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U.S. GEOLOGICAL SURVEY

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

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INTRODUCTION

From the eastern-most edges of suburban Seattle, the Skykomish River quadrangle stretches east across the low rolling hills and broad river valleys of the Puget Lowland, across the forested foothills of the North Cascades, and across high meadowlands to the bare rock peaks of the Cascade crest. The quadrangle straddles parts of two major river systems, the Skykomish and the Snoqualmie Rivers, which drain westward from the mountains to the lowlands (figs. 1 and 2).

In the late 19th Century mineral deposits were discovered in the Monte Cristo, Silver Creek and the Index mining districts within the Skykomish River quadrangle. Soon after came the geologists: Spurr (1901) studied base- and precious-metal deposits in the Monte Cristo district and Weaver (1912a) and Smith (1915, 1916, 1917) in the Index district. General geologic mapping was begun by Oles (1956), Galster (1956), and Yeats (1958a) who mapped many of the essential features recognized today. Areas in which additional studies have been undertaken are shown on figure 3. Our work in the Skykomish River quadrangle, the northwest quadrant of the Wenatchee 1° by 2° quadrangle, began in 1975 and is part of a larger mapping project covering the Wenatchee quadrangle (fig. 1).

Tabor, Frizzell, Whetten, and Booth have primary responsibility for bedrock mapping and compilation. Zartman carried out the zircon uranium-thorium-lead (U-Th-Pb) isotopic analyses and advised in the interpretation of isotope ages. Booth mapped most of the unconsolidated deposits of the western half of the quadrangle. Waitt mapped most of the unconsolidated deposits of the eastern half; in the eastern two-thirds of the map area, mostly along the crest of the mountains, talus and other morphologically distinct surficial units were mapped primarily from aerial photographs. Details of the unconsolidated deposits in the western half of the map are shown on a separate map (Booth, 1990).

ACKNOWLEDGMENTS

Our field work was helped considerably by Eduardo Rodriguez (1975), Bill Gaum and Kim Marcus (1977), Sam Johnson, Brett Cox, Elizabeth Lincoln Mathieson and Nora Shew (1978), P. Thompson Davis (1979), M. Jean Hetherington and Joe Marquez (1979-80), Jim Talpey, Paul Carroll, and Kathy Lombardo (1979), Steve Connelly, Stephen A. Sandberg, Susan Cook, Fredrika Moser, and Fred Beall (1981). Jean Hetherington, Steve Connelly, Kathleen Ort, and Fred Zankowsky helped in the office and laboratory. Dennis H. Sorg supplied clean mineral concentrates for radiometric dating.

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Doug Bucklew (1978), John Nelson (1978), Tim Bonin (1979), and the late Jack Johnson (1979-81) piloted helicopters; we are indebted to their skill.

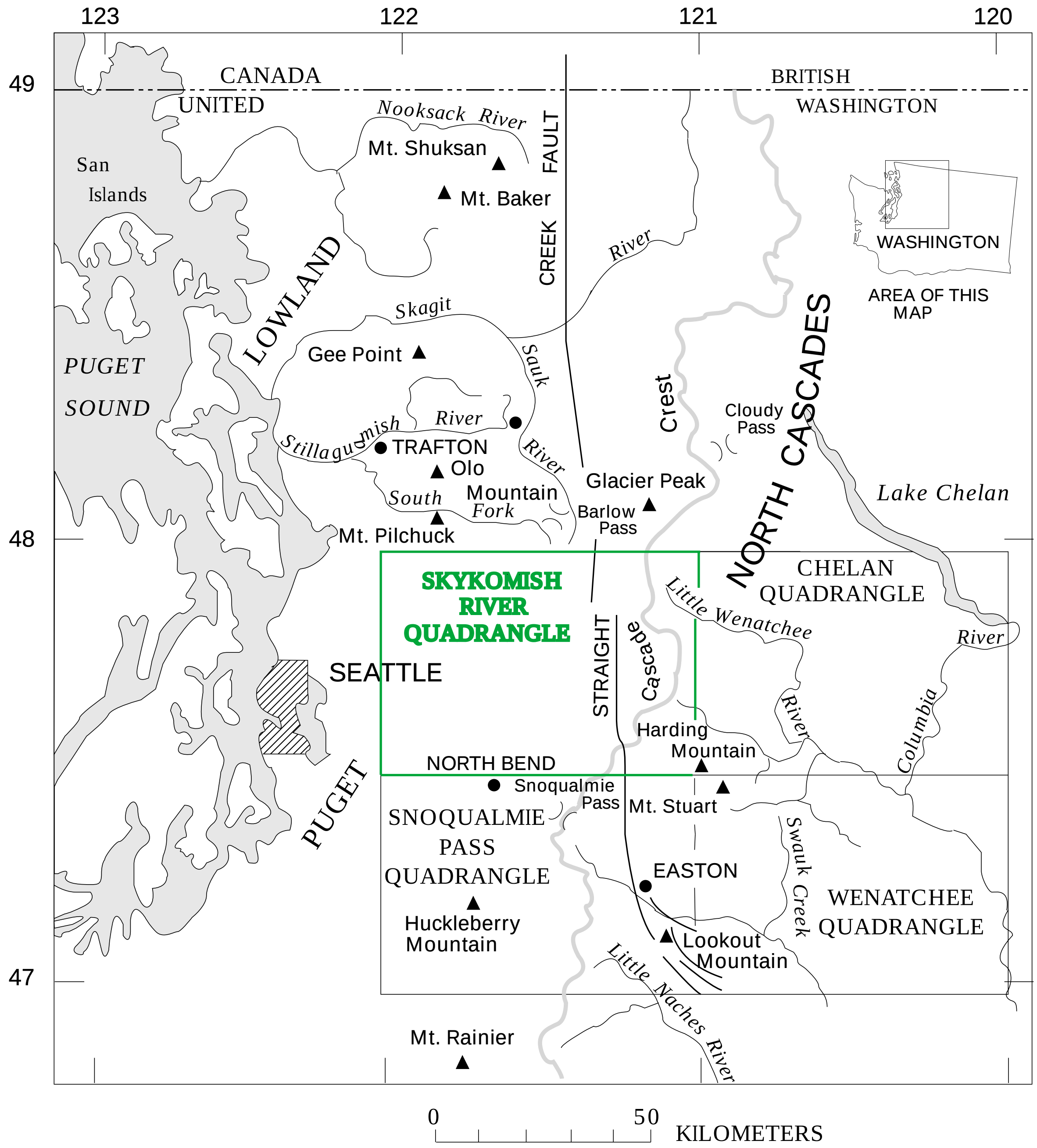

Figure 1. Index map of northwestern Washington showing the Skykomish River and three adjoining 30- by 60 minute quadrangles that compose the Wenatchee 1° by 2° quadrangle (original in black and white only).

Discussions with John Berti, Erik Erikson, Bernard Evans, Ken Fox, Ralph Haugerud, James McDougall, Robert Miller, James Minard, Joseph Vance, Robert Yeats, and Jim Yount have been highly stimulating and useful. Erik Erikson supplied mineral separates for potassium-argon (K-Ar) radiometric dating of rocks from the Snoqualmie batholith.

SUMMARY OF GEOLOGIC HISTORY

The Skykomish River quadrangle is almost bisected by the Straight Creek fault (figs. 1, 4) and contains evidence of the fault's Tertiary history. This major structure extends from central Washington into Canada and has been interpreted to have from 80 to 192 km of right-lateral strike-slip offset (Misch, 1977; Vance and Miller, 1981; Monger, 1985). Within the quadrangle, Neogene plutons have intruded the fault and have obscured its exact location, but a complex of smaller faults cutting Tertiary rocks as well as fault-bounded pre-Tertiary units suggest the Tertiary influence of this major structure. The Evergreen fault bounds the east side of this fault complex, and it may represent a late en echelon strand of the Straight Creek fault.

In general, the Straight Creek fault separates unmetamorphosed and low-grade metamorphic Paleozoic and Mesozoic oceanic rocks on the west from medium- to high-grade metamorphic rocks on the east. Within the Skykomish River quadrangle, this contrast is less distinct, and low-grade metamorphic rocks assigned to the herein-revised Early Cretaceous Easton Metamorphic Suite (in part equivalent to the Shuksan Metamorphic Suite of Misch, 1966) that crop out only west of the fault north of the quadrangle occur on both sides of the fault within the quadrangle and continue on the east side south of the quadrangle. The offset of the Easton Metamorphic Suite reflects the dextral strike-slip movement. On the south margin of the quadrangle and beyond to the south, the fault separates the lower Eocene Swauk Formation on the east from the upper Eocene and Oligocene(?) Naches Formation on the west. The clearly identified Swauk Formation or its correlatives does not crop out in Washington north of the Skykomish area on the east side of the fault, but west of the fault, the upper Eocene and Oligocene(?) Barlow Pass Volcanics of Vance (1957b), correlative with the Naches Formation, continues to the north. The Barlow Pass and questionably correlative strata appear to lie across a major strand of the fault in the aforementioned complex of faults, suggesting that major strike-slip movement was concluded by middle Eocene time. Predominantly vertical movement with the east side up could account for the distribution of the Eocene and Oligocene rocks seen today.

West of the Straight Creek fault, the oldest rocks are relatively unmetamorphosed Paleozoic and Mesozoic melanges. A western belt is predominantly argillite and graywacke; sedimentary and gabbroic components yield Late Jurassic and Early Cretaceous ages, and marble phacoids are late Paleozoic in age. An eastern belt is predominantly chert and greenstone but appears also to have both Paleozoic and Mesozoic components. The melanges may have undergone both sedimentary and tectonic mixing. Their origin appears to be accretionary. Marble in the eastern belt contains Permian fusulinids with Tethyan affinities, which led Danner (1970; 1977, p. 500) to propose that the rocks including the marble did not become part of North America until middle Mesozoic time.

North of the quadrangle, a widespread unit west of the Straight Creek fault is the Easton Metamorphic Suite. This unit of phyllite, greenschist and blue-amphibole schist is thought to have a protolith age of Middle and (or) Late Jurassic and to have been metamorphosed in the Early Cretaceous (Brown and others, 1982; Brown, 1986, p. 146). In the Skykomish River

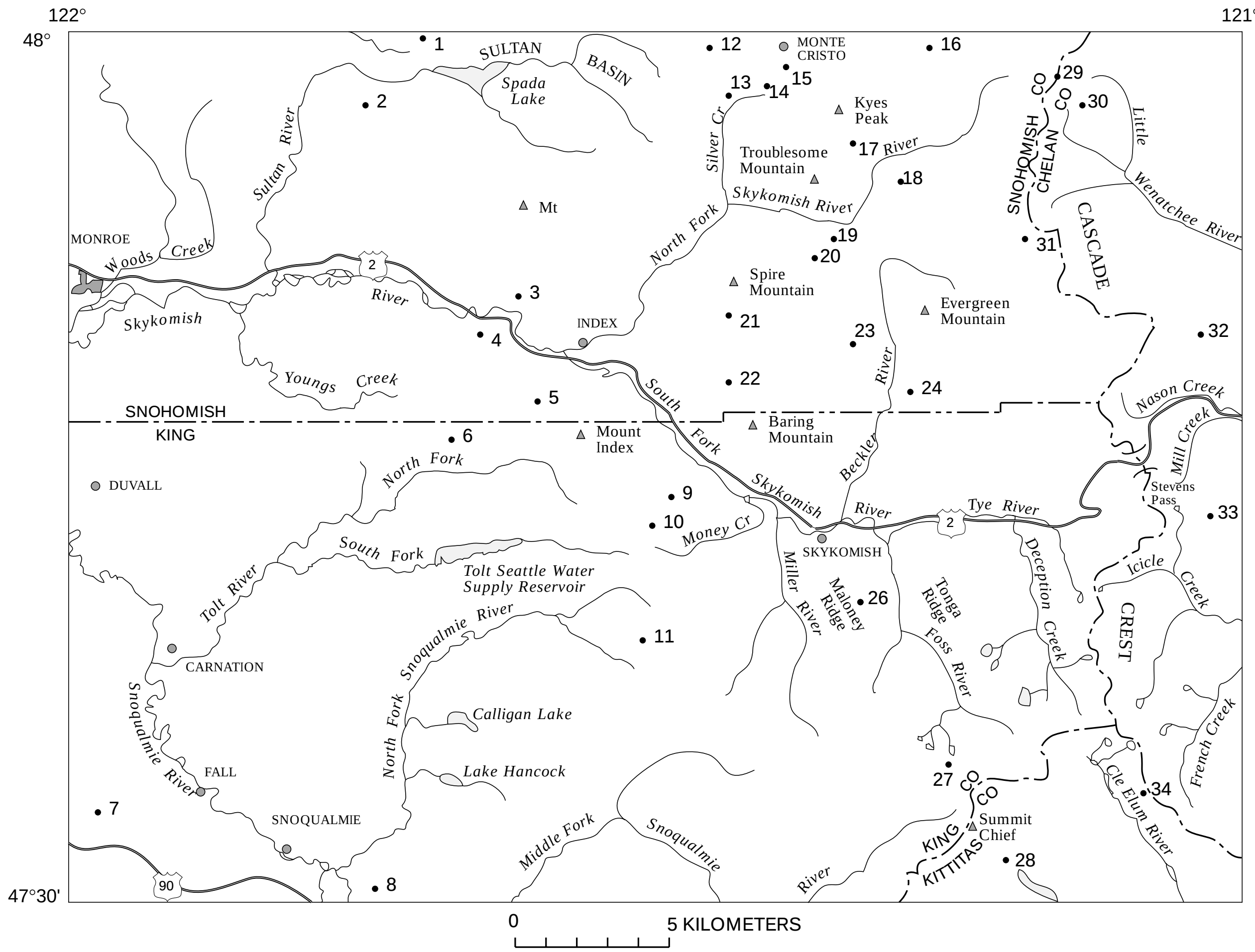

Figure 2. Generalized geographic map of Skykomish River quadrangle, Washington. Numbers indicate localities of obscure place names referred to in text.

quadrangle, the Easton is sparsely represented by the Darrington Phyllite and the Shuksan Greenschist that are exposed near and within the Straight Creek fault zone.

Between probable en echelon faults within the fault zone are the low- to medium-grade metamorphosed pelites and scarce metaigneous rocks of the Tonga Formation of Yeats (1958b). The Tonga has a late kinematic to static metamorphic overprint that locally has increased its grade from greenschist on the south to amphibolite facies on the north. The Tonga appears to grade into the amphibolite-grade Chiwaukum Schist of the Nason terrane although the exact gradation is interrupted by faults and intrusive rocks.

The Nason terrane is composed mostly of metapelite assigned to the Chiwaukum Schist and banded gneiss derived from the schist. The protolith age of the Chiwaukum Schist is uncertain, but the Chiwaukum may contain sedimentary inclusions of the Late Jurassic or Early Cretaceous Ingalls Tectonic Complex, indicating that its age could lie between the Late Jurassic and the Late Cretaceous. However, some workers (Evans and Berti, 1986, p. 698; Magloughlin, 1986, p. 263-264) assign a Triassic and (or) Jurassic protolithic age to the Chiwaukum on the basis of Rb-Sr isochrons established for the Chiwaukum and its probable correlative in Canada.

The Late Jurassic or Early Cretaceous Ingalls Tectonic Complex is mostly an unmetamorphosed melange that crops out east of the Straight Creek fault, although in the Skykomish River quadrangle the complex is thermally metamorphosed by the Late Cretaceous Mount Stuart batholith. The Ingalls appears to be an ophiolite complex (Southwick, 1974; Hopson and Mattinson, 1973; Miller, 1977; Miller and Frost, 1977, p. 287) thrust over the Chiwaukum Schist (Miller, 1980a, b, 1985).

During the Late Cretaceous, the Ingalls Tectonic Complex, the Chiwaukum Schist, and the Tonga Formation of Yeats (1958b) were intruded by the Mount Stuart batholith and Beckler River stocks. The intrusions produced hornfels in the Ingalls and late- to post-kinematic mineral growth in the Tonga Formation, but the timing of metamorphic events and intrusion of the Mount Stuart into the Chiwaukum Schist is still under debate. The deeper seated, Late Cretaceous Sloan Creek and Tenpeak Mountain plutons also invaded the Chiwaukum Schist, and these plutons, although retaining igneous textures and structures, are predominantly metamorphic in fabric and structure (see Tabor and others, 1980, 1982a).

By early Tertiary time the Cretaceous and older rocks had been uplifted and partially eroded. Lithofeldspathic subquartzose sandstone and conglomerate of the lower Eocene Swauk Formation and its intercalated Silver Pass Volcanic Member were deposited unconformably on the pre-Tertiary rocks. Following deformation, uplift, and erosion of the lower Eocene rocks, various volcanic rocks and subquartzose sand of the upper Eocene and Oligocene(?) Naches Formation, and the correlative Barlow Pass Volcanics of Vance (1957b) were deposited. Similar sedimentation and volcanism is expressed farther west in the quadrangle in the volcanic rocks of Mount Persis and in the Puget Group.

Strong deformation continued in the mountainous region of the North Cascades. The folded Barlow Pass and Naches are overlain unconformably by less deformed upper Oligocene and Miocene calc-alkalic volcanic rocks laterally equivalent to the Ohanapecosh and Stevens Ridge Formations near Mt. Rainier (fig. 1) (see Frizzell and others, 1984). In a preliminary report (Tabor and others, 1982a), we stated that the Oligocene and Miocene rocks on the west flank of the Cascades conformably overlay the lower Tertiary Puget Group. Further mapping and reevaluation of the structural differences lead us to think that the Oligocene and Miocene rocks unconformably overlie the Puget Group, although with less angular discordance than that of the corresponding unconformity in the mountains to the east (Frizzell and others, 1984).

Roughly contemporaneous with the volcanism, tonalite and granodiorite batholiths invaded the crust of the area. The Index batholith cooled about 34 Ma during the Oligocene and the Snoqualmie and Grotto batholiths about 25 Ma in the Oligocene and (or) Miocene.

Alpine river valleys in the quadrangle record multiple advances and retreats of alpine glaciers. Multiple advances of the Cordilleran ice sheet, originating in the mountains of British Columbia, Canada, have left an even more complex sequence of outwash and till along the western mountain front, up these same alpine river valleys, and over the Puget Lowland.

PRE-QUATERNARY BEDROCK UNITS

By R.W. Tabor, V.A. Frizzell, Jr., and R.E. Zartman

PRE-TERTIARY ROCKS

ROCKS WEST OF THE STRAIGHT CREEK FAULT

Easton terrane

Easton Metamorphic Suite

A relatively distinctive belt of greenschist, blue-amphibole schist, and phyllite stretches northward from central Washington, about 35 km south of the quadrangle, to beyond the Canadian border. Rocks of a part of the belt were originally named the Easton Schist by Smith (1904, p. 3). Phyllite in the belt near Darrington (fig. 1) was called the Gold Hill unit by Vance (1957a, p. 44). These rocks were later named the Darrington Phyllite by Misch (1966, p. 109) and included within his Shuksan Metamorphic Suite along with greenschist and blue-amphibole schist that he named the Shuksan Greenschist (Misch, 1966, p. 109). An earlier use of the name Shukson (original spelling) Formation for fossiliferous Upper Jurassic marine sandstone and shale (rocks probably now included in the Nooksack Formation) by Weaver (1945, p. 1392) and Imlay (1952, p. 977) has been appropriately unused and, because of vague descriptions, logically abandoned.

Yeats (1977, p. 267) and Vance and others (1980, p. 362) combined the Darrington Phyllite and Shuksan Greenschist of Misch (1966, p. 109) into the Easton Schist as restricted by Stout (1964, p. 323). Silberling and others (1987, p. 12) included the Easton Schist in their Shuksan terrane. We here revise the Easton Schist as the Easton Metamorphic Suite, which consists of the here-adopted Darrington Phyllite and the here-adopted Shuksan Greenschist as defined by Misch (1966, p. 109) and further described by Brown (1986).

The type locality of the Shuksan Greenschist is on Mount Shuksan in the vicinity of 121°36', 48°50', north of the quadrangle (fig. 1), and has been described by Misch (1966, p. 109). The type locality of the Darrington Phyllite is on Gold Mountain near Darrington mostly in secs. 16-21, 28-33, T. 32 N., R. 10 E., (Misch, 1966, p. 109).

In the central part of the Skykomish River quadrangle, we include the Shuksan Greenschist rocks that Yeats (1958a, p. 64-67; 1958b) called the Eagle Greenschist, but we exclude those rocks that Yeats (1958a, p. 40-63; 1958b) called the Tonga Formation for reasons described in the section on the Tonga. Along the south edge of the quadrangle, we also include the Shuksan rocks mapped originally as the Easton Schist by Ellis (1959). Farther south, rocks mapped as greenschist or phyllite, shown by earlier workers as the Easton Schist (Smith, 1904; Smith and Calkins, 1906; Ellis, 1959, fig. 44; Foster,

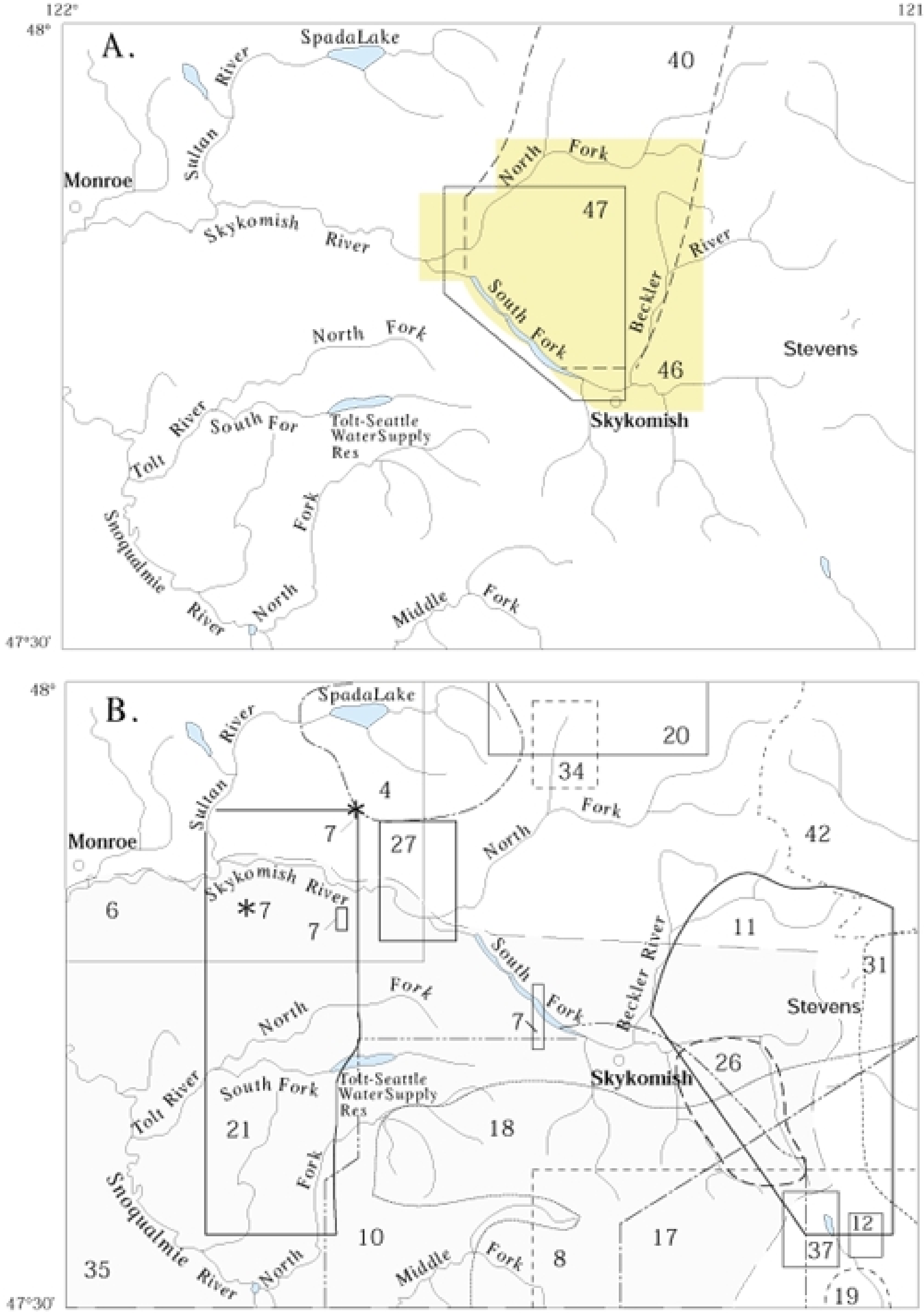

Figure 3. Previous geologic studies (figure 1 continues on next page).

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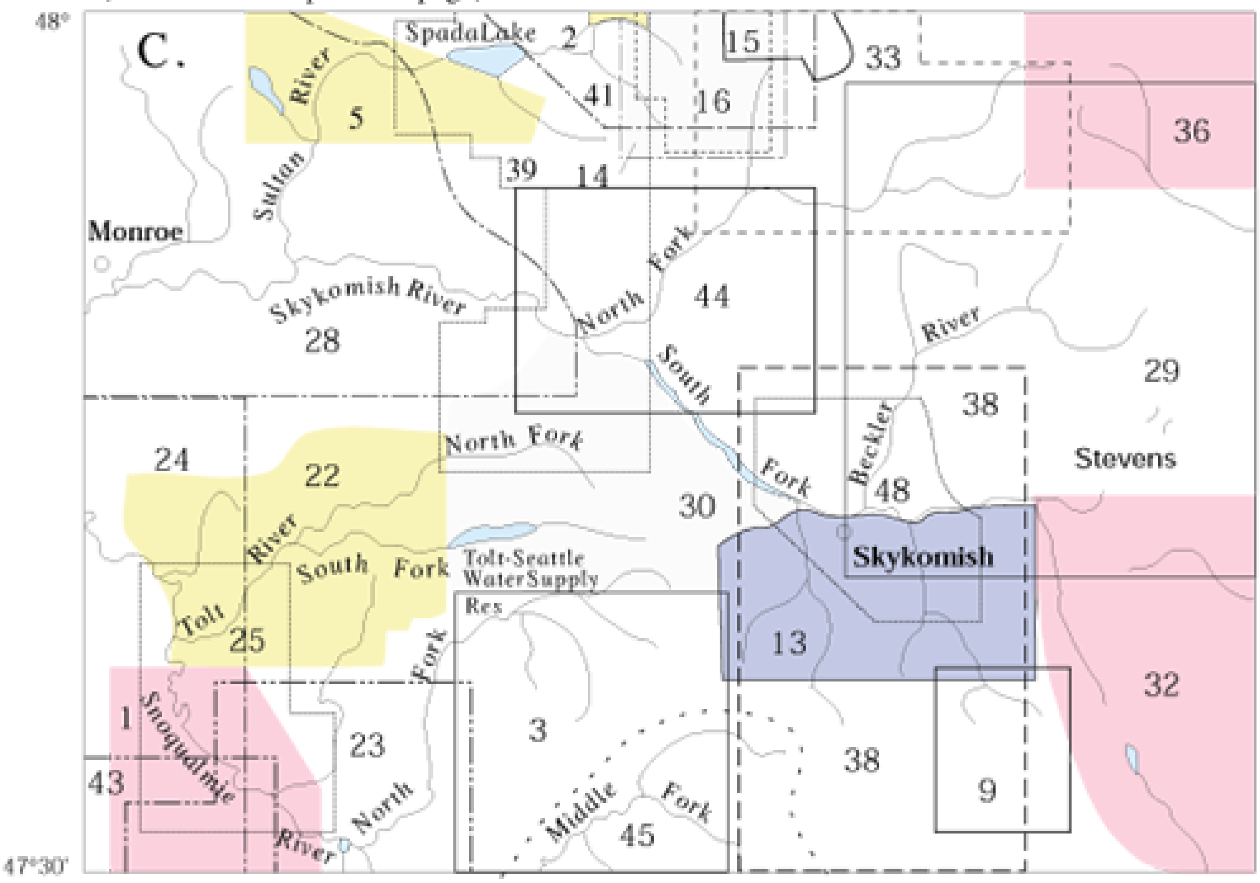

Sources of map compilation data	Map
1. Anderson, 1965	C
2. Baum, 1968	C
3. Bethel, 1951	C
4. Carithers and Guard, 1945	B
5. Converse Ward Davis Dixon Inc., 1979	C
6. Danner, 1957	B
7. Danner, 1966	B
8. Ellis, 1959	B
9. Erikson, 1965	C
10. Erikson, 1968, 1969	B
11. Erikson, 1977a, and written commun., 1976	B
12. Frost, 1973	B
13. Galster, 1956	C
14. Grant, 1969	C
15. Griffin, 1948	C
16. Griffis, 1977	C
17. Gualtieri and others, 1973	B
18. Gualtieri and others, 1975	B
19. P. Hammond, written commun., 1976	B
20. Heath, 1971	B
21. Jett, 1986	B
22. Knoll, 1967	C
23. Kremer, 1959	C
24. Leisch and others, 1963	C
25. L.R. Lepp and J. Walker, written commun., 1980	C

Sources of map compilation data	Map
26. McDougall, 1980	B
27. McPhee and Baumann, 1911	B
28. Newcomb, 1952	C
29. Oles, 1956	C
30. Plummer, 1964	C
31. Plummer, 1969, 1980	B
32. Pratt, 1958	C
33. Pytlak, 1970	C
34. Ream, 1972	B
35. Richardson and others, 1968	B
36. Rosenberg, 1961	C
37. Simonson, 1981	B
38. Smith, 1915	C
39. Snyder and Wade, 1972	C
40. Tabor and others, 1982b	A
41. Vance and others, 1980	C
42. Van Diver, 1964a	B
43. Warren and others, 1945	C
44. Weaver, 1912a	C
45. Williams, 1971	C
46. Yeats, 1958a, and written commun., 1978	A
47. Yeats, 1964	A
48. Yeats, 1977	C

Figure 3. Previous geologic studies within the Skykomish River quadrangle, Wash. A, Much data used with little to modest modification. B, Some data used. C, Consulted extensively but data not used directly on map (original in black and white only).

1960, pl. 1; Stout, 1964, pl. 1; Tabor and others, 1982c; and Frizzell and others, 1984), are here reassigned to either the Shuksan Greenschist or the Darrington Phyllite, respectively.

We tentatively include in the Easton Metamorphic Suite those subordinate rocks of the Shuksan Metamorphic Suite of Misch (1966) in the Gee Point area north of the quadrangle (fig. 1) and elsewhere that have been described by Brown and others (1982) and Brown (1986) as epidote amphibolite and eclogite. These rocks have a more complex metamorphic history than most of the Easton Metamorphic Suite and have participated in the Early Cretaceous blueschist metamorphism.

On the basis of numerous K-Ar and Rb-Sr isotopic measurements, Brown and others (1982, p. 1096) concluded that the Shuksan Metamorphic Suite was metamorphosed about 130 Ma (Early Cretaceous) and that the protolith age was not much older, presumably Jurassic. In confirmation, Brown (1986, p. 146) reports a Pb-Pb zircon age of about 164 Ma from a metadiorite pluton that appears to be part of the protolith igneous suite of the Shuksan.

Misch (1966, p. 109) felt that the protolith oceanic basalt of the Shuksan Greenschist stratigraphically overlay the protolith marine, mostly pelitic sediments of the Darrington Phyllite. Haugerud and others (1981, p. 377) and Brown (1986, p. 145) consider the sediments to have overlain the basalt, a more conventional sequence. A number of studies (Staatz and others, 1972; Vance and others, 1980; Haugerud and others, 1980; Brown and others, 1982; Dungan and others, 1983) have shown that the Darrington Phyllite contains minor, probable stratigraphic, intercalations of greenschist and blue-amphibole schist, and that the Shuksan Greenschist contains minor phyllite layers.

All contacts of the Easton Metamorphic Suite with pre-Tertiary rocks are faulted; we do not know the original thickness of the Easton rocks.

Darrington Phyllite

The phyllite in the Monte Cristo area has been extensively described by Heath (1971, p. 80-88). It appears to be in fault contact with banded gneiss along the Straight Creek fault north of the quadrangle, overlain unconformably by the Tertiary Barlow Pass Volcanics of Vance (1957b) near Monte Cristo, and intruded extensively by satellitic stocks of the Grotto batholith. No ages are available for the Darrington Phyllite in or near the Monte Cristo area, but its age is presumably the same as that interpreted for other parts of the Easton Metamorphic Suite to the north.

Other outcrops of the Easton Metamorphic Suite east of the Straight Creek fault are described below.

Western and eastern melange belts

Highly disrupted oceanic rocks that crop out west of the Straight Creek fault have been assigned a variety of names and ages by early workers. For the Skykomish River quadrangle we have separated these rocks into western and eastern melange belts (also called "western belt" and "eastern belt", for convenience) on the basis of their overall lithologies and geographic positions. Frizzell and others (1987) summarize their characteristics and discuss their tectonic history. The western melange belt is predominantly argillite and graywacke (subquartzose sandstone) containing generally lesser amounts of mafic volcanic rocks, conglomerate, chert, and marble. Ultramafic rocks, mostly serpentinite, are present but very scarce. Outcrop- to mountain-sized phacoids of metagabbro, metadiabase, and metatonalite occur in the western belt. The resistant megaclasts of sandstone, chert, marble, and metagabbro generally stand out boldly in a matrix of poorly foliated argillite or thin-bedded argillite and disrupted sandstone beds. Commonly the matrix is not well exposed, but disruption of beds, crude foliation, or

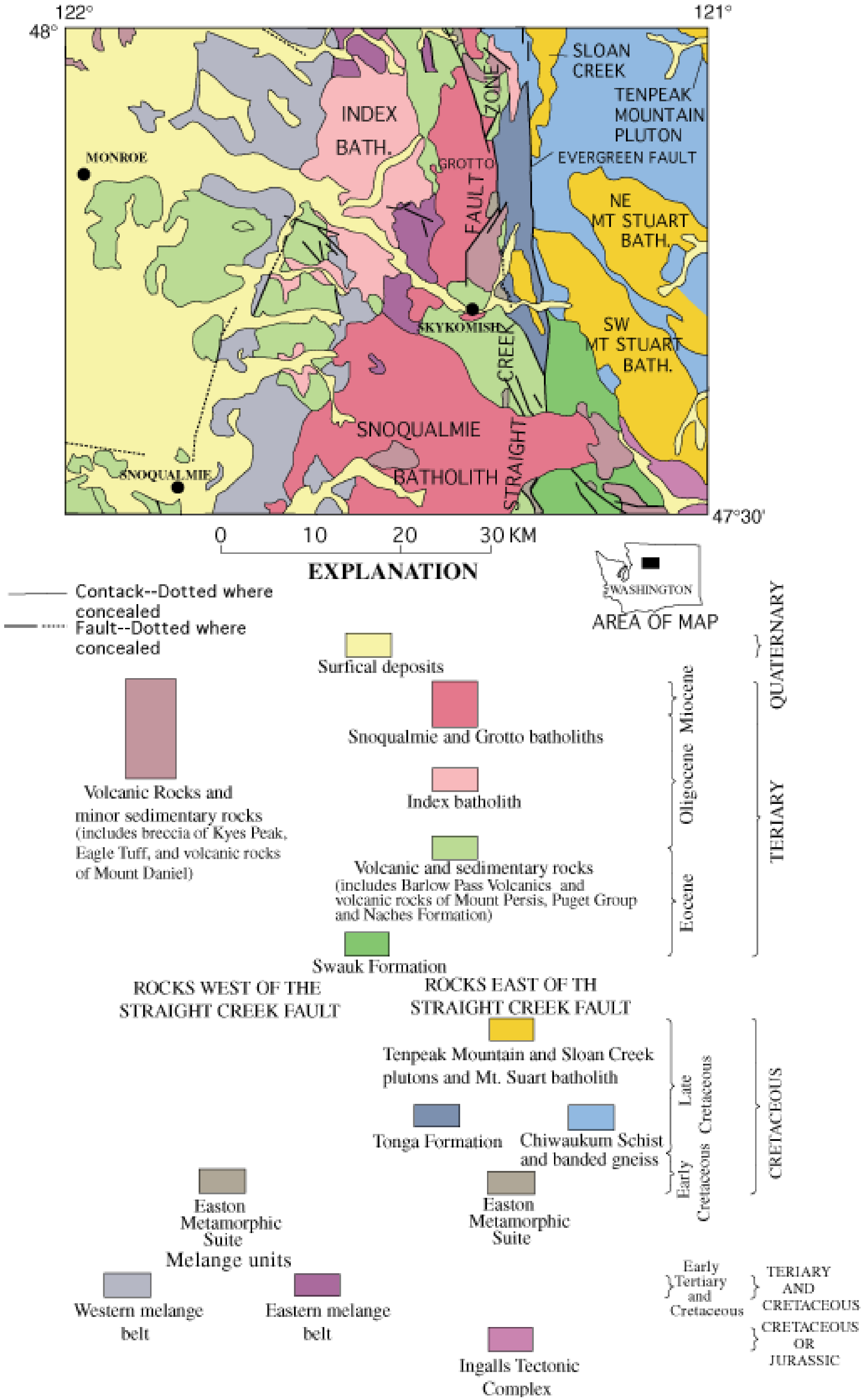

Figure 4. Generalized geologic map of the Skykomish River quadrangle, Wash. (original in b and w).

pervasive cataclasis is apparent in most outcrops. The eastern part of the western belt is more thoroughly metamorphosed than the rest of the belt; in the general area of the lower Sultan Basin, the disrupted rocks grade to slate, phyllite, and semischist and contain minor greenschist and chert.

The eastern melange belt, on the other hand, consists predominantly of mafic volcanic rocks and chert with minor argillite and graywacke. Marble is conspicuous locally, and large and small pods of ultramafic rocks are present throughout the belt. Metadiabase and a mafic migmatitic gneiss complex also crop out in the eastern belt. In the Skykomish River quadrangle, much of the eastern melange belt is exposed as screens or pendants surrounded by Tertiary batholiths. In the upper Sultan Basin area, we delineated the eastern belt from phyllitic rocks of the western belt on the basis of gradually increasing amounts of volcanic and ultramafic rocks. The amount of penetrative deformation in the eastern belt is difficult to estimate because of thermal metamorphism by the nearby Tertiary batholiths, but north of the quadrangle the clastic rocks in the eastern belt have well-developed penetrative foliation. Heath (1971, pl. 1) mapped a fault between the eastern and western belts. The disruption in Heath's wide fault zone seems to us to be no more severe than disruption elsewhere within the melange belts, and we prefer to base the contact on the lithologic change that occurs farther west.

Although some of the disruption of beds in the melange belts may be of olistostromal origin, the mixing in both belts is probably tectonic, judged by (a) overall penetrative deformation, (b) the local synkinematic metamorphism in the western belt, and (c) strong cataclasis in crystalline megaclasts. Silberling and others (1987, p. 9, 12) have correlated our western and eastern melange belts with regional tectonostratigraphic terranes that they call the Olney Pass and San Juan terranes, respectively. The appropriate grouping of units in regional terranes and their naming are still under study, but an oceanic origin for these disrupted Paleozoic and Mesozoic rocks, now cropping out west of the Straight Creek fault, and their subsequent accretion to the North American continent are accepted by many students of Northwest tectonics (Danner, 1970; 1977; Davis and others, 1978; Vance and others, 1980; Whetten and others, 1980; Brandon and others, 1983).

Rocks of the western melange belt

The graywacke, argillite, chert, metavolcanic rocks, marble, and metagabbro of the western melange belt south of the quadrangle were first mapped and described by Fuller (1925, p. 29-53). Other workers (Culver, 1936; Carithers and Guard, 1945, p. 14-15, 18-22; Bethel, 1951, p. 22-25; Kremer, 1959, p. 40-68; Heath, 1971, p. 97-102; Dungan, 1974, p. 8-21) have further described rocks in the belt and applied local and correlative names, but the most definitive descriptions are by Danner (1957, p. 333-371), who included most of the sedimentary and volcanic rocks in his Sultan unit.

On the basis of the lithology and the widespread internal deformation, Jett (1986, p. 16) and Jett and Heller (1988) concluded that the western melange belt formed in an accretionary wedge.

Argillite and graywacke

Argillite may well be the most abundant rock type in the western melange belt, but because it was easily eroded and is now covered by unconsolidated deposits, the predominant exposures are sandstone. Most outcrops of interbedded argillite and sandstone reveal the penetrative cleavage that disrupts bedding, but in some areas bedding is preserved, and original structures such as graded bedding, small-scale crossbedding, scour marks, and load casts are abundant. Slate-chip breccias are common.

The most common exposures are of massive-looking sandstone that has little preserved bedding and is cut by anastomosing brittle shears.

Good outcrops of the melange matrix in the western belt are scarce, but some reveal the weak to strong scaly cleavage. Melange of the western belt, well exposed on the South Fork of the Stillaguamish River east of Granite Falls (fig. 1), lacks consistent penetrative cleavage and is composed of lenticular and locally necked blocks of sandstone, greenstone, limestone, and rare metatonalite in a massive argillite matrix. The melange resembles Cowan's (1985, p. 454-456) type-II melange, evolved from submarine landslides of a once-coherent but varied stratigraphic sequence.

Potassium feldspar-bearing sandstone

Parts of the western belt appear to be richer in potassium feldspar than other parts, although rocks with or without potassium feldspar may be found in adjacent outcrops. Jett and Heller (1986, 1988) and Jett (1986, p. 52-63) included the potassium feldspar-bearing sandstones in their arkosic petrofacies and noted that a pre-Jurassic potassium feldspar source has not been recognized in the adjoining terranes. They also noted similarity of the bimodal sandstone of the western melange belt to bimodal sandstones of the Californian Franciscan Complex. The distribution of potassium feldspar-rich rocks shown on the geologic map was determined by estimating values from stained thin sections and slabs and from modal data in Jett (1986, p. 13). In contrast, sandstones from the eastern belt have almost no potassium feldspar.

Slate, phyllite, and semischist

Sandstone and argillite in the western melange belt grade eastward into slatey argillite, slate, phyllite, and semischist in the upper Sultan Basin area. The change from nonfoliate to foliate rocks typically takes place over a few hundred meters. Greenstone and tuffaceous rocks grade into phyllitic greenstone or fine-grained greenschist.

This slatey argillite and phyllite unit appears to be continuous with rocks that Danner (1957, p. 423-455) included in his phyllitic Olo Mountain unit, north of the quadrangle boundary. Danner felt that the Olo Mountain unit was also lithologically similar to the Nooksack Formation exposed on the upper Nooksack River (fig. 1), except that the former contained more chert. Similarly, our phyllitic unit contains more chert than the less foliated rocks to the west. On the north side of the Sultan River, however, we also include in our phyllitic unit the lowermost Cretaceous fossiliferous rocks, which Danner included in his Sultan unit (table 1).

Metagabbro, metadiabase, and metatonalite

Metagabbro in the western melange belt ranges from slightly uralitized ophitic gabbro through protomylonite to well-recrystallized gneissic amphibolite.

The mode of formation and emplacement of the gabbroic masses is important to the interpretation of theorigin of the melange unit. Danner (1957, p. 535-541) considered the metagabbro bodies (his Woods Creek intrusive bodies) to be intrusive into the sedimentary rocks. Relatively wide-spread and strongly uralitized diabase dikes, though sparse, are clearly intrusive into the sedimentary rocks. Similar rocks, presumably dikes, are present in the overlying Tertiary volcanic rocks as well. However, most contacts between the larger gabbro bodies and adjoining rocks are strongly deformed and faulted; small knockers of metagabbro are clearly tectonically emplaced in the sedimentary rocks, which have no hornfelsic textures adjacent to the metagabbro. Metagabbro and metatonalite masses yield U-Th-Pb zircon ages of 170 to 150 Ma (table 2, nos. 55-58), which indicate that the plutonic rocks are minimally about the same age as or older than the enclosing Jurassic and Lower Cretaceous sedimentary rocks. A Buchia from matrix argillite and graywacke beds (table 1, nos. 1F-3F) appears to be restricted to the Tithonian (Danner, 1957, p. 410), and more definitive radiolarian samples indicate ages from Kimmeridgian to Valanginian (Frizzell and others, 1987) that, in numerical age, range from 156 to 131 Ma based on the time scale of Harland and others (1982).

Whetten and others (1980, p.365-366) considered the Woods Creek plutonic rocks and the massif of Mount Si [8][1] to be in-folded or in-faulted klippen of their Haystack thrust, a regional thrust plate emplaced in earliest Late Cretaceous time. In an alternative hypothesis, they also suggested that these rocks could be a large-scale melange with imbricated exotic blocks of Mesozoic ophiolite. We now view the western melange belt as an imbricated mixture of marine sedimentary rocks, volcanic rocks, and probable underlying gabbroic basement rocks.

We placed the concealed contact of metagabbro in the northwestern part of the quadrangle by inspection of aeromagnetic anomalies (U.S. Geological Survey, 1977).

Metavolcanic rocks and phyllitic greenstone

Nonschistose and schistose metavolcanic rocks in the western melange belt crop out mostly in the Blue Mountain [2] area south of the Sultan River and just west of Mount Si. The original rocks were mostly mafic, probably basaltic; some were formed underwater as shown by pillow structures. Probable quartz porphyry dikes, now boudins along penetrative shearing in the Mount Si area, are the only silicic metavolcanic rocks that we have found in the western melange belt.

Ultramafic rocks

Ultramafic rocks are very scarce in the western melange belt, a characteristic that helps distinguish it from the eastern belt. A discontinuous layer of ultramafic rocks is present along the gneissic contact of the Bald Mountain pluton. McPhee and Baumann (1911) report an ultramafic body near Hogarty Creek [3]. North of the quadrangle, several bodies of ultramafic rocks crop out near Granite Falls in the western melange belt, and south of the quadrangle a small pod of serpentized peridotite is associated with sheared and isolated outcrops of protomylonitic metagabbro.

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[1] Numbers in brackets refer to obscure place names on fig. 2.

Chert

The largest masses of banded chert crop out in the northern part of the quadrangle within the slate, phyllite, and semischist part of the western melange belt. Most chert occurs as discontinuous pods or isolated blocks in highly disrupted sandstone and argillite. A few cherts yield identifiable radiolarians (table 1).

Marble

Most marble in the western melange belt is coarsely crystalline. Only one outcrop of marble, near Proctor Creek [4], has yielded identifiable fossils (table 1, no. 7F), but several marble outcrops from the western melange belt north of the quadrangle are fossiliferous (see below).

Age, correlation, and emplacement of the western melange belt

The ages of most components of the western melange belt appear to be Jurassic and Early Cretaceous, based on fossils from several locations throughout the belt (table 1) and U-Th-Pb zircon ages in the range of 170-150 Ma (table 2, nos. 55-58) from four metatonalite-metagabbro masses. Cherts from several localities north of the quadrangle in the western melange belt (Tabor and Booth, 1985) contain Early Jurassic radiolarians (Charles Blome, written commun., 1985). Conventional K-Ar ages of hornblende from the uralitic metagabbro are around 100 Ma (table 2, nos. 53-54) and probably have been degraded by superimposed metamorphism. The marble near Proctor Creek contains considerable ichthtyolith fragments and vertebrae of a possible tetrapod indicating it is probably Mississippian to early Permian in age (table 1, no. 7F). Confirming this pre-Jurassic age of marble in the melange are mid- and Late Permian fusulinids recovered from marble outcrops in the western melange belt to the north (Wiebe, 1963, p. 6; Danner, 1966, p. 319-322, 325).

Danner considered the oceanic sedimentary rocks of the western melange belt (his Sultan unit) to be correlative lithologically and in age with the relatively undeformed Late Jurassic Nooksack Formation (Misch, 1966, p. 118; see also Sondergaard, 1979). Jett (1986, p. 52-57) questioned this correlation because, in particular, the Nooksack lacks the arkosic petrofacies found in the western melange belt.

Less disrupted rocks of similar general age and lithologies on the San Juan Islands (fig. 1) are the Constitution and Lummi Formations (Vance, 1975, p. 13; 1977, p. 182, 186; Brandon and others, 1983, p. 16-23) and even farther west on Vancouver Island, the Pacific Rim Complex (Brandon, 1985).

The age of emplacement of the western melange belt is not well constrained. Tectonic mixing of the melange components, the emplacement of the melange along the margin of North America, and possible major displacement along strike-slip faults such as the Straight Creek fault are discussed in more detail in Frizzell and others (1987).

The western melange belt is intruded within the quadrangle by the Fuller Mountain plug and north of the quadrangle by the Granite Falls and Mount Pilchuck stocks, all of which yield early Eocene K-Ar ages of 47 Ma (table 2, no. 34), 44 Ma, and 49 Ma respectively (Yeats and Engels, 1971, p. D36). We do not know whether the stocks intruded before or after melange accretion or fault emplacement, but preliminary paleomagnetic work in the Granite Falls stock (Beck and others, 1982, p. 516) suggests that emplacement, tectonic mixing, and significant translation along faults were completed by sometime in the early Tertiary.

If the phyllitic rocks represent the highest metamorphic grade attained during imbrication of the Paleozoic and Mesozoic rocks, then the K-Ar cooling age of about 48 Ma (table 2, no. 37) on newly formed sericite, in a well-recrystallized phyllite from the unit, is a minimum age of melange formation.

The western melange belt is overlain unconformably by the gently deformed, 38-Ma (late Eocene) volcanic rocks of Mount Persis [5]. Lack of deformation and the apparent correlation of the Mount Persis volcanic rocks with at least part of the Puget Group (see below), appear to qualify the former as a post-accretion, overlap unit. However the Mount Persis volcanic rocks overlie only the western melange belt, and their lack of deformation contrasts with the strong deformation in the contemporaneous strata of the adjoining Puget Group (see Vine, 1969; Turner and others, 1983), suggesting that the entire block of the western melange belt overlain by the volcanic rocks of Mount Persis is in fault contact with the Puget Group.

In summary, emplacement, melange formation, and significant strike-slip translation, if any, must have taken place between the Early Cretaceous and the early Eocene. As will be indicated, the eastern melange belt was definitely emplaced by late Eocene time and perhaps as early as the mid-Cretaceous. Tabor and Booth (1985) have suggested that the western melange belt may be in fault contact with the eastern melange belt, but the two belts may have been accreted to North America about the same time.

Rocks of the eastern melange belt

The eastern melange belt is an assemblage of diverse rocks, including metavolcanic rocks (basalt), chert, argillite, graywacke, and marble, as well as migmatitic gneiss, metagabbro, metadiabase, metatonalite, and ultramafic rocks. These rocks are considerably deformed, slightly metamorphosed to greenschist facies, and statically recrystallized by Tertiary plutons. Evidence for extreme disruption of the belt is locally abundant: penetrative foliation, small-scale folds, and zones of tectonic breccia (Yeats, 1964, p. 556-557). The belt is highly fragmented, mostly by intrusion of the Tertiary Snoqualmie, Grotto, and Index batholiths.

In the eastern belt, we include rocks in the Weden Creek area [12], mapped by Heath (1971, p. 90-94) as the Chilliwack(?) Group of Misch (1966), and thermally metamorphosed volcanic rocks and chert associated with ultramafic rocks on the north side of Silver Creek. We also include metabasalt and ribbon chert exposed on Garfield Mountain. A roof pendant of mostly graywacke on Bare Mountain [11] could belong to either the eastern or western melange belts, but Gualtieri and others (1975, p. 71) report metavolcanic and ultramafic rocks in the nearby Illinois Creek area that indicate the pendant belongs with the eastern melange belt. Metamorphosed oceanic rocks, including metabasalt, metachert, marble, and metagabbro, exposed near Snoqualmie Pass (fig. 1) are also isolated remnants of the eastern melange belt (see Danner 1957, p. 249-255; Frizzell and others, 1982, 1984).

Chert and metachert, marble, mafic metavolcanic rocks, argillite and graywacke

Rocks cropping out northwest of Skykomish have been named the Gunn Peak and Barclay Creek Formations by Yeats (1964, p. 556). The Gunn Peak Formation, composed predominantly of ribbon chert and quartzite (metachert) and containing marble pods, grades upward into the Barclay Creek Formation. The formations are lithologically similar, but locally the Barclay Creek contains more banded siliceous and calcareous argillite, graywacke, and greenstone. Yeats (1958a, p. 102-114; 1964, p. 556) restricted the Gunn Peak Formation as originally defined by Weaver (1912a, p. 36-38), which had also included the migmatitic gneiss and parts of the Swauk Formation.

Although in a previous report (Tabor and others, 1982b) we indicated that the formations described by Yeats could not be mapped away from the Skykomish area, a chert-rich unit has been mapped north of the quadrangle in rocks that are continuous with the eastern melange belt (Vance, 1957a; Baum, 1968) and appears to terminate along the North Fork of the

Sultan River. We here include the rocks mapped by Yeats as his Gunn Peak Formation in our chert and metachert unit, although an age correlation has not been shown.

Migmatitic gneiss

The summit areas of Gunn Peak, Merchant Peak [22], and Baring Mountain are composed mostly of migmatitic hornblende gneiss that ranges in composition from amphibolite to trondhjemite. Detailed petrographic studies by Yeats (1958a, p. 83-98; 1964, p. 551-555) indicate that the gneiss underwent regional dynamic metamorphism and granitization, cataclastic deformation, and static recrystallization (by Tertiary batholiths). The cataclastic deformation is pervasive and especially prominent at its contacts with the sedimentary and volcanic rocks. On the basis of a regional correlation with similar sheared metamorphic complexes that apparently overlie unmetamorphosed rocks as described by Misch (1960, 1963, 1966, p. 106), Yeats (1964, p. 559) considered the migmatitic gneiss to be klippen of pre-Middle Devonian basement rocks that were thrust over younger rocks. Uranium-thorium-lead ages of about 190 Ma from a tonalite phase of the migmatitic gneiss led Whetten and others (1980, p. 365) to suggest that the gneiss was part of a regionally overthrust sheet (their Haystack terrane) of Mesozoic ophiolite.

Evidence that these gneisses are in tectonic contact with the sedimentary and volcanic rocks is, indeed, convincing. However, argillite is imbricated with the gneiss in many places (Yeats, 1964, p. 556) and even lies atop the gneiss on Baring Mountain. Furthermore, some contacts presumed to be horizontal are, in fact, steep, such as on the south side of Gunn Peak. All of the faults bounding the crystalline rocks, including the high-angle faults mapped by Yeats (1958a, pl. II, and 1964, pl. 1) and thought by him to be younger than the thrust, may be the same age. An alternative interpretation to the overthrust hypothesis is that the gneiss masses are mostly steep-sided exotic blocks in a melange, an interpretation alluded to by Yeats (1964, p. 558) when he referred to the klippen as megabreccia.

Metadiabase and metatonalite

Danner (1957, p. 513-517) and Plummer (1964, p. 52-56) considered a large mass of metadiabase on Crosby Mountain [10] to be intrusive into the pre-Tertiary sedimentary and volcanic rocks. Erikson (1969, pl. 1) included the diabase in his early phase of the Miocene Snoqualmie batholith.

The uralitized diabase is similar to diabase in the western melange belt and locally displays steeply dipping crude foliation. It has a sharp contact against sheared pods of metatonalite associated with highly deformed argillite and graywacke on the west side of Crosby Mountain, but we do not know the relative ages of the two igneous rocks. Zircons with $^{207}Pb/^{206}Pb$ ages of around 70-60 Ma from the metatonalite in this area (table 2, no. 60) may be partially reset. We think that the discordancy exhibited by these zircons reflects new zircon growth during intrusion of the nearby Tertiary batholiths. Zircons recovered from metatonalite surrounded by the Tertiary batholith on Garfield Mountain show a similar pattern in their isotopic systematics (table 2, no. 57).

On the steep walls of Money Creek, intrusion of the Snoqualmie batholith has produced extensive contact breccia, where dark diabase clasts are set in a white quartzofeldspathic matrix (see Plummer, 1964, p. 52-53) and permeation of diabase by quartz is conspicuous in thin section where the pyroxene and calcic plagioclase float in a quartz mesostasis.

Ultramafic rocks

Pods of ultramafic rocks are scattered throughout the eastern melange belt but are also concentrated along the sheared and imbricated margin of the migmatitic gneiss. A conspicuous belt of hornfelsic peridotite cuts across the upper Sultan River. In the Skykomish area, most of the ultramafic rocks are partially or completely altered to tremolite and serpentine minerals, but relict pyrogenic minerals indicate that the pods were originally pyroxenite, peridotite, and dunite (Yeats, 1958a, p. 116-118). On the east side of Weden Creek [12], a large sliver of dunite appears to be faulted against the Barlow Pass Volcanics of Vance (1957b). Dungan (1974, p. 98-100) argued from detailed petrologic and petrochemical data that correlative ultramafic pods on strike to the north, the Stillaguamish ophiolite (Vance and others, 1980), were once part of a coherent ophiolite complex.

Age and correlation of the eastern melange belt

On Palmer Mountain [9], Danner (in Thompson and others, 1950, p. 49; see also Danner, 1966, p. 362-363) found Permian fusulinids in a float block of limestone in an area where most of the limey rocks in outcrop are well-recrystallized marble, barren of diagnostic fossils. Nevertheless, on the basis of overall lithologic similarity, Danner (1966, p. 363) referred these rocks to his Trafton sequence exposed in a belt farther north. The fusulinids in the Trafton are Tethyan in affinity, indicating to Danner (1977, p. 500) that the rocks including them did not become a part of North America until at least the middle Mesozoic. The Trafton sequence contains fossils ranging from Devonian to Middle Jurassic in age (Danner, 1977, p. 492-493; Whetten and Jones, 1981). A wide range of ages in the eastern melange belt indicates considerable tectonic mixing: the limestone components of probable Permian age, the tonalite component of the migmatitic gneiss of Early Jurassic protolith age, and metagabbro of Late Jurassic age in the eastern melange belt near Snoqualmie Pass (Frizzell and others, 1982). West of Darrington (fig. 1), chert and marble of the chert and metachert unit, equivalent to the Barclay Creek Formation of Yeats (1958b), are Late Triassic based on radiolarian and conodonts, respectively (C.D. Blome, written commun., 1985, and K.S. Schindler and A.G. Harris, written commun., 1984). The age range of ages in the eastern melange belt corresponds well to the age range of components in the Trafton sequence reported by Whetten and Jones (1981).

Mafic and ultramafic rocks of the belt are likely correlative with the dismembered Stillaguamish ophiolite (Vance and others, 1980, p. 362-363, fig. 3) mostly exposed on strike to the north of the quadrangle. On the basis of regional correlations, Vance and others (1980, p. 378) suggest a Middle and Late Jurassic age for original igneous crystallization. They inferred a Middle Jurassic to mid-Cretaceous age for the associated volcanic rocks.

On the basis of petrologic, chemical, and isotopic evidence, Dungan (1974, p. 216-217), Vance and Dungan (1977), and Johnson and others (1977) considered the northern parts of the Stillaguamish ophiolite to have been metamorphosed at least to the middle amphibolite facies of regional metamorphism prior to fault emplacement adjacent to the unmetamorphosed rocks where they are now found. This regional metamorphism occurred in the Middle or Late Jurassic (Vance and others, 1980, p. 378, 384), and imbrication of the ophiolite and its sedimentary and volcanic cover took place in the mid-Cretaceous, an age in agreement with the proposed time of emplacement of the Haystack terrane of Whetten and others (1980). Direct evidence for the time of tectonic mixing and (or) emplacement of the eastern melange belt in the Skykomish River quadrangle is lacking, but we know that the melange was emplaced by the late Eocene because it is overlain by the Barlow Pass Volcanics of Vance (1957b).

Bald Mountain pluton

Biotite granodiorite exposed along the north margin of the quadrangle on Bald Mountain [1] is medium to coarse grained, bears trace amounts of cordierite and garnet, and is distinct from most other Tertiary intrusions in grain size, composition, gneissic margins, and prominent cataclasis. Some local deformation on the south side is due to local shearing along a major high-angle fault in the Pilchuck River valley. The north margin of the Bald Mountain pluton is cataclastically sheared and bordered by a thin discontinuous layer of ultramafic rock. Most of this margin is better exposed north of the quadrangle and was described as a fault by Dungan (1974, p. 32-33).

Dungan (1974, p. 31-34) correlated the Bald Mountain pluton with the nearby 49-Ma Mount Pilchuck stock (Yeats and Engels, 1971, p. D36, D37), north of the quadrangle, which is similar compositionally, although slightly more potassic, and also contains cordierite (Wiebe, 1963, p. 20). However, the stock is circular in shape, strongly discordant, and nonfoliate. U-Th-Pb ages obtained from zircons from the Bald Mountain pluton suggest that it also crystallized or recrystallized about 55-50 Ma, but the much older $^{207}Pb/^{206}Pb$ ages (table 2, no. 50) either indicate a Pb component that could reflect xenocrystic zircons picked up in the magma, presumably from the surrounding Mesozoic rocks, or indicate that the pluton originally was much older and has been recrystallized by the intrusion of the Mount Pilchuck stock. Although the similarity in peraluminous composition argues for the Mount Pilchuck stock and Bald Mountain pluton to be the same age and probably comagmatic, the contrast in texture, contacts, and shape may mean that the pluton is considerably older than the stock. Some sheared granodiorite of the pluton is thermally metamorphosed by the Mount Pilchuck stock, showing that it is at least somewhat older than the stock.

Miscellaneous gabbros

Several bodies of mafic rocks, mostly variably metamorphosed gabbro, have been mapped previously as early phases of the Miocene Snoqualmie batholith by Erikson (1969, pl. 1). Their ages are uncertain, but most are near or at the margin of the Snoqualmie batholith, are thermally metamorphosed by it, and are associated with sedimentary rocks of the melange. They are commonly cut by dark tonalite to quartz diorite dikes, which are difficult to distinguish from the gabbro. As a map unit, the miscellaneous gabbros may be a mixture of Snoqualmie batholith, its dikes, and older rocks, in particular, remnants of metagabbro from the western melange belt.

Hypersthene-clinopyroxene gabbro, locally with cumulate layering, that crops out along the north wall of Money Creek was first described by Plummer in his thesis (1964, p. 48-52) as the "Money Creek gabbro"; he noted its affinity with the Snoqualmie batholith. We observed no contacts of the gabbro with either the Snoqualmie or the Index batholith, but evidence of strong thermal metamorphism in the main body of rock is lacking. However, the gabbro is faulted against sandstone and conglomerate, here tentatively included with the Barlow Pass Volcanics of Vance (1957b). Thoroughly recrystallized ultramylonites in the sheared contacts indicate that the gabbro is considerably older than the Snoqualmie batholith. Locally within the western melange belt–and far from the batholith–relatively undeformed two-pyroxene gabbro that is very similar to the gabbro on Money Creek crops out. The Money Creek gabbro unit may therefore be an anomalously undeformed large phacoid in the melange.

We include thermally metamorphosed heterogeneous rocks, ranging from uralitized pyroxene gabbro to tonalite, which crop out in the Middle Fork of the Snoqualmie River, in this unit, but are less certain of their affinity to the metagabbro. Some outcrops of these rocks are a mixture of black hornfels and gabbro. We also include in this unit the uralitized gabbro exposed on Palmer Mountain [9], rocks which we once thought might be an early phase of the Index batholith (Tabor and others, 1982a).

Erikson (1968; 1969, p. 2219) reported chemical data for samples of the miscellaneous gabbros that are associated with the Snoqualmie batholith. The fact that many of these data do not fit well with the variation curves plotted for the batholith as a whole (Erikson, 1969, p. 2228) further suggests that the gabbro bodies may be part of the melange units.

ROCKS EAST OF THE STRAIGHT CREEK FAULT

Within the Skykomish River quadrangle, we include much of the pre-Tertiary bedrock east of the Straight Creek fault in two tectonostratigraphic terranes: the Nason terrane and the terrane composed of the Ingalls Tectonic Complex. The Easton Metamorphic Suite crops out east of the fault as well; it is especially well exposed south of the quadrangle. Within the quadrangle, rocks that we correlate with the Easton and with the Tonga Formation of Yeats (1958b) are more accurately described as occurring within the fault zone, but for convenience they are described here. Extensive pre-Tertiary synmetamorphic plutons that represent terrane overlap units intrude all of the terranes east of the fault and the Tonga Formation within the fault zone.

On the basis of anomalous Late Cretaceous magnetic pole directions in one of the synmetamorphic plutons, namely the Mount Stuart batholith, Beck and Noson (1971) and Beck (1981) have suggested pre-Eocene clockwise rotation and (or) considerable northward translation of all or part of the Nason terrane and the Ingalls Tectonic Complex and by analogy the Tonga Formation of Yeats (1958b). Beck (1980, p. 7125) argued on theoretical grounds that deep-seated tilt cannot have had significant effect on the observed rotations. Thus, in situ post-intrusion tilt of the batholith could not have produced much, if any, of the pole discordance, unless the batholith were rotated in small separate blocks on faults as yet undiscovered. We do know that the Swauk Formation has been tilted strongly westward on the west side of the batholith, indicating that some post-Eocene tilting has taken place.

Ingalls Terrane

Ingalls Tectonic Complex

The Ingalls Tectonic Complex crops out most extensively southeast of the Skykomish River quadrangle (Tabor and others, 1982c), where tectonically mixed sandstone and argillite, radiolarian chert, pillow basalt, and ultramafic rocks indicate that the unit is derived from an ophiolite complex (Hopson and Mattinson, 1973; Southwick, 1974, p. 399; Miller, 1977; Miller and Frost, 1977, p. 287; and Miller, 1980a, b). A definitive study and detailed explanation of the origin of the Ingalls Tectonic Complex is in Miller (1985). Silberling and others (1987, p. 8) include the complex in their Mount Ingalls terrane, but Ingalls terrane (Tabor and others, 1987a) is more appropriate.

The Ingalls Tectonic Complex southeast of the quadrangle was metamorphosed in the prehnite-pumpellyite and greenschist facies (Miller, 1975, p. 23) prior to Late Cretaceous recrystallization that accompanied the intrusion of the Mount Stuart batholith.

Frost (1973, 1975) studied the thermal metamorphism and recognized the tectonic mixing of oceanic rocks in the Ingalls Tectonic Complex at Paddy Go Easy Pass [34], where components of the complex are thoroughly recrystallized by the Mount Stuart batholith. Some components retain their protolith structures and textures, however, revealing their origin as peridotite, basalt, pillow basalt, fine-grained volcaniclastic rocks, argillite, chert, and gabbro. Totally recrystallized rocks are most common east of the uppermost Cle Elum River. Miller (1985, p. 30-36) includes most of the rocks in the Paddy Go Easy Pass area in his Cle Elum Ridge fault zone, which he believes represents an oceanic fracture zone (see also Cowan and Miller, 1980).

Gabbro from the type locality of the Ingalls Tectonic Complex along Ingalls Creek (fig. 1) is Late Jurassic according to a 156-Ma U-Pb age of zircon from it (J.M. Mattinson, quoted in Miller, 1985, p. 29). Chert from the complex in the Wenatchee quadrangle contains radiolarians restricted to the Late Jurassic (Tabor and others, 1982c). Although the complex could contain additional tectonic components of different ages, we accept these ages for the protolith. Presumably the complex was assembled during the Late Jurassic or Early Cretaceous. Miller (1980a, 1980b, p. 390-404) proposed that the Ingalls was thrust onto the Chiwaukum Schist prior to intrusion of the Late Cretaceous Mount Stuart batholith. Evidence for this thrust relation is fairly persuasive in the Chelan quadrangle to the east (Miller, 1980a, 1980b, p. 405-410; 1985; Tabor and others, 1987a), and some intermixing of ultramafic rocks and the Chiwaukum (discussed below) suggest more widespread imbrication.

Easton Metamorphic Suite

East of the Straight Creek fault, the Easton Metamorphic Suite (see also discussion under "Rocks West of the Straight Creek Fault") crops out predominantly in two areas separated by an eastern lobe of the Tertiary Snoqualmie batholith.

Darrington Phyllite

Fault-bounded phyllite that crops out along the Cascade crest in the southern part of the quadrangle is highly deformed, locally mylonitized, and subsequently statically recrystallized. This phyllite, along with greenschist and blue-amphibole schist of the Shuksan Greenschist, extends almost continuously to Easton, south of the quadrangle (fig. 1) (Frizzell and others, 1984).

Ellis (1959, p. 101-104) described the western bounding fault in detail, and our observations confirm his conclusion that there has been no post-intrusion faulting in this area. North of the batholith in the West Fork of the Foss River, we include hornfelsic outcrops of strongly deformed phyllite in the Darrington Phyllite, although these rocks could be part of the Tonga Formation of Yeats (1958b).

Shuksan Greenschist

Small isolated outcrops of greenschist and blue-amphibole schist that crop out west of the Foss and Beckler Rivers were called the Eagle Greenschist by Yeats (1958a, p. 41; 1958b; 1977, p. 267), and he correlated them with the Easton Schist and the Shuksan Greenschist. The unique blueschist lithology makes this correlation seem appropriate. We presume that these rocks share the same Middle and Late Jurassic protolith age and Early Cretaceous metamorphic age as the Shuksan elsewhere.

U-Th-Pb ages of zircon recovered from a banded greenschist (metatuff) in Eagle Creek [25] are strongly discordant (table 2, no. 52). The U-Pb and Th-Pb ages probably mainly record crystallization during the Early Cretaceous metamorphism as well as during the thermal metamorphism engendered by the nearby 25-Ma Grotto batholith. The Pb-Pb age, however, also indicates an initial Precambrian zircon component, probably in the form of detrital grains. This hint of a Precambrian provenance for some Easton protolith sediments may help constrain reconstruction of their paleogeographic setting.

Blastomylonite and recrystallized tectonic breccia that are found in isolated exposures on Eagle Creek adjacent to the Grotto batholith may be derived from the Darrington Phyllite, although these rocks could also be strongly deformed rocks of the eastern melange belt. They might have been deformed along the Straight Creek fault, now mostly engulfed by the Grotto batholith (fig. 4).

Tonga Formation of Yeats (1958b)

Yeats (1958a, p. 42; 1958b) named a belt of predominantly pre-Tertiary metasedimentary rocks exposed on Tonga Ridge the Tonga Formation. The unit is bounded on the west by faults and Tertiary plutons and on the east by the prominent Evergreen fault. The Tonga appears to be a fault block in a zone of en echelon rupture along the Straight Creek fault.The belt of fine-grained metapelite and metasandstone grades from black phyllite and semischist in the Tonga Ridge area south of the South Fork of the Skykomish River to graphitic-staurolite-garnet-biotite schist and fine-grained hornblende-biotite gneiss on the North Fork. Intercalations of mafic rocks, presumably metamorphosed basalt flows and dikes, grade from greenschist in the south to fine-grained amphibolite in the north and east.

Yeats (1958a, p. 42-70), who described the Tonga Formation in detail, identified irregular metamorphic zones, which he separated by isograds that define an overprint of a northward increase of higher grade metamorphism in the phyllite: graphitic chlorite-sericite phyllite (south of the South Fork of the Skykomish River), graphitic garnet-biotite phyllite, and graphitic garnet-staurolite-biotite schist. Although contacts of the Beckler Peak stocks with the Tonga are commonly sheared, the phyllite and schist are also commonly sharply upgraded metamorphically near the contacts, particularly noticeable south of the biotite isograd, where phyllite rapidly grades to garnet-biotite schist a few meters from the stocks. Yeats did not include the local upgrading in his regional isograds, but he recognized (1977, p. 267) that the phyllite was overprinted by moderately kinematic to static, higher grade metamorphism at the same time it was intruded by the Beckler Peak stocks, which are satellites of the Late Cretaceous Mount Stuart batholith. In a like manner, schist adjacent to the Mount Stuart batholith in the Nason terrane to the east is also upgraded although at an overall higher metamorphic grade. The isograds shown in the Tonga on the map are adapted from Yeats (1958a, pl. V), and we have added a staurolite isograd in the vicinity of the main mass of the Beckler Peak stock.

The correlation of the Tonga is somewhat uncertain. The character of the phyllite, which appears to be associated with the rare outcrops of blue-amphibole-bearing greenschist in the Eagle Creek [25] area and to the north, led Yeats (1958a, p. 41; 1977, p. 267; Misch 1966, p. 111) to correlate the Tonga with the Easton Schist (equivalent to part of the herein-revised Easton Metamorphic Suite) to the south and the Darrington Phyllite of Misch (1966, p. 103) to the north. The blueschist is the most characteristic element of the Easton Metamorphic Suite, but it is exposed only along the west side of the Tonga Formation; contacts between the Tonga and the blueschist are not exposed. Greenschist and low-rank amphibolite that are intercalated with the phyllite and schist of the Tonga are found mostly along the east side of the outcrop belt. The contact between the Tonga and the blueschists on the west may well be a fault. Yeats (1977, fig. 3; written commun., 1986) suggested that the discordance in structure between the blueschist (Shuksan Greenschist) and the Tonga Formation is compelling evidence of a fault between the units.

The Tonga displays a fine-crenulation lineation on the principal foliation surfaces, much like that of the Darrington Phyllite (Yeats, 1958a, p. 48; Haugerud and others, 1981, p. 378; Brown, 1986, p. 147). This feature was used by workers in the field to distinguish the Darrington Phyllite from phyllites in other units, but several other features in the Tonga are unlike those of the Darrington. The Tonga Formation differs from most of the Darrington by having more metasandstone and better preserved original sedimentary features in the metasandstone and, ironically, by having an overprint of higher grade minerals (Misch, 1971) and by grading into amphibolite-grade schist.

Because the contact between the Tonga and the blueschist outcrops may be a fault and because of the lithologic differences, the correlation of the Tonga with the Easton Metamorphic Suite is suspect. The Tonga Formation appears to grade into the Chiwaukum Schist, a relation alluded to by McDougall (1980, p. 25), but discontinuous outcrops, shearing, and granitoid plutons obscure the transition or contact between the Tonga and the Chiwaukum. The Evergreen fault apparently separates rocks of slightly to moderately different metamorphic grade. Although we follow the lead of earlier studies (Yeats 1958a; Tabor and others, 1982b, d) and include rocks east of the fault and south of Johnson Creek [24] in the Chiwaukum, these rocks could just as easily be assigned to the Tonga Formation. From a regional view, the increase in grade in the Tonga from south to north continues in the Chiwaukum Schist in the Cadet Creek area [16] where staurolite-grade schist gives way to kyanite-grade and then sillimanite-grade schists near the contact with the banded gneiss north of the quadrangle (see also Heath, 1971, pl. 1).

As we suggested in earlier reports (Tabor and others, 1982a, d), the Tonga may be the lower-grade stratigraphic equivalent of the Chiwaukum Schist. In a subsequent paper, Tabor and others (1987b) argue that the Tonga is a correlative of the Darrington Phyllite and, as a correlative of the Easton Metamorphic Suite that had undergone a high-pressure, low-temperature blueschist metamorphism, was less likely to be a correlative of the Chiwaukum Schist because the latter lacked evidence of the blueschist metamorphism. As we have noted here, the correlation of the Tonga with the Easton Metamorphic Suite is uncertain; at present we believe the preponderance of evidence upholds its correlation with the Chiwaukum Schist. As will be described below, the protolith age of the Chiwaukum is uncertain.

Stout (1964, p. 321) suggested that his Lookout Mountain Formation, exposed about 60 km to the south, also between strands of the Straight Creek fault, might be a correlative of the Tonga. The two units are so similar lithologically that their correlation is attractive, although Goetsch (1978, p. 26) felt that they did not have a similar metamorphic history. The Lookout Mountain unit is faulted against a zone of highly tectonized rocks, some of which are blue-amphibole schist (Stout, 1964; Goetsch, 1978; Frizzell and others, 1984), but no blue-amphibole schist has been found intercalated directly with the schist of the Lookout Mountain Formation. The Lookout Mountain is intruded by metatonalite that yields U-Pb ages of zircon of about 155 Ma (Hopson and Mattinson, 1973). Goetsch's objections notwithstanding, we tentatively correlate the Lookout Mountain and the Tonga Formations. The Jurassic pluton intruding the Lookout Mountain unit might represent the same intrusive episode that produced the gneissic tonalite of Excelsior Mountain (see below). If the correlation of the Tonga with the Lookout Mountain is correct, then the protolithic age of the Tonga is pre-155 Ma or pre-Late Jurassic.

Gneissic tonalite of Excelsior Mountain

An elongate gneissic tonalite mass crops out on Excelsior Mountain [18] and extends northward across the North Fork of the Skykomish River. It appears to intrude both the Tonga Formation of Yeats (1958b) and the Chiwaukum Schist, but we observed no definitive contacts; the contacts could be faults. The pluton is highly mylonitic and cataclastic; much cataclasis may be caused by the nearby Evergreen fault.

U-Th-Pb analyses of zircon (table 2, no. 49) indicate considerable Late Cretaceous recrystallization, but $^{207}Pb/^{206}Pb$ ages as old as 120 Ma in the finer grained fraction probably reflect pre-Cretaceous crystallization of the original pluton.

Except for the older zircon component, the gneissic tonalite bears considerable resemblance to the Sloan Creek plutons (discussed below). However, we think that it more likely is an older pluton intruded into the Tonga, similar perhaps to the Jurassic plutons that intruded the Lookout Mountain Formation of Stout (1964), a tentative correlative of the Tonga.

Nason terrane

The major bedrock unit in the Nason terrane is the Chiwaukum Schist, made up predominantly of aluminous mica schist and subordinate amphibole-bearing schist and amphibolite. Intimately associated with the Chiwaukum is banded gneiss derived from the schist by metasomatic and igneous processes. The Nason terrane is one of several distinct tectonostratigraphic terranes in the crystalline core of the North Cascades (see Tabor and others, 1982d, 1987b).

East of the quadrangle, the Nason terrane is bounded on the northeast by a probable fault separating it from the Mad River terrane (Tabor and others, 1987a,b) and on the east by the Chiwaukum graben. The west boundary is along the Evergreen fault and, north of the quadrangle, the major west strand of the Straight Creek fault. On the south, the terrane has been thrust over by, and imbricated with, the Ingalls Tectonic Complex (Miller, 1980a; 1980b, p. 405-410; 1985).

Chiwaukum Schist

Two major units comprise the Chiwaukum Schist: (1) a structurally and probably stratigraphically lower unit of mica schist with subordinate amphibolite, amphibole-mica schist, calc-silicate schist, marble and relatively rare ultramafic rock and (2) an upper predominantly mica schist unit. The upper mica schist unit is widespread to the east (see Tabor and others, 1980; 1987a), especially in the Chiwaukum Creek area where it was first described by Page (1939, p. 15-16; 1940). Previous workers in the Skykomish River quadrangle (Oles, 1956, p. 41-86; Yeats, 1958a, p. 17-40; Rosenberg, 1961, p. 1-34; Van Diver, 1964a, p. 15-38; and Heath, 1971, p. 12-26) have described rocks that we now correlate with the Chiwaukum Schist and the associated banded-gneiss unit. Most workers have considered the Chiwaukum to be a metamorphosed sandy to argillaceous sedimentary sequence with local carbonate and mafic igneous rocks. Magloughlin (1986, p. 101-104) discusses the probable ocean-floor depositional setting of the Chiwaukum protolith.

The metamorphic history of the Chiwaukum Schist has been interpreted in contrasting ways, although most recent workers (Heath, 1971; Getsinger, 1978; Plummer, 1980; Kaneda, 1980; Berti, 1983; Miller, 1985; Evans and Berti, 1986; Magloughlin, 1986) recognize several stages of deformation. These stages were highlighted by growth of porphyroblasts of andalusite, staurolite, kyanite, and sillimanite and were promoted in part by the intrusion of the Late Cretaceous Mount Stuart batholith. Estimates of when the peak metamorphic pressures were reached and the timing of the intrusion differ, but the most recent work suggests that andalusite, formed in an early episode of metamorphism associated with the intrusion of the Mount Stuart batholith, has been replaced by kyanite. This relation led Evans and Berti (1986) to propose tectonic burial by overthrusting of the Nason terrane in post-Late Cretaceous (Mount Stuart) time. On the contrary, age data from the

Mount Stuart batholith and the Sloan Creek plutons, as described below, demand rapid uplift and erosion following emplacement of the plutons. Magloughlin (1986, p. 226) summarizes several deformation and intrusion scenarios.

The isograds shown on the map in the Chiwaukum Schist and associated banded-gneiss unit are projected from outside the quadrangle—from the east (Plummer, 1980, p. 387) and from the north (Crowder and others, 1966)—and are also derived from Heath (1971), scattered data in Rosenberg (1961), Van Diver (1964a), and Oles (1956), and from our own reconnaissance work. The isograds express mineral growth in at least two recognized episodes of metamorphism. Data are sparse in the upper North Fork of the Skykomish River area and the overall distribution of regional sillimanite is uncertain; most workers found sillimanite only in rocks near the Mount Stuart batholith and the Sloan Creek plutons, whereas we found it some distance from these plutons in the upper North Fork of the Skykomish River area.

The isograd pattern suggests that the greatest intensity of metamorphism was in the banded gneiss unit in the upper North Fork of the Skykomish River area, in the vicinity of the Sloan Creek plutons. This pattern may well indicate a greater degree of uplift in this area. The close spacing in the isograds and the decrease in metamorphic grade across the Evergreen fault zone confirm such an interpretation. The parallelism of isograds in the Chiwaukum Schist and the Tonga Formation of Yeats (1958b), west of the Evergreen fault, strongly suggests that the latest episode of metamorphism in the Tonga was the same as that in the Chiwaukum but at a lower grade.

In the Chelan quadrangle to the east, Tabor and others (1980; 1987a) describe broad west-northwest-trending folds in the Chiwaukum Schist and banded-gneiss unit. This structure is not well shown by planar foliation in the Skykomish River quadrangle, presumably because the intrusion of the Mount Stuart batholith and Sloan Creek plutons has dilated and distorted the earlier structural pattern. The banded-gneiss unit (kyanite and sillimanite zone) represents the core of a major antiform flanked by the lower grade Chiwaukum Schist (staurolite zone) on the northeast and southwest. West of the Evergreen fault, the change in grade in the Tonga Formation from greenschist-facies rocks on the south to staurolite-grade rocks on the north probably reflects the same structural uplift toward the crest of the antiform, although at the overall lower grade.

We do not know the age of the original sediments and volcanic rocks that were metamorphosed to become the Chiwaukum Schist. In earlier reports (Tabor and others, 1987a), we suggest that the protolith age of the unit might be sometime during the Late Jurassic to Late Cretaceous, on the basis of relations with the Ingalls Tectonic Complex. Well within the Chiwaukum Schist, mostly exposed in the Chelan quadrangle to the east (Tabor and others, 1987a) but also above Whitepine Creek [33], a narrow zone of scattered ultramafic bodies contains a remarkably thin and continuous slab of metaperidotite, which parallels compositional layering in the Chiwaukum and is associated with fine-grained sugary amphibolite similar to Ingalls amphibolite. Imbrication of the Ingalls and the Chiwaukum could explain the distribution of the ultramafic rocks, but alternatively this slab and, by analogy, other small metamorphosed ultramafic bodies might be metamorphosed serpentine slides that descended onto Chiwaukum protolith mud from an adjacent uplifted Ingalls ophiolite prior to metamorphism of the two units.

In contrast, considerable new Rb-Sr data has been interpreted to suggest a protolithic age of 210 Ma, latest Triassic and (or) earliest Jurassic. From 15 samples of the Chiwaukum Schist, Magloughlin (1986, p. 263-264) obtained a somewhat scattered whole-rock isochron showing an age of 210±22 Ma and a $^{87}Sr/^{86}Sr$ initial intercept of 0.7043. An almost identical whole-rock isochron is derived from Rb-Sr data from the Settler Schist in British Columbia, Canada (Gabites, 1985, p. 68).

On the basis of a comparison of lithology and metamorphic history, Lowes (1972, p. 167), Misch (1977), and Evans and Berti (1986, p. 697) have suggested that the Settler Schist is an offset correlative of the Chiwaukum Schist, 190 km to the northwest and across the Straight Creek fault. The Settler is also intruded by Late Cretaceous calkalkaline plutons similar to the Mount Stuart batholith. The whole-rock Rb-Sr isochrons for both the Settler and the Chiwaukum are interpreted to be sedimentary ages (Bartholomew, 1976, p. 100; Gabites, 1985, p. 70; R.L. Armstrong in Magloughlin, 1986, p. 264). The Rb-Sr data seem to confirm the correlation of the Chiwaukum with the Settler Schist, but the Rb-Sr ages are suspect because of the poorly defined isochrons. In addition, the initial $^{87}Sr/^{86}Sr$ ratios from the whole-rock isochrons are low (0.7043), which is surprising because U-Pb ages from zircons from the Settler suggest a modified Precambrian component in the protolith sediments (Gabites, 1985, p. 70). If there is a Precambrian detrital component, the initial ratio should be higher. One other clue supportive of a Triassic protolithic age of the Chiwaukum Schist may be found in the probable correlations with the Tonga Formation of Yeats (1958b) and the Chiwaukum Schist. Because the Tonga may be a correlative of the Lookout Mountain Formation of Stout (1964) and is intruded by a Late Jurassic pluton, the Chiwaukum like the Tonga and Lookout Mountain must have a pre-Late Jurassic protolith. We tentatively consider the Chiwaukum protolith age to be pre-Late Jurassic.

Potassium-argon ages of biotite, muscovite, and hornblende from schist, gneiss, pegmatite, and amphibolite of the Nason terrane cluster tightly around 85-81 Ma (table 2, no. 39; Tabor and others, 1987a). Concordant biotite and muscovite ages from gneissic biotite granodiorite described below are also about 82 Ma (table 2, no. 38). This near concordancy of different minerals from a variety of rocks suggests that the ages represent rapid cooling, such as by uplift, following the last episode of regional metamorphism and (or) the intrusion of the youngest synkinematic pluton of the Mount Stuart batholith dated at about 87 to 85 Ma (see also the discussion of the Sloan Creek plutons below). These ages are in keeping with the 90- to 60-Ma range for regional metamorphism reported by Mattinson (1972, p. 3778) in the Chelan area 55 km east of the quadrangle and our work in the Chelan quadrangle (Tabor and others, 1987a). In contrast, Magloughlin (1986, p. 278-282), on the basis of pressure and temperature paths, prefers a regional metamorphic culmination between 102 and 92 Ma.

Banded gneiss

Gneiss, schist, and amphibolite

The Chiwaukum Schist grades into banded gneiss characterized by conspicuous, thin to very thick layers and irregular masses of light-colored tonalite gneiss and light-colored, fine-grained to pegmatitic dikes and sills. Much of the unit is alternating mica schist, hornblende schist, amphibolite, and light-colored tonalite gneiss. The amount of gneiss and light-colored dike rock in the unit ranges from 10 to 99 percent. Contacts between the gneiss and schist are sharp in some places and gradational in others. The rocks are locally migmatitic, especially where light-colored gneiss predominates. Foliation is generally conspicuous everywhere; massive rocks are rare.

The banded gneiss corresponds to Rosenberg's (1961, p. 35-54) Poe Mountain subdivision of the Green Mountain-White Chuck unit of Ford (1959) and is continuous with rocks mapped as biotite gneiss by Crowder and others (1966) in the Glacier Peak quadrangle to the north.

Early workers (Oles, 1956, p. 86-111; Rosenberg, 1961, p. 35-54; Van Diver, 1964a, p. 51-66; 1964b, p. 146-147) considered much of the gneiss to be of replacement origin, although Rosenberg (1961, p. 21-30) considered some of the fine-grained gneiss to have a sedimentary protolith that was metamorphosed without appreciable metasomatism. Gradational contacts, relicts of schist and mafic schlieren, and textural evidence of replacement all suggest that the banded gneiss formed from the Chiwaukum Schist; the schist was at least partially replaced by quartzofeldspathic (leuco-trondhjemitic) material during regional synkinematic metamorphism. Considerable material has been added to the banded gneiss by intrusion, as shown by crosscutting internal contacts, dilation, and relict igneous textures in some gneiss. Layers of porphyroblastic, mylonitic gneiss throughout the unit suggest considerable local, deep-seated shearing.

Gneissic biotite granodiorite

Gneissic biotite granodiorite similar to some thin layers of light-colored gneiss in the banded gneiss also crops out in larger, relatively uniform masses. Contacts are generally conformable and interlayered with schist but are locally crosscutting. Textural features such as euhedrally zoned plagioclase cores and intergranular quartz suggest an early igneous history, although the bodies are now predominantly crystalloblastic and in the same metamorphic facies as the surrounding schist. Biotite and muscovite from the gneissic biotite granodiorite on Rainey Creek [32] yield concordant K-Ar ages of 81 and 83 Ma respectively (table 2, no. 38), which fall within the range of 90-60 Ma for the last episode of regional metamorphism for the North Cascades espoused by Mattinson (1972, p. 3779).

Gneissic pyroxene-biotite tonalite

A relatively uniform body of tonalite crops out at Pear Lake [31]. Relict igneous texture and zoning in plagioclase indicate its igneous origin, but we observed no intrusive contacts.

Terrane-overlap units

Late Cretaceous late-kinematic to synkinematic plutons cut metamorphic terranes throughout the North Cascades (Tabor and others, 1987b). The Mount Stuart batholith intrudes both the Nason terrane and the Ingalls Tectonic Complex. The Tenpeak Mountain pluton intrudes along the presumed tectonic contact between the Nason terrane and the Mad River terrane exposed east of the Skykomish River quadrangle (Tabor and others, 1987a).

Sloan Creek plutons

Large sill-like bodies of uniform biotite-hornblende tonalite gneiss crop out in the northeastern part of the quadrangle and extend to the north where they have been called the Sloan Creek plutons by Crowder and others (1966) and Tabor and others (1982b).

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 healed cataclasis indicate that the original rock was a phaneritic igneous rock. Layers of biotite-hornblende tonalite flaser gneiss are common in schist and banded gneiss near the plutons.

Hornblende and biotite from tonalite gneiss from the southeast face of Sloan Peak, north of the quadrangle, yield K-Ar ages of about 90 and 75 Ma respectively. U-Th-Pb ages of zircons from the same sample are concordant at about 90 Ma (table 2, no. 48). The younger biotite age may be due to slow cooling or possibly to thermal effects of the nearby Tertiary Monte Cristo stock, but the concordancy of the hornblende and the zircon isotope ages is convincing evidence of Late Cretaceous crystallization, followed by rapid uplift.

Tenpeak Mountain pluton

A small part of the extensive Tenpeak Mountain pluton extends into the northeast corner of the Skykomish River quadrangle. In texture and structure, the Tenpeak Mountain pluton is similar to the Sloan Creek plutons. It also appears to be a synkinematic pluton, intruded at mesozonal to catazonal depths (Buddington, 1959, p. 708) during the Late Cretaceous metamorphic episode. Zen and Hammarstrom (1984) suggest that it crystallized at more than 25 km deep. Cater (1982, p. 31-35), who described the Tenpeak Mountain in detail and recorded chemical and modal analyses, felt that the pluton was a deep-seated igneous body, but unaffected by regional metamorphism and displaying predominantly protoclastic textures. Several new U-Th-Pb zircon ages confirm its Late Cretaceous age (R.A. Haugerud and Thomas Stern, written commun., 1986). See Tabor and others (1980, p. 17-18; 1987a) for a brief history of ideas regarding the origin of the pluton, citations of other work, and further description.

Rocks of the Mount Stuart batholith

The Mount Stuart batholith, composed of two elongate tonalite to granodiorite plutons and several satellitic bodies, intrudes the Nason terrane and the Ingalls Tectonic Complex. The eastern and western plutons are separated by a thin screen composed of the Chiwaukum Schist and the Ingalls Tectonic Complex. Of all the Late Cretaceous plutons in the Nason terrane, the Mount Stuart looks the most igneous in texture and structure. In spite of its emplacement prior to or during the latest episode of regional metamorphism, only the earliest phases show significant metamorphic features.

Russell (1900, p. 105-107) first described the rocks of the batholith, and Smith (1904, p. 4, 5) named the Mount Stuart Granodiorite for exposures to the southeast of the quadrangle. Subsequently much study (Page, 1939, p. 44-54; Pratt, 1958, p. 46-49; Plummer, 1969, p. 10-34; Engels and Crowder, 1971) has been focused on the batholith, especially its petrochemical evolution (Pongsapich, 1974; Erikson, 1977b).

A rather complex array of discordant isotopic ages (table 2, nos. 40-47 and Tabor and others, 1987a) indicates that the age of the eastern pluton is about 93±3 Ma and the western pluton about 85 Ma. The Harding Mountain pluton, a southern extension of the western pluton and having a slightly different jointing habit, has concordant hornblende and biotite ages of about 88 Ma (table 2, no. 42).

Although the western pluton appears to be a separate magmatic pulse about 8 m.y. younger than the eastern pluton, the two plutons differ little chemically (Erikson, 1977b); on the basis of modal determinations, the eastern pluton is slightly more mafic (see "Description of Map Units" on the map).

Intruding the Tonga Formation of Yeats (1958b) are the satellitic Beckler Peak stocks (Yeats, 1958a, 1977) that are about 92 m.y. old (Yeats and McLaughlin, 1968; Yeats and Engels, 1971). The stocks, essentially the same age as the eastern pluton of the Mount Stuart batholith, seem anomalously positioned to the west of the younger, western pluton. The Beckler Peak stocks are exposed in a probable downdropped block, and the eastern Mount Stuart pluton is a concordant sill-like body dipping to the east, a geometry that suggests the eastern pluton and Beckler Peak stocks may have been connected as a large east-dipping intrusive layer prior to later intrusion of the western pluton, concomitant rotation of the foliation, faulting, and erosion.

Plummer (1969, p. 31-36) and Erikson (1977b, p. 184) identified early phases of metadiorite and metagabbro associated with the eastern pluton of the Mount Stuart batholith. These more mafic rocks are more deformed and metamorphosed than the main phases of the batholith. A metagabbro in the Chelan quadrangle is about 96 m.y. old, based on concordant U-Th-Pb isotope ages of zircon (Tabor and others, 1987a). This age is similar to or slightly older than the main eastern pluton.

TERTIARY ROCKS

Swauk Formation and Silver Pass Volcanic Member

The Swauk Formation is predominantly thin- to thick-bedded feldspathic sandstone of fluviatile origin. Interbeds of siltstone and argillite, pebbly layers, and conglomerate are also common. Yeats (1958a, p. 127) and McDougall (1980, Appendix A) indicate that conglomerate is particularly prominent east of Tonga Ridge where the Swauk is in contact with the Mount Stuart batholith. We show McDougall's irregular depositional contact on the map, although he (1980, p. 47) discusses this contact as though it were a syndepositional fault and shows it as a normal fault on a cross-section (B-B', Appendix B).

Sandstone east of the Evergreen fault is continuous with the Eocene Swauk Formation at its type locality to the southeast (Tabor and others, 1982c; 1984), except where it is interrupted by a reentrant of the Snoqualmie batholith and overlying middle Tertiary volcanic rocks.

Andesitic to dacitic volcanic rocks interbedded with feldspathic sandstone on Summit Chief Mountain and at Spada Lake appear to be the Silver Pass Volcanic Member of the Swauk.

Feldspathic sandstone west of the Evergreen fault, in an isolated patch north of Fourth of July Creek [23] and forming a screen between Neogene batholiths from Trout Creek to Silver Creek, has been either included in the Swauk or questionably correlated with the Swauk in earlier studies (Yeats, 1958a, p. 128-150; Pytlak, 1970, p. 9-12; Heath, 1971, p. 105-109; Ream, 1972, p. 8-12; Tabor and others, 1982a, d). Because of new data reported north of the quadrangle and regional structural considerations described below, we now correlate these rocks with the late Eocene Barlow Pass Volcanics of Vance (1957b). For similar reasons the overlying and locally interbedded volcanic rocks south of Skykomish that we once referred to the Silver Pass Volcanic Member of the Swauk Formation (Tabor and others, 1982a) are also now correlated with the Barlow Pass Volcanics.

The Swauk Formation southeast of the Snoqualmie batholith is folded and cut by many northwest-trending faults. The unit appears to be steeply faulted against the Darrington Phyllite in the Straight Creek fault zone. Because of its steep dip, we interpret this fault to be a normal fault and thus a branch of the Straight Creek fault. Gualtieri and Simmons (1973) and Gualtieri and others (1973) consider this fault to be one of several east-dipping thrusts in the upper Waptus River area [28].

Fuller Mountain plug

Northeast of the town of Snoqualmie a small plug of hornblende-biotite-pyroxene granodiorite intrudes graywacke of the western melange belt, forming the erosionally resistant backbone of Fuller Mountain. Hornblende yields a K-Ar age of about 47 Ma (table 2, no. 34), suggesting that this plug is related to early Eocene plutons in the Granite Falls and Mount Pilchuck area north of the quadrangle (Yeats and Engels, 1971, p. D36-D37).

Raging River Formation

Conformably underlying nonmarine rocks of the Tiger Mountain and Tukwila Formations of the Puget Group (Vine, 1969, p. 16) are Eocene marine sandstone, siltstone, and shale with minor conglomerate. These marine rocks are exposed in a northwesterly plunging anticline in the southwest corner of the quadrangle. Sandstone of the Raging River Formation is rich in volcanic clasts, making strong contrast with the conspicuously feldspathic fluviatile sandstones of Eocene age elsewhere in western Washington. Foraminifers from the unit are considered to be middle Eocene in age (Vine, 1969, p. 16; Rau, 1981, fig. 11).

Puget Group

The Tiger Mountain and Tukwila Formations of the Puget Group, which crop out in very limited exposures in the southwest corner of the quadrangle, have been described in detail by Vine (1969). We have included outcrops of predominantly volcanic rocks with minor interbeds of sedimentary rocks in the Tukwila, although Vine (1969), mapping at a larger scale, generally separated the two interfingering units. Breccia near the top of the Tukwila west of the map area yields a zircon fission-track age of 41 Ma and a hornblende K-Ar age of about 42 Ma (Turner and others, 1983). Ash beds in coal from interfingering sedimentary rocks south of the quadrangle yield plagioclase K-Ar and apatite fission-track ages ranging from about 45 to 41 Ma (Turner and others, 1983; Frizzell and others, 1984).

The pronounced folding and abundant interbeds of feldspathic sandstone, locally with coal, in the Tukwila and Tiger Mountain Formations differentiate them from the low-dipping volcanic rocks of Mount Persis, which crop out on Rattlesnake Mountain and to the north, and from a totally volcanic sequence, mostly Oligocene and younger in age, which crops out southeast of the map area.

We also include in the Tukwila the volcanic rocks that display questionable, steeply dipping and sheared bedding in the vicinity of Grand Ridge [7] and east of it. Alternatively, some or all of the volcanic rocks in this area could be the volcanic rocks of Mount Persis.

Barlow Pass Volcanics of Vance (1957b)

The "earlier andesites" of Spurr (1901, p. 791-796) in the Monte Cristo area form a thick pile of altered basalt, andesite, and rhyolite that crops out continuously from the North Fork of the Skykomish River to beyond Barlow Pass (north of the quadrangle, fig. 1) where they were named the Barlow Pass Volcanics by Vance (1957a, p. 275-287; 1957b). Pytlak (1970, p. 12-19), Heath (1971, p. 116-122), and Ream (1972, p. 13-15) have also described the Barlow Pass Volcanics. Although much of the Barlow Pass Volcanics is characterized by feldspathic sandstone interbeds, northwest of the type locality at Barlow Pass the dominant lithology becomes sandstone.

The Barlow Pass Volcanics forms characteristically dark, massive outcrops that contrast highly with the unconformably overlying, light-colored, very thick bedded breccia of Kyes Peak. The exact location of the unconformity, however, is hard to find in many places. Bedding is also very difficult to find in the Barlow Pass unit except in interbedded feldspathic sandstone and shale. Vance (1957a, p. 275) estimated a thickness of at least 1,220 m of Barlow Pass volcanic rocks and sandstone interbeds in the type locality.

The Barlow Pass Volcanics rests unconformably on schist and phyllite of pre-Tertiary age. Vance and Naeser (1977) reported a zircon fission-track age of 35 Ma, but this age has probably been reduced by later intrusions (J.A. Vance, written commun., 1981). Several zircon fission-track ages from rhyolite tuff interbeds in feldspathic sandstone in the Barlow Pass Volcanics of the Deer Creek area (fig. 1) are 46 to 42 Ma (Tabor and others, 1984, p. 36; J.A. Vance, written commun., 1986). On the basis of a sparse fossil-leaf collection, Spurr (1901, p. 795-796) correlated the Barlow Pass with the Eocene Puget Group.

Vance (1957a, p. 287) proposed that the Barlow Pass is correlative with the upper Eocene and Oligocene(?) Naches Formation as defined by Foster (1960; 1967) and redescribed by Tabor and others (1984, p. 35-36). On the basis of the unit's lithology, especially the thick basalt flows, rhyolite, and interbedded feldspathic sandstone, we think that this correlation is correct.

With some uncertainty we include three areas of mostly fluviatile feldspathic sandstone and conglomerate, locally with interbedded volcanic rocks, in the Barlow Pass Volcanics.

One area lies immediately west of the main outcrop area of the Barlow Pass and forms a screen of folded strata between the Index and Grotto batholiths, along Trout and Silver Creeks. These rocks were first described by Spurr (1901, p. 789-791) and subsequently studied by Weaver (1912a), Smith (1915; 1916, p. 565-566), Galster (1956), Yeats (1958a, p. 128-150), Pytlak (1970, p. 9-12), Heath (1971, p. 105-109), and Ream (1972, p. 8-12). The sandstone appears to have been deposited unconformably on the eastern melange belt. Most of the sandstone is strongly thermally metamorphosed and bears sulfides adjacent to tonalite dikes (Spurr, 1901, p. 829; Ream, 1972, p. 9). In earlier reports, we (Tabor and others, 1982a,b) tentatively correlated these rocks with the Swauk Formation. Although volcanic interbeds are very rare in this outcrop belt within the Skykomish River quadrangle, the sandstone belt extends 40 km north to the Deer Creek area where the upper Eocene rhyolite tuff interbeds mentioned above are prominent. This thick belt of feldspathic sandstone is mostly faulted against volcanic rocks of the Barlow Pass unit, but in the Silver Creek area, the bedding attitudes suggest that Barlow Pass volcanic rocks overlie the sandstone with a strong angular unconformity. An unconformity would present a strong argument for correlating the sandstone of Silver Creek and Trout Creek with the lower Eocene Swauk Formation, but in the area in question the rocks are cut by many small faults, and most rocks are highly hornfelsic due to the nearby Grotto batholith and younger stocks; exact relations are unclear.

The second area of sandstone crops out near and southeast of Skykomish and includes a thick sequence of overlying and interbedded volcanic rocks. These rocks were originally described by Galster (1956, p. 43), Yeats (1958a, p. 133), and McDougall (1980, appendix A). The sandstone is in fault contact on the east with the Tonga Formation of Yeats (1958b). Small pods of serpentinized peridotite along the fault and partially imbricated with sheared sandstone are similar to imbricated ultramafic rocks in sandstone of the Barlow Pass(?) Volcanics north of the quadrangle (Vance, 1957a; Vance and Dungan, 1977). In previous reports, we (Tabor and others, 1982a, b) included these sandstones in the Swauk Formation. The sandstone in this area appears to be separated from the Swauk Formation to the east by the Evergreen fault. McDougall (1980, p. 66), although attesting to the reality of the fault, felt that the bedding in the sandstone was uninterrupted across it. Petrologically the sandstone of the lower Eocene Swauk Formation is similar to the sandstone in the upper and middle Eocene Barlow Pass Volcanics and its partial correlative, the Naches Formation to the south. Detailed sandstone petrology indicates some differences between Naches and Swauk, but data on the Barlow Pass(?) sandstones are limited (Frizzell, 1979).

South of Skykomish, sandstone and conglomerate of the Barlow Pass(?) Volcanics are overlain and interbedded with volcanic rocks, a relation recognized by Galster (1956, p. 44). Other workers (Smith, 1915, p. 154; and Yeats, 1958a, p. 154; 1977, p. 273) have considered the eruptive rocks to overlie the sandstone unconformably. The volcanic rocks are a heterogeneous mixture of andesite to rhyolite; they include dark-green to black porphyritic andesite, dark dacite tuff and breccia, rhyolite tuff, flow-banded rhyolite, and, less commonly, breccia with sandstone and schist clasts. Although these rocks are not as strongly bimodal as the Barlow Pass, we think that they are correlative with that unit.

The volcanic rocks south of the Skykomish area were first described by Smith (1915, p. 162-165), who assigned them to the (Miocene) Keechelus Andesitic Series of Smith and Calkins (1906, p. 8). The volcanic rocks were further described by Galster (1956, p. 43, 54-69) in a thesis. He divided and named them the Temple Mountain andesite and Lookout breccias (Galster, 1956, p. 55).

Although we are uncertain about their affinity, we also include in the Barlow Pass Volcanics a variety of volcanic rocks, mostly porphyritic andesite, that cap ridges north of Money Creek and crop out as isolated roof pendants in the Grotto batholith west of the Beckler River. Yeats (1958a, p. 160-162) has described the latter occurrences. Most of the pendants and a great deal of the main volcanic pile exposed in the quadrangle are thermally metamorphosed by underlying plutons. Many of the rocks are hornfels and have only a few relict textures or structures left to indicate their volcanic origin.

A zircon fission-track age of 28 Ma (Vance and Naeser, 1977; table 2, no. 36) from the Barlow Pass(?) Volcanics south of Skykomish is undoubtedly a minimum age because of the close proximity of the Snoqualmie and Grotto batholiths. A sample of dacite ash-flow tuff from the Barlow Pass(?) Volcanics east of the Miller River apparently is so thoroughly recrystallized by the nearby batholith that its U-Th-Pb zircon ages (table 2, no. 35) now show a strong Miocene overprinting. The $^{207}Pb/^{206}Pb$ ages of the coarse- and fine-mesh fractions (about 111 and 103 Ma, respectively) give some evidence for the partial survival of detrital zircon from the metamorphic and plutonic terrane to the east.

An isolated, down-faulted block of sandstone and conglomerate north of Money Creek was first described by Plummer (1964, p. 25-30), who implied that these thermally metamorphosed rocks were pre-Tertiary in age. Because they resemble Tertiary fluviatile sandstones in their coarse crossbedding and graded bedding we include them in the Barlow Pass(?) Volcanics.

Volcanic rocks of Mount Persis

Composed of predominantly porphyritic andesite flows, the volcanic rocks of Mount Persis form a west-descending upland surface south of the Skykomish River and mostly west of the Index and Snoqualmie batholiths. The once-continuous outcrop area of the volcanic rocks is now interrupted by an eroded north-trending horst composed of the western melange belt (see map cross section A-A'). Volcanic rocks of the eastern part of this unit were first briefly described by Weaver (1912a, p. 44-46) as the West Index Andesitic Series. The peak that was called West Index in Weaver's day is now Mount Index, and, inexplicably, very little of Weaver's West Index unit is exposed on it. As Weaver mentioned, however, the unit is well exposed on Mount Persis [5], especially on the precipitous northeast face. In the North Fork Snoqualmie River area and along the forks of the Tolt River, Bethel (1951, p. 60-75) and Plummer (1964, p. 8-13), respectively, in their theses included the volcanic rocks of Mount Persis in Bethel's Mount Phelps volcanics. In his thesis, Danner (1957, p. 460-479) designated rocks in the western outcrop area of the Mount Persis rocks as his Snohomish Formation, originally mapped in an earlier thesis as the Snohomish andesite unit to the west by McKnight and Ward (1925).

The composition of the volcanic rocks of Mount Persis is mostly andesitic. Porphyritic two-pyroxene andesite flows are most common, but breccia and tuff as well as volcanic conglomerate, sandstone, and shale occur sporadically, especially near the top of the section to the west. Aphyric basalt is a rare constituent. Altered, variegated andesitic breccia and tuff on Mount Persis in the eastern outcrop area is capped by thick flows of massive hornblende dacite breccia, a splendid, well-indurated rock type that is coarsely jointed and forms bold cliffs.

The age of the volcanic rocks is somewhat uncertain. They rest unconformably on Mesozoic melange and, west of Monroe, apparently are overlain by unnamed micaceous sandstone of Oligocene age (Minard, 1981). The volcanic unit is intruded and thermally metamorphosed by the 34-Ma (early Oligocene) Index batholith.

Hornblende from the dacite breccia on Mount Persis yields a K-Ar age of 38.1±3.3 Ma (table 2, no. 32), and an apatite fission-track age from a massive andesite flow in the western outcrop area is 47±4 Ma (table 2, no. 33). Because of possible heating by the underlying Index batholith, the hornblende age is probably a minimum. If the structural argument that we offer below is correct, the fission-track age would appear to be too old.

The volcanic rocks of Mount Persis appear to be about the same age as the Tukwila Formation (about 42 Ma) of the Puget Group and are almost continuous with the Tukwila that is mapped in the southwestern part of the quadrangle. They differ from the Tukwila in their lack of pronounced deformation and lack of micaceous and (or) feldspathic sandstone interbeds. The gentle dips in the volcanic rocks of Mount Persis suggest that the Mount Persis unit is younger than the Tukwila, but it is probably no younger than 38 Ma and cannot be younger than 34 Ma because it is intruded by the Index batholith. Although exposures are scarce where the units adjoin in the crucial area near North Bend (fig. 1), we suspect that the Puget Group is separated from the Mount Persis unit by major faults. In the crucial area, a probable zone of faulting buried by unconsolidated deposits is shown on the west edge of the map, extrapolated from a steep east-west gravity gradient (Danes and Phillips, 1983) and faults suggested by Gower and others (1985).

Two-pyroxene andesite flows that form Rattlesnake Mountain south of North Bend are here included in the volcanic rocks of Mount Persis, although in a preliminary report we (Tabor and others, 1982a) suggested the correlation of the Rattlesnake Mountain rocks with younger volcanic rocks to the south. There is little to differentiate the two-pyroxene andesite on Rattlesnake Mountain from fresh-flow rocks in any of the middle and upper Tertiary units. The Rattlesnake Mountain rocks are faulted against the Puget Group on the southwest, and in their overall thickness and uniformity they seem more like the volcanic rocks of Mount Persis than volcanic rocks in any of the other more varied units.

Naches Formation

The Naches Formation, which is faulted against the Easton Metamorphic Suite in a small area along the Straight Creek fault in the southern part of the Skykomish River quadrangle, is almost continuously exposed southward to more extensive outcrops in the type locality along the Little Naches River, about 40 km south of the quadrangle (Ellis, 1959; Foster, 1960; Stout, 1964; Frizzell and others, 1984). The unit is characterized on the whole by mostly basaltic and rhyolitic volcanic rocks with minor andesitic rocks and interbedded feldspathic sedimentary rocks (Tabor and others, 1984, p. 35-37).

In the Skykomish River quadrangle, the Naches consists mostly of steeply dipping to overturned dark basaltic rocks, minor interbeds of white feldspathic sandstone, and a mapped flow of white- to orange-weathering rhyolite. Most of the rocks have been recrystallized by the intrusion of the nearby Snoqualmie batholith.

Tabor and others (1984, p. 39-41) have shown that the Naches is middle and late Eocene and Oligocene(?) in age on the basis of K-Ar and fission-track ages of about 44-40 Ma. The Naches appears to at least partly correlate in time with the Puget Group, the volcanic rocks of Mount Persis to the west, and the Barlow Pass Volcanics of Vance (1957b) to the north.

Unnamed sandstone

Deeply weathered sandstone and conglomerate crop out north of Monroe and appear to be continuous with shallow-marine rocks of Oligocene age to the west (Minard, 1981). Minard considers them to be correlative with the Blakely Formation and reports that a few kilometers west of the quadrangle they unconformably overlie volcanic rocks that are probably continuous with the volcanic rocks of Mount Persis. Similar rocks 18 km northwest of the quadrangle are described in a thesis as the Oligocene Riverside formation by Danner (1957, p. 492-499) and as the upper Eocene to lower Oligocene Bulson Creek unit of Lovseth (1975) by Whetten and others (1988).

Index batholith

The Index batholith ranges from quartz diorite to rare granite, but it is predominantly tonalite and granodiorite. Originally described by Weaver (1912a, p. 39-42), the Index batholith is continuously exposed over a total area of about 285 km^2. The batholith sharply intrudes older rocks and has an irregular, thermal metamorphic aureole as wide as several kilometers. Yeats (1958a, p. 192-216) described the rocks of the Index batholith, but did not always separate them from those of the Grotto batholith in his descriptions. Griffis (1977, p. 80-95) also described the northern part of the Index batholith. Until the advent of isotopic dating of the batholiths (Yeats and Engels, 1971), most workers (see for instance Plummer, 1964, p. 30-43) considered the Snoqualmie, Grotto, and Index batholiths to be the same intrusive mass. The rocks of the Index batholith tend to differ from those of the younger Grotto in the general lack of pyroxene and lack of mesostasic quartz. Sulfide mineralization associated with the batholith is described by Weaver (1912a), Griffis (1977), and Church and others (1983a, b).

Roughly concordant hornblende and biotite K-Ar ages from the Index batholith are about 34 Ma. Zircon also yields U-Pb ages of about 34 Ma and a fission-track age of 33 Ma (table 2, nos. 24-26).

In the Index batholith, we include tonalite exposed along the North Fork of the Tolt River, a stock and associated plug in Youngs Creek, and an elongate stock on Goblin Creek [17], although the plug and stock contain considerable pyroxene. The Sunday Creek stock, originally described by Bethel (1951, p. 145-152), is more potassic than the Index batholith, but a hornblende K-Ar age of about 33 Ma (table 2, no. 28) suggests that the Sunday Creek is of the Index intrusive episode. The age is poorly reproducible and could be minimum due to thermal effects caused by the nearby Miocene Snoqualmie batholith. Armstrong and others (1976, p. 241-242) report an age of 9.9 Ma from a biotite concentrate recovered from a hydrothermal zone in the volcanic rocks of Mount Persis(?) adjacent to a "dacite porphyry pluton" that, from the reported location, must be the Sunday Creek stock or porphyritic granophyre dike associated with it (Bethel, 1951, p. 146). This is probably a minimum age of mineralization.

Metaporphyry of Troublesome Mountain

Metaporphyry on Troublesome Mountain (fig. 2) bears abundant subhedral plagioclase and clinopyroxene phenocrysts, the latter partly to completely replaced by green hornblende. The metaporphyry unit is intruded by the Grotto batholith and, judging from iron-stained gullies along the contact, appears to be faulted against the Barlow Pass Volcanics. The genetic relation of the metaporphyry to other units is unclear, but relict zoning of the plagioclase phenocrysts suggests it might be a hypabyssal phase of the Index batholith that has been recrystallized by the intrusion of the younger Grotto batholith.

Volcanic rocks

Thermally metamorphosed breccia, tuff, ash-flow tuff, and porphyritic flow rocks on Garfield Mountain and vicinity could be correlative with the nearby volcanic rocks of Mount Persis or the younger volcanic rocks of Huckleberry Mountain (fig. 1) exposed continuously to the south and correlative in part with the Ohanapecosh Formation (Frizzell and others, 1984). Smith (1915, p. 163-165) first described the volcanic rocks on Garfield Mountain; Bethel (1951, p. 56-60) and Ellis (1959, p. 82-83) expanded the record and correlated the volcanic rocks with the volcanic accumulations just south of the quadrangle, which at that time were referred to as the Keechelus Andesitic Series, a name now abandoned (see Tabor and others, 1984). We favor a correlation with these southern volcanic rocks because the Garfield Mountain rocks are heterogeneous, with thick, massive, coarse breccia beds, features typical of the volcanic rocks of Huckleberry Mountain.

Volcanic rocks of Mount Daniel

Bedded volcanic breccia, tuff, and flow rocks overlie the lower Eocene Swauk Formation with strong angular unconformity in the southeast corner of the quadrangle near Mount Daniel and extend 5 to 6 km south of the quadrangle (Frizzell and others, 1984). The rocks are mostly dacite and andesite with lesser amounts of rhyolite. Simonson (1981, p. 41-42), who has made the most recent study, considered the main mass of volcanic rocks in the Mount Daniel area to be silicic ash-flow tuffs and breccias. The rocks are intruded on the west by the 25-Ma phase of the Snoqualmie batholith, and some lines of evidence suggest that they may be related to it. Coarse sandstone breccias containing clasts as much as 10 m across are present at the base of the unit, and volcanic breccia dikes intrude the unit and the underlying Swauk, mostly near the volcanic contact. Many of the breccias are monolithologic, but Ellis (1959, p. 66) and Simonson (1981, p. 40) described sandstone breccia with a volcanic matrix, indicating deposition during volcanic activity. The basal breccias may well be catastrophic debris-flow deposits, possibly related to faulting accompanying eruption, a scenario suggested by Hammond (1965). Fissures in the older rock, shattered along the faults, may have been filled with breccia to form the dikes.

Smith and Calkins (1906) mapped volcanic rocks on Goat Mountain just to the south of the quadrangle and included them in their Keechelus Andesitic Series. Ellis (1959, p. 64-82), Pratt (1954, p. 37-42), and McDougall (1980, p. 53-58) found that the volcanic rocks extended north to Mount Daniel.

The age of the volcanic deposits appears to be latest Oligocene or Miocene, but the evidence is somewhat contradictory. The volcanic rocks are older than the 25-Ma Snoqualmie batholith that intrudes them. On ridge tops and peaks, erosional remnants of what may have been a pile of continuous flat-lying andesitic breccia and tuff form a tell-tale track to the main mass of volcanic rocks south of Snoqualmie Pass, where strongly deformed early Tertiary rocks are overlain by the 30- to 32-Ma gently folded andesitic to dacitic volcanic rocks of Huckleberry Mountain that are probably in part correlative with the Ohanapecosh Formation (Tabor and others, 1984, p. 28-29; Frizzell and others, 1984). Thus the similarity of structural position and lithology suggests that the rocks of Mount Daniel may also be correlative with the Ohanapecosh. An apatite fission-track age of 33.5±3.8 Ma from a dacite tuff in the volcanic rocks of Mount Daniel just south of the quadrangle (Frizzell and others, 1984) supports this correlation. However, fission-track ages of zircons from the Mount Daniel area suggest ages of about 25 Ma for these volcanic rocks (table 2, nos. 21-23). These younger ages led Simonson (1981, p. 41) and Vance (1982) to correlate the volcanic rocks of Mount Daniel with the Stevens Ridge Formation exposed near Mount Rainier. The Stevens Ridge yields a number of zircon fission-track ages that indicate a late Oligocene and (or) early Miocene age (Vance, 1982; Frizzell and Vance, 1983; Frizzell and others, 1984). Because the age of the volcanic rocks is so close to the cooling age of the Snoqualmie batholith, Simonson (1981, p. 75-76) proposed that the volcanic rocks were an eruptive phase of the batholith.

To counter the notion that the fission-track ages might be reset by the intrusion of the batholith, Simonson (1981, p. 66-68) argued that several grains of zircon from a lithic tuff gave ages of about 47 Ma and that these zircons were probably from rhyolite fragments derived from the lower Eocene Silver Pass Member of the Swauk Formation exposed to the north. Because the older grains appeared not to have been annealed by the batholith, he thought the main zircon population yielding ages of 26 Ma also would not have not been reset. We think the argument is unconvincing because the undated rocks he presumed to be Silver Pass are more likely to be the younger Barlow Pass Volcanics of Vance (1957b), and the older zircons might be from even older rocks and be partly annealed.

Simonson (1981, p. 70-73) suggested that the volcanic rocks of Mount Daniel erupted from a caldera to the west that has since been engulfed by the Snoqualmie batholith. Hammond (1965) proposed that volcanic rocks on Goat Mountain to the south, which are continuous with the Mount Daniel accumulation, fill a small collapsed caldera.

The Mount Daniel-Goat Mountain volcanic pile may indeed be part of an extensive volcanic-tectonic depression and similar in that respect to the Eagle Tuff of Yeats (1977) and the breccia of Kyes Peak. These floundering blocks of volcanic rocks more or less cluster along the east side of the Straight Creek fault (fig. 4) and along the margin of the Snoqualmie and Grotto batholiths. From this view of structural affinity with other deposits presumed to be related to the batholiths, the volcanic rocks of Mount Daniel may also be related to the batholiths, although somewhat older than 25 Ma.

Snoqualmie and Grotto batholiths

The rocks of the Snoqualmie batholith were first described by Smith and Calkins (1906, p. 9-11) as the Snoqualmie Granodiorite. The batholith crops out over an area of about 580 km^2 in the Skykomish River quadrangle and to the south of the quadrangle. Although 80 percent of the batholith is medium-grained granodiorite, it ranges in composition from gabbro to alaskite (Erikson, 1969, p. 2213). Many workers have helped to delineate the outcrop area of the batholith (see fig. 3). Erikson (1965, 1969) has made the most comprehensive study of the petrology and chemistry of the batholith and its several phases. Our work has drawn heavily on Erikson's mapping but with some important modifications. We think that some of the more mafic rocks, gabbro to mafic tonalite, that Erikson mapped as early phases of the batholith may be large phacoids of the invaded melanges (see previous section on "Miscellaneous Gabbros") that have been partially engulfed by the batholith. We were unable to map Erikson's pyroxene granodiorite and late granodiorite phases of the batholith.

Since the early days, the Snoqualmie batholith has been considered to be Miocene, a determination substantiated by early K-Ar ages from outcrops near Snoqualmie Pass, south of the quadrangle. A considerable number of new K-Ar ages (table 2, nos. 4-11), most from mineral separates provided by E.H. Erikson, indicate that the age of the northern, mostly tonalite, part of the batholith is about 25 Ma (near the Oligocene-Miocene boundary), that the age of the central granodiorite to granite part is a minimum of about 20 Ma (Miocene), and that the age of the southern, mostly granodiorite to tonalite part exposed south of the quadrangle is about 18 Ma. Most of the biotite and some of the hornblende ages are interpreted to reflect degassing by intrusion of the younger phases of the batholith. Field evidence for different ages for these major phases of the batholith is not compelling.

Erikson (1969, p. 2220) considered the granite of the Mount Hinman stock to be younger than the main phase of the Snoqualmie batholith and described an intrusive contact on the east side. We found the western contact to be gradational, and discordant hornblende and biotite K-Ar ages (table 2, no. 11) indicate that the stock is probably about the same age as the northern part of the batholith. Erikson (1969, p. 2221) reports both gradational and intrusive contacts of the central granodiorite and granite (his Preacher Mountain quartz monzonite stock) with more mafic phases of the batholith. South of the quadrangle, we found evidence of mutual intrusion of the southern tonalite phase and the central granodiorite-granite phase.

Rocks of the Grotto batholith are similar to those of the Snoqualmie in composition and age. The two batholiths no doubt are continuous under a thin roof of Tertiary rocks south of Skykomish. Yeats (1958a, p. 189) first recognized and named the Grotto batholith as a pluton separate from the Snoqualmie batholith. Continuous outcrops of the Grotto cover approximately 130 km^2, and the associated Monte Cristo and smaller stocks, exposed to the north, cover an additional 20 km^2.

The Grotto batholith is also compositionally variable, ranging from granite poor in mafic minerals to tonalite. A mappable area of biotite granite and graphic granite crops out mostly east of San Juan Creek [20]. We found no contacts between the granite and the more mafic granodiorite of the Grotto, and neither rock appears to be thermally metamorphosed. Granophyric intergranular textures in granodiorite adjacent to the granite suggest a gradational contact. The granite is highly sheared and faulted along the contact with the Tonga Formation of Yeats (1958b).

The age of the Grotto also is about 25 Ma (table 2, nos. 14-17). Hornblende and biotite from the Monte Cristo stock in Elliot Creek, north of the quadrangle, yield concordant K-Ar ages of about 25 Ma (Yeats and Engels, 1971, p. D36). Hornblende from the small stock in the Columbia Glacier area and a biotite from Foggy Peak, both at the north edge of the quadrangle, yield ages of about 23 and 24 Ma, respectively.

Mafic phases of the Grotto are gabbro and quartz gabbro that crop out as dark caps on the batholith at Spire and Townsend Mountains. The gabbro grades over a distance of a few meters into underlying granodiorite.

Both batholiths have thermal aureoles, as wide as 0.8 km according to Erikson (1969, p. 2215), and have produced pyroxene-hornfels facies rocks near the contacts. Erikson (1969, p. 2225) concluded that the Snoqualmie was intruded at a depth of 2 to 5 km. Sulfide mineralization is scattered throughout the Grotto and Snoqualmie batholiths. Zones of shearing, brecciation, and veining are characterized by copper porphyry-type deposits and have been described by Grant (1969, p. 78-88), Gualtieri and others (1973, 1975), and Church and others (1983a, b).

Breccia of Kyes Peak

Unconformably overlying the folded Barlow Pass Volcanics of Vance (1957b) are andesitic to rhyolitic breccia, tuff, and flows that Spurr (1901, p. 799-801) called the "later andesites". These rocks have been called the Monte Cristo Volcanic Breccias (Pytlak, 1970, p. 19; Heath, 1971, p. 122-127; 1972), but the name Monte Cristo is preempted, so Tabor and others (1982b) called them the breccia of Kyes Peak. The breccia of Kyes Peak is only gently folded, but individual outcrops are difficult to distinguish from the underlying Barlow Pass Volcanics. We include in the Kyes Peak unit all breccia containing numerous metamorphic and granitic clasts, rocks that are uncommon or absent in the Barlow Pass.

Because the unit contains monolithologic breccia of pre-Tertiary country rock and clasts greater than 200 m long by 50 m thick, we suspect that it may have been deposited during active faulting, perhaps in a grabenlike structure controlled by northwest-trending faults (see Tabor and others, 1982b). The Eagle Tuff of Yeats (1977), cropping out to the south, may have erupted into a similar depression about the same time.

Definitive evidence for the age of the breccia of Kyes Peak is elusive. On the divide at the head of Seventysix Gulch [14] are very large blocks (as much as 15 m in diameter) of monolithologic granodiorite breccia, presumedly shed from basal layers of the Kyes Peak unit that overlie granodiorite of the Grotto batholith. The granodiorite clasts in the breccia are sheared and altered to epidote, much like the granodiorite in the fault zone below the divide on the south. According to Heath (1971, p. 126; see also Spurr, 1901, p. 800), the granodiorite breccia rests on the batholith in an eroded depression along the major fault that crosses the ridge between Twin Lakes and Seventysix Gulch. Heath considered the breccia to be younger than that of the Kyes Peak unit, made up of materials eroded from it and granodiorite debris that filled the eroded trough along the fault. His interpretation is consistent with his observation that the breccia of Kyes Peak was intruded by the Monte Cristo stock (Heath, 1971, p. 122-123). Tabor and others (1982b) found that the stock intrudes the Barlow Pass Volcanics but not the breccia of Kyes Peak, although above the Glacier Creek basin [15] the breccia of Kyes Peak is thermally metamorphosed. We suggest that unrecognized plugs of the 20-Ma porphyritic tonalite of Silver Creek (see below) may have thermally metamorphosed the breccia of Kyes Peak in the Glacier Creek basin area and that the granodiorite breccia above Seventysix Gulch is indeed part of the Kyes Peak unit. Furthermore, shearing in clasts of the breccia is evidence that movement on the fault that presently offsets the Kyes Peak unit preceded deposition of the basal breccia, supporting the idea that the breccia of Kyes Peak was deposited during active faulting.

A 24-Ma zircon fission-track age reported by Vance and Naeser (1977; table 2, no. 20) may be a little old because it implies extremely rapid cooling, uplift, and erosion of the 25-Ma Grotto batholith. On the other hand if the 20-Ma intrusive event did thermally metamorphose the breccia of Kyes Peak, its age is neatly bracketed. The breccia erupted between two pulses of intrusive magmatic activity, and it represents a surface eruption from the same Miocene magmas that produced the batholiths.

Eagle Tuff of Yeats (1977)

A thick pile of silicic tuff and breccia unconformably overlies the Swauk Formation and pre-Tertiary rocks in the vicinity of Eagle Creek [25] and on Eagle Rock (Yeats, 1958a, p. 172-182). The breccia and tuff probably erupted in a highly explosive volcanic event, during which time many fragments of the country rock were incorporated (Yeats, 1958a, p. 181).

The breccia and tuff appear to be faulted against the Grotto batholith and older rocks to the west. Lack of thermal metamorphism in the Eagle Tuff near the Grotto batholith suggests that it is younger than the intrusion, an interpretation supported by zircon fission-track ages of 22-24 Ma (Vance and Naeser, 1977). However, the tuff and breccia could also have been faulted from beyond the thermal aureole. Its near contemporaneity with the batholith suggests that the Eagle Tuff may be related to the intrusion (Yeats, 1977, p. 273). The Eagle Tuff could have been emplaced in a small subsidiary graben, part of a major subsidence feature, which also was filled with the breccia of Kyes Peak exposed farther north.

Tonalite of Silver Creek and associated intrusive breccia

Small stocks and a plethora of dikes of somewhat porphyritic tonalite in the Silver Creek drainage area are similar to some phases of the Grotto batholith, but one stock yields a concordant K-Ar age of 20 Ma from hornblende and biotite (table 2, no. 2). A 17.3-Ma age on very fine grained hydrothermal biotite from a mineralized zone adjacent to a similar tonalite plug to the east, as reported by Armstrong and others (1976, p. 241-242), may be a minimum. In and just above Red Gulch [13], the main tonalite stock in Silver Creek is a sericitized and silicified breccia of hornfels fragments in a matrix of calcite and sulfides. This rock, described in detail by Ream (1972, p. 10), appears to be an intrusive explosion breccia, as indicated by the hydrothermal alteration and the shattered country rock. The Miocene stocks in Silver Creek anchor a dribble of tonalite stocks that form a northeast-trending lineament that ends 40 km to the northeast at the Miocene Cloudy Pass batholith, a pluton with several associated intrusive explosion breccias and considerable mineralization (Tabor and Crowder, 1969, p. 15-17; Cater, 1960; 1969). The Miocene tonalite lineament roughly corresponds to the Glacier Peak transverse structural belt described by Grant (1969, p. 40).

Intrusive volcanic breccia

Heterogeneous volcanic breccia that crops out in upper Silver Creek is enigmatic. The breccia contains angular clasts as much as 0.5 m across. Many clasts resemble the Miocene porphyritic tonalite of Silver Creek, and other clasts are sulfides that could have been derived from the explosion breccia. The overall appearance of the intrusive volcanic breccia is similar to that of some of the breccia at Kyes Peak, and in an earlier report we interpreted the intrusive breccia to have been a feeder for the breccia of Kyes Peak (Tabor and others, 1982b). However, we now recognize that the intrusive breccia may be younger than the Kyes Peak unit because the former contains clasts of the tonalite of Silver Creek, which, on rather speculative evidence, appears to be younger than the Kyes Peak unit. At a steep contact of the intrusive breccia with a porphyritic tonalite stock, shattered tonalite of the stock grades into monolithologic breccia of tonalite, which in turn grades into volcanic breccia with fewer and fewer tonalite clasts. This contact, and the apparent circular outcrop pattern of the breccia, indicates that the body is intrusive, albeit the breccia is locally compositionally layered.

Similar unmapped breccia with tonalite clasts crops out on the steep hillside north of Silver Creek but is difficult to differentiate from breccia in the Barlow Pass Volcanics.

Another intrusive volcanic breccia, on Conglomerate Point and described by Yeats (1958a, p. 182-185), seems to be similar to the Silver Creek intrusive volcanic breccia. It too has a steep contact with the enclosing tonalite of the Grotto batholith, is rich in clasts of tonalite at the contact, and is faintly bedded. The matrix of the breccia changes from fine-grained dacite at the base of the exposure to devitrified glass at the top, a feature leading Yeats to consider the breccia to be a volcanic feeder for the breccia of Kyes Peak. We have no data to constrain the age of the breccia at Conglomerate Point.

Volcanic rocks of Cady Ridge

Dacite dikes in two swarms crop out at the pass between the North Fork of the Skykomish and the Sauk Rivers and on Cady Ridge [30]. Bedded dacite breccia in a rock spine at the pass indicates an eruptive or near-surface phase. The other large masses of the dacite appear to be intrusive, as do small dacite plugs reported along the Sauk a few kilometers to the north (Crowder and others, 1966). Ubiquitous pyrite in the rocks in the swarm areas has spurred some economic exploration (Grant, 1982, p. 35). Tabor and Crowder (1969, p. 50) suggested that the spine at the head of the Sauk River was a volcanic neck. On the basis of the columnar joint pattern, Rosenberg (1961, p. 89-92) argued that a dacite mass north of Wards Pass was a feeder for dacite eruptive rocks. The general area seems to have been a volcanic center.

Hornblende from a probable cogenetic dacite dike that intrudes the breccia spine yields a minimum K-Ar age of about 5 Ma; its biotite age of 0.6 Ma appears highly degraded (table 2, no. 1).

QUATERNARY MATERIALS AND LANDFORMS

By R.B. Waitt and D.B. Booth

INTRODUCTION

Quaternary materials in the Skykomish River quadrangle are products of four environments: (1) the late Pleistocene Puget lobe of the Cordilleran ice sheet and its marginal drainage in the lowlands along and west of the west front of the Cascade Range, (2) scores of late Pleistocene local cirque and valley glaciers and their outwash streams in the mountainous eastern two-thirds of the area, (3) Holocene streams and mass-wasting hillslopes throughout the area, and (4) scattered small volcanoes. Along the Cascade front the east margin of the Cordilleran ice sheet sloped from altitude 1,080 m at the north boundary of the quadrangle to about 800 m at the south boundary; most alpine valleys harbored smaller glaciers. Below these levels many areas mapped as bedrock are extensively but discontinuously veneered by glacial and water-laid deposits.

Most of our map units, while based to some degree on lithology, either are of inferred genesis or are local coeval stratigraphic units distinguished by geographic relations to neighboring units and to topography. In alpine terrain, for instance, landslide material (Ql), talus (Qt), and alpine-glacial debris (Qgp) may be lithologically identical but are distinguished by genesis on the basis of depositional surface topography. The surficial deposits are correlated by lateral continuity, by geographic position, by relation to gradients of present streams and former glaciers and lakes, by stratigraphic relation to each other and to regional tephra layers, and by amount of weathering and soil development. Deposits from the last major glaciation are between 17,000 and 13,000 yr old as determined by numerous radiocarbon ages from outside the quadrangle (Porter and others, 1983; Waitt and Thorson, 1983, fig. 3-2). Many map-unit contacts are based on topographic relations revealed on aerial photographs. In alpine areas of the eastern half of the quadrangle, most mapping was done in the field, but many of the smaller, isolated, trailless valley heads and unvegetated high-altitude slopes were mapped from characteristics seen on aerial photographs.

LANDSCAPE EVOLUTION AND RELATION TO MAP UNITS

The overall landscape of the quadrangle is dominated by the Cascade Range and the east edge of the Puget Lowland. The Cascade Range probably rose in late Miocene and Pliocene time; the area to the west has been a relative lowland even longer (Mullineaux, 1970, p. 9-26). Many valleys in the Cascades are excavated within belts of erosionally weak rocks, which trend generally but not everywhere northwest. During and after uplift of the Cascade Range, many streams in the quadrangle exploited these belts of weak rock and developed as classic subsequent streams at the expense of neighboring drainages in granitic and other resistant rocks. Beckler River, for instance, flows south in a broad valley excavated in erosionally weak phyllite that is sandwiched between resistant gneissic and granitic rock bodies on the east and west.

Between lat 47°40' and 47°50', many upland ridgecrests are broad and crudely accordant in altitude, apparently remnants of a former mature erosion surface. From the Cascade crest westward almost to the Cascade front, the undulating surface generally descends at an average gradient of 16 m/km. Areas of sharp-crested, higher relief, nonaccordant ridgecrests lie to the north and south. The depth of present trunk streams, which are incised hundreds of meters below the older erosion surface, suggests that the surface predates and was uparched by the late Miocene and Pliocene growth of the Cascade Range.

The Quaternary units mapped in the quadrangle exist within the context of the topography. Late Tertiary uparching produced a range that intercepted moisture that was driven eastward from the Pacific Ocean. Deep valleys were eroded during the Pliocene and early Pleistocene; during the climatic coolings of the Pleistocene, valleys in the east were episodically occupied and eroded by valley glaciers, and valleys in the west were covered and eroded by the Cordilleran ice sheet as well. With rare exceptions, the surficial deposits in the quadrangle lie on topography beveled by these glaciers.

Tephra

Quaternary tephra, though not thick or continuous enough to distinguish as a map unit, is indispensible for dating and correlating the mapped surficial deposits in the eastern two-thirds of the quadrangle. Four informally designated tephra layers are especially useful as marker beds: Glacier Peak tephra of Porter (1978) (about 11,250 yr B.P.) and Mazama ash bed (6,900 yr B.P.) and ash layers Yn (3,400 yr B.P.) and Wn (450 yr B.P.) from Mount St. Helens in southern Washington (Mullineaux, 1974; Porter, 1978; Mehringer and others, 1984). The tephra layers are distinguished by field characteristics, such as grain size and color, that are the same as those in petrographically verified occurrences to the east. Thus in the northeast it is impossible to mistake Glacier Peak tephra (lapilli) for the Mount St. Helens tephras (fine ash).

QUATERNARY MAP UNITS

Basalt flows and cones

Basaltic deposits and flows (unit Qbf) that lie scattered in the northeastern part of the quadrangle are similar to isolated basaltic materials farther north (Ford, 1959, p. 306-308; Tabor and Crowder, 1969, p. 47). A scoriaceous cinder cone at the head of Indian Creek at the north map boundary is on a steep slope; its modest erosion suggests that it is Pleistocene in age. Scoriaceous basaltic lava flows, bombs, and lapilli, previously described by Rosenberg (1961, p. 94-95), lie north of Wards Pass [29] on the Cascade crest.

In the nearby North Fork Skykomish River valley, porphyritic olivine basalt and weakly lithified interbedded scoriaceous breccia having steep, downvalley-dipping foreset bedding are apparently part of an eroded cinder-cone complex. This deposit thins upvalley, downvalley, and against the valley sides; it deranged the drainage into two streams that have incised each margin of the deposit. The valley had been eroded to its full depth before the flow and breccia unit was emplaced; since then, the streams have incompletely incised the valley-floor deposit. The maximum age of the deposit is therefore late(?) Pleistocene. The volcanic materials are overlain by till that is capped by Mazama ash (6,900 yr B.P.). The basalt therefore probably erupted before the last major alpine glaciation (before 19,000? yr. B.P.) and certainly before the Rat Creek advance (about 13,000? yr B.P.). These materials may be approximately the same age as cinder cones that predate the Glacier Peak tephra (11,250 yr B.P.) 5 km north of the quadrangle (Beget, 1981). A separate porphyritic olivine-basalt flow 7 km farther down the Skykomish River valley also was emplaced after the valley had been eroded to its present depth; the flow has since been incised about 40 m by the North Fork Skykomish River. Its valley-floor position and its only modest dissection suggest that the flow is late Pleistocene in age.

PRE-FRASER GLACIAL AND NONGLACIAL DEPOSITS

The Puget Lowland contains a discontinuous stratigraphic record of several Pleistocene advances of the Cordilleran ice sheet that alternate with nonglacial episodes (Armstrong and others, 1965; Easterbrook and others, 1981). Oxidation rinds on clasts and other weathered features in drift in and near the quadrangle give evidence of at least two alpine glaciations and at least one ice-sheet glaciation predating the Fraser glaciation (Crandell and Miller, 1974; Porter, 1976; Booth, 1990). Pre-Fraser fluvial deposits and drift of the Cordilleran ice sheet (unit Qpf) are identified in the quadrangle by their advanced weathering and by their stratigraphic position beneath deposits of Fraser age. Oxidation rinds on fine-grained volcanic clasts in the older deposits are at least 1.5 mm thick; some stones are weathered to clay or to grus. Typical soil on these deposits has an argillic B horizon 15 cm or more thick and a C_{ox} horizon that extends 2.5 m or more below the surface; some deposits are cemented. Wood in fluvial sediments sandwiched between the till of the Vashon stade of the Fraser glaciation (hereafter informally referred to as Vashon till) and an underlying till 8 km downstream from the Tolt Reservoir yields a ^{14}C age of 25,600±320 yr B.P. (USGS-1625).

DEPOSITS OF FRASER-AGE CORDILLERAN ICE SHEET

During the Fraser glaciation, between 19,000 and 13,000 yr B.P., alpine glaciers expanded from numerous high-altitude areas in the central and eastern parts of the quadrangle, and the western side of the quadrangle was invaded by the Puget lobe of the Cordilleran ice sheet (Porter and others, 1983; Waitt and Thorson, 1983). During the maximum stand of the ice sheet, the east margin of the Puget lobe lay along the west front of the Cascade Range. Tongues of ice flowed eastward up mountain valleys freshly vacated by alpine glaciers. Mountain-valley lakes dammed by these ice tongues drained generally southward both subaerially and subglacially (Booth, 1986). After its maximum stand about 14,000 yr B.P., the Puget lobe of the Cordilleran ice sheet receded northwestward from the quadrangle; ice-dammed lakes in the western part of the quadrangle enlarged and coalesced with each other and with lakes in the Puget Lowland (Thorson, 1980; Booth, 1990).

Most Pleistocene deposits in the western third of the quadrangle were derived from the Puget lobe of the Cordilleran ice sheet; these deposits were laid down in laterally adjacent areas, and some of them are also in stratigraphic succession. West of the Cascade front, fluvial sand and gravel (Qva) derived from ice advancing from the north was later eroded by the ice or was covered by till (Qvt). The till in turn was dissected by streams or was partly covered by outwash and associated lacustrine deposits (Qvr). In mountain valleys, ice-sheet tongues deposited embankments of till and coarse fluvial debris, which typically grade upvalley into silt and clay (Qvgl) that was deposited in the lakes impounded in the western Cascade valleys. During ice recession a series of lakes formed and migrated generally westward as lower valleys successively became deglaciated.

Anomalous valleys, cut across present drainage lines and not part of the major postglacial drainage lines, are occupied by underfit streams or have only lakes and swamps. One such nearly continuous valley crosses successive divides from the Skykomish River valley near Index to the North Fork Tolt, the South Fork Tolt, and the North Fork Snoqualmie valleys. Smaller channels cut across the broad spurs that jut west from the Cascade front between the Skykomish, Tolt, and North Fork Snoqualmie River valleys. Some such valleys formerly classed as ice-marginal channels (Mackin, 1941) are now thought to have carried and have been partly formed by subglacial water, as indicated by quantitative simulation of ice-water relations (Booth, 1984; 1986). Such valleys are variously floored by bedrock, till (Qvt), and recessional outwash and glaciolacustrine sediment (Qvr).

Advance outwash

Beneath Vashon till west of the Cascade front, bedded materials record aqueous environments that lay in front of the south-advancing ice-sheet terminus. Sparsely exposed near the base of sandy fluvial debris, discontinuous beds of laminated, unoxidized gray clay to silty clay record an interval of ponding. The fact that this fine-grained unit is common across the southern Puget Lowland suggests an interval of widespread ponding ahead of the advancing ice sheet. Most of this lacustrine sediment in the quadrangle correlates with the upper part of the transitional beds unit of Booth (1990) and Minard (1985a, b), with parts of the Pilchuck Clay Member of the Vashon Drift (Newcomb, 1952), and with the Lawton Clay Member of the Vashon Drift (Mullineaux and others, 1965). Somewhat older preglacial fine-grained sediments, however, would be indistinguishable from early glaciolacustrine sediments.

Between these fine-grained sediments and the overlying till is a sand and gravel unit that corresponds to the Esperance Sand Member of the Vashon Drift (Mullineaux and others, 1965). This unit is the deposit of meltwater streams that issued south from the south-advancing glacier. The sand is commonly crossbedded, and in thick exposures it grades upward into compact gravelly layers. Along the Snoqualmie River west of Carnation, more than 100 m of deltaic sand and gravel is exposed between river level and the till that caps the bluff, but along the Skykomish River east of Monroe the unit is a discontinuous bed less than 1 m thick. The contact with overlying lodgment till is typically abrupt.

Till

The till is a compact, matrix-supported diamicton. Most clasts are dark, fine-grained rocks locally derived from Tertiary volcanic rock units and components of the pre-Tertiary melange belts; granitic and other exotic rocks commonly make up several percent of the clasts. Exposed thickness of the till is generally less than a few meters, but it can range from almost nothing to tens of meters. Commonly the upper meter is looser and more oxidized than the compact till below, probably as a result of Holocene weathering. Weathered rinds on fine-grained rocks are thinner than 1 mm, and only a few percent of the granitic clasts are rotted to grus. Oxidation extends 1 m or less into the deposit, and, although there may be a color-defined B horizon, the soil is little enriched in clay.

Much of the rolling uplands west of the Cascade front is mantled by this till. These uplands are commonly marked by subparallel linear flutes and ridges hundreds of meters long that delineate rather consistent southeastward ice-flow directions. These ridges may consist wholly of till or mostly of bedrock or be a blanket of till over barely exposed bedrock. Moraines of more bouldery till are exposed in some areas that have been recently cleared by logging. About 8 km south of the town of

Startup, subparallel lateral moraines that lie 15 to 30 m below the 945-m-altitude drift limit change discontinuously into end moraines farther east.

Glaciolacustrine deposits

Upvalley of ice-deposited embankments (see below), thick beds of stratified mud (Qvgl) show that the glacier and its morainal embankments dammed sizable lakes in Cascade valleys. The lacustrine sediment generally is silty clay to fine sand, but in downvalley areas it includes wedges of coarser sand. These deposits are plane bedded and laminated, and they typically contain sparse dropstones. Such deposits are thicker than 30 m and extensively underlie parts of the floors and lower slopes of the Sultan, Skykomish, North Fork Snoqualmie, and Middle Fork Snoqualmie River valleys. They form and underlie conspicuous terraces in some valleys that are crudely graded to the embankment tops. In the Skykomish-Tye-Beckler River valley above Skykomish, thick glaciolacustrine deposits extend as high as altitude 460 m and sporadically as high as 475 m; in the upper and lower North Fork Skykomish River valley they lie as high as 490 m. These deposits indicate that for much of its existence glacial Lake Skykomish drained subaerially through the 490-m spillway along Dry Creek [6] into the North Fork Tolt River drainage (Booth, 1986).

Recessional outwash and associated lake deposits

All principal valleys along the Cascade front, from the Sultan Basin on the north to the Middle Fork Snoqualmie on the south, are obstructed by great wedges of till and water-laid gravel and sand (Qvt, Qvr, and Qva). The exotic lithology of some clasts and the rarely exposed upvalley dip of foreset bedding indicate that these sediments originated from ice and outwash that flowed upvalley from the west, as Mackin (1941) inferred of similar bodies just south of the map boundary. Some embankments consist largely of water-laid till of the Puget lobe; nearly all of them are mantled with recessional outwash. The crestal altitudes of the blockading embankments vary unsystematically between 720 and 520 m, and in all valleys the maximum drift limit is 100 to 600 m above the top of the embankments. Therefore the embankments must record local depositional conditions in each valley and not the ice-maximum position or a widespread stillstand during ice recession. The internal structure of the embankments and the reconstructed ice-surface profiles suggests that these deposits formed by sedimentation into ice-dammed lakes (Booth, 1986).

Gravel, sand, and mud, deposited by meltwater and lakes during glacial retreat, discontinuously mantle the bedrock terrain and lodgment till in the lower ends of mountain valleys west of the embankments and along and west of the Cascade front. This deposit (unit Qvr) ranges from a veneer only centimeters thick to deltas thicker than 100 m along the east side of the Snoqualmie River valley. Water-laid ice-contact deposits that are mapped as part of this unit include the west sides of embankments and scattered deposits that are pocked by kettles or are internally deformed west of the mountain front because of collapse when the buried ice melted. Water currents were regulated mainly by the north-south trends of valleys and by the generally east or northeast trend of the retreating ice margin, and foreset beds in gravel and sand generally dip to the southeast, south, or southwest. Foreset beds thinner than 1 m may be crossbedded outwash, but those thicker than 2.5 m probably are deltaic. Lacustrine bodies of clay and silt are interspersed laterally and stratigraphically between alluvial bodies of gravel and sand.

Some conspicuous, flat depositional surfaces are formed across several lithologic facies. For instance, a nearly level surface along the valley wall and 60 m above the confluence of the Skykomish and Snoqualmie Rivers is underlain by till that grades southward into boulder outwash, pebble-and-sand outwash, foreset deltaic sand, and lacustrine mud. The flat depositional surface thus links contemporaneous deposits of ice, outwash river, and glacial lake. Booth (1990) maps several such surfaces in detail.

During part of its existence, glacial Lake Skykomish probably drained subglacially, but at times during glacial recession it drained subaerially through four channels that cut across the divide south of the Skykomish River valley. The eastern channel, now occupied by underfit Dry Creek [6], leads southward to the North Fork Tolt drainage. The lake that used this spillway at altitude 490 m persisted long enough for the thick, extensive lacustrine sediment upvalley to accumulate up to this altitude in the Skykomish River valley. During ice recession this spillway was abandoned in favor of spillways farther west and now at altitudes 180, 130, and 70 m that cross the divide into the Snoqualmie River drainage.

Successively lower lakes during occupation of these later channels produced a complex of flat-topped gravel and sand bodies that cover almost 40 km^2 along the north side of the Skykomish River valley. These bodies have tall, delta-foreset beds that dip southeast, south, southwest, and west. The level surfaces and the contacts between topset and foreset beds lie between altitudes 155 and 50 m, about 40 to 130 m above the present valley floor. The principal sources of sediment for the higher deposits were outwash and inwash streams that flowed southward along and east of the margin of the dwindling Puget lobe; consequently the sediments accumulated mainly on the north side of glacial Lake Skykomish.

During deglaciation, a glacial lake also occupied the Snoqualmie River drainage basin and first spilled southward at altitudes between 480 and 280 m (Mackin, 1941; Williams, 1971). Continued recession by the ice uncovered other potential west-draining spillways that are presently at altitudes between 160 and 45 m, near the southwest corner of the quadrangle. Deltas were built into the lake at the mouths of the North Fork Snoqualmie River, Tokul Creek, and Harris Creek. Delta tops or contacts between topset and foreset beds register various altitudes of the lake surface between about 275 and 32 m, which, when corrected for isostatic rebound, correspond to the levels of the potential spillways (Booth, 1990). The lowest local spillway was abandoned when ice receded far enough north that the lake became an arm of a more extensive late-deglacial lake occupying the central Puget Lowland (Thorson, 1980).

DEPOSITS RELATED TO ALPINE GLACIERS

Alpine glacial drift

Most valleys in the Skykomish River quadrangle contained valley glaciers during part of the Fraser glaciation, glaciers governed by a west-sloping regional snowline some 900 m below the present snowline (Porter, 1977). Glaciers also must have formed during many earlier glaciations; as we found weathered drift in only a few areas, we do not distinguish it at this map scale. The higher reaches of many valleys in the eastern two-thirds of the Skykomish River quadrangle are U-shaped troughs with steeply truncated spurs and hanging tributary valleys that start in cirques along the divides. Valleys like those of the Foss River tributaries that are U-shaped and floored with drift (Qag) for their entire length contributed confluent ice to a trunk glacier in the valley below. Hundreds of other tributaries, however, have a driftless canyon above their confluence with a glaciated trunk valley and must have contained only small headward glaciers that did not contribute to a trunk glacier.

Most of the U-shaped valley segments are partly floored by scarcely weathered, cobbly till (Qag) that extends hundreds of meters up the valley walls in many places. The angular to rounded drift stones are locally derived and vary from valley to valley. The floors of most mountain valleys contain narrow trains or terraces of gravel and sand deposited as outwash during recession of the valley glaciers. Postglacial alluvial fans and mass-wastage deposits discontinuously mantle this drift.

Compared with areas in the eastern Cascades, the Skykomish River quadrangle has fewer recognized alpine moraines (included in unit Qag). The sparseness of observed moraines is due to steeper slopes and narrower valleys, to the denser forests, and to burial of some valley-glacier deposits by ice-sheet drift. But recessional moraines do lie in many valleys. For instance, just below the glacier-scoured rock basin of Evans Lake [26] in the western headwaters of the Foss River, conspicuous lateral moraines of compact till as thick as 8 m neatly outline the termini of former cirque glaciers.

The inferred age of alpine drift is limited by relations to ice-sheet deposits in a few areas. Deposits of the maximal extent of the alpine glaciers are inferred to underlie deposits of the maximum extent of the Puget lobe. Surface sediment in the Skykomish River and its tributary valleys near Skykomish is the silt and clay (Qvgl) that accumulated in the near-maximal glacial Lake Skykomish, and it buries any valley-floor effects of alpine glaciers. In the Middle Fork Snoqualmie River valley, Williams (1971) mapped alpine glacier recessional outwash that merges with deposits of a lake dammed by a near-maximal Puget lobe. Yet exposures in the sparse roadcuts in this material suggest instead that it is mainly a postglacial sidestream deposit. Upvalley of the Vashon embankment that obstructs Olney Creek near the north map boundary, however, poor outcrops of downvalley-dipping gravel beds (included within unit Qvgl) suggest that outwash from a nearby icecap may have built a delta into a lake that was contemporaneously dammed by the ice sheet.

Scattered tephra deposits also provide limits to the inferred age of alpine glaciers. Many alpine-glacial deposits are capped by the 6,900-yr-B.P. Mazama ash bed, and some in the northeast are capped by the 11,250-yr-B.P. Glacier Peak tephra. Conspicuous moraines that lie high in many glaciated valleys and in lower altitude cirques probably are contemporaneous with the late-glacial Rat Creek moraines (Porter, 1976, 1978; Waitt and others, 1982). Porter inferred that such moraines at Snoqualmie Pass (south of quadrangle) and at Stevens Pass postdate the Glacier Peak tephra and date from about 11,000 yr old. But many cirque floors northeast of Stevens Pass are floored by the Glacier Peak tephra. Furthermore, near the head of Smith Brook valley 7 km north of Stevens Pass, moraines at the same altitude as Rat Creek moraines at Stevens Pass are capped by the Glacier Peak tephra; similar moraines in headwaters of the Little Wenatchee valley are also capped by the Glacier Peak tephra. Therefore, the Rat Creek drift deposits farther down valley also predate the Glacier Peak tephra, probably from at least 12,000 yr old. Many probably contemporaneous moraines accumulated at the termini of glaciers high in other valleys.

Glacial, protalus, and talus deposits

Dozens of small glaciers occupy niches and cirques in the highest parts of the quadrangle. Fronting these glaciers and outlining vanished glaciers are moraines of coarse angular rock debris (Qgp) that mark formerly more advanced positions of the glacier termini. These moraines commonly merge laterally, upslope, or downslope with other moraines or with similar debris that has the form of talus aprons or protalus ramparts or is a discontinuous blanket (Qgp, Qt, Qra). This unvegetated, coarse rock waste was largely derived by mass wastage and only locally was redistributed into moraines. Some of the high-altitude talus and moraines merge downslope into coarse fans of debris that are scantly to moderately vegetated with grass and shrubs. Talus, glacial, and mountain-stream deposits typically grade into one another, and the map symbol shows the dominant deposit type in a unit that is commonly polygenetic.

Some of the high-altitude moraines and protalus ramparts in the quadrangle are nested in older ones, and outer ones are overlain by the 6,900-yr-B.P. Mazama ash bed. The controlling snowline for such moraines is only 100 m or less below present-day snowlines and represents a glacial advance that is indicated by radiocarbon ages to the north (Beget, 1984) and by weathering data to the east (Waitt and others, 1982) and to have been early Holocene rather than late Fraser in age. A prominent series of such pre-Mazama moraines lies in the Necklace Valley [27]; scores of other such moraines front other existing or vanished cirque glaciers.

Nested inside the Mazama-capped moraines are moraines not capped by the Mazama ash bed. Some of the post-Mazama moraines, protalus ramparts, and talus deposits are overlain by either or both of the Mount St. Helens Yn (3,400 yr B.P.) or Wn ash layers (450 yr B.P.); others lack the Wn ash and some even lack lichens. Clearly there were several episodes of expansion and contraction of alpine glaciers during the late Holocene, and the most recent ones were within the past century or so.

OTHER DEPOSITS

Alluvium

Alluvial deposits (Qa) range from angular boulder gravel moved by high-gradient headwater creeks and mountain rivers to mud deposited overbank by rivers in the lowlands. Fan alluvium ranges from slope-deposited talus to stream-deposited alluvium; in different places it has characteristics of each. It is generally poorly sorted boulder-to-pebble gravel of angular to subangular clasts. In alpine troughs some of the material was deposited by spring-snow avalanches. Fans at the mouths of small tributaries are partly Holocene in age, as shown in places where these materials overlie glaciated deposits or where the Mazama ash bed or the Mount St. Helens Yn ash layer is intercalated. In the northeast many fans are capped by the Glacier Peak tephra and thus mostly accumulated shortly after Fraser-age glaciers receded. Alluvium along present or abandoned river channels is boulder-to-pebble gravel; overbank deposits that floor the lower Snoqualmie River are mud, peat, and buried logs.

Mass-wastage and landslide deposits

Dozens of individual landslide deposits (Ql, Qra, Qmw) are mapped in the quadrangle. Most of them have a characteristic hummocky, bulbous depositional topography downslope from an arcuate source-area scar, but some are distinguished by textural and lithologic characteristics of the deposits. Generally the slide deposit is a nonsorted, nonstratified diamicton containing angular pebbles to boulders of only one or a few local rock types that are commonly set in a gravelly mud matrix. Landslides that have descended into deglaciated mountain valleys, in places ponding lakes or swamps, must be younger than about 16,000 yr B.P.; many such slides are overlain by the Mount St. Helens Yn ash layer (3,400 yr B.P.), and some by the Mazama ash bed (6,900 yr B.P.), and therefore are probably pre-late Holocene in age. Some extensively crevassed bedrock areas on steep slopes denote incipient landslides (Qli), which could be hazardous during a major earthquake.

A diamicton that contains angular boulders of quartz diorite as large as 5 m in intermediate diameter and smaller phyllite clasts forms the surface deposit over about 2.5 km^2 of the Skykomish River valley floor just above the town of Skykomish. The deposit irregularly thickens northeastward toward a thick, broken blockslide at the base of the steep valley wall from which the slide apparently originated. The wide extent of the deposit over a gentle slope suggests that the slide was catastrophic rather than creeping. The deposit is overlain by the Mount St. Helens Wn ash layer but not by the Mount St. Helens Yn ash layer or Mazama ash bed, which lie beyond the margins of the slide material, and therefore the slide occurred between 3,400 and 450 yr B.P.

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Table 1. *Fossils and fossil localities in the western and eastern melange belts*

Map Number	Sample Number	Location Latitude	Longitude	Description	Age	Reference
1F	WA 132	47°58.5'	121°44.4'	"Strongly sheared and deformed" *Aucella* sp. (*Buchia* sp.).	Contemporary with WA 133.	Danner (1957, p. 410-411)
2F	WA 133	47°59.1'	121°45.7'	do.	Earliest Early Cretaceous.	Do.
3F	76-192	47°59.1'	121°45.7'	*Buchia concentrica*	Late Jurassic	D.L. Jones and J.W. Miller (written commun., 1977).
4F	VF 79-521	47°50.3'	121°47.3'	Radiolarians in chert	do.	D.L. Jones and Benita Murchey (written commun., 1980).
5F	JTW 80-109	47°56.0'	121°41.0'	do.	Probably Mesozoic	Do.
6F	JTW 80-107	47°54.3'	121°37.6'	do.	do.	Do.
7F	KO 82-88	47°49.6'	121°39.6'	Fragmental ichthyoliths in marble; possible tetrapod vertibrae.	Mississippian through Triassic.	A.G. Harris and Nicholas Hotten III (written commun., 1983).
8F	RWT 145-81	47°36.3'	121°45.7'	Radiolarians in chert	Late Jurassic	C.D. Bloom (written commun., 1983)
9F	VF 81-513	47°32.2'	121°40.9'	Radiolarians in chert pebbles in chert conglomerate.	Late Triassic	C.D. Bloom (written commun., 1982)
10F	VF 81-497	47°32.2'	120°41.4'	Radiolarians in chert	Jurassic	C.D. Bloom (written commun., 1983)
11F	VF 81-496	47°42.2'	121°42.2'	Radiolarians in chert	Early Cretaceous	Do.
12F	RWT 251-78	47°26.7'	121°41.4'	Radiolarians in chert; just south of quadrangle.	Mesozoic	Do.
13F	WA 126	47°44.9'	121°28.0'	Crinoid stems in limestone	Indeterminate	Danner (1957, p. 271)
14F	UW 3488	47°44.8'	121°27.7'	Fusulinids in limestone float	Permian	Thompson and others (1950, p. 49) and Danner (1957, p. 270-271).

Table 2 *Fission-track and isotope analyses of rocks in Skykomish River quadrangle and vicinity*

[Map number refers to location on map, except for samples noted in comment. All fission-track ages (FT) calculated with $F=7.03 \times 10^{-17} yr^{-1}$. All USGS K-Ar ages calculated on basis of 1976 IUGS decay and abundance constants. K-Ar ages from Engels and others (1976) and earlier reports are corrected by use of table in Dalrymple (1979). Errors on single new K-Ar ages of this report are based on empirically derived curve relating coefficient of variation in age to percent radiogenic argon (Tabor and others, 1985). U-Th-Pb ages reported in following order $^{206}Pb/^{238}U$; $^{207}Pb/^{235}U$; $^{207}Pb/^{206}Pb$; $^{208}Pb/^{232}Th$. Where two data sets are reported, each is preceded by mesh size in parentheses]

Map number	Sample number	Method	Materials	Location Lat	Location Long	Unit	Age (m.y.)	Map unit and (or) commment	References
1	RWT 408-80	K-Ar	Hornblende	47°59.0'	121°0.9'	Volcanic rocks of	5.1±0.4	Tcb	Table 3
		K-Ar	Biotite			Cady Ridge.	0.6±0.2		
2	RWT 133-81	K-Ar	Hornblende	47°57.6'	121°26.6'	Silver Creek stock	20.0±1.3	Tts	Table 3
		K-Ar	Biotite				20.3±0.4		
3	Unavailable	K-Ar	Biotite	47°57'	121°24'	do.	17.3±0.6	Location uncertain; hydrothermal potassic zone at contact of Tts.	Armstrong and others (1976).
4	EE 382 B	K-Ar	Biotite	47°33.9'	121°14.3'	Snoqualmie batholith	22.4±0.5	Tst	Table 3
5	EE 404	K-Ar	Hornblende	47°37.7'	121°22.8'	do.	23.0±1.2	do.	Do.
		K-Ar	Biotite				22.7±0.4		
6	EE 395	K-Ar	Hornblende	47°33.6'	121°17.4'	do.	23.0±0.9	do.	Do.
		K-Ar	Biotite				20.5±0.7		
7	EE 239	K-Ar	Hornblende	47°34.1'	121°32.7'	do.	24.1±0.5	Tsm	Do.
		K-Ar	Biotite				20.4±0.4		
8	EE 255	K-Ar	Hornblende	47°36.9'	121°32.8'	do.	25.2±2.3	Tst	Do.
9	VF 80-234	K-Ar	Hornblende	47°42.0'	121°31.2'	do.	25.6±1.0	do.	Do.
		K-Ar	Biotite				21.5±0.4		
10	EE 500	K-Ar	Hornblende	47°34.2'	121°32.9'	do.	25.6±1.0	do.	Do.
		K-Ar	Biotite				20.5±0.5		
11	RWT 642-79	K-Ar	Hornblende	47°34.6'	121°13.7'	do.	26.7±1.7	Tsh	Do.
		K-Ar	Biotite				22.8±0.6		
12	9	FT	Zircon	47°35'	121°10.5'	do.	21.4±1.4	Tst	Simonson (1981)
13	52	FT	Zircon	47°33.5'	121°14'	do.	22.8	Location uncertain.	Do.

14	JTW 79-218	K-Ar	Hornblende	47°57.2'	121°20.7'	Grotto batholith	23.0±3.9	Tg	Table 3
15	JTW 79-219	K-Ar	Biotite	48°00'	121°22'	do.	24.1±0.4	Tg; Monte Cristo stock.	Do.
16	RWT 13-68	K-Ar	Hornblende	48°02.4'	121°22.7'	do.	24.5±1.0	Tg; north of quadrangle.	Yeats and Engels (1971)
		K-Ar	Biotite				24.8±1.1		
17	RWT 16-68	K-Ar	Hornblende	47°53.9'	121°25.3'	do.	25.7±1.5	Tg	Do.
		K-Ar	Biotite				27.0±8.0		
18	R-17	FT	Zircon	47°45.6'	121°21.5'	Eagle Tuff	22.6	Tte	J.A. Vance and C.W. Naeser (written commun.,1983).
19	R-18	FT	Zircon	47°46.4'	121°19.4'	do.	24.8	do.	
20	R-91	FT	Zircon	47°57.7'	121°20.1'	Breccia of Kyes Peak	23.7	Tbk	
21	R 157 (46)	FT	Zircon	47°33'	121°09.5'	Volcanic rocks of Mount Daniel.	24.6±1.2	Tdd	Simonson (1981).
22	R158 (11)	FT	Zircon	47°32.5'	121°09.5'	do.	25.1±1.1	do.	Tabor and others (1984).
23	R222 (12)	FT	Zircon	47°32'	121°10'	do.	26.7±1.5	do.	
24	JE 10-67	K-Ar	Hornblende	47°46.7'	121°29.5'	Index batholith	33.3±2.5	Tig	Yeats and Engels (1971).
		K-Ar	Biotite				33.3±1.2		
25	JV-246	K-Ar	Hornblende	47°49.2'	121°34.3'	do.	35.9±1.4	do.	Table 3
			Biotite				33.6±0.9		
		FT	Zircon				33		J.A. Vance and N.B. Walker (written commun.,1985).
		U-Pb	Zircon				34		
26	3	K-Ar	Biotite	47°49.2'	121°34.3'	do.	34±5	do.	Yeats and McLaughlin (1968).
		Rb-Sr	Biotite				35±5		
27	4	Rb-Sr	Biotite	47°47.7'	121°30.5'	do.	40±2	do.	Do.
28	VF 81-470	K-Ar	Hornblende	47°39.0'	121°36.6'	do.	32.6±1.5	Tigs	Table 3
29	NF	K-Ar	Biotite	47°38'	121°37'	do.	9.9±0.4	Location uncertain but probably Tigs.	Armstrong and others (1976).
30	RWT 445-78	K-Ar	Hornblende	47°46.9'	121°38.8'	Dike	33.1±2.3	Intrudes Tpa	Table 3
31	JH 80-66A	K-Ar	Hornblende	48°02.5'	121°25.8'	Dike complex; intrudes Barlow Pass Volcanics.	36.8±9.2	North of quad.	Table 3
	JH 80-66B	K-Ar	Hornblende				23.3±7.0		
32	RWT 509-80	K-Ar	Hornblende	47°46.6'	121°37.4'	Volcanic rocks of Mount Persis.	38.1±3.3	Tphb	Table 3
33	VF 79-531	FT	Apatite	47°48.4'	121°45.2'	do.	47.0±4.0	Tpa	See footnote 1
34	DB 81-568	K-Ar	Hornblende	47°35.1'	121°44.9'	Fuller Mountain plug	46.6±2.0	Tfm	Table 3

35	RWT 389-80	U-Th-Pb	Zircon	47°41.0'	121°22.5'	Barlow Pass(?) Volcanics.	(-200+250)29.8; 30.8; 111.2; 27.0 (-250+325)27.0; 27.8; 102.5; 24.5	Tbv(?); reset age; see text.	Table 4
36	R-16	FT	Zircon	47°41.5'	121°20.0'	do.	28	Tbv(?); reset age; see text.	J.A. Vance and C.W. Naeser (written commun., 1983).
37	RWT 372-80	K-Ar	Sericite	47°55.8'	121°37.9'	Western melange belt.	47.8±0.8	TKws; cooling age.	Table 3
38	RWT 25-82	K-Ar K-Ar	Biotite Muscovite	47°49.2'	121°01.7'	Gneissic biotite granodiorite.	81.2±1.4 82.7±1.5	Kbgg	Do.
39	RWT 198-80	K-Ar	Hornblende	47°58.6'	121°05.7'	Chiwaukum Schist	81.4±1.8	Kca	Do.
40	VF 80-214	K-Ar K-Ar	Hornblende Biotite	47°45.5'	121°10.3'	Mount Stuart batholith.	82.4±2.0 82.4±1.3	Ksw	Do.
41	JE 13-67	K-Ar	Hornblende Biotite	47°42.6'	121°09.9'	do.	85.5±2.7 84.6±2.5	do.	Engels and Crowder (1971)
	28±3								
42	RWT 475-80	K-Ar K-Ar	Hornblende Biotite	47°34.2'	121°01.8'	do.	87.5±3.0 87.7±0.2	Kswh	Table 3
43	JE 14-67	K-Ar K-Ar FT	Hornblende Biotite Apatite	47°46.5'	121°04.5'	do.	95.0±3.3 82.3±2.4 62±4	Kse	Yeats and Engels (1971).
44	RWT 18-68	K-Ar K-Ar FT FT FT FT	Hornblende Biotite Apatite Allanite Allanite Epidote	47°43.3'	121°16.7'	do.	92.1±2.7 92.1±2.7 42±5 84±12 98±14 83±20	Ksb	Do.
45	1	Rb-Sr	Biotite	47°42.9'	121°16.3'	do.	94.2±16	Ksb	Yeats and McLaughlin (1968).

46	2	Rb-Sr	Biotite	47°42.9'	121°17.2'	do.	86±14	do.	Do.
		K-Ar	Biotite				82.3±5		
		K-Ar	Biotite				78±5		
47	JE 12A-67	K-Ar	Biotite	47°42.9'	121°16.3'	do.	93.2±2.8	do.	Engels and Crowder (1971).
48	79-200	K-Ar	Hornblende	48°02.4'	121°20.4'	Sloan Creek plutons.	89.9±2.2	Ksc; north of quad.	Table 3
		K-Ar	Biotite				75.3±1.2		
		U-Th-Pb	Zircon				(-100+150)89.7; 89.8; 91.2; 89.8		Table 4
							(-200+250)89.4; 89.5; 93.1; 88.2		
49	RWT 390-80	U-Th-Pb	Zircon	47°55.4'	121°17.2'	Gneissic tonalite.	(-250+325)88.5; 89.5; 115.3; 91.0	Kgt	Table 4
							(-325+400)91.4; 92.5; 119.7; 100.6		
50	RWT 297-83	U-Th-Pb	Zircon	47°59.9'	121°39.1'	Bald Mountain pluton.	(-150+200)53.6; 55.1; 119.4 ; 60.3	bm	Table 4
							(-250+325)49.2; 50.8; 126.0; 51.7		
51	RWT 55-81	K-Ar	Biotite	47°59.4'	121°39.4'	do.	44.3±1.3		Table 3
52	RWT 49-81	U-Th-Pb	Zircon	47°44.8'	121°19.6'	Easton Metamorphic Suite.	(-100+200)61.3; 74.3; 516.3; 64.9	Kes	Table 4
53	RWT 70-81	K-Ar	Hornblende	47°49.5'	121°40.2'	Western melange belt.	96.3±4.0	TKwg	Table 3
54	JTW 76-199	K-Ar	Hornblende	47°56.9'	121°48.4'	do.	118.0±7.7	do.	Do.
55	JTW 76-191	U-Th-Pb	Zircon	47°59.0'	121°46.9'	do.	(-100+150)164; 164; 168; 165	TKwt	Whetten and others (1980).
							(-270+325)172; 173; 184; 167		
56	RWT 278-80	U-Th-Pb	Zircon	47°42.4'	121°34.5'	do.	(-150+200)148.1; 149.0; 163.3; 146.7	do.	Table 4
							(-250+325)149.8; 150.5; 161.1; 149.8		
57	RWT 316-80	U-Th-Pb	Zircon	47°46.8'	121°40.7'	do.	(-150+200)148.2; 149.1; 162.3; 143.0	TKwg	Do.
							(-250+325)148.1; 149.5; 172.0; 145.9		
58	JTW 77-215	U-Th-Pb	Zircon	47°30.9'	121°45.5'	do.	(-100+150)152; 152; 159; 146	do.	Whetten and others (1980).
						do.	(-200+270)148; 149; 169; 144		
59	JTW 79-214	U-Th-Pb	Zircon	47°48.7'	121°27.2'	Eastern melange belt.	(-100+150)186; 187; 199; 195	TKeg	Do.
							(-200+270)191; 193; 211; 196		
60	RWT 513-80	U-Th-Pb	Zircon	47°43.6'	121°29.5'	do	(-150+200)39.4; 39.8; 62.6; 37.9	TKet; see text.	Table 4
							(-250+325)47.0; 47.5; 72.0; 46.6		
61	JTW 79-215	U-Th-Pb	Zircon	47°33.5'	121°29.2'	do.	(-200+250)28.1; 28.7; 77.2; 29.1	TKet; see text.	Do.
							(-250+325)34.4; 34.9; 73.3; 33.0		

[1] Analytical data for VF 79-531: r_sx 10^6/cm^2 = 810; r_ix10^6/cm^2 = 10.5; fx10^{15} neutrons/cm^2 = 1.02; U = 3 ppm. Constants from Steiger and Jager (1977).

Table 3. *New K-Ar ages from Skykomish River quadrangle and vicinity, Wash.*

[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, Dave Vivit, M. Taylor, and J.H. Christie]

Map number	Sample number	Mineral	K_2O percent	Ar^{40}Rad moles/gmx10^{10}	ArRad (percent)	Age (m.y.)
1	RWT 408-80	Hornblende	0.265, 0.279, 0.266, 0.255	0.021, 0.018	4.83, 4.01	5.1±0.4
		Biotite	7.98, 7.98	0.091, 0.049	3.23, 5.45	0.6±0.2
2	RWT 133-81	Hornblende	0.449, 0.455, 0.484, 0.451	0.133	20.4	20.0±1.3
		Biotite	8.82, 8.82	2.59	74.2	20.3±0.4
4	EE 382 B	Biotite	8.94, 8.93	2.90	66.1	22.4±0.5
5	EE 404	Hornblende	0.513, 0.514, 0.517, 0.512	0.171	25.4	23.0±1.2
		Biotite	8.69, 8.70	2.86	73.6	22.7±0.4
6	EE 395	Hornblende	0.490, 0.488, 0.489, 0.489	0.163	34.1	23.0±0.9
		Biotite	8.76, 8.78	2.61	48.9	20.5±0.7
7	EE 239	Hornblende	0.580, 0.579, 0.572, 0.574	0.198, 0.205	25.7, 31.4	24.1+0.5
		Biotite	8.45, 8.45	2.50	68.2	20.4±0.4
8	EE 255	Hornblende	0.566, 0.569, 0.559, 0.563	0.185, 0.221	19.4, 33.3	25.2±2.3
9	VF 80-234	Hornblende	0.540, 0.531, 0.527, 0.532, 0.529	0.196	34.8	25.6±1.0
		Biotite	8.96, 8.98	2.80	76.8	21.5±0.4
10	EE 500	Hornblende	0.526, 0.527, 0.532, 0.529	0.196	34.8	25.6±1.0
		Biotite	7.94, 7.94	2.36	60.1	20.5±0.5
11	RWT 642-79	Hornblende	0.349, 0.349, 0.338, 0.340	0.133	21.1	26.7±1.7
		Biotite	9.16, 9.17	3.03	58.7	22.8±0.6
14	JTW 79-218	Hornblende	0.391, 0.384, 0.383, 0.383	0.128	6.26	23.0±3.9
15	JTW 79-219	Biotite	8.94, 8.96	3.13	84.0	24.1±0.4
25	JV 246	Hornblende	0.369, 0.368, 0.370, 0.363	0.192	36.7	35.9±1.4
		Biotite	8.55, 8.55	4.170	57.2	33.6±0.9
28	VF 81-470	Hornblende	0.266, 0.262, 0.264, 0.263	0.119, 0.131	15.2, 14.2	32.6±1.5
30	RWT 445-78	Hornblende	0.265, 0.258, 0.263, 0.261	0.126	18.7	33.1±2.3
31	JH 80-66A	Hornblende	0.224, 0.216, 0.207, 0.214	0.086, 0.144	2.16, 3.25	36.8±9.2
	JH 80-66B	Hornblende	0.222, 0.221, 0.218, 0.220	0.074	2.89	23.3±7.0
32	RWT 509-80	Hornblende	0.224, 0.217, 0.226, 0.234	0.114, 0.137	12.3, 22.2	38.1±3.3
34	DB 81-568	Hornblende	0.535, 0.537, 0.529, 0.543	0.364	31.2	46.6±2.0
37	RWT 372-80	Sericite	8.9, 8.9	6.21	79.5	47.8±0.8
38	RWT 25-82	Biotite	9.13, 9.14	10.93	79.7	81.2±1.4
		Muscovite	10.23, 10.21	12.45	77.7	82.7±1.5
39	RWT 198-80	Hornblende	0.522, 0.521, 0.526	0.628	62.7	81.4±1.8
40	VF 80-214	Hornblende	0.283, 0.288, 0.283, 0.281	0.344	58.1	82.4±2.0
		Biotite	8.34, 8.32	10.1	82.4	82.4±1.3
42	RWT 475-80	Hornblende	0.292, 0.286, 0.295, 0.292	0.376	40.7	87.5±3.0
		Biotite	9.48, 9.39	12.2, 12.2	79.6, 88.4	87.7±0.2
48	79-200	Hornblende	0.484, 0.484, 0.478, 0.472	0.636	59.1	89.9±2.2
		Biotite	8.85, 8.89	9.81	84.8	75.3±1.2
51	RWT 55-81	Biotite	7.91, 7.92	5.11	52.1	44.3±1.3
53	RWT 70-81	Hornblende	0.153, 0.132, 0.136, 0.132	0.200	33.8	96.3±4.0
54	JTW 76-199	Hornblende	0.193, 0.191, 0.195, 0.189	0.337	20.5	118.0±7.7

Table 4. *Uranium-thorium-lead isotopic ages of zircon from rocks of Skykomish River quadrangle, Wash.*

[Constants: $^{238}U=1.55125x10^{-10}yr^{-1}$, $^{235}U=9.8485x10^{-10}yr^{-1}$, $^{232}Th=4.9475x10^{-11}yr^{-1}$, $^{238}U/^{235}U=137.88$. Isotopic composition of common lead assumed to be $^{204}Pb:^{206}Pb:^{207}Pb:^{208}Pb$ = 1:18.60:15.60:38.60]

	Mesh size (fraction)	Concentration (ppm) U	Th	Pb	Isotopic composition of lead (atom percent) ^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{232}Th$
35	RWT 389-80 Dacite tuff of the Barlow Pass(?) Volcanics, (Tbv?)											
	-200+250	167.4	68.3	1.497	0.6472	56.68	12.25	30.42	29.8	30.8	111.2	27.0
	-250+325	166.1	73.1	0.905	0.2965	71.75	7.809	20.14	27.0	27.8	102.5	24.5
48	79-200 Sloan Creek plutons (Ksc)											
	-100+150	167.9	30.7	2.393	0.0862	86.14	5.389	8.384	89.7	89.8	91.2	89.8
	-200+250	191.2	37.3	2.728	0.0883	85.80	5.407	8.704	89.4	89.5	93.1	88.2
49	RWT 390-80 Gneissic tonalite of Excelsior Mountain (Kgt)											
	-250+325	967.8	109.1	12.768	0.0288	90.64	4.804	4.530	88.5	89.5	115.3	91.0
	-325+400	939.2	100.2	12.876	0.0363	90.22	4.902	4.843	91.4	92.5	119.7	100.6
50	RWT 297-83 Bald Mountain pluton (bm)											
	-150+200	988.2	132.4	9.326	0.2231	80.26	7.170	12.35	53.6	55.1	119.4	60.3
	-250+325	1165.2	171.8	8.666	0.0352	89.25	4.851	5.861	49.2	50.8	126.0	51.7
52	RWT 49-81 Easton Metamorphic Suite (Kes)											
	-100+200	427.1	159.5	5.043	0.2338	74.04	7.670	18.05	61.3	74.3	516.3	64.9
56	RWT 278-80 Metatonalite block in the western melange belt (TKwt)											
	-150+200	685.1	375.9	17.257	0.0354	80.04	4.468	15.46	148.1	149.0	163.3	146.7
	-250+325	629.9	324.4	15.714	0.0173	81.41	4.266	14.31	149.8	150.5	161.1	149.8
57	RWT 316-80 Metatonalite block in the western melange belt (TKwg)											
	-150+200	310.2	139.7	7.444	0.0090	83.56	4.252	12.18	148.2	149.1	162.3	143.0
	-250+325	337.5	144.6	8.098	0.0143	83.60	4.349	12.04	148.1	149.5	172.0	145.9
60	RWT 513-80 Metatonalite block in the eastern melange belt (TKet)											
	-150+200	283.2	104.1	2.003	0.1786	77.94	6.313	15.57	39.4	39.8	62.6	37.9
	-250+325	290.9	104.2	2.477	0.1874	77.51	6.436	15.87	47.0	47.5	72.0	46.6
61	JTW 79-215 Metatonalite block in the eastern melange belt (TKet)											
	-200+250	877.5	254.2	4.441	0.1995	78.14	6.657	15.00	28.1	28.7	77.2	29.1
	-250+325	684.2	205.7	4.276	0.2163	77.60	6.873	15.31	34.4	34.9	73.3	33.0