss, and quartzite. On west side, unit is hornblende-biotite metatonalite and tonalite flaser gneiss with layers of hornblendite and hornblende schist (Crowder and others, 1966)

Kfc **Foam Creek stock (Late Cretaceous)**—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

Nason terrane

Chiwaukum Schist (Late Cretaceous)—Divided into:

Kca **Biotite schist and amphibolite**—Mostly fine grained 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. Grades into unit Kcgg

Kcm **Marble**—Thin to thick layers of coarsely crystalline white to gray marble, commonly with thin schist interbeds and associated calc-silicate schist. Cyan diamond indicates outcrop of carbonate rocks too small to show at this map scale

Kch **Hornblende schist and amphibolite**—Black to light-green, fine- to medium-grained garnet-hornblende-quartz-plagioclase schist, gneiss, and amphibolite. Lepidoblastic to granofelsic, rarely garbenschiefer, with pods or layers rich in biotite, clinopyroxene, and (or) epidote

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

Kcu **Ultramafic rocks**—Asterisk (shown on map explanation) indicates outcrop of ultramafic rocks, which is too small to show at this map scale

Chelan Mountains terrane

Rocks southwest and northeast of the Entiat Fault

Cascade River Schist (Tertiary and Late Cretaceous)—Divided into:

TKcs **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; less commonly staurolite and kyanite. Rare chloritoid. Many rocks have blue-green tourmaline. Hornblende-biotite-andesine schist, garbenschiefer, and fine-grained amphibolite common. Calcareous mica schist locally. Hornblende is commonly blue green. Relict clastic textures common in metasandstone; unit includes small-pebble metaconglomerate. Most descriptions abstracted from Tabor (1961, p. 81–115). On Spider Mountain, unit includes phyllitic quartz-rich schist, calcareous mica schist, grading to impure marble, and silicic metaporphyry

TKcc
Kcc **Metaconglomerate and plagioclase-rich mica schist**—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 lineation. Identifiable protoliths of clasts are quartzite, volcanic rocks, and granitoid rocks. Unmapped granule conglomerate rich in granitoid and meta-quartzite clasts occurs elsewhere in the Cascade River Schist south of the North Fork of the Cascade River [34]

TKcma **Marble**—Coarsely crystalline gray to white marble with many impurities of quartz, plagioclase, and mica. Grades into calcareous mica schist. Asterisk indicates outcrop of carbonate rocks, which is too small to show at this map scale

Kcmv **Metavolcanic rocks (Late Cretaceous)**—Fine-grained leucogreenschists, commonly with relict highly flattened phenocrysts of plagioclase or mafic minerals

Marblemount pluton (Tertiary and Late Cretaceous)—Divided into:

TKmd
Kmd **Meta-quartz diorite**—Hornblende meta-quartz diorite, metatonalite, and tonalitic gneiss; minor metadiorite, hornblendite, and schistose hornblendite. Light-colored metatonalite dikes. Most common rock type has CI=16–54 (Ford and others, 1988, p. 96). West of the Entiat Fault and in the South Fork of the Cascade River area, the rocks are medium grained, pale green, containing numerous anastomosing shears rich in chlorite, epidote, and actinolitic hornblende, and vary 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 local biotite

TKmf
Kmf **Flaser gneiss**—Dark-colored epidote-chlorite-muscovite-quartz-plagioclase flaser gneiss, locally with chlorite schist. Subhedral to subidioblastic sodic plagioclase in a foliate matrix, locally with biotite

TKmm **Magic Mountain Gneiss (Tertiary and 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 and 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 most commonly 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 as thick as 60 m. Locally this contact is marked by a monolithologic breccia of equidimensional light-colored gneiss clasts, commonly augen shaped and as large as 10 cm in a greenschist matrix. Descriptions abstracted from Tabor (1961, p. 38–72)

Napeequa Schist (Tertiary and Late Cretaceous)—Divided into:

TKns Kns **Mica-quartz schist and hornblende schist**—Predominantly fine grained, mica-quartz schist, hornblende schist, amphibolite, hornblende-mica 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 blasto-mylonitic. 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

TKnm Knm **Marble**—Coarsely crystalline white marble grading into calcareous schist and locally calc-silicate schist. Cyan diamond indicates outcrop of carbonate rocks too small to show at this map scale

TKnu Knu **Ultramafic rocks**—Thick, large layers along Downey Creek are mostly metadunite (Grant, 1966, p. 110). Other bodies are serpentinized metadunite and metaperidotite. Rocks are dark green to black on fresh surfaces, weathering rusty orange to brown with relicts of olivine in a felted mat of antigorite, talc, and tremolite (Crowder and others, 1966). The large body on Jordan Creek is mostly serpentinized peridotite (Bryant, 1955, p. 51–53). Many small pods of talc-tremolite schist are unmapped. Asterisk indicates outcrop of ultramafic rocks too small to show at this map scale

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 tonalitic gneiss

REFERENCES CITED

Adams, J.B., 1964, Origin of the Black Peak quartz diorite, northern Cascades, Washington: American Journal of Science, v. 262, no. 3, p. 290–306.

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., and Noble, J.B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, p. 321–330.

Armstrong, R.L., 1980, Geochronology of the Shuksan metamorphic suite, North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 12., no. 3, p. 94.

Armstrong, R.L., Harakal, J.E., Brown, E.H., Bernardi, M.L., and Rady, P.M., 1983, Late Paleozoic high-pressure metamorphic rocks in northwestern Washington and southwestern British Columbia: the Vedder Complex: Geological Society of America Bulletin, v. 94, p. 451–458.

Armstrong, R.L., and Misch, Peter, 1987, Rb-Sr and K-Ar dating of mid-Mesozoic blueschist and late Paleozoic albite-epidote-amphibolite and blueschist facies metamorphism in the North Cascades, Washington and British Columbia, and fingerprinting of eugeosynclinal rock assemblages, *in* Schuster, J.E., Selected papers on the Geology of Washington: Washington Department of Natural Resources Bulletin 77, p. 85–105.

Armstrong, R.L., Taubeneck, W.H., and Hales, P.O., 1977, Rb-Sr and K-Ar geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho: Geologic Society of America Bulletin, v. 88, p. 397–411.

Babcock, R.S., Armstrong, R.L., and Misch, Peter, 1985, Isotopic constraints on the age and origin of the Skagit Metamorphic Suite and related rocks [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 6, p. 339.

Babcock, R.S., and Misch, Peter, 1988, Evolution of the crystalline core of the North Cascades Range, *in* Ernst, W.G., ed., Rubey Volume VII, Metamorphism and crustal evolution of the western United States: Englewood Cliffs, N.J., Prentice Hall, p. 214–232.

———1989, Origin of the Skagit migmatites, North Cascades Range, Washington State: Contributions to Mineralogy and Petrology, v. 101, p. 485–495.

Baum, L.F., 1968, Geology and mineral deposits, Vesper Peak stock area, Snohomish County, Washington: Seattle, University of Washington, M.S. thesis, 75 p.

Beach, W.K., 1962, A geological investigation of the Bonanza Queen Mine, Snohomish County, Washington: Seattle, University of Washington, B.S. thesis, 85 p.

Bechtel, Inc., 1979, Report for geologic investigations in 1978–1979: Skagit Nuclear Power Project, for Puget Sound Power and Light Co., Seattle, Washington: Bechtel, Inc., v. 1, 2, and 3.

Beget, J.E., 1981, Postglacial eruption history and volcanic hazards at Glacier Peak, Washington: Seattle, University of Washington, Ph.D. dissertation, 192 p.

———1982, Postglacial volcanic deposits at Glacier Peak, Washington and potential hazards from future eruptions: U.S. Geological Survey Open-File Report 82–830, 77 p.

Berggen, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, no. 11, p. 1407–1418.

Berti, J.W., 1983, Barrovian-type metamorphism superimposed on low-pressure metamorphism in the Chiwaukum Schist, Stevens Pass, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 15, p. 437.

Bittenbender, P.E., 1991, Mid-Cretaceous orogenesis in the Huckleberry Mountain area, North Cascades, Washington: Austin, University of Texas, M.A. thesis, 137 p.

Bittenbender, P.E., and Walker, N.W., 1990, Constraints on timing of metamorphism, deformation, and plutonism in the Huckleberry Mountain area, North Cascades, Wash. [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 8.

Blackwell, D.L., 1983, Geology of the Park Butte-Loomis Mountain area, Washington (eastern margin of the Twin Sisters dunite): Bellingham, Western Washington University, M.S. thesis, 253 p.

Boak, J.L., 1977, Geology and petrology of the Mount Chaval area, North Cascades, Washington: Seattle, University of Washington, M.S. thesis, 87 p.

Booth, D.B., 1986, Mass balance and sliding velocity of the Puget-lobe ice sheet during the Vashon stade (late Pleistocene): Quaternary Research, v. 25, p. 269–280.

———1987, Timing and processes of deglaciation on the southern part of the Cordilleran ice sheet, *in* Ruddiman, W.F., and Wright, H.O., Jr., eds., North America and adjacent oceans during the last deglaciation: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K–3, p. 71–90.

———1989, Surficial geologic map of the Granite Falls 15-minute quadrangle, Snohomish County, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1852, scale 1:50,000.

———1990, Surficial geologic map of the Skykomish and Snoqualmie Rivers area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map, I–1745.

Booth, D. B., and Goldstein, Barry, 1994, Patterns and processes of landscape development by the Puget lobe ice sheet, *in* Cheney, E.S., and Lasmanis, Raymond, eds., The geology of Washington State, Washington Division of Geology and Earth Resources Bulletin 80, p. 207–218.

Brandon, M.T., Cowan, D.S., and Vance, J.A., 1988, The Late Cretaceous San Juan thrust system, San Juan Islands, Washington: Geological Society of America Special Paper 221, 81 p.

Brown, E.H., 1974, Comparison of the mineralogy and phase relations of blueschists from the North Cascades, Washington, and greenschists from Otago, New Zealand: Geological Society of America Bulletin, v. 85, no. 3, p. 333–344.

———1986, Geology of the Shuksan suite, North Cascades, Washington, USA, *in* Evans B.W., and Brown, E.H., ed., Blueschists and eclogites, Geological Society of America Memoir 164, 423 p.

———1987, Structural geology and accretionary history of the Northwest Cascades System of Washington and British Columbia: Geological Society of America Bulletin, v. 99, p. 201–214.

Brown, E.H., Bernardi, M.L., Christenson, B.W., Cruver, J.R., Haugerud, R.A., and Rady, P.M., 1981, Metamorphic facies and tectonics in part of the Cascade Range and Puget Lowland of northwestern Washington: Geological Society of America Bulletin, v. 92, Part I and Part II, p. 170–178 and p. 515–553.

Brown, E.H., Blackwell, D.L., Christenson, B.W., Frasse, F.I., Haugerud, R.A., Jones, J.T., Leiggi, P.L., Morrison, M.L., Rady, P.M., Reller, G.J., Sevigny, J.H., Silverberg, D.L., Smith, M.T., Sondergaard, J.N., and Zielger, C.B., 1987, Geologic map of the northwest Cascades, Washington: Geological Society of America Map and Chart Series., MC 61, 10 p.

Brown, E.H., Bradshaw, J.Y., and Mustoe, G.E., 1979, Plagiogranite and keratophyre in ophiolite on Fidalgo Island, Washington: Geological Society of America Bulletin, v. 90, pt I, p. 493–507.

Brown, E.H., Cary, J.A., Dougan, B.E., Dragovich, J.D., Fluke, S.M., and McShane, D.P., 1994 , Tectonic evolution of the Cascades crystalline core in the Cascade River area, Washington: *in* Cheney, E.S., and Lasmanis, Raymond, eds., The geology of Washington State, Washington Division of Geology and Earth Resources Bulletin 80, p. 93–113.

Brown, E.H., and Walker, N.W., 1991, Plutonism is the cause of Barrovian metamorphism in the southeast coast plutonic complex, British Columbia and Washington [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 2, p. 8.

———1993, A magma-loading model for Barrovian metamorphism in the southeast Coast Plutonic Complex, British Columbia and Washington: Geological Society of America Bulletin, v. 105, no. 4, p. 479–500.

Brown, E.H., Wilson, D.L., Armstrong, R.L., and Harakal, J.E., 1982, Petrologic, structural, and age relations of serpentinite, amphibolite, and blueschist in the Shuksan Suite of the Iron Mountain-Gee Point area, North Cascades, Washington: Geological Society of America Bulletin, v. 93, no. 11, p. 1087–1098.

Bryant, B.H., 1955, Petrology and reconnaissance geology of Snowking area, North Cascades, Washington: Seattle, University of Washington, Ph.D. dissertation, 321 p.

Cairnes, C.E., 1944, Hope Sheet, British Columbia: Geological Survey of Canada Map 737A.

Campbell, A.R., 1991, Petrology and petrogenesis of the Lost Peak and Monument Peak stocks, Okanogan County, Washington: Seattle, University of Washington, M.S. thesis, 136 p.

Carithers, L.W., and Guard, A.K., 1945, Geology and ore deposits of the Sultan Basin, Snohomish County, Washington: Washington Division of Mines and Geology Bulletin 6, 90 p.

Cary, J.A., 1990, Petrology and Structure of the Lookout Mountain -Little Devil Peak area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 164 p.

Cary, A.S., and Carlston, C.W., 1937, Notes on Vashon stage glaciation of the South Fork of the Skykomish River valley, Washington: Northwest Science, v. 11, p. 61–62.

Cater, F.W., 1960, Chilled contacts and volcanic phenomena associated with the Cloudy Pass batholith, Washington: U.S. Geological Survey Professional Paper 400–B, p. B471–B473.

———1969, The Cloudy Pass epizonal batholith and associated subvolcanic rocks: Geological Society of America Special Paper 116, 52 p.

———1982, The intrusive rocks of the Holden and Lucerne quadrangles, Washington—the relation of depth zones, composition, textures, and emplacement of plutons: U.S. Geological Survey Professional Paper 1220, 108 p.

Cater, F.W., and Crowder, D.F., 1967, Geologic map of the Holden quadrangle, Snohomish and Chelan Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–646, scale 1:62,500.

Cater, F.W., and Wright, T.L., 1967, Geologic map of the Lucerne quadrangle, Chelan County, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–647, scale 1:62,500.

Christenson, B.W., 1981, Structure, petrology and geochemistry of the Chilliwack Group, near Sauk Mountain, Washington: Bellingham, Western Washington University, M.S. thesis., 181 p.

Cowan, D.S., 1985, Structural styles in Mesozoic and Cenozoic mélanges in the western Cordillera of North America: Geological Society of America Bulletin, v. 96, p. 451–462.

Cowie, J.W., and Bassett, M.G., 1989, International Union of Geological Sciences 1989 Global Stratigraphic Chart, *in* Episodes 12, (2) Supplement, June 1989.

Crandell, D.R., 1963, Surficial geology and geomorphology of the Lake Tapps quadrangle, Washington: U.S. Geological Survey Professional Paper 388A, 84 p.

Crandell, D.R., and Mullineaux, D.R., 1958, Pleistocene sequence in the southeastern part of the Puget Sound lowland, Washington: American Journal of Science, v. 256, p. 384–397.

Crowder, D.F., 1959, Granitization, migmatization, and fusion in the northern Entiat Mountains, Washington: Geological Society of America Bulletin, v. 70., p. 827–878.

Crowder, D.F., Tabor, R.W., and Ford, A.B., 1966, Geologic map of the Glacier Peak quadrangle, Snohomish and Chelan Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–473, scale 1:62,500.

Cruver, J.R., 1983, Petrology and geochemistry of the Haystack Mountain Unit, lower Skagit Valley, Washington: Bellingham, Western Washington University, M.S. thesis, 149 p.

Dalrymple, G.B., 1979, Critical tables for the conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558–560.

Daly, R.A., 1912, Geology of the North American Cordillera at the forty-ninth parallel: Geological Survey of Canada Memoir, v. 38, 840 p.

Danner, W.R., 1957, A stratigraphic reconnaissance in the northwestern Cascade Mountains and San Juan Islands of Washington State: Seattle, University of Washington, Ph.D. dissertation, 561 p.

———1966, Limestone resources of western Washington: Washington Division of Mines and Geology Bulletin 52, 474 p.

———1977, Paleozoic rocks of northwestern Washington and adjacent parts of British Columbia, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., ed., Paleozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 1, Los Angeles., Pacific Section, Society of Economic Paleontologists and Mineralogists, 502 p.

Dawes, R.L., 1993, Mid-crustal, Late Cretaceous plutons of the North Cascades: petrogenesis and implications for growth of continental crust: Seattle, University of Washington, Ph.D. dissertation, 272 p.

———1996, Origin of Archean-type tonalites-trondhjemites-granodiorites of the North Cascades, Washington state, by lower crustal melting [abs.]: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 60.

Debari, S.M., Parent, Laura, Miller, R.B., and Paterson, S.R., 1996, Mafic border complexes in deep-crustal Cordilleran magma chambers: the Tenpeak, Cardinal Peak, and Entiat plutons, North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 61.

Dethier, D.P., and Whetten, J.T., 1980, Preliminary geologic map of the Clear Lake SW quadrangle, Skagit and Snohomish Counties, Washington: U.S. Geological Survey Open-File Report 80–825, scale 1:24,000, 11 p.

Dethier, D.P., Whetten, J.T., and Carroll, P.R., 1980, Preliminary geologic map of the Clear Lake SE quadrangle, Skagit County, Washington: U.S. Geological Survey Open-File report 80–303, scale 1:24,000.

Dotter, J.A., 1977, Prairie Mountain Lakes area, southeast Skagit County, Washington: Structural geology, sedimentary petrography, and magnetics: Corvallis, Oregon State University, M.S. thesis, 105 p.

Dougan, B.E., 1993, Structure and metamorphism in the Magic Mountain-Johannesburg Mountain area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 110 p.

Dougan, B.E., and Brown, E.H., 1991, Structure and metamorphism in the Magic Mtn.-Johannesburg Mtn. area, north Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 23, no. 2, p. 19.

Dragovich, J.D., 1989, Petrology and structure of the Cascade River Schist in the Sibley Creek area, Northern Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 167 p.

Dragovich, J.D., Cary, J.A., and Brown, E.H., 1989, Stratigraphic and structural relations of the Cascade River Schist, North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 74.

Dragovich, J.D., and Derkey, R.E., 1994, A Late Triassic island-arc setting for the Holden volcanogenic massive sulfide deposit, North Cascades, Washington: Washington Geology, v. 22, no. 1, p. 28–39.

Dragovich, J.D., McKay, D.T., Jr., Dethier, D.P., and Beget, J.E., 2000a, Voluminous laharic inundation of the lower Skagit River valley, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. A11.

Dragovich, J.D., Troost, M.L., Norman, D.K., Anderson, Garth, Cass, Jason, and McKay, D.T., Jr., 2000b, Geologic Map of the Anacortes South and La Conner 7.5-minute quadrangles, western Skagit County, Washington: Washington State Department of Natural Resources, Washington Division of Geology and Earth Resources, Open File Report 2000–2.

Dubois, R.L., 1954, Petrology and genesis of ores of the Holden Mine area, Chelan County, Washington: Seattle, University of Washington, Ph.D. dissertation, 222 p.

Duggan, K.M., 1992, Regional significance of the Tonga Formation, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 117 p.

Duggan, K.M., and Brown, E.H., 1994, Correlation of the Tonga Formation and the Chiwaukum Schist, North Cascades, Washington: implications for Late Cretaceous orogenic mechanisms: Tectonics, v. 13, no. 6, p. 1411–1424.

Dungan, M.A., 1974, The origin, emplacement, and metamorphism of the Sultan mafic-ultramafic complex, North Cascades, Snokomish County, Washington: Seattle, University of Washington, Ph.D. dissertation, 227 p.

Dungan, M.A., Vance, J.A., and Blanchard, D.P., 1983, Geochemistry of the Shuksan greenschists and blueschists, North Cascades, Washington: variably fractionated and altered metabasalts of oceanic affinity: Contributions to Mineralogy and Petrology, v. 82, p. 131–146.

Easterbrook, D.J., Crandell, D.R., and Leopold, E.B., 1967, Pre-Olympia Pleistocene stratigraphy and chronology in the central Puget Lowland, Washington: Geological Society of America Bulletin, v. 78, p. 13–20.

Engels, J.C., Tabor, R.W., Miller, F.K., and Obradovich, J.D., 1976, Summary of K-Ar, Rb-Sr, U-Pb, and fission-track ages of rocks from Washington State prior to 1975 (exclusive of Columbia Plateau Basalts): U.S. Geological Survey Miscellaneous Field Studies Map MF–710, scale 1:500,000.

Evans, B.W., and Berti, J.W., 1986, Revised metamorphic history for the Chiwaukum Schist, North Cascades, Washington: Geology, v. 14, p. 695–698.

Evans, J.E., and Ristow, J.R., Jr., 1994, Depositional history of the southeastern outcrop belt of the Chuckanut formation: implications for the Darrington-Devil's Mountain and Straight Creek fault zones, Washington (U.S.A): Canadian Journal of Earth Sciences, v. 31, no. 12, p. 1727–1743.

Ewing, B.W., 1980, Paleogene tectonic evolution of the Pacific Northwest: Journal of Geology, v. 88, p. 619–638.

Fluke, S.M., 1992, Metamorphism and plutonism of the Mt. Buckindy-Snowking region, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 100 p.

Ford, A.B., 1957, The petrology of the Sulphur Mountain area, Glacier Peak quadrangle, Washington: Seattle, University of Washington, M.S. thesis, 103 p.

———1959, Geology and petrology of the Glacier Peak quadrangle, northern Cascades, Washington: Seattle, University of Washington, Ph.D. dissertation, 336 p.

———1983, Map of bedrock geologic data sites, Glacier Peak Wilderness Study, Chelan, Skagit, and Snohomish Counties, Washington: U.S. Geological Survey Open-File Report 83–454, scale 1:100,000.

Ford, A.B., Drinkwater, J.L., and Garwin, S.L., 1988, Petrographic data for plutonic rocks and gneisses of the Glacier Peak Wilderness and vicinity, northern Cascades, Washington: U.S. Geological Survey Open-File Report 85–432, 120 p.

Franklin, W.E., 1974, Structural significance of meta-igneous fragments in the Prairie Mountain area, North Cascade Range, Snohomish County, Washington: Corvallis, Oregon State University, M.S. thesis, 109 p.

Frizzell, V.A., Jr., Tabor, R.W., and Zartman, R.B., 1987, Late Mesozoic or early Tertiary mélanges in the western Cascades of Washington, *in* Schuster, J.E., ed., Selected Papers on the geology of Washington, Washington Division of Mines and Geology Bulletin 77, p. 129–148.

Fugro-Northwest, 1979, Interim report on geologic feasibility studies for Copper Creek dam, for Seattle City Light: 79–504, 145 p.

Gabites, J.E., 1985, Geology and geochronometry of the Cogburn Creek - Settler Creek area, northeast of Harrison Lake, B.C.: Vancouver, University of British Columbia, M.S. thesis, 153 p.

Gallagher, M.P., Brown, E.H., and Walker, N.W., 1988, A new structural and tectonic interpretation of the western part of the Shukson blueschist terrane, northwestern Washington: Geological Society of America Bulletin., v. 100, p. 1415–1422.

Grant, A.R., 1966, Bedrock geology and petrology of the Dome Peak area, Chelan, Skagit and Snohomish Counties, northern Cascades, Washington: Seattle, University of Washington, Ph.D. dissertation, 270 p.

———1969, Chemical and physical controls for base metal deposition in the Cascade Range of Washington: Washington Division of Mines and Geology Bulletin 58, 107 p.

———1982, Summary of economic geology data for the Glacier Peak wilderness, Chelan, Snohomish, and Skagit Counties, Washington: U.S. Geological Survey Open-File Report 82–408, 37 p.

Griffis, R.J., 1977, Igneous petrology, structure and mineralization in the eastern Sultan Basin, Snohomish County, Washington: Pullman, Washington State University, Ph.D. dissertation, 270 p.

Haugerud, R.A., 1980, The Shuksan Metamorphic Suite and Shuksan thrust, Mt. Watson area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 125 p.

———1987, Argon geochronology of the Tenpeak pluton and untilting of the Wenatchee block, North Cascades Range, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 64, no. 52, p. 1814.

Haugerud, R.A., Brown, E.H., Tabor, R.W., Kriens, B.J., and McGroder, M.F., 1994, Late Cretaceous and early Tertiary orogeny in the North Cascades, *in* Swanson, D.A., and Haugerud R.A., eds., Geologic field trips in the Pacific Northwest: Geological Society of America Annual Meeting in Seattle, October 24–27, Department of Geological Sciences, University of Washington, Seattle, Washington, v. 2, p. 2E1–2E51.

Haugerud, R.A., Morrison, M.L., and Brown, E.H., 1981, Structural and metamorphic history of the Shuksan Metamorphic Suite in the Mount Watson and Gee Point areas, North Cascades, Washington: Geological Society of America Bulletin, v. 92, Part 1, p. 374–383.

Haugerud, R.A., Tabor, R.W., and Blome, C.D., 1992, Pre-Tertiary stratigraphy and multiple orogeny in the western North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 32.

Haugerud, R.A., van der Heyden, Peter, Tabor, R.W., Stacey, J.S., and Zartman, R.E., 1991, Late Cretaceous and early Tertiary plutonism and deformation in the Skagit Gneiss Complex, North Cascades Range, Washington and British Columbia: Geological Society of America Bulletin, v. 103, p. 1299–1307.

Heath, M.T., 1971, Bedrock geology of the Monte Cristo area, north Cascades, Washington: Seattle, University of Washington, Ph.D. dissertation, 164 p.

———1972, Bedrock Geology of the Monte Cristo area: Dissertation Abstracts International, v. 32, no. 8, p. 4670B–4671B.

Heller, P.L., 1978, Pleistocene geology and related landslides in the lower Skagit and Baker Valleys, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 154 p.

Heller, P.L., Tabor, R.W., and Suczek, C.A., 1987, Paleogeographic evolution of the United States Pacific Northwest during Paleogene time: Canadian Journal of Earth Sciences, v. 24, p. 1652–1667.

Hildreth, Wes, 1996, Kulshan caldera: A Quaternary subglacial caldera in the North Cascades, Washington: Geological Society of America Bulletin, v. 108, no. 7, p. 786–793.

Hopson, C.A., and Mattinson, J.M., 1971, Metamorphism and plutonism, Lake Chelan region, northern Cascades, Washington, *in* Symposium on metamorphism in the Canadian Cordillera, Programme and Abstracts, Vancouver, B.C.: Geological Association of Canada, Cordilleran Section, p. 13.

———1990, Chelan migmatite complex: a Cretaceous protodiapiric mash zone in the North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 29.

———1994, Chelan migmatite complex, Washington: field evidence for mafic magmatism, crustal anatexis, mixing and protodiapiric emplacement, *in* Swanson, D.A., and Haugerud, R.A., Geologic field trips in the Pacific Northwest: Geological Society of America Annual Meeting in Seattle, October 24–27, Department of Geological Sciences, University of Washington, Seattle, Washington, v. 2, p. 2Ll1–2L19.

Huntting, M.T., Bennett, W.A.G., Livingston, V.E., Jr., and Moen, W.S., 1961, Geologic map of Washington: Washington Division of Mines and Geology, scale 1:500,000.

Jenne, D.A., 1978, Structural geology and metamorphic petrology of the Gold Mountain area, Snohomish County, Washington: Corvallis, Oregon State University, M.S. thesis, 177 p.

Jett, G.A., 1986, Sedimentary petrology of the western mélange belt, North Cascades, Washington: Laramie, University of Wyoming, M.S. thesis., 85 p.

Jett, G.A., and Heller, P.L., 1988, Tectonic significance of polymodal composition in mélange sandstone, western mélange belt, North Cascades Range, Washington: Journal of Sedimentary Petrology, v, 58, p. 52–61.

Johnson, J.H., and Danner, W.R., 1966, Permian calcareous algae from northwestern Washington and southwestern British Colombia: Journal of Paleontology, v. 40, no. 2, p. 424–432.

Johnson, S.Y., 1984, Stratigraphy, age, and paleogeography of the Eocene Chuckanut Formation, northwest Washington: Canadian Journal of Earth Sciences, v. 21, p. 92–106.

———1985, Eocene strike-slip faulting and nonmarine basin formation in Washington, *in* Biddle, K.T., and Christie-Blick, N.H., eds., Strike-slip deformation, basin formation and sedimentation, Society of Economic Paleontologists and Mineralogists Special Publication, 37, p. 283–302.

Jones, R.W., 1959, Geology of the Finney Peak area, north Cascades, Washington: Seattle, University of Washington, Ph.D. dissertation, 205 p.

Keroher, G.C., 1970, Lexicon of geologic names of the United States for 1961–1967: U.S. Geological Survey Bulletin, v. 1350, p. 848.

Kinder-Cruver, Susan, 1981, The geology and mineralogy of bentonites and associated rocks of the Chuckanut Formation, Mt. Higgens area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 105 p.

Longtine, M.W., 1991, Mid- to Late Cretaceous structural, metamorphic, and magmatic evolution of the Sloan Peak area, North Cascades, Washington: Austin, University of Texas, M.A. thesis, 139 p.

Lovseth, T.P., 1975, The Devils Mountain fault zone, northwestern Washington: Seattle, University of Washington, M.S. thesis, 29 p.

Mackin, J.H., 1941, Glacial geology of the Snoqualmie-Cedar area, Washington: Journal of Geology, v. 49, p. 449–481.

Magloughlin, J.F., 1986, Metamorphic petrology, structural history, geochronology, tectonics, and geothermometry/geobarometry in the Wenatchee Ridge area, North Cascades, Washington: Seattle, University of Washington, M.S. thesis, 344 p.

———1989, New perspectives on the deformational history of the Nason terrane and the White River shear zone [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 110.

———1993, A Nason terrane trilogy: I. Nature and significance of pseudotachylyte; II. Summary of the structural and tectonic history; III. Major and trace element geochemistry, and strontium and neodymium isotope geochemistry of the Chiwaukum Schist, amphibolite, and meta-tonalite gneiss of the Nason terrane: Duluth, University of Minnesota, Ph.D. dissertation, 306 p.

———1994, Migmatite to fault gouge: fault rocks and the structural and tectonic evolution of the Nason terrane, North Cascade Mountains, Washington, *in* Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest: Geological Society of America Annual Meeting in Seattle, October 24–27, Department of Geological Sciences, University of Washington, Seattle, Washington, v. 2, p. 2B1–2B17.

Marcus, K.L., 1980, Eocene-Oligocene sedimentation and deformation in the northern Puget Sound area, Washington: Northwest Geology, v. 9, p. 52–58.

———1981, The rocks of Bulson Creek: Eocene-Oligocene sedimentation and tectonics in the Lake McMurray area, Washington: Bellingham, Western Washington University, M.S. thesis, 84 p.

Mattinson, J.M., 1972, Ages of zircons from the northern Cascade Mountains, Washington: Geological Society of America Bulletin, v. 83, p. 3769–3784.

McCleary, J.R., Dohrenwend, J.C., Cluff, Lloyd, and Hanson, K.L., l978, Straight Creek Fault zone study and appendices A–D; 1872 earthquake studies, Washington Public Power Supply System Nuclear Project nos. 1 and 4: prepared for United Engineers and Constructors, Contract no. 0.0. 52028, San Francisco, California, Woodward-Clyde Consultants, 75 p.

McGroder, M.F., 1991, Reconciliation of two-sided thrusting, burial metamorphism, and diachronous uplift in the Cascades of Washington and British Columbia: Geological Society of America Bulletin, v. 103, no. 2, p. 189–209.

McKnight, E.F.T., and Ward, A.H., 1925, Geology of the Snohomish quadrangle: Seattle, University of Washington, M.S. thesis, 95 p.

McShane, D.P., 1992, Petrology and structure of the Eldorado Peak area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 74 p.

McShane, D.P., and Brown, E.H., 1991, Age of loading of the Skagit Gneiss and implications for orogeny in the North Cascades crystalline core: Geological Society of America Programs with Abstracts, v. 23, no. 2, p. 78.

Menzer, F.J., Jr., 1966, Structural controls of ore deposition at Helena Peak, Snohomish County, Washington: Texas Journal of Science, v. 18, no. 3, p. 291–295.

Miers, J.H., 1970, Ultramafic dikes on Jumbo Mountain, Snohomish County, Washington: Seattle, University of Washington, M.S. thesis, 54 p.

Miller, D.C., 1969, Chronology of neoglacial moraines in the Dome Peak area, North Cascade Range, Washington: Arctic and Alpine Research, v. 1, no. 1, p. 49–66.

Miller, G.M., 1979, Western extent of the Shuksan and Church Mountain thrust plates in Whatcom, Skagit, and Snohomish Counties, Washington: Northwest Science, v. 53, no. 4, p. 229–241.

Miller, R.B., 1989, The Mesozoic Rimrock Lake inlier, southern Washington Cascades: Implications for basement to the Columbia Embayment: Geological Society of America Bulletin, v. 101, p. 1289–1305.

Miller, R.B., Haugerud, R.A., Murphy, Fred, and Nicholson, L.S., 1994a, Tectonostratigraphic framework of the northeastern Cascades: Washington Division of Geology and Earth Resources Bulletin 80, 227 p.

Miller, R.B., Paterson, S.R., DeBari, S.M., and Whitney, D.L., 2000, North Cascades Cretaceous crustal section: changing kinematics, rheology, metamorphism, pluton emplacement and petrogenesis from 0 to 40 km depth, *in* Woodsworth, G.J., Jackson, I.E., Nelson, J.L., and Ward, B.C., eds., Guidebook for geological field trips in southwestern British Columbia and northern Washington: Geological Association of Canada, Cordilleran Section, p. 229–278.

Miller, R.B., Paterson, S.R., Whitney, D.L., and Bowring, S.A., 1994b, Evolution of the Cretaceous and Paleogene crystalline core of the North Cascades: relationships between metamorphism and plutonism [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 75.

Miller, R.B., Whitney, D.L., and Geary, E.E., 1993, Tectono-stratigraphic terranes and the metamorphic history of the northeastern part of the crystalline core of the North Cascades: evidence from the Twisp Valley Schist: Canadian Journal of Earth Science, v. 30, p. 1306–1323.

Milnes, P.T., 1976, Structural geology and metamorphic petrology of the Illabot Peaks area, Skagit County, Washington: Corvallis, Oregon State University, M.S. thesis, 118 p.

Minard, J.P., 1981, Distribution and description of the geologic units in the Maltby quadrangle, Washington: U.S. Geological Survey Open-File Report 81–100, scale 1:24,000.

———1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–1541, scale 1:24,000.

———1985a, Geologic map of the Arlington East quadrangle, Snohomish County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–1745, scale 1:24,000.

———1985b, Geologic map of the Lake Stevens quadrangle, Snohomish County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–1742, scale 1:24,000.

Misch, Peter, 1952, Geology of the northern Cascades of Washington: The Mountaineers, v. 45, p. 3–22.

———1959, Sodic amphiboles and metamorphic facies in Mount Shukan belt, northern Cascades, Washington [abs.]: Geological Society of America Bulletin, v. 70, p. 1736–1737

———1963, Crystalline basement complex in northern Cascades of Washington [abs.]: Geological Society of America Special Paper 76, p. 213–214

———1965, Radial epidote glomeroblasts formed under conditions of synkinematic metamorphism—a new mechanism of collective crystalloblastesis: Geologisches Rundschau, v. 54, pt. 2, p. 944–956.

———1966, Tectonic evolution of the northern Cascades of Washington State—a west-cordilleran case history, *in* Symposium on the tectonic history, mineral deposits of the western Cordillera in British Columbia and in neighboring parts of the U.S.A., Vancouver, Canadian Institute of Mining and Metallurgy, Special Volume 8, p. 101–148.

———1977a, Dextral displacements at some major strike faults in the North Cascades [abs.]: Geological Association of Canada Programme with Abstracts, v. 2, p. 37.

———1977b, Bedrock geology of the north Cascades, *in* Brown, E.H., and Ellis, R.C., eds., Geological excursions in the Pacific Northwest, Field Guide, annual meeting, Seattle: Geological Society of America, p. 1–62.

———1979, Geologic map of the Marblemount quadrangle, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Geologic Map GM–23, scale 1:48,000.

Monger, J.W.H., 1977, Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran evolution: Canadian Journal of Earth Science, 14, 1832–1859.

———1990, Correlation of Settler Schist with Darrington Phyllite and Shuksan Greenschist and its tectonic implications, Coast and Cascade Mountains, British Columbia and Washington: Canadian Journal of Earth Sciences, v. 28, p. 447–458.

Morrison, M.L., 1977, Structure and stratigraphy of the Shuksan metamorphic suite in the Gee Point-Finney Park area, North Cascades: Bellingham, Western Washington State College, M.S. thesis, 69 p.

Mullineaux, D.R., Waldron, H.H., and Rubin, Meyer, 1965, Stratigraphy and chronology of late interglacial and early Vashon time in the Seattle area, Washington: U.S. Geological Survey Bulletin 1194–O, p. O1–O10.

Newcomb, R.C., 1952, Ground-water resources of Snohomish County, Washington: U.S. Geological Survey Water-Supply Paper 1135, 135 p.

Nockolds, S.R., 1954, Average chemical composition of some igneous rocks: Geological Society of America Bulletin, v. 65, no. 10, p. 1007–1032.

Ort, K.M., Tabor, R.W., and Frizzell, V.A., 1983, Chemical analyses of selected Tertiary and Quaternary volcanic rocks, Cascade Range, Washington: U.S. Geological Survey Open-File Report 83–1, 14 p.

Ort, M.H., and Tabor, R.W., 1985, Major- and trace-element composition of greenstones, greenschists, amphibolites, and selected mica schists and gneisses from the North Cascades, Washington: U.S. Geological Survey Open-File Report 85–434, 12 p.

Pessl, F.J., Dethier, D.P., Booth, D.B., and Minard, J.P., 1987, Surficial geologic map of the Port Townsend 30- by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1198, scale 1:100,000.

Porter, S.C., 1964, Composite Pleistocene snow line of the Olympic Mountains and Cascade Range, Washington: Geological Society of America Bulletin, v. 75, p. 477–482.

———1976, Stratigraphy and distribution of tephra from Glacier Peak (of 12,000 year ago) in the northern Cascade Range, Washington: U.S. Geological Survey Open-File Report 76–186, scale 1:850,000.

———1977, Present and past glaciation threshold in the Cascade Range, Washington, U.S.A.: topographic and climatic controls: Journal of Glaciology, v. 18, p. 101–116.

Price, R.A., Monger, J.W.H., and Roddick, J.A., 1985, Cordilleran cross-section Calgary to Vancouver, *in* Templeman-Kluit, D.J., ed., Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera, Trip 3, GSA Cordillera Meeting, Vancouver, B.C.: Geological Association of Canada, p. 3-1–3-85.

Rady, P.M., 1980, Structure and petrology of the Groat Mountain area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 132 p.

Rasbury, T.E., and Walker, N.W., 1992, Implications of Sm-Nd model ages and single grain U-Pb zircon geochronology for the age and heritage of the Swakane Gneiss, Yellow Aster Complex, and Skagit Gneiss, North Cascades, Wash. [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 7, p. A65.

Reller, G.J., 1986, Structure and petrology of the Deer Peak area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 105 p.

Ristow, R.J., Jr., 1992, Depositional environments and provenance of the Chuckanut Formation (Eocene) in the vicinity of Barlow Pass, north Cascade Range, Washington: Bowling Green, Ohio, Bowling Green State University, M.S. thesis, 160 p.

Robertson, C.A., 1981, Petrology, sedimentation, and structure of the Chuckanut Formation, Coal Mountain, Skagit County, Washington: Seattle, University of Washington, M.S. thesis, 41 p.

Russell, I.C., 1900, A preliminary paper on the geology of the Cascade Mountains in northern Washington: U.S. Geological Survey Annual Report 20, pt. 2, p. 83–210.

Sawyko, L.T.I., and Evans, B.W., 1994, Metamorphism of the Swakane Biotite Gneiss, North Cascades [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 88.

Sevigny, J.H., 1983, Structure and petrology of the Tomyhoi Peak area, North Cascades Range, Washington: Bellingham, Western Washington University, M.S. thesis, 203 p.

Sevigny, J.H., and Brown, E.H., 1989, Geochemistry and tectonic interpretations of some metavolcanic rock units of the western North Cascades, Washington: Geological Society of America Bulletin, v. 101, p. 391–400.

Shapiro, Leonard, and Brannock, W.W., 1962, Rapid analysis of silicate, carbonate, and phosphate rocks, Chapter A in Contributions to Geochemistry, 1961–63: U.S. Geological Survey Bulletin 1144, p. A1–A56.

Silverberg, D.S., 1985, Structure and petrology of the White Chuck Mountain—Mt. Pugh area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 173 p.

Smith, M.T., 1985, Structure and petrology of the Grandy Ridge-Lake Shannon area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 103 p.

———1988, Deformational geometry and tectonic significance of a portion of the Chilliwack Group, northwestern Cascades, Washington: Canadian Journal of Earth Science, v. 25, p. 433–441.

Spurr, J.E., 1901, The ore deposits of Monte Cristo, Washington: U.S. Geological Survey Annual Report 22, pt. 2, p. 777–865.

Stewart, Mary, ©1973, The Hollow Hills: New York, NY, Harper Collins Publishers, p.87.

Streckeisen, A.L., 1973, Plutonic rocks classification and nomenclature recommended by the IUGS subcommission of the systematics of igneous rocks: Geotimes, v. 7, no. 12, p. 331–335.

———1979, Classification and nomenclature of volcanic rocks, lamprophyres, carbonatites, and melilitic rocks: recommendations and suggestions of the IUGS Subcommission on the Systematics of Igneous Rocks: Geology, v. 7, no. 12, p. 331–335.

Street-Martin, L.V., 1981, The chemical composition of the Shuksan Metamorphic Suite in the Gee Point-Finney Creek area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 91 p.

Tabor, R.W., 1958, The structure and petrology of the Magic-Formidable region in the northern Cascades of Washington: Seattle, University of Washington, M.S. thesis, 80 p.

———1960, Diaphthoritic gneiss in the northern Cascades, Washington and its structural significance [abs.]: Geological Society of America Bulletin, 71, pt. 2, p. 2079.

———1961, The crystalline geology of the area south of Cascade Pass, northern Cascade Mountains, Washington: Seattle, University of Washington, Ph.D. dissertation, 205 p.

———1962, The crystalline geology of the area south of Cascade Pass, northern Cascade Mountains, Washington: Dissertation Abstracts, v. 22, p. 3160.

———1963, Large quartz diorite dike and associated explosion breccia, northern Cascade Mountains, Washington: Geological Society of America Bulletin, v. 74, p. 1203–1208.

———1994, Late Mesozoic and possible early Tertiary accretion in western Washington State: the Helena-Haystack mélange and the Darrington-Devils Mountain fault zone: Geological Society of America Bulletin, v, 106, no. 2, p. 217–232.

Tabor, R.W., and Booth, D.B., 1985, Folded thrust fault between major mélange units of the western North Cascades, Washington, and its relationship to the Shuksan thrust [abs.]: Geological Society of America Abstracts with Programs, v. 17, p. 412.

Tabor, R.W., Booth, D.B., Vance, J.A., Ford, A.B., and Ort, M.H., 1988, Preliminary geologic map of the Sauk River 30- x 60-minute quadrangle, Washington: U.S. Geological Survey Open-File Report 88–692.

Tabor, R.W., and Crowder, D.F., 1969, On batholiths and volcanoes—intrusion and eruption of late Cenozoic magmas in the Glacier Peak area, North Cascades, Washington: U.S. Geological Survey Professional Paper 604, 67 p.

Tabor, R.W., Frizzell, V.A, Jr., Booth, D.B., and Waitt, R.B., Jr., 2000, Geologic map of the Snoqualmie Pass 30- by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–2528, scale, 1:100,000.

Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., Waitt, R.B., Whetten, J.T., and Zartman, R.E., 1993, Geologic map of the Skykomish 30- by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1963, scale 1:100,000.

Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., Whetten, J.T., and Waitt, R.B., Jr., 1982a, Preliminary geologic map of the Skykomish River 1:100,000 quadrangle, Washington: U.S. Geological Survey Open-File Report 82–747.

Tabor, R.W., Frizzell, V.A., Jr., Vance, J.A., and Naeser, C.W., 1984, Ages and stratigraphy of lower and middle Tertiary sedimentary and volcanic rocks of the Central Cascades, Washington: applications to the tectonic history of the Straight Creek Fault: Geological Society of America Bulletin, v. 95, no. 1, p. 26–44.

Tabor, R.W., Frizzell, V.A., Jr., Whetten, J.T., Waitt, R.B., Jr., Swanson, D.A., Byerly, G.R., Booth, D.B., Hetherington, M.J., and Zartman, R.E., 1987a, Geologic map of the Chelan 30-minute by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1661, scale1:100,000.

Tabor, R.W., Frizzell, V.A., Jr., Yeats, R.S., and Whetten, J.T., 1982b, Geologic map of the Eagle Rocks-Glacier Peak Roadless Areas (U.S.F.S. RARE II nos. 6031 and 6054), U.S. Geological Survey Miscellaneous Field Studies Map MF–1380–A, scale 1:100,000.

Tabor, R.W., and Haugerud, R.A., 1999, Geology of the North Cascades: A Mountain Mosaic: The Mountaineers, Seattle, 144 p.

Tabor, R.W., Haugerud, R.A., Hildreth, Wes, and Brown, E.H., in press, Geologic map of the Mount Baker 30' by 60' quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series I–2660, scale 1:100,000.

Tabor, R.W., Haugerud, R.A., and Miller, R.B., 1989, Overview of the geology of the North Cascades, *in* American Geophyiscal Union Guidebook, 28th International Geologic Congress Field Trip T307, American Geophysical Union, Washington, D.C., p. 1–33.

Tabor, R.W., Mark, R.K., and Wilson, F.H., 1985, Reproducibility of the K-Ar ages of rocks and minerals: An empirical approach: U.S. Geological Survey Bulletin 1654, 5 p.

Tabor, R.W., Zartman, R.E., and Frizzell, V.A., Jr., 1987b, Possible tectonostratigraphic terranes in the North Cascades crystalline core, Washington, *in* Schuster, E.R., ed., Selected papers on the geology of Washington: Washington State Department of Natural Resources Bulletin 77, p. 107–127.

Vance, J.A., 1957a, The geology of the Swauk River area in the northern Cascades of Washington: Seattle, University of Washington, Ph.D. dissertation, 312 p.

———1957b, The geology of the Swauk River area in the northern Cascades of Washington: Dissertation Abstracts, v. 17, no. 9, p. 1984.

———1985, Early Tertiary faulting in the North Cascades [abs]: Geological Society of America Abstracts with Programs, v. 17, no. 6, p. 415.

Vance, J.A., Clayton, G.A., Mattinson, J.M., and Naeser, C.W., 1987, Early and middle Cenozoic stratigraphy of the Mount Rainier-Tieton River area, southern Washington Cascades, *in* Schuster, J.E., ed., Selected papers on the geology of Washington, Washington Division of Geology and Earth Resources Bulletin 77, p. 269–290.

Vance, J.A., and Dungan, M.A., 1977, Formation of peridotites by deserpentinization in the Darrington and Sultan areas, Cascade Mountains, Washington: Geological Society of America Bulletin, v. 88, p. 1497–1508.

Vance, J.A., Dungan, M.A., Blanchard, D.P., and Rhodes, J.M., 1980, Tectonic setting and trace element geochemistry of Mesozoic ophiolitic rocks in western Washington: American Journal of Science, v. 280–A, p. 359–388.

Vance, J.A., and Miller, R.B., 1981, The movement history of the Straight Creek Fault in Washington State: the last 100 million years (mid-Cretaceous to Holocene) [abs.], *in* symposium of geology and mineral deposits in the Canadian Cordillera, Vancouver, B.C.: Geological Association of Canada, Programme with Abstracts, p. 39–41.

———1992, Another look at the Fraser River-Straight Creek Fault (FRSCF) [abs.]: Geological Society of America Abstracts with programs, v. 24, no. 5, p. 88.

Vance, J.A., Walker, N.W., and Mattinson, J.M., 1986, U/Pb ages of early Cascade plutons in Washington State [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 2, p. 194.

Videgar, F.D., 1975, A geochemical study of the Tertiary volcanic rocks of northwestern Washington: Bellingham, Western Washington University, M.S. thesis, 83 p.

Walker, N.W., and Brown, E.H., 1991, Is the southeast Coast Plutonic Complex the consequence of accretion of the Insular superterrane? Evidence from zircon geochronometry in northern Washington Cascades: Geology, v. 19, p. 714–717.

Waters, A.C., 1932, A petrologic and structural study of the Swakane gneiss, Entiat Mountains, Washington: Journal of Geology, v. 40, no. 6, p. 604–633.

Weaver, C.E., 1912, A preliminary report on the Tertiary paleontology of western Washington: Washington Geological Survey Bulletin 15, 80 p.

Whetten, J.T., Carroll, P.R., Gower, H.D., Brown, E.H., and Pessl, Fred, Jr., 1988, Bedrock geologic map of the Port Townsend quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1988–G, scale 1:100,000.

Whetten, J.T., Dethier, D.P., and Carroll, P.R., 1979, Preliminary geologic map of the Clear Lake NE orthophoto quadrangle, Skagit County, Washington: U.S. Geological Survey Open-File Report 79–1468, 10 p., scale 1:24,000.

———1980a, Preliminary geologic map of the Clear Lake NW quadrangle, Skagit County, Washington: U.S. Geological Survey Open-File Report 80–247, 13 p., scale 1:24,000.

Whetten, J.T., Zartman, R.E., Blakely, R.J., and Jones, D.L., 1980b, Allochthonous Jurassic ophiolite in northwest Washington: Geological Society of America Bulletin, v. 91, pt. 1, no. 6, p. I359–I368.

White, L.D., Maley, C.A., Barnes, Ivan, and Ford, A.B., 1988, Oxygen isotope data for plutonic rocks and gneisses of the Glacier Peak Wilderness and vicinity, northern Cascades, Washington: U.S. Geological Survey Open-File Report 86–76, 36 p.

Wiebe, R.A., 1963, The geology of Mount Pilchuck: Seattle, University of Washington, M.S. thesis, 52 p.

———1968, Plagioclase stratigraphy: a record of magmatic conditions and events in a granitic rock: American Journal of Science, v. 266, p. 690–703.

Wilson, D.L., 1978, The origin of serpentinites associated with the Shuksan Metamorphic Suite near Gee Point, Washington: Bellingham, Western Washington University, M.S. thesis, 53 p.

Yeats, R.S., 1958a, Geology of the Skykomish area in the Cascade Mountains of Washington: Seattle, University of Washington, Ph.D. dissertation, 249 p.

———1958b, Geology of the Skykomish area in the Cascade Mountains of Washington [abs.]: Dissertation Abstracts, v. 19, no. 4, p. 775.

Yeats, R.S., and Engels, J.C., 1971, Potassium-argon ages of plutons in the Skykomish-Stillaguamish areas, north Cascades, Washington: U.S. Geological Survey Professional Paper, 750-D, p. D34–D38.

Yeats, R.S., Erikson, E.H., Jr., Frost, B.R., Hamond, P.E., and Miller, R.B., 1977, Structure, stratigraphy, plutonism, and volcanism of the central Cascades, Washington, *in* Brown, E.H., and Ellis, R.C., eds., Geological Excursions in the Pacific Northwest, Geological Society of America Annual Meeting, Seattle, p. 265–308.

Zen, E-an, and Hammarstrom, J.M., 1984, Magmatic epidote and its petrologic significance: Geology, v. 12, p. 515–518.

Table 1. *Fossils and fossil localities in the Sauk River quadrangle, Washington*
[Some fossil localitites appear to be in Quaternary units because bedrock exposures are too small to show at this map scale]

Map No.	Sample No.	Latitude N	Longitude W	Description	Age	Reference
				Western melange belt		
1f	VP 39-84	48°14.6'	121°54.1'	Radiolarians in chert	Late Jurassic	C.D. Blome (written commun., 1985)
2f	RWT 5-83	48°02.5'	121°50.7'	Pelecypod in concretion in argillite	Late Jurassic	J.W. Miller (written commun., 1984)
3f	KO 83-47	48°02.9'	121°40.0'	Radiolarians in chert	Mesozoic	C.D. Blome (written commun., 1984)
4f	KO 83-52	48°02.6'	121°39.6'	Radiolarians in chert	Mesozoic	C.D. Blome (written commun., 1984)
5f	RWT 19-83	48°05.4'	121°49.3'	Radiolarians in chert and argillite	Mesozoic	C.D. Blome (written commun., 1984)
6f	---	48°07.0'	121°55.6'	Fusulinids in limestone	Late Permian	Danner (1966, p. 318-322)
7f	---	48°06.2'	121°54.7'	Fusulinids in limestone	Late Permian	Danner (1966, p. 322-323)
8f	WA 134	48°08.4'	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 commun., 1984)
10f	RWT 436-84	48°12.3'	121°47.3'	Radiolarians in chert	Mesozoic, (Early? To Middle Jurassic)	C.D. Blome (written commun., 1984)
11f	FMZ 41-83	48°04.7'	121°51.7'	Radiolarians in chert	Early Jurassic	C.D. Blome (written commun., 1984)
12f	---	48°02.7'	121°48.9'	Fusulinids and algae in limestone	Mid-Permian	Danner (1966, p. 324-325), Wiebe (1963, p. 6), Johnson and Danner (1966, p. 427-428)
				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 commun., 1986)
14f	FMZ 75-83	48°08.2'	121°51.9'	Radiolarians in chert	Early Jurassic	C.D. Blome (written commun., 1984)
15f	KO 83-72	48°09.1'	121°54.2'	Radiolarians in chert	Mesozoic, (Jurassic?)	C.D. Blome (written commun., 1984)
16f	RWT 427-84	48°13.3'	121°53.5'	Radiolarians in chert	Mesozoic, (Late Triassic?)	C.D. Blome (written commun., 1986)
17f	RWT 116-83	48°12.3'	121°53.9'	Radiolarians in chert	Paleozoic	C.D. Blome (written commun., 1984)
18f	---	48°10.4'	121°57.0'	Fusulinids in limestone	Late Permian	Danner (1966, p. 315-317)
19f	---	48°12.0'	121°59.5'	Fusulinids in limestone	Late mid-Permian	Danner (1966, p. 311-315)
20f	JTW 77-15A,B	48°11.9'	121°59.5'	Radiolarians	Triassic	D.L. Jones and J.T. Whetten (written commun., 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 commun., 1985)

Table 1. *Fossils and fossil localities in the Sauk River quadrangle, Washington—continued*

Map No.	Sample No.	Latitude N	Longitude W	Description	Age	Reference
				Eastern melange belt		
23f	RWT 39-84	48°14.0'	121°44.3'	Radiolarians in chert	Jurassic	C.D. Blome (written commun., 1986)
24f	RWT 92-83	48°05.0'	121°40.4'	Radiolarians in chert	Mesozoic	C.D. Blome (written commun., 1984)
				Eastern melange belt: chert unit		
25f	RWT 326-84	48°15.4'	121°45.8'	Radiolarians in chert	Mesozoic, (Triassic?)	C.D. Blome (written commun., 1986)
26f	RWT 327-84	48°15.4'	121°46.0'	Radiolarians in chert	Late Triassic	C.D. Blome (written commun., 1985)
27f	RWT 153-84	48°14.3'	121°43.9'	Radiolarians in chert	Mesozoic	C.D. Blome (written commun., 1985)
28f	RWT 154-84	48°14.3'	121°43.7'	Radiolarians in sheared chert	Mesozoic, (Jurassic?)	C.D. Blome (written commun., 1985)
				Eastern melange belt: volcanic rocks of White Horse Mountain		
29f	RWT 155-84	48°13.9'	121°43.0'	Conodonts in marble	Late Triassic	K.S. Schindler and A.G. Harris (written commun., 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 commun., 1985)
				Helena-Haystack melange		
31f	RWT 216-83	48°19.9'	121°53.2'	Radiolarians in chert	Mesozoic, (Triassic?)	C.D. Blome (written commun., 1984)
32f	RWT 460-85	48°23.0'	121°59.9'	Ostracods	Indeterminate	C.D. Blome (written commun., 1986)
				Chilliwack Group of Cairnes (1994) 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 commun., 1985)
				Bell Pass melange		
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 commun., 1986)

Table 2. *Radiometric analyses of rocks in the Sauk River quadrangle and vicinity, Washington*

[All new ages calculated on the basis of 1976 IUGS decay and abundance constants. K-Ar ages from reports earlier than 1976 corrected after Dalrymple (1979). All fission-track ages (FT) calculated with F = 7.03 x $10^{-17}yr^{-1}$. Errors on single new K-Ar ages referenced to this report 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: $^{206}Pb/^{238}U$; $^{207}Pb/^{235}U$; $^{207}Pb/^{206}Pb$; $^{208}Pb/^{232}Th$. -- = no data. Where two age data sets are reported, each is followed by a notation of magnetic suseptibilty (m or nm) and approximate mesh size or grain size in μm in parentheses. Constants: $\lambda^{238}U$ = 1.55125 x $10^{-10}yr^{-1}$; $\lambda^{235}U$= 9.8485 x $10^{-10}yr^{-1}$; $\lambda^{232}Th$ = 4.9475 x 10^{-1}; $^{238}U/^{235}U$ = 137.88. Isotopic composition of common lead assumed to be $^{204}Pb:^{206}Pb:^{207}Pb:^{208}Pb$ = 1:18:40:60:38.20. Map numbers in parentheses are not on this map]

Map No.	Sample No.	Method	Material	Latitude (North)	Longitude (West)	Unit	Age (Ma)	Map unit	Reference
1	JV218	FT	Zircon	48°09.0'	121°03.7'	volcanic rocks of Gamma Ridge	2.0±0.3		Table 4
2	JV219	FT	Zircon	48°09.2'	121°03.6'	do.	1.6±0.3		
3	81F345A	K-Ar	Hornblende	48°06.4'	121°04.6'	Cool Glacier stock	3.90±3		R.J. Fleck (written commun. to A.B. Ford, 1987)
		K-Ar	Biotite				3.70±1		
4	80GX2189	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)
		K-Ar	Biotite				15.0±0.1		
5	80L19B	K-Ar	Hornblende	48°23.7'	121°16.5'	do.	14.4±0.2		Do.
		K-Ar	Biotite				14.5±0.1		
6	818-5C	K-Ar	Hornblende	48°23.2'	121°17.2'	do.	14.5±0.2		Do.
		K-Ar	Biotite				13.8±0.1		
7	82T2A	K-Ar	Hornblende	48°21.4'	121°13.4'	do.	14.0±0.9	Dike	Do.
		K-Ar	Biotite				14.4±0.3		
8	PM 23	K-Ar	Biotite	48°28'	121°04'	Cascade Pass dike	18.6±1		Engels and others (1976)
9	RWT479-67	K-Ar	Hornblende	48°28.6'	121°03.9'	do.	18.5±1.5		
		K-Ar	Biotite				18.8±1.0		
10	827-5A	K-Ar	Hornblende	48°28.7'	121°04.0'	do.	16.1±0		R.J. Fleck (written commun. to A.B. Ford, 1987)
		K-Ar	Biotite				17.9±0.1		
11	818-5F	K-Ar	Hornblende	48°21.9'	121°03.9'	Cloudy Pass batholith	21.3±1.3	South Cascade Glacier stock	Do.
		K-Ar	Biotite				23.3±0.2		
12	81F307A	K-Ar	Hornblende	48°06.6'	121°09.3'	do.	20.1±2.	Sitkum Creek stock	Do.
		K-Ar	Biotite				20.8±1.1		
13	JTW79-219	K-Ar	Biotite	48°00.1'	121°22.0'	Grotto batholith	24.1±0.3	Monte Cristo stock	Tabor and others (1982a)
14	RWT13-68	K-Ar	Hornblende	48°02.4'	121°22.6'	do.	24.5±1.0		Yeats and Engels (1971, p. D36)
		K-Ar	Biotite				24.8±1.1		
15	JV-159	K-Ar	Hornblende	48°10.3'	121°22.0'	do.	28.5±1.0	Dead Duck pluton: stream boulder	Table 3
		K-Ar	Biotite				27.2±0.5		
		FT	Zircon				26.0±3.0		Table 4
16	827-6G	K-Ar	Hornblende	48°09.2'	121°21.9'	do.	25.0±0.3	Dead Duck pluton	R.J. Fleck (written commun. to A.B. Ford, 1987)
		K-A	Biotite				25.7±0.2		
(17)	none	K-Ar	Whole rock	location uncertain		Vesper Peak stock	32.7±2	Composite chip sample	Griffis (1977, p. 96)
(18)	none	K-Ar	Whole rock	location uncertain		do.	28.2±1	Mineralized tonalite clast in Sunrise breccia pipe	T. Gates (in Griffis, 1977, p. 203)

Table 2. *Radiometric analyses of rocks in the Sauk River quadrangle and vicinity, Washington—continued*

Map No.	Sample No.	Method	Material	Latitude (North)	Longitude (West)	Unit	Age (Ma)	Map unit	Reference
19	RWT48-84	U/Pb	Zircon	48°09.6'	121°37.0'	Squire Creek stock	35.7;36.0;----;---- (coarse)		Vance and others (1986) and N. Walker (written commun., 1985)
	(JV-317)						35.0;35.3;----;---- (fine)		
		K-A	Hornblende				42.1±3.5	Age too old; hornblende contaminated by mafic inclusions	Table 3
		K-Ar	Biotite				33.4±0.4		
		FT	Zircon				33.6±3.4		Table 4
20	PM 32	K-Ar	Hornblende	48°10.2'	121°35.5'	do.	35.1±1.8		Yeats and Engels (1971, p. D36)
		K-Ar	Biotite				35.1±1.4		
21	JV-289	K-Ar	Hornblende	48°21.8'	121°51.5'	Granite Lakes pluton	38.5±7.0		Table 3
22	DB-98-85	K-Ar	Hornblende	48°21.6'	121°51.3'	do.	36.7±4.0		Do.
		FT	Zircon				30.2±3.5		Table 4
23	RWT12-68	K-Ar	Hornblende	48°06.2'	121°57.2'	Granite Falls stock	44.4±1.4		Yeats and Engels (1971, p. D36)
24	RWT15-84	FT	Zircon	48°18.4'	121°58.1'	Barlow Pass Volcanics of Vance (1957a,b)	45.7±4.6		Table 4
25	JV-229	FT	Zircon	48°09.8'	121°30.3'	do.	43.9±4.4		Do.
26	JV-1357	FT	Zircon	48°04.1'	121°29.3'	do.	34.9±3.6	Age probably reset	Do.
27	JV-43	FT	Zircon	48°03.3'	121°28.8'	do.	46.1±4.5		Do.
28	JV-169	FT	Zircon	48°22'	121°47'	do.	44.7±4.0	Bentonite bed in sandstone	Cruver (1983, p. 38)
29	JV-48	FT	Zircon	48°21.5'	121°45.3'	do.	35.2 ±3.5	Age possibly reset; see text	Table 4
30	RWT373-85	K-Ar	Hornblende	48°04.9'	121°25.8'	Sauk ring dike	40.5±5.4	Dike swarm in volcanic rocks	Table 3
		FT	Zircon				32.3±4		Table 4
31	JH80-66A	K-Ar	Hornblende	48°02.5'	121°25.9'	do.	36.8±9.2	Landslide block, suspect age	Tabor and others (1993)
	JH80-66B	K-Ar	Hornblende	48°02.5'	121°25.9'	do.	23.3±7		
32	27	K-Ar	Whole rock	48°24.6'	121°46.7'	Basalt dike(?)	46.0±8		Bechtel, Inc. (1979, Appendix F)
33	RWT20-68	K-Ar	Biotite	48°03.7'	121°48.2'	Pilchuck Mountain stock	48.8±1.4		Yeats and Engels (1971, p. D36)
		K-Ar	Muscovite				49.2±1.7		
34	JV 406	FT	Zircon	48°03.7'	121°48.2'	do.	45.2±3.5		Table 4
35	FMZ-22-83	K-Ar	Sanidine	48°03.4'	121°51.1'	Rhyolite of Hanson Lake	45.7±0.8	Probably a minimum age	Table 3
36	JV-53	K-Ar	Biotite	48°03.4'	121°51.0'	do.	52.8±2.0	Geochron age	R.L. Gresens, (written commun., 1978)
		FT	Zircon				33.6±3.4	Suspect age	C.W. Naeser (written commun., 1977)
37	26	K-Ar	Hornblende	48°22.5'	121°51.3'	Dioritic stock(?) intruding unit Tbs	53.0±8	Suspect age	Bechtel, Inc. (1979, Appendix F)
38	80L38A	K-Ar	Biotite	48°24.5'	121°18.3'	Cyclone Lake pluton	26.8±0.1	Ae reset by Mount Buckindy pluton	R.J. Fleck (written commun., 1987 to A.B. Ford)
		K-Ar	Muscovite				57.9±0.3		

Table 2. *Radiometric analyses of rocks in the Sauk River quadrangle and vicinity, Washington—continued*

Map No.	Sample No.	Method	Material	Latitude (North)	Longitude (West)	Unit	Age (Ma)	Map unit	Reference
39	818-5E	K-Ar	Biotite	48°25.0'	121°17.0'	do.	28.7±0.1	do.	Do.
		K-Ar	Muscovite				57.3±0.3		
40	818-5D	K-Ar	Biotite	48°23.4'	121°17.4'	do.	14.3±0.1	do.	Do.
41	RWT185-86	K-Ar	Biotite	48°25.4'	121°14.7'	do.	55.5±1.6		Table 3
			Muscovite				58.8±0.9		
42	80N33D	K-Ar	Hornblende	48°22.1'	121°10.0'	Tonalitic gneiss of Bench Lake	58.9±0.3		R.J. Fleck (written commun., 1987 to A.B. Ford)
		K-Ar	Biotite				51.9±0.3		
43	818-5G	K-Ar	Hornblende	48°21.5'	121°10.4'	do.	64.2±1.2		Do.
		K-Ar	Biotite				44.7±0.8		
44	DFC285-62	K-Ar	Hornblende	48°14.8'	121°05.6'	Sulphur Mountain pluton	72.2±2.1		Engels and others (1976)
		K-Ar	Biotite				59.2±1.7		
45	80R117A	K-Ar	Biotite	48°14.1'	121°07.7'	do.	57.5±0.3		R.J. Fleck (written commun., 1987, to A.B. Ford)
46	80R118B	K-Ar	Pyroxene	48°14.8'	121°07.5'	do.	286.0±4.3	Excess argon	
47	818-6A	K-Ar	Hornblende	48°15.3'	121°02.8'	do.	63.2±1.1	Age reset by Cloudy Pass batholith	Do.
		K-Ar	Biotite				26.1±0.5		
48	818-6B	K-Ar	Hornblende	48°14.3'	121°06.8'	do.	59.5±0.5	do.	Do.
		K-Ar	Biotite				54.2±0.4		
49	GP88-1	U-Pb	Zircon	48°14.5'	121°08.6'	do.	95.9; 96.0; 104±10; ---(nm, 64-75 μm)		Walker and Brown (1991) and N.W. Walker (written commun. 1991)
							96.3; 96.3; 96±8;--- (nm, 75-100 μm)		
50	RWT29-86	K-Ar	Biotite	48°29.5'	121°20.9'	Jordan Lakes pluton	57.6±1.2		Table 3
51	81F109A	K-Ar	Hornblende	48°27.2'	121°19.0'	do.	73.7±0.5		R.J. Fleck (written commun., 1987, to A.B. Ford)
		K-Ar	Biotite	58.9±0.3					
52	827-6A	K-Ar	Biotite	48°26.6'	121°19.6'	do.	61.1±0.3		
53	827-6B	K-Ar	Biotite	48°27.8'	121°21.4'	do.	61.4±0.3		Do.
54	164-17	U-Pb	Zircon	48°28.4'	121°19.9'	do.	73.3; 73.7; 91±5;--- (nm, 100-150 μm)		Walker and Brown (1991)
							73.6; 74.1; 89±4;--- (nm, 75-100 μm)		
55	RWT413-85	K-Ar	Biotite	48°10.4'	121°19.5'	Chiwaukum Schist	75.7±1.5		Table 3
56	PM88-1	U-Pb	Zircon	48°14.0'	121°21.2'	Nason Ridge Migmatitic Gneiss	95.7; 97.2; 147±5;-- (nm, 250 + μm)		Walker and Brown (1991) and N.W. Walker (written commun., 1991)
							91.5; 92.2; 134±5;-- (nm, 75-100 μm)		
57	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		

Table 2. *Radiometric analyses of rocks in the Sauk River quadrangle and vicinity, Washington—continued*

Map No.	Sample No.	Method	Material	Latitude (North)	Longitude (West)	Unit	Age (Ma)	Map unit	Reference
58	RWT211-62	K-Ar	Biotite	48°03.4'	121°07.2'	do.	29.0±0.8	Age reset by Cloudy Pass batholith	Do.
59	827-6D	K-Ar	Biotite	48°30.0'	121°12.0'	Hidden Lake stock	37.6±0.3		R.J. Fleck (written commun., 1987, to A.B. Ford)
60	827-6E	K-Ar	Biotite	48°29.6'	121°10.9'	do.	46.4±0.		Do.
61	80N41A	K-Ar	Hornblende	48°20.5'	121°22.0'	Chaval pluton	78.9±0.5	do.	
62	80S36A	K-Ar	Hornblende	48°20.9'	121°18.1'	do.	81.7±0.4	do.	
63	818-5A	K-Ar	Hornblende	48°20.3'	121°18.4'	do.	72.3±3.1	do.	
		K-Ar	Biotite				54.4±1.3		
64	818-5B	K-Ar	Hornblende	48°22.3'	121°19.6'	do.	63.8±0.7	do.	
65	164-35	U-Pb	Zircon	48°24.7'	121°23.5'	do.	91.6; 92.0; 96±6;--- (m, 100-150 μm)		Walker and Brown (1991) and N.W. Walker (written commun. 1991)
66	SM88-2	U-Pb	Zircon	48°19.8'	121°20.2'	do.	91.6; 92.0; 100±5;-- (nm, 150-250 μm)		
67	SM88-1	U-Pb	Zircon	48°19.6'	121°19.2'	do.	92.7; 93.8; 106±8;-- (nm, 150-250 μm)	Dike in Chiwaukum Schist	Do.
		U-Pb	Zircon				92.5; 93.5; 102±9;-- (nm, 75-100 μm)		
68	DFC60-62	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		
69	RH85-518A	U-Pb	Zircon	48°01.7'	121°00.1'	do.	92.1; 92.4; 103±5;-- (nm, 64-100 μm)		Walker and Brown (1991) and R.A. Haugerud (written commun., 1992)
							92.2; 92.4; 97±5;--- (nm, 40-64 μm)		
70	JV-529	U-Pb	Zircon	48°09'	121°17'	Sloan Creek plutons	90.0; 90.6; 106.0;--- (-100+170)	Location uncertain	W. Hoppe (written commun., 1981)
		K-Ar	Hornblende				77.1±8.9		Table 3
		K-Ar	Biotite				78.4±1.2		
		FT	Zircon				58.1±5.9		Table 4
71	RD 61-10	FT	Zircon	48°06.1'	121°21.3'	do.	52.0±5.5		Table 4
72	JTW79-200	U-Th-Pb	Zircon	48°02.4'	121°20.3'	do.	89.7; 89.8; 91.2; 89.8 (-100+150)		Tabor and others (1982a, 1993)
							89.4; 89.5; 93.1; 88.2 (-200+250)		
		K-Ar	Hornblende				89.9±2.1		
		K-Ar	Biotite				75.3±1.0		

Table 2. *Radiometric analyses of rocks in the Sauk River quadrangle and vicinity, Washington—continued*

Map No.	Sample No.	Method	Material	Latitude (North)	Longitude (West)	Unit	Age (Ma)	Map unit	Reference
73	SP89-2	U-Pb	Zircon	48°03.3'	121°20.5'	do.	90.1; 90.2; 93±6;--- (nm, 150-250 μm)		Walker and Brown (1991) and Longtine (1991)
							90.2; 90.8; 97±6;--- (nm, 100-150 μm)		
74	SP89-1	U-Pb	Zircon	48°03.4'	121°20.5'	do.	90.4; 90.5; 93±4;--- (nm, 100-150 μm)		
							90.2; 90.6; 100±5; -- (nm, 75-100 μm)		
75	RT-58-63	K-Ar	Hornblende	48°24.9'	121°05.1'	Magic Mountain Gneiss	117.4±3.5		Table 3
76	RWT176-86	U-Pb	Zircon	48°27.1'	121°03.2'	do.	195; 197; 223; --- (-150+250)		J.S. Stacey (written commun., 1987)
							206; 209; 240; --- (-250)		
77	PG 135-88	FT	Zircon	48°19.0'	121°36.1'	Easton Metamorphic Suite	97.2±9.5		Table 4
78	PM2a	K-Ar	Muscovite	48°28'	121°56'	do.	150.0±5		Armstrong and Misch (1987, p. 94)
79	38S	K-Ar	Muscovite	48°24.8'	121°47.4'	do.	128.0±4	Graphitic-qtz-alb- musc schist	Brown and others (1982, p. 1095)
80	67-53	K-Ar	Hornblende	48°26.1'	121°50.8'	do.	148.0±5	Epidote amphibolite	Do.
81	67-45B	K-Ar	Muscovite	48°26.1'	121°50.7'	do.	164.0±6	do.	Do.
82	RF-75120	K-Ar	Crossite	48°25.8'	121°45.3'	do.	104.5±7		Armstrong and Misch (1987, p. 94)
83	RF-75098 RF-75116	K-Ar	Whole rock	48°12.9'	121°23.5'	do.	97.2±2		Do.
84	81F192A	K-Ar	Blue amphibole	48°13.2'	121°23.5'	do.	110.9±1.3	Minimum metamorphic age	R.J. Fleck (written commun., to A.B. Ford, 1987)
85	JV-243	U-Pb	Zircon	48°09.5'	121°32.1'	Helena-Haystack mélange	146.7; 147.1; 155;-- (coarse)	Tonalite and amphibolite block	N. Walker (written commun., 1985)
							148.7; 149.0; 155; -- (fine)		
		K-Ar	Hornblende				128.6±6.0		Table 3
		FT	Zircon				137.7±14		Table 4
86	JV-MC (RF-75096)	K-Ar	Hornblende	48°10.2'	121°32.0'	do.	141±6	do.	Vance and others (1980, p. 365); Armstrong and Misch (1987, p. 94)
87	JV-236	U-Pb	Sphene	48°11.4'	121°33.4'	do.	36.5	Meta-rhyolite block	N. Walker (written commun., 1985)
		K-Ar	Muscovite				89.7±3.1	do.	R.L. Armstrong (written commun., 1984)
		FT	Sphene				37.3±6.0	Hydrothermal?	Table 4
88	3a	K-Ar	Plagioclase	48°20.5'	121°59.3'	do.	133.±10	Metagabbro block	Bechtel, Inc. (1979, Appendix F)
	3b	K-Ar	Pyroxene	48°20.5'	121°59.3'	do.	164.±24		

Table 2. *Radiometric analyses of rocks in the Sauk River quadrangle and vicinity,Washington—continued*

Map No.	Sample No.	Method	Material	Latitude (North)	Longitude (West)	Unit	Age (Ma)	Map unit	Reference
89	none	U-Pb	Zircon	48°23.9'	121°51.5'	do.	168	Metadacite block; loc. uncertain	N. Walker (in Brown and others, 1987)
90	RWT263-83	K-Ar	Hornblende	48°05.7'	121°40.3'	Eastern mélange belt	121.4±4.2	Amphibolite block	Table 3
91	JV-339	FT	Zircon				125.9±13	Tonalite block	Table 4
92	JTW 76-204	U-Th-Pb	Zircon	48°11.5'	121°56.3'	Trafton terrane	296; 299; 327; 350 (-50+100) 295; 297; 317; 304 (200+270)	Tonalite block	R.E. Zartman (written commun., 1983)
93	RWT51-84	K-Ar	Blue amphibole	48°10.2'	121°25.3'	Bell Pass mélange	214.4±15.6	Blocks of siliceoous schist of Vedder Complex of Armstrong and others (1983)	Table 3
		K-Ar	Muscovite				266.9±3.0		
	RWT52-84	K-Ar	Muscovite	48°10.2'	121°25.3'	do.	249.4±2.7		Do.
	RWT53-84	K-Ar	Muscovite	48°10.2'	121°25.3'	do	238.1±2.8		Do
94	JV-PM	U-Th-Pb	Zircon	48°16.8'	121°27.6'	do.	370; 374; 398; 402 (-100+150) 366; 371; 402; 399 (-200+250)	Siliceous gneiss of Yellow Aster Complex of Misch (1966)	R. E. Zartman (written commun., 1983)
		K-Ar	Hornblende				406±17	do. Geochron age	R.B. Forbes (written commun., 1980)
		FT	Zircon				178±18		Vance and others (1980, p. 364)

Table 3. *New K-Ar ages from the Sauk River quadrangle and vicinity, Washington*

[All USGS K-Ar ages calculated on the basis of 1976 IUGS decay and abundance constants; errors on single K-Ar ages are based on an empirically derived curve relating coefficient of variation in the age to percent radiogenic argon (Tabor and others, 1985). K_2O was determined by flame photometry by analysts Paul Klock, Sarah Neil, Terry Fries, L. Espos, S. MacPherson, and Mathew Taylor]

Map No.	Sample No.	Mineral	K_2O percent	^{40}Ar Rad moles/gm×10^{-10}	^{40}Ar Rad (percent)	Age (Ma)
15	JV-159	Hornblende	0.611, 0.623, 0.610, 0.60	0.253	40.4	28.5±1.0
		Biotite	8.40, 8.45	3.320	71.4	27.2±0.5
19	RWT48-84	Hornblende	0.339, 0.336	0.227, 0.196, 0.198	16.5, 22.1, 19.0	42.1±3.5
		Biotite	8.81, 8.80	4.314, 4.220	70.1, 71.3	33.4±0.4
21	JV-289	Hornblende	0.235, 0.237	0.156, 0.108	4.3, 6.6	38.5±7.0
22	DB 98-85	Hornblende	0.245, 0.247, 0.239, 0.249	0.116, 0.145	6.7, 8.3	36.7±4.0
30	RWT373-85	Hornblende	0.239, 0.232	0.139	9.5	40.5±5.4
35	FMZ-22-83	Sanidine	3.89, 3.63	2.459	63.0	44.9±2.4
41	RWT185-86	Biotite	9.34, 9.32	7.573	22.7	55.5±1.6
		Muscovite	11.05, 10.98	9.481	79.9	58.8±0.9
50	RWT29-86	Biotite	9.64, 9.63	8.116	79.9	57.6±1.2
55	RWT413-85	Biotite	9.00, 8.99	10.008	63.6	75.7±1.5
70	JV-529	Hornblende	0.682, 0.677, 0.683, 0.685	0.682, 0.864	30.9, 73.1	77.1±8.9
75	RT-58-63	Hornblende	0.220, 0.218	0.382	49.5	117.4±3.5
85	JV 243	Hornblende	0.259, 0.247, 0.248, 0.245	0.479	32.1	128.6±6.0
90	RWT263-83	Hornblende	0.239, 0.234	0.428	39.3	121.4±4.2
93	RWT51-84	Glaucophane	0.337, 0.339	1.023, 1.193	42.1, 58.9	214.4±15.6
		Muscovite	9.56, 9.50	39.446	92.1	266.9±3.0
	RWT52-84	Muscovite	9.27, 9.31	35.771	92.3	249.4±2.7
	RWT53-84	Muscovite	9.43, 9.44	34.575	90.6	238.1±2.8

NOTE: Tables 5 and 6 inserted in text, p. 10 and p. 22, respectively.

Table 4. *Data for new zircon fission-track ages from the Sauk River quadrangle, Washington*

[Ages calculated with F = $7.03\times10^{-17}yr^{-1}$]

Map No.	Sample No.	Reactor Run No.	Tracks counted		Track density $\times10^6/cm^2$		Calculated phi$\times10^{15}n/cm^2$	Grains counted	Age (Ma)
			Fossil	Induced	Fossil	Induced			
2	JV218	1/8/81 #29	407	224	1.14	17.56	1.02	10	2.0±0.3
3	JV219	6/5/86 #6	149	2,842	1.70	32.15	1.00	7	1.6±0.3
15	JV-159	4/11/80 #18	1,912	2,131	5.06	5.64	0.97	10	26.0±3.0
19	JV-317	4/7/85 #17	945	920	3.76	3.66	1.10	8	33.6±3.4
22	DB-98-85	3/17/89b #2	784	767	2.24	2.19	0.99	8	30.2±3.5
24	RWT15-84	4/17/85 #23	1,166	822	6.09	4.29	1.08	7	45.7±4.6
25	JV-229	12/13/82 #21	758	499	3.99	2.63	0.97	6	43.9±4.4
26	JV-1357	1/19/75 #8	948	1,104	8.96	10.43	1.36	5	34.9±3.6
27	JV-43	1/28/77 #4	1,163	767	3.99	2.64	1.02	10	46.1±4.5
28	JV-169	4/10/80 #21	3,692	2,367	7.25	4.65	0.96	20	44.7±4.0
29	JV-48	1/28/77 #5	1,809	1,548	7.90	6.75	1.01	9	35.2±3.5
30	RWT373-85	3/26/87 #12	686	647	3.01	2.84	1.02	7	32.3±4
34	JV-406	3/4/88 #22	1,641	1,136	10.31	7.14	1.05	8	45.2±4.5
70	JV-529	4/11/80 #24	1,359	655	12.74	6.14	0.94	8	58.1±5.9
71	RD 61-10	3/17/89b #12	1,645	911	5.66	3.12	0.96	9	52.0±5.5
77	PG135-88	3/26/87 #6	2,232	689	9.00	2.78	10.00	10	97.2±9.5
85	JV-243	12/13/82 #25	1,591	341	9.58	2.05	0.99	7	137.7±14
87	JV-236*	3/23/82 #18	117	86	0.37	0.27	0.92	6	37.3±6.0
91	JV-339	6/5/86 #21	1,845	461	14.76	3.68	1.06	6	125.9±13

* Sphene