TO ACCOMPANY MAP I–2538

GEOLOGIC MAP OF THE SNOQUALMIE PASS 30 × 60 MINUTE QUADRANGLE, WASHINGTON

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INTRODUCTION

GEOLOGIC OVERVIEW

The Cascade Range of Washington State, a western rampart of the North American Cordillera, comprises an older basement of accreted terranes and a cover of sedimentary and volcanic rocks. The Snoqualmie Pass quadrangle (fig. 1, on map sheet) lies at the north edge of the volcanic cover, where the regional structural uplift to the north elevated the older rocks to erosional levels. Most of the quadrangle is underlain by Tertiary rocks, but mélanges of Paleozoic and Mesozoic rocks are exposed in structural highs in the northern part of the quadrangle.

North of the quadrangle, the north-trending Straight Creek Fault cuts the mosaic of accreted terranes and mostly separates higher grade metamorphic rocks of the North Cascade crystalline core to the east from lower grade and unmetamorphosed rocks to the west. Rocks west of the fault are further partitioned by a Late Cretaceous and (or) Paleogene suture (the Helena-Haystack mélange) and coincident Paleogene, high-angle Darrington-Devils Mountain Fault Zone. Rocks north and east of the suture are in the Northwest Cascade System of Misch (1966), as modified by Tabor and others (1989). Rocks in the suture zone itself comprise the Helena-Haystack mélange of Tabor and others (1988, 1989; also Tabor, 1994), and rocks southwest of the suture form the western and eastern mélange belts (Frizzell and others, 1987; Tabor and others, 1993). These latter named three fundamental western terranes are represented sparingly in the Snoqualmie Pass quadrangle.

The Straight Creek Fault, and its probable extensions in Canada and Alaska (Price and others, 1985, p. 3-48, 3-49), is a major strike-slip fault with post-mid-Cretaceous to pre-middle Eocene(?) right-lateral displacement variously estimated between 180 and 90 km (Misch, 1977; Frizzell, 1979; Vance and Miller, 1981). The zone of faulting, representing the probable southward extension of the Straight Creek Fault exposed in the Snoqualmie Pass quadrangle, has possibly also been the locus of strike-slip faulting in the Darrington-Devils Mountain Fault Zone, which intersects the Straight Creek Fault at an acute angle (fig. 1). The Darrington-Devils Mountain Fault Zone, mostly coincident with the Helena-Haystack mélange, is recognized in the Manastash Ridge area in the southwest corner of the quadrangle. Tabor (1987) and Tabor and others (1989, p. 13) discuss the possibility that the Darrington-Devils Mountain Fault Zone has been the most recently active structure, locally following the Straight Creek trend, but in fact truncating the earlier structure. We will continue to refer to the north-south zone of faulting as the Straight Creek Fault Zone (leaving out the and(or) Darrington-Devils Mountain Fault Zone).

Near the southeast corner of the quadrangle, the Straight Creek Fault Zone intersects the Olympic-Wallowa Lineament of Raisz (1945; see also Kienle and others, 1977; Tabor and Frizzell, 1979) in a complex of curving faults and folds. The Olympic-Wallowa lineament, as originally defined, is expressed physiographically from the Wallowa Mountains in Oregon to the Strait of Juan de Fuca between the Olympic Peninsula and Vancouver Island (see for example, Pike and Thelin, 1989). The lineament traverses the Snoqualmie Pass quadrangle almost diagonally from the southeast to northwest (fig. 1) and is expressed by a broad zone of faults and folds in rocks ranging in age from Jurassic to Miocene. The lineament is most strongly expressed in the faulted and folded rocks of the Manastash River Block (fig. 2, on map sheet; Tabor and others, 1984, fig. 2) where the lineament meets the Straight Creek Fault Zone.

Faults in the Straight Creek Fault Zone appear to swing southeastward into the lineament trend* (Tabor and Frizzell, 1979). The lineament loses definition where it crosses the Cascade Crest just west of the the Straight Creek Fault, but it appears to be expressed in broad northwest-trending folds and faults in Miocene volcanic rocks between the South Fork of the Snoqualmie and White Rivers. The nature of the deep-seated structure or structures producing the lineament is uncertain. It may contain elements of structures of different ages, including the Darrington-Devils Mountain Fault Zone.

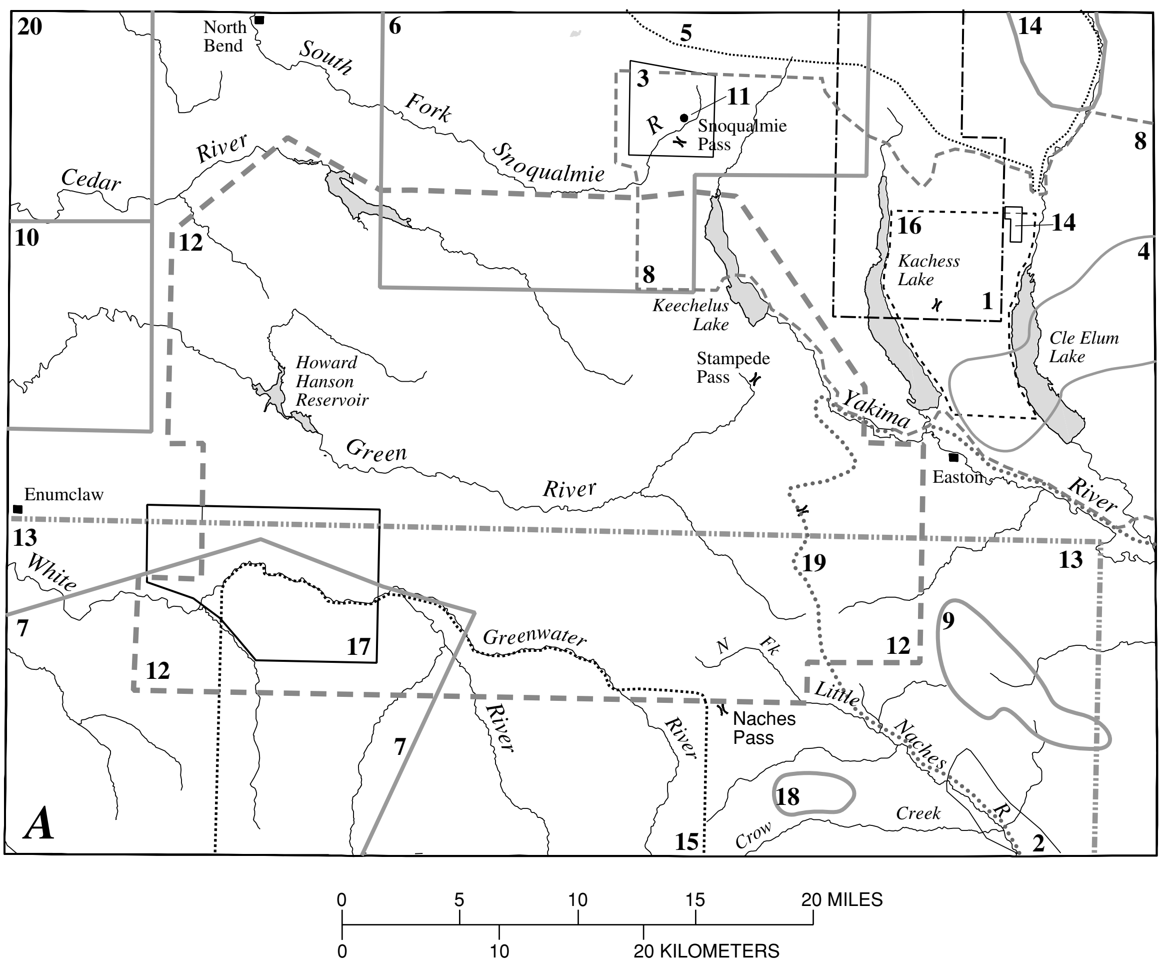
*Recent Mapping and stratigraphic revisions by Eric Cheney (Cheney, 1999; see also Cheney, 2000) in the vicinity of Easton suggest that the Straight Creek Fault continues more or less straight south from the northern part of Lake Kachess. The interested reader may want to evaluate this new work.

Pre-arc rocks of the North Cascades to the north of the Snoqualmie Pass quadrangle are offset right laterally across the Straight Creek Fault and, in the quadrangle terranes of the Northwest Cascade System, crop out east of the fault.

During the early to early middle Eocene, when the Straight Creek Fault and the Darrington-Devils Mountain Fault Zone were most active, regional extensional and transtensional faulting dominated the Pacific Northwest (Tabor and others, 1984; Johnson, 1985; Heller and others, 1987; Tabor, 1994). The faulting promoted the formation of local basins wherein fluvial feldspathic sediments and subordinate volcanic materials accumulated. By the middle Oligocene, movement on the major structures had waned and the north-trending Cascade volcanic arc was well established; it flooded the Cascade Range with calk-alkaline volcanic rocks, the principal rocks exposed in the Snoqualmie Pass quadrangle.

HISTORY OF GEOLOGIC MAPPING AND ACKNOWLEDGMENTS

Geologic work in the Snoqualmie Pass 1:100,000 quadrangle began before the turn of the century with investigations of coal found along the Green River (Willis, 1886, p. 759-760). The basic geologic framework east of the Cascade Crest was established by Smith and Calkins (1906) in the Snoqualmie Pass 30-minute quadrangle, and subsequently many workers



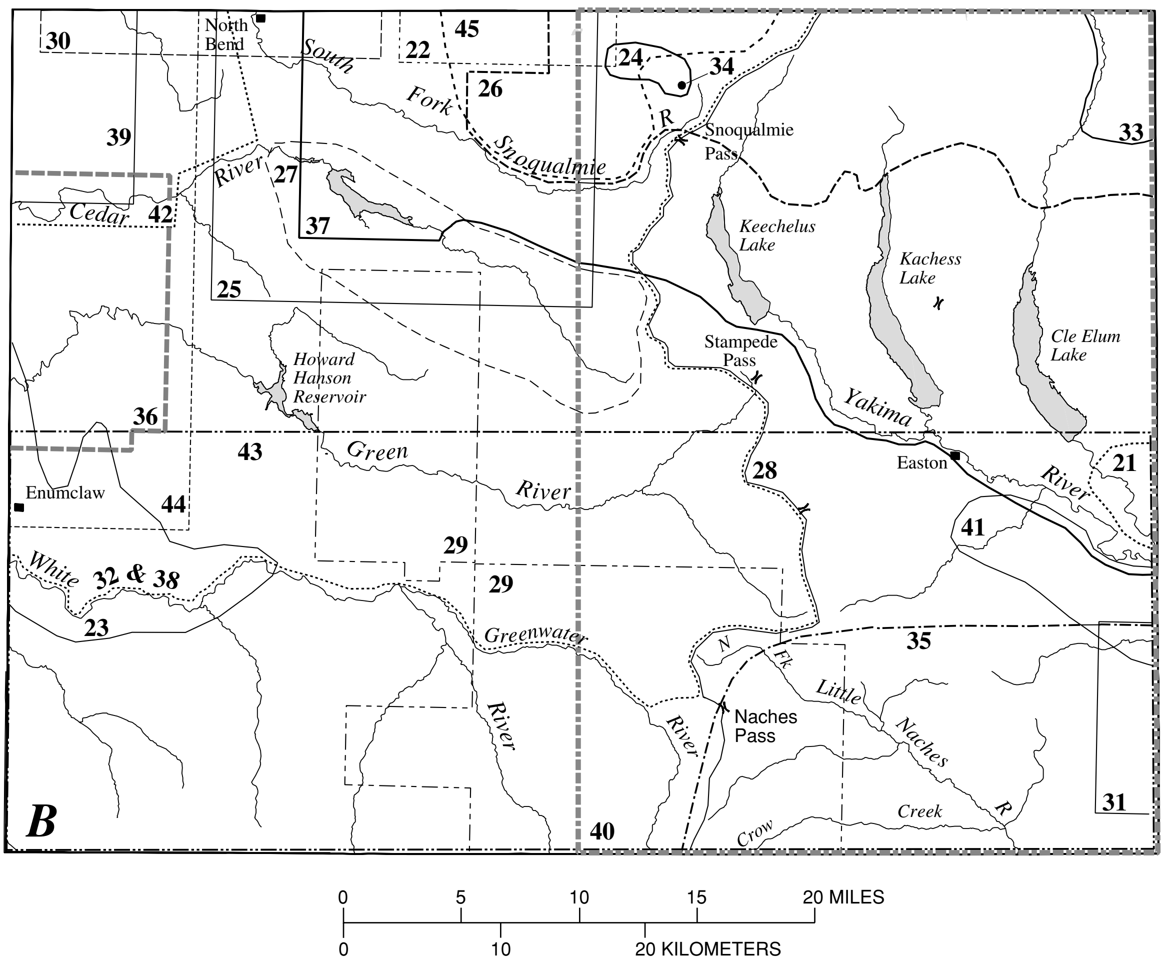
1. Ashleman, 1979	**6.** Erickson, 1969	**12.** Hammond, 1963	**17.** McCulla, 1986
2. Cambell, Newell (written commun., 1986)	**7.** Fischer, 1970	**13.** Hammond, 1980	**18.** Smith, Gary (written commun., 1986)
3. Chitwood, 1976	**8.** Foster, 1960, 1967	**14.** Hammond, P.E. (written commun., 1977)	**19.** Stout, 1964
4. Clayton, 1973	**9.** Goetsch, 1978	**15.** Hartman, 1973	**20.** Vine, 1962, 1969
5. Ellis, 1959	**10.** Gower and Wanek, 1963	**16.** Lofgren, 1974	
	11. Gualtieri and others, 1975		

Figure 3. Sources (keyed to map by number) of map compilation data for Snoqualmie Pass 1:100,000 sheet. ***A*** *(1-20)*, for area 10 and 20 much data used with little to modest modifications. All other areas, some data used. Figure 3 continued on next page.

(see fig. 3) have drawn on their ideas. Fuller (1925) was one of the first to address the complexities of what we call the western mélange belt and to develop the idea that some of the bodies of magma that ultimately formed the Tertiary batholiths vented to form the Tertiary volcanic cover rocks, a theme since expanded upon (Cater, 1960, 1969; Fiske and others, 1963; Tabor and Crowder, 1969). Hammond (1963) was the first to attack the difficult problems of regional correlation presented by post-Eocene volcanic rocks, and he has continued his regional studies in subsequent years (Hammond, 1977, 1980). Detailed mapping in the western foothills was begun on modern base maps by Vine (1962) and Gower and Wanek (1963).

Our work, begun in 1975, is part of a larger project that includes mapping the Wenatchee 2° quadrangle at 1:100,000 scale (Tabor and others, 1982b, 1987a, 1993). Frizzell, Tabor, and Booth, with the ongoing assistance of Kathleen Ort, compiled and mapped most of the bedrock geology. Booth mapped the unconsolidated deposits in the northwestern third of the map area and Waitt mapped unconsolidated deposits elsewhere in the quadrangle.

Our field work was considerably aided by the efforts of Sharon Allshouse and Eduardo Rodriquez in 1975, Jay Coburn and Ron Tal in 1976, Bill Gaum, Margaret Goddard, and Kim Marcus in 1977, Elizabeth L. Mathieson and Nora Shew in 1978, Steve Connally, Stephen A. Sandberg, Fred Beall, Frederika



21. Beikman and others, 1961
22. Bethel, 1951
23. Crandell, 1973
24. Danner, 1966
25. Fuller, 1925
26. Gualtieri and Simmons, 1989
27. Hirsch, 1975
28. Kinnison and Sceva, 1963
29. Koesters, 1984
30. Kremer, 1959
31. Lewellen, 1983; Lewellen and others, 1985
32. Livingston, 1971
33. Miller and Mogk, 1987
34. Mogk, 1978
35. Newcomb, 1970
36. Phillips, 1984
37. Porter, 1976
38. Richardson and others, 1968
39. Rosengreen, 1965
40. Smith and Calkins, 1906
41. Treat, 1987
42. Walsh, 1984
43. Walsh and others, 1987
44. Warren and others, 1945
45. Williams, 1971

Figure 3—Continued. Sources (keyed to map by number) of map compilation data for Snoqualmie Pass 1:100,000 sheet. ***B** (21-45)*, areas consulted extensively but not used directly in compilation.

C. Moser, and Susan Cook in 1981, and by Carol Eddy, Kathleen Ort, and Tad Schirmer in 1982. M. Jean Hetherington, Steve Connelly, Bill Gaum, Mark Gordon, and Kathleen Ort also helped with lab and office work; Catherine R. McMasters provided drafting support. Dennis H. Sorg and Betty Hamachi made radiometric dating experiments feasible by supplying clean mineral separates. The late Jack Johnson, helicopter pilot extraordinary, flew us to the rocks in 1979 and 1981.

We benefited from conversations with many colleagues including Newell Campbell, Larry Chitwood, Eric Erickson, Sheri Goetsch, Howard Gower, Daryll Guzzi, Paul Hammond, Ralph Haugerud, Bob Miller, Bill Phillips, Don Turner, Joe Vance, Tim Walsh, Ray Wells, John Whetten, and Jim Yount. Donald A. Swanson provided unpublished data on the Columbia River Basalt Group. Jim Mattinson, Joe Vance, and Bob Zartman graciously discussed and shared isotopic data with us.

GEOLOGIC SUMMARY

PRE-TERTIARY ACCRETED TERRANES

The pre-Tertiary rocks of the Snoqualmie Pass quadrangle crop out in several isolated tracts. In the northeast corner of the quadrangle at the edge of continuous outcrops of uplifted metamorphic and plutonic rocks of the North Cascades crystalline core (figs. 1, 2), a tectonic mélange of serpentinite, serpentinized peridotite, gabbro, diabase, and greenstone is continuous with the Ingalls Tectonic Complex, which is exposed to the east and northeast (Tabor and others, 1982b; Tabor and others, 1993). The Ingalls Tectonic Complex is a dismembered ophiolite containing mostly Late Jurassic components. In the mid-Cretaceous, it was thrust over the protolith of the Chiwaukum Schist (Miller, 1980a) of the North Cascade crystalline core, prior to the Late Cretaceous metamorphic event documented by Mattinson (1972). The relation of the Ingalls Tectonic Complex to the other rocks of the Northwest Cascade System is unknown.

Definite rocks of the Northwest Cascade System crop out adjacent to and east of the Straight Creek Fault Zone. The Easton Metamorphic Suite and structurally underlying unnamed metavolcanic rocks on North Peak [14; number in brackets indicates position on location map, fig. 4] are exposed in anticlinal cores of Eocene rocks. The North Peak rocks are probably correlative with the Chilliwack Group of Cairnes (1944), an extensive component of the Northwest Cascade System exposed across the Straight Creek Fault Zone to the northwest of the quadrangle. The Easton, composed of phyllite, greenschist, and blue-amphibole schist, previously referred to as the Shuksan Metamorphic Suite by Misch (1966), is thought to have a protolith age of Middle and Late Jurassic and a metamorphic age of Early Cretaceous (Brown and others, 1982). Just south of Easton, the greenschist grades into fine-grained amphibolite in a tectonic zone, and the amphibolite appears to be derived from hornblende tonalite orthogneiss that yields 150-Ma (Late Jurassic) zircons.

Near Manastash Ridge the rocks of the Northwest Cascade System are truncated by a northwest-trending zone of high-angle faults that bound slivers of metavolcanic and metaplutonic rocks, as well as metasedimentary rocks and serpentinite in a tectonic mélange referred to as the tectonic complex by Stout (1964). Tabor (1987; 1994) correlated the tectonic complex with the Helena-Haystack mélange and the coincident Darrington-Devils Mountain Fault Zone exposed to the northwest. Northwest of the quadrangle, the Helena-Haystack mélange and Darrington-Devils Mountain Fault Zone separate the Northwest Cascade System from the western and eastern mélange belts. In the Snoqualmie Pass quadrangle, Tertiary intrusions and eruptive rocks isolate outcrops of western and eastern mélange belts from the Helena Haystack mélange (tectonic complex of Stout, 1964) and the Darrington-Devils Mountain Fault Zone. On Manastash Ridge, the Lookout Mountain Formation of Stout (1964) lies adjacent to, and is incorporated in, the tectonic complex. The Lookout Mountain Formation is mostly aluminium-rich staurolite-garnet mica schist containing lenses of gneissic amphibolite. It was intruded by the 157-Ma Quartz Mountain stock prior to metamorphism.

The western and eastern mélange belts crop out in limited exposures along the north margin of the quadrangle. We correlate thermally metamorphosed chert, basalt, and marble north of Snoqualmie Pass with the eastern mélange belt more widely exposed for about 80 km to the north (Frizzell and others, 1982, 1987; Tabor and others, 1988, 1993). In the northwest part of the quadrangle, exposures of graywacke, argillite, chert, and metagabbro represent the western mélange belt, which is also extensively exposed to the north. In those more northern areas, the mélange belts contain Permian marbles as well as Late Jurassic to Early Cretaceous chert, argillite, and gabbro components, all of which were accreted to North America, probably after the Early Cretaceous and before the middle Eocene (Tabor, 1987).

PALEOGENE TRANSTENSIONAL DEPOSITS

The most complete geologic record in the Snoqualmie Pass quadrangle was recorded during the Tertiary, a period marked in the early Paleogene by the development of local fluviatile basins filled with feldspathic sandstone and conglomerate, and subordinate volcanic rocks. The region was undergoing extension, cut by right-lateral, north-trending strike-slip faults (Tabor and others, 1984; Johnson, 1985; Heller and others, 1987), although earlier workers referred the volcanic rocks to the Challis Volcanic Arc (Armstrong, 1978; Vance, 1982). By the late Paleogene, the north trending Cascade Arc dominated the region (Frizzell and Vance, 1983; Vance and others, 1987).

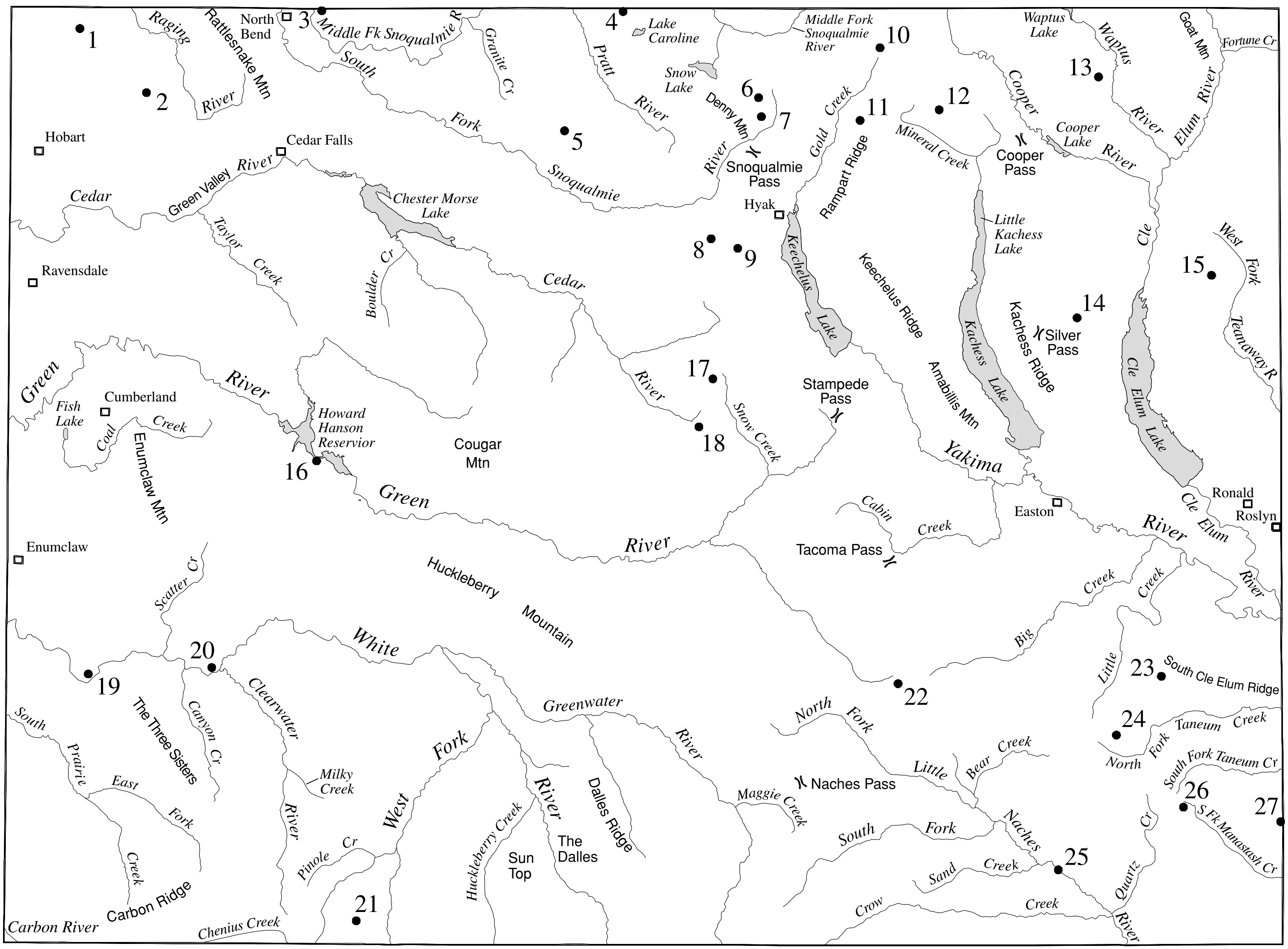


Figure 4. Generalized geographic map of obscure place names, Snoqualmie Pass quadrangle, Washington. Number indicates locality referred to in text.

Most rocks of Tertiary age can be assigned to three structural blocks distinguished in part by stratigraphy and in part by differing degrees of Tertiary deformation. East of the Straight Creek Fault Zone, the oldest Paleogene rocks crop out in two uplifted structural blocks: the Teanaway River Block and the Manastash River Block (fig. 2; Tabor and others, 1984). In the Teanaway River Block, the tightly folded and faulted early and middle Eocene Swauk Formation consists of fluvial feldspathic subquartzose sandstone, siltstone, and conglomerate and the interbedded and overlying dacite and andesite flows, breccia, and tuff of its early Eocene Silver Pass Volcanic Member. The relatively undeformed middle Eocene Teanaway Formation of andesite and basalt flows, tuff, and breccia with minor rhyolite unconformably overlies the Swauk. The fluvial middle and late Eocene Roslyn Formation conformably overlies the Teanaway and is composed of subquartzose feldspathic sandstone, is conglomerate rich in its lowermost part, and contains extensively mined coal beds in the uppermost of its three subunits.

The lower part of the sequence in the Teanaway River Block—clastic rocks, silicic and intermediate volcanic rocks, and basalt—is repeated in the Manastash River Block (fig. 3, 5) where all the rocks are tightly folded and faulted along structures that help define the intersection of the Straight Creek Fault Zone with the Olympic-Wallowa Lineament (Tabor and Frizzell, 1979; Tabor and others, 1984). In the Manastash River Block, the feldspathic subquartzose to quartzose sandstone and lesser amounts of siltstone, conglomerate, and bituminous coal of the early Eocene Manastash Formation are partly correlative with the Swauk Formation. Andesite, dacite, and rhyolite in flows, tuff, and breccia of the early Eocene Taneum Formation conformably overlie the Manastash Formation and are correlative with the Silver Pass Volcanic Member. Above the Taneum, the conformable, middle Eocene basalt of Frost Mountain correlates with the Teanaway Formation (fig. 5).

West of the Straight Creek Fault Zone, the early Eocene nonmarine part of the section is missing. In the eastern part of the Green River-Cabin Creek Block, near the Straight Creek Fault Zone, the strongly deformed Naches Formation consists of middle Eocene to early Oligocene(?) volcanic rocks and interbedded fluvial feldspathic subquartzose sandstone. The Naches, in part, correlates with the relatively undeformed Roslyn Formation of the Teanaway River Block (fig. 5).

In the western foothills of the Cascade Range, on the west margin of the quadrangle, the mildly deformed rocks of the middle and late Eocene Puget Group are lithologically similar to the Naches, but separated from that unit by a cover of younger Tertiary volcanic rocks. Both the Naches Formation and the Puget Group are recognized by their distinct bimodal volcanic constituent, consisting prominently of basaltic and rhyolitic rocks. Whereas, the Naches overlies pre-Tertiary metamorphic and granitic rocks, the Puget Group conformably overlies middle Eocene shallow marine volcanic lithic subquartzose sandstone of the Raging River Formation. The Raging River Formation is somewhat younger than the terriginous Swauk and Manastash Formations, east of the Straight Creek Fault. The Naches Formation and the Puget Group are nowhere seen in contact with each other, but they may be continuous under the younger volcanic cover. Both sequences may have been deposited by a single middle to late Eocene fluvial-deltaic system along the Eocene continental margin (see Johnson, 1985, p. 292).

The volcanic rocks of Mount Persis, mostly exposed north of the quadrangle (Tabor and others, 1993), are in fault contact with the Puget Group on Rattlesnake Mountain, and the mild deformation of the former unit contrasts with the pronounced deformation of the Puget Group rocks suggesting an appreciable age difference. The volcanic rocks of Mount Persis appear to be late(?) Eocene in age and thus be at least partly contemporary with volcanic rocks in the middle and late Eocene Puget Group.

CASCADE ARC

A thick sequence of Oligocene and Miocene volcanic rocks of the Cascade Arc underlies most of the Snoqualmie Pass quadrangle (fig. 1, 2) and forms the bulk of the southern Cascade Range in Washington and Oregon. In the quadrangle, these rocks crop out mostly in the Green River-Cabin Creek Block, but this block is traversed by the northwest-trending White River Fault, which separates the volcanic rocks into two slightly different sequences.

The sequence of rocks south of the White River Fault is in part equivalent to, and continuous with, rocks mapped south of the quadrangle near and around Mt. Rainier (fig. 1; Fiske and others, 1963). These rocks underlie the youngest component of the Cascade Arc, the Quaternary volcanoes that give the southern Cascade Range its striking profile. The oldest unit, the Oligocene Ohanapecosh Formation, consists mostly of colorful, highly altered, well-bedded andesite to dacite breccia, volcaniclastic sedimentary rocks, and locally abundant altered basalt and andesite flows (fig. 2). Relatively fresh basalt and andesite flows, breccias, and subordinate rhyodacite ash-flow tuff and breccia, and volcanic sedimentary rocks of the early Miocene Fifes Peak Formation, as redefined by Vance and others (1987), unconformably overlie the Ohanapecosh and flank a structural high in the White River area. A prominent Fifes Peak member, herein called the Sun Top unit, was deposited in pronounced canyons cut into the Ohanapecosh Formation; another prominent interbed in the upper part of the Fifes Peak Formation, herein called the rhyolite unit of Clear West Peak, appears to be an extracaldera ash-flow tuff equivalent to rhyolite ash flow tuffs and intrusions filling a caldera on Clear West Peak [21] (Fiske and others, 1963; Fischer, 1970; Mattinson, 1977; McCulla, 1986).

We assign well-bedded tuff, breccia, and minor flows of highly altered andesite, basalt, and dacite north of the White River Fault to the Ohanapecosh Formation found south of the fault. Likewise, we assign the overlying flows of generally fresh porphyritic andesite, subordinate breccia, and locally conspicuous interbeds of mudflow breccia to the Fifes Peak Formation, but, as mapped north of the White River Fault, some flows assigned here to the lowermost part of the Fifes Peak may actually be deposits of Ohanapecosh eruptions.

Among the few outliers of the Oligocene to Miocene volcanic cover that crop out north of the extensive Cascade Arc rocks exposed south of Snoqualmie pass is a prominent accumulation of volcanic rocks east of the Straight Creek Fault Zone. Andesite and dacite breccia and tuff in the Goat Mountain area are continuous with the volcanic rocks of Mount Daniel just to the north (Tabor and others, 1993). A partial ring dike on Goat Mountain and nearby catastrophic breccias

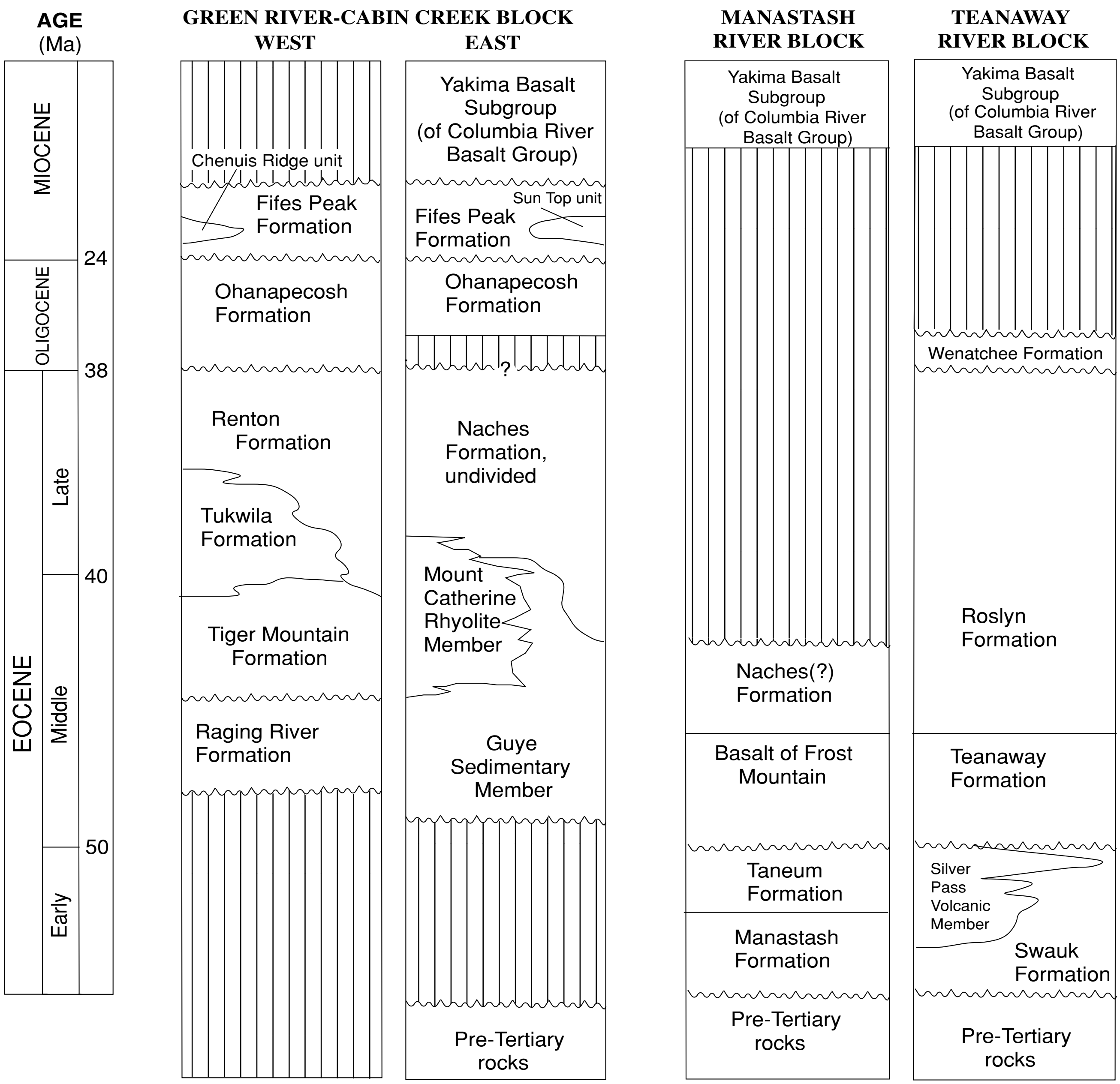


Figure 5. Correlation of selected Tertiary units in Snoqualmie Pass quadrangle, Wash. Absolute time scale from Berggren and others (1985). Modified from Tabor and others (1984, fig. 7).

of probable landslide origin suggest that these volcanic materials were deposited in a tectonovolcanic depression (Hammond, 1965; Tabor and others, 1984).

The Miocene Grande Ronde Basalt of the Columbia River Basalt Group overlies the Fifes Peak Formation along the lower Little Naches River. Along the southwest side of the Manastash River Block, this flood basalt has been offset vertically more than 1,000 m along north-northwest-trending high-angle faults that parallel the Olympic-Wallowa Lineament.

Although the isotopic ages obtained from mapped units of the Oligocene to Miocene volcanic rocks are imprecise, they suggest that these units have considerable temporal overlap, and that the overlap hampers exact correlation and reconstruction of eruptive events. The eruption of these volcanic rocks in the Snoqualmie Pass quadrangle appears to have begun about 35 Ma (early Oligocene) and ended about 20 Ma (early Miocene) (Vance, 1982; Frizzell and Vance, 1983; Turner and others, 1983).

The Oligocene and Miocene Snoqualmie batholith and related stocks intrude the volcanic rocks of the Cascade Arc north of the White River Fault. Rocks of the arc are also intruded by the Miocene Carbon River stock (a pluton in the Tatoosh volcanic-plutonic complex of Mattinson, 1977), which is exposed south of the quadrangle) and related plugs near the southwest corner of the quadrangle. Intrusive events at 25 and 17-20 Ma formed the Snoqualmie and Tatoosh bodies; a 14-Ma event is recorded in a Tatoosh pluton (Mattinson, 1977). Numerous smaller intrusive bodies invaded the volcanic pile between these large plutons and may be high-level apophyses connected in the subsurface to a continuous batholith.

An outlier of late Miocene volcanic rocks and associated dikes, the Howson Andesite, crops out on ridge tops on both sides of Cle Elum Lake. Pliocene and Pleistocene flows and pyroclastic deposits of olivine basalt overlie flows of the Fifes Peak Formation on ridge tops of Dalles Ridge and above Canyon Creek.

A thick flow of early Pleistocene andesite, an early lava of the Mount Rainier volcano, caps a ridge near Huckleberry Creek. In the past 10,000 yr, numerous mudflows swept down the White River valley from Mount Rainier (Crandell, 1969), and several eruptions have blanketed the southern part of the area with various thicknesses of tephra (Mullineaux, 1974).

Moraines and outwash deposits record as many as three alpine glaciations in the high Cascades. Late Pleistocene and Holocene alpine glacial deposits occupy many of the higher mountain valleys and cirques. In the west quarter of the quadrangle, multiple advances of the Puget lobe of the Cordilleran ice sheet left a record dominated by the most recent invasion of ice about 14,000 yr B.P. (Crandell, 1963; Waitt and Thorson, 1983) during the Vashon stade of the Fraser glaciation (Armstrong and others, 1965). Marginal and submarginal drainage has blanketed much of this area with waterlain ice-contact deposits and recessional outwash, which, together with a sequence of channels, spillways, and terraces, express the progressive northwest retreat of the Vashon ice margin during deglaciation (Booth, 1984).

GENERAL DESCRIPTION OF THE UNITS

PRE-TERTIARY ROCKS

ROCKS NORTHEAST OF THE DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

The Northwest Cascade System in the Snoqualmie Pass quadrangle (see geologic overview) consists of metavolcanic rocks of North Peak, the Easton Metamorphic Suite, tonalite gneiss of Hicks Butte, associated tectonic zone, and banded gneiss. Because the affinity of the Ingalls Tectonic Complex is unknown, that unit is included here for convenience. A small tonalite stock at Fortune Creek intrudes the Ingalls and is a terrane overlap unit (Tabor and others, 1987a).

Ingalls Tectonic Complex

The Ingalls Tectonic Complex crops out only in the northeast corner of the Snoqualmie Pass quadrangle, but is extensively exposed to the east (Tabor and others, 1982b) where tectonically mixed sandstone and argillite, radiolarian chert, pillow basalt, and ultramafic rocks indicate that the unit is an ophiolite complex or mélange (Hopson and Mattinson, 1973; Southwick, 1974; Miller, 1977; Miller and Frost, 1977, p. 187; and Miller, 1980b, 1985). The tectonic emplacement of the Ingalls over higher grade metamorphic rocks of the North Cascade crystalline core (fig. 1) is discussed by Miller (1980a,b, 1985), Whetten and others (1980), Vance and others (1980), and Tabor and others (1987b).

Foliated serpentinite (shown with pattern on the geologic map) forms a band across the southern outcrops of ultramafic rocks in the Ingalls Tectonic Complex. At the south margin of the belt, Miller and Mogk (1987, fig. 1) identify partially serpentinized harzburgite and dunite. The north edge of the serpentinite belt grades into a zone of mylonitized hornblende peridotite and lherzolite that in turn grades to the north into unserpentinized lherzolite and harzburgite, which correspond to Miller's (1980b, p. 52-69) South Peak unit. Cowan and Miller (1980), and in greater detail, Miller and Mogk (1987, p. 286-287) infer that the ultramafic rocks formed in an oceanic fracture zone. The mylonitic rocks are derived from the lherzolite and harzburgite by shearing in the evolving fracture zone, and the foliated serpentinite formed during a later metamorphism of the mantle materials either at the upper mantle-lower crust contact or in the shallower reaches of the fracture zone.

On the basis of isotopic ages of gabbro and radiolarians in chert in the Wenatchee quadrangle, components of the Ingalls Tectonic Complex are Late Jurassic in age (Tabor and others, 1982b; Miller and others, 1993). Although the complex could contain tectonic components of different ages, we accept these ages for the protolith. North of the quadrangle, the complex is intruded by the Late Cretaceous Mount Stuart batholith. The age of tectonic mixing of the complex is, thus, Late Jurassic or Early Cretaceous. Correlations of the Ingalls with units of the Northwest Cascade System to the northwest is uncertain. Other correlations are discussed by Vance and others (1980), Whetten and others (1980), Brandon (1989), and Miller and others (1993).

Easton Metamorphic Suite

First described and named by Smith and Calkins (1906, p. 2), the Easton Schist included rocks of varied composition and metamorphic history. Stout (1964, p. 322-323) restricted the formation to greenschist, blue amphibole schist, and phyllite. The low-grade schist and phyllite of the Easton have been traced northward for 100 km (Ellis, 1959; Yeats, 1958a; Vance, 1957a) and correlated across the Straight Creek Fault with the Shuksan Metamorphic Suite of Misch (1966) (Yeats, 1977; Dungan and others, 1983). Tabor and others (1993) revised the Easton Schist as the Easton Metamorphic Suite and adopted Misch's (1966) names "Shuksan Greenschist" for its greenschist and blueschist component and "Darrington Phyllite" for its phyllite component. Misch (1966), Haugerud and others (1981), Brown and others (1982), Dungan and others (1983), and Brown (1986) cite evidence for the basaltic ocean-floor origin of the greenschist (and blueschist) and the marine shale and sandstone origin of the phyllite. Ashelman (1979) describes a similar origin for greenschist and phyllite in what is now called the Easton Metamorphic Suite along Kachess Lake.

Brown and others (1982) and Brown (1986) interpreted a collection of K-Ar ages and Rb-Sr isochron data and zircon U-Pb ages from the Easton Metamorphic Suite exposed many kilometers north of the Snoqualmie Pass quadrangle as indicating a protolithic age of Middle and Late Jurassic and a metamorphic age of Early Cretaceous. They suggested that the high-pressure metamorphism of the Easton occurred in a deep subduction-zone environment. Ages have not been obtained from rocks in the area of the map, but we assume that the ages and the metamorphic history are the same as those described by Brown and his coworkers.

Tonalite gneiss of Hicks Butte and rocks of the tectonic zone

Biotite hornblende tonalite and tonalite gneiss on Hicks Butte [23] display uniform textures and composition indicating an igneous plutonic origin, although we did not see intrusive contacts. On the southwest side, the pluton is mostly unconformably overlain by Tertiary sandstone. A small exposure of banded gneiss adjacent to the pluton suggests a primary contact, but the actual contact is not exposed. The contact on the northeast side appears to be tectonic and reveals some enigmatic features. The relatively undeformed granitoid rock grades northeastward into a tectonic zone of blastomylonitic gneiss that in turn grades through a zone of very fine grained amphibolite into rocks typical of the Shuksan Greenschist of the Easton Metamorphic Suite. The contact of the tonalite gneiss with the Shuksan Greenschist to the northeast, thus, appears to be a deep-seated fault. Highly deformed, partially recrystallized rocks are exposed in the tectonic zone over a width of 1 km. In the vicinity of Big Creek, we show the contact of the tonalite gneiss and the Shuksan Greenschist as a single fault, because the tectonic zone appears to be missing.

Although Smith and Calkins (1906, p. 4) felt that the tonalite had intruded the Shuksan Greenschist prior to faulting in the tectonic zone, Stout (1964, p. 321-322) astutely noted that the contact rocks are not hornfelsic but have been recrystallized in the greenschist facies during and after penetrative shear.

J.M. Mattinson and C.A Hopson (written commun., 1980; table 1, no. 66) obtained relatively concordant U-Pb ages of 153 Ma from zircon separated from the tonalite gneiss of Hicks Butte. This Late Jurassic protolith age for the tonalite gneiss is similar to the probable protolith age of the Easton Metamorphic Suite (see discussion of that unit) and suggests a related origin for these two rock units. Amphibolite from the gneiss near the tectonic zone yields a 128-Ma K-Ar hornblende age (table 1, no. 63), which may be a minimum. Correlative amphibolite, associated with similar Late Jurassic tonalite in the Helena-Haystack mélange exposed about 100 km to the northwest, yields a K-Ar hornblende age of about 141 Ma (Tabor and others, 1988). We consider this older age more reliable but also a minimum cooling age for the amphibolite metamorphism.

In a detailed study, Treat (1987, p. 76-80) concluded that the amphibolite was probably derived by shearing and recrystallization from a mafic phase of the Hicks Butte pluton, and, because the pluton and the amphibolite contained no evidence of the high-pressure metamorphism of the Shuksan Greenschist, she considered the pluton to have been juxtaposed with the Shuksan along a deep-seated fault in post-Shuksan metamorphism time (post-130 Ma). The recently determined age of the hornblende in the amphibolite seems to preclude this history. Indeed relicts of hornblende in the greenschist described by Treat (1987, p.23) confirm the earlier amphibolite event.

Gallagher and others (1988) describe a Middle Jurassic tonalite 150 km to the north that they conclude was root material of a volcanic arc that supplied detritus to metatuffs interbedded with rocks in the Easton Metamorphic Suite. The Hicks Butte pluton and Easton could represent a similar association, but the data in the Snoqualmie Pass quadrangle indicate only that the pluton crystallized about the same time that the protolith of the Shuksan Greenschist formed, that these two units were juxtaposed along a deep-seated fault shortly after intrusion of the pluton, and that they were then later metamorphosed in the blueschist facies about 130 Ma. The lack of blue amphiboles indicative of low-pressure metamorphic minerals in the Hicks Butte pluton may be due to its bulk composition and resistance to deformation in the second metamorphism. Miller and others (1993) discuss the juxtaposition of the pluton with the Easton Metamorphic Suite in detail and offer several other hypotheses to explain the relations of these rocks.

Banded gneiss

A narrow outcrop belt composed of fine-grained and granoblastic gneiss and schist crops out along the southwest side of the tonalite gneiss of Hicks Butte. The banded gneiss lacks cataclastic textures or evidence of strong penetrative deformation common in the other rocks of the Manastash Ridge area. Textures in the banded gneiss suggest that it was predominantly recrystallized under static conditions. The protolith of the banded gneiss could have been calcareous sediments. Although we observed no contacts with the tonalite gneiss of Hicks Butte, the protolith of the banded gneiss may have been intruded and metamorphosed by the pluton.

Metavolcanic rocks of North Peak

Low-grade metavolcanic rocks and impure marble cropping out west of Cle Elum Lake may be the oldest rocks in the Snoqualmie Pass quadrangle, although they are considerably less metamorphosed than the surrounding Easton Metamorphic Suite. Smith and Calkins (1906, p. 2-3) thought that the North Peak [14] rocks were younger than the phyllite and greenschist of the Easton and tentatively included them in the Peshastin and Hawkins Formations (now part of the Ingalls Tectonic Complex) exposed a few kilometers east of the quadrangle. They and later workers (Foster, 1960, p. 102; Lofgren, 1974, p. 15-18) considered the unit to be unconformable on the Easton, preserved as an infolded and infaulted block. Our work confirms Ashelman's (1979, p. 27) conclusion that the North Peak rocks structurally underlie the Easton Metamorphic Suite and are exposed in the core of a Tertiary anticline. Their relatively low degree of recrystallization, abundant lawsonite and pumpellyite, and only incipient actinolite and blue amphibole indicate that they are of lower metamorphic grade than the overlying rocks of the Easton Metamorphic Suite and suggest that they have been overthrust by the Easton after its regional metamorphism (Ashelman, 1979, p. 25-26).

Ashelman (1979, p. 25) suggested that the original volcanic rocks were silicic to mafic in composition with minor sedimentary and limestone interbeds. The Chilliwack Group of Cairns (1944), exposed along the Sauk River about 100 km to the north and west across the Straight Creek Fault (Vance 1957a; Brown and others, 1987), is of similar lithology and metamorphic grade. Along the Sauk River and farther to the north, the Chilliwack also tectonically underlies the Easton Metamorphic Suite. If the metavolcanic rocks of North Peak are indeed correlative with the Chilliwack Group, then their protolith age is Devonian to Permian (Danner, 1966, p. 64-65). The age of metamorphism of the Chilliwack is thought to be about mid-Cretaceous (Smith, 1986, p. 131-134).

Tonalite

As originally described by Smith and Calkins (1906, p. 4), a small tonalite stock exposed at Fortune Creek on the Cle Elum River is a satellite of the Mount Stuart batholith exposed about 6 km east of the quadrangle. A K-Ar hornblende age of about 84 Ma (table 1, no. 61) confirms its affinity with the batholith.

ROCKS IN THE DARRINGTON MOUNTAIN FAULT ZONE

Tectonic complex of Stout (1964) and ultramafic rocks

On Manastash Ridge, separated from the Hicks Butte pluton and other rocks of the Northwest Cascade System by early Tertiary volcanic rocks, a mixture of strongly deformed rocks cut by high-angle faults was called the tectonic complex by Stout (1964). Cataclastic to blastomylonitic elongate blocks of fine-grained schistose amphibolite and highly foliate serpentinite and serpentinized pyroxenite or peridotite and dunite (Goetsch, 1978, p. 45-47) in slivers and pods are characteristic. Also abundant are phyllite, greenstone, blue-amphibole schist, tonalite gneiss, leucogreenstone, silicic metatuff, and metasandstone.

The tectonic complex contains blocks of silicic metatuff petrographically identical to blocks of metatuff in the Helena-Haystack mélange exposed 100 km to the northwest (Tabor, 1994). The Helena-Haystack mélange is cut by and coincident with high-angle Tertiary faults of the Darrington-Devils Mountain Fault Zone, and the similarity of lithology and structure between Helena Ridge and Manastash Ridge led J.A. Vance (in Tabor, 1987) to suggest that the high-angle faults at Helena Ridge and faults at Manastash Ridge could be connected by undoing right lateral offset along the Straight Creek Fault. Because most of the Straight Creek Fault is obscured by younger plutons and deposits in the region of this offset and because of the acute angle of intersection between the two major fault zones, Tabor (1987) and Tabor and others (1989) suggested that the Darrington-Devils Mountain Fault Zone truncated the Straight Creek Fault or moved concurrently with it.

ROCKS SOUTHWEST OF DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Lookout Mountain Formation of Stout (1964)

Fine-grained graphitic andalusite-staurolite-garnet-biotite schist and hornblende schist and amphibolite exposed on Lookout Mountain [24] and Quartz Mountain [26] were named the Lookout Mountain Formation by Stout (1964, p. 320), who felt that Smith and Calkins (1906, p. 2-3) erred in assigning these rocks to the Peshastin Formation, a unit that we have included in the Ingalls Tectonic Complex (Tabor and others, 1982b). The schist of the Lookout Mountain Formation retains sedimentary features, such as graded bedding, load casts, and clastic textures even though it reached staurolite-andalusite zone of Buchan-type regional metamorphism (Goetsch, 1978, p. 32). Metadacite porphyry sills and dikes are abundant and small masses of metagabbro to gabbro scattered throughout the formation were thought by Goetsch (1978) to have been intrusive into the schist or its protolith, but their origin is obscure.

Along the northeastern margin of the Lookout Mountain Formation, mica schist (map unit pTlm) appears to be interlayered (Stout, 1964, p. 321) or imbricated (Goetsch, 1978, p. 31) with very fine grained amphibolite and metatonalite or metagabbro, lithologically similar to rocks in adjacent amphibolite and hornblende tonalite gneiss (pTla) (hereinafter called the amphibolite for simplicity). Miller and others (1993) consider the fine-grained mica schist of the Lookout Mountain Formation and the adjacent amphibolite unit to be in fault contact on the basis of differences in metamorphic history. The amphibolite is made up of fine-grained schistose amphibolite, hornblende metatonalite, metadiorite, and metagabbro that has been unevenly penetratively sheared and recrystallized to blastomylonitic gneiss and amphibolite. Some fine-grained amphibolite and minor biotite-hornblende schist have no relict textures that suggest derivation from coarser grained rocks such as diorite or gabbro; they could have been derived from mafic volcanic rocks. Goetsch (1978, p. 17) suggested that the protolith of the amphibolite unit was a mixture of basalt flows and mafic intrusions. The amphibolite grades into the tectonic complex of Stout (1964) by increase in penetrative shear and increase in disparate rock types such as ultramafic rocks, phyllite, greenschist, and metasandstone. Goetsch (1978, p. 41-49) has described the tectonic complex in detail, and much of the mapped gradational contact with the amphibolite and hornblende tonalite gneiss of the Lookout Mountain Formation is from her mapping.

Stout (1964, p. 321) proposed that the Lookout Mountain Formation might correlate with the Tonga Formation of Yeats (1958b) exposed 60 km to the north on the east side of the Straight Creek Fault (fig. 1). The Tonga is locally associated with greenschist and blue-amphibole schist that has been correlated with the Easton Metamorphic Suite (Yeats 1958a; see also Tabor and others, 1982a, 1987a). Tabor and others (1993) discuss the correlation of the Tonga with the Easton, but conclude that the Tonga is unlikely to be part of the Easton and that it is more likely a low-grade equivalent of the Chiwaukum Schist exposed in the higher grade core of the North Cascades (see also Duggan, 1992a, b). The Tonga Formation is a metapelite with an early, greenschist synkinematic metamorphism overprinted by a late-kinematic to static metamorphism producing biotite and stuarolite. This latter Barrovian event was shared by the metamorphic rocks in the crystalline core of the North Cascades, exposed mostly north of the map area. The presence of metatonalite in the Tonga, which might correlate with the Quartz Mountain stock (see below; Tabor and others, 1993), and the general lithologic similarity of the Tonga and the Lookout Mountain make their correlation attractive. However, according to Goetsch (1978, p. 26, 80), the Lookout Mountain Formation displays a late greenschist overprint that is lacking in the Tonga. Further difficulties lie in trying to juxtapose the Tonga and the Lookout Mountain by undoing offset on any of the major faults such as the Straight Creek Fault or the Darrington-Devils Mountain Fault Zone. The Straight Creek Fault Zone appears to merge and bend into faults aligned with the northwest-trending Olympic-Wallowa Lineament (Tabor and Frizzell, 1979; Tabor and others, 1984). If the main strand passes northeast of the schist of the Lookout Mountain Formation, as seems likely, the schist could only have been separated from the Tonga Formation by significant left-lateral movement on the Straight Creek Fault, contrary to all other evidence of right-lateral movement. If the ancestral Straight Creek Fault originally extended south along its modern trend, then the Lookout Mountain Formation is on the same (east) side of the fault as the Tonga Formation and could not have been separated from the Tonga by offset on the Straight Creek Fault. A similar argument can be made for offset on the Darrington-Devils Mountain Fault Zone.

An amphibolite block in the tectonic complex of Stout (1964) yields a hornblende K-Ar age of about 113 Ma (table 1, no. 65). Presuming that the block is derived from the amphibolite and tonalite gneiss subunit of the Lookout Mountain Formation, the age probably represents a minimum age of metamorphism for the formation. The Lookout Mountain Formation is intruded by the Late Jurassic Quartz Mountain stock (see below) and both are metamorphosed. Late Cretaceous metamorphism (at about 90 Ma) for much of the North Cascades is well documented (see Tabor and others, 1987a, b), but considering the probable minimum age of metamorphism (Early Cretaceous) documented in the amphibolite block and the uncertain correlation of the Lookout Mountain Formation with other units of the North Cascades, its metamorphism may be Late Jurassic to Early Cretaceous in age and its protolithic age is pre-Late Jurassic but otherwise unknown.

Quartz Mountain Stock

The small intrusive stock on Quartz Mountain was first mapped by Smith and Calkins (1906), who considered it a satellite of the Late Cretaceous Mount Stuart batholith. We now know its protolithic age to be 157 Ma (Late Jurassic) on the basis of relatively concordant U-Pb ages of zircon by J.M. Mattinson and C.A. Hopson (written commun., 1980; table 1, no. 64). The pluton sharply intrudes schist of the Lookout Mountain Formation of Stout (1964), but contains garnet and considerable signs of recrystallization such as poikilitic sodic plagioclase rims on more calcic plagioclase and K-feldspar and aggregates of biotite, all of which indicate that it may have been metamorphosed along with the schist. The composition of the pluton is not well known. Smith and Calkins (1906, p. 4) classified it a granodiorite and described both crystals and intergranular K-feldspar, whereas Goetsch (1978, p. 40-41) found no K-feldspar. We noted considerable K-feldspar in our one sample, mostly found as orthoclase cores surrounded by sodic plagioclase. Zonally arranged clinozoisite in the core of the K-feldspar suggest that K-feldspar has replaced an earlier calcic plagioclase.

Western and eastern mélange belts

In the north-central part of the Snoqualmie Pass quadrangle and in the western foothills of the North Cascades to the north, highly disrupted oceanic rocks underlie much of the pre-Tertiary terrane west of the Straight Creek Fault. Although these oceanic rocks have been assigned a variety of names and ages by early workers, the varied association of rock types and overall penetrative deformation indicates that they are mélanges. On the basis of their overall lithologies and geographic positions, we have separated the rocks into the western and eastern mélange belts. Frizzell and others (1982, 1987) and Tabor and others (1993) summarize and discuss the characteristics and tectonic history of these rocks.

Rocks of the western mélange belt

The western mélange belt consists of argillite and graywacke with generally lesser amounts of metavolcanic rocks, conglomerate, chert, marble, metagabbro, and rare serpentinite. Outcrop- to mountain-size phacoids of metagabbro, metadiabase, and metatonalite and megaclasts of sandstone, chert, and marble stand out boldly in a matrix of poorly foliated argillite or disrupted thin-bedded argillite and sandstone.

Fuller (1925, p. 29-39, 46-55) described extreme deformation, characterized by blocks of graywacke imbedded in contorted argillite, in rocks exposed in the vicinity of the South and Middle Forks of the Snoqualmie River. This deformation and lithology is typical of the western mélange belt.

Bethel (1951, p. 22-56) mapped feldspathic graywacke and argillite at the southern outcrop limit of the western mélange belt, but he incorrectly correlated the rocks with the Swauk Formation (see discussion below). Working just north of this quadrangle and drawing upon the work of Danner (1957), Kremer (1959, p. 40-62) also recognized the high degree of deformation in these rocks and assigned the graywacke and associated argillite and chert a Late Jurassic and Early Cretaceous age. The mostly hornfelsic argillite and graywacke exhibit bedding, and some relatively subtle sedimentary features survive in disrupted sedimentary rocks adjacent to the Snoqualmie batholith near Granite Creek. Resistant blocks of metavolcanic rocks on Little Si [3] and metagabbro on Mount Si form bold ridges just north of this quadrangle. Inclusions of metagabbro in Tertiary volcanic breccia indicate that the mélange extends in the subsurface at least as far south as Chester Morse Lake.

Jett and Heller (1988, p. 52) inferred that the western mélange belt consists of three distinct petrofacies that were "mixed together in an accretionary wedge within an active subduction belt." Miller (1989) described isolated outcrops in the Rim Rock Lake inlier, about 45 km to the south of the Snoqualmie Pass quadrangle, which have components of both the eastern and western mélange belts, and he (p. 1303) noted especially distinctive lithic similarities with rocks of the western mélange belt.

A heterogeneous gabbro body, exposed on the South Fork of the Snoqualmie River, southwest of Mount Defiance [5], is mostly recrystallized by thermal metamorphism, and in some samples secondary groundmass quartz replaces cloudy plagioclase suggesting considerable silicification. Erickson (1965, 1968, and 1969) included this gabbro in his early mafic phase of the Snoqualmie batholith. However, because of its metamorphic features, we consider it to be a large tectonic block of metagabbro of the western mélange belt, which has been partially engulfed by the batholith.

Components of the western mélange belt have been dated from localities north and south of this quadrangle (Frizzell and others, 1987; Miller, 1989; Tabor and others, 1993). Most clastic sedimentary components appear to be Late Jurassic to Early Cretaceous in age on the basis of megafossils in argillite and radiolarians found in chert pods. Many marble outcrops in the western mélange belt well north of this quadrangle yield mid- and Late Permian fusulinids (Weibe, 1963, p. 6; Danner, 1966, p. 319-322, 325). Four metatonalite-metagabbro masses north of the quadrangle yield U-Th-Pb zircon ages in the range of 150-170 Ma. Hornblende from uralitic metagabbro bodies yields conventional K-Ar ages of about 160 Ma. Newly formed sericite in a well-recrystallized phyllite from the western mélange belt about 47 km north of the quadrangle yielded a 48-Ma K-Ar age determination. This may be a minimum age for the formation of the mélange if the phyllite assemblage represents the highest grade attained during penetrative deformation.

The western mélange belt is overlain by the gently deformed volcanic rocks of Mount Persis (late Eocene) and is in fault contact with middle and late Eocene rocks of the Puget Group. In the Rimrock Lake area to the south of the quadrangle, rocks probably correlative with the western mélange belt (Miller, 1989) appear to be overlain unconformably by well-dated middle Eocene volcanic rocks (Vance and others, 1987). Thus, formation of the mélange, emplacement against the continent, and, possibly, significant strike-slip translation must have occurred between the Early Cretaceous and the middle Eocene.

Rocks of the eastern mélange belt

Rocks of the eastern mélange belt crop out just north of Snoqualmie Pass as three discrete fault-bounded exposures engulfed by intrusive plutonic rocks. These considerably deformed and metamorphosed rocks consist of metagraywacke, metabasalt, metachert, marble, and metagabbro. Ultramafic rocks, scattered throughout the eastern mélange belt north of the Snoqualmie Pass quadrangle (Tabor and others, 1988, 1993), have not been found in this part of the mélange.

Smith and Calkins (1906, p. 7) included rocks comprising the eastern mélange belt in what they called the Guye Formation (now called the Guye Sedimentary Member of the Naches Formation by Tabor and others, 1984) and reservedly considered them to be Miocene, although they also indicated that the rocks could be Paleozoic in age. Foster (1957, p. 111) renamed small bodies of marble, hornfels, and chert adjacent to Denny Mountain the Denny Formation. Partly on the basis of other's work, he concluded that these rocks could be either Permian or Jurassic to Cretaceous in age.

Few fossils have been found in the eastern mélange belt, and no fossils have been recovered from its metasedimentary components in the Snoqualmie Pass quadrangle. Danner (1957, p. 249-255; 1966, p. 375-386) investigated the marble outcrops at Denny Mountain in some detail and suggested that, although barren, the association of limestone, basalt, and chert suggested correlation with his Trafton sequence. Danner (1977, p. 497, 500) and Whetten and Jones (1981) now consider the Trafton to contain fossils ranging in age from Devonian to Middle Jurassic.

Tabor and others (1993) consider the eastern mélange belt north of the Snoqualmie Pass quadrangle to be roughly correlative with the Trafton sequence, but note that the relative stratigraphic coherence in the eastern mélange belt contrasts with the more pervasive disruption in the Trafton. However, in contrast to the Trafton (see above), most components of the eastern mélange belt to the north are Mesozoic in age, including the marble. A distinctive metachert and meta-andesite sequence is Late Triassic in age. Zircons from a small unmapped metagabbro body on Cave Ridge [6] yielded U-Th-Pb ages of about 165 Ma (Middle Jurassic; Frizzell and others, 1987; table 1, no. 69), which we interpret to be the age of magmatic crystallization of that component.

Direct evidence for the timing of tectonic mixing and emplacement of the eastern mélange belt is lacking. The mélange may have been emplaced as early as the mid-Cretaceous (Vance and others, 1980; Whetten and others, 1980). Emplacement, at least by the middle Eocene, is indicated by the unconformable relation between the rocks of the eastern mélange belt and those of the Naches Formation and the partially correlative Barlow Pass Volcanics of Vance (1957a,b), 60 km north of the Snoqualmie Pass quadrangle. In summary, ages from the western and eastern mélange belts and from terrane overlap units indicate that the mélanges were emplaced between the Early Cretaceous and the middle Eocene.

TERTIARY ROCKS

EARLY TERTIARY ROCKS

Early Tertiary sedimentary and volcanic materials in the quadrangle likely were deposited in basins formed by strike-slip faulting along the continental margin; they crop out in three structural blocks east and west of the Straight Creek Fault (figs. 1, 2)—the Teanaway River Block, the Manastash River Block, and the Green River-Cabin Creek Block. The Teanaway River and Manastash River Blocks, east of the Straight Creek Fault, contain the oldest Tertiary rocks in the map area. In the Teanaway River Block, strongly deformed early Eocene sandstone and siltstone of the Swauk Formation and the interbedded intermediate volcanic rocks of its Silver Pass Volcanic Member are succeeded upsection by the relatively undeformed lava flows of the middle Eocene Teanaway Formation that are in turn overlain by the coal-bearing fluvial sandstone beds of the Roslyn Formation. The Swauk-Silver Pass-Teanaway sequence in the Teanaway River Block is repeated in the Manastash River Block by sandstone, siltstone, and coal beds of the Manastash Formation, andesitic to rhyolitic volcanic rocks of the Taneum Formation, and the basalt of Frost Mountain. Rocks of this latter sequence are all tightly folded and faulted along structures that help define the intersection of the Straight Creek Fault and the Olympic-Wallowa Lineament.

Complexely deformed Paleogene sedimentary and interbedded volcanic rocks occur west of the Straight Creek Fault in two parts of the Green River-Cabin Creek Block (previously discussed as the Cabin Creek Block of Tabor and others, 1984, and the Green River Block of Frizzell and others, 1984). The early middle Eocene shallow-marine Raging River Formation and the overlying middle and late Eocene Puget Group occur near the west margin of the map. These rocks are separated from the strongly deformed middle Eocene to early Oligocene(?) Naches Formation by an intervening cover of mildly deformed late Oligocene and early Miocene volcanic rocks. The Naches crops out immediatly west of the Straight Creek Fault. Similarities in sandstone petrology, fossil flora, and age determinations, all support a persuasive model for the deposition of these deformed units in a single fluvial-deltaic basin—the Puget-Naches basin of Johnson (1985).

Basaltic intrusions

Mapped diabasic, gabbroic, and basaltic intrusive bodies and numerous unmapped dikes that invaded the early and middle Tertiary sedimentary and volcanic rocks east of the Straight Creek Fault may be the intrusive equivalents of the Teanaway Formation and likely were intruded before deposition of the Roslyn Formation, because such intrusions have not been found in the Roslyn Formation. West of the Straight Creek Fault, lithologically similar rocks that intrude the Naches also may be related genetically to the Teanaway Formation, but this seems improbable because significant movement on the Straight Creek Fault likely would have displaced 47-Ma rocks well to the north. Although Stout (1961) suggested that relatively fresh diabase intrusions on both sides of the Straight Creek Fault fed flows of the Columbia River Basalt Group, the preponderance of evidence suggests that these Miocene flows came from the southeast (Swanson and Wright, 1978, p. 54-55; Tabor and others, 1982b, p. 13). In the Puget Lowland, intrusive rocks may represent more than one igneous event.

ROCKS EAST OF THE STRAIGHT CREEK FAULT

Teanaway River Block

Swauk Formation

Dark-colored feldspathic to lithofeldspathic subquartzose sandstone characterizes the early and middle Eocene, nonmarine Swauk Formation, which also contains interbeds of less abundant siltstone, pebbly sandstone, and conglomerate. Tightly folded beds of the Swauk occupy a belt between an uplifted block of the Easton Metamorphic Suite north of Cle Elum Lake and an uplifted block of sheared serpentenite of the Ingalls Tectonic Complex in the northeast corner of the quadrangle.

Outcrops of the Swauk Formation in the Snoqualmie Pass quadrangle are continuous with those near Swauk Creek (Tabor and others, 1982b), the type locality, where Russell (1900, p. 118-119) first used the name Swauk in reference to the sandstone sequence. Smith (1904, p. 5) and Smith and Calkins (1906, p. 4-5) extended the Swauk into the area of this map. Ellis (1959, p. 21-24), Foster (1960, p. 103-104), Lofgren (1974, p. 19-23), and Ashleman (1979, p. 38-43) also mapped the Swauk here and provided useful descriptions of the unit; Pongsapich (1970) and Frizzell (1979) studied the sandstone petrology of the Swauk and other Paleogene nonmarine sandstone units. Tabor and others (1984) discussed the depositional history of the Swauk and related early and middle Tertiary units. Taylor and others (1988, fig. 17), on the basis of work near Swauk Pass, east of this quadrangle, present a more detailed model for deposition for the Swauk in alluvial fan, braided river, meandering river(?), lacustrine-deltaic, and lacustrine environments in a strike-slip basin (see also, Johnson, 1985). Tabor and others (1982b, 1984) describe several subunits of the Swauk, and two of these, basal ironstone subunit and the Silver Pass Volcanic Member, warrant discussion here.

Thin discontinuous beds of iron-rich (limonite, hematite, and magnetite) sandstone, shale, and conglomerate occur where the Swauk Formation unconformably overlies serpentinite of the Ingalls Tectonic Complex. These ironstone deposits attest to relative stability of the region and, perhaps, low relief in pre-Swauk time, and they may have been derived by recrystallization of transported laterite (Lupher, 1944; Lamey and Hotz, 1951, p. 56-57). Lupher (1944) considered the basal ironstone beds to be considerably older than the Swauk and called them the Cle Elum Formation. We found that the ironstone beds are locally interbedded with characteristic sandstone of the Swauk and consider them the lowest part of the formation as did Smith (1904, p. 5), Lamey (1950), and Lamey and Hotz (1951). These and other basal beds of the Swauk were undoubtably deposited on the pre-Tertiary basement rocks, and the resulting contacts are generally depicted as depositional. Minor faulting ("shearing off" of Misch, 1966, p. 137) between the Swauk and basement likely occurred in many localities.

The Silver Pass Volcanic Member of the Swauk Formation comprises mostly dacitic to andesitic flows and pyroclastic rocks exposed between Lake Kachess and Cle Elum Lake and ribs of lithologically similar volcanic rocks and scattered outcrops of mafic tuff to the east, especially north of Swauk Creek about 25 km to the east of the Snoqualmie Pass quadrangle (Tabor and others, 1982b). The area between Kachess and Cle

Elum Lakes was regarded by Smith and Calkins (1906, p. 5) as the so-called type of the now-abandoned Kachess Rhyolite; Foster (1960, p. 105-107) called these rocks the Silver Pass volcanic rocks for exposures near Silver Pass. Foster (1960) and Lofgren (1974, p. 323-334) considered the rocks to unconformably overlie the Swauk, a theme since championed by Cheney (1994, p. 121-125). However, we believe that the interbedding of the silicic tuffs of Silver Pass age within the Swauk sandstone is well established and that the unit represents a unique lithology in the Swauk. For this reason, Tabor and others (1984, p. 32-33) adopted and revised the name of the unit to that used herein—the Silver Pass Volcanic Member of the Swauk Formation.

Tabor and others (1984) estimated the thickness of a homoclinal sequence of the Swauk Formation, about 10 km east of this map area, at a maximum of 4,800 m from the basal unconformity to a tongue of volcanic rocks (Silver Pass Volcanic Member, itself about 1,800 m thick at Silver Pass) near its top. They inferred several thousand meters of section overlying the Silver Pass in the Swauk Creek area, and Taylor and others (1988) measured more than 3,200 m of section above the lowest Silver Pass interbed there. The Swauk, therefore, may approach 8,000 m in total stratigraphic thickness.

Palynomorph assemblages from the Swauk Formation indicate an early Eocene to middle Eocene age (Newman, 1975). Fission-track ages on zircon from the formation's medial Silver Pass Volcanic Member mostly indicate 50- to 52-Ma ages (early Eocene) (Vance and Naeser, 1977; Tabor and others, 1984; table 1, nos. 58, 59). On the basis of the established stratigraphic thickness of the Swauk above the latest early Eocene Silver Pass Volcanic Member, we now consider the Swauk everywhere to be early and middle Eocene in age.

Apparently, the 8,000 m thickness of the Swauk Formation was deposited after uplift of the Mount Stuart batholith (55 Ma: Erikson and Williams, 1976; Tabor and others, 1984, p. 41) and before the eruption of the volcanic rocks of the Teanaway Formation (see below). This scenario indicates a very high, minimum sediment accumulation rate for the Swauk: about 96 to 160 cm/1,000 yr for the part below the Silver Pass Volcanic Member and 64 to 160 cm/1,000 yr for the part above it—an overall average rate of about 100 cm/1,000 yr for the formation.

Teanaway Formation and Teanaway dike swarm

The Teanaway Formation contains lava flows that range compositionally from basalts to rhyolites (Ort and others, 1983); dark-colored flows of basalt and (or) andesite predominate in some exposures. Tuff and breccia constitute much of the unit, and minor feldspathic sedimentary rocks are also present (Clayton, 1973, p. 35-36). The unit crops out along the east edge of the map and is mostly exposed in the steep west limb of a broad southeasterly plunging faulted syncline that is more completely exposed east of the quadrangle (Tabor and others, 1982b). Smith and Willis (1901, p. 359) named the unit the Teanaway Basalt for the Teanaway River just east of this map. Because of the variation in composition and lithology, Tabor and others (1984, p. 33) renamed the unit the Teanaway Formation. Smith (1904, p. 5-6), Clayton (1973, p. 16-30), and Lofgren (1974, p. 41-46) have described the Teanaway in detail.

Dense swarms of diabase dikes crop out in the northeast corner of the map area. We use different density of symbols to depict the proportion of terrain underlain by the dikes. Chemical analysis of dikes and the absence of dikes in the Roslyn Formation indicate that the dikes were feeders for the Teanaway Formation. Tabor and others (1982b, p. 11) summarized previous investigations of the dikes.

On the basis of K-Ar age determinations, Tabor and others (1984, p. 40, table 1; table 1, no. 56) consider the Teanaway Formation to be 47 Ma (middle Eocene) in age. Estimated thickness for the unit ranges from less than 10 m near Table Mountain, about 25 km east of the Snoqualmie Pass quadrangle (Tabor and others, 1982b) to at least 2,500 m near Lake Kachess. The Teanaway is overlain conformably by the middle and late Eocene Roslyn Formation.

Roslyn Formation

Willis (1886) first mentioned the mining of coal from the so-called Roslyn beds, which were, he said, similar to those in the Puget Sound area. The main body of the Roslyn Formation, characterized by white, thick-bedded lithofeldspathic sandstone, crops out east of this map (Tabor and others, 1982b), but the once-active coal mining areas of Roslyn and Ronald are in the Snoqualmie Pass quadrangle. Russell (1900, p. 123-127) named the formation that was described subsequently by Smith (1904, p. 6-7) and Smith and Calkins (1906, p. 4). Bressler (1951, 1956) studied the Roslyn definitively, documented its fluvial origin, and divided it into three sandstone subunits, which consist of a lower member with abundant conglomerate, a middle member, and an upper coal-bearing member. The three members total some 2,000 m in thickness. Pongsapich (1970) and Frizzell (1979) reported sandstone clast compositions from these members. Walker (1980) described the Roslyn and its coal beds and, on the basis of structural interpretations, estimated its thickness to be 2,590 m.

We believe that interbedded basaltic materials and sandstone layers reported by Clayton (1973, p. 13) indicate a conformable relation between the Roslyn Formation and the underlying Teanaway Formation, although Bressler (1951, p. 441) felt the contact was disconformable.

Foster (1960, p. 109) considered the Roslyn Formation to be of middle and (or) late Eocene age on the basis of fossil leaves and sparse vertebrate remains. Palynomorph assemblages led Newman (1981, p. 58) to correlate the upper coal-bearing member with part of the Franklin coal zone (of Vine, 1969) of the Puget Group, and we concur with his conclusion that the Roslyn is middle and late Eocene in age.

Manastash River Block

Manastash Formation

Smith (1904, p. 7) applied the name "Manastash Formation" to a unit of subquartzose to quartzose sandstone with minor siltstone, chert- and quartz-bearing conglomerate, and coal exposed in the area of Manastash and Taneum Creeks, 2 to 3 km east of the Snoqualmie Pass quadrangle (see Tabor and others, 1982b). The unit was further described by Saunders (1914, p. 119-129, 133-136), Beikman and others (1961, p. 25, 33), Stout (1964, p. 324), and Lewellen (1983, p. 15-16). Tabor and others (1984, p. 37-39) discussed the nomenclatural history of the unit.

The Manastash Formation rests unconformably on phyllite and greenschist of the Easton Metamorphic Suite and the tonalite gneiss of Hicks Butte. The Taneum Formation overlies the Manastash. Diabase dikes that intrude the Manastash were the bane of early coal prospectors; these dikes may be related either to eruptive rocks of the Taneum Formation or to the basalt of Frost Mountain.

The Manastash Formation varies considerably in thickness. A section approximately 550 m thick is present on pre-Tertiary rocks in the vicinity of Little Creek. Another section approximately 750 m thick is exposed in the faulted northern limb of the northwest-trending syncline on Manastash Creek about 4 km east of this map area, where Lewellen and others (1985, p. 12) calculated that the unit may be thicker than 950 m.

Sandstone in the Manastash Formation exhibits an uncommon sparkle because it contains relatively more quartz than do other major Paleogene nonmarine sandstone units in Washington (Frizzell, 1979, fig. 8, table 1). Lewellen (1983, p. 38-51, table 1) felt that the composition of sandstone in upper Taneum Creek differed significantly from that in the Manastash Creek area and that otherwise equivalent rocks in the two areas should be considered different formations. Although the rocks in the Manastash Creek area are somewhat coarser grained and richer in monocrystalline quartz than those in the Taneum Creek area, plagioclase and mica content and the amount and ratios of different lithic clasts do not differ significantly (Frizzell, 1979). Tabor and others (1984, p. 41) considered the Manastash a distal equivalent of the Swauk Formation; the differences in framework grain composition between the suggested Manastash-equivalent "facies" of the Swauk and the composition of the overall Swauk are greater than the differences perceived within the Manastash.

Leaves of plants collected from the Manastash Formation have not been recognized in either the Swauk or the Roslyn Formations, but palynological data suggest that the Manastash is equivalent to the lower part of the Swauk (Newman, 1977), and we consider the age of the Manastash Formation everywhere to be early Eocene.

Taneum Formation

A sequence of dacitic to andesitic lavas and pyroclastic rocks overlies the Manastash Formation with apparent conformity, although, on the basis of bedding inclinations, Lewellen and others (1985, p. 13-14) felt that an angular unconformity separates the two units. Too little data exist to confirm an unconformity, but generally steeper dips in the Manastash probably indicate some deformation before deposition of the Taneum Formation. We accept the early Eocene age and correlation of the Taneum with the Silver Pass Volcanic Member of the Swauk Formation as proposed by Tabor and others (1984, fig. 7, section A). Unit thickness varies considerably along strike, but an estimated minimum section of 1,000 m is present on Taneum Ridge. Tabor and others (1984, p. 38) discussed the nomenclatural history and correlations of the Taneum.

Basalt of Frost Mountain

A sequence of basalt and andesite flows and breccia was informally referred to as the basalt of Frost Mountain by Tabor and others (1982b, p. 11), describing good exposures in the vicintity of Frost Mountain [Not named on map; 27]. These volcanic rocks are best exposed in the core of the northwest-trending syncline whose southwest limb is juxtaposed against the Lookout Mountain Formation and the tectonic complex of Stout (1964, see above) by splays of the Straight Creek Fault and (or) faults in the Darrington-Devils Mountain Fault Zone.

The basalt of Frost Mountain appears to overlie the Taneum Formation conformably. Pronounced thinning of the Taneum Formation along strike to the west either may be erosional and indicative of an unconformity, or it may represent thinning away from the vent areas. Variations in strike of bedding make accurate estimates of thickness impossible in the apparently thickest part of the sequence between the South Fork of Taneum Creek and the South Fork of Manastash Creek, but a minimum thickness of about 400 m is exposed in the faulted section that crosses Little Creek. Despite ambiguities in isotopic data (table 1, no. 57), Tabor and others (1984, p. 38, 39) concluded that the basalt of Frost Mountain is correlated with the Teanaway Formation and is about 47 Ma (middle Eocene) in age.

ROCKS WEST OF THE STRAIGHT CREEK FAULT

Green River-Cabin Creek Block

Raging River Formation

The lower(?) and middle Eocene Raging River Formation (Vine, 1962, p. 7-11; Johnson and O'Conner, 1994) is the only Tertiary unit of predominantly marine origin in the map area. The unit comprises marine and alluvial sedimentary rocks that conformably underlie the rocks of the Puget Group. The sandstone, siltstone, shale, and minor conglomerate comprising this unit are exposed in a faulted northwesterly plunging anticline in the northwestern corner of the Snoqualmie Pass quadrangle. Volcanic detrital materials predominate in the sandstone and conglomerate, contrasting with the conspicuously feldspathic fluviatile sandstones of middle Eocene age found east of the Puget Lowland. Although no more than 300 m of the Raging River Formation are exposed in any exposure, the projection of outcrops into a composite section indicates that the unit is at least 700 m thick (Johnson and O'Conner 1994, p. A26).

W.W. Rau (*in* Johnson and O'Conner, 1994, p. A6) considered benthonic foraminifera from the upper part of the Raging River Formation to be early Narizian in age (early middle Eocene), and Johnson and O'Conner (1994, p. A6) considered underlying unfossiliferous strata to be early(?) and early middle Eocene in age.

Johnson and O'Conner (1994) divided the Raging River Formation into three informal units and, on the basis of fossil content and sedimentological features, concluded that the lowest unit of interbedded sandstone, mudstone, and conglomerate was mostly deposited in a shallow marine environment; the middle unit of sandstone and conglomeratic sandstone was probaly fluviatile, but the uppermost unit of predominently sandstone and shale was deposited in the transition from marine shelf to slope at bathyal depths (500 to 2,000 m).

The Raging River Formation demonstrates a major ocean transgression in its upper part, probably controlled by tectonism (Johnson and O'Conner, 1994), and a final regression with the influx of the predominently terrestrial deposits of the Puget Group.

Puget Group

The Puget Group predominates along the west margin of the Snoqualmie Pass quadrangle where it is discontinuously covered by unconsolidated glacial deposits and consists of three interbedded units, from oldest to youngest, the Tiger Mountain, Tukwila, and Renton Formations. Coal-bearing arkosic sedimentary rocks of the Puget Group in the Green River and Tiger Mountain [1] area consist of micaceous feldspathic subquartzose sandstone, siltstone, claystone, and coal (Vine, 1969, p. 6-13). The Tukwila Formation in the Tiger Mountain area consists of andesitic volcaniclastic rocks and tuff-breccia beds that form resistant ledges. Most of the rocks of the Puget Group were deposited in a terrestrial environment, but Johnson and O'Conner (1994) considered the lower part of the Tiger Mountain Formation to have formed in a marine prodelta shelf setting.

Willis (1886, p. 759-760) referred to these rocks as the Coal Measures of Puget Sound and correlated them with rocks of Late Cretaceous age in the Rocky Mountain region. White (1888, p. 446), while discussing the estuarine nature of fossil mollusks, first used the name "Puget Group" for outcrops in the Puget [Sound] Lowland, and Willis and Smith (1899, p. 2) properly assigned them an Eocene age. Subsequent workers continued this, or closely similar, nomenclature until Waldron (1962) named the Eocene volcanic rocks in the Seattle area the Tukwila Formation and included the formation in the Puget Group. Waldron (1962) also named the Renton Formation for the coal-bearing arkosic sedimentary rocks that overlie the Tukwila Formation and included them in the Puget Group as well. Arkosic sandstone that underlies the volcanic rocks of the Tukwila Formation on Tiger Mountain was named the Tiger Mountain Formation by Vine (1962, p. 12) and included in the Puget Group.

In the northwest part of the map, we depict areas underlain by interfingering rocks of the Tiger Mountain and Tukwila Formations as a separate map unit. Just south of the Snoqualmie Pass quadrangle, Gard (1968) named the Carbonado, Northcraft, and Spiketon Formations as correlatives of the formations comprising the Puget Group.

The Puget Group has a minimum composite thickness of about 3,400 m in the vicinity of Tiger Mountain (Vine, 1969, p. 17, 20, 24), whereas, in the Green River area, Vine (1969, p. 6) estimated a minimum thickness of about 1,900 m. Immediately south of the map area, the Puget Group attains a minimum thickness of about 3,200 m (Gard, 1968, p. B6, B8, B11). The absence of volcanic units in the Green River area at least partly explains the relative thinness of the Puget Group there. In comparison, the section at Tiger Mountain contains volcanic units with maximum thickness of about 2,100 m.

Buckovic (1979, fig. 5-7) and Johnson (1985, fig. 9) elegantly modeled the depositional environment of the Puget Group as a middle to late Eocene delta plain prograding over and covering shallow marine strata of the Raging River Formation. Local accumulations of andesitic volcanic rocks were inundated by younger fluvial deltaic deposits. Deposition occurred at a rather rapid rate; unit thicknesses and isotopic determinations led Johnson (1985, p. 292) to suggest sedimentation rates of 50 to 110 cm/1,000 yr for the Puget Group.

We do not completely understand the contact separating the Puget Group from the overlying Ohanapecosh Formation. South of Cedar Falls, attitudes in both of these units more or less parallel the contact separating them. Between Coal Creek and the Green River, the sandstone-clast composition changes rapidly upward across that contact from feldspathic sandstone to volcanic sandstone that is interbedded with siltstones rich in organic material reminiscent of those in the Puget. These two facts indicate a conformable contact, but differences in severity of deformation between the two units suggest that the contact could be an unconformity.

Abundant plant fossils provided the basis for the age assignments of early Eocene to early Oligocene to the Puget Group (Wolfe, 1968). Wolfe (1981, p. 41-42, fig. 5) revised these assignments to a range from late early Eocene to late Eocene, using an Eocene-Oligocene boundary of 32 Ma. In this report, we use the following boundary ages: early-middle Eocene, 52 Ma; middle-late Eocene, 40 Ma; and Eocene-Oligocene, 36.6 Ma (Berggren and others, 1985). Thus, K-Ar and fission-track ages from ash partings in coal beds of the Green River area, with a time span of about 41 Ma to 45 Ma, indicate a middle Eocene age (Turner and others, 1983, fig. 2; table 1, nos. 40-44). The Tiger Mountain Formation overlies the Raging River Formation and, thus, is likely mostly middle Eocene in age as indicated by Turner and others (1983, fig. 3), who erred in their text (p. 528) by also refering the Tiger Mountain to the late early Eocene. West of the map area, breccia of the Tukwila Formation has yielded a zircon fission-track age of 41 Ma and an average K-Ar age of about 42 Ma (late Eocene; Frizzell and others, 1979; Turner and others, 1983). The Tukwila likely ranges into the middle Eocene as well. The Renton Formation is also likely middle and late Eocene in age (Turner and others, 1983, p. 528, fig. 3).

Volcanic rocks of Mount Persis

On the basis of overall similarity of thickness and appearance, we consider the highly altered two-pyroxene andesite flows and breccias forming Rattlesnake Mountain south of North Bend equivalent to the volcanic rocks of Mount Persis of Tabor and others (1993) in the Skykomish River quadrangle, although little distinguishes the rocks at Rattlesnake Mountain from fresh flow rocks in any of the middle and late Tertiary units mapped elsewhere in the Snoqualmie Pass quadrangle. Previously, the rocks on Rattlesnake Mountain were either correlated with flows of the Cascade Arc such as the Ohanapecosh or Fifes Peak Formations (Tabor and others, 1982a) or informally called the volcanic rocks of Rattlesnake Mountain (Walsh, 1984).

The age of the volcanic rocks of Mount Persis remains enigmatic despite several attempts to determine it (Tabor and others, 1993). The rocks appear to be about the same age as the Tukwila Formation (about 42 Ma) of the Puget Group against which they are faulted, but they lack the micaceous and feldspathic sandstone interbeds and the pronounced deformation exhibited by the Tukwila. On the other hand, although the lack of strong deformation in the Mount Persis rocks suggest that the unit is younger than the Tukwila, it cannot be younger than the 34-Ma Index batholith, which intrudes it north of the Snoqualmie Pass quadrangle (Tabor and others, 1993). The Mount Persis rocks are considered to be late(?) Eocene in age in this report.

Naches Formation

The complexly deformed nonmarine Naches Formation spans the map from south to north immediately west of the Straight Creek Fault. The Naches is characterized by mostly rhyolitic to basaltic volcanic rocks with interbedded feldspathic subquartzose sandstone and siltstone and minor coal. Tabor and others (1984, p. 35-37) resolved a confused nomenclatural history and more fully described the Naches subunits that are briefly presented here.

Complex faulting and tight folding in the Naches make accurate estimates of thickness difficult, but inspection of cross sections through the probable thickest part of the unit southeast of Rampart Ridge indicate between 1,500 and 3,000 m of section. Basaltic breccia and rhyolitic ash-flow tuff unconformably overlie mica schist and tonalite of the Lookout Mountain Formation of Stout (1964) in the sparse exposures of contacts with pre-Tertiary rocks. The contact between the Naches Formation and the Ohanapecosh Formation is a marked angular unconformity.

Two members of the Naches Formation crop out near Snoqualmie Pass. Tabor and others (1984, p. 36-37) reduced the Guye Formation, as restricted by Foster (1957, 1960, p. 111-112), in rank to the Guye Sedimentary Member of the Naches, retaining the unit's geographic designation, although Guye Peak [7] is not underlain by the member. Interbedded leaf-bearing carbonaceous argillite, dark sandstone, and chert-rich conglomerate characterize this member. Clasts in the conglomerate probably originated from chert bodies in the eastern mélange belt, now mostly engulfed by the Snoqualmie batholith. Rocks of the Guye Sedimentary Member are interbedded with volcanic rocks of the Naches, including its Mount Catherine Rhyolite Member.

Tabor and others (1984, p. 37) redesignated the Mount Catherine [9] Rhyolite of Foster (1957, 1960) as the Mount Catherine Rhyolite Member of the Naches Formation because it also intertongues with other rocks of the Naches Formation. Just south of Snoqualmie Pass, this distinctive ash-flow tuff sequence forms bold outcrops and delineates an arcuate pattern that defines an anticline; the tuff also underlies Guye Peak.

Fossil leaves from the redefined Naches Formation indicate an Eocene age for the unit. Fission-track ages on zircon from rhyolite ash-flow tuff and whole-rock K-Ar ages on basalt, both low in the Naches section, indicate a 40- to 44-Ma age for the Naches (middle and late Eocene; Tabor and others, 1984, table 1 and 2, nos. 16-20; table 1, nos. 45-49, 53-55); the upper parts of the Naches may be as young as early Oligocene(?). The Naches is, therefore, considered to be middle Eocene to early Oligocene(?) in age in this report.

MIDDLE AND LATE TERTIARY ROCKS

Mildly deformed Oligocene and Miocene volcanic and sedimentary rocks cover the area between exposures of the Puget Group and the Naches Formation and dominate the Cascade Range south of the Snoqualmie Pass quadrangle. Smith and Calkins (1906) assigned part of this heterogeneous sequence of post-Eocene rocks to their Keechelus Andesitic Series. Warren and others (1945) used the name "Keechelus" for rocks along the west margin of our map. The Keechelus Andesitic Series spawned several units of formational rank, including the Ohanapecosh and Fifes Peak Formations discussed below, before being abandoned by Tabor and others (1984, p. 35) following the suggestion and arguments of Waters (1961, p. 56).

Ohanapecosh Formation

Multicolored andesitic to dacitic tuff and breccia, volcaniclastic sedimentary rocks, and basaltic to andesitic lava flow and mudflow complexes dominate the Oligocene Ohanapecosh Formation in the central and south central parts of the map. The formation was named for rocks some 28 km south of the Snoqualmie Pass quadrangle in the vicinity of Ohanapecosh Hot Springs southeast of Mt. Rainier (Fiske and others, 1963, p. 4-20). North of the White River Fault, the Ohanapecosh consists of rocks previously called the Enumclaw Volcanic Series by Weaver (1916, p. 84, 232-235), called the Enumclaw (in part), Huckleberry Mountain, and Snow Creek Formations by Hammond (1963, p. 77-163; 1964), and called the unnamed volcanic rocks by Vine (1969, p. 27-29). Frizzell and others (1984) informally called the rocks comprising all of these units, the volcanic rocks of Huckleberry Mountain and suggested that they probably were correlative with the Ohanapecosh Formation. South of the White River Fault, Fischer (1970, p. 25-34) and Hartman (1973) described several occurrences of Ohanapecosh rocks. Rocks referred to the Ohanapecosh underlie large parts of the southern Washington Cascades south of the Snoqualmie Pass quadrangle (Wise, 1970; Hammond, 1980; Evarts and others, 1987; Walsh and others, 1987; Vance and others, 1987; and Smith, 1993). The eruption of these rocks marked the end of Eocene strike-slip faulting and magmatism (Tabor and others, 1984; Johnson, 1985) in the Pacific Northwest and the initiation of the Cascade [Magmatic] Arc (Vance, 1982; Frizzell and Vance, 1983).

The Ohanapecosh Formation is not always easily distinquished from the underlying Naches Formation or Puget Group, and the contact between these units is rarely exposed. We mapped the Ohanapecosh on the basis of abundant multicolored volcaniclastic beds, lack of feldspathic sandstone interbeds, and less deformation where lithologic criteria were scarce. The apparently conformable contact with the underlying Puget Group is described in the section on the Puget. The unconformable contact with the Naches can be best observed on the geologic map and in the field north of the Little Naches River and Tacoma Pass. Locally, the Ohanapecosh is overlain unconformably by the revised Fifes Peak Formation (Vance and others, 1987; and see discussion below).

Fiske (1963) considered that most of the well-bedded volcaniclastic materials of the Ohanapecosh Formation were deposited as subaqueous pyroclastic flows derived from active underwater volcanoes, and that accumulations of tuff-breccia represented the remnants of those volcanoes. Although sedimentary structures in many exposures clearly indicate the reworking of materials in aqueous environments, Vance and others (1987) likely are correct that much of the unit was deposited subareally.

The Ohanapecosh Formation is here considered to be Oligocene in age, although on the basis of paleontological data, Fiske and others (1963, p. 20) concluded that the rocks of the Ohanapecosh in Mt. Rainier National Park to the south ranged in age from middle Eocene to early Oligocene, but were mostly late Eocene. The lower part of the Ohanapecosh just west of Enumclaw Mountain contains fossil plant remains assigned to the Kummerian Stage (lower Oligocene; Wolfe, 1968, 1981; Vine, 1969, p. 28). Near the middle of the quadrangle, zircon from a tuff at Stampede Pass yielded fission-track ages of 30 to 32 Ma (Tabor and others, 1984; table 1, nos. 33), and zircons from near Bear Creek in the Little Naches River area produced an age of 32 Ma (Vance and others, 1987; table 1, no. 35). Similarly, a whole-rock K-Ar determination on altered andesite from a flow breccia east of Cumberland indicated a minimum age of about 35 Ma (Turner and others, 1983; table 1, no. 38). In the northeastern exposures of the quadrangle, the tuff member of Lake Keechelus, in part equivalent to the Stampede Tuff of Hammond (1963, p. 123-144; 1964), who described the member in detail, contained zircons that indicate a 30-Ma age (Tabor and others, 1984; table 1, no. 34). Numerous fission-track ages on zircon from tuff south of the quadrangle, have indicated that the rocks of the Ohanapecosh erupted from 36 to 28 Ma (Vance and others, 1987), mostly in the early and middle Oligocene. In light of these numerous determinations and the likely age (early Miocene) for the overlying Fifes Peak Formation in the quadrangle, the ages of the tuff west of Chester Morse Lake (25 Ma, table 1, no. 31) and in the area of the upper Little Naches River (26 Ma; table 1, no. 30) seem too young.

Argon loss from the biotite (no. 30) could explain its apparent discrepancy, but the youthful fission-track age (no. 31) is not as easily explained.

Volcanic rocks of Mount Daniel

Bedded volcanic breccia, tuff, and flows, here called the volcanic rocks of Mount Daniel, overlie the early and middle Eocene Swauk Formation with pronounced angular unconformity on Goat Mountain and extend 9-10 km north of the Snoqualmie Pass quadrangle to Mount Daniel (Tabor and others, 1993). These rocks are mostly dacite and andesite with lesser amounts of rhyolite. Simonson (1981, p. 41-42), who has made the most recent study to date, considered the main mass of volcanic rocks in the Mount Daniel area to be silicic ash-flow tuffs and breccias.

Basal coarse sandstone breccias, containing clasts to 3 m across and volcanic breccia dikes intruding both the volcanic rocks of Mount Daniel and the underlying sandstone of the Swauk Formation, are of particular significance to the origin of the volcanic rocks of Mount Daniel. Many of the sandstone breccias are monolithologic, but Ellis (1959, p. 66) and Simonson (1981, p. 40) describe breccia with volcanic matrix, which indicates deposition during volcanic activity. The basal breccias may well be catastrophic debris-flow deposits related to faulting accompanying eruption. Hammond (1965) first suggested this scenario when he proposed that the volcanic rocks on Goat Mountain filled a small collapsed caldera. The dikes may represent fissures in the older rocks that formed by shattering along the faults and were subsequently filled with breccia.

Smith and Calkins (1906) mapped the volcanic rocks on Goat Mountain and included them in their now-abandoned Keechelus Andesitic Series (Tabor and others, 1984; see also Waters, 1961, p. 56). We think these rocks correlate with the Ohanapecosh Formation to the south, but the evidence is somewhat contradictory. For example, isolated outcrops of flat-lying volcanic breccia and tuff that crop out on Chikamin Peak [10] and on peaks to the south may be remnants of deposits that formerly were continuous with the main mass of the Ohanapecosh Formation on Huckleberry Mountain. An apatite fission-track age of about 34 Ma (table 1, no. 39) from a dacite tuff in the volcanic rocks of Mount Daniel supports this correlation. However, fission-track ages of zircons in the area of Mount Daniel itself suggest that the volcanic rocks are about 25 Ma (Simonson, 1981, p. 66-67; Tabor and others, 1984). These younger ages led Simonson (1981, p. 141) and Vance (1982) to correlate the volcanic rocks of Mount Daniel with the Stevens Ridge Formation as defined by Fiske and others (1963; see discussion under Fifes Peak Formation). Tabor and others (1993) discuss the conflicting ages and conclude that the younger ages may be reset by the intrusion of the nearby Snoqualmie batholith.

Simonson (1981, p. 75-76) proposed that the volcanic rocks represent an eruptive phase of the batholith possibly derived from a caldera to the west that has since been engulfed by the Snoqualmie batholith. The Mount Daniel-Goat Mountain volcanic pile may indeed be part of a caldera or an extensive volcanic-tectonic depression and, in that respect, similar to the Eagle Tuff of Yeats (1958b, 1977) and breccia of Kyes Peak exposed about 36 km and 55 km to the northwest (Tabor and others, 1988; 1993). These floundered blocks of volcanic rocks more or less cluster along the east side of the Straight Creek Fault (fig. 2) and along the margin of the Snoqualmie batholith and to the north along the Grotto batholith. The volcanic rocks of Mount Daniel appear to be too old to be directly related to the Snoqualmie batholith, but their emplacement may reflect the same structural controls that emplaced the younger Eagle Tuff and breccia of Kyes Peak.

Volcanic rocks

Isolated masses of mostly coarse volcanic breccia and tuff with minor ash flow tuff and rare flow rocks crop out west and north of Snoqualmie Pass on Denny Mountain, Chikamin Peak [10] and Alta Mountain [11]. As mapped, these rocks may include some volcanic rocks of the unconformably underlying Naches Formation, but they are generally distinguishable from the older rocks (Tabor and others, 1984, p. 35-36) on the basis of coarse angular andesitic breccia, small amount of deformation, and lack of interbedded feldspathic sandstone. Most of these ridge-capping volcanic rocks are highly recrystallized and many are hornfelsic. Isolated outcrops of hornfels near the South Fork of the Snoqualmie River are recrystallized, but relict structures and textures suggest that they were originally porphyritic volcanic rocks. We think that these rocks may well be outliers of the volcanic rocks of the Ohanapecosh Formation, separated from the main outcrop mass of the Ohanapecosh by erosion and by intrusion of the Snoqualmie batholith.

Fifes Peak Formation

The Fifes Peak Formation consists predominantly of basaltic andesite and basalt flows, flow breccia and interbedded breccia and tuff and subordinate mudflow breccia, volcaniclastic sedimentary rocks, and crystal lithic air-fall tuff and ash-flow tuff that all unconformably overlie the Ohanapecosh Formation. This interpretation of the unit is one of several that have been offered through the years. Warren (1941) first distinguished the andesitic flows, agglomerates, and tuffs (his Fifes Peak Andesite) from the all-encompassing Keechelus Andesitic Series of former usage in an area about 3 km south of the Snoqualmie Pass quadrangle near Fifes Peak. He noted that the Fifes Peak Formation underlies the Yakima Basalt Subgroup of the Columbia River Basalt Group (his Yakima Basalt) and unconformably overlies flows, dikes, breccia, and sedimentary rocks that later were called the Ohanapecosh Formation. Abbott (1953) mapped the Fifes Peak in an area about 40 km south of this map area to include basal silicic tuff beds; Fiske and others (1963; see also Waters, 1961) excluded these beds from the unit when they revised and renamed it the Fifes Peak Formation. These workers showed that silicic beds are locally present between the Ohanapecosh and the Fifes Peak Formations, and they assigned them to a third unit, the Stevens Ridge Formation, named for a locality 10 km south of the Snoqualmie Pass quadrangle.

Whereas, the distinction of the Ohanapecosh, Stevens Ridge, and Fifes Peak Formations by Fiske and others (1963) presented a useful model for understanding the middle Tertiary volcanic and volcaniclastic sequence in the immediate vicinity of Mt. Rainier National Park, recent work by Vance and others (1987) questioned the use of the name “Stevens Ridge Formation” outside that area. Vance and others (1987, p. 279-282) pointed out that various silicic units that occur stratigraphically between the Fifes Peak and the Ohanapecosh (but beyond the Stevens Ridge type locality) differ in age and (or) lithology from the type Stevens Ridge and, thus, cannot be physically correlative with it. These various silicic tuffs, including the type Stevens Ridge, are broadly the same age as the Fifes Peak. Vance and others (1987), therefore, suggested revising the Stevens Ridge to a member of the Fifes Peak Formation and designating the other silicic tuff units in similar stratigraphic position as members of the Fifes Peak Formation with separate local names.

Frizzell and others (1984) have previously mapped various local tuff outcrops in the Snoqualmie Pass quadrangle as the Stevens Ridge Formation. Following Vance and others (1987), we here agree to geographically restrict the Stevens Ridge Formation to ash-flow and related volcaniclastic sedimentary rocks in its type locality south of this quadrangle. Rock units on our map, even though laterally continuous with a tuff named the Stevens Ridge by Fiske and others (1963), but not continuous with that unit in its type locality and lithologically similar tuffs in the same stratigraphic position elsewhere in this map area, are designated as local informal members of the Fifes Peak Formation.

Andesitic and basaltic flows and breccias overlying the Ohanapecosh Formation and parts of the intervening rhyodacite tuff south of the White River Fault were referred by Fischer (1970) to the Enumclaw Formation of Hammond (1963, 1964). In contrast, Hartman (1973) referred them to the Fifes Peak Formation. Both Fischer and Hartman referred much of the rhyodacite tuff outcrops in intervening areas to the Stevens Ridge Formation. We correlate the rhyodacite tuff with the Sun Top tuff (what we herein call the Sun Top unit), an informal member of the Fifes Peak Formation as described by Vance and others (1987). The Sun Top unit boldly crops out on both sides of the White River at Sun Top and on Dalles Ridge. It is discontinuously exposed as far west as Camp Creek. We informally refer to less well exposed bodies of dacite tuff in the southwest corner of the map as the Chenuis Ridge unit of the Fifes Peak Formation, named for a larger dacite tuff body exposed just south of the map area. These rocks are separated from, and may be slightly older than, the rocks at Sun Top.

A silicified rhyolite tuff interbedded with lavas of the Fifes Peak Formation on the north side of the White River but clearly part of an extracaldera flow from the Clear West Peak eruptive center is here considered an informal member of the Fifes Peak Formation as well.

Well-bedded tuff, breccia, and volcanic sandstone, characterized by reworked volcanic material and probable stream and lake deposits, form a thick wedgelike interbed in the Fifes Peak Formation that is well exposed in Maggie Creek, an eastern tributary of the Greenwater River. These rocks may represent a filled depression between an eroded ridge of the Ohanapecosh Formation exposed north of Government Meadows and the once-growing shield of Fifes Peak lavas on the south. Hartman (1973, p. 25) assigned these sedimentary rocks and the fresh-looking flows overlying them to what he called the “upper” Keechelus Andesitic Series of Smith and Calkins (1906, p. 8), but the freshness of the flows at Naches Pass does not convince us that this part of the section is significantly younger than the rest of the Fifes Peak. The uniqueness of that section may be explained by the buttress unconformity.

The clear distinction between the generally altered, bedded tuffs and breccias of the older Ohanapecosh Formation and the unconformably overlying generally unaltered younger tuffs and flows of the Fifes Peak Formation and the basal silicic ash-flow tuffs of the Fifes Peak makes mapping of the units straight forward in most areas. In at least two areas of the Snoqualmie Pass quadrangle, however, these distinctive criteria for separating the Ohanapecosh from the overlying rocks are missing.

In the first area, Boundary Creek east of the White River, the Sun Top unit partly filled steep-walled canyons cut into tuff and breccia of the Ohanapecosh Formation and was later covered with Ohanapecosh debris eroded from the canyon walls, giving rise to apparent interbedding of the Sun Top unit and Ohanapecosh tuff and breccia. Such details cannot be shown at the scale of our map, but similar relations can be expected elsewhere near the contact between the Ohanapecosh and Fifes Peak Formations. We expect that similar relations are responsible for a hybrid unit that we call the volcanic rocks of Eagle Gorge.

Fifes Peak Formation and the volcanic rocks of Eagle Gorge

North of the White River Fault, the Fifes Peak Formation overlies the Ohanapecosh Formation in two northwest-trending synclines, which help define the Olympic-Wallowa Lineament in this area. These rocks were previously called the Eagle Gorge Andesite, the Cougar Mountain Formation, and (part of) the Snow Creek Formation by Hammond (1963, 1964). We use the informal name, "volcanic rocks of Eagle Gorge" here for a unit locally present between the Ohanapecosh and Fifes Peak Formations.

Our volcanic rocks of Eagle Gorge [16] is a hybrid unit consisting mostly of Fifes Peak-equivalent basaltic flows, minor breccia and tuff, and Ohanapecosh-equivalent lavas. In the area of the Green River and south of the Cedar River, we were unable to find an unconformity between the Ohanapecosh and the Fifes Peak Formations, and the generally definitive silicic ash-flow tuff at the base of the Fifes Peak is lacking.

Traversing up section from the Ohanapecosh Formation into the volcanic rocks of Eagle Gorge, we mapped the contact of these units at the base of prominent thick andesite flows. Within the Eagle Gorge unit, some of the flows look like lavas of the Fifes Peak Formation, and others resemble Ohanapecosh lavas. A locally prominent interflow breccia resembles Ohanepecosh breccia. On Cougar Mountain, we drew the contact between the Eagle Gorge unit and the Fifes Peak Formation where the first mudflow breccia of mostly black andesite appears. These are typical of interflow breccia in the Fifes Peak elsewhere. Along the Green River, the basal part of the Fifes Peak is marked by an apparently conformable rhyodacite ash-flow tuff several hundred meters thick, which probably represents the silicic volcanism in evidence to the south and east, where the contact also is marked by a pronounced unconformity.

Fiske and others (1963, p. 30) concluded from regional correlations that their Fifes Peak Formation in the Mount Rainier National Park area was "probably early Miocene" in age. Subsequently, isotopic data from rocks in the Tieton Reservoir-Mt. Rainier area south of the Snoqualmie Pass quadrangle indicate that the here-revised Fifes Peak Formation ranges from 20 to 27 Ma in age (Vance and others, 1987), making the unit late Oligocene and early Miocene in age in that area. In this quadrangle, andesite lava of the Fifes Peak Formation has yielded 22- to 24-Ma whole-rock potassium-argon ages (early Miocene; Hartman, 1973; table 1, nos. 21; these and other determinations from the literature have been converted using the revised constants of Dalrymple, 1979). A K-Ar determination of 17 Ma on plagioclase from a site about 32 km south of the quadrangle (Hartman, 1973, p. 25; table 1, no. 15) seems too young but has a large error indicating a questionable age.

In the Snoqualmie Pass quadrangle, the Sun Top unit of the revised Fifes Peak Formation ranges in age from about 20 to 24 Ma (Miocene; table 1, nos. 23-27). The crystal lithic tuff (Tfc) above the volcanic rocks of Eagle Gorge yielded an age of 21 Ma (table 1, no. 29), similar to that of the Sun Top unit. The Chenuis Ridge unit of the Fifes Peak yielded a 23-Ma age (table 1, no. 28). Although we believe that biotite from a sample collected near the confluence of Camp Creek and the White River yields a reasonable age for the Sun Top unit (24 Ma, Fischer, 1970, p. 51-52, 1976; table 1, no. 25), the 35-Ma age of the hornblende in the sample is anomalous and too old for the Fifes Peak as we presently interpret it. Fischer (1970, 1976) accepted the older age as that of the unit and ascribed the younger age of the biotite to a reheating event.

Rhyolite unit of Clear West Peak

A large mass of mostly altered, gray, sparsely porphyritc rhyolite constitutes Clear West Peak [21] and surrounding ridges. Fischer (1972; see also 1970, p. 93-114) made a thorough study of these rocks, which he informally named the Clear West complex and concluded that the mass might be a caldera filling, a single sill, or a complex of sills. McCulla (1986) considered the mass a caldera fill characterized mostly by a thick section of rhyolite ash-flow tuffs.

The rhyolite mass is somewhat eliptical and appears to have mostly steep contacts with the surrounding andesite of the Fifes Peak Formation. Although McCulla (1986, p. 66) emphasized pervasive eutaxitic textures throughout the mass, we found slightly devitrified microporphyritic rhyolite predominates. Within the unit, flow banding is mostly steep and variable, but generally vertical to subhorizontal short columnar joints suggest that the main mass of rhyolite is predominently a complex of dikes or small intrusions. Exposures near the top of the mass have pronounced vitroclastic textures suggesting ash-flow tuffs. McCulla (1986, p. 67) documents an exposure of welded tuff low in the pile on Milky Creek. We agree with McCulla that the mass may be a caldera filled with extrusive tuff and intrusive rhyolite.

Northwest of this main mass of rhyolite, a thick rhyolite tuff is identical to that exposed in the proposed caldera. Fischer (1970, p. 104-107) presented convincing petrographic and chemical data for this correlation. He (1970, p. 98-103) described evidence indicating that the rhyolite tuff erupted as an ignimbrite but was locally plastic enough to flow after welding, hence he called it a rheoignimbrite.

Stratigraphic relations and radiomentric ages indicate that the intracaldera filling and extracaldera flows of the rhyolite unit of Clear West Peak were contemporary with andesite flows of the Fifes Peak Formation. The extracaldera rhyolite tuff is interbedded with the Fifes Peak lavas north of the White River and a small remnant of andesite breccia overlies the tuff east of the Clearwater River. Two zircon fractions from the intracaldera rhyolite at the east base of Clear West Peak have yielded 21.8- and 22.6-Ma U-Th-Pb ages according to Mattinson (1977, p. 1512; table 1, no. 18), who favored the younger age. A whole-rock K-Ar age of about 19 Ma from the rhyolite reported by Hartman (1973, p. 30; table 1, no. 17) appears to be too young. In the Snoqualmie Pass quadrangle, the overall range of ages in the Fifes Peak is about 20-24 Ma (Frizzell and Vance, 1983), indicating contemporeneity with the rhyolite unit of Clear West Peak.

Fiske and others (1963, p. 64) and Mattinson (1977, p. 1512) thought that the rhyolite was related to the Carbon River stock, which Mattinson (1977) considered to be part of his Tatoosh volcanic-plutonic complex. This is a reasonable assumption on the basis of ages and proximity, but as yet, it is unsupported by detailed chemical or isotopic studies.

INTRUSIVE ROCKS

Numerous small stocks, plugs, dikes, and sills cut Oligocene or younger stratified rocks of the Snoqualmie Pass quadrangle. Of the many actual exposures, more remain unmapped than are represented here. These small intrusions are probably calc-alkaline and likely related to the volcanic rocks that they intrude and (or) the Snoqualmie and Tatoosh batholiths. Several areas in the Ohanapecosh Formation are so rich in fine-grained to glassy volcanic dikes that distinguishing dike from country rock is very difficult. Concentrated swarms of dikes are prominent along the east side of Huckleberry Ridge near the south boundary of the quadrangle and along the north side of the Green River above Chester Morris Lake.

Altered porphyry

An altered porphyry commonly containing hornblende, intrudes the Ohanapecosh Formation. Individual dikes are too small to map, whereas, mapped irregular bodies of altered porphyry may be mostly tightly spaced dikes. Hammond (1963, p. 187-189) described some of the altered porphyry dikes, but some rocks in his descriptions seem more appropriately included with our pyroxene andesite porphry or dacite porphyry. The hornblende-bearing altered porphyry intruded prior to emplacement of the Miocene Snoqualmie batholith and its satellites (Hammond, 1963, p. 187) and may be related to the Ohanapecosh and its age equivalents.

Pyroxene andesite porphyry, dacite porphyry, and tonalite

Units crop out in small bodies and dikes throughout the area. They are probably part of the same igneous episode expressed by the major rock units of the Snoqualmie batholith (and Carbon River stock) and the Fifes Peak Formation. The petrographic similarity between pyroxene andesite porphyry intrusions and fresh lavas of the Fifes Peak Formation is particularly striking. The dacite porphyry may have been derived from the same magma as the ash-flow tuffs of the Stevens Ridge Formation in Mount Rainier National Park or other silicic tuffs of the Fifes Peak Formation.

By an increase in phenocryst content some porphyry bodies grade into pyroxene diorite, gabbro, or tonalite. Many such small tonalite bodies are satellitic to the Snoqualmie batholith. On Meadow Mountain [17], porphyritic rocks grade into medium-grained tonalite (Smith and Calkins, 1906, p. 9), although Hammond (1963, p. 192) thought that the coarser grained rocks intruded the porphyry. A K-Ar analysis of hornblende (table 1, no. 13) indicates that the age of the the porphyry on Meadow Mountain is about 24 Ma; it may be the chilled margin of a high-level cupola of the Snoqualmie batholith.

Isolated plug-like bodies of porphyritic andesite grading to diabase and gabbro near Enumclaw are included here in the pyroxene andesite porphyry. Some apparent plugs could be remnant cores of thick flows of the Fifes Peak Formation though, and at least one (table 1, no. 22) yields 21- to 23-Ma whole-rock K-Ar determinations, well within the age range of the Fifes Peak Formation.

We also include in the pyroxene andesite porphyry a heterogeneous intrusive body on South Prairie Creek that appears to be a mixture of highly altered pyroxene andesite and uralitic pyroxene diorite and quartz diorite.

Not mapped separately for this report, but conspicuous in the eastern part of the outcrop area of the Fifes Peak Formation, are dikes and irregular intrusive bodies of black olivine basalt.

Rocks of the Snoqualmie batholith

The rocks of the Snoqualmie batholith were first briefly noted by Smith and Mendenhall (1900, p. 225-228). Subsequently Smith and Calkins (1906, p. 9-11) described the rocks in more detail and applied the name “Snoqualmie Granodiorite.” Although 80 percent of the batholith is medium-grained granodiorite, the composition ranges from gabbro to alaskite (Erikson, 1969, p. 2213). The batholith crops out over an area of about 580 km^2, mostly in the Skykomish River quadrangle to the north (fig. 2; Tabor and others, 1993). Erikson (1965, 1968, 1969) 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 have included some of Erikson’s early mafic phase exposed on the South Fork of the Snoqualmie River in the western mélange belt, and we were not able to map separately Erikson's pyroxene granodiorite and late granodiorite phases of the batholith.

Erikson (1969, p. 2221) reported both gradational and intrusive contacts of the granodiorite and granite (his informally named Preacher Mountain [4] quartz monzonite) with more mafic phases of the batholith. We found evidence of mutual intrusion: near Lake Caroline, angular inclusions of tonalite in the granite show little recrystalization, but in nearby talus blocks tonalite surrounds angular blocks of granodiorite.

The Snoqualmie batholith has been considered to be of Miocene age since it was first described, an assertion substantiated by K-Ar age determinations from outcrops near Snoqualmie Pass. A considerable number of new, but discordant, K-Ar ages—many from mineral separates provided by Erik Erikson—indicate that the northern part of the batholith, exposed mostly north of the Snoqualmie Pass quadrangle, is about 25 Ma (near the Oligocene-Miocene boundary; Tabor and others, 1993). The central mass of granodiorite to granite has a minimum age of about 20 Ma, and the southern part of mostly granodiorite to tonalite has an age about 17 to 20 Ma (table 1, nos. 7-11). Most of the determinations on biotite and some of them on hornblende may reflect argon loss caused by intrusion of the younger phases of the batholith. A probable reset fission-track age on zircon from a rhyolite tuff near the intrusion on the Cedar River is 18.6 Ma (table 1, no. 12).

A granodiorite stock on Three Queens (peak) [12] is a probable satellite of the batholith. Although hornblende K-Ar ages were difficult to reproduce, two, that roughly average 27 Ma (table 1, no. 13), indicate the stock may belong to the northern phase of the pluton.

South of the Snoqualmie batholith proper, a retinue of porphyry bodies may show a subsurface extension of the batholith that connects the Snoqualmie with the Carbon River stock (Tatoosh volcanic-plutonic complex of Mattinson, 1977) as suggested by Coombs (1936) and Fiske and others (1963, p. 40-41). The 24-Ma dacite-porphyry cupola (table 1, no. 13) on Meadow Mountain [17] suggests that the older phase of the Snoqualmie batholith is not far below the surface, even though the main exposures of the older phase lie far to the north. Mattinson (1977) rigorously analyzed U-Th-Pb isotopes in zircons from Tatoosh plutons and revealed intrusive episodes at 24-26, 17.5, and 14 Ma, which were apparently mirrored in the Snoqualmie batholith, although rocks as young as 14 Ma have not yet been found.

The Snoqualmie batholith produced thermal aureoles as wide as 0.8 km according to Erikson (1969, p. 2215); pyroxene-hornfels facies rocks crop out at the contacts. Erikson (1969, p. 2225) concluded that the Snoqualmie batholith was intruded at a depth of 2-5 km.

Sulphide mineralization is scattered throughout the Snoqualmie batholith; zones of shearing, brecciation, and veining are characterized by copper prophyry-type deposits and have been described by Grant (1969, p. 78-88), Gualitieri and others (1973, 1975), and Church and others (1983).

Carbon River stock

The calc-alkaline Carbon River stock crops out in the southwest corner of the quadrangle. The rock is mostly phaneritic biotite-hornblende granodiorite with relicts of uralitized clinopyroxene and hyphersthene. Fischer (1970, p. 124-182) thoroughly described the stock and concluded that it was intruded shallowly at 2-3 km and may have in part domed its roof. Mattinson (1977) included the stock in his Tatoosh volcanic-plutonic complex. McCulla (1986) developed this theme even further, suggesting that the Carbon River stock was a resurgent pulse of magma into the caldera setting of the Clear West complex of Fischer (1972; see also 1970) and that related shallow plutons beneath the White River area to the north were responsible for the silicic argillic alteration and mineralization in the overlying rhyolite flow of Clear West Peak and nearby andesite. McCulla's (p. 106) 20.4-Ma $^{40}Ar/^{39}Ar$ age (table 1, no. 20) on alunite in the altered zone supports his model.

The eastern and western sides of the stock appear to be sharply crosscutting. Fischer (1970, p. 129-137) felt that a sporadically exposed fine-grained, locally cataclastic and healed border zone was an early comagmatic sill-like intrusion. He (1970, p. 164-173) also concluded that much of the pervasive replacement of pyroxene by pale green amphibole and accompanying magnetite and biotite occured in late magmatic stages in the most hydrous parts of the stock. Roughly concordant K-Ar ages in hornblende (19 Ma) and biotite (17 Ma; table 1, no. 6) indicate its main phase is comparable in age to that of other plutons in the Tatoosh volcanic-plutonic complex.

COLUMBIA RIVER BASALT GROUP

Yakima Basalt Subgroup

The Columbia River Basalt Group underlies small parts of the southeast corner of the quadrangle, adjacent to the Little Naches River and extends far east and southeast of this map, forming the Columbia Plateau of eastern Washington and adjacent Oregon and Idaho. The Yakima Basalt Subgroup (Swanson and others, 1979) consists of three formations (in ascending stratigraphic order): Grand Ronde, Wanapum, and Saddle Mountain Basalts. Only the Grande Ronde Basalt crops out within the Snoqualmie Pass quadrangle where it consists of tholeiitic basalt flows that are nonporphyritic or contain sparse small plagioclase phenocrysts. K-Ar and paleontological evidence indicates that the Grande Ronde is of late early and middle Miocene age, about 17 to 14 Ma (Swanson and others, 1979,

p. G21; Reidel and others, 1987). The basalt was erupted from fissure vents east of the quadrangle (Swanson and others, 1979, p. G20-21), and outcrops in this quadrangle are probably very near the original westernmost margin of the lava flows where they lapped upon older rocks that formed the Cascade highland.

The Grande Ronde Basalt on the Columbia Plateau south and east of the map area (Swanson and others, 1979; Tabor and others, 1982b, p. 13-15) is divided into four magnetostratigraphic units on the basis of magnetic polarity; the two youngest units, the flows of reversed magnetic polarity (Tgr_2) and the upper flows of normal magnetic polarity (Tgn_2), are found in the Snoqualmie Pass quadrangle.

Ellensburg Formation

The Ellensburg Formation consists of weakly indurated sedimentary rocks that are extensively interbedded with flows of the Yakima Basalt Subgroup. The unit was mapped and named by Smith (1903) for widespread outcrops to the east of the Snoqualmie Pass quadrangle. An isolated elongate outcrop that caps the ridge at the head of Sand Creek, west of the the Yakima Basalt in the Little Naches River drainage was shown as the Ellensburg by Smith and Calkins (1906), Warren (1941), and described as such by Waters (1961) and Fiske and others (1963). Frizzell and others (1984) erroneously depicted the outcrop as consisting of both volcaniclastic sedimentary rocks of the Fifes Peak Formation and alpine glacial deposits. Gary A. Smith (written commun., 1986; 1988) pointed out that, although Fifes Peak lithologies dominate in the gravels, the distinctive porphyritic hornblende dacite characteristic of the Ellensburg is present and locally dominates in both debris flows and sandstone. Furthermore, cementation argues against a Quaternary age for the sandstone. Smith (1988) has suggested that the sedimentary rocks were deposited in an east-sloping paleochannel incised into flows of the Fifes Peak Formation.

Volcaniclastic rocks of Cooper Pass

Just north of Little Kachess Lake at Cooper Pass, a small body of tuffaceous sandstone and interbedded rhyodacitic volcanic conglomerate, breccia, and tuff unconformably overlies the Swauk Formation in the axis of a major syncline. The syncline terminates against the nearby Straight Creek Fault, where some of the tuff has been injected as clastic dikes into brecciated rocks of the fault zone. These interbedded sedimentary and volcanic rocks lithologically resemble the Silver Pass Volcanic Member of the Swauk Formation, but several discordant fission-track ages and a K-Ar age suggest that they are younger than the Silver Pass Member and probably overlie the Swauk unconformably. Ashelman (1979) mentioned these volcanic rocks and suggested that they were late Tertiary in age.

The apparent age of hornblende from an andesitic tuff is 12 Ma (table 1, no. 4), but zircon fission-track ages attest to two populations with ages of about 14 and 28 Ma (table 1, no. 4). Although we cannot explain the discrepant 9-Ma zircon fission-track age from a lithic rhyodacite tuff (table 1, no. 5), the data do suggest a middle and late Miocene eruptive age for these rocks. The zircons that yielded the 28-Ma ages are probably partly reset and reworked from the older volcanic rocks, perhaps from the Ohanapecosh-age equivalents that remain only as isolated, hornfelsic remnants capping nearby ridges.

Howson Andesite

Gray hornblende porphyry of the Howson Andesite crops out on and near Sasse Mountain [15] northeast of Cle Elum Lake and on North Peak [14] west of the lake. These rocks actually are dacitic in composition and were first described by Smith and Calkins (1906, p. 10), who speculated that they may have been the source for the hornblende andesite (now referred to as dacite) boulders in the Ellensburg Formation. Lofgren (1974, p. 51-52) first noted the North Peak exposure and correlated it with the Howson of Smith and Calkin (1906).

Outcrops of porphyry east of Cle Elum Lake exhibit crude columnar joints with variable orientations. Chaotic talus fields occur below the columnar ramparts, but one limited exposure of the basal contact with the underlying Swauk Formation reveals reddish-colored sandstone, indicating heating of the Swauk by the andesite. The porphyry on North Peak exhibits some flowlike textures; its limited outcrop area and shape indicate that it may be a shallow intrusion.

Hornblende from the porphyry has yielded a K-Ar age of about 6 Ma (late Miocene; table 1, no. 3); the rock seems too young to have been a source for the boulders in the Ellensburg Formation.

Basalt of Dalles Ridge

Olivine basalt occupies a position atop Dalles Ridge east of the White River. Hartman (1973, p. 36-39) recognized five flows ranging from 3 to 24 m thick and totalling about 91 m. Individual flows exhibit well-developed columnar joints and have scoriacous tops and bottoms. Hartman (1973, p. 37) and Hammond (1980, p. 18) considered the flows to be Quaternary in age, but two acid-treated splits of a whole-rock sample of the basalt both yielded K-Ar ages of 2.4 Ma (Pliocene; table 1, no. 2). Tabor and others (1984) have shown that acid treatment of young volcanic rocks increases the reliability of the K-Ar determinations by removing altered materials, which appear to have lost not only radiogenic argon, but K_2O as well.

QUATERNARY VOLCANIC ROCKS

Andesite of Mount Rainier

A thick intercanyon flow of andesite, here called the andesite of Mt. Rainier, on the south margin of the Snoqualmie Pass quadrangle west of Huckleberry Creek, marks the northernmost advance from Mt. Rainier of the early informally named Grand Park flow of Fiske and others (1963, p. 68), who described Mt. Rainier lavas in detail (p. 65-80). A flow that underlies Burroughs Mountain and Yakima Park crops out in a similar stratigraphic position immediately south of the quadrangle and has yielded 615- and 330-ka ages by the K-Ar method on plagioclase and whole-rock samples, respectively (Crandell and Miller, 1974, p. 17).

Basalt of Canyon Creek

Fischer (1970, p. 86-90) first described the olivine basalt that flowed into Canyon Creek from the southern summit knob of The Three Sisters ridge in the southwest part of the map. The associated cinder cone consists of consolidated and semiconsolidated tuff and breccia and owes its relative stature to dikes, which intrude it (Fischer, 1970, p. 87-88). At least one smaller pile of pyroclastic material exhibits crude outward radiating dips. On the basis of petrography, Fischer (1970, p. 87) distinguished four flows that attain a combined thickness of 120 m. Fischer assigned a "late Pleistocene or Recent" age to the cones because of their youthful morphology. Hammond (1980, p. 18) agreed and referred to it as less than 700,000 years old. Potassium-argon determinations on four splits of a single sample of the basalt (table 1, no. 1) support these age assignments. Two splits [(-60+100) and (-100+200) mesh] without acid treatment have yielded ages of 200 and 410 ka, respectively. Two similarly sized splits treated with hydrofluoric acid yield ages of 580 and 530 ka, respectively. The latter are probably closer to the age of extrusion.

QUATERNARY SURFICIAL DEPOSITS AND LANDFORMS

BY D.B. BOOTH AND R.B. WAITT

INTRODUCTION

Quaternary materials mapped in the Snoqualmie Pass quadrangle are products of four agents of geologic activity: (1) glaciations producing scores of late Pleistocene local cirque and valley glaciers and their outwash streams in the mountainous eastern two-thirds of the quadrangle, (2) glaciation by multiple advances of the late Pleistocene Puget lobe of the Cordilleran ice sheet and the ice-marginal drainage in the lowlands along and west of the front of the Cascade Range, (3) lahars and lava flows from Mt. Rainier volcano, and (4) stream erosion in valleys and mass wasting on slopes. Most of our surficial map units, although based to some degree on lithology, are either of inferred origin or are local time-stratigraphic units distinguished by their geographic relation to neighboring units and to topography. In alpine terrain for instance, lithologically similar landslide material (Ql), talus (Qt), and modern glacial deposits (Qag in part) are distinguished by their constructional surface topography. In the White River valley many laharic deposits, hyperconcentrated-flow deposits, alpine till, proximal alpine outwash, various alluvial deposits, and landslide deposits all are lithologically and texturally similar. They can be distinguished only by using multiple lithologic, topographic, and geomorphic criteria (for example, Crandell, 1971, p. 4-8; Eyles and others, 1983, p. 404). We correlated surficial deposits using lateral continuity, geographic position, relation to gradients of present streams and former glaciers and lakes, stratigraphic relation to each other and to regional tephra layers, and weathering and soil development. Many map-unit contacts were drawn by topographic relations revealed on aerial photographs. Although most mapping was done in the field, in alpine areas of the eastern part of the quadrangle, surficial deposits in many isolated valley heads and sparsely vegetated slopes were mapped only by characteristics observed on aerial photographs.

LANDSCAPE AND RELATION TO MAP UNITS

The overall landscape of the Snoqualmie Pass quadrangle is dominated by the Cascade Range and the east edge of the Puget Lowland. The Cascade Range rose in late Tertiary time; the area to the west has been a lowland even longer (Mullineaux, 1970, p. 9-26). Many of the larger valleys in the quadrangle trend generally northwest, parallel to most major bedrock structures. These valleys must have been cut in late Tertiary and early Pleistocene time by subsequent streams at the expense of neighboring drainages in resistant rocks. Most surficial deposits are fillings in low parts of this erosional topography.

TEPHRA

Quaternary tephra layers, though not thick or continuous enough to distinguish as separate map units, are indispensible for dating and correlating the mapped surficial deposits in parts of the quadrangle. Three ash layers are especially useful marker beds: layer O (6,850 yr B.P.) from Mount Mazama (Crater Lake), and layers Yn (3,400 yr B.P.) and Wn (450 yr B.P.) from Mt. St. Helens (Mullineaux, 1974; Porter, 1978; Bacon, 1983; Mehringer and others, 1984). In the area of the White River and its tributaries, tephra layers D (6,000 yr B.P.) and especially C (2,200 yr B.P.) from Mt. Rainier are useful as well (Crandell, 1971;

Mullineaux, 1974). In the South Fork of the Little Naches valley, Mt. St. Helens layer T (A.D. 1800) is found. The tephra layers are distinguished on field characteristics, such as grain size and color, and traced from petrographically verified occurrences both within the quadrangle and from the northeast or south.

PRE-FRASER GLACIAL AND NONGLACIAL DEPOSITS OF THE PUGET LOWLAND

The Puget Lowland contains a discontinuous stratigraphic record of several Pleistocene advances of the Cordilleran ice sheet alternating with nonglacial intervals (Armstrong and others, 1965; Easterbrook and others, 1967). In the Snoqualmie Pass quadrangle, fluviatile deposits and drift that predate the Fraser glaciation of the Cordilleran ice sheet (map unit Qpf) are identified in only two localities, in contrast to their greater abundance to the west (for example, Crandell, 1963). One occurrence of horizontally bedded sand and silt is exposed southeast of North Bend on the face of the embankment that blocks the South Fork of the Snoqualmie River valley (Booth, 1986). Wood in this deposit, in part converted to lignite, yielded a ^{14}C age of >50,000 yr B.P. (sample number UW-243; Porter, 1976). A more extensive exposure of pre-Fraser fluviatile, lacustrine, and glacial sediments is exposed along the Cedar River near the west boundary of the quadrangle. A pre-Fraser age is indicated by stratigraphic position and locally intense oxidation, but the deposits cannot otherwise be correlated with the pre-Fraser drifts of either Crandell (1963; see also Easterbrook and others, 1981) to the west or Booth (1990a) to the north.

DEPOSITS OF THE FRASER-AGE CORDILLERAN ICE SHEET

During the Vashon stade of the Fraser glaciation, between about 16,000 and 14,000 yr B.P., the west margin of the Snoqualmie Pass quadrangle was invaded by the Puget lobe of the Cordilleran ice sheet (Waitt and Thorson, 1983, figs. 3-1 and 3-2). Fluviatile sand (Qva) derived from ice advancing from the north was later locally eroded by the ice and covered by till (Qvt). During the maximum stand of the ice sheet, about 15,000 yr B.P., the east margin of the Puget lobe lay along the west front of the Cascade Range, where it sloped from an altitude of 800 m along the north boundary of the quadrangle to about 400 m near the southwest corner. Tongues of ice flowed eastward filling mountain valleys that had been vacated by alpine glaciers several thousand years earlier (Porter and others, 1983). In the Snoqualmie, Cedar, and White River valleys, ice-sheet tongues and associated meltwater deposited embankments of coarse fluviatile debris and till that grade up valley into sand, silt, and clay layers that were deposited in ice-impounded lakes (Booth, 1986). These ice-dammed lakes drained generally southward, adjacent to, but more commonly beneath, the eastern margin of the ice sheet. Anomalous valleys now occupied only by underfit streams, ponds, and swamps cut across present drainage lines and record the path of subglacial drainage. These channelways (Booth, 1990a) are well expressed southeast of Ravensdale and northeast of Enumclaw; they are part of an anastomosing valley system crossing successive divides along the Cascade front from the Snoqualmie River valley southward to the White River valley. Such valleys, formerly classed exclusively as 'ice-marginal' channels (Mackin, 1941), probably conveyed subglacial water, an inference supported by quantitative simulation of ice-water relations (Booth, 1984, 1986). These valleys, like their northern equivalents in the Skykomish River and Granite Falls areas (Booth, 1989, 1990a,b), are floored by bedrock, till (Qvt), and sediments deposited during glacial retreat (Qvi, Qvr).

After the maximum stand of the Puget lobe, the ice receded northwestward from the Snoqualmie Pass quadrangle. The till (Qvt) was dissected by streams or was partly covered by ice-marginal debris (Qvi) and by outwash and associated lacustrine deposits (Qvr). Ice-dammed lakes along the west margin of the quadrangle enlarged and coalesced with each other and with lakes in the Puget Lowland (Crandell, 1963; Thorson, 1980; Booth, 1990a).

Advance outwash

West of the Cascade front, bedded materials beneath till of the last glacial advance record aqueous environments that lay in front of the south-advancing ice sheet terminus. Sand of the outwash deposits (Qva) is exposed at two localities, where it is identified stratigraphically by an overlying layer of till (Qvt). At one locality, southeast of North Bend, the sand layers have been tipped and sheared by the subsequently overriding ice in dramatic exposure along the South Fork of the Snoqualmie River. Although not necessarily strictly contemporaneous or laterally continuous, this unit correlates with the Esperance Sand Member of the Vashon Drift as defined by Mullineaux and others (1965). No exposures of the slightly older, unoxidized gray clay to silty clay, typically correlated with the Lawton Clay Member of the Vashon Drift as defined by Mullineaux and others (1965), were found in this quadrangle, in spite of their common occurrence elsewhere across the southern Puget Lowland.

Till

Rolling slopes along and west of the Cascade front are underlain by till of the last glaciation (Qvt), a compact, matrix-supported diamicton commonly containing about 20 percent clasts, some of them faceted and striated. Most clasts are dark, fine-grained volcanic and dike rocks locally derived from Tertiary volcanic-rock bodies; several percent of granitic, gneissic, amphibolite, and other exotic types are also commonly present. Exposed thickness of the till is generally less than a few meters, but it ranges from almost zero to over ten meters. Commonly, the upper meter is looser and more oxidized than the compact till below, probably a result of Holocene weathering. Weathered rinds on volcanic rocks are thinner than 1 mm and few granitic clasts are rotted to grus. Oxidation extends 1 m or less into the deposit, and the B-horizon of this soil is scarcely enriched in clay.

Recessional outwash and associated lake deposits

The lower ends of three mountain valleys—the Middle and South Forks of the Snoqualmie River—and the Cedar River—and all of Taylor Creek (preglacial course of the Green River) are obstructed by embankments of till and waterlaid gravel and sand, mapped as recessional outwash (Qvr). Lithologically similar latest-glacial material underlies laharic deposits in the White River valley but does not form a notable embankment. The exotic lithology of some clasts and gently upvalley dip of uncommon foreset beds indicate that these sediments originated from ice and currents flowing up valley from the west. The embankments contain various facies ranging from current-winnowed stratified clast-supported gravel and sand to laminated mud to massive matrix-supported diamictons with boulders larger than 1 m. The diamictons seem to be diverse flowtill, waterlaid till, and proximal outwash of the Puget lobe. Mackin (1941) interpreted the embankments blocking the Snoqualmie and Cedar River valleys as exclusively products of grounded ice and subaerial drainage. Alternatively, they formed in ice-marginal lakes by subglacial and subaqueous sedimentation (Eyles and Eyles, 1983) and only later were covered by a layer of recessional outwash (Booth, 1986). Exposures in the valleys of this quadrangle are insufficient to prove either hypothesis, although farther north, a complex subaqueous history appears most likely for these features.

Intercalated with and up valley of the range-front drift embankments, beds of stratified mud show that the Puget lobe and its deposits dammed sizable lakes in valleys of the Cascade Range. Proglacial coarse sand and gravel merges up valley with plane-bedded, laminated lacustrine silty clay to fine sand containing rare dropclasts. In the South Fork of the Snoqualmie River valley, these deposits are as thick as 15 m and extensively underlie parts of the valley floor, forming a high terrace graded to the top of the drift embankment. In the Middle Fork of the Snoqualmie River valley, some lacustrine beds show a succession of as many as 20 regular, graded sand-to-mud beds, 10 to 20 cm thick and up valley-directed paleocurrent indicators. These beds are strikingly similar to deposits of periodic, colossal Pleistocene jökulhlaups in eastern Washington (Waitt, 1980). The rhythmic beds in the Middle Fork valley, thus, may record periodic subglacial drainage from ice-dammed lakes farther north along the Puget lobe that are discussed by Booth (1986).

Along and west of the Cascade front, bedrock and lodgment till are discontinuously mantled by gravel, sand, and mud deposited by meltwater and in lakes during glacier retreat. This deposit (Qvr) ranges from a veneer centimeters thick to numerous deltas thicker than 15 m. Extensive gravel deposits (Qvi) locally containing boulders as large as 1.5 m are pocked by kettles as deep as 25 m or are internally deformed owing to collapse over buried ice. Foreset beds in gravel and sand generally dip to the southeast, south, or southwest: currents were regulated by the north trends of valleys and by the generally east trend of retreating ice margins. Lenses of lacustrine clay and silt are interspersed with alluvial gravel and sand.

DEPOSITS RELATED TO ALPINE GLACIERS

Pre-Fraser drift

In the southern part of the Snoqualmie Pass quadrangle, alpine drift (Qpfa) in scattered outcrops predates the Flaser glaciation. In the lower White River valley and tributaries, a compact brown till contains volcanic clasts with oxidation rinds 1-3 mm thick and is capped by a brown soil with a weak argillic B horizon. These characteristics indicate a pre-Fraser age (Crandell and Miller, 1974; Porter, 1975, 1976; Colman and Pierce, 1981). Similar till, in places thicker than 5 m and with weathering rinds of 1-5 mm (average 2 mm) on andesite clasts, covers large areas along the Little Naches River valley and tributaries, in places above a sharp upper limit of scarcely weathered Fraser-age till. Along the lower East Fork of South Prairie Creek, a distinct left-lateral moraine of weathered drift lies just outside the outermost Fraser-age moraine of minimally weathered drift. Along the lower West Fork valley of the White River, an alluvial fill (mapped as part of unit Qu), probably outwash, with hard but weathered clasts and a strongly oxidized matrix, is overlain by gray unoxidized outwash of Fraser age. All these deposits are evidence of a pre-Fraser alpine glaciation more extensive than the Fraser itself (Crandell and Miller, 1974). The general degree of weathering, weathering-rind development, soil development, and presence of moraines make this drift similar to the Kittitas Drift exposed about 6 km east of the quadrangle (Porter, 1976; Waitt, 1979; Tabor and others, 1982b), the alpine drift of Mt. Stickney about 45 km north of the quadrangle (Booth, 1990a), and the nearby Hayden Creek and Wingate Hill Drifts as defined by Crandell and Miller (1974). Colman and Pierce (1981, appendix A, fig. 21, and p. 33-34). All these units produced similar rind-thickness data and convincingly argue that the Hayden Creek Drift correlates with isotope stage 6 (135,000-145,000 yr B.P.), consistent with the proposed age of the Kittitas Drift (Porter, 1976; Waitt, 1979).

Upland areas just east of the Cascade front on both sides of the White River valley are extensively covered by yellowish to reddish till whose clasts are more weathered and have thicker rinds and whose matrix is more clayey than the drift of inferred stage-6 age. In the large patch mapped north of the White River, clasts as well as matrix are highly weathered to soft clay. The extreme weathering suggests at least one and perhaps two glaciations several hundred thousand years old (see Colman and Pierce, 1981, fig. 21).

These weathered deposits indicate that during several glaciations predating the Fraser glaciation, glaciers flowed northeast and northwest from the Mt. Rainier area far more extensively than did the Fraser glaciers. Either the climate was colder or the Cascade Range near Mount Rainier was higher during earlier Pleistocene glaciations than during the Fraser.

Fraser-age drift

During the Fraser glaciation, most mountain valleys in the Snoqualmie Pass quadrangle contained valley glaciers governed by a west-sloping regional snowline some 900 m below the present-day snowline (Porter, 1977; Porter and others, 1983). Many up-valley reaches in the northeastern part of the quadrangle are U-shaped troughs with truncated spurs and hanging tributary valleys heading in cirques along the divides. Within the valleys, erosional evidence such as striae, whalebacks, and stoss-and-lee topography are consistent with down-valley ice flow. Because of irregular depth of glacial scour, irregular distribution of drift, and postglacial superposition of streams through drift, streams in most glacial valleys flow alternately across drift and through rock gorges.

Most of the U-shaped valley segments are partly floored by scarcely weathered, nonsorted, matrix-supported cobbly diamicton that in many places extends hundreds of meters up the valley walls. Clearly this deposit is till. It is as thick as 5 m and has clasts as large as 2 m, but generally much smaller; many of the clasts are faceted and striated. In some places, such as Tacoma Pass, Cedar Notch [18], and Olallie Meadows [Not named on map; 8], till extends through passes, indicating that ice-cap glaciers flowed across the Cascade Crest. The angular to rounded drift clasts are locally derived and, thus, vary in composition from valley to valley reflecting lithology of the local bedrock. Volcanic clasts in the till have oxidation-weathering rinds thinner than 1 mm, generally 0.5 mm or less, and soils are nonargillic and thinner than 0.7 m. The till (mapped as part of unit Qag) is discontinuously mantled by postglacial colluvium, alluvial fans, and river alluvium.

The floors of most mountain valleys also contain noncompact, clast-supported gravel and sand forming narrow trains or terraces, some of them graded to moraines. This material, also included as part of alpine glacial deposits (Qag), was deposited as outwash during recession of the valley glaciers. Postglacial alluvial fans and debris-flow deposits extensively mantle the valley-floor drift. Soils and weathering rinds on these deposits are meagerly developed, as are those on till.

The most extensive alpine-glacier system occupied the upper Yakima River drainage basin east of the Cascade Crest, which was thoroughly discussed by Porter (1976). The Snoqualmie Pass quadrangle includes only deposits of the last glacial advance; the quadrangle adjacent on the east (Tabor and others, 1982b) shows more extensive deposits of the Kittitas Drift and other deposits predating those of the Fraser glaciation. The Yakima valley glacier was fed by three principal tributaries from the valleys that contain Cle Elum, Kachess, and Keechelus Lakes. The latest glacial terminal moraine lies near the east edge of the map; up valley lie three sets of recessional moraines, one set impounding the lakes. The moraines are of water-laid gravel and bouldery till as thick as 12 m; material of the moraines overlies and grades into thick deposits of outwash gravel and contorted lacustrine mud, which indicates that the moraines were built by glacial readvances rather than by recessional stillstands. A morainal body near Hyak has a hummocky stagnant-ice topography rather than looped moraines. Numerous small deposits of water-laid sediments—outwash, deltaic material, glaciolacustrine deposits—overlie till well above present-day valley floors, apparently deposited by the receding ice or carried by meltwater into ice-ponded lakes. Outwash forms extensive terraces, veneered by loess.

The inferred age of most recent glacial alpine drift is limited by relations to ice-sheet deposits in only a few areas. In the South Fork of the Snoqualmie River valley, for example, silt and clay that accumulated in the near-maximal glacial Lake Snoqualmie (15,000 yr B.P.) buries valley-floor deposits of alpine glaciers that are inferred to have extended to or beyond the mountain front (Porter, 1976).

Conspicuous moraines that lie high in many glaciated valleys and cirques probably are contemporaneous with the late-glacial moraines of the Rat Creek advance (equivalent to Hyak Member of the Lakedale Drift of Porter, 1976) of the Fraser glaciation (Porter, 1976, 1978; Waitt and others, 1982). Peaty deposits on and up valley of these moraines between Hyak and Snoqualmie Pass in the Yakima River valley contain ashes derived from Mt. Mazama (6,850 yr B.P.) and Mt. St. Helens (layer Yn 3,400 yr B.P.), but not Glacier Peak (11,250 yr B.P.). Porter (1976) inferred that these moraines and similar ones at Stevens Pass, 27 km north of the Snoqualmie Pass quadrangle, are about 11,000 yr old. But cirque floors and some Rat Creek moraines in the Stevens Pass area are capped by the Glacier Peak tephra (11,250 yr B.P.; Tabor and others, 1993). Therefore, Rat Creek drift predates the Glacier Peak tephra and probably is at least 11,250 yr old.

Holocene talus and glacial deposits

Talus (Qt) throughout the quadrangle consists of angular fragments at the bases of rocky cliffs. Talus fans form by spring snow avalanches, rockslides, and downslope movement of individual blocks. Moraines of coarse angular rock debris are deposits of vanished glaciers in niches and cirques of the highest parts of the quadrangle and mark the advanced positions of glacier termini. These moraines commonly merge with similar debris that forms talus aprons or protalus ramparts (Qt). This talus is unvegetated, coarse, rock waste that was largely derived by mass wastage and only locally redistributed into moraines. Some high-altitude talus and moraines merge downslope into coarse fans of debris (Qa) that are scantily to moderately vegetated with grass and shrubs. Talus, glacial, and mountain-stream deposits typically grade into one another. Although, all these units are mapped by the dominant deposit, they are commonly polygenetic.

The 6,850-yr-B.P. Mazama ash bed (hereinafter also informally called the Mazama ash for simplicity) overlies the outermost high-altitude moraines and protalus ramparts. The controlling snowline for such moraines is only 100 m or less below present-day snowlines—a glacial advance that weathering data and radiocarbon ages to the northeast (Waitt and others, 1982; Beget, 1984) suggest occurred in the early Holocene or possibly in the very late part of the Fraser glaciation. Nested inside the Mazama-capped moraines at the higher altitudes are moraines not capped by the Mazama ash. Some of the post-Mazama moraines, protalus ramparts, and talus deposits are overlain by either or both the Mt. St. Helens Yn ash (3,400 yr B.P.) or Wn ash (450 yr B.P.); others lack the Wn ash and some even lack lichens. These deposits must record several episodes of expansion and contraction of alpine glaciers during the late Holocene, most recently within the last century or so.

MASS-WASTAGE AND ALLUVIAL DEPOSITS

Landslide deposits

We have mapped dozens of individual landslides and a few mass wastage deposits (Qmw) in the Snoqualmie Pass quadrangle. Some we identified from textural and lithologic characters of the deposits, but most of them we recognized by their characteristic hummocky topography with bulbous margins downslope from a steep-walled arcuate source-area scar. Generally, deposits are nonsorted, nonstratified diamicton containing angular pebbles to boulders of only one or a few local rock types, commonly set in a gravelly mud matrix. Landslides have occurred in various rock types, but, as in the adjacent Wenatchee quadrangle (Tabor and others, 1982b), the largest and greatest concentration are on steep slopes where resistant volcanic rocks of the Grande Ronde Basalt or lava flows in the Fifes Peak Formation overlie weaker beds, such as tuff in the Fifes Peak Formation.

In several narrow valleys, mud or other sediments deposited in ponds or lakes lie immediately upstream of small landslides. Bouldery deposits immediately downstream from some of these slides suggest that the ponded water may have been released catastrophically.

Some blockslides underlie alpine drift that predates the Fraser glaciation in the lower Little Naches River valley and, therefore, must be older than 20,000 yr B.P. Landslides that have descended into deglaciated mountain valleys, in places ponding lakes or swamps, must be younger than about 15,000 yr B.P.; some such slides are overlain by the Yn tephra (3,400 yr B.P.) and some by the Mazama ash (6,900 yr B.P.) and, therefore, are pre-mid Holocene. A slide deposit on the floor of the West Fork of the White River valley just below Pinochle Creek [Pinole Creek on map] is free of the W and older tephras that are conspicuous nearby, and the deposit supports only an immature first-growth forest. This deposit is probably younger than 100 yr.

Lahar deposits

Lahar deposits are spread along the floor and terraces of the White River valley and extend across a broad area west of the Cascade Range front. These deposits range widely from nonsorted clay-rich matrix-supported diamicts (bouldery mud to muddy boulder gravel), to clast-supported sandy gravel, to massive sand. All deposits contain clasts of porphyritic andesite derived from Mount Rainier volcano just south of the map boundary mixed with abundant locally derived clasts. Most of the deposits are postglacial in age, but one lahar deposit in the West Fork of the White River valley seems to underlie till and to predate the Fraser glaciation.

The extensive Greenwater lahar (Crandell, 1971) is a mud-poor sandy gravel that is rich in rounded gravel clasts but in many places also contains numerous unusual conical hummocks 2 to 12 m high that consist partly of brecciated Mt. Rainier andesite. Such hummocks previously were noted at various other volcanoes in the world, but remained poorly understood before the May 18, 1980, eruption of Mt. St. Helens. These features are evidence that the Greenwater lahar began as a huge debris avalanche on the slopes of Mt. Rainier (Siebert, 1984). The Greenwater lahar mantles terraces in broad reaches of the White River valley at and up valley of Greenwater. The lahar spilled through a saddle into the lower part of this valley and overtopped nearby rock knolls, which indicates that the lahar moved as a plug at least 100 m thick. In the upper White River valley, the lahar overlies the Mazama ash (Crandell, 1971), and the 4,900-yr-B.P. Osceola Mudflow is nested below its surface. The Greenwater lahar ^{14}C age is, therefore, between 5,000 and 6,900 yr old. Hummocks similar to those near Greenwater lie above the general level of the Osceola Mudflow on both sides of the White River valley and up valley of Mud Mountain [19]. A 2-m-thick granular coarse sand lahar immediately beneath the Osceola Mudflow in lower Scatter Creek [Not named on map; fig. 4] valley is stratigraphic evidence that a pre-Osceola lahar reached the margin of the Puget Lowland. The sandy texture of this laharic deposit, however, contrasts with the gravelly texture of the Greenwater lahar near Greenwater. The sub-Osceola deposit at Scatter Creek, therefore, may represent either a previously unrecognized lahar or it may be a relatively low-energy distal facies of the Greenwater lahar. Alternatively, the hummocks along the lower White River valley were part of the Osceola Mudflow (discussed below) that lapped over terraces that lay above the general upper surface of the Osceola.

The most extensive lahar deposit in the Snoqualmie Pass quadrangle is the Osceola Mudflow (Crandell and Waldron, 1956), which left deposits along both the White River and its West Fork. After exiting the lower White River canyon, this lahar spread broadly westward across part of the Puget Lowland to Puget Sound, some 40 km away (Crandell, 1963; Mullineaux, 1970). The Osceola Mudflow carried abundant angular to subangular boulders as large as 1.5 m in diameter. The clayey matrix of the deposit resulted from its content of hydrothermally altered andesite from Mt. Rainier (Crandell, 1969, p. 26-29). Consequently, a broad area near Enumclaw underlain by the Osceola Mudflow is poorly drained and boggy. The deposit mantles various low-relief older features such as outwash terraces; it is only 1 m or less thick on higher areas such as Mud Mountain [19] but is many meters thick where it filled valleys in the lowland west of the mountain front. Tree logs incorporated by the Osceola give ^{14}C ages of about 4,900 yr B.P. (Crandell, 1971). Crandell (1963, p. 67-68; 1971, p. 25-26) argues convincingly that near the west boundary of the map area, the Osceola Mudflow diverted the White River from a formerly southwestwardly course to the Carbon River into its present northwestward course. The debris-avalanche hummocks along the lower White River valley (noted above) may have been transported by the Osceola lahar that lapped up over surfaces 5 to 10 m above the general level of the Osceola surface.

Several smaller mud-poor post-Osceola lahars descended the White River and West Fork valleys. The lahars range in age from 5,000 yr B.P. to post-450 yr B.P., on the basis of their stratigraphic relations with the Yn and W ash layers derived from Mt. St. Helens and with C ash, derived from Mt. Rainier (Crandell, 1971; Mullineaux, 1974). Two of the post-Osceola Mudflows extended down the White River valley at least as far as 7 km below Greenwater.

Alluvium and colluvium

Alluvial deposits (Qa) range from angular boulder gravel, moved by high-gradient headwater creeks and mountain rivers, to overbank mud deposits laid down by rivers in the lowlands. Fan alluvium generally is poorly sorted boulder to pebble gravel with angular to subangular clasts; boulders may be as large as 1 m. In alpine troughs, some of the material was deposited by spring-snow avalanche. Fan alluvium grades upslope into talus (Qt). Fans at the mouths of small tributaries are at least partly Holocene in age, as shown in places where these materials overlie glacial-related deposits or where the Mazama ash or Yn ash layer is intercalated. Side-stream fans are the dominant surface deposit in many alpine valleys; in places the rate of fan deposition dominates erosion by the main stream, impounding lakes such as Cooper Lake and Waptus Lake in the upper Cle Elum River tributaries. Alluvium along present or abandoned river channels is boulder to pebble gravel; the overbank facies on broad valley floors of the Snoqualmie and White Rivers is sand and silty mud.

Colluvium is common on slopes throughout the quadrangle but is generally too patchy and thin to be shown at 1:100,000 scale. Colluvium is in places 2 m and more thick, however, and it grades into fan alluvium (included as part of unit Qa) and talus (Qt); the larger patches are shown on the map. A few patches of mass-wastage deposits of undetermined origin (Qmw) may also be partly composed of colluvium.

DESCRIPTION OF MAP UNITS

[Number in brackets refers to obscure place name on fig. 4]

MASS WASTAGE AND ALLUVIAL DEPOSITS

m **Man-Modified land (Holocene)**—Gravel or diamicton as fill, or extensively graded natural deposits that obscure underlying units

Qa **Alluvium (Holocene and Pleistocene)**—Moderately sorted cobble gravel along rivers to poorly sorted gravelly sand on small-tributary fans; some fan material is lithologically similar to that included in talus (unit Qt). Includes postglacial terrace gravels that are perched above present-day flood-plain surfaces

Qb **Bog deposits (Holocene and Pleistocene)**—Peat and alluvium. Poorly drained and at least intermittently wet. Grades into alluvium and lahar deposits (units Qa and Qlh)

Ql **Landslide deposits (Holocene and Pleistocene)**—Diamicton of angular clasts of bedrock and surficial deposits derived from upslope. Mostly shown with arrow(s) depicting downslope movement direction

Qmw **Mass-wastage deposits (Holocene and Pleistocene)**—Colluvium, soil, or landslide debris with indistinct morphology, mapped where sufficiently continuous and thick to obscure underlying material. Unit is gradational with landslide deposits (Ql) and alluvium (Qa)

Qt **Talus deposits (Holocene and Pleistocene)**—Nonsorted angular boulder gravel to boulder diamicton. Found low on hillslopes, gradational with alluvium (Qa). At higher altitudes, includes small rock-avalanche deposits as well as some Holocene moraine, rock glacier, and protalus rampart deposits that lack characteristic morphology. Generally unvegetated

Qlh **Lahar deposits (Holocene and Pleistocene)**—Nonsorted muddy boulder diamicton to moderately sorted sand in the White River valley and adjacent lowlands. Includes deposits of numerous Holocene catastrophic mudflows from Mt. Rainier volcano south of the Snoqualmie Pass quadrangle. Most extensively exposed is the Holocene Osceola Mudflow (Crandell and Waldron, 1956). Also includes hyperconcentrated streamflow deposits (Smith, 1986) originating from volcanic source terrane and inferred to result from volcanic activity

GLACIAL DRIFT AND RELATED DEPOSITS

Qu **Surficial deposits, undivided (Holocene and Pleistocene)**

Qag **Alpine glacial deposits (Pleistocene)**—Glacial deposits ranging from boulder till in uplands and up valley to gravel or sand outwash on broad valley floors. On valley sides and uplands includes areas veneered with drift but also includes bedrock, alluvial fans, colluvium, or talus deposits. On valley floors also includes small fans, bogs, and modern stream alluvium. Areas of thin, sparse drift not distinguished from bedrock.

Deposits of Vashon stade of Fraser glaciation of Armstrong and others (1965) of Cordilleran ice sheet (Pleistocene)—Divided into:

Qvr **Recessional outwash deposits**—Stratified sand and gravel, moderately to well sorted, and well-bedded silty sand to silty clay deposited in proglacial and ice-marginal environments. Subscripts (1-7) indicate chronologic sequence of major fluvial deposits, with 1 being the oldest

Qvi **Ice-contact deposits**—Stratified water-laid sand and gravel, silt, clay, and minor till with abrupt grain-size changes and collapse features indicating deposition adjacent to active or stagnant ice. Subscripts (1-5) follow the same chronology as for recessional outwash deposits (Qvr) and indicate probable ice-marginal zones during deposition of corresponding recessional outwash deposit

Qvt **Till**—Mainly compact diamicton with subangular to rounded clasts, glacially transported and deposited. Includes minor stratified fluvial deposits. In ice-marginal areas and where covered by thin layer of recessional outwash, contact with recessional-outwash or ice-contact deposits (Qvr or Qvi) is gradational

Qva **Advance outwash deposits**—Well-bedded gravelly sand to fine-grained sand, generally unoxidized, deposited in proglacial streams. Includes minor stratified sediments that predate the Fraser glaciation

Qvu **Vashon Drift, undivided**

Qpf **Glacial and nonglacial deposits of pre-Fraser glaciation age (Pleistocene)**—Firm gray clay and deeply weathered stratified sand and gravel. Evidence of strong in-place weathering throughout exposures, includes oxidation, weathering rinds, and clay-mineral replacement

Qpfa **Alpine glacial drift of pre-Fraser glaciation age (Pleistocene)**—Deeply weathered till with oxidized matrix and weathering rinds on clasts

BEDROCK

Qra **Andesite of Mt. Rainier (Pleistocene)**—Gray, porphyritic two-pyroxene andesite rich in phenocrysts of zoned plagioclase, augite, hypersthene, and opacitised hornblende. Pilotaxitic groundmass with plagioclase, pyroxene, and opaque minerals

Qcc **Basalt of Canyon Creek (Pleistocene)**—Light-gray olivine basalt. Olivine, partially altered to iddingsite rims, present as phenocrysts in intergranular groundmass of plagioclase microlites and clinopyroxene, opaque minerals, and olivine. In part vesicular. Described by Fischer (1970, p. 86-92). Locally, includes:

Qcct **Basaltic tuff and breccia**—Unconsolidated to partially consolidated and crudely bedded basaltic tuff and breccia

Tbd **Basalt of Dalles Ridge (Pliocene)**—Light gray, pilotaxitic basalt flows with phenocrysts of olivine, partially to completely altered to iddingsite, in groundmass composed of plagioclase, clinopyroxene, olivine, and opaque minerals. Described by Hartman (1973, p. 36-37)

Th **Howson Andesite (Miocene)**—Gray hornblende porphyry containing plagioclase and either oxyhornblende or common hornblende phenocrysts, in part with hypersthene microphenocrysts, in groundmass of plagioclase, potassium feldspar, quartz, and opaque minerals. Locally includes volcanic rock fragments

Tcp **Volcaniclastic rocks of Cooper Pass (Miocene)**—Tuffaceous sandstone and volcanic conglomerate. Light-green to dark-gray dacitic tuffaceous sandstone that grades into gray volcanic clast-rich conglomerate and breccia; hornblende-bearing dacite tuff with partially altered plagioclase and quartz. Well-bedded tuffaceous sandstone contains altered plagioclase, quartz (in part rounded and embayed), opaque mineral grains, and volcanic, sedimentary, metamorphic, and granitic lithic clasts in matrix altered to clay minerals. Sandy volcanic conglomerate and breccia contains volcanic, sandstone, siltstone, phyllite, schist, chert, and granitic clasts. Age is middle and late Miocene

Columbia River Basalt Group—In this area, consists of Yakima Basalt Subgroup, divided into:

Grande Ronde Basalt (Miocene)—Flows of fine-grained, aphyric to slightly plagioclase-phyric basalt (units Tgn_2 and Tgr_2 of Swanson and others,1979). Commonly columnar or hackly jointed. Interbeds of tuffaceous fine-grained sandstone, siltstone, and mudstone abundant. Flows generally have dense interiors and vesicular upper zones. Invasive flows—lava flows that invade sedimentary deposits, generally as sill-like bodies—are common and have dense upper zones. Pillows present locally, such as 500 m southeast of old Jungle Creek Campground [Not named on map; 25] on the Little Naches River (D.A. Swanson, written commun., 1983). Divided into:

Tgn_2 **Flows of normal magnetic polarity**

Tgr_2 **Flows of reverse magnetic polarity**

Te **Ellensburg Formation (Miocene)**—Volcanic breccia, tuff, debris flows, and sandstone. Clasts mostly derived from Fifes Peak Formation, but hornblende dacite clasts and pumice are also present and locally dominate (G.A. Smith, written commun., 1986). Sandstone is partially well cemented

Rocks of Snoqualmie batholith—Divided into:

Tsgs **Tonalite and granodiorite, southern phase (Miocene)**—Hornblende-biotite granodiorite and tonalite, medium grained, mostly equigranular with hypidiomorphic texture, locally with clinopyroxene. CI (Color Index) = 9-24. As indicated by normative minerals from chemical analyses (Erikson, 1969, appendix 2), southern phase of pluton is overall slightly more K-feldspar rich than northern phase (Tstn) described below. Southern phase is mostly light colored and coarsely jointed. Hammond (1963, p. 198-199) described a tonalite (his quartz diorite) border zone

Tsgf **Fine-grained monzonite (Miocene)**—Highly altered, light-colored, fine-grained monzonite containing cloudy plagioclase and chloritized hornblende in discontinuous mesostasis of quartz

Tsgg **Granodiorite and granite (Miocene)**—Medium-grained hypidiomorphic granular to porphyritic granophyric granodiorite and granite (Erikson, 1969, p. 2221). Mostly with biotite. CI of 1-5, rarely to 10. Normative composition is mostly granodiorite (Erikson, 1969, appendix 2), but with considerably more quartz than northern and southern phases. Includes most of Erikson's informally named Preacher Mountain quartz monzonite

Tstn **Tonalite and granodiorite, northern phase (Miocene and Oligocene)**—Biotite-hornblende granodiorite and tonalite, medium grained, mostly equigranular, with hypidiomorphic texture; locally with clinopyroxene. CI = 9-24. Mostly light-colored, coarsely jointed rock. Description adapted from Erikson (1969, p. 2218-2219). On Three Queens (peak) [12], rock is characterized by graphic intergrowth of K-feldspar and quartz. Considerable sulphide is associated with tonalite in Mineral Creek

Tsm **Mafic diorite and gabbro (Miocene and Oligocene)**—Biotite-hornblende diorite and gabbro, including mafic pyroxene-bearing tonalite and quartz diorite. CI = 20-40 (Erikson, 1969, p. 2217). On Pratt River, mafic quartz diorite is associated with considerable amounts of thermally metamorphosed porphyritic andesite and andesite breccia

Tcr **Carbon River stock (Miocene)**—Hypidiomorphic-granular biotite pyroxene granodiorite in main body and subordinate sills. Locally, main body has microtonalite border phase. Main phase approximately 40 to 50 percent euhedral to subhedral phenocrystic plagioclase with twinning and oscillatory zoning, 20 percent slightly elongate interstitial orthoclase, 20 to 25 percent equant interstitial quartz, 5 percent biotite that is generally present as small grains in the groundmass, and 5 to 10 percent euhedral pyroxene or uralite. Description adapted from Fischer (1970, p. 137-150). Pyroxene crystals are mostly uralitized; scarce primary hornblende is interstitial

Intrusive rocks (Miocene and Oligocene)—Divided into:

Tip **Pyroxene andesite porphyry**—Gray to green hypersthene and (or) clinopyroxene andesite with hyalocrystalline to intergranular groundmass. Generally partially altered with glass replaced by smectite. Fresh rocks of unit, mostly in area underlain by Fifes Peak Formation, are black with unaltered brown glass. Vine (1969, p. 32-34) described parts of unit as slightly altered, mostly clinopyroxene-bearing porphyritic rocks intrusive into Puget Group

Tit **Tonalite**—Uralitic pyroxene tonalite, mostly with hypersthene and clinopyroxene grading to rare granodiorite or quartz diorite. Most bodies are plagioclase-pyroxene phyric and have fine-grained hypidiomorphic granular texture; quartz is interstitial and commonly mesostasic. Some bodies are texturally transitional to pyroxene andesite porphyry (Tip). Intrusion north of Blowout Mountain [22] ranges to quartz gabbro (Stout, 1964, p. 331). Small intrusions on Dalles Ridge, Amabilis Mountain, and west of Tacoma Pass are quartz-bearing olivine-pyroxene gabbro. Many small tonalite masses may be satellitic to Snoqualmie or Tatoosh batholiths. Small masses in Cedar River area are rich in sulphides, mostly pyrite (Hammond, 1963, p. 200). Tonalite bodies may also grade into dacite porphyry (Tidp). Some areas mapped as tonalite may be made up of closely spaced dikes

Tiap **Altered porphyry**—Highly altered brown to green hornblende and pyroxene plagioclase phyric andesite with holocrystalline to intersertal groundmass, locally trachytoid. Includes some dacite with groundmass quartz. Commonly altered to smectite and zeolite

Tidp **Dacite porphyry**—Gray hornblende and (or) pyroxene dacite and rhyodacite porphyry with fine-grained to microgranular holocrystalline or devitrified groundmass. Contains clinopyroxene and hypersthene where fresh. Generally, mafic minerals and groundmass are partially altered to smectites and calcite. Includes some highly altered quartz-bearing volcanic rocks and some microporphyritic rhyolite on North Fork of Little Naches River

Tf **Fifes Peak Formation (Miocene)**—Basaltic andesite and basalt flows, flow breccia, and interbedded andesite breccia and tuff, mudflow breccia, volcaniclastic sedimentary rocks, and crystal-lithic tuff. Dark-reddish, dark-green to dark-gray or black, porphyritic to microporpyritic andesite contains 20 to 30 percent, generally well-zoned, plagioclase (An_{50} to An_{30}) and 5 to 15 percent hypersthene and clinopyroxene as phenocrysts (Fischer, 1970). Groundmass textures are trachytic to intersertal to intergranular with plagioclase microlites, pyroxene, opaque, or reddish-brown glass with secondary smectites, hematite, calcite, and quartz. Black basalt with plagioclase and pyroxene microphenocrysts in fine-grained holocrystalline or hyalocrystalline, in part, pilotaxitic groundmass; locally contains olivine that has generally been altered to smectite clays (iddingsite). Flow banding is indicated by color bands and layers with different amounts of crystals. Flows exhibit platy jointing, columnar jointing with uniform to splayed orientations, vesicular tops, scoriaceous and amygdaloidal zones, and minor drusy quartz zones. Massive to well-bedded, green, red, and brown polymictic tuff and breccia and less colorful monolithologic tuff and breccia contain angular to well-rounded porphyritic andesite clasts; breccia matrix is commonly rich in feldspar crystals. Breccia may predominate locally, but is not as easily seen as flows. Minor volcanic sandstone, conglomerate, and siltstone, dacite, and mudflow breccia. Well-bedded greenish volcanic conglomerate, and fine-grained silty layers, locally rich in organic materials, contains leaf fossils. Quartz-bearing, crystal-rich, lithic ash-flow and air-fall tuff interbeds are locally prominent. According to Hartman (1973, p. 39-48), andesite flows and breccia of Fifes Peak Formation in the Snoqualmie Pass quadrangle were only slightly affected by "low-grade metamorphism" (primarily heulandite-clay-(chlorite)-quartz). Rocks of Fifes Peak Formation in this quadrangle were described in part by Hammond (1963, p. 144-152, 169-178), Fischer (1970, p. 54-81), and Hartman (1973, p. 21-25). Locally, divided into:

Tfv **Volcaniclastic rocks**—Well-bedded andesitic breccia, tuff, and volcanic sandstone, cropping out in vicinity of Maggie Creek. Porphyritic andesite breccia clasts commonly multicolored. In part, pebbly volcanic sandstone. Cut-and-fill structures and graded bedding present in some exposures. Thin pumice-bearing white ash layers and leaf fossils present but uncommon. Interbedded with flows of Fifes Peak Formation

Tfb **Andesite and basalt megabreccia**—Megabreccia containing blocks as large as 4 m across. Clasts of andesite similar to Fifes Peak Formation (Tf), and including very fine grained, sugary to coarse-grained andesite porphyry. Interbedded and gradational with flows of Fifes Peak Formation (Tf)

Tfc **Crystal-lithic tuff**—White to gray tuff containing crystals of plagioclase, pyroxene, and quartz, and clasts of pumice and volcanic rocks in brownish matrix of devitrified glass. At Boulder Creek, grades upward into diamictite consisting of matrix similar to tuff studded with andesite and basalt blocks

Rhyolite unit of Clear West Peak—Divided into:

Tfci **Intracaldera rhyolite**—Mostly gray to purple, sparsely plagioclase phyric devitrified rhyolite. Equivalent in part to the informally named Clear West complex of Fischer (1972; see also 1970). Local exposures of ash-flow tuff with vitroclastic and eutaxitic textures (McCulla, 1986, p. 65-68). Most rocks highly altered but Fischer (1970, p. 102-113) described black vitrophyre containing plagioclase, augite and hypersthene phenocrysts, and abundant crystallites of hornblende. Many of the altered rocks have pseudomorphs of smectite clays after hornblende(?). Rocks are conspicuously banded perpendicular to columnar joints and commonly subhorizontally arrayed, suggesting steep and variable flow layering or multiple dikes. McCulla (1986, p. 68) suggested that intrusions are concentrated near south margin of caldera. Mass is locally intruded by andesite dikes and also includes some andesite xenoliths. See Fischer (1970, p. 93-114) and McCulla (1986, p. 66-70) for detailed descriptions, modes, and chemical analyses

Tfce **Extracaldera rhyolite tuff**—Gray to white devitrified, mostly banded rhyolite with rare black welded vitrophyre and local basal unwelded pumice-perlite tuff (reported by Fischer 1970, p. 98). Mineralogy and chemistry (Fischer, 1970, p. 93-113) are similar to intracaldera rhyolite (Tfci), but flattened shards and local folded flow bands are more prominent. Locally, rare beds of rhyolitic sandstone, siltstone, and coal. Rhyolite tuff near unnamed hill [20] north and locally south of White River is considerably altered, mostly to conspicuously massive white silica and hematite. McCulla (1986, p. 108-174, plate 2) described replacement silica cap over argillitic, iron oxide-rich zone with local quartz, kaolinite, alunite, and pyrite veining. Silicified rhyolite is shown with diagonal line pattern and may include some silicified andesite

Tfrt **Rhyodacite tuff**—Predominately tan, locally light-green, in part flow-banded, crystal-lithic ash-flow tuff with vitroclastic texture. Rounded, resorbed quartz, euhedral to rounded feldspar, clinopyroxene, and volcanic lithic clasts (as large as 1.5 cm) in matrix of mostly undeformed glass shards and glass dust

Tfst **Sun Top unit**—Rhyodacite ash-flow tuff and well-bedded volcaniclastic sedimentary rocks. Equivalent to informally named Sun Top tuff of Vance and others (1987). Typically light gray or tan, locally reddish tan or light green. Vitric to crystal-lithic tuff and interbedded air-fall tuff, volcanic sandstone, conglomerate, and siltstone. Rhyodacite ash-flow tuff generally contains abundant euhedral to subrounded plagioclase, clinopyroxene, hornblende, hypersthene, and biotite, rounded and embayed quartz, pumice and felsic to mafic volcanic rock fragments in generally highly altered matrix of glass shards and dust and very fine grained minerals. Alteration minerals include smectites, chlorite, and calcite. Alteration is locally so pervasive that original grain types and textures are not discernable, but rocks are generally less altered than dacite tuff in Ohanapecosh Formation. Locally welded and with crude columns. Gray to tan, in part greenish, well-bedded polymictic volcanic sandstone, conglomerate, siltstone, and tuff locally exhibit sedimentary structures such as cross-bedding and ripple marks. Includes rare mudflow breccia. Rocks in quadrangle are in part described by Fischer (1970, p. 34-53), Hartman (1973, p. 15-21, tables 6, 7), and Vance and others (1987)

Tfcr **Chenuis Ridge unit**—Light-greenish-gray rhyodacitic ash-flow tuff, breccia, and minor interbedded volcaniclastic sedimentary rocks. Similar to Sun Top unit. Near Carbon River stock (fig. 2), rocks are locally hornfelsic

Teg **Volcanic rocks of Eagle Gorge (Miocene and Oligocene)**—Basaltic andesite and basalt flows, breccia, and minor well-bedded tuff and volcanic sedimentary rocks. Predominantly dark-green to black andesitic flows and flow breccia. Flows variously exhibit platy or columnar jointing, vesicular tops, scoriaceous or amygdaloidal zones, and minor drusy quartz zones. Breccia generally monolithologic. Plagioclase, clinopyroxene, and lesser hypersthene and hornblende phyric andesite exhibit intersertal and intergranular texture; with secondary smectites, hematite, calcite, and quartz. Minor well-bedded multicolored tuff and breccia; volcanic sandstone, conglomerate, siltstone, and dacite; rare mudflow breccia

Volcanic rocks of Mount Daniel (Oligocene)—Divided into:

Tdv **Andesite, dacite, and rhyolite volcanic rocks**—Predominantly clinopyroxene and clinopyroxene-hypersthene andesite and dacite tuff, breccia, and subordinate flows. Breccia beds as thick as 25 m. Commonly highly altered to calcite and smectites. Some thinly bedded (water-laid?) tuff and volcanic sandstone. Detailed descriptions in Ellis (1959, p. 65-70) and, for rocks north of Snoqualmie Pass quadrangle, in Simonson (1981)

Tdgr **Granophyre and rhyolite porphyry**—Intrusive rocks east of Waptus River grade, from medium-grained hornblende granite to fine-grained porphyritic granophyre. Highly altered to chlorite, epidote, sericite, and prehnite. West of river, plagioclase and quartz phyric rhyolite with devitrified groundmass. On Cle Elum River, intrusive rhyolite porphyry breccia is filled with inclusions of country rock and broken phenocrysts of quartz, plagioclase, and K-feldspar. These rocks are closely associated with tonalite dikes and they are thermally metamorphosed

Tdrd **Rhyodacite tuff**—Vitric crystal-lithic dacite tuff, commonly containing plagioclase, resorbed quartz and silicic to intermediate volcanic fragments in devitrified glassy matrix. Probably of ash-flow origin. Similar to the member of Lake Keechelus (Tolk), but with more quartz phenocrysts

Tdb **Breccia**—Monolithologic breccia composed of angular sandstone clasts as large as 3 m across derived from Swauk Formation. Rare volcanic clasts. Further descriptions in Ellis (1959, p. 66-67) and Simonson (1981, p. 40-41)

Tdr **Rhyolite**—Quartz and plagioclase phyric devitrified rhyolite. Mostly tuff and breccia rich in devitrified shards, locally eutaxitic. Rhyolite on Cone Mountain [13] may be intrusion

To **Ohanapecosh Formation (Oligocene)**—Well-bedded, multicolored, volcanic- and crystal-lithic andesitic tuff and breccia and volcaniclastic sedimentary rocks alternating with massive tuff breccia, subordinate basalt and andesite flows and flow breccia, and minor rhyolite tuff. Characteristically light green, but also pistachio green, light-bluish green, purplish, black, brown, or white. Mixed volcanic-lithic, in part pumice-rich or feldspar-rich tuff, lapilli, and breccia. Massive to well-bedded, mono- and polymictic breccias contain red, yellow, brown, green, or blue-green clasts of andesite porphyry and basalt in feldspar crystal-rich matrix. Clasts generally about 2 to 6 cm in diameter, but as large as 2 m. Well-bedded volcanic sandstone and comglomerate are rich in plagioclase crystals and contain variety of volcanic rock fragments and rare chert and granitoid clasts. Volcanic argillite is, in part, rich in organic material and contains leaf impressions. Minor fresh to mostly highly altered andesite and basalt flows, flow breccia, and mudflow breccia are locally present, particularly in basal parts of unit on northeast and east side of outcrop area. Dark-green, brown or black, weathering to light-green or brown, one- and two-pyroxene andesite porphyry contains phenocrysts or glomerocrysts of plagioclase or plagioclase and pyroxene. Commonly trachytic with groundmass composed of plagioclase microlites, clinopyroxene, opaque minerals, and alteration products. Flows locally exhibit platy jointing, columns, and vesicular tops. Dark basalt with small plagioclase, clinopyroxene, and olivine phenocrysts set in groundmass of plagioclase, opaque, clinopyroxene, and alteration minerals. Plagioclase locally replaced by calcite, and pyroxene by smectite. Other alteration minerals include quartz, zeolite, calcite, chalcedony, smectite, clays, and chlorite that replace minerals, lithic grains, or fill vugs. Hartman (1973, p. 38-48, fig.8) reported minerals indicative of "low-grade metamorphism" (laumontite-chlorite-quartz and epidote-prehnite-chlorite-quartz assemblages), but added that rocks were not pervasively altered and that alteration likely had hydrothermal origin. Minor crystal-rich dacite and rhyolite ash-flow tuff generally contains plagioclase and partially embayed quartz crystals as well as volcanic rock fragments, pumice, or altered glass shards in generally altered matrix, which may contain potassium feldspar. In part, with clinopyroxene microphenocrysts that in general are at least partially altered to smectite clays. On south side of Huckleberry Mountain, between strands of the White River Fault, unit includes variety of atypical rocks, including dacite ash-flow tuffs similar to Sun Top unit (Tfst) and poorly consolidated tuffaceous shales that may be much younger than Ohanapecosh Formation (To). Locally, includes:

Tolk **Tuff member of Lake Keechelus**—Dacite crystal-vitric tuff and breccia consisting of plagioclase (20 to 25 percent), quartz (7 to 11 percent), and pyroxene (trace to 4 percent, altered to smectite) phenocrysts in groundmass of quartz, plagioclase, potassium feldspar, and devitrified glass. Light greenish, weathering to light pink or salmon. Bedding locally defined by flattened pumice. Breccia blocks as large as 1 m. Rocks of unit described in detail by Hammond (1963, p. 123-144)

Tv **Volcanic rocks (Oligocene)**—Mostly andesite with minor dacite and rhyolite in coarse breccia, tuff, ash flow-tuff, and rare flows. Mostly highly recrystallized by thermal metamorphism; many rocks are hornblende-biotite hornfels. As mapped, may include some rocks belonging to underlying Naches Formation

ROCKS WEST OF STRAIGHT CREEK FAULT

Tdg **Diabase, gabbro, and basalt (Oligocene? and Eocene)**—In Puget Lowlands, consists of dark-gray porphyritic calcic andesite and may include minor basalt or dacite (Vine, 1969, p. 32-34). Euhedral to subhedral phenocrysts of andesine and augite dominate; variously altered to smectite clays, calcite, and chlorite. Found mostly as sills or sill-like bodies less than 10 m thick, but some as thick as 50 m, and one about 125 m

GREEN RIVER-CABIN CREEK BLOCK

Tn **Naches Formation (early Oligocene? to middle Eocene)**—Rhyolite, andesite, and basalt flows, tuff, and breccia with interbeds of feldspathic subquartzose sandstone and siltstone as well as rare coal. Well-bedded andesite and basalt flows and breccia are nondescript, porphyritic to aphyric, dark-green to black rocks, weathering to brown. In part amygdaloidal, with columns, or with brecciated and vesicular tops. Rhyolite forms mostly flow-banded flows or domes and minor ash-flow tuffs. Interbedded sedimentary rocks are white to light-tan or gray, coarse-grained micaceous feldspathic sandstones, exhibiting crossbeds and graded bedding, and black argillite and laminated siltstone. Both volcanic and sedimentary rocks are thermally metamorphosed adjacent to Miocene stocks and plutons. Ort and others (1983) presented chemistry of volcanic rocks. Locally, divided into:

Tns **Feldspathic sandstone and volcanic rocks (late and middle Eocene)**—Well-bedded, medium- to coarse-grained, tan to gray, predominantly micaceous feldspathic to feldspatholithic subquartzose sandstone and interbedded siltstone and shale, with conspicuous rhyolite, andesite, and basalt flows, tuff, and breccia. Contains interbeds of coal-bearing shale and rare volcanic clast-rich pebble conglomerate and quartz-pebble grit. Leaf fossils locally common. Volcanic clasts constitute only about 28 percent of framework grains in sandstone (Frizzell, 1979, p. 47)

Tnr **Rhyolite (late and middle Eocene)**—Mostly white to gray, flow-banded, platy-jointed flows or domes with ash-flow tuff containing flattened pumice fragments. In beds meters to hundreds of meters thick. Includes some probably intrusive rhyolite, especially near Rampart Ridge north of Keechelus Lake. Mainly aphyric or with minor plagioclase or quartz phenocrysts; completely devitrified to white spherulitic masses. Contains minor interbeds of basaltic tuffs and flows and feldspathic sandstone

Tnb **Basalt (late and middle Eocene)**—Mostly basalt flows and breccia with interbedded feldspathic sandstone and siltstone. Basalt forms nondescript, porphyritic to aphyric, dark-green to black rocks that weather brown. Holocrystalline to intersertal microporphyritic rocks contain plagioclase, clinopyroxene, opaques, glass, and alteration minerals. Many are so highly altered to smectite or calcite that identification of original textures and minerals is difficult

Tng **Guye Sedimentary Member (late and middle Eocene)**—Light to dark-gray feldspathic sandstone, black slaty shale, and hard chert-pebble conglomerates; rare volcanic interbeds. Argillite is leaf bearing. Locally hornfelsic. Discussed by Foster (1960, p. 111-113), Hammond (1963, p. 45-48), and Tabor and others (1984)

Tnmc **Mount Catherine Rhyolite Member (late and middle Eocene)**—Commonly flow-banded, platy jointed, black, welded, crystal-lithic ash-flow tuff containing highly flattened pumice lapilli, some volcanic breccia, and minor thin feldspathic sandstone and shale interbeds. Unusual hardness and apparent freshness probably are due to recrystallization during intrusion of Snoqualmie batholith. Unit described by Foster (1960, p. 114), Hammond (1963, p. 50-54), and Tabor and others (1984)

Tnbg **Glomeroporphyritic basalt (late and middle Eocene)**—Mostly basalt and glomeroporphyritic basalt with interbeds of andesite and rare feldspathic sandstone and siltstone. Thick flows, in part with vesicular tops, some of which contain tabular plagioclase phenocrysts as large as 2 cm across, that in some flows are strongly flow aligned. Described in some detail by Foster (1967, p. 39, 40)

Tp **Puget Group**—Micaceous feldspathic subquartzose sandstone, siltstone, claystone, and coal. Rocks in the Green River area (described in detail by Vine, 1969, p. 6-13) are white, very fine grained to gritty sandstone with subangular to rounded grains consisting of about 40 to 60 percent quartz, 30 to 50 percent feldspar, and about 5 percent lithic clasts (Frizzell, 1979, appendix III). Tabular beds of sandstone are massive to cross bedded and occasionally exhibit channel cut-and-fill structures. Light to dark siltstones form poor outcrops, are commonly thinly laminated, and contain organic matter. Coal beds are as thick as 5 m and are described in detail by Beikman and others (1961).

In northwest corner of map area, near Tiger Mountain, unit consists of interbedded nonmarine sandstone and volcanic breccia belonging to undivided Tiger Mountain and Tukwila Formations, which were previously separated by Vine (1969). Immediately north of Green Valley along Cedar River and along western edge of map area, north of Enumclaw, rocks (Tp?) may be nonmarine sandstones of the Puget(?) Group that are in contact with Ohanapecosh Formation (To); Walsh (1984) and Phillips (1984) provide more details in Tiger Mountain and Green River areas. In Snoqualmie Pass quadrangle, divided into:

Tpr **Renton Formation (late and middle Eocene)**—Fine- to coarse-grained feldspathic to lithofeldspathic subquartzose sandstone with interbedded siltstone, claystone, and coal. Fluvial to nearshore marine rocks (Vine, 1969, p. 23-26), attain at least 670 m thickness near Taylor Mountain [2]. Contains 30 to 45 percent quartz, 40 to 50 percent feldspar, and 10 to 20 percent lithic grains (Frizzell, 1979, appendix III)

Tpt **Tukwila Formation (late and middle Eocene)**—Volcanic breccia, conglomerate, sandstone, and flows with intercalated feldspathic sandstone and impure coal beds. Tuff and breccia with clasts of porphyritic andesite and dacite and polymictic volcanic conglomerate appear to predominate, but flow rocks (in part sills or dikes?) form resistant layers (Vine, 1969, p. 19-23). On Lookout Mountain, north of Cedar River, unit includes massive, columnar-jointed flows unlike flows in most Tukwila Formation. These rocks were previously mapped as unnamed volcanic rocks by Vine (1969) and Walsh (1984; written commun., 1994)

Tptm **Tiger Mountain Formation (middle Eocene)**—Light-colored, medium-grained, micaceous feldspathic subquartzose sandstone interbedded with siltstone, minor pebble conglomerate, and coal beds. Vine (1969, p. 16-19) and Johnson and O'Conner

(1994) describe the Tiger Mountain Formation

Tmp **Volcanic rocks of Mount Persis (late? Eocene)**—Mostly gray to black, locally reddish, porphyritic two-pyroxene andesite lava and breccia. Phenocrysts and glomerocrysts of plagioclase, clinopyroxene, hypersthene, and opaque minerals in devitrified groundmass. Mostly highly altered. Massive to blocky joints. Flow layering obscure

Trr **Raging River Formation (middle Eocene)**—Shallow marine and alluvial, volcanic clast-rich sandstone, siltstone, and shale. Locally highly fossiliferous; plant remains common. Minor conglomerate predominantly consists of volcanic clasts, but locally contains chert pebbles. For detailed descriptions see Vine (1969, p. 13-16) and Johnson and O'Conner (1994)

ROCKS EAST OF STRAIGHT CREEK FAULT

TEANAWAY RIVER BLOCK

Roslyn Formation (late and middle Eocene)—Divided into:

Tru **Upper member (late Eocene)**—Medium- to fine-grained, nonmarine, white, weathering to yellow, micaceous lithofeldspathic sandstone, some with calcite cement. Dark olive-gray to greenish-yellow siltstone, predominantly quartz and feldspar; thin-bedded to laminated. Subordinate 0.6- to 6-m-thick seams of well-jointed, banded bituminous coal. See "Coal Measures" of Bressler (1951, p. 31)

Trm **Middle member (late and middle Eocene)**—Similar to upper member (Tru) but contains only minor stringers of coal

Trl **Lower member (middle Eocene)**—Mostly white, weathering to yellowish and pale orange, nonmarine, medium- to coarse-grained, micaceous, lithic, feldspathic, and lithofeldspathic sandstone. Beds to 15 cm thick with crossbedding, pebble stringers, and cut-and-fill structures. In part zeolitic; Pongsapich (1970, p. 54, table 6) reported laumontite in eight samples and clinoptilolite in one. Calcite cement locally abundant. Abundant conglomerate and pebbly sandstone with rounded pebbles of granitic and aphanitic extrusive or hypabyssal rock. Includes Bressler's (1951, p. 35) basal beds of red to red-brown, fine-grained sandstone with minor angular clasts of quartz, metamorphic rock fragments, some feldspar, and other rock types

Tt **Teanaway Formation (middle Eocene)**—Basalt, basaltic tuff, and breccia with minor andesite, dacite, and rhyolite. Black, generally dense to glassy nonporphyritic pyroxene and rare olivine basalt, weathering red brown to yellow. Commonly fine-grained intersertal groundmass with plagioclase laths and clinopyroxene; interstices of brown glass or alteration products (Clayton, 1973, p. 18-19). Blocky to columnar-jointed flows characterized by large chalcedony and calcite amygdules. Tuff and breccia commonly altered to clays. Silicic varieties including welded tuff are white, purple, and highly altered but contain relict phenocrysts of quartz, plagioclase, and rare K-feldspar. Contains minor feldspathic sedimentary rock (Clayton, 1973, p. 35-36). Teanaway dike swarm composed of dark-green and brown to black basalt and diabase dikes that weather reddish brown. Includes pale, dull holocrystalline dikes containing plagioclase laths and granular clinopyroxene in intergranular texture. Interstices are filled with quartz, plagioclase, zeolite, and clays (Southwick, 1966, p. 9). Waxy, partly glassy dikes with andesine, clinopyroxene, and minor olivine; altered to chlorophaeite and devitrified glass (Southwick 1966, p. 10-11). Percent of area underlain by dikes shown by density of symbols

Tdg **Diabase, gabbro, and basalt (Eocene)**—Fine- to medium-grained black diabase and gabbro dikes and plugs that weather to brown and reddish brown. Contains labradorite, clinopyroxene, rare olivine, and opaque ores. Subophitic to ophitic texture; variously altered to smectite clays, calcite, and chlorite (Stout, 1961, p. 350)

Swauk Formation (middle and early Eocene)—Divided into:

Tss **Sandstone**—Predominantly fluvial, gray-weathering to tan, zeolitic, locally carbonate-cemented, medium-grained, micaceous feldspathic to lithofeldspathic subquartzose sandstone averaging 40, 48, and 12 percent quartz, feldspar, and lithic clasts, respectively, and containing 40 to 80 percent quartz, 20 to 50 percent feldspar, and 5 to 15 percent lithics in map area (Frizzell, 1979). In part contains laumontite, clinoptilolite, and prehnite (Pongsapich, 1970). Basal beds resting on Easton Metamorphic Suite consist of pebbly sandstone containing quartz and phyllite clasts, which rapidly grade up section into more feldspathic sandstone. Thin to very thick bedded, poorly sorted, locally crossbedded, and with lesser interbeds of carbonaceous siltstone and shale, pebbly sandstone, and conglomerate. Pattern indicates zone of sheared rocks

Tsc **Conglomerate facies (middle and early Eocene)**—Unit contains 20 to 50 percent conglomerate and conglomeratic sandstone interbeds in feldspathic and lithofeldspathic sandstone, siltstone, and shale. Boulders to pebbles of quartzite, chert, argillite, granite, phyllite, and serpentinite in matrix of micaceous feldspathic and lithofeldspathic sandstone. Locally exhibits crossbedding and cut-and-fill structures

Tssp **Silver Pass Volcanic Member (early Eocene)**—Mostly dacite and andesite flows and pyroclastic rocks, but compositions range from rhyolite to basalt (Ort and others, 1983). Light-tan to dark-green-gray andesite and feldspar porphyry with phenocrysts, microphenocrysts, and glomerocrysts of plagioclase-hypersthene and plagoclase-clinopyroxene in groundmass of plagioclase microlites, pyroxene, opaques, and alteration minerals. Commonly highly altered with plagioclase altered to calcite and chlorite and pyroxene altered to smectite. Locally contains zeolite-filled amygdules. Altered rhyolite or dacite ash-flow tuff and tuff breccia contain plagioclase and quartz crystals, volcanic clasts, and flattened shards and pumice. Described in greater detail by Lofgren (1974, p. 25-34)

Tsi **Ironstone (early Eocene)**—Iron-rich sandstone, shale, and conglomerate, locally well bedded. Conglomerate locally composed of peridotite and serpentinized peridotite clasts in an iron-rich matrix consisting of limonite, hematite, magnetite, and serpentenite. Most deposits are rich in nickel (Lamey, 1950)

MANASTASH RIVER BLOCK

Tbf **Basalt of Frost Mountain (middle Eocene)**—Dense black micro-porphyritic olivine basalt; microphenocrysts of plagioclase, clinopyroxene, and olivine in intersertal groundmass of plagioclase, clinopyroxene, opaque minerals, and brown glass. Weathers red and is locally columnar jointed. Locally altered to siliceous white rock. Locally, divided into:

Tbfb **Basalt breccia and tuff**—Brown to red oxidized basaltic breccia and tuff with thin basalt flows. Crudely bedded

Tta **Taneum Formation (early Eocene)**—Mostly gray to green and brown, generally highly altered porphyritic to nonporphyritic andesite, dacite, and rhyolite flows, tuff, and breccia; greenish-blue, purple, and white altered ash-flow tuff, commonly welded, with quartz and plagioclase phenocrysts and flattened pumice lapilli

Tm **Manastash Formation (early Eocene)**—Nonmarine sandstone, siltstone, and conglomerate. Light-greenish-gray or tan, massive to well-bedded, medium- to coarse-grained feldspathic quartzose to subquartzose sandstone, thin siltstone, and interbeds of conglomerate. Averages 55 to 60 percent quartz and 5 to 10 percent lithic clasts (Frizzell, 1979). Fine to coarse planar and through crossbeds locally present. Minor seams of bituminous coal; fossil leaves locally present

ROCKS SOUTHWEST OF DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Rocks of western mélange belt (middle Eocene and (or) Late Cretaceous)—Divided into:

TKwa **Argillite and graywacke**—Well-bedded marine sandstone and argillite and subordinate pervasively sheared argillite. Purplish, reddish, gray and black, fine- to coarse-grained and pebbly lithofeldspathic and volcanolithic subquartzose sandstone interbedded with black argillite. Sandstone commonly is mixed type containing clasts of mostly plagioclase, chert, volcanic rocks, and quartz, as well as sandstone, siltstone, phyllite, biotite, muscovite, and epidote. Alteration minerals include calcite, chlorite, sericite, limonite, epidote, and prehnite. Near Tertiary plutons, rocks are hornfelsic, commonly show conspicuous metamorphic biotite. Sedimentary features such as graded bedding and load casts are locally well preserved. Contains highly folded, sheared and recrystallized banded cherts. Unit includes metagabbro, both polymictic and quartz-pebble conglomerate, and shale-chip breccia. East of North Bend, sandstone and argillite are highly sheared, forming outcrops of lenticular sandstone clasts in crudely foliated argillite. This deformational style is typical of western mélange belt in exposures north of quadrangle (Tabor and others, 1982b, 1988, 1993; Frizzell and others, 1987). Jett and Heller (1988) described sandstone composition

TKwv **Metavolcanic rocks**—Greenstone, greenstone breccia, and metadiabase with boudinaged metaquartz porphyry dikes

TKwg **Metagabbro**—Massive to foliated, fine- to medium-grained metagabbro. Many outcrops sheared at all scales. In massive rocks, euhedral, mottled, locally crushed plagioclase, intergranular to euhedral uralitized clinopyroxene, and opaque minerals common. Metamorphic minerals include uralite, chlorite, sphene, and calcite. Unit includes rare hornblende metatonalite and well-recrystallized amphibolite

TKwu **Ultramafic rocks**—Serpentinized pyroxenite near Northbend. Predominantly coarse-grained anhedral and fine-grained subhedral to euhedral clinopyroxene in sea of serpentine minerals with mesh structure

Rocks of eastern mélange belt (middle Eocene and (or) Late Cretaceous)—Divided into:

TKev **Chert, mafic metavolcanic rock, amphibolite, and marble**—Highly deformed chert and medium- to fine-grained banded purplish biotite quartzite (metachert) intimately mixed with tectonized greenstone, greenstone breccia, and marble. Includes hornblende schist and muscovite, biotite quartz schist and dikes of metadiorite and metagabbro. Original sedimentary and volcanic textures largely obscured by penetrative deformation and static thermal metamorphism. Adjacent to Snoqualmie batholith, rocks are greenish pyroxene hornfels. In part described by Chitwood (1976, p. 10-14)

TKem **Marble**—Lenticular beds and pods of banded, white to grayish, medium- to fine-grained crystalline marble that is locally intercalated with metachert, metagabbro, and greenstone. Includes minor fine-grained pale-green silica carbonate replacement masses (Danner, 1966; Mogk, 1978)

pTqm **Quartz Mountain stock (pre-Tertiary)**—Medium-grained hornblende metatonalite and metagranodiorite, locally with biotite and garnet. Hypidiomorphic granular, but with local bent plagioclase and statically recrystallized plagioclase, crystalloblastic growth of sodic plagioclase rims on K-felsdpar and plagioclase, replacement of feldspar cores by clinozoisite, and recrystallization of biotite. Stock and many of its many apotheses intruded Lookout Mountain Formation of Stout (1964) with sharp contacts

Lookout Mountain Formation of Stout (1964) (pre-Tertiary)—Divided into:

pTlm **Mica schist**—Black, very fine grained graphitic garnet biotite schist, locally with staurolite, andalusite, and rare cordierite. Relict bedding, graded bedding, and relict clastic grains are common. Includes mafic hornblende metatonalite and gabbro, not mapped separately

pTla **Amphibolite and hornblende tonalite gneiss**—Mostly very fine grained schistose epidote amphibolite with green to blue-green hornblende, locally with biotite. Plagioclase is commonly replaced by microcrystalline pumpellyite(?). Includes some mica schist (see Stout, 1964, p. 319). Also includes small masses of metadiorite and metagabbro. With increasing heterogeneity and increased shearing grades into tectonic complex of Stout (TKt). Goetsch (1978, p. 16-17) describes small bodies of cataclastic hornblende tonalite gneiss

pTlg **Gabbro and metagabbro**—Cataclastically foliated to medium-grained massive gabbro and metagabbro, metatonalite, and metaquartz-diorite. A small mass on south side of Lookout Mountain [24] is mostly hornblendite with relict pyroxene (Goetsch, 1978, p. 28-29)

ROCKS IN DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

TKt **Tectonic complex of Stout (1964) (Tertiary and (or) Cretaceous)**—Cataclastic to blastomylonitic blocks and slivers of predominantly fine-grained schistose amphibolite, as well as phyllite, greenstone and pillowed greenstone, blueschist, tonalite gneiss, leucogreenschist (metatuff), metasandstone, and ultramafic rocks. Stout (1964, p. 323), in addition, reports tectonic breccia, biotite gneiss, slate, and argillite in unit. Locally divided into:

TKtu **Ultramafic rocks**—Mostly serpentinite and serpentinized peridotite. Strongly foliated. Depicted by ✳ where too small to show at map scale

ROCKS NORTHEAST OF DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Kt **Tonalite (Late Cretaceous)**—Medium-grained hornblende-biotite tonalite exhibiting hypidiomorphic texture exposed in small stock near Fortune Creek

Knp **Metavolcanic rocks of North Peak (Late Cretaceous)**—Greenstone, green to red metamafic to silicic tuff, breccia, metacalcareous tuff, and impure marble. Ashleman (1979, p. 21) reports meta-andesite and rhyodacite. Although volcanic and clastic textures are well preserved, rocks are slightly schistose and contain metamorphic minerals including chlorite, quartz, albite (?), carbonate, pumpellyite, and lawsonite

Easton Metamorphic Suite (Early Cretaceous)—Divided into:

Kes **Shuksan Greenschist**—Very fine grained albite-epidote-chlorite schist with varying amounts of quartz, actinolite, crossite and (or) late glaucophane, pumpellyite, and muscovite. Schist also contains minor sphene, opaques, and calcite. Ashleman (1979, p. 12) reported lawsonite in actinolite schist and described intercalations of ironstone and ferruginous quartzite in greenschist. Locally with layers of phyllite. Most rocks are highly foliated and thoroughly recrystallized with fair mineral segregation, but many rocks south of Little Kachess Lake are texturally undifferentiated and retain relict textures suggesting derivation from porphyritic volcanic rocks, tuffs, and rare mafic intrusive rocks. North of Hicks Butte [23], greenschist retains pillow structures, and in Kachess Lake area, Ashleman (1979, p. 13) also reported possible pillow structures

Ked **Darrington Phyllite**—Mostly black to gray graphitic chlorite-sericite-quartz phyllite with minor albite(?), and opaque minerals. Ashleman (1979, p. 7) reported minor spessartine and stilpnomelane. Phyllite is commonly highly crinkled and contains quartz segregation lenses and veins that are commonly ptygmatically folded. Phyllite predominates and is locally interbedded with greenschist and blueschist

Ktz **Tectonic zone (Early Cretaceous)**—Mostly fine-grained epidote hornblende schist and hornblende pumpellyite(?) schist. Zoisite clearly replaces plagioclase. Rocks are blastomylonitic and porphyroblastic with lenses of coarser mylonitic hornblende gneiss derived from tonalite gneiss (Khb). Some epidote quartz schist and actinolitic greenschist. Grades into greenschist (Kes). For more complete description see Treat (1987, p. 40-53)

Khb **Tonalite gneiss of Hicks Butte (Early Cretaceous)**—Lineated, medium-grained hornblende tonalite and tonalite gneiss, locally porphyroclastic and mylonitic. In least-deformed rock, green hornblende and labradorite are subhedral with intergranular quartz, opaque minerals, and minor biotite. Patchy alteration of plagioclase and hornblende to epidote and late microcrystalline pumpellyite

Kbg **Banded gneiss (Early Cretaceous)**—Very fine grained pyroxene granofelsic gneiss. Locally with replacement veins of poikiloblastic clinozoisite and plagioclase replaced by pumpellyite(?)

Ingalls Tectonic Complex (Early Cretaceous or Late Jurassic)—Divided into:

KJis **Foliated and massive serpentinite and serpentinized meta-peridotite**—Southern exposures (with pattern) mostly gray and gray-green to dark-green, commonly foliated and slickensided rubbly serpentinite — part of Cowan and Miller's (1981; see also Miller, 1985) Navaho Divide Fault Zone. Less serpentinized rock there is harzburgite and dunite. Northern exposures (shown without pattern) partly serpentinized lherzolite and harzburgite, originally described by Frost (1973, p. 8-12) north of Snoqualmie Pass quadrangle where it was named South Peak unit by Miller (1980b, p. 52-69). Includes some mylonitic hornblende peridotite. Detailed descriptions in Miller and Mogk (1987)

KJim **Metabasalt, tuff, and breccia**—Mostly coarse monolithologic pillow breccia; green with red to purple oxidized zones (Miller, 1980b, p. 148-149). Clasts are porphyritic and amygdaloidal; originally plagioclase and augite phyric, intergranular to diabasic. Altered to chlorite, sphene, epidote, opaque minerals and fine-grained unidentified material. Includes minor siliceous argillite and chert

KJid **Diabase and gabbro**—Mostly heterogeneous uralitized pyroxene diabase and gabbro in complex of dikes and irregular intrusive bodies (Miller, 1980b, p. 99-107)

KJia **Amphibolite**—Medium-grained, locally diopside-bearing, layered, polymetamorphic amphibolite, locally with impure metachert and hornblende-biotite schist (Miller, 1980b, p. 221-222)

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Table 1. *Radiometric analyses of rocks in Snoqualmie Pass quadrangle, Washington*

[All new ages calculated on basis of 1976 IUGS decay and abundance constants. K-Ar ages from reports earlier than 1976 corrected after Dalrymple (1979). All fission-track ages (F-T) calculated with $F=7.03x10^{-17}yr^{-1}$. Errors on single K-Ar ages referenced to this report based on empirical function relating coefficient of variation in age to percent radiogenic argon (Tabor and others, 1985). Uranium-thorium-lead isotope ages reported in following order: $^{206}Pb/^{238}U$; $^{207}Pb/^{235}U$; $^{207}Pb/^{206}Pb$; $^{208}Pb/^{232}Th$. Map numbers in parentheses indicate sample just off map]

Map No.	Sample No.	Method	Materials	Location		Unit	Age (Ma)	Comment and (or) subunit (see Description of Map Units)	Reference
				Latitude	Longtitude				
1	RWT-336-83	K-Ar	Whole rock	47°05.5'	121°50.8'	Basalt of Canyon Creek	0.58±0.07, 0.53±0.06, 0.20±0.2, 0.41±0.1	Acid treated fractions A, B, C, D; see text	Table 2
2	RWT-335-83	K-Ar	do.	47°05.5'	121°33.8'	Basalt of Dalles Ridge	2.4±0.1		Do.
3	VF-76-479	K-Ar	Hornblende	47°21.4'	121°04.0'	Howson Andesite	6.2±1.8		Do.
4	VF-78-370	K-Ar	Hornblende	47°25.3'	121°13.7'	Volcaniclastic rocks of Cooper Pass	12.4±1.7		Do.
	VF-78-370	F-T	Zircon				28.5±0.8;14.4±0.6	Two populations.	Table 3
5	VF-75-148	F-T	do.	47°25.5'	121°14.0'	do.	9.4±0.4	Switched sample?	Do.
6	VF-82W-565	K-Ar	Hornblende	47°00.8'	121°51.8'	Carbon River stock	19.4±3.0		Table 2
			Biotite				17.1±0.4		
7	RWT-608-79	K-Ar	Biotite	47°29.2'	121°30.6'	Rocks of the Snoqualmie batholith	19.7±0.5	Unit Tsgg	Do.
8	PEH 3-68	K-Ar	do.	47°21.0'	121°34.5'	do.	16.9±2	do.	Laursen and Hammond, 1974, p. 19
9	PEH 2-68	K-Ar	do.	47°23.7'	121°27.2'	do.	20.5±2	do.	Do.
10	None	K-Ar	do.	47°24.3'	121°26.8'	do.	17.0	Unit Tsgg; loc. uncertain	Lipson and others, 1961, p. 460
11	Ar-91	K-Ar	do.	47°24.1'	121°26.9'	do.	18.5±0.9	do.	Baadsgard and others, 1961, p. 691
12	RWT-262-81	F-T	Zircon	47°17.1'	121°29.4'	Tuff in Ohanepecosh Fm.	17.6±0.6	Reset by unit Tsgs	Table 3
13	RWT-525-77	K-Ar	Hornblende	47°17.6'	121°26.4'	Dacite porphyry	24.2±1.7	Intrusive into unit To	Table 2
14	RWT-361-79	K-Ar	do.	47°26.4'	121°14.8'	Stock on Three Queens	27.0±3.0	Likely unit Tsgn	Do.
(15)	None	K-Ar	Plagioclase	46°59'	121°51'	Fifes Peak Fm.	17.1±4.3	Andesite, south of map; probably too young	Hartman, 1973, p. 25
(16)	None	K-Ar	do.	do.	do.	do.	20.8±2.6	Andesite, south of map	Do.
17	None	K-Ar	Whole rock	47°00.4'	121°42.3'	do.	19.1±0.4	Unit Tfci; probable minimum	Hartman, 1973, p. 30
18	71-21b	U-Pb	Zircon	47°00.2'	121°42.5'	do.	21.8	Unit Tfci	Mattinson, 1977, p. 1512, Table 1
	71-21a	U-Pb	do.	do.	do.	do.	22.6	do.	Do.

Table 1. *Radiometric analyses of rocks in Snoqualmie Pass quadrangle, Washington—Continued*

Map No.	Sample No.	Method	Materials	Location		Unit	Age (Ma)	Comment and (or) subunit (see Description of Map Units)	Reference
				Latitude	Longtitude				
19	JV-163	F-T	do.	47°03.3'	121°44.1'	do.	20.0±2.0	Unit Tfci; loc. approx.	Vance and others, 1987, p. 282
20	C69D	K-Ar	Alunite	47°09.3'	121°50.9'	do.	20.4±0.1	Hydrothermal alteration	McCulla, 1986, p. 106, 206
21	None	K-Ar	Whole rock	47°00.5'	121°28.3'	do.	22.3±1.9	Andesite; loc. uncertain	Hartman, 1973, p. 24
	None	K-Ar	do.	do.	do.	do.	24.0±1.4	do.	Do.
22	FM-81-109	K-Ar	do.	47°13.0'	121°56.7'	do.	22.2±3.0, 21.2±0.7, 20.6±0.5, 22.9±1.0	Acid treated fractions A, B, C, D	Table 2
23	R-165	K-Ar	Hornblende	47°02.3'	121°35.7'	do.	22.0±1.6	Unit Tfst	Do.
		U-Pb	Zircon	do.	do.	do.	22.2±0.3, 22.2±0.5	do.	Vance and others, 1987, p. 282
		F-T	do.	do.	do.	do.	24.5±2.0	do.	Do.
24	JV 36	F-T	do.	47°03.1'	121°33.8'	do.	24.0±2.8	do.	Do.
25	CRS-413	K-Ar	Hornblende	47°08.8'	121°42.4'	do.	34.9±1.2	Unit Tfst; probably too old	Fischer, 1976
		K-Ar	Biotite				23.9±0.9		
26	None	K-Ar	Plagioclase	47°03.1'	121°34.2'	do.	21.0±1.5	Unit Tfst	Hartman, 1973, p. 21
	None	K-Ar	do.	do.	do.	do.	20.0±1.8	do.	Do.
27	RWT-76-82	K-Ar	Hornblende	47°07.1'	121°39.8'	do.	21.3±0.6	do.	Table 2
		K-Ar	Biotite	do.	do.	do.	22.0±0.7	do.	Do.
28	RWT-289-81	F-T	Zircon	47°02.1'	121°57.3'	do.	23.1±0.7	Unit Tfcr	Table 3
29	DB-81-421	F-T	Zircon	47°15.2'	121°43.2'	do.	20.8±0.7	Unit Tfrt	Do.
30	VF-82W-699	K-Ar	Biotite	47°06.0'	121°21.4'	Ohanapecosh Fm.	26.5±0.8	Probably too young	Table 2
31	RWT-252-81	F-T	Zircon	47°23.2'	121°47.8'	do.	24.7±1.7	do.	Table 3
32	DT-78-28A	K-Ar	Whole rock	47°16.0'	121°52.8'	do.	27.9±1.6	Intrusion into unit To	Turner and others, 1983, Table 1
33	R-14	F-T	Zircon	47°16.8'	121°21.2'	Ohanapecosh Fm.	30.2±1.1		Tabor and others, 1984, Table 2
	VF-78-323	F-T	do.	do.	do.	do.	32.4±0.6		Do.
34	R-6	F-T	do.	47°20.6'	121°21.4'	do.	30.4±1.2	Unit Tolk	Do.
35	JV-96	F-T	do.	47°05.0'	121°14.7'	do.	32.0	Location approximate	Vance and others, 1987, p. 277
36	DT-78-20	K-Ar	Whole rock	47°17.8'	121°57.3'	do.	29.1±1.8	Basalt intruding unit Tp	Turner and others, 1983, Table 1
37	DT-78-27B	K-Ar	do.	47°16.1'	121°52.7'	do.	32.5±2.0	Intrusion into unit To	Do.
38	DT-78-30A	K-Ar	do.	47°15.9'	121°52.8'	do.	35.2±2.2	Flow breccia	Do.

Table 1. *Radiometric analyses of rocks in Snoqualmie Pass quadrangle, Washington—Continued*

Map No.	Sample No.	Method	Materials	Location		Unit	Age (Ma)	Comment and (or) subunit (see Description of Map Units)	Reference
				Latitude	Longtitude				
39	RWT-365-79	F-T	Apatite	47°28.6'	121°04.0'	Volcanic rocks of Mount Daniel	33.5±3.8	Unit Tdd	Tabor and others, 1984, table 2
40	DT-78-32A	K-Ar	Plagioclase	47°16.9'	121°58.8'	Puget Group	43.4±1.9	Ash parting in coal	Turner and others, 1983, fig. 2
41	DT-26	K-Ar	do.	47°18.7'	121°57.3'	do.	41.2±1.8	do.	Do.
	DT-27A	K-Ar	do.	47°18.7'	121°57.3'	do.	55.4±2.6	Unit Tdd; age unreliable	Do.
		F-T	Apatite	do.	do.	do.	42.2±7.8	Ash parting in coal	Do.
42	DT-36F	K-Ar	Plagioclase	47°19.3'	121°56.8'	do.	44.2±2.1	do.	Do.
43	DT-31B	K-Ar	do.	47°18.1'	121°57.0'	do.	45.0±2.1	do.	Do.
44	DT-37A	K-Ar	do.	47°19.1'	121°56.0'	do.	41.7±3.1	do.	Do.
		F-T	Apatite	do.	do.	do.	46.8±6.0	do.	Do.
	DT-37B	K-Ar	Plagioclase	do.	do.	do.	44.4±2.0	do.	Do.
45	R-11	F-T	Zircon	47°19.8'	121°19.7'	Naches Fm.	39.9±1.6	Rhyolite, unit Tnr	Tabor and others, 1984, Table 2
46	RWT-363-79	F-T	do.	47°05.4'	121°07.3'	do.	40.0±1.4	do.	Do.
47	R-130	F-T	do.	47°05.2'	121°06.9'	do.	43.8±2.5	do.	Do.
48	R-38	F-T	do.	47°02.1'	121°03.1'	do.	44.0±1.8	do.	Do.
49	R-129	F-T	do.	47°05.9'	121°08.6'	do.	44.6±3.2	do.	Do.
50	R-12	F-T	do.	47°19.9'	121°20.2'	do.	30.4±2.8	Unit Tdd; probably reset	Do.
51	R-13	F-T	do.	47°23.6'	121°23.1'	do.	35.5±1.4	Unit Tnmc; probably reset	Do.
52	R-15	F-T	do.	47°23.0'	121°23.3'	do.	35.9±1.5	do.	Do.
53	RWT-336-77C	K-Ar	Whole rock	47°10.7'	121°10.6'	do.	40.5±0.3	Basalt; prob. min. age	Tabor and others, 1984, Table 1
54	BG-209-77A	K-Ar	do.	47°06.1'	121°09.0'	do.	43.2±3.9	do.	Do.
55	M84A-77A	K-Ar	do.	47°03.7'	121°05.2'	do.	43.0±8.3	Basalt; age unreliable	Tabor and others, 1984, p. 40
56	RWT 140-75B	K-Ar	Whole rock	47°16.2'	121°10.2'	Teanaway Fm.	46.7±1.1		Tabor and others, 1984, Table 1
57	RWT-250-77A	K-Ar	do.	47°05.0'	121°02.2'	Basalt of Frost Mountain	47.4±4.6		Do.
58	R-20	F-T	Zircon	47°19.8'	121°11.9	Swauk Fm.	52.2±1.9	Unit Tssp	Tabor and others, 1984, Table 2
59	R-19	F-T	do.	47°19.8'	121°11.9'	do.	54.1±2.1	do.	Do.
60	PEH-5-68	K-Ar	Plagioclase	47°28.4'	121°02.5'	Stock at Fortune Creek	50±4	Too young to be crystallization age	Laursen and Hammond, 1974, p. 18

Table 1. *Radiometric analyses of rocks in Snoqualmie Pass quadrangle, Washington—Continued*

Map No.	Sample No.	Method	Materials	Location		Unit	Age (Ma)	Comment and (or) subunit (see Description of Map Units)	Reference
				Latitude	Longtitude				
61	RWT-151-75	K-Ar	Hornblende	47°28.4'	121°02.5	do.	83.6±2.2		Table 2
62	MR2	U-Pb	Zircon	47°08.7'	121°02.7'	Tonalite gneiss of Hicks Butte	153±2; 153±2; 153±10 153±2; 153±2; 153±5	(coarse mesh fraction) (fine mesh fraction)	J.M. Mattinson and C.A. Hopson, written commun., 1980; and Miller and others, 1993, Table 1
63	RWT-379-87	K-Ar	Hornblende	47°07.65	121°01.5'	do.	127.7±16		Table 2
64	MR1	K-Ar	Zircon	47°04.4'	121°04.7'	Quartz Mountain stock	157±2; 157±2; 165±5		J.M. Mattinson and C.A. Hopson, written commun., 1980; and Miller and others, 1993, Table 1
65	RWT 1-88	K-Ar	Hormblende	47°03.4'	121°02.2'	Tectonic complex of Stout (1964)	113.6±4	Amphibolite phacoid	Table 2
66	JTW-79-216	U-Th-Pb	Zircon	47°27.2'	121°24.5'	Rocks of the Eastern melange belt	164.7; 165.9; 183.4; 173.4 158.2; 159.3; 175.9; 152.3	Metagabbro (coarse mesh fraction). (fine mesh fraction)	Frizzell and others, 1987, Table 1

Table 2. *New K-Ar ages from Snoqualmie Pass quadrangle, Washington*

[All USGS K-Ar ages calculated on basis of 1976 IUGS decay and abundance constants (Steiger and Jager, 1977); errors on single K-Ar ages are based on empirically derived curve relating coefficient of variation in age to percent radiogenic argon (Tabor and others, 1985). K_2O was analyzed by S. Neil, P. Kloch, D. Vivit, J.H. Christie, B. Lai, and M. Taylor]

Map No.	Sample No.	Mineral	K_2O (percent)	^{40}ArRad (moles/gmx10^{10})	^{40}ArRad (percent)	Age (Ma)
1	RWT-336-83A*	Whole rock	1.48, 1.42, 1.49, 1.48	0.0121	12.08	0.58±0.07
	RWT-336-83B*	Whole rock	1.28, 1.27, 1.28, 1.32	0.00986	12.73	0.53±0.06
	RWT-336-83C*	Whole rock	1.40, 1.41, 1.45, 1.44	0.00399	2.37	0.20±0.2
	RWT-336-83D*	Whole rock	1.29, 1.28, 1.29, 1.30	0.00755	3.71	0.41±0.1
2	RWT-335-83H**	Whole rock	1.34, 1.29, 1.29, 1.35	0.0457	46.47	2.4±0.1
3	VF-76-479	Hornblende	0.507, 0.512, 0.506, 0.523 0.518, 0.516, 0.520	0.0344, 0.0355	10.6, 10.9	6.2±1.8
4	VF-78-370	Hornblende	0.400, 0.398, 0.410, 0.398	0.0707, 0.0815, 0.0627	9.67, 19.23, 12.99	12.4±1.7
5	VF-82W-565	Hornblende	0.373, 0.371, 0.371, 0.371	0.105	7.495	19.4±3.0
		Biotite	9.17, 9.17	2.18, 2.29	25.44, 46.144	17.1±0.4
6	RWT-608-79	Biotite	9.11, 9.03	2.58	76.55	19.7±0.5
12	RWT-525-77	Hornblende	0.570, 0.574, 0.577, 0.578	0.201	23.51	24.2±1.7
13	RWT-361-79	Hornblende	0.519, 0.524, 0.518, 0.517	0.181, 0.220	11.35, 20.01	27.0±3.0
21	FM-81-109A***	Whole rock	0.66, 0.69	0.218	49.25	22.2±3.0
	FM-81-109B***	Whole rock	0.56, 0.58	0.175	36.6	21.2±0.7
	FM-81-109C***	Whole rock	0.67, 0.68	0.201	64.70	20.6±0.5
	FM-81-109D***	Whole rock	0.59, 0.60	0.191, 0.203	31.96, 33.78	22.9±1.0
22	R-165	Hornblende	0.393, 0.409, 0.400, 0.392	0.127	18.81	22.0±1.6
27	RWT-76-82	Hornblende	0.644, 0.614, 0.617, 0.616	0.192	44.87	21.3±0.6
		Botite	8.57, 8.50	2.71	48.22	22.0±0.7
30	VF-82W-699	Biotite	8.27, 8.25	3.18	50.74	26.5±0.8
65	RWT-151-75	Hornblende	0.305, 0.297, 0.312, 0.298	0.377, 0.358	57.39, 52.26	83.6±2.2
68	RWT-1-88	Hornblende	0.238	0.4016	41.0	113.6±4

*Sample crushed, sieved, and split into 4 fractions: A, (-60+100) mesh, 30 s in 5% HF, 30 min in 50% HCl; B, (-100+200) mesh, acid treated as with split A; C, (-60+100) mesh, no acid treatment; D, (-100+200) mesh, no acid treatment.

**(-10+100) mesh, 60 s in 5% HF, 30 min in 50% HCl.

***Sample crushed and sieved, and split into 4 fractions: A and B sized and treated with acid as with RWT-336-83 A and B, but with 60 s in HF; C and D sized as RWT-336-83 C and D, not treated with acid.

Table 3. *Data for new zircon fission-track ages from Snoqualmie Pass quadrangle, Washington*

[Ages calculated with F = 7.03 x10^{-17} yr^{-1}]

Map No.	Sample No. Reactor run No.	Tracks counted/ Squares counted		Track density x10^6/cm^2		Calculate phi x10^{15}n/cm^2	Grains counted	Age (Ma)
		Fossil	Induced	Fossil	Induced			
4	VF78 370 12/14/78#9	297/267	579/272	1.01	3.86	0.920	3	14.4±0.6
4	Do.	244/178	244/184	1.24	2.40	0.922	3	28.5±0.8
4a	VF 75 148 68/28/77#12	275/241	1082/241	1.03	8.14	1.23	5	9.4±0.4
11	RWT 262 81 4/17/82#9	285/148	475/148	1.75	5.82	0.979	4	17.6±0.6
28	RWT 289 81 4/17/82#15	652/614	824/614	0.96	2.43	0.978	6	23.1±0.7
29	DB 81 421 4/17/82#5	562/368	801/368	1.38	3.95	0.992	5	20.8±0.7
31	RWT 252 81 4/17/82#12	459/172	541/172	2.42	5.72	0.976	5	24.7±1.7