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Geologic Map of the Mount Baker 30- by 60-Minute Quadrangle, Washington

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By R.W. Tabor[1], R.A. Haugerud[2], Wes Hildreth[1], and E.H. Brown[3]

INTRODUCTION

The Mount Baker 30- by 60-minute quadrangle encompasses rocks and structures that represent the essence of the geology of the North Cascade Range (fig. 1, sheet 2; fig. 2, sheet 1). The quadrangle is mostly rugged and remote and includes much of the North Cascade National Park and several dedicated wilderness areas managed by the U.S. Forest Service. Geologic exploration has been slow and difficult. In 1858 George Gibbs (1874) ascended the Skagit River part way to begin the geographic and geologic exploration of the North Cascades. In 1901, Reginald Daly (1912) surveyed the 49th parallel along the Canadian side of the border, and George Smith and Frank Calkins (1904) surveyed the United States' side. Daly's exhaustive report was the first attempt to synthesize what has become an extremely complicated geologic story.

Modern geologic work began almost a half a century later when, in 1948, Peter Misch began his intensive study of the North Cascade Range (Misch, 1952, 1966, and see other references). His insights set the stage for all later work in the North Cascades. Considerable progress in understanding the North Cascades in light of modern plate tectonic theory has been made by E.H. Brown and his students. We have used much of their detailed geologic mapping (fig. 3, sheet 2). Although our tectonic reference frame has changed much with the recognition of plate tectonics and exotic terranes, Misch's observations prove to be remarkably accurate.

Our work in the Mount Baker quadrangle began in 1983 as part of a project to map and compile the geology of the Wenatchee and Concrete 1° by 2° quadrangles at 1:100,000 scale (fig. 1), work that we began in 1975. We have mapped in cooperation with the Division of Geology and Earth Resources, Washington State Department of Natural Resources. We have also benefited by the cooperation and helpfulness of the National Park Service and the U.S. Forest Service.

THE PROBLEM OF NAMES

Previous workers, including the present authors, have applied four kinds of names to geologic units in the map area: lithologic, time-stratigraphic, structural, and stratigraphic-structural (terranes). The plethora of terms is confusing to everyone, but the complexity of the geology allows little simplification. Much of the crust in northwest Washington appears to be built of accreted terranes, hence many units have been given terrane names in the past (see Tabor and others, 1987a,b, 1989; Brandon, 1989). On this map, even though most pre-Tertiary units are terranes or probable terranes, where possible, we have used established lithologic or time-stratigraphic names. In discussion, we commonly move up the nomenclatural ladder to a more comprehensive terrane name. Within the main text describing each unit or group of units, we discuss the use of the appropriate names. Names used in the General Geology overview derive from the more lengthy discussion.

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R.W. Tabor produced this digital map with GIS technology using Alacarte (Wentworth and Fitzgibbon, 1991). Many computer and (or) GIS experts helped, especially Tracey Felger, Todd Fitzgibbon, Patricia Helton, Eric Lehmer, Bob Mark, Chad Nelson, Geoff Phelps, and Pahdy McCarthy. Many thanks to Carl Wentworth, who, no matter how busy, always answered questions about Alacarte.

GENERAL GEOLOGY

Rocks in the Mount Baker quadrangle represent almost all the geologic events recorded in the entire North Cascades: (1) pre-mid-Cretaceous assembly of Mesozoic and Paleozoic terranes that have different paleogeographic origins and structural and metamorphic histories (Tabor and others, 1989; Tabor 1994), (2) mid-Cretaceous to Late Cretaceous thickening by thrusting and pluton accumulation (Misch, 1966; McGroder, 1991; Brown and Walker, 1993; Haugerud and others, 1994), accompanied and followed by regional metamorphism, (3) Eocene strike-slip faulting, extensional faulting, basin development, and continued metamorphism and plutonism (Johnson, 1984, 1985; Brown, 1987; Miller and Bowring, 1990; Haugerud and others, 1991; Miller, 1994), (4) growth of the Cascade magmatic arc in Oligocene to Holocene time (Vance and others, 1986, 1987; Smith, 1993; Tabor and others, 1989), and (5) Quaternary glacial erosion, drainage derangement, and deposition of glacial-derived sediments (Booth, 1987, 1990).

We summarize this geology here. More detailed discussions of bedrock lithologies, young volcanic rocks of Kulshan Caldera and Mount Baker volcanic center, unconsolidated deposits and Quaternary history, complete with more detailed references, follow.

The Straight Creek Fault and the Ross Lake Fault Zone divide the rocks of the quadrangle into a core of deep-seated, thoroughly metamorphosed rocks, flanked by less metamorphosed rocks on either side (fig. 1, sheet 2; fig. 2, sheet 1). These major faults are thought to be predominantly strike-slip (Misch, 1977a; Vance and Miller, 1981, 1992; Miller, 1994), though the rocks of the metamorphic core have been uplifted 15 to 25 km relative to rocks on either side. The Straight Creek Fault, although now predominantly obliterated by Tertiary arc plutons, almost bisects the quadrangle. It separates core rocks on the east from the Northwest Cascades System on the west. Estimates of right-lateral strike slip on the Straight Creek Fault range from about 90 to 190 km (Vance and Miller, 1981, 1992; Vance, 1985; Monger in Price and others, 1985; Kleinspehn, 1985; Coleman and Parrish, 1991; McGroder, 1991). Miller and Bowring (1990) described structural evidence of an early episode of strike slip on the Ross Lake Fault, and Haugerud (1985) and Miller and others (1994) indicated a strong discontinuity in metamorphic grade and history across the zone. Kriens (1988) and Kriens and Wernicke (1990a,b) suggested that the Ross Lake Fault Zone is a minor dislocation in an essentially uninterrupted cross section of a Mesozoic arc ranging from the deep roots in the North Cascade core to the unmetamorphosed marine and terrestrial fore-arc deposits of the Methow terrane to the east.

PRE-MID-CRETACEOUS ROCKS

Rocks west of the Straight Creek Fault: the Northwest Cascades System

West of the Straight Creek Fault, the North Cascades appear to be composed of two fundamental regional structural blocks separated by a complex tectonic belt and high-angle faults (fig. 1, sheet 2; fig. 4, sheet 1; see also Tabor and others, 1989; Tabor, 1994; Tabor and Haugerud, 1999). The northeastern structural block, exposed primarily in the Mount Baker quadrangle, is mostly composed of Paleozoic and Mesozoic volcanic arc and associated clastic wedge deposits along with more thoroughly metamorphosed oceanic rocks, thrust in the mid-Cretaceous into a series of nappes. The overall structure has been likened to a regional mélange by Brown (1987) who, modifying the earlier terminology of Misch (1966, p. 128), called rocks of this structural block the Northwest Cascade System. As explained below, we now think that the structure displays more order than regional mélange implies. The southwestern block, exposed just south of the Mount Baker quadrangle, is mostly Mesozoic clastic rocks of submarine-fan origin and relatively unmetamorphosed oceanic rocks. Tabor and others (1989, 1993, 2002), Frizzell and others (1987), and Tabor (1994) described this block as the western and eastern mélange belts.

Four major nappes, stacked along folded thrusts, and their probably autochthonous footwall make up the Northwest Cascades System (fig. 4, sheet 1; fig. 5, sheet 2). The structural stratigraphy of the Northwest Cascades System appears to be consistent over a wide area of northwest Washington. The rocks in the three lowermost nappes and the autochthon differ enough in lithology, structure, and metamorphic history to warrant consideration as separate terranes (Tabor and others, 1989; Haugerud and others, 1994), but the highest and youngest Gold Run Pass Nappe consists of slices of the lower nappes and autochthon.

The stacked nappes have been displaced by extensional faults. The Glacier Extensional Fault is a regional structure that cuts out the nappe stratigraphy along the west side of the Mount Baker quadrangle.

Rocks of the autochthon

Nooksack Formation (new name adopted here)

At the bottom of the exposed stack of nappes is the Middle Jurassic–Early Cretaceous Nooksack Formation consisting of marine clastic rocks overlying and interfingering stratigraphically with the Middle Jurassic Wells Creek Volcanic Member (newly adopted herein). Sondergaard (1979) considered the rocks of the Nooksack Formation to be a submarine fan deposit associated with a volcanic arc. The Nooksack is generally not strongly penetratively deformed and recrystallized, although in many areas it has slaty cleavage and has been partially recrystallized in sub-greenschist facies.

Excelsior and Welker Peak Nappes

Chilliwack Group of Cairnes (1944) and Cultus Formation of Brown and others (1987)

Structurally overlying the Nooksack Formation along the Excelsior Ridge Thrust Fault (the Church Mountain thrust of Misch, 1966; see table 1) is the Chilliwack Group of Cairnes (1944), composed of partly metamorphosed basaltic and andesitic volcanic rocks, sandstone, siltstone, shale, and minor limestone. The rocks of the Chilliwack formed in an arc setting, and marble in the unit yields fossils ranging in age from Silurian(?) and Devonian to Permian, though most are Mississippian. Rocks are slaty to phyllitic, and planar structures are commonly low angle. Lawsonite and aragonite are common metamorphic minerals but generally are very fine grained. The Chilliwack is depositionally overlain by the Cultus Formation of Brown and others (1987), a Triassic to Early Jurassic marine and dacitic volcanic unit. The Chilliwack Group and Cultus Formation occur mainly in the Excelsior Nappe (fig. 5, sheet 2). The Excelsior Nappe contains significant internal thrusts; rocks of the Chilliwack Group and Cultus Formation are regionally overturned, and they have penetrative fabrics in most locales, suggesting a pre-mid-Cretaceous, possible pre-Late Jurassic tectonic event not seen in the underlying Nooksack Formation.

A unit with similarities to the clastic facies of the Chilliwack Group, as well as other units in the Northwest Cascade System, is the slate of Rinker Ridge. It is poorly exposed in the lower Skagit River valley of the Mount Baker quadrangle. Good exposures in the Sauk River quadrangle to the south (fig. 1; Tabor and others, 2002) indicate that the slate of Rinker Ridge appears to be a fault-bounded block within extensive outcrops of the Easton Metamorphic Suite. Tabor and others (2002) discuss the possible protoliths for the slate of Rinker Ridge and tentatively assign it to the Chilliwack Group. We include it in the Excelsior Nappe in figure 4. Dragovich and others (2002) consider the slate of Rinker Ridge to be Darrington Phyllite.

Bell Pass mélange

The Chilliwack Group and Cultus Formation are overlain along the Welker Peak Thrust Fault by the Bell Pass mélange, much of which is composed of the Elbow Lake Formation of Brown and others (1987), a mixed assemblage of foliated sandstone, argillite (phyllite), ribbon chert, basalt, and very rare marble. Commonly in or associated with the Elbow Lake Formation are ultramafic rocks, various blocks of gneiss and schist, and granitoid rocks ranging from granite to gabbro in composition. These are locally mapped as the Twin Sisters Dunite of Ragan (1963), the blueschist of Baker Lake, the Vedder Complex of Armstrong and others (1983), and the Yellow Aster Complex of Misch (1966). Ages of radiolarians from chert blocks in the Elbow Lake Formation range from Pennsylvanian to Jurassic. Gneiss and schist of the Vedder Complex yield K-Ar and Rb-Sr ages indicating Permian metamorphism. Zircons from Yellow Aster paragneiss have discordant U-Pb ages interpreted to be Precambrian and probably representing detritus derived from Proterozoic basement. Zircons from orthogneiss in the complex yield middle Paleozoic ages. These rocks make up the Welker Peak Nappe (figs. 4, 5). In part, the Bell Pass mélange is coincident physically and in concept with the thick tectonic zone at the base of the mid-Cretaceous Shuksan Thrust Fault as described by Misch (1966, 1980), which separates more thoroughly metamorphosed rocks of the Easton Metamorphic Suite—equivalent to Misch's (1966) Shuksan Metamorphic Suite—from the structurally underlying Nooksack Formation, Chilliwack Group, and Cultus Formation. However, we suspect that some of the mixing and deformation within the Bell Pass mélange predates mid-Cretaceous tectonism and is unrelated to the Shuksan Thrust Fault (see description of the Bell Pass mélange below).

Shuksan Nappe

Easton Metamorphic Suite

The Easton Metamorphic Suite, also referred to the Easton terrane (Tabor and others, 1989), is composed of the Shuksan Greenschist and the Darrington Phyllite. It generally overlies lower nappes along the Shuksan Thrust Fault. The Easton records a more thorough episode of high P/T metamorphism than the other units in the Northwest Cascades System.

The well-recrystallized Shuksan Greenschist and Darrington Phyllite were metamorphosed in blueschist facies, with blue amphibole and lawsonite in rocks of appropriate composition. Chemical composition of most Shuksan Greenschist indicates it was derived from mid-ocean ridge basalt (MORB). Based on isotopic analyses, Armstrong (1980) and Brown and others (1982) interpret the Easton to have a Middle to Late Jurassic depositional age (about 150–160 Ma) and an Early Cretaceous metamorphic age (about 120–130 Ma), with evidence for local earlier metamorphism.

The semischist and phyllite of Mount Josephine crops out in extensive tracts along the west side of the Mount Baker quadrangle and farther west. This unit overlies the Bell Pass mélange along a thrust here correlated with the Shuksan

Thrust Fault. Rocks of this unit are similar lithologically to the Darrington Phyllite, but differ in that their protolith was sandier and that they appear less thoroughly recrystallized than the Darrington. Previous workers have included this unit in the Darrington Phyllite. Greenschist and blueschist intercalations are lacking and rare metavolcanic rocks are greenstone.

Rocks between the Straight Creek Fault and the Ross Lake Fault Zone

In the Mount Baker quadrangle, the high-grade metamorphic core of the North Cascades (fig. 1) is made up of the Chelan Mountains terrane and plutons that intrude it, as well as the Skagit Gneiss Complex, derived from the supracrustal rocks of the Chelan Mountains terrane by higher-grade metamorphism and pervasive deep-seated intrusion. K-Ar ages of schists and gneisses in much of the region between the Straight Creek Fault and the Ross Lake Fault Zone are almost all middle and late Eocene, reflecting early Tertiary unroofing and cooling. Much of the core has been intruded by arc-root magmas of the Tertiary Chilliwack composite batholith.

Chelan Mountains terrane

Rocks of the Chelan Mountains terrane include the Napeequa Schist, the metaplutonic rocks of the Marblemount-Dumbell belt (fig. 1), and the Cascade River Schist. Rocks of the Napeequa Schist are mostly micaceous quartzite, fine-grained hornblende schist, and amphibolites derived from a protolith of oceanic chert and basalt. Minor marble and small bodies of metamorphosed ultramafic rock are also characteristic.

Protolith of the Cascade River Schist was a thick sequence of arc-derived clastic rocks with minor volcanic rocks, now metamorphosed to plagioclase-rich mica schist, metaconglomerate, and amphibolitic schist. Prominent in the metaconglomerate are clasts of the Marblemount pluton, indicating that the Cascade River protolith was deposited on or near eroded Marblemount pluton. Minor constituents of the Cascade River Schist are silicic schists (metatuff), marble, and amphibolite. U-Pb analysis of zircons from a dacitic metatuff yielded ages of about 220 Ma, that is, Late Triassic.

The Marblemount pluton makes up the northern end of the Marblemount-Dumbell plutonic belt which stretches about 75 km southeast from the Mount Baker quadrangle (fig. 1). The crystallization age of the Marblemount protolith is also 220 Ma. That the Cascade River Schist and the Marblemount pluton are the same age suggests deposition of the Cascade River Schist protolith in a forearc or intra-arc basin wherein intrusion of arc-root plutons, such as the Marblemount pluton, was followed by rapid unroofing and further deposition of arc volcanic rocks.

Large amounts of tonalitic to granodioritic magma intruded the supracrustal rocks of the Chelan Mountains terrane in Late Cretaceous and earliest Tertiary time. These stitching plutons were deformed and partially recrystallized to orthogneisses, a process that began in the Late Cretaceous and continued into the early Tertiary as shown by Eocene K-Ar ages and fabrics similar to demonstrably Eocene fabrics in the nearby Skagit Gneiss Complex. South of the Mount Baker quadrangle, the plutons can be grouped by mineral composition, $\delta^{18}O$ content, and some structural features into two groups, which in general reflect modal compositions.

Within a tonalitic group, the orthogneisses of Haystack Creek and Mount Triumph are lithologically similar to orthogneiss bodies within the Skagit Gneiss Complex (see below) which have 60–70 Ma U-Pb zircon ages.

Within a granodioritic group, the Eldorado Orthogneiss was intruded at 90 Ma and is strongly deformed and extensively recrystallized; the orthogneiss of Marble Creek was intruded at about 75 Ma and is extensively deformed and recrystallized; the Hidden Lake stock, apparently on the edge of the deep and thoroughly metamorphosed orogen, was intruded at 75 Ma and is well recrystallized but less deformed than the tonalitic bodies mentioned above; the orthogneiss of Alma Creek is even less deformed and perhaps slightly younger.

The Skagit Gneiss Complex (Skagit Gneiss of Misch, 1966) is banded biotite gneiss, banded amphibolitic gneiss, and large bodies of tonalitic orthogneiss, all mostly migmatitic. The banded gneisses contain abundant orthogneiss layers on all scales. Small bodies of mafic gneiss, mafic migmatite, ultramafic rock, and marble crop out also. All of the complex is pervaded by concordant to discordant deformed bodies of light-colored tonalite and tonalitic pegmatite. Based on composition and observed transition to the protoliths, the banded gneisses appear to be highly metamorphosed Cascade River and Napeequa Schists. The orthogneiss of The Needle yields discordant U-Pb zircon ages and has textural evidence of multiple deformation, suggesting it is a highly metamorphosed pluton of the Late Triassic Marblemount intrusive episode. Much of the Skagit is permeated by dikes and irregular bodies of granite and, locally, granitic pegmatite which are characterized by a prominent lineation and weak, or absent, foliation; isotopic ages of the granites indicate middle Eocene intrusion.

ROCKS IN THE ROSS LAKE FAULT ZONE

Regionally the northwest-trending Ross Lake Fault Zone juxtaposes the higher-grade North Cascade core rocks with a little-metamorphosed sequence of Mesozoic marine and terrestrial deposits of the Methow terrane to the east (fig. 1). In the Mount Baker quadrangle several faults in the zone separate higher-grade metamorphic core rocks from a sliver of lower-grade schist and phyllite—the rocks of Little Jack Mountain—and a tract of minimally metamorphosed Late Paleozoic and Mesozoic oceanic rocks—the Hozomeen

Group. For much of their contact, the rocks of the Hozomeen Group overlie the Little Jack terrane along a low-angle thrust, which probably predates the high-angle faults of the Ross Lake Fault Zone.

Within the Ross Lake Fault Zone, a group of plutons ranging from gabbro to granodiorite in composition and intruding rocks of the Little Jack terrane and of the Skymo Complex of Wallace (1976) makes up the Ruby Creek Heterogeneous Plutonic Belt of Misch (1966). Gneissic and massive plutons suggest a long history of intrusion during and after deformation in the Ross Lake Fault Zone. The only age available from the Ruby Creek belt is middle Eocene (Miller and others, 1989), from a body that on structural grounds must be among the youngest components of the belt.

The Skymo Complex of Wallace (1976), of unknown protolith age and terrane affinity, consists of locally orthopyroxene-bearing mafic to ultramafic cumulate igneous rocks intruded by clinopyroxene gabbro. Hyatt and others (1996), Whitney and others (1996), and Baldwin and others (1997) suggest that the petrologic history of the Skymo Complex is unlike any other unit in the North Cascades. The unit is faulted against the phyllite and schist of Little Jack Mountain, in part along low-angle faults. Skymo rocks are also faulted against orthogneiss of the Skagit Gneiss Complex on the west but are partially engulfed in tonalitic material associated with the metamorphism affecting the Skagit, suggesting that the faults separating the two units have had only modest displacements since Late Cretaceous metamorphism.

Hozomeen Group

Following the example of McTaggart and Thompson (1967) we have, in reconnaissance, roughly subdivided the Hozomeen Group (newly adopted name) into a lowermost exposed unit of probable upper Paleozoic greenstone with minor chert and limestone; a middle unit of predominantly Middle and Late Triassic ribbon chert and argillite; and an upper unit of predominantly Late Triassic greenstone, clastic sedimentary rocks, ribbon chert, and limestone, with minor Jurassic chert and clastic sedimentary rocks. These three units appear to correlate with the upper three of McTaggart and Thompson's four units.

Phyllite and Schist of Little Jack Mountain

Phyllite and schist of Little Jack Mountain comprise mostly biotite±amphibole-bearing metapelite and lesser meta-arenite, with minor fine-grained amphibolite and rare recrystallized ribbon chert and marble. Scattered pods of meta-ultramafic rocks are characteristic of the unit. Metadacite porphyry dikes, some with little deformation and others strongly lineated and (or) foliated, are abundant. The protolith age is pre-Late Cretaceous but otherwise unknown; we tentatively consider it to be Mesozoic, the age of most dominantly clastic terranes in the Pacific Northwest.

ROCKS EAST OF THE ROSS LAKE FAULT ZONE

A small area of sandstone and argillite, probably correlative with the Thunder Lake unit (O'Brien, 1986) exposed to the north in British Columbia, crops out on the east side of the quadrangle. These rocks are in the Methow terrane (fig. 1) and are separated from the Hozomeen Group by the Hozomeen Fault.

LATE OROGENIC AND POSTOROGENIC DEPOSITS

Eocene extension associated with strike-slip faulting opened depressions at shallow levels, where fluviatile feldspathic sandstone and conglomerate accumulated (Tabor and others, 1984; Johnson, 1985; Heller and others, 1987), while metamorphism continued in the Skagit Gneiss Complex. Most of such deposits are preserved outside of the Mount Baker quadrangle, but a few remnants crop out in the quadrangle. Sandstone and conglomerate of the Eocene Chuckanut Formation crop out along the west side of the quadrangle, in part separated from underlying older rocks by low-angle extensional faults. Smaller patches of probably partly correlative rocks (mapped as older sandstone and conglomerate) are preserved on Mount Despair, near Bacon Peak, under and near the volcanic rocks of Big Bosom Buttes, and along the Straight Creek Fault. Younger sandstone and conglomerate crops out along the Straight Creek Fault north of Marblemount where a clast of Marblemount pluton with a zircon fission-track age of 45 Ma shows the deposit to be late middle Eocene or younger.

ROCKS OF THE CENOZOIC CASCADE MAGMATIC ARC

The oldest known Cascade arc rocks in the Mount Baker quadrangle are the 34-Ma gabbro of Copper Lake and the 32-Ma granodiorite of Mount Despair, early phases of the Chilliwack composite batholith. The birth of the Cascade magmatic arc was about 36 Ma (Vance and others, 1987; Smith, 1993). Arc-root plutons of the batholith range from gabbro to alaskite in composition and from 32 to 2.5 Ma (Oligocene to Pliocene) in age. In the quadrangle, plutons of the batholith with ages of about 30 Ma and older appear to belong to the Index family of arc-root plutons as defined by Tabor and others (1989). Those in the range of about 30 to 20 Ma are in the Snoqualmie family, and those younger than 20 Ma are in the Cascade Pass family.

Volcanic rocks of the Cascade magmatic arc are sparse—preserved in scattered down-faulted blocks or caldera-fill deposits. They commonly were erupted on eroded early phases of the Chilliwack composite batholith and then intruded by younger phases. The volcanic rocks of Big Bosom Buttes, of Mount Rahm, and of Pioneer Ridge range from dacite to less common andesite and basalt in composition and are probably Oligocene in age. The Hannegan Volcanics are mostly rhyolitic to dacitic and erupted in the Pliocene. The volcanic deposits of Kulshan Caldera are mostly rhyodacites and are Pleistocene. The Kulshan deposits underlie andesitic breccia and lava of the Mount Baker volcanic center, the youngest part of which includes Mount Baker itself, an active calc-alkaline stratovolcano.

QUATERNARY GLACIAL AND NON-GLACIAL DEPOSITS

[Bracketed numbers refer to locations shown on figure 6]

Glaciations in the Mount Baker quadrangle are recorded by deposits of both alpine and ice-sheet glaciers. Valley-bottom and valley-wall deposits in the upland trunk drainages (such as Big and Little Beaver Creeks, Silver Creek [74], Perry Creek [77], Goodell Creek [96], Thunder Creek [69], and the Cascade River include till and outwash from alpine glaciers that originated at the drainage headwalls. Most of these deposits probably date from the Evans Creek stade of the Fraser glaciation of Armstrong and others (1965), about 20,000 yr B.P., but were probably augmented during the Vashon stade, about 15,000 yr B.P., when the high peaks in the east two-thirds of the Mount Baker quadrangle appear to have once again been a significant ice source. Additional deposits have been derived from lesser expansions of these same glaciers in Holocene time.

In the western part of the quadrangle, deposits derived from the Puget lobe of the Cordilleran ice sheet fill many of the lower valleys and mantle the upland surfaces. Virtually all of these deposits date from the Vashon stade of the Fraser glaciation culminating about 15,000 yr B.P. (Booth, 1987).

Unvegetated moraines and outwash are common in many alpine cirques in the quadrangle, especially below still-active alpine glaciers.

Landslides, many of them still active, ornament slopes throughout the quadrangle. Large, probably catastrophic, slides came down into the valley of the North Fork of the Nooksack River, the Skagit River valley, and the Baker River valley. The Baker River slide is probably latest Pleistocene in age. The North Fork Nooksack and Skagit slides are clearly Holocene.

DESCRIPTION OF THE BEDROCK UNITS

By R.W. Tabor and R.A. Haugerud

[Bracketed numbers refer to locations shown on figure 6]

ROCKS WEST OF THE STRAIGHT CREEK FAULT

Rocks of the Northwest Cascade System

The terminology of the nappes and terranes has varied considerably since the rocks of Northwest Cascade System were first studied by Misch (1952, 1966). Table 1 illustrates nomenclatural development. Although we recognize that each of the major units herein described is a probable terrane, we will use their lithologic or time-stratigraphic names or refer to them in their structural position as a nappe.

From highest to lowest, nappes and autochthon of the Northwest Cascades System (figs. 4 and 5) are the Gold Run Pass Nappe composed of parts of the underlying nappe and autochthon units, the Shuksan Nappe composed of the Easton Metamorphic Suite, the Welker Peak Nappe composed of the Bell Pass mélange, the Excelsior Nappe composed of the Chilliwack Group of Cairnes (1944) and Cultus Formation of Brown and others (1987), and the probable autochthon composed of the Nooksack Formation, including its Wells Creek Volcanic Member (both newly named herein). We have recognized the Gold Run Pass Nappe (fig. 4) only locally, in the vicinity of Gold Run Pass [48]. Complicated imbrication of units east of Goat Mountain [46] suggests that Gold Run Pass Nappe or another nappe could be present here also.

Brown (1987) describes the nappe-bounding faults. Many show evidence of both brittle and mylonitic deformation, the later especially along the margins of more rigid crystalline rocks. Because the Bell Pass mélange was strongly deformed prior to development of the nappes (see below), early formed fabrics and structures in it may not be easily separated from structures developed during mid-Cretaceous thrusting. The true characteristics of the Welker Peak and Shuksan Thrust Faults are thus obscured. The Excelsior Ridge Thrust Fault is described by Sevigny (1983, p. 139–140; his Church Mountain thrust) on the east end of Excelsior Ridge, about the only place it is well exposed. Sevigny describes mylonitic rocks including serpentinite, tectonic blocks of metachert, and volcanic rocks, including a large block of titaniferous basalt. These lithologies are more appropriate for the Bell Pass mélange than for a fault zone between Nooksack Formation and Chilliwack Group rocks, suggesting that more complex faulting may be involved here also.

We have mapped the Glacier Extensional Fault (GEX) on the west side of the quadrangle (figs. 2 and 4), where it bounds the Eocene Chuckanut Formation. We have traced it south to where it separates rocks of the Welker Peak Nappe and the Nooksack Formation. Earlier workers (see Misch, 1966; Brown and others, 1987) mapped parts of the southern extent of the fault as a thrust fault. Previously, we (Tabor and others, 1994) correlated it with the Welker Peak Thrust. Because where it bounds the dipping beds of the Chuckanut Formation, it is clearly extensional (cross sections A–A' thru D–D' and I–I') and because where it separates the Welker Peak Nappe and the underlying Nooksack Formation several thousand meters of structural stratigraphy are missing, we now interpret this fault as extensional (see Wernicke, 1981, p. 645). In the vicinity of Sulphur Creek, the hangingwall picks up all the structural units, suggesting displacement is dying out to the south (cross sections D–D'' and I'–I''). We cannot be certain where the fault goes beyond the Sulphur Creek area, but we have tentatively placed it between the Chilliwack Group and the Nooksack Formation west of Lake Shannon. The Excelsior Nappe is thinner here than elsewhere supporting the extensional interpretation.

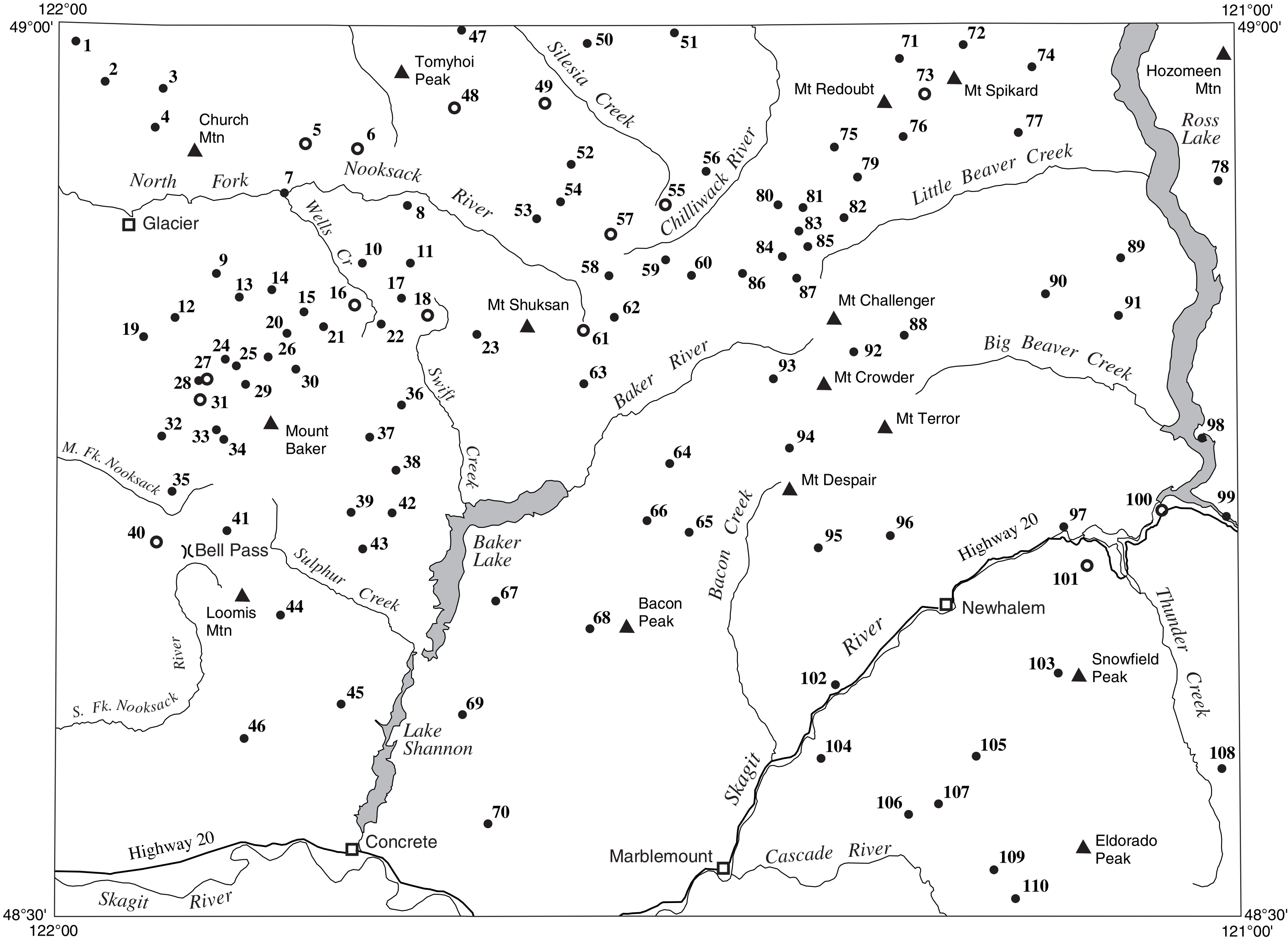

Figure 6. Locations of obscure places in the Mount Baker quadrangle. Numbers indicate localities referred to in text. Numbered circles are places not named on the 1:100,000-scale base.

A second inferred extensional fault cuts out a section southwest of Goat Mountain where it separates Darrington Phyllite from the slate of Rinker Ridge, a probable Chilliwack Group correlative. The Bell Pass mélange is missing. This area is extremely complex, however, for there seems to be a slice of the Gold Run Pass Nappe in the hanging wall (cross section E–E'). The scarce outcrops and somewhat unusual lithologies for the units allow many interpretations.

Misch (1966) first described the thrust stratigraphy of the Northwest Cascade System and attributed the thickening of crust to west-verging shortening. Since his pioneering work, other workers (for instance, Brandon and Cowan, 1985; McGroder, 1991) have defended east-west or northeast-southwest shortening. Brown (1987) first proposed that the units were stacked by northwest-southeast shortening. Haugerud and others (1994) summarize the evidence and arguments for these opposing views. Most workers agree that thrusting took place in the mid-Cretaceous (Brandon and others, 1988; Brown, 1987). Extensional faults have not been widely recognized in the North Cascades, although deposition of early middle Eocene sedimentary and volcanic rocks in localized basins indicates at least local extension, and much of this has been related to a strike-slip regime (Tabor and others, 1984; Johnson, 1985). Movement on the Glacier Extensional Fault was in part post middle Eocene and may have helped unroof the deeply formed Eocene rocks of the North Cascade metamorphic core (Skagit Gneiss Complex).

Shuksan Nappe

Easton Metamorphic Suite

In an earlier paper, we (Tabor and others, 1993. p. 6) revised the Easton Schist as the Easton Metamorphic Suite, which, as used here, indicates the rocks referred to by many workers as the Shuksan Metamorphic Suite of Misch (1966) and (or) the Shuksan Suite of Brown (1986). The **Shuksan Greenschist** and **Darrington Phyllite** make up the Easton Metamorphic Suite. The Easton Metamorphic Suite within the Northwest Cascades System extends about 88 km southeast of the Mount Baker quadrangle and is also exposed east of the Straight Creek Fault in the vicinity of the Yakima River (fig. 1). Brown and Blake (1987) discuss possible correlations of the rocks of the Easton Metamorphic Suite with similar units in Oregon and Washington. The Easton Metamorphic Suite is the sole component of the Easton terrane (Brandon, 1989; Tabor and others, 1989, 2002; Nokleberg and others, 1994).

Much has been written about the Shuksan Greenschist and Darrington Phyllite in and adjacent to the Mount Baker quadrangle, beginning with the pioneering work of Vance (1957, p. 12–60) and Misch (1959, 1966, p. 109–112). Brown (1974, 1986), Morrison (1977), Haugerud (1980), Haugerud and others (1981), Street-Martin (1981), Brown and others (1982), Dungan and others (1983), Owen (1988), and Dragovich and others (1999, 2000) report chemical and isotopic data and describe the Easton Metamorphic Suite. We summarize briefly here.

The Shuksan Greenschist is predominantly fine-grained, but well-recrystallized, epidote-chlorite-amphibole-quartz albite schist. The amphibole is typically crossite, Na-actinolite, or actinolite, depending mostly on the bulk-rock Fe^{3+} content. Epidote balls, knots, and masses formed during early static hydrothermal metasomatism; the balls are vesicle fillings (Haugerud, 1980; Haugerud and others, 1981; compare with Misch, 1965). Co-occurrence of abundant white mica, Na-amphibole, and hematite suggests oxidation and incorporation of potassium during submarine weathering. Haugerud and others (1981, p. 380) and Brown (1986, p. 151) show that the Easton Metamorphic Suite crystallized at T = 330° C to 400° C and at P = 7–9 kb.

Chemistry and relict textures indicate that the Shuksan Greenschist was derived from mid-ocean-ridge basalt (MORB) (Dungan and others, 1983). Relict textures indicate that much of the protolith was pillows or breccia.

Darrington Phyllite is predominantly muscovite-chlorite-albite-quartz schist, locally with lawsonite. The phyllite typically fractures along well-developed secondary pressure-solution cleavages with concentrations of fine-grained graphite and (or) oxides, giving the impression in hand specimen that mineral grains are much smaller than is evident in thin section. Much of the rock is really a schist. Multiple crenulations on cleavage surfaces are common. Bulk composition of most Darrington phyllite suggests the protolith was a siliceous siltstone; coarser grained, more feldspathic schists were sandstones, and rare, more siliceous lithologies with quartz-rich layers may be meta-chert.

Originally, Misch (1966, p. 109) thought that the protolith basalt of the Shuksan Greenschist stratigraphically overlay the protolith sediments of the Darrington Phyllite, but Haugerud and others (1981, p. 377) and Brown (1986, p. 145) consider the Darrington to have stratigraphically overlain the Shuksan. On a small scale, the two units are interlayered, although the expected sequence on the ocean floor would be sediments over basalt; Morrison (1977, p. 66–67) and Dungan and others (1983, p. 132) suggest that thin ferruginous chert beds between greenschist and phyllite, mostly present south of the Mount Baker quadrangle (Tabor and others, 2002), represent submarine hot-spring deposits on freshly erupted ocean-floor basalt. Owen (1988, p. 7–17) discusses the chemistry and origin of the ferruginous rocks at length.

Armstrong (1980) and Brown and others (1982, p. 1095) proposed that the protolith age of the Easton Metamorphic Suite is Jurassic, possibly Late Jurassic. A probable Middle Jurassic protolith age for the Easton is indicated by a 163-Ma zircon age from a diorite body in the probable correlative semischist and phyllite of Mount Josephine (see below). The Easton was metamorphosed at about 130 Ma (Brown and others, 1982). A discordant U-Th-Pb age of probable detrital zircon from blueschist considered to be correlative with the Shuksan Greenschist, about 80 km south of the quadrangle, suggests a Precambrian source for the zircon (Tabor and others, 1993, p. 13).

Semischist and phyllite of Mount Josephine

A large area of phyllitic rocks exposed north of the Skagit River and mostly west of the Mount Baker quadrangle has long been correlated with the Darrington Phyllite of the Easton Metamorphic Suite (Misch, 1966; Miller, 1979; Brown, 1986; Brown and others, 1987; Gallagher and others, 1988). Within the Mount Baker quadrangle, these rocks are very much like the Darrington, differing only in having a sandier protolith and generally lacking the prominent multiple crenulations characteristic of the Darrington Phyllite. Farther west, however, the unit contains silicic metatuff, metaconglomerate, metadiorite, and other mafic igneous rocks as well as scattered ultramafic rocks (Gallagher, 1986). All of these lithologies are rare in the Easton Metamorphic Suite exposed in the Mount Baker quadrangle, and, although Gallagher and others (1988, p. 1420) indicate metamorphic conditions in the semischist and phyllite of Mount Josephine were similar to those in the Easton Metamorphic Suite, well-recrystallized greenschist and blueschist have not been found. However, on a regional scale, the Mount Josephine rocks are on strike with typical Darrington Phyllite exposed in the Shuksan Nappe south of the Skagit River (fig. 4). In the northwest part of the quadrangle the Mount Josephine unit appears to form the west limb of a large antiform in the Shuksan Nappe (cross sections A–A" and B–B').

No isotopic ages are available from the semischist and phyllite of Mount Josephine, but $^{206}Pb/^{238}U$ ages from zircon obtained from an isolated metadiorite body on Bowman Mountain (fig. 1; about 4 km west of the Mount Baker quadrangle) surrounded by semischist containing clasts of metadiorite yield a 163 Ma age (Middle Jurassic) (Brown, 1986, p. 146; Gallagher and others, 1988, p. 1420). Gallagher and others (1988, p. 1420–1421) argue that the metadiorite is part of a volcanic arc penecontemporaneous with deposition of the sediments that became the Mount Josephine unit.

Although we consider the correlation of the semischist and phyllite of Mount Josephine with the Darrington Phyllite to be essentially correct, we have mapped the units separately to emphasize their lithologic and structural contrasts.

Excelsior Nappe

Above the Excelsior Ridge Thrust Fault, the Excelsior Nappe is composed mostly of the Chilliwack Group of Cairnes (1944) and the overlying Cultus Formation of Brown and others (1987). These rocks are truncated by the Welker Peak Thrust Fault. We also include the slate of Rinker Ridge, a unit of uncertain correlation exposed mostly to the south of the Mount Baker quadrangle, in the Excelsior Nappe.

Misch (1960; 1966, p. 125) considered the Chilliwack Group to be separated from the underlying Nooksack Group of Danner (1957, 1958) by the Church Mountain Thrust, named for a fault on the south side of Church Mountain. We consider the namesake fault on Church Mountain to be a younger high-angle fault, probably of Tertiary age and unrelated directly to the mid-Cretaceous faulting that has emplaced the nappes. The thrust that separates Late Paleozoic Chilliwack Group rocks from the underlying Mesozoic Nooksack Formation is rarely well exposed, but Sevigny (1983; p. 139–141) describes the low-angle fault exposed on the east end of Excelsior Ridge [6], and we prefer the name Excelsior Ridge Thrust Fault for the lower bounding fault of the Excelsior Nappe.

The Chilliwack Group, Cultus Formation of Brown and others (1987), and the Slate of Rinker Ridge (a probable Chilliwack Group correlative) are the major components of the Chilliwack River terrane (Nokleberg and others, 1994).

Chilliwack Group of Cairnes (1944)

A thick sequence of metagraywacke, argillite, phyllite, and greenstone with minor marble along the Canadian border in the Mount Baker quadrangle was mapped by Daly (1912) as his Chilliwack Series. Cairnes (1944) described these same rocks as the Chilliwack Group. The unit is extensively exposed in a series of thrust slices north of 49° N., where it has been described by Monger (1966, 1970, 1989). The rocks of the Chilliwack Group of Cairnes (1944) crop out throughout the west side of the Mount Baker quadrangle and have been traced to the south for about 30 km (the Excelsior Nappe in fig. 4; Vance, 1957; Misch, 1966). Correlatable rocks appear on the east side of the Straight Creek Fault, north of the Yakima River, 140 km south of the Mount Baker quadrangle (fig. 1; Tabor and others, 2002).

Misch (1952; 1966, p. 116; 1979) included chert, some greenstone, argillite, and lithic graywacke in the Chilliwack Group which we include in the Elbow Lake Formation of Brown and others (1987) (see description of Bell Pass mélange below).

Within the Chilliwack Group we have mapped separately areas of predominantly mafic volcanic flows and breccias. In addition we show separately the volcanic rocks and sedimentary rocks of Mount Herman [11]. Bedding is generally obscure in the volcanic rocks of Mount Herman, but where found, is steeper than much of the bedding in other rocks of the Chilliwack Group.

The rocks of the Chilliwack Group grade from little-deformed to strongly penetratively deformed with phyllitic foliation mostly parallel to bedding. Where metamorphosed, the rocks are recrystallized to phyllite, semischist, greenstone, or greenschist, mostly in sub-greenschist facies. Lawsonite and aragonite occur throughout the Chilliwack Group and in the Cultus Formation of Brown and others

(1987). Brown and others (1981, p. 172–173) and Smith (1986) describe metamorphic mineral assemblages of the Chilliwack Group. Bedding data and original top directions shown by graded beds, scour structures, and load casts indicate complex structure including extensive domains of overturned gently dipping beds. Monger (1970, p. 52–53) reports large-scale recumbent folds and thrusts in the Chilliwack Group rocks in British Columbia. As the underlying Nooksack Formation appears generally less recrystallized and has much simpler structure, we surmise that the Chilliwack was strongly deformed, although perhaps not metamorphosed, prior to formation of the mid-Cretaceous nappes (Haugerud and others, 1992). Smith (1986, p. 131–134) and Brown (1987, p. 209) suggest that the metamorphism was mid-Cretaceous.

Fossils are locally abundant in calcareous rocks of the Chilliwack Group and range from Silurian–Devonian to Permian in age (table 2, Nos. 13f–33f). Distinctive 1- to 3-cm-diameter crinoid columnals led Danner (1966) to correlate many marble outcrops with his Red Mountain limestone unit, exposed west of the Mount Baker quadrangle (fig. 1), which he considered to be Pennsylvanian in age. Liszak (1982) restudied the Red Mountain limestone fauna and determined a Mississippian (late Visean) age for it, which we adopt for all the large-crinoid limestones of the Chilliwack Group (table 2, Nos. 17f, 18f, 21f, 23f, 25f, 29f, 30f). Single crystal U-Pb ages of detrital zircons from Chilliwack clastic rocks in the Jackman Creek area suggest Late Devonian deposition of the original sediments (McClelland and Mattinson, 1993). The irregular distribution of Devonian, Mississippian, Pennsylvanian, and Permian fossils substantiates the complex structure shown by bedding orientation and facing directions and suggests that few intact stratigraphic sections remain.

The youngest rocks of the Chilliwack Group are the well-bedded sedimentary rocks of Mount Herman. However, the kinship of rock that bears fossils with the volcanic rocks of Mount Herman is not unassailable. Guadalupian (Late Permian) (?) radiolaria (table 2, No. 34f) occur in a small block of well-bedded siliceous siltstone that overlies the early Quaternary ignimbrite of the Kulshan Caldera and to the southwest is in contact with metagabbro in the caldera wall. The siltstone is presumably a block that slid from the caldera wall, probably from the nearby volcanic rocks of Mount Herman, but we found no similar sedimentary rocks with the nearby undisturbed Mount Herman strata. However, the distinctive strata of the block are identical to well-bedded siltstone that we have found southwest of Lake Ann [23] as talus blocks below cliffs of hornfelsic sediment that we map as the sedimentary rocks of Mount Herman.

Franklin (1974, p. 69), Monger (1977, p. 1851), and Christenson (1981, p. 125–151) suggest that the clastic sedimentary rocks of the Chilliwack Group represent deep-water fan deposits and that they and the associated volcanic rocks were derived from a calc-alkalic island arc. Chilliwack Group rocks in the Mount Baker quadrangle are described by Misch (1966, p. 116), Christenson, (1981), Blackwell (1983, p. 16–65), Sevigny (1983, p. 45–76), and Smith (1986, 1988). Monger (1966, 1970) described the unit just north of the border in British Columbia. Chemical and some isotopic analyses of volcanic rocks of the Chilliwack Group are in Christenson (1981, p. 172–179), Blackwell (1983, p. 209–217), and Sevigny and Brown (1989, p. 394).

Cultus Formation of Brown and others (1987)

Well-bedded tuffaceous siltstone, fine-grained sandstone, and thin limestone beds and lenses characterize the Cultus Formation of Brown and others (1987) in the Mount Baker quadrangle. Daly (1912, p. 516–517) mapped and named the Cultus Formation along the Canadian border, but he either did not observe or at least did not emphasize the volcanic component of the formation. Monger (1966, p. 94–95; 1970, p 11–12) described volcanic-rich sandstone in the Cultus in British Columbia, immediately to the north of the Mount Baker quadrangle, though he found only one volcanic outcrop in the sequence. Blackwell (1983, p. 70–74) identified dacitic extrusive rocks with thin, fossiliferous limestone interbeds (table 2, Nos. 4f, 5f) in Cultus lithologies. Brown and others (1987) included Triassic dacitic tuff and flows south of Mount Baker volcano in the Cultus Formation, and we follow their example here.

Monger (1970, p. 12) describes a depositional, albeit disconformable, contact between rocks we would assign to the Cultus Formation of Brown and others (1987) and the underlying Chilliwack Group of Cairnes (1944), but he also observed that the Chilliwack was in part thrust over the Cultus (Monger, 1970, p. 52). On a ridge north of Canyon Creek [3] and on the main ridge south of Thunder Creek [69], the Cultus appears to overlie rocks of the Chilliwack Group. The nature of the contacts, however, is unknown. Planar structures in rocks north of Loomis Mountain suggest strata of the Cultus Formation extend beneath rocks of the Chilliwack Group, indicating a thrust fault.

In the Mount Baker quadrangle, radiolarians from several localities are Triassic in age (table 2, Nos. 5f, 6f, 11f), but in the area of Frost Creek [1], a chert layer yields probable Middle to Late Jurassic radiolarians (table 1, No. 9f). Chert pods in faulted rocks on the ridge north of Canyon Creek yield questionable Late Triassic radiolaria (table 2, No. 7f). The rocks at this site are well-bedded limestone with tuffaceous argillite and siltstone interbeds, typical of the Cultus. Unfortunately, Daly (1912, p. 510, 515) reported a collection of Paleozoic fossils typical of the Chilliwack Group from very near this locality (table 2, No. 16f, as best as can be determined from the old descriptions). We have inferred a fault between the two fossil localities. Monger (1970, p. 12–13) reported fossil ages from Late Triassic to Late Jurassic in the Cultus Formation of British Columbia. For further descriptions, see Monger (1966, p. 91–102; 1970, p. 11–14) and Blackwell (1983, p. 70–74).

Gabbroic and tonalitic intrusions

Several mappable metagabbro and metatonalite bodies intrude rocks of the Chilliwack Group and Cultus Formation. Some were mapped by previous workers as tectonic blocks of the Yellow Aster Complex of Misch (1966), but locally show good evidence of intrusion. See the description of the Bell Pass mélange below for further discussion of this problem. The best example is a gabbro intruding Chilliwack north of Canyon Creek. Blackwell (1983, p. 105–106, 213) describes and reports chemical data for a gabbroic body on the south side of Loomis Creek [44].

Slate of Rinker Ridge

Isolated outcrops of slate and thin-bedded sandstone crop out in the vicinity of the Skagit River, south and west of Concrete. Rhythmite is locally common. Rare outcrops of greenstone can generally be identified as dikes. Previous workers have considered these outcrops part of the Darrington Phyllite (Misch, 1966; Huntting and others, 1961; Brown and others, 1987; Dragovich and others, 2002), but we correlate them with the slate of Rinker Ridge, exposed more extensively in the Sauk River quadrangle to the south. Tabor and others (2002) describe the criteria by which these rocks may be distinguished from the Darrington Phyllite. In general, the slate of Rinker Ridge has the same metamorphic mineralogy but is less recrystallized than Darrington Phyllite, contains more metasandstone, has more prominent bedding that is commonly not parallel to foliation, and shows less evidence of multiple deformation. We have found no high-pressure minerals such as aragonite or lawsonite.

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

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

2. Chilliwack Group of Cairnes (1944). To the south the slate of Rinker Ridge is on strike with and not easily distinguished from rocks assigned to the Chilliwack Group (see Tabor and others, 2002). The similarity of the clastic rocks and the degree of deformation in the Chilliwack and the Rinker Ridge units suggest that the slate of Rinker Ridge may be a clastic facies of the Chilliwack, albeit more pelitic than that found elsewhere in that unit. In the Excelsior Nappe, it appears to link two areas of Chilliwack as a structural high (fig. 4), faulted up from a structural position underlying the Shuksan Nappe (Easton Metamorphic Suite).

3. Semischist of Mount Josephine. Another candidate postulated as a correlative of the slate of Rinker Ridge is the semischist of Mount Josephine. The age of the Mount Josephine unit is also unknown, but its rocks have been correlated with the Darrington Phyllite (Misch, 1966; Brown and others, 1987). The Mount Josephine unit commonly contains considerable metasandstone. The degree of metamorphism in the Mount Josephine unit commonly appears to be intermediate between those of the slate of Rinker Ridge and the Darrington Phyllite.

For the present, the structural position and along-strike equivalency with the Chilliwack Group are the most compelling arguments, and we tentatively correlate the slate of Rinker Ridge to the Chilliwack Group. It would then be part of the upfolded or upfaulted Excelsior Nappe defining a broad structural high extending from the Mount Baker window southeastward to the Straight Creek Fault (fig. 4). We have no direct evidence for the metamorphic age of the slate of Rinker Ridge, but if it was metamorphosed with the rest of the Chilliwack Group, its metamorphic age is mid-Cretaceous.

Welker Peak Nappe

Bell Pass mélange

Structurally above the Nooksack Formation, Chilliwack Group of Cairnes (1944), and Cultus Formation of Brown and others (1987) is a unit we call the Bell Pass mélange, which is mostly made up of the late Paleozoic and Mesozoic Elbow Lake Formation of Brown and others (1987). Most earlier workers included rocks of the Elbow Lake Formation in the Chilliwack Group (Misch, 1966, p. 116, 1979; Vance, 1957, p. 200–210; Rady, 1980, p. 86–88). Haugerud (1980, p. 62–87) recognized the fragmented, mixed character of some of these rocks, and Blackwell (1983, p. 81–86), Sevigny (1983, p. 93–97), Jones (1984, p. 63–69), Ziegler (1986, p. 66), and Leiggi (1986, p.45–46) distinguished these rocks as the Elbow Lake unit, the chert-basalt unit, or the Haystack Mountain unit of Cruver (1983). The Elbow Lake [40] Formation is mostly disrupted clastic rocks with associated banded radiolarian chert and greenstone. The mélange also contains exotic clasts: gneiss of the Yellow Aster Complex of Misch (1966); blueschist- and albite-epidote-amphibolite-facies mafic and siliceous schists of the Vedder Complex of Armstrong and others (1983); very low-T, high-P rocks of the blueschist of Baker Lake; and scattered ultramafic rocks, the largest of which is the Twin Sisters Dunite of Ragan (1963). Some parts of the Bell Pass in which tectonic mixing is more severe were mapped as mélange by Brown and others (1987). Although all contacts of the exotic blocks are probably faults, we show them as unfaulted except in the case of very large phacoids such as the Twin Sisters Dunite and the large slabs of Yellow Aster Complex at Yellow Aster Meadows and at Park Butte.

Components of the Bell Pass mélange were included in the Chilliwack River terrane by Nokleberg and others, 1994, but could well be considered a separate terrane on the basis of age, lithology, and tectonic history.

The Elbow Lake Formation of Brown and others (1987) consists of highly disrupted lithic subquartzose sandstone, argillite, wispy mafic tuff and argillite, ribbon chert, and greenstone. The latter two lithologies dominate locally. Small marble phacoids are also present. Clastic rocks grade over a few meters to slate, phyllite, and semischist. Within the Mount Baker quadrangle, there are no areas free of outcrop-scale disruption; we cannot describe an undisturbed stratigraphic section of the Elbow Lake Formation. Greenstone in the Elbow Lake Formation is derived from Ti-rich oceanic basalt, including mafic tuff, diabase, and gabbro. Based on lithology and some basalt chemistry, several workers (Sevigny, 1983, p. 93–97; Blackwell, 1983, p. 85–86; Jones, 1984, p. 69; Leiggi, 1986, p. 45–48) correlated the lithologies of the Elbow Lake Formation with the Haystack Mountain unit of Cruver (1983), exposed near Haystack Mountain about 9 km southwest of the Mount Baker quadrangle (fig. 1). Tabor (1994) discussed some of the chemical differences and suggested that the Haystack Mountain unit is part of the Helena-Haystack mélange, a tectonic unit younger than the Bell Pass mélange, characterized by a very different tectonic assemblage (fig. 4). Sevigny and Brown (1989) report chemical characteristics of the high-Ti metabasalts of the Elbow Lake Formation of Brown and others (1987).

Metamorphism in rocks of the Elbow Lake Formation is generally sub-greenschist facies, locally with pumpellyite and lawsonite (Blackwell, 1983, p. 80). Very fine grained blueschist crops out locally within the Elbow Lake Formation, locally interlayered with marble or metachert (Brown and others, 1987, p.4). This rock, the **blueschist of Baker Lake** (Baker Lake Blueschist of Brown and others, 1987), is characterized by distinctive high-pressure/low-temperature crossite + lawsonite ± aragonite metamorphism. The protolith assemblage for the blueschist—commonly basalt with high-Ti clinopyroxene—and the association with chert strongly suggest the blueschists are derived from the Elbow Lake Formation, which appears to be largely Triassic and older, thus suggesting that metamorphism is post-Late Triassic. Brown and others (1987) report a 127 Ma whole-rock K-Ar age from associated metachert of uncertain significance (table 3, No. 68), but an age which is appropriate for metamorphism of the Easton Metamorphic Suite. Leiggi (1986, p. 113–136), Ziegler (1986, p. 85–92), and Brown and others (1987, p. 4) describe petrographical, mineralogical, and chemical aspects of the blueschist of Baker Lake. Brown and others (1987, p. 4) suggest the protolith was an alkali basalt, not MORB as characteristic of the Shuksan Greenschist.

Ribbon chert of the Elbow Lake Formation, commonly highly deformed and locally occurring as resistant knockers, yields mostly Triassic and Middle Jurassic radiolarians (table 2, Nos. 35f–55f); a few late Paleozoic forms (Nos. 37f, 40f, 41f, 52f) have been identified. Based on correlations with rocks in the San Juan Islands and evidence there for a Middle to Late Jurassic orogenic event discussed by Haugerud and others (1994, p. 2E–44, 45), a sample (table 2, No. 36f) yielding Late Jurassic radiolarians is anomalous.

Misch (1960, 1966, p. 104–105, 1963) described pyroxene gneiss, variously deformed and metamorphosed tonalitic to gabbroic intrusions, and ultramafic rocks as his **Yellow Aster Complex**, which he thought was basement to the volcanic and sedimentary rocks of the Northwest Cascades System. Misch (1966) suggested that, although one could only say with certainty that the age of the Yellow Aster was pre-Devonian, the evidence of a long and complex history of metamorphism and intrusion in the complex suggested the older components might be Precambrian. He concluded that most rocks of the Yellow Aster Complex occurred as faulted slivers along the Shuksan Thrust Fault. Since Misch's mapping, we have identified other lithologies in the Yellow Aster Complex, including definite supracrustal materials such as marble and associated calc-silicate gneiss. Gneissic granite porphyry crops out on Kidney Creek, northeast of Church Mountain. The association of the gneiss and mostly mafic igneous rocks is typical of the Yellow Aster, but in many areas distinguishing younger (upper Paleozoic and (or) Mesozoic) intrusions from older intrusive material that was emplaced tectonically is difficult. We have separated crystalline rocks, all of which were formerly mapped as Yellow Aster Complex, into three units:

1. **Gneissic rocks** of the Yellow Aster Complex of Misch (1966). Well-layered pyroxene gneiss, calc-silicate gneiss, and associated marble and meta-igneous rocks. Strongly mylonitic quartz-rich tonalites are distinctive members of this association, and thus, even where we have not identified layered gneisses we have mapped these tonalites as part of the gneissic rocks of the Yellow Aster.
2. **Non-gneissic rocks** of the Yellow Aster Complex of Misch (1966). Meta-igneous rocks, not associated with layered gneiss, with no evidence of preserved intrusive contacts with supracrustal units that would indicate a late Paleozoic or younger age. We observe or infer their structural setting to be comparable with that of nearby layered gneisses of the Yellow Aster Complex.
3. Mesozoic and Paleozoic intrusions which we divide into subunits of **tonalitic and gabbroic intrusions**. These rocks generally show direct evidence of intrusion into Chilliwack Group or younger units or their structural position suggests that they are intrusions, not tectonically emplaced slivers. They may be deformed and metamorphosed, but are not conspicuously mylonitic.

Rocks of the Yellow Aster Complex of Misch (1966) have a greenschist or sub-greenschist-facies metamorphic overprint, with pumpellyite and prehnite (Brown and others, 1981). Misch (1966, p. 105, 1971) speculated that the pyroxene gneisses of the complex may have undergone granulite facies metamorphism, but only an early amphibolite metamorphism has been documented (Sevigny, 1983, p. 42; Blackwell, 1983, p. 92; Ziegler, 1986, p. 106).

With recognition that elements of the Northwest Cascades System may constitute unrelated terranes, even the certainty that the Yellow Aster is pre-Devonian has evaporated. Discordant U-Pb ages of zircon and sphene from pyroxene gneisses range from 64 to 912 Ma (table 3, Nos. 84–88). Mattinson (1972) interpreted a 1.4-Ga (Proterozoic) Pb-Pb age for pyroxene gneiss, thought to be orthogneiss, to represent a minimum protolith age for rocks metamorphosed at about 400 Ma (Devonian) and perhaps at about 270 Ma (Permian) as well. Rasbury and Walker (1992) report analyses of single zircon grains from similar gneiss (table 3, Nos. 89, 90), but interpret the zircons to be detrital relics of 1.85 Ga crust, nevertheless deposited in the Proterozoic (Rasbury and Walker, written commun., 1995). Zircons from a metatonalite block in the Bell Pass mélange above Anderson Creek yield discordant U-Pb ages of about 330–390 Ma (table 3, No. 76), suggesting igneous crystallization in the mid-Paleozoic.

Ultramafic rocks crop out throughout the Bell Pass mélange. Most of these are serpentinite or serpentinized harzburgite. Many are in or closely associated with the gneisses or mafic igneous rocks of the Yellow Aster Complex of Misch (1966). Tabor and others (1994) separated the ultramafic rocks associated with the Yellow Aster Complex from ultramafic rocks in the mélange, but the distinction is somewhat arbitrary and they are not shown separately here. For further descriptions see Sevigny (1983, p. 84–92) and Leiggi (1986, p. 49–84).

The largest mass of ultramafic rock in the Bell Pass mélange and in the Northwest Cascades System is the **Twin Sisters Dunite of Ragan (1961, 1963)**. The dunite is exposed in two bodies, in the Twin Sisters range itself and at Goat Mountain to the southeast. The rock varies from enstatite-olivine rock (harzburgite) making up to one-half of the Twin Sisters mass overall to pure olivine rock. Only the margins are notably serpentinized (Ragan, 1963, p. 552). Olivine has a high-temperature tectonite fabric indicative of a mantle origin (Christensen, 1971; Hersch, 1974; Levine, 1981). Ragan (1963) describes high-temperature metamorphic layering of chromite and pyroxenes, generally steep and parallel to the long axis of the body as well as to zones of finely recrystallized olivine. The relatively pure dunite of the Twin Sisters massif has been mined for refractory material for many years (Ragan, 1961, p. 78–79; Gulick, 1994, p. 22).

Ragan (1963, p. 551) considered the dunite mass to have intruded along a major fault in post early Eocene time. Thompson and Robinson (1975) proposed that the body was tectonically emplaced along the Shuksan Thrust Fault. Whetten and others (1980) included it in their Haystack thrust plate, a regional nappe which they thought was the highest nappe in the Northwest Cascade System. We consider the Twin Sisters Dunite to be a large phacoid in the Bell Pass mélange, but bounded on the west by high-angle faults. We show the east contact of this phacoid as a thrust in deference to its size. On the basis of gravity and magnetic measurements, Thompson and Robinson (1975) show the mass to be a plate-like body, mostly less than 2 km thick, but with a serpentinite keel on the west (see cross sections C–C' and D–D').

Scattered irregularly throughout the Bell Pass mélange are outcrops of the **Vedder Complex of Armstrong and others (1983)**. These well-recrystallized schists and amphibolites are characteristically siliceous and some contain the blue amphibole barroisite. In the quadrangle, K-Ar ages range from 196 to 283 Ma (table 3, Nos. 69–74), and on Vedder Mountain, 13 km west of the quadrangle (fig. 1), Rb-Sr ages of minerals and rocks are in the 229- to 285-Ma range (Armstrong and others, 1983). Petrographic, chemical, and isotopic data are in Armstrong and others (1983) and Armstrong and Misch (1987).

Misch (1966, p. 123–124) ascribed the extreme deformation of the rocks in the Bell Pass mélange to an imbricate zone beneath the Shuksan Thrust Fault. Although the bounding thrusts have deformed the mélange, we believe it was mixed and deformed as well in an earlier deformation. Rocks correlative with components of the Bell Pass mélange in the San Juan Islands bear witness to this early episode of tectonism. Brown and Vance (1987) and Brandon and others (1988, p. 15, 24), correlate the Deadman Bay Volcanics of Brandon and others (1988) and Orcas Chert of Brandon and others (1988) with the Elbow Lake Formation of Brown and others (1987), and they correlate the Garrison Schist of Vance (1975) with the Vedder Complex of Armstrong and others (1983). The Garrison Schist is distributed as tectonic slivers along a major thrust fault in the San Juan Island rocks (Brandon and others, 1988). Conglomerate clasts of the Garrison Schist and the Orcas Chert occur in the presumed Late Jurassic-Early Cretaceous Constitution Formation of Vance (1975), which although now in thrust contact with the correlatives of the Elbow Lake Formation appears to have been deposited on them at one time (Vance, 1975, p. 12–13, 1977; Brandon and others, 1988, p. 24). Apparently, the Garrison Schist was tectonically mixed with the Elbow Lake correlatives prior to the Late Jurassic (see also Tabor, 1994). We infer similar pre-Late Jurassic mixing in the Bell Pass mélange.

The Bell Pass mélange was further deformed and mixed during emplacement of the Welker Peak Nappe, and some of the tectonic mixing of the unit may be due to early Tertiary faulting along high-angle faults or low-angle extensional faults, such as in the region west of Mount Baker volcano (see cross sections A–A', B–B', C–C', and I–I'–I'').

Conglomerate of Bald Mountain

Boulder conglomerate rich in chert cobbles holds up the steep slopes of Bald Mountain [2]. Highly strained sandstone and slaty argillite associated with the conglomerate indicates the unit has participated in Mesozoic orogeny; lack of penetrative deformation in the main mass of the conglomerate is probably due to its strength. Poorly preserved pollen from an argillite interbed in the conglomerate suggests a Late Cretaceous to early Tertiary age (table 2, No. 1f). We consider its age to be Late Cretaceous.

Misch (1966, p. 103) thought that the Bald Mountain rocks were possibly correlative with the Late Triassic to Early Jurassic Cultus Formation of Daly (1912), but the unit is unlike the Cultus lithologically. Two chert clasts yield possible Triassic and Late Triassic radiolarians, indicating derivation from the nearby Elbow Lake Formation and supporting a post-Cultus age. Based on similarity to nearby Tertiary conglomerate and the ambiguous age call on pollen (see above), Johnson (1982, p. 50–54) considered these rocks to be part of the Eocene Chuckanut Formation. See Johnson (1982) for further descriptions.

We correlate a small outcrop of chert pebble conglomerate in a fault zone east of Goat Mountain [46] with the conglomerate of Bald Mountain. If this correlation is correct, the faulted sliver indicates latest Cretaceous movement on some thrust faults of the Northwest Cascade System. Just west of the Mount Baker quadrangle, southwest of North Twin Sister, another sliver of conglomeratic sandstone, caught up in high-angle faults west of the Twin Sisters Dunite of Ragan (1963), may be a correlative of the Bald Mountain rocks. The rock is a lithic subquartzose sandstone with up to 10 percent K-feldspar and abundant chert grains. The rock is not penetratively deformed but locally highly sheared and imbricated with low-grade metavolcanic rocks. A fission-track age of detrital zircon is between 60 and 73 Ma (table 3, No. 38) supporting the possibility of a Late Cretaceous depositional age.

Rocks of the autochthon

Nooksack Formation

The Mesozoic Nooksack Formation (name newly adopted herein) and the underlying and interfingering **Wells Creek Volcanic Member** (newly named herein) make up the lowest structural package in the Northwest Cascade System. The Middle Jurassic to Early Cretaceous Nooksack Formation characteristically varies from thick, massive black argillite beds with minor lithic subquartzose sandstone interbeds to predominantly thick sandstone and (or) conglomeratic beds with minor black argillite interbeds. The argillite interfingers with and overlies a sequence of Middle Jurassic dacitic tuffs and flows. Argillite in the interbedded zone above the volcanic rock is rich in plagioclase and quartz phenoclasts of probable pyrogenic origin.

Misch (in McKee, 1956, p. 3) referred to the Late Jurassic and Early Cretaceous sedimentary rocks exposed in the area of Mount Baker as the Nooksack formation. Danner (1957, p. 332–456; 1958) correlated rocks south of the Mount Baker quadrangle with these rocks and referred to them as the Nooksack Group, the name used by Misch (1966, p. 118) and subsequent workers. Danner's (1957) correlation is probably erroneous (Tabor, 1994; Tabor and others, 2002; see also Jett, 1986, p. 52–57; Jett and Heller, 1988).

We include in the Nooksack Formation all the Late Jurassic and Early Cretaceous clastic rocks and associated Middle Jurassic dacitic volcanic rocks exposed in the Baker River drainage. We designate the type area of the Nooksack Formation to be the valley walls of the North Fork Nooksack River in the vicinity of lat 48°54' N., long 121°53' W. (Glacier 7.5' quadrangle). We propose that the volcanic rocks be called the Wells Creek Volcanic Member of the Nooksack Formation. We designate the type area of the Wells Creek Volcanic Member to be lower Wells Creek, in the vicinity of lat 48°54' N., long 121°48' W. (Bearpaw 7.5' quadrangle).

Isolated belemnite molds, pieces of *Buchia* shell, and (rarely) *Buchia* hashes in nearly featureless black to brown siltstone are hallmarks of the Nooksack Formation. Where fossils are absent, some of the more deformed clastic rocks of the Nooksack are difficult to distinguish from rocks of the Late Paleozoic Chilliwack Group of Cairnes (1944). Most of the mapped Nooksack Formation in the quadrangle has yielded belemnites or contains concretions with Mesozoic radiolaria.

Aside from the Wells Creek Volcanic Member, several distinct lithologic units are present in the Nooksack Formation and contrast with the more typical thick-bedded dark argillite. In the area of Thompson Creek on the north side of Mount Baker, and also on Excelsior Divide to the north, are thick-bedded sandstones and thick-bedded sandy siltstones with scattered shell fragments and pyritic patches, evidently the product of extensive bioturbation. Sandstones west of Glacier Creek [12], near the Glacier Fault, locally bear muscovite. We also noted a few beds of calcarenite in the Glacier Creek drainage. Above Bear Creek [45], south of Mount Baker, Nooksack Formation strata are thick-bedded sandstone and siltstone with conspicuous ellipsoidal calcareous concretions. On the south and east slopes of Barometer Mountain [10] is another area rich in sandstone, but here the sandstone is conspicuously conglomeratic with poorly rounded to angular pebbles. Coarse conglomerate beds rich in dacite and tonalite boulders occur in and south of Excelsior Pass [5], just above the Wells Creek Volcanic Member, and in Boulder and Rainbow Creeks, east of Mount Baker. Misch (1966, p. 118; 1977, p. 6) describes a lens of channel conglomerate in the eastern part of the outcrop area that contains limestone boulders identical to late Paleozoic limestone in the Chilliwack Group of Cairnes (1944). We did not find this lithology (see also Sevigny, 1983, p. 104–106).

At the top, the Nooksack Formation is bounded by the Excelsior Ridge Thrust Fault. The base of the Wells Creek Volcanic Member is not exposed. Misch (1966, p. 118) considered the rocks composing the Nooksack Formation to be autochthonous, but noted that they too could be part of an allochthonous nappe. Sondergaard

(1979, p. 7) estimated the clastic part of the Nooksack Formation to be between 5,800 and 7,300 m thick, but did not allow for folding or repetition by faulting. We estimate that the clastic part of the Nooksack is at least 4,300 m thick as exposed across Glacier Creek (cross section A–A') and that the Wells Creek Volcanic Member is at least 700 m thick.

Compared to the other units of the Northwest Cascade System, the Nooksack Formation is relatively undeformed. Broad areas of rock are almost horizontal or have low dips. West of Skyline Divide [13], good exposures show that the low-dipping rocks are cut by low-dipping reverse faults marked by steep dips in the hanging wall. Local outcrops with steep dips elsewhere in the Nooksack probably indicate more faults.

The development of slaty cleavage varies from weak and mostly steep north of Mount Baker to strong and moderately dipping on the east side of the peak. Sondergaard (1979, p. 52) found metamorphic prehnite and pumpellyite in the Nooksack Formation. Sevigny (1983, p. 104), Jones (1984, p. 47), and Ziegler (1986, p. 59) reported incipient development of lawsonite as well, but the very fine grained mineral was identified by x-ray methods which are unreliable: Brandon and Vance (1992, p. 597) and Brandon (written commun., 1991) have shown that even very rigorous x-ray and electron probe determinations of calcium aluminum silicates in fine-grained metamorphic rocks do not adequately discriminate between lawsonite and pumpellyite. The lack of aragonite in the Nooksack Formation (Sevigny, 1983, p. 104) suggests that the Nooksack was only metamorphosed in the prehnite-pumpellyite facies in contrast to overlying nappes that contain lawsonite and aragonite indicative of higher pressures (see below). Brown and others (1981) discuss metamorphic assemblages in the Nooksack Formation.

The clastic part of the Nooksack Formation exposed north of Mount Baker contains a fairly rich fossil record with assemblages of definite Late Jurassic (Oxfordian) and Early Cretaceous (Valanginian) ages (table 2, Nos. 56f–91f). Except for a few belemnite casts and radiolaria, fossils have not been found on the west, south, and east sides of Mount Baker. Misch (1966, p. 118) reported Middle Jurassic or younger fossils in the Wells Creek Volcanic member. The Middle Jurassic age is corroborated by mildly discordant U-Pb ages of 173–187 Ma obtained from a dacitic tuff (table 3, No. 64). Unpublished fossil ages recorded by the late Peter Misch (table 2, Nos. 70f, 75f, 77f, 78f) suggest an area of Early Cretaceous rocks in the vicinity of Glacier. The age-calls in the archives are unattributed. If these Early Cretaceous ages are correct, their location in the valley bottom, flanked by older strata on the canyon sides, requires considerable faulting. Based on the principle style of faulting in the Northwest Cascade System and the intraformational thrust faults present in the Nooksack Formation elsewhere, such a younger stratigraphic window could be bound by thrust faults bringing older Nooksack rocks over younger.

Strata in the Nooksack Formation suggest a diversity of depositional environments; we noted mudflow deposits, turbidites, extensively bioturbated beds, and shell hashes that may be storm lags. Sondergaard (1979) considered the rocks of the Nooksack Formation to have been deposited in submarine fans associated with a volcanic arc, presumably in part represented by the Wells Creek Volcanic Member.

Misch (1966, p. 118–119) thought that his Nooksack Group correlated with the Harrison Lake Formation of Crickmay (1930). Tabor and others (1989, 1994) included rocks of the Nooksack Formation and Wells Creek Volcanic Member in the Harrison Lake terrane which is named for the Mesozoic strata exposed along Harrison Lake in southern British Columbia, about 28 km north of the Mount Baker quadrangle (Monger, 1986, 1993; Arthur and others, 1993). Rocks of the Harrison Lake terrane range from Middle Triassic to Middle Jurassic. Nokleberg and others (1994, p. 15) assign Late Jurassic and Early Cretaceous rocks of the Harrison Lake area to the Gravina-Nutzotin-Gambier volcanic-plutonic belt that onlaps the Harrison Lake terrane and correlate rocks of the Nooksack Formation with this onlap assemblage. Either correlation now seems suspect because the Nooksack Formation includes continuous strata correlative with both the Harrison Lake terrane and the onlap assemblage.

Gabbroic intrusion

Below the Roosevelt Glacier [29], a small stock of metagabbro intrudes the Nooksack Formation. A swarm of metadiabase dikes cut Nooksack sedimentary rocks to the east. These intrusions are post-Valanginian (Early Cretaceous) in age and (by their metamorphism) probably predate Middle to Late Cretaceous stacking of the Northwest Cascades System nappes.

ROCKS EAST OF THE ROSS LAKE FAULT ZONE

Sedimentary rocks

Exposed only in a small area on the east side of Desolation Peak [78] and more extensively east of the Mount Baker quadrangle are dark lithic sandstone, argillite, tuffaceous sandstone, and conglomerate. These rocks are part of the Methow terrane (fig. l), and ammonites from just east of the quadrangle in Lightning Creek are Late Jurassic in age (table 2, No. 116f). Argillaceous and tuffaceous lithologies suggest that these rocks are part of the Ladner Group of British Columbia as described by Monger (1989) and Ray (1990, p. 22–25). The Late Jurassic age is more in keeping with a correlation with the Thunder Lake sequence of O'Brien

(1986, p. 754), previously described as part of the Dewdney Creek Group of Coates (1974, fig. 2). As noted by Ray (1990, p. 23), Ladner-style deposition locally seems to have persisted into Thunder Lake time.

ROCKS IN THE ROSS LAKE FAULT ZONE

Hozomeen Group

Hozomeen* Group (newly adopted herein) comprises greenstone, chert, clastic sedimentary rocks, gabbro, and minor limestone. Daly (1912, p. 500–504) first described these rocks, which he referred to the Hozomeen Series. Subsequent workers (Cairnes, 1944; Misch, 1966, p. 116; McTaggart and Thompson, 1967, p. 1199–1205; Staatz and others, 1971, p. 19–21, 1972, p. 20–22; Haugerud, 1985; Ray, 1986, 1990, p. 9–16; Tabor and others, 1989, p. 3) have referred these rocks to the Hozomeen (or Hozameen) Group, although Monger (1989) called them the Hozameen Complex, probably in deference to their internal disruption. We here adopt the name Hozomeen Group for the oceanic rocks herein described and designate exposures in the vicinity of Hozomeen Mountain (lat 48°59' N., long 121°01' W.; Hozomeen 7.5' quadrangle) as the type area. The greenstones and associated marine sedimentary rocks are exposed in a continuous north- to northwest-trending belt 132 km long, from Crater Mountain, east of the Mount Baker quadrangle, to the Fraser River Fault in British Columbia.

McTaggart and Thompson (1967) divided the Hozomeen Group into four units, three of which appear to correlate with units in the Mount Baker quadrangle. McTaggart and Thompson's (1967, p. 1201) lowermost unit of predominantly ribbon chert but with a thick limestone sequence does not crop out in the Mount Baker quadrangle; Ray (1990, p. 16) noted that this lowermost unit may actually be a structural repetition of their fourth, uppermost, unit. We correlate rocks, mostly exposed on the east side of Ross Lake, with the next to lowermost unit of McTaggart and Thompson, a unit of predominantly greenstone with minor limestone and chert, based on observed continuity with their greenstone unit in British Columbia (McTaggart and Thompson, 1967, fig. 5; Monger, 1989, Sheet 1). This lower greenstone unit in the Mount Baker quadrangle also contains minor argillite and graywacke. Above the greenstone unit, and probably interfingering with it, is a ribbon chert unit with minor argillite and marble, exposed west of Ross Lake, and probably correlative with the third unit of McTaggart and Thompson (1967; Haugerud, 1985, p.80). Overlying the chert unit is a second greenstone and chert unit, exposed north of Little Beaver Creek, and probably correlative with the fourth and highest unit of McTaggart and Thompson (Haugerud, 1985, p. 80). Total stratigraphic thickness of the unit is difficult to determine because not only is the unit bound everywhere by faults, but internal structure is complex and the unit may be thickened by faulting. Nevertheless, McTaggart and Thompson estimated about 7,900 m total thickness as exposed in Canada. We estimate about 11,000 m total thickness exposed in the Mount Baker quadrangle. Probable partial stratigraphic equivalency of the above described units due to facies changes suggests the true thickness may be less.

Radiolarians from chert lenses in the lowermost greenstone unit off the quadrangle to the east are Permian (table 2, No. 115f). Within the Mount Baker quadrangle, a limestone lens in the greenstone unit northeast of Mount Hozomeen contains Early to Middle Pennsylvanian conodonts (table 2, No. 92f).

Radiolarians in the younger chert-rich unit are mostly Triassic in age, but fossil calls from an apparently homoclinal sequence of mostly chert and minor greenstone on the ridge south of No Name Creek [89] indicate the unit extends into the Jurassic. Poorly preserved forms from near the top of the sequence are probably Early Jurassic (table 2, No. 102f); calls from higher in the sequence are less definitive (Nos. 103f–105f). In a previous report (Tabor and others, 1994), we reported that very poorly preserved radiolaria from near the top of the sequence indicated an Early Cretaceous age. C.A. Blome (written commun., 1995) has re-evaluated the sample (table 2, No. 107f) and concluded that, at best, it can be proclaimed Jurassic and younger.

No fossils have been found in the highest greenstone unit in the quadrangle, but it appears to correlate with Triassic and Jurassic rocks in the Maselpanik area, about 10 km north of the Canadian border, and is described by Haugerud (1985, p. 13–34).

South of 49° N. the Hozomeen Group is nearly everywhere partially recrystallized in prehnite-pumpellyite facies (Haugerud, 1985, p. 37). Exceptions are where the unit is in contact with Tertiary plutons and at Jack Point, on Ross Lake, where a sheared sample appears to be metamorphosed in the amphibolite facies.

Within the Mount Baker quadrangle, the unit is bounded on the east by the Hozomeen Fault, the easternmost fault in the Ross Lake Fault System (Miller, 1994), on the south and west by the Jack Mountain Thrust Fault, and on the west by a strand of the Ross Lake Fault. In British Columbia, Ray (1986) includes in the Hozomeen Group a serpentinite body faulted against the lower greenstones. He (p. 1035–1039) thought that the ultramafic rock was derived from oceanic mantle and considered the Hozomeen to be a dismembered ophiolite, with volcanic rocks including both arc tholeiites and oceanic island seamount subalkaline basalts. Based on pyroxene chemistry, Haugerud (1985, p. 81)

*Most Canadian authors use Hozameen, spelled with an 'a' instead of an 'o' which is the spelling in the United States. Daly (1912) used Hozomeen and we will use his spelling here.

showed that the uppermost greenstone unit of the Hozomeen Group had an alkali-basalt protolith that erupted as within-plate seamount(s). Further description of rocks of the Hozomeen Group can be found in Misch (1966, p. 116), McTaggart and Thompson (1967, p. 1199–1205), Staatz and others (1971, p. 19–21; 1972, p. 20–22), Haugerud (1985, p. 13–83), and Ray (1990, p. 9–16, 81). Ray (1986, 1990) and Haugerud (1985) report chemical data for the Hozomeen in Canada.

The Hozomeen Group is one of several oceanic rock assemblages in the Pacific Northwest Cordillera. Within the Mount Baker quadrangle, the abundance of Late Triassic chert and high titanium basalt of probable intraplate origin in the Elbow Lake Formation of Brown and others (1987) make that unit an attractive correlative. Compare, for instance, Hozomeen Group greenstones and Elbow Lake basalt chemistry (Ray, 1986, fig. 11 and Sevigny and Brown, 1989, fig 10). The Elbow Lake Formation, however, has abundant argillite and chert-lithic sandstone, rocks relatively scarce in the Hozomeen. The oceanic Napeequa Schist is also a possible correlative (Tabor and others, 1989, p. 7–8; Miller and others, 1993b, p. 1312–1313), but the Napeequa contains scattered ultramafic rocks throughout, a component not found in the southern part of the Hozomeen, though present in some rocks mapped as Hozomeen Group in British Columbia.

The Hozomeen Group appears to correlate also with the Mississippian to late Middle Jurassic Bridge River Complex across the Fraser River Fault in British Columbia (Davis and others, 1978; Potter, 1983; Haugerud, 1985; Cordey and Schiarizza, 1993) and has been considered a part of the oceanic Bridge River terrane (Nokleberg and others, 1994). Beginning with Daly (1912, p. 502), many workers (for instance, Monger, 1977, p. 1842; Potter, 1983) have also correlated the Hozomeen Group with the Carboniferous to Middle(?) Jurassic Cache Creek Complex of British Columbia. The Cache Creek consists of two lower Mesozoic oceanic mélange units flanking a very thick Carboniferous marble unit (Monger, 1989), suggesting that at best the Hozomeen Group could only be partly correlative. Rare blueschists found in the Cache Creek Complex (Monger, 1977, p. 1844) have not been found in the Hozomeen.

Clasts of Hozomeen Group rocks in the mid-Cretaceous Virginian Ridge Formation of Barksdale (1948), which crops out to the east and southeast of the Mount Baker quadrangle, demonstrate that the rocks of the Hozomeen were adjacent to the Methow terrane by mid-Cretaceous time (Tennyson and Cole, 1978).

Phyllite and schist of Little Jack Mountain

Little Jack Mountain lies just off the quadrangle to the east, north of Ruby Arm [99]. Phyllite and schist of Little Jack Mountain commonly are fine grained, and have well-preserved textures. Even so they contain metamorphic biotite and locally bear staurolite, garnet, andalusite and more rarely sillimanite. Ribbon chert and marble are rare constituents, but scattered throughout are small masses of metaperidotite.

Metamorphism ranges from amphibolite facies on the southwest side of the outcrop belt, adjacent to the Skymo Complex of Wallace (1976), to sub-greenschist facies on the northeast, off the quadrangle to the east. The age of dynamothermal metamorphism is not well constrained but we suspect it is Late Cretaceous to middle Eocene, the same as metamorphism of the adjoining Skagit Gneiss Complex. The Little Jack unit appears to be thermally metamorphosed as well by middle Eocene and older plutons of the Ruby Creek Heterogeneous Plutonic Belt of Misch. The phyllite and schist of Little Jack Mountain are described further by Wallace (1976, p. 75–86), Kriens (1988, p. 81–88), and Baldwin and others (1997).

Misch (1966, p. 115) called these rocks the Jack Mountain Phyllite and thought that they were metamorphosed correlatives of the Mesozoic sedimentary rocks exposed to the east in the Methow terrane. Later workers (Staatz and others, 1971; Tennyson, 1974, p. 78–79; McGroder, 1991, p. 193) noted the continuation of the Hozomeen Fault between the phyllite of Little Jack Mountain and unmetamorphosed rocks of the Methow terrane to the east.

The dominant clastic component of the rocks of Little Jack Mountain indicates a probable Mesozoic age, but otherwise their age and correlatives are uncertain. Even so, when viewed from a regional perspective the Little Jack rocks are on strike with and structurally continuous with rocks to the southeast now thought to be correlative with unmetamorphosed Mesozoic clastic strata of the Methow terrane (Miller and others, 1994; Dragovich and others, 1997). Tabor and others (1989) included the Little Jack rocks in their Little Jack terrane which also included the metamorphosed Methow terrane correlatives, but direct correlation of Little Jack rocks with Methow rocks is problematic, although several correlations have been suggested. Kriens (1988, p. 81) correlated the Little Jack unit with the Late Jurassic(?) Newby Group of Barksdale (1975) exposed in the Methow terrane to the southeast in the Twisp quadrangle (fig. 1). Haugerud and others (1994, p. 2E–36) correlated phyllitic rocks on McKay Ridge with the Twisp Formation of Barksdale (1975). The McKay Ridge rocks are exposed just east of the Mount Baker quadrangle, south of Ruby Arm [99], and are of similar aspect and apparently continuous with the rocks of Little Jack Mountain. None of these possible correlative rock units contain ultramafic material as is found in the Little Jack unit, and this unique characteristic forestalls certain correlation.

Skymo Complex of Wallace (1976)

Metamorphosed troctolite, gabbronorite, and anorthosite intruded by irregular patches and veins of lighter colored medium- to coarse-grained gabbro and rare tonalitic pegmatite crop out in the Skymo Lake [91] area, west of Ross Lake. The rocks of this complex are faulted against the rocks of Little Jack Mountain and the Skagit Gneiss Complex, but they are locally infused with the leucosomes typical of the Skagit, indicating their participation in the metamorphism effecting the Skagit (Staatz and others, 1972, p. 17), and hence have not been faulted far since metamorphism.

Wallace (1976) and Hyatt and others (1996) identified a small patch of fine-grained metasedimentary rocks (unit TKsf), faulted within the Skymo Complex igneous rocks, as a fragment of the original wall rocks of the Skymo intrusive body. We previously (Tabor and others, 1994) mapped this patch as phyllite and schist of Little Jack Mountain, but its composition and probable granulite metamorphic history suggest it was the original wall rock of the Skymo intrusive rocks, not Little Jack (Hyatt and others, 1996; Baldwin and others, 1997).

Wallace (1976) and Whitney and Hirschmann (1994) describe the complex as a highly disrupted and metamorphosed layered mafic cumulate body. The foregoing authors and Misch (1966, p. 105) suggested that it had undergone granulite facies metamorphism prior to amphibolite facies metamorphism, although Whitney and Hirschmann (1994) allowed that the earlier anhydrous recrystallization might have been deuteric. Misch (1966, p. 105, 133) assumed that the Skymo Complex was an older basement to the metamorphosed supracrustal rocks in the Skagit Gneiss Complex, correlative to his Yellow Aster Complex on the west side of the range. The age of the unit is unknown, and Hurlow and Whitney (1996), Hyatt and others (1996), Whitney and Hirschmann (1996), and Baldwin and others (1997) emphasize that the Skymo magmatic evolution, deformation, and its metamorphism are unique in the North Cascades, although the latter authors (p. 677) indicate the metasedimentary material in the Skymo Complex and rocks of the Little Jack terrane could have come from the same marine environment even if their subsequent metamorphic histories differ.

Alberti (1988, p. 143–144, tables 1–3) presents samarium, neodymium, rubidium, and strontium isotopic data for a few samples of the Skymo Complex.

Ruby Creek Heterogeneous Plutonic Belt of Misch (1966)

Misch (1966, p. 139) mapped a complex zone of gabbroic to granodioritic plutons intruding mostly rocks of the Little Jack terrane and aligned along the Ross Lake Fault Zone and named it the Ruby Creek Heterogeneous Plutonic Belt. Staatz and others (1971, p. 35) referred to these rocks as the granodiorite dike and sill complex. The belt stretches southeastward from Ross Lake to about 6 km beyond the Mount Baker quadrangle where it is abruptly truncated by the intrusive middle Eocene Golden Horn batholith.

Many of the igneous rocks in the complex have a northwest-striking, steep foliation, which in thin section is entirely cataclastic. Kriens (1988, p. 89–91) described a sequence of intrusions in this belt from State Highway 20, about 5 km east of the quadrangle: the oldest dikes of diabase which had intruded metasedimentary rocks were intruded by quartz diorite and subsequently by granodiorite. Kriens (1988) felt that much of the foliation he observed was igneous. Some of the more mafic hornblende tonalite of the complex is lithologically similar to rocks of the Late Cretaceous (90-Ma) Black Peak batholith (Kriens, 1988, p. 91; Haugerud and others, 1994, p. 2E–36), exposed on strike with the belt to the southeast. Just east of the quadrangle on State Highway 20, U-Pb analyses of zircons from a light-colored tonalite yield an age of 48 Ma (Miller and others, 1989). The Golden Horn batholith, which appears to intrude the belt, crystallized about 48–49 Ma also. Much of the granodioritic rock in the Ruby Creek Heterogeneous Complex could be related to the Golden Horn, although granodiorite in the Ruby Creek is unlike the granite porphyry dikes more commonly associated with the Golden Horn batholith (Misch, 1966, p. 139; Tabor and others, 1968).

Misch (1966, p. 133) felt that the plutonic rocks had intruded along and obliterated the trace of the Ross Lake Fault (as he had mapped it). Kriens (1988) and Kriens and Wernicke (1990b) dispute the significance of the fault overall and in this locality in particular. For further discussion of this problem see Haugerud and others (1994, p. 2E–13–14, 2E–36–37).

ROCKS BETWEEN THE STRAIGHT CREEK FAULT AND THE ROSS LAKE FAULT ZONE

Chelan Mountains terrane

The major units of the Chelan Mountains terrane in the Mount Baker quadrangle are the Napeequa Schist, the Cascade River Schist, metaplutonic rocks of the Marblemount pluton, and the Skagit Gneiss Complex. Miller and others (1994, p. 88) favor a separate terrane for the Napeequa Schist, based on studies in correlative rocks to the southeast of the quadrangle. Below, we show that the protolithic arc rocks of the Cascade River Schist could have been deposited on the protolithic oceanic rocks of the Napeequa, a stratigraphic relation confining the two units to the same terrane. As Miller and others (1994) indicated, further work may prove them separate terranes. Tabor and others (2002) detail the nomenclatural history of these units.

Napeequa Schist

Fine-grained micaceous quartz schist, garnet-mica-quartz-plagioclase schist, hornblende-mica schist, hornblende schist, and amphibolite are characteristic rocks of the Napeequa Schist. In addition, the unit contains small masses of metamorphosed igneous rocks including granitoid stocks and porphyritic dikes ranging from tonalite to granodiorite in composition, as well as marble and scattered small to large masses of metamorphosed ultramafic rocks. Except for the ultramafic rocks, the igneous components are less conspicuous in the Mount Baker quadrangle than they are to the south (Tabor and others, 1987a,b, 2002). Talc deposits (meta-ultramafic rocks) in the Napeequa along the Skagit River have been quarried in the past (Valentine, 1960, p. 130–131; Misch, 1977b, p. 32). The predominance of quartzitic schist derived from chert, amphibolitic rocks derived from basaltic rocks, and scattered ultramafic rocks indicates that the Napeequa Schist has an oceanic origin.

The largest tracts of supracrustal Napeequa Schist, untransformed by injected igneous material, crop out on the southwest and northeast sides of the Cascade crystalline core uplift or antiform (Haugerud and others, 1988, 1994; Tabor and others, 1989). Lenses of schist which we think are derived from Napeequa are common throughout the Skagit Gneiss Complex. The Twisp Valley Schist of Adams (1964), a likely correlative of the Napeequa Schist (Tabor and others, 1989, p. 8; Miller and others, 1993b, p. 1312–1313), crops out about 48 km southeast of the Mount Baker quadrangle on the east flank of the antiform. On the basis of chemistry, Miller and others (1993b) consider the Twisp Valley Schist to contain both ocean-island basalts and mid-ocean ridge basalts. The rocks forming both Napeequa and Twisp Valley Schists have been correlated with the late Paleozoic and early Mesozoic, oceanic Hozomeen Group or the Bridge River Complex (Misch, 1966, p. 116–117; Tabor and others, 1989; Miller and others, 1993b), which crop out east of the crystalline core of the range.

Detailed descriptions of the rocks that form the Napeequa Schist, mostly south of the Mount Baker quadrangle, are in Bryant (1955, p. 32, 56–76), Tabor (1961, p. 117–120), Dragovich (1989, p. 30–38), and Dougan (1993, p. 20–23). Chemical analyses of Napeequa rocks are in Ort and Tabor (1985), Babcock and Misch (1989), and Dragovich (1989, p. 160–162).

The protolith age of the Napeequa Schist is not known. Based on correlation with other oceanic assemblages in the Pacific Northwest, the age may be Permian to Triassic. Tabor and others (2002) discuss the age in detail and conclude that the protolith is pre-Late Triassic. The metamorphic age of the Napeequa Schist is discussed below.

Dragovich and others (1989), Dragovich (1989, p. 135–136), Dougan and Brown (1991), and Brown and others (1994) interpreted the rocks forming the Napeequa Schist in the Sibley Creek [109] area to overlie the Cascade River Schist in an overturned north-plunging syncline. Major evidence for the syncline is relict graded beds in coarse metaclastic rocks of the Cascade River Schist in the east upright limb of the fold. Because the oceanic origin of the Napeequa Schist suggests that its protolith was unlikely to have been deposited on the coarse clastic rocks of the Cascade River Schist, Dragovich (1989, p. 136), Dragovich and Derkey (1994), and Brown and others (1994) suggested that the rocks comprising the Napeequa Schist were thrust over the Cascade River Schist before folding. Intercalation of Napeequa and Cascade River lithologies might be due to premetamorphic folding or fault imbrication.

Based on the southward plunge of regional structure in the Cascade Pass area to the south, Tabor and others (2002) interpret the Napeequa Schist to be exposed in a southeast-plunging antiform, a structural configuration which would put the Napeequa below the Cascade River Schist. This structural interpretation would support a view that the Napeequa is oceanic basement to the arc rocks represented by the Cascade River Schist (see also Haugerud, 1989). The antiform interpretation is in harmony with the relative uplift of the northeast side of the Entiat Fault which would have brought up the antiformal core.

Cascade River Schist

Within the Mount Baker quadrangle, the Cascade River Schist consists of a heterogeneous assemblage of fine-grained mica-quartz-plagioclase schist, biotite paragneiss, hornblende-biotite schist, calcareous mica schist, metaconglomerate, and rare amphibolite, hornblende schist, and marble. Many of these rocks are characterized by a low degree of metamorphic recrystallization, although metaconglomerate clasts are so strongly deformed in some outcrops that they can only be recognized on surfaces perpendicular to the regional lineation. The Cascade River Schist appears to be arc derived. For descriptions and chemical analyses, see Tabor (1961, p. 81–109), Ort and Tabor (1985), Babcock and Misch (1988, p. 221–223), Dragovich (1989, p. 15–27, 39–49), Cary (1990, p. 28–59), and Dougan (1993, p. 14–19).

The protolith of the Cascade River Schist overlay the protolith of the Marblemount pluton unconformably. Clasts in metaconglomerate resemble rock of the Marblemount pluton. Silicic mica schist (metarhyolite) about 500 m stratigraphically above the Marblemount contact (Cary, 1990) and overlain by metaconglomerate contains zircons that yield concordant 220-Ma ages (Tabor and others, 1988, 1994). A K-Ar age of muscovite from a meta-quartz diorite clast in metaconglomerate is about 46 Ma (table 3, No. 58), reflecting Eocene unroofing, and is discussed more in the section on the age of metamorphism (below).

On the east, the Cascade River Schist is in tectonic contact with the Eldorado Orthogneiss, a Late Cretaceous syntectonic pluton which probably intruded the schist (McShane and Brown, 1991; McShane, 1992). Southeast of the quadrangle, Cascade River Schist and strongly deformed Eldorado pluton are complexly interlayered suggesting either original lit-par-lit intrusion or intense tectonic imbrication (Tabor, 1961, p. 145–152).

Marblemount pluton

Rocks composing the Marblemount pluton were called the Marblemount Meta Quartz Diorite by Misch (1966; see also, 1952, p. 4), who named them for outcrops along the Skagit River in the vicinity of Marblemount. The major protolith rock type is quartz diorite; original lithologies within the metaplutonic belt range from gabbro and locally hornblendite to tonalite (Tabor 1961, p. 14; Ford and others, 1988, p. 95; Cary, 1990, p. 16) . Metamorphosed pegmatite and aplite are also present. Rocks now range from massive to schistose. Along the Cascade River the Marblemount has been mostly metamorphosed in the greenschist facies and contains chlorite, epidote, quartz, and albite on the northwest. Greenschist and hornblende-bearing greenschist zones and layers are common. South of the Mount Baker quadrangle, increasing amounts of hornblende, more calcic plagioclase, and local biotite in the deformed pluton indicate an increase in grade to amphibolite facies. On the northwest end, east of Bacon Creek, the pluton is less metamorphosed and bears considerable fresh igneous hornblende. For modes, additional chemical data, and oxygen isotope values of the Marblemount pluton, see Ford and others (1988, p. 18–27, 94–96), White and others (1988, p. 28), Cary (1990, p. 41–42), and Tabor and others (2002).

The pluton was traced southeast by Bryant (1955, plate XLVIII), by Tabor (1961, plate l), who called it the Le Conte Gneiss, and by Grant (1966, plate II). Southeast of the south fork of Agnes Creek (southeast of the quadrangle), Grant (1966, plate II) and Ford and others (1988, p. 94) mapped meta-quartz diorite, which they considered to be the Marblemount pluton and which is essentially continuous with the Dumbell Mountain plutons of Cater and Crowder (1967). The Dumbell Mountain plutons are mostly tonalite and quartz diorite and are described in detail by Dubois (1954, p. 156–168), Crowder (1959, p. 838–852), and Cater (1982, p. 8–18).

Misch (1966, p. 105; 1963a, p. 1736–1737) considered the Marblemount pluton to be an anticlinal uplift of basement rocks, equivalent to the pre-Devonian Yellow Aster Complex of Misch (1966) exposed in the less metamorphosed region west of the Straight Creek Fault. Boulders of meta-quartz diorite and metatonalite in the Cascade River Schist (Tabor, 196l, p. 91; Misch, 1963a, 1966) confirm that the Marblemount is basement to the Cascade River Schist, but concordant U-Pb ages of zircons (Mattinson, 1972, p. 3777) from the Marblemount indicate a Late Triassic crystallization age of 220 Ma, too young for the unit to be included in the Yellow Aster Complex and essentially the same age as metatuffs in the Cascade River Schist.

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

The flaseroid margin of the pluton adjacent to the Napeequa Schist was highly deformed during metamorphism. South of the Mount Baker quadrangle (Tabor and others, 2002) the pluton locally overlies the Napeequa Schist, suggesting that the pluton has been thrust over the schist.

Metamorphic muscovite from a light-colored metatonalite sill or dike in the Marblemount pluton yields a K-Ar age of about 94 Ma (Tabor and others, 2002) which probably represents the age of metamorphism (see below, Age and cause of metamorphism).

STITCHING PLUTONS AND RELATED UNITS

During Late Cretaceous-earliest Tertiary metamorphism, all the units between the Ross Lake Fault and the Straight Creek Fault were invaded by large, deep-seated, synmetamorphic plutons. On the basis of both modal and normative mineralogy and $\delta^{18}O$ values, Tabor and others (2002) divided synmetamorphic plutons, mostly exposed south of the Mount Baker quadrangle, into (1) a tonalitic group and (2) a granodioritic group. Most of the plutons in the tonalitic group are characterized by both igneous and metamorphic features and those for which data are available have $\delta^{18}O$ values less than 10 (White and others, 1988). They crop out across the North Cascades in several different terranes. The granodioritic plutons of the second group intrude only the Napeequa Schist. The granodioritic plutons commonly contain muscovite and have fewer relict textures and structures revealing their probable igneous origin, and those for which data are available have higher $\delta^{18}O$ values (greater than 10; White and others, 1988) than the tonalitic group. Plutons of this group also tend to contain zircons with discordant ages suggesting inherited lead. Plutons of both groups lack static thermal aureoles and are generally elongate parallel to the regional foliation.

In the Mount Baker quadrangle the division between tonalitic plutons and granodioritic plutons is not well established. Probably in the tonalitic group are the orthogneisses of Haystack Creek and Mount Triumph. Definitely in the granodioritic group is the Hidden Lake stock. Probably in the granodioritic group are the orthogneiss of Marble Creek and the Alma Creek pluton. We include the Eldorado Orthogneiss in the granodioritic group because of its composition, but it has much in common with the tonalitic group (see below).

We describe the Skagit Gneiss Complex here with the stitching plutons because it is composed primarily of Late Cretaceous orthogneiss bodies, although it also contains considerable metamorphosed supracrustal material derived from rock units of the Chelan Mountains terrane. Tonalitic and pegmatitic dikes are common. Dikes and irregular bodies of middle Eocene granitic orthogneiss permeate the complex.

Plutons of the granodioritic group

Alma Creek pluton

The orthogneiss of Alma Creek [104], equivalent to Alma Creek leucotrondhjemite of Misch (1966, 1979), forms a large pod southeast of the Skagit River. Small masses of light-colored metagranodiorite and metatonalite in Napeequa Schist northwest of the Skagit River are probably correlative. The pluton has not been dated by U-Pb methods but muscovite and biotite K-Ar ages of about 49 and 39 Ma, respectively (table 3, No. 41), probably reflect Eocene unroofing.

Hidden Lake stock

The biotite-bearing rocks of the Hidden Lake stock, underlying Hidden Lake Peaks [110], are tonalites modally, but granodiorites chemically (Ford and others, 1988, p. 26, 116–117). White and others (1988, p. 32) report data indicating $\delta^{18}O$ values are greater than 10. The stock is massive and sharply intrusive into the Napeequa Schist. Dragovich (1989, p. 124–128) describes the mylonitic north margin of the pluton which contrasts strongly with its undeformed core. Haugerud and others (1991) interpret 73- and 75-Ma zircon U-Pb ages (table 3, No. 47) to represent primary crystallization at 75 Ma. A 38-Ma K-Ar biotite age probably reflects Tertiary unroofing, perhaps with additional argon loss due to reheating by a subjacent intrusion of the Cascade magmatic arc.

Brown and others (1994, fig. 8) indicate the pluton crystallized at about 4 kb in contrast to peak metamorphic pressures of 6–9 kb in the country rock adjoining it. This pressure difference suggests intrusion late in the metamorphic event as the terrane was being uplifted.

The Hidden Lake stock is less deformed and less recrystallized than other stitching plutons of the Mount Baker quadrangle. Numerous workers (Dragovich, 1989; Haugerud and others, 1991; Brown and others, 1994; Tabor and others, 2002) have discussed the contrast with the more strongly deformed, contemporary Marble Creek pluton. Although an unresolved difference in their true ages might account for the difference, we favor the conclusion of Haugerud and others (1991, p. 1304–1305) that the post-75 Ma deformation strongly decreased to the southeast between the two plutons; this gradient may largely reflect subsequent greater uplift to the north.

Eldorado Orthogneiss

Massive to gneissic metamorphosed quartz biotite-hornblende granodiorite and monzodiorite exposed on Eldorado Peak were named the Eldorado Orthogneiss by Misch (1966). From its northwest end in the Mount Baker quadrangle, the large elongate pluton extends at least 45 km to the southeast. The main mass of the pluton within the quadrangle is a lineated to slightly gneissic medium-grained granitoid rock, locally with a strong hornblende lineation. McShane (1992, p. 15) ascribes much of the foliation and lineation in the more massive rock to primary igneous flow. The west margin of the pluton is flaser gneiss, with anastomosing mafic layers and augen of filled plagioclase or quartz, plagioclase, and K-feldspar.

The north and east sides of the pluton are enveloped in pegmatite dikes and masses that have obliterated much of the contact between the Eldorado Orthogneiss and its country rock. Much of the pegmatite is highly strained and similar to other late granitoid intrusions in the Skagit Gneiss Complex. In the Newhalem Creek [105] area, McShane and Brown (1991) and McShane (1992, p. 8–14) found evidence that the protolith of the Eldorado pluton intruded Napeequa Schist. Southeast of the quadrangle, highly strained flaser gneiss of the Eldorado is interlayered with schist and amphibolite suggesting either an original lit-par-lit complex or tectonic imbrication (Tabor, 1961, p. 104, 145–146).

The Eldorado Orthogneiss does not fit well into the division of granodioritic and tonalitic plutons, for it has characteristics of both groups. The pluton is a monzodiorite and granodiorite modally and a granodiorite normatively, but $\delta^{18}O$ values are less than 10 (Ford and others, 1988, p. 24–25, 106–108; White and others, 1988, p. 30). In addition the pluton has many field characteristics in common with the tonalite group, such as strong elongation parallel to the regional grain and well-preserved igneous textures. The pluton has higher K_2O content relative to silica than most of the other stitching plutons (Ford and others, 1988) suggesting a more complicated petrogenesis. We include it with the granodioritic plutons, albeit with reservations.

Misch (1966, p. 105) first described the Eldorado Orthogneiss and considered it to be basement to his Cascade River Schist, structurally similar to his Marblemount Meta Quartz Diorite and, as such, part of his pre-Devonian Yellow Aster Complex exposed to the west. Concordant U-Pb isotope ages of zircon of about 88 to 92 Ma from the Eldorado Orthogneiss (table 3, No. 57; Tabor and others, 2002) indicate that the Eldorado is one of the Late Cretaceous suites of synkinematic plutons. A hornblende K-Ar age of 43 Ma (southeast of quadrangle; see Engels and others, 1976) reflects Eocene unroofing of the unit.

Paleobarometry of igneous hornblende in the Eldorado Orthogneiss and lack of igneous epidote suggest that it was crystallized at only 3.7–5 kb, in contrast to the nearby Cascade River Schist with metamorphic crystallization pressures of 6.5–7.5 kb (Dragovich, 1989, p. 78; Brown and others, 1994). Babcock and Misch (1988, p. 21) proposed that the pluton was thrust over the Skagit Gneiss and Cascade River Schist, but Tabor and others (1989, p. 40) suggested that the pluton had been faulted down into the Cascade River Schist from a higher structural level. McShane and Brown (1991) and McShane (1992) concluded that the pluton was intrusive into the Cascade River Schist prior to magmatic loading which produced higher-pressure metamorphism in the schist; the low pressures are relict. Presumably the metamorphosed margins of the pluton reflect this last episode of metamorphism.

Descriptions of the Eldorado Orthogneiss are in Tabor (1961, p. 145–151), Tabor and others, (1989, p. 40), and

McShane (1992). Ford and others (1988, p. 18–27, 106–108) and White and others (1988, p. 30) report modes, oxygen isotope values, and some chemical data.

Plutons of the tonalitic group

Orthogneiss of Mount Triumph

The orthogneiss of Mount Triumph [95], composed of weakly gneissic epidote-biotite-hornblende tonalite, is similar to orthogneisses in the Skagit Gneiss Complex but separated from them by a screen of mostly fine grained schistose amphibolite of the Napeequa Schist. Though in general much less ductilely deformed, the unit is analogous to the orthogneiss of Marble Creek and, like it, contains distinct layers and lenses of metamorphosed supracrustal material. It is intruded and thermally metamorphosed by the Oligocene granodiorite of Mount Despair. Locally this contact is a younger fault. Contact metamorphism has blurred the textural details necessary to confirm a primary, igneous origin for the coarse prisms of green epidote that are intergrown with biotite and hornblende in the orthogneiss of Mount Triumph.

Orthogneiss of Haystack Creek

The orthogneiss of Haystack Creek [107] (Haystack Creek Leucotrondhjemitic Orthogneiss of Misch, 1979) is distinguished from other orthogneiss bodies in and associated with the Skagit Gneiss Complex by the blotchy patches of aggregated mafic minerals. K-Ar ages of muscovite and biotite are about 48 and 44 Ma, respectively (table 3, No. 42) and reflect Eocene metamorphism and (or) unroofing. Misch (1979) considered this body and the orthogneiss of Marble Creek to have intruded early in the metamorphic cycle that formed the Skagit Gneiss Complex.

Orthogneiss of Marble Creek

A body of hornblende-biotite tonalite to granodiorite gneiss forms a distinct tear-shaped pod in the vicinity of Marble Creek and Monogram Lake [106]. Misch (1966, 1979) called this body the Marble Creek Trondhjemitic Orthogneiss. This body is characterized by lenses and schlieren of Napeequa Schist, numerous mylonitic zones, and scattered pods of ultramafic rocks. Textures in the Marble Creek body are mostly crystalloblastic, and although relict igneous textures remain, the pluton has been thoroughly metamorphosed. U-Pb ages of zircon are slightly discordant at about 75 Ma (table 3, No. 44). Haugerud and others (1991, p. 1304–1305) interpret this to be the age of intrusion and discuss the contrast in deformation with the contemporary Hidden Lake stock. K-Ar ages of muscovite and biotite—about 50 and 44 Ma, respectively (table 3, No. 45)—reflect Eocene metamorphism and (or) unroofing of the unit.

Skagit Gneiss Complex

Misch (1952; 1966, p. 112–113) first described the migmatitic banded biotite gneiss, banded amphibolite gneiss, and gneissic tonalite that crop out along the canyon of the Skagit River, mostly between Newhalem and Ross Lake. The banded gneisses contain abundant gneissic tonalite layers on all scales. Small bodies of mafic gneiss, mafic migmatite, ultramafic rock, and marble crop out also. Concordant to discordant foliated bodies of light-colored tonalitic pegmatite and lineated granitic dikes and granite pegmatites pervade all of the complex. Based on composition and observed transition to predominantly schistose rocks, the banded gneisses appear to be highly metamorphosed Cascade River Schist and Napeequa Schist.

Throughout much of his work in the North Cascades, Misch (1952, 1988; see also Misch and Onyeagocha, 1976; Babcock and Misch, 1988, 1989) considered the tonalite gneiss layers to have been formed by metasomatic replacement of supracrustal schists. In later years he recognized that many of the larger masses of tonalite, at least, were metamorphosed igneous bodies. His students and colleagues have gone on to detail the role of anatexis in formation of the migmatites (Whitney and Evans, 1988; Whitney, 1989, 1991, 1992a,b). As discussed in Haugerud and others (1991), we now feel that most of the tonalite material is intrusive igneous material. Haugerud and others (1991) formally defined the Skagit Gneiss Complex.

Within the Skagit Gneiss Complex we have mapped banded gneiss with considerable supracrustal component and orthogneiss bodies. The banded gneiss can be further divided into **banded gneiss, mostly bioite gneiss**, dominated by biotite schist layers (unit TKsbg), and **banded gneiss, mostly amphibolite gneiss and amphibolite** rich in hornblende schist layers (unit TKsbga), but not always dominated by hornblendic rocks. These subunits were mapped on the basis of gross lithologic aspect. The biotitic and amphibolitic banded gneiss subunits do not necessarily correspond to protolithic supracrustal materials derived from the Cascade River Schist and Napeequa Schist, respectively, although banded gneiss with ultramafic pods may well be derived from the Napeequa Schist. The amphibolitic banded gneiss in the area of Mount Prophet [90] contains abundant marble and calc-silicate rocks. Haugerud and others (1988) suggested that this area might be the lowermost structural horizon exposed in the core of the antiform that uplifts the deep-seated rocks of the Skagit Gneiss Complex.

Mapped **orthogneiss** bodies (unit TKo) in the Skagit Gneiss Complex are mostly gneissic hornblende-biotite tonalite. Orthogneiss with distinct composition or texture are mapped as **mafic orthogneiss**, **mafic migmatite**, and **orthogneiss of The Needle** [103]. Concordant to moderately discordant U-Pb ages of zircons from several bodies of orthogneiss suggest original igneous crystallization between 75 and 60 Ma (table 3, Nos. 51, 52, 53, 54, 56). In a recent study, Wernicke and Getty (1997) analysed Sm and Nd of a mafic Skagit orthogneiss body; they interpreted the Sm-Nd data and previously obtained U-Pb ages of zircon (table 3, No. 52) to represent igneous crystallization at 68 Ma. They interpreted Ar-Ar ages of 47 and 45 Ma of hornblende and biotite to represent cooling, in agreement with K-Ar data from elsewhere in the Skagit Complex. A biotite K-Ar age of about 30 Ma from Newhalem (table 3, No. 51) must reflect subsequent heating by the nearby Chilliwack batholith.

The orthogneiss of the Needle displays textures and isotope ages suggesting a more complex history. U-Pb ages of zircons are discordant, ranging from 113 to 122 Ma (table 3, No. 55), considerably older than other orthogneisses in the Skagit Gneiss Complex. Haugerud and others (1991, p. 1304) suggest that the gneiss is a recrystallized Triassic pluton, coeval with the Marblemount pluton.

Misch (1966, 1968), Babcock (1970), Misch and Onyeagocha (1976), Yardley (1978), Babcock and Misch (1988, 1989), Whitney and Evans (1988), Whitney (1989, 1991, 1992a,b), Haugerud and others (1991; 1994, p. 2E–37), and Wernicke and Getty (1997) describe the Skagit Gneiss Complex and discuss its petrogenesis. For discussion and description of ultramafic bodies in the Skagit, see Whitney and Evans (1988), Misch and Rice (1975), and Tabor and others (1989, p 44–45).

Age and cause of metamorphism

The metamorphic and plutonic rocks of the North Cascades core crop out in two structural-metamorphic blocks, the Chelan block, located northeast of the Entiat Fault, and the Wenatchee block, to the southwest (fig. 2) (Haugerud and others, 1991). Rocks in the Wenatchee block were mostly metamorphosed in the Late Cretaceous, whereas rocks in at least the northern part of the Chelan block were also metamorphosed in the Eocene. Metamorphism from Cretaceous to Eocene was continuous (Wernicke and Getty, 1997) or renewed in the middle Eocene (Haugerud and others, 1991). Hopson and Mattinson (1994, 1996) describe an Early Cretaceous metamorphic event in the Chelan area of the Chelan block some 120 km east-southeast of the Mount Baker quadrangle. Much of the evidence for the ages of metamorphism comes from the ages of the synkinematic or metamorphosed terrane stitching plutons that have been dated by the U-Pb method.

Only a small wedge of the Wenatchee block is exposed in the Mount Baker quadrangle: the triangular terrane between the Straight Creek Fault, the Entiat Fault, and the south boundary of the quadrangle (fig. 2). Walker and Brown (1991, p. 492–493) and Tabor and others (2002) describe the Late Cretaceous, deep-seated and synmetamorphic plutons as well as K-Ar cooling ages that suggest metamorphism occurred from about 96–85 Ma in the Wenatchee block. The 94-Ma age of metamorphic muscovite from the Marblemount pluton (table 3, No. 62), well removed from the deep seated, Late Cretaceous plutons, confirms that regional metamorphism proceeded during intrusion of mid-Cretaceous magmas.

McShane and Brown (1991) and McShane (1992, p. 61) concluded that andalusite-bearing rocks in the Cascade River Schist were upgraded to kyanite grade following the shallow intrusion of the Eldorado pluton at 90 Ma. Whether the andalusite formed during regional metamorphism or was produced by contact metamorphism surrounding the pluton is not clear. Seventy kilometers or more to the southeast in the Chelan Block, Miller and Bowring (1990) describe extended Late Cretaceous to middle Eocene metamorphism. In this same region, Miller and others (1993b, p. 1320) consider the metamorphism of the Twisp Valley Schist to have culminated at about 91–88 Ma and at about 68–60 Ma. Some 75 km farther to the southeast in the Chelan area, rocks of the Chelan block were recrystallized during deep-seated metamorphism and plutonism occurring from 120 to about 70 Ma (Mattinson, 1972, p. 3778; Tabor and others, 1987a, p. 8; Hopson and Mattinson, 1990). In the Skagit Gorge (the northern part of the Chelan block), Wernicke and Getty (1997) conclude that intrusion of tonalite orthogneisses at 68 Ma preceeded metamorphism of the wall rocks that reached peak temperatures of about 690°–750°C. These authors interpret cooling to have been rapid until about 60 Ma, slow until about 45 Ma, and then rapid, and attribute rapid cooling to be the result of unroofing. Younger (Eocene) metamorphism is evident in the Mount Baker quadrangle where 45-Ma granitic sills and dikes in the Skagit Gneiss Complex are strongly deformed (Haugerud and others, 1991). A boulder of the Marblemount pluton from a Tertiary conglomerate sliver in the Straight Creek Fault zone contains zircons that yielded a 45-Ma fission-track age (table 3, No. 37), suggesting that some rocks of the Marblemount pluton did not cool until the middle Eocene and that detritus was supplied from Marblemount plutons east of the Entiat Fault (Vance and Miller, 1992).

Lacking more precise data and for the sake of simplification, we have assigned a Cretaceous metamorphic age to all the rock units of the Chelan Mountains terrane southwest of the Entiat Fault, that is, in the Wenatchee block, and a Cretaceous and Tertiary metamorphic age to all those northeast of the fault, in the Chelan block. Available ages and the lack of deformation in the Hidden Lake stock—probably on the edge of the region that was strongly deformed and recrystallized by the middle Eocene event (Haugerud and others, 1991)—support this division.

The cause of metamorphism in the North Cascades is still under much debate. So far invoked are terrane collision (Monger and others, 1982), stacking of thrust plates by east-west contraction (Misch, 1966; Brandon and Cowan, 1985; McGroder, 1991), heating by arc-root magmatism (Kriens and Wernicke, 1990a,b), magma loading (Brown and Walker, 1993; Miller and others, 1993a), and thickening by intracrustal subduction (Wernicke and Getty, 1997). A common theme for many of these hypotheses is some sort of crustal thickening. For a detailed summary of these ideas and a full bibliography see Miller and others (1993a), Haugerud and others (1994), and Wernicke and Getty (1997).

Ductile deformation had ceased by 34 Ma (early Oligocene) when the region was intruded by Cascade magmatic arc-root plutons that uniformly lack penetrative fabrics.

LATE OROGENIC AND POSTOROGENIC DEPOSITS

Older sandstone and conglomerate

Small patches of relatively undeformed fluviatile sandstone, conglomerate, and argillite crop out along the Straight Creek Fault and locally west of it. Many patches occur as hornfelsic roof pendants in the Chilliwack batholith but nevertheless aligned on the Straight Creek Fault trend. These patches continue into Canada where they are associated with the Fraser River Fault Zone. Earlier workers (Misch, 1966; Staatz and others, 1972, p. 30–32) correlated some of these isolated patches with the Eocene Chuckanut Formation.

Deposits exposed south of Mount Hagan have a thin basal conglomerate composed of clasts of vein quartz and phyllite derived from the underlying Easton Metamorphic Suite. Higher in the section the rocks are uniformly feldspathic sandstone and conglomerate with a variety of clast types, including quartzite, and argillite. Fossil logs and trees and abundant trough crossbedding attest to fluvial deposition.

We are not certain how old these deposits are, but judging from similar deposits farther south along the Straight Creek Fault, they are middle Eocene. About 105 km to the south of the Mount Baker quadrangle, in the Snoqualmie Pass and Wenatchee quadrangles (fig. 1), early middle Eocene sandstone and conglomerate crop out adjacent to and east of the Straight Creek Fault and late(?) middle Eocene sandstone, conglomerate, and volcanic rocks crop out adjacent to and to the west of the fault (Tabor and others, 1984, 1993, 2002). Fluviatile conglomerate and sandstone in the Fraser River Fault Zone just north of Hope, B.C., have been dated as middle Eocene on the basis of pollen (Glenn Rouse in Monger, 1989).

Younger sandstone and conglomerate

A coarse cobble conglomerate rich in clasts derived from the Triassic Marblemount pluton crops out west of lower Bacon Creek, within the Straight Creek Fault Zone. A fission-track age of about 45 Ma from a meta-quartz-diorite clast (table 3, No. 37) indicates that the faulted sliver of conglomerate and sandstone is late middle Eocene or younger in age, assuming that the zircon ages date cooling of the Marblemount prior to erosion of the clasts and their incorporation in the conglomerate.

Chuckanut Formation

The Chuckanut Formation crops out mostly west of the Mount Baker quadrangle. It consists of an aggregate thickness of about 6 km (Johnson, 1982, p. 12) of fluviatile feldspathic sandstone, conglomerate, argillite, and coal. In the Mount Baker quadrangle, we have restricted the Chuckanut Formation to rocks continuous with mapped Chuckanut to the west (Johnson, 1982, 1984). Chuckanut beds within the map area have been referred to as the Bellingham Bay, Slide, and Warnick Members by Johnson (1984) who considered these rocks to range from early to late(?) Eocene in age. J.A. Vance (oral commun., 1993) reports that detrital zircon populations separated from numerous samples of the Chuckanut Formation throughout the section each show an age peak of about 56 Ma, implying that most of the unit is younger than Paleocene. Small amounts of anthracite have been mined from deformed, pyritic beds near the basal contact north of Lookout Mountain [19] (Moen, 1969, p. 20). For detailed descriptions see Johnson (1984).

ROCKS OF THE CASCADE MAGMATIC ARC

The Cascade magmatic arc, stretching from northern California to Alaska, became active about 36 Ma (Vance and others, 1987; Smith, 1993). In the Mount Baker quadrangle, the arc is mostly represented by granitic arc-root plutons, but the oldest is the 34-Ma gabbro of Copper Lake, an early phase of the Chilliwack composite batholith.

Volcanic rocks of the Cascade magmatic arc are sparse, preserved in down-faulted blocks or collapsed calderas in several areas. They commonly were erupted on eroded early phases of the Chilliwack batholith and then intruded by younger phases. Misch (1966) included most of them in his Hannegan Volcanics, but we have separated these volcanic accumulations geographically, because they appear to be different ages. They are the volcanic rocks of Pioneer Ridge, of Big Bosom Buttes, and of Mount Rahm, the Hannegan Pass Volcanics, and the volcanic deposits of Kulshan Caldera. The latter deposits underlie andesitic breccia and lava of Mount Baker volcanic center. Mount Baker is an active calc-alkaline stratovolcano.

Volcanic Rocks of Pioneer Ridge

Volcanic mudflow breccia and dacitic flow rock on Pioneer Ridge [93] overlie granodiorite of Mount Despair and are intruded by tonalite of the Perry Creek phase of the Chilliwack batholith. The age of the volcanic rocks is thus somewhere between about 32 Ma and 25 Ma. We include thermally metamorphosed volcanic mudflow breccia on Easy Ridge [86] in the Pioneer Ridge unit because the granodiorite of the Indian Mountain phase (about 26 Ma or older) intrudes it.

Volcanic rocks of Big Bosom Buttes

We have mapped three units in the volcanic rocks of Big Bosom Buttes [49]: basal monolithologic granite breccia, a probable talus and (or) landslide deposit from caldera walls; dacite tuff; and volcanic breccia made up mostly of dacitic fragments. The basal breccia is mostly made of biotite granite of the Pocket Peak phase of the Chilliwack batholith and demonstrates that the volcanic unit overlies the granite unconformably. Based on bedding attitudes, the overlying volcanic rocks also overlie feldspathic sandstone of the older sandstone and conglomerate unit (cross section A'–A").

Although the volcanic rocks of Big Bosom Buttes unconformably overlie the 30-Ma Pocket Peak phase, they appear to be intruded by tonalite of the Baker River phase, which elsewhere appears to be older than about 31 Ma (see below). We assume that the ages are imprecise or that the areally extensive Baker River phase consists of more than one pluton. We tentatively assign an Oligocene age to the volcanic rocks of Big Bosom Buttes.

Volcanic rocks of Mount Rahm

A thick pile of mostly silicic volcanic breccia and tuff crops out along Silver Creek, west of Ross Lake, and extends into Canada. The rocks are strongly thermally metamorphosed locally due to intrusion by phases of the Chilliwack batholith. Bedding is obscure except in the western part of the unit where there are abundant tuffs.

The volcanic rocks of Mount Rahm were originally called the Skagit Volcanic Formation by Daly (1912), included in the Hannegan Volcanics by Misch (1966), and renamed the Skagit Volcanics by Staatz and others (1972). The rocks have been called the Skagit Formation in Canada (Monger, 1989). The name Skagit Volcanics was subsequently abandoned by Haugerud and others (1991, Appendix A). The volcanic rocks of Mount Rahm are older than the 22- to 25-Ma Perry Creek phase of the Chilliwack batholith (unit Tcpc) that intrudes them. K-Ar ages of about 13 Ma reported by Mathews and others (1981; locations on Monger, 1989) have probably been reset by the young quartz monzodiorite of Redoubt Creek [76] that also intrudes the volcanic rocks of Mount Rahm.

Descriptions of the volcanic rocks of Mount Rahm are provided by Daly (1912, p. 528–531), Shideler (1965), Staatz and others (1972, p. 22–23), Haugerud (1985, p. 196–197), and Mathews and others (1981).

Tonalite of the Cascade Pass dike

An unusually large dike of mostly tonalite extends 16.5 km from Fisher Creek [108], just east of the southeast corner of the Mount Baker quadrangle, southwestward to beyond the South Fork of the Cascade River, south of the quadrangle. At maximum surface exposure, the dike is about 1 km wide. Tabor (1963) described the Cascade Pass dike and suggested that it intruded at only a few kilometers depth. A number of samples of hornblende and biotite from the Cascade Pass area, south of the Mount Baker quadrangle, yield K-Ar ages ranging from 16 to 19 Ma (Engels and others, 1976; Tabor and others, 2002). Concordant pairs suggest that the age of this pluton is about 18 Ma. Ford and others (1988, p. 32–34) and White and others (1986, p. 19) report modal, some chemical, and oxygen isotope data for the Cascade Pass dike.

Hannegan Volcanics

A thick accumulation of andesitic to dacitic volcanic breccia overlies white-weathering rhyolitic tuff in the vicinity of Hannegan Pass [57]. Misch (1966, p. 138) first described and named these rocks and the name was adopted by Staatz and others (1972, p. 32). We restrict the Hannegan Volcanics to the volcanic rocks at Hannegan Pass and nearby patches. Like many of the volcanic accumulations in the North Cascades, megabreccias of the underlying rocks crop out within the volcanics, suggesting derivation from caldera walls.

A Pliocene age for the unit is well established. Hornblende from two separate clasts of andesite from the upper breccia unit yields K-Ar ages of 3.6 and 3.3 Ma (table 3, No. 4). Zircon from a vitrophyre within the lower tuff unit yields a fission-track age of 4.4 Ma (table 3, No. 5) and Hildreth and others (2003) report a $^{40}Ar/^{39}Ar$ age of 3.72±0.02 Ma from plagioclase of an intracaldera ignimbrite vitrophyre. Further descriptions of the Hannegan Volcanics are in Staatz and others (1972, p. 32–34).

ROCKS OF THE CHILLIWACK COMPOSITE BATHOLITH

These arc-root plutons range from gabbro to alaskite in composition and from 32 to 2.5 Ma in age. Tabor and others (1989, p. 17) noted that arc-root plutons of the North Cascades fall into three age groups, or families; we now think that the age ranges of these families are Index family, 29–35 Ma; Snoqualmie family, 22–28 Ma; and Cascade Pass family, less than 20 Ma.

Most of the calc-alkaline plutons are of intermediate composition and are medium-grained hypidiomorphic granular. We have mapped separate plutons or phases of the batholith based on mineral composition, contact relations, and isotopic ages where known. The reconnaissance mapping has established some areally extensive phases which undoubtedly will be further divided by more detailed work. Where the mapped unit is very large and our sampling suggests inhomogeneities that might represent separate plutons, we refer to the unit as a phase. Igneous rock names and color index (CI) are based on modes, both point-counted and visually estimated from thin section. Rock classification is that of the IUGS (Streckheisen, 1973). Tepper (1985, 1991) has mapped some areas of the batholith in detail and has made the most complete study of the batholith overall; our descriptions below draw heavily on his work. On the basis of chemical and isotopic studies, Tepper and others (1993) have shown that the gabbronorite at Mount Sefrit and other gabbroic rocks associated with the Chilliwack composite batholith were derived from mantle basalt that invaded and heated amphibolitic lower crust which also melted to produce the more silicic phases of the batholith.

Index family

Several large plutons or phases of the Chilliwack composite batholith appear to be within the Index family age bracket of about 29 to 35 Ma. The oldest is the **gabbro of Copper Lake** [56] which Tepper (1991, p. 20–28) describes in detail. He notes that it has a small core of poikilitic-hornblende gabbro surrounded by hornblende diorite. A 3-point Rb-Sr isochron for the gabbro gives an age of 34 Ma (table 3, No. 34), an age supported by evidence of intrusion of the gabbro by tonalite of the 26-Ma Chilliwack valley phase of the Chilliwack batholith. For chemical, modal, and isotopic data, see Tepper (1991, p. 242–299).

We do not know the ages of **miscellaneous gabbro and diorite** bodies. Biotite-pyroxene quartz diorite near Mount Despair is somewhat hornfelsic suggesting it was emplaced prior to the 32-Ma granodiorite of Mount Despair. Moore (1972) and Tepper and others (1993, p. 334) considered mafic plutons north of Whatcom Pass to be younger than adjoining plutons of the batholith, although from geochronologic studies we know that mafic magma bodies, such as the Mount Sefrit Gabbronorite of Tepper and others (1993) (see below), formed at about the same time as some intermediate plutons during the 32-Ma growth of the batholith (Tepper 1991, p. 29). For further descriptions and some modal, chemical, and isotope data see Moore (1972) and Tepper (1991, p. 245–246, 263, 273, 278, 295, 299).

The largest pluton of the Index family is the **granodiorite of Mount Despair**, with a mapped extent of 118 km^2. Misch (1966, p. 140) considered this pluton to be the main phase of the batholith. Modally the granodiorite is much like some of the Baker River phase (described below). Large quartz eyes visible in hand specimen help distinguish the rocks, but the difference is commonly subtle in the field, and probably for this reason we never found a distinct contact with the younger(?) Baker River phase. A spectacular **agmatite** of large (up to several meters across) rounded mafic inclusions in a light-colored matrix is associated with the granodiorite of Mount Despair at and south of Jasper Pass [94]. Similar agmatites are present east of the middle reaches of Bacon Creek. An array of isotope ages from the Mount Despair pluton ranges from about 30 to 35 Ma (table 3, Nos. 27–32). Tepper (1991) reports a Rb-Sr age of 33.5±2 Ma credited to J. Gabites. J. A. Vance (written commun., 1986) reports a zircon fission-track age of about 20 Ma. The pluton's age is probably about 32 Ma. It is sharply intruded by the 30-Ma biotite alaskite of Mount Blum. Tepper (1991, p. 67, 247, 282, 288–289, 296) refers to this rock as the quartz diorite of Thornton Creek and reports modal and chemical data.

The **Pocket Peak phase** is very similar mineralogically and texturally to the granite of the Mineral Mountain pluton, and in a preliminary report we (Tabor and others, 1994) mapped these units together (see section on the Mineral Mountain pluton). K-Ar ages of muscovite and biotite from near Pocket Peak [50] are concordant at 29.5 and 30.9 Ma respectively (table 3, No. 25). Hornblende from a dike cutting rock that we include in the Pocket Peak phase yielded a K-Ar age of about 32.5±2.1 Ma (table 3, No. 26), suggesting that granite in the headwaters region of the Chilliwack River could be older than about 30 Ma. On the ridge east of the upper West Fork of Silesia Creek, tonalite dikes of the Chilliwack valley phase of the batholith intrude the granite of Pocket Peak. As mapped, the Pocket Peak phase includes a granodiorite porphyry on Copper Ridge described by Tepper (1991, p. 73). Richards and McTaggart (1976) described the apparent continuation of this pluton north of 49° N. as the Mount Rexford quartz monzonite, but they report a younger K-Ar age of biotite at 26±1 Ma from 0.8 km north of the border (p. 941).

The **biotite alaskite of Mount Blum** sharply intrudes the granodiorite of Mount Despair on the north ridge of Mount Blum [64]. Two biotite K-Ar ages are 29.4 and 30.8 Ma. Biotite and whole-rock Rb-Sr analyses give an age of about 30 Ma (table 3, No. 24). Zircon fission-track ages from adjacent hornfels are about 20 Ma (J.A. Vance, written commun., 1986). Tepper (1991, p. 81–83, 252, 298, 300) describes the Mount Blum pluton and reports modal, chemical, and isotopic data.

The **Silesia Creek pluton** is a heterogeneous body ranging from granodiorite to quartz diorite and characterized by a great range of mafic mineral content and fuzzy layers or inclusions of granite. In some outcrops, mafic minerals and inclusions are conspicuously aligned by flow. Near the fault bounding the east side of the pluton, tonalite is finer grained, that is chilled, against inclusions of granite which may be derived from the Pocket Peak phase. Concordant K-Ar ages of hornblende and biotite are about 30 Ma (table 3, No. 23). This pluton is petrologically similar to the Baker River phases of the batholith which may be about the same age, but it is also similar to the 22- to 25-Ma Perry Creek phase.

The **tonalite of Maiden Lake** forms a small pluton southwest of Mount Shuksan and is enigmatically more thoroughly metamorphosed than any other Cascade Arc pluton so far examined by us. The rock is medium-grained subidiomorphic granular but most plagioclase is completely filled with sericite, carbonate, prehnite, and pumpellyite. Biotite is mostly altered to chlorite, but relatively unaltered hornblende, somewhat mottled, remains. The rock is sharply intrusive into metasedimentary rocks of the Chilliwack Group; dikes of the tonalite extend into the country rock as well. Ziegler (1986, p. 99–103) considered the pluton to be part of the Yellow Aster Complex, and we (Tabor and others, 1994) mapped it as a Paleozoic or Mesozoic intrusion based on its greenish color and metamorphism. U-Pb ages of two fractions of zircons (table 3, No. 22) are discordant, but the third, coarsest fraction is concordant at 29 Ma, which suggests to W. McClellan (written commun., 1996) that the older, discordant ages reflect inheritance. The metamorphic minerals in this rock strongly suggest it is a pre-Tertiary pluton, but based on the concordant U-Pb ages we tentatively include it in the Chilliwack batholith.

The **Baker River phase** is composed of granodiorite with lesser amounts of tonalite and quartz diorite, except for the **Price Glacier pluton** and for rocks in the Skagit Range [52] where tonalite and quartz diorite predominate. Hornblende and biotite are conspicuous. On the west side of Mount Blum [64], the unit is in gradational contact with the 30-Ma granodiorite of Mount Blum, but rounded inclusions of the darker colored Baker River phase are contained in the granodiorite. Engels and others (1976) interpreted a K-Ar age of an impure hornblende sample to place an older limit of 27 Ma on the southern part of this unit, but the relations at Mount Blum suggest the Baker Valley phase is a little older than 30 Ma. Tonalite in the Skagit Range, for now included in this phase, may be younger because it intrudes the volcanic rocks of Big Bosom Buttes, which in turn depositionally overlie 30-Ma granite of the Pocket Peak phase.

Tepper's (1985; 1991, p. 64–66, 247, 296, 300) descriptions and chemical, modal, and isotopic data for his granodiorite of Hannegan Peak can be applied to the Baker River phase as mapped here in the Skagit Range. Some of Tepper's (1985; 1991, p. 61–64, 247, 296, 300) descriptions and chemical, modal, and isotopic data for his granodiorite of Ruth Mountain (samples CB92–009, –015, –027, –029, –032) can be applied to the Price Glacier Pluton as mapped here.

Snoqualmie family

Formerly, we (Tabor and others, 1994) included granodiorite making up the **Indian Mountain phase** of the batholith in the granodiorite of Mineral Mountain on the basis of gross modal similarity. Aside from the difference in isotopic ages, now confirmed with further work (see description of the Mineral Mountain pluton below), the Indian Mountain [80] phase generally contains hornblende and biotite, thus differing from the Mineral Mountain pluton which has only biotite. Outcrops in upper Brush Creek [84] suggest that the Mineral Mountain pluton intrudes the rocks of the Indian Mountain phase. The Indian Mountain phase is heterogeneous and age relations are conflicting, suggesting that the unit is composed of several plutons. It is mostly granodiorite and granite but includes quartz monzonite and quartz monzodiorite. A chloritized sample of the granodiorite of Indian Mountain from east of the Chilliwack River contains hornblende and biotite which yield K-Ar ages of about 26 and 23 Ma, respectively (table 3, No. 21). These discordant ages indicate argon loss. In addition the rocks are altered and the sample site is within 500 m or so above the 26-Ma old Chilliwack valley phase, which could have reset the argon clocks. Some of the granodiorite of Indian Mountain could be as old as the other 30-Ma granitic bodies. We include in the Indian Mountain unit the rocks mapped as the granodiorite of Lake Reveille [81] by Moore (1972) and Tepper (1991, p. 80). Tepper (oral commun., 1995) reports that granodiorite similar to the Lake Reveille unit, but isolated from it, intrudes the 10-Ma quartz monzodiorite of Redoubt Creek. For additional description and data, see Moore (1972, p. 46–48) and Tepper (1991, p. 80, 251).

Rocks of the **Chilliwack valley phase** (named for rocks along the valley walls of the Chilliwack River valley south of the Canadian border) have a higher color index (CI) than rocks of the Indian Mountain phase. They are mostly granodiorite and tonalite. Two K-Ar hornblende ages are about 24 and 27 Ma, and a biotite age is 26 Ma (table 3, Nos. 19, 20). The errors suggest that an age of about 26 Ma is about right, which is appropriate for evidence that the tonalite of this phase intrudes 30-Ma granite of the Pocket Peak phase and the 34-Ma gabbro of Copper Lake. The unit probably includes several plutons. Tepper (1991, p. 69–70, 248, 283, 297) describes the rocks forming a small part of this unit as the tonalite of Copper Mountain.

Misch (1966, p. 140) first described the **Perry Creek phase** of the Chilliwack batholith and considered it younger than his main phase (our granodiorite of Mount Despair). The Perry Creek phase is mostly hornblende-biotite tonalite and granodiorite and it differs little in lithology from the Baker River and Chilliwack valley phases, although it appears to be slightly younger. As mapped, the Perry Creek phase is nowhere in contact with the other dark granodioritic to tonalitic phases. Tepper mapped some of our Perry Creek phase as the tonalite of Hozomeen Camp and the quartz diorite of East Lakes [82]. He (Tepper, 1991, p. 71–72, 249, 297) describes some of the rocks of the Perry Creek phase and reports chemical data.

K-Ar ages on hornblende and biotite from the Perry Creek phase range from about 22 to 25 Ma (table 3, Nos. 15, 16, 18); a single biotite age of 32 Ma (table 3, No. 17) seems too old. On the east side of lower Perry Creek [77], tonalite of the Perry Creek phase intrudes **biotite granodiorite of Little Beaver Creek**. Hornblende and biotite from the latter pluton have K-Ar ages of about 25 Ma and 23 Ma (table 3, No. 14), respectively, suggesting that the Perry Creek phase and the rocks of the Little Beaver Creek pluton may be about the same age.

A wide zone of **tectonized tonalite** on Whatcom Peak [87] appears to be mainly derived from rocks of the Perry Creek phase, but includes remnants of other plutons and country rock as well. We do not know the significance of the zone. It might be an expression of the northeast-trending faults mapped north of Whatcom Pass [85] and northeastward to Silver Lake [72].

Mount Sefrit Gabbronorite of Tepper and others (1993) crops out at the west edge of the batholith on Mount Sefrit [53]. A Rb-Sr isochron age is 23 Ma (table 3, No. 13). For further description and considerable chemical and isotopic data see Tepper (1985; 1991, p. 29–51, 243–244, 254–259, 271–273, 276–278, 285–287, 294, 299, 301) and Tepper and others (1993).

Cascade Pass family

The ages of the **miscellaneous granodiorite bodies** are unknown, but we include them in the youngest family of plutons of the Chilliwack batholith because some of the rocks are similar to the very young Lake Anne stock. We have seen no contacts for the body on the north side of Mount Hagan [66], but its outcrop shape suggests a plug-like mass intruding the 30-Ma biotite alaskite of Mount Blum.

The **quartz monzodiorite of Redoubt Creek** [76] forms an elongate northeast-trending pluton north of Little Beaver Creek. The pluton is heterogeneous, varying from granite to diorite. Most varieties contain pyroxene as well as biotite and hornblende. Hornblende yields a K-Ar age of 10.8 Ma (table 3, No. 11). Mathews and others (1981) report a 12-Ma K-Ar age for a stock at the head of McNaught Creek in Canada, which lies along trend just north of the quadrangle, and which we interpret to be part of the Redoubt Creek pluton (table 3, No. 12). Tepper (1991, p. 67–69, 248, 296, 300) calls this body the quartz monzodiorite of Indian Creek [79]; he gives detailed descriptions, modes, and chemical and isotopic data.

In the cirque of upper Depot Creek [71], a small plug, the **granite of Depot Creek**, intrudes the quartz monzodiorite of Redoubt Creek.

The **granite of western Bear Mountain** [75] is petrographically similar to the Mineral Mountain and Ruth Creek plutons but more heterogeneous and commonly contains more hornblende. Tepper (1991, p. 79–80) describes aplite dikes, some with molybdenite. We did not see contacts with adjoining intrusions. The age of the pluton is uncertain. Tepper (1991, p. 251, 297) reports modal and chemical data.

Two plutons that look very much alike, the **Mineral Mountain pluton** and the **Ruth Creek pluton,** contain conspicuous quartz eyes up to several centimeters across, have low CI, mostly bear biotite, and are about the same age. Tepper (1991, p. 79) comments on the their similarity.

U-Pb isotopic analysis of zircons from the Mineral Mountain pluton indicates an age of about 7 Ma (table 3, No. 8). In an earlier report we (Tabor and others, 1994) questioned this age because very similar granites in other localities had yielded older K-Ar ages. A new fission-track age on a separate aliquot of the zircons dated by the U-Pb method is 6.5 Ma confirming that the young age is valid. We thus have mapped separately the Mineral Mountain pluton from the more extensive granite units, although the contacts have not been rigorously traced. We know that the Mineral Mountain pluton is partially faulted against granodiorite of the Baker Valley phase on the west side of Mineral Mountain [60]. Based on topography, we infer another fault separates the pluton from granite of Pocket Peak east of Chilliwack Pass [59]. This fault appropriately parallels a caldera fault at the margin of the Hannegan Volcanics to the west. The contact to the northeast with similar granodiorite of the Indian Mountain phase is less certain, but outcrops in the upper reaches of Brush Creek [84] reveal a light-colored granitic rock intruding a darker granitic rock to the north. Along the apogee of Easy Ridge, the granite contains dark pillow-like inclusions suggesting magma mixing near a contact.

The contact of the Mineral Mountain pluton with the granodiorite of Mount Despair is obscure because both rocks display conspicuous quartz eyes, but we map the contact in Mineral Creek where the overall CI increases and hornblende becomes conspicuous in the Mount Despair pluton.

Biotite and whole-rock Rb-Sr analyses of the Ruth Creek [54] pluton define an age of 8.7 Ma (table 3, No. 10). As mapped the pluton includes Tepper's (1991, p. 70–71) porphyritic tonalite of Hannegan trail, a dike-like body which intrudes the Ruth Creek pluton and, nevertheless, yielded a zircon fission-track age of 8.7 Ma (table 3, No. 9). Near the contact with the Ruth Creek pluton, but intruding the adjoining granodiorite of the Baker Valley phase of the batholith, are numerous aplite and pegmatite dikes presumably derived from the Ruth Creek pluton. Tepper (1991, p. 76–79, 250–251, 297, 300, 301) describes both the Ruth Creek pluton (his granodiorite of lower Ruth Creek) and the Mineral Mountain pluton and reports modal, chemical, and isotopic data.

The **granite porphyry of Egg Lake** [55] is a small body intruding granodiorite of Pocket Peak north of the upper Chilliwack River. Petrographically similar rocks crop out in isolated areas on Easy Ridge, but are not shown on the map. At Egg Lake the granite porphyry underlies the Hannegan Volcanics, but a dike of similar rock intrudes the northern arcuate fault bounding the Hannegan Volcanics, suggesting that the granite porphyry is about the same age as the volcanic rocks overall or about 3.6 Ma. Tepper (1991, p. 81, 251, 298, 300) describes the rocks and reports modal, chemical, and isotopic data.

In the Nooksack cirque [61] area, a group of nested plutons suggests an intrusive suite. They are the **quartz diorite and quartz monzodiorite of Icy Peak** [62], the **granite of Ruth Mountain**, and the **quartz monzonite and granite of Nooksack cirque**. The undated Price Glacier pluton may be an older member of this suite based on map pattern, but we have considered it a part of the Baker Valley phase based on its composition, and if this correlation is correct, it is much older than the other plutons in the Nooksack cirque area. In the intrusive suites of the Sierra Nevada, individual plutons show some chemical or mineralogical relationships or are gradational into each other (Bateman, 1992, p. 67–68). Nested plutons of intrusive suites generally progress from more mafic to more silicic inward. Our data are so sparse that we are not certain the plutons of the Nooksack cirque area meet all these criteria.

Quartz diorite and quartz monzodiorite of Icy Peak intrude the Hannegan Volcanics in the western cirque of upper Pass Creek. The Icy Peak pluton is faulted against the granite of Ruth Mountain but is intruded by the quartz monzonite and granite of Nooksack cirque. We did not find a contact between the granite of Ruth Mountain and the quartz monzodiorite and granite of Nooksack cirque, but the nested pattern suggests that the Ruth Mountain body is the older of the two, although its age relative to the Icy Peak pluton is unclear. The nested plutons may all be younger than 4.4 Ma and may be in part resurgent into the caldera filled with the Hannegan Volcanics.

Some of Tepper's (1985; 1991, p. 61–64, 247, 296; in particular samples CB82–041, 063) descriptions and chemical and modal data for his granodiorite of Ruth Mountain can be applied to the granite of Ruth Mountain as mapped here.

One of the youngest plutons of the Chilliwack composite batholith is the **Lake Ann stock** [23]. Biotite from the stock and from hornfels within a few meters of it yielded K-Ar ages of 2.7 and 2.5 Ma respectively (table 3, Nos. 6, 7). These ages are only a little younger than the 4-Ma Hannegan Volcanics. As suggested by James (1980, p. 33–34) the volcanics and the stock may be derived from the same magma and the stock may be an offshoot from magma that fed the nested plutons of Nooksack cirque. The Lake Ann stock is overlain unconformably by the volcanic deposits of Kulshan Caldera which are dated at about 1.1 Ma. Detailed petrographic and chemical data for the stock are in James (1980).

A small pluton in Bar Creek yields K-Ar dates of about 0.7 Ma, thought to represent hydrothermal alteration, but its crystallization age may in fact be as young as middle Pleistocene (Hildreth and others, 2003).

DEPOSITS OF KULSHAN CALDERA AND MOUNT BAKER VOLCANIC CENTER

By Wes Hildreth

Quaternary magmatism has consisted of two contrasting episodes, (1) an early Pleistocene caldera-related sequence dominated by eruption of rhyodacite and (2) middle Pleistocene to Holocene development of a cluster of predominantly andesitic cones and satellite vents. Since 4 Ma, the principal focus of active magmatism has migrated about 25 km southwestward from Hannegan Caldera (fig. 2), through the 2.7-Ma Lake Ann stock and 1.1-Ma Kulshan Caldera, to present-day Mount Baker.

K-Ar ages mentioned here for Kulshan Caldera (Hildreth, 1966) and the Mount Baker volcanic cluster (Hildreth and others, 2003) are the results of work in the Menlo Park, Calif. laboratory of M.A. Lanphere (Hildreth and Lanphere, 1994). Most of these new ages are not in Table 3 or located on the map.

VOLCANIC ROCKS OF KULSHAN CALDERA

Kulshan Caldera is a 4.5- by 8-km steep-walled cylindroid that collapsed and filled with more than 1,000 m of rhyodacite ignimbrite during a single catastrophic eruption at 1.15 Ma. Three main suites of precaldera rocks enclosing the caldera—the Nooksack Formation, Chilliwack Group, and Lake Ann stock—subsided and shattered during the collapse event and occur as lithic fragments and megabreccia in the intracaldera ignimbrite. In contrast to many arc calderas like Katmai and Crater Lake, there was no precaldera edifice. A pluton-sized magma body apparently developed without precursory stratovolcanoes and reached a sufficiently shallow level to vent explosively a volume large enough to induce roof collapse. A few extracaldera andesitic to rhyodacitic dikes and lava remnants (shown on Cougar Divide [8b]) could have predated collapse, but if a silicic domefield were present, its destruction contributed virtually no lithic fragments to the exposed intracaldera tuff.

Topographic expression of Kulshan Caldera is obscured by the rugged relief carved on postcaldera lavas that overlie the intracaldera ignimbrite. Recurrent advances of the Cordilleran ice sheet lowered the caldera rim and much of the surrounding landscape, removing every vestige of extracaldera (outflow) ignimbrite and helping to produce as much as 1,180 m of intracaldera relief. No fallout is known to have survived glaciation in the North Cascades, but distal plinian fallout is as thick as 30 cm in the southern Puget Lowlands near Tacoma, about 200 km south of the caldera (Hildreth, 1996).

Intracaldera **ignimbrite of Swift Creek** (unit Qkig) is exposed best along the many forks of Swift Creek but also along Sholes Creek [21] and widely in the upper basin of Wells Creek. Exposures range in elevation from 810 m to 1,830 m, and the area of structural subsidence within which the ignimbrite is ponded covers 30 km^2. This suggests an intracaldera volume of at least 30 km^3, and the base of the ignimbrite is nowhere exposed. The deposit is predominantly massive, unstratified, poorly sorted, pumice-rich nonwelded tuff—white to pale grey except locally where altered ochre to orange brown. It is everywhere well indurated owing to light sintering, incipient silicification, and slight to moderate clay alteration of vitric shards. The tuff is lithic poor centrally, but within about 1 km of the walls caldera-collapse breccias and dispersed lithic fragments of wall rocks are abundant. The breccias include zones of shattered basement rock adjacent to the walls, sheets of wall-rock rubble enclosed by massive ignimbrite, and stacks of graded layers of lithic-rich ignimbrite that impart a crudely stratified aspect to some sections. Also enclosed by ignimbrite are a few 0.1-to1-km blocks of wall-collapse megabreccia, two of which are large enough to depict individually on the 1:100,000-scale map. Pumice in the ignimbrite is nearly all rhyodacite (about 72 percent SiO_2) containing 10-15 wt percent phenocrysts (plagioclase >> hypersthene hornblende > biotite > FeTi oxides > rounded quart > apatite zircon). Andesitic pumice is also present as sparse bands and blobs in the rhyodacite and as rare lapilli and granules. Pumice clasts larger than 50 cm are present, but few exceed 10 cm, and those smaller than 2 cm greatly predominate. The upper 100–200 m of the tuff tends to be poor in pumice lapilli and lithics, consisting largely of vitric ash and pumice granules. Deeper levels of exposure are pumice rich, but the ashy matrix is notably crystal enriched and unusually depleted in vitric fine ash. The eruption may have been in part phreatoplinian, perhaps starting subglacially (Hildreth, 1994, 1996). The $^{40}Ar/^{39}Ar$ age of the intracaldera ignimbrite is 1.15±0.01 Ma (Hildreth and Lanphere, 1994).

Caldera-lake sedimentary deposits as thick as 120 m rest directly upon the ignimbrite. Preserved only beneath or adjacent to protective younger lavas, sediments that have survived erosion have a present-day extent of only 3 km^2, but they probably once covered most of the 30-km^2 caldera floor. Well-lithified and variably altered hydrothermally, the sedimentary remnants are rich in calcite, clays, and pyrite. They are cut by numerous andesitic and silicic dikes, which locally deformed them or produced pépéritic breccias. Three main kinds of sedimentary deposits are interstratified: laminated ashy mudstone; ash-dominated diamictic debris-flow layers 0.1–7 m thick, containing matrix-supported clasts of caldera-wall rocks, pumice, and intraclasts of laminated mudstone; and sheets of ash-poor lithic breccia 0.1–5 m thick that probably originated as rockfalls from unstable caldera walls. No evidence for fluvial, channelized, or deltaic processes is recognized in the sediments. The main facies preserved suggest a steep-walled closed basin where avalanches and ashy mudflows were shed into standing water. All sediments could have come from unconsolidated ignimbrite and coignimbrite ashfall that draped the caldera rim and from continued crumbling of the walls. Most sedimentary sections dip 10°–15° toward the middle of the caldera, probably owing to differential secular compaction of the ignimbrite, which is likely to be thicker and less intermixed with collapse breccia centrally.

Rhyodacite lavas representing at least seven intracaldera eruptive units rest directly upon the ignimbrite or upon the ashy sediments overlying it. Several associated rhyodacite feeders, dikes, and irregularly shaped intrusions cut the ignimbrite. The original extent of these glaciated lavas may have been twice the 5 km^2 covered by the surviving remnants. Most conspicuous are 200-m-high Oreamnos dome at the caldera's south-central margin and 350-m-high Ptarmigan dome about 1 km south of Table Mountain [17]. In addition, outside the caldera, there are five smaller remnants of similar rhyodacite on Cougar Divide and one on the divide between Swift and Rainbow Creeks [36]; only one of these is truly extrusive, as glacial scour has reduced the others to the level of shallow feeders. At least three of these isolated extracaldera rhyodacites are of precaldera age. All of the intracaldera rhyodacite lavas postdate collapse by less than 160 k.y.

ROCKS OF THE MOUNT BAKER VOLCANIC CENTER

The episode of rhyodacite-dominated eruptive activity terminated by 0.99 Ma. Since that time, volcanic activity has been predominantly andesitic, accompanied by rare eruptions of basalt and dacite but only one of rhyodacite. This long interval of andesite-dominant eruptive activity has involved many vents, scattered as far as 17 km from the central vent of the present-day stratocone.

The volcanic record for the interval 1.0 to 0.5 Ma has largely been destroyed by glacial erosion. Nonetheless, numerous andesitic dikes and several ridge-capping remnants of andesitic lava flows attest to voluminous and extensive volcanism at that time. At least 60 andesitic dikes and irregular intrusions cut the intracaldera ignimbrite and sediments of Kulshan Caldera; a few are relatively fresh and feed surviving lavas younger than 0.5 Ma, but many more are propylitized, pyrite bearing, and evidently older. These dikes were probably emplaced after consolidation of the subcaldera silicic magma body but prior to extinction of the intracaldera hydrothermal system, which probably died out before emplacement of the unaltered intracaldera andesitic lavas of Lasiocarpa Ridge [8c] at about 515 ka. Another major focus of andesitic magmatism is represented by 15–20 north-trending dikes on Chowder Ridge, northwest of Hadley Peak [26], and on upper Dobbs Cleaver [20]. Most cut only the Nooksack Formation, but others in the swarm also cut a 1.02-Ma rhyodacite intrusive body at the south end of Cougar Divide. There were evidently one or more andesitic volcanoes centered near present-day Hadley Peak, now wholly stripped but possibly the source of several ridge-capping lava-flow remnants to the north and west. These include reversely magnetized olivine-pyroxene andesite lavas at Lookout Mountain[19] and Thompson Creek [9] (unit Qbm) and a complex stack of normally magnetized **andesite lavas on Cougar Divide** [14] and upper Dobbs Creek (unit Qbcd). Exposures are poor at Cougar Divide and Dobbs Creek, but at least five flows are present, each 20–120 m thick; maximum total thickness preserved is about 180 m. The lowest flow on the west side of Cougar Divide yields a K-Ar age of 613±8 ka; younger flows here give ages from 334±9 ka to as young as 105±8 ka. Part of the section is repeated by slumping on the east slope.

Roughly contemporaneous with the early andesitic activity near Hadley Peak and within Kulshan Caldera was the emplacement of a basaltic lava flow near Park Butte [41] 10–11 km to the south. The vent remains unrecognized and is probably covered by Mount Baker. The **basalt of Park Butte** (unit Qbpb) yields a K-Ar age of 716±45 ka.

Around 500 ka, the main volcanic focus shifted to an unusually productive central vent about 10 km southwest of the caldera margin, constructing there a long-lived stratovolcano—the gutted remains of which are today called **Black Buttes** [34]. Lavas and stratified fragmental deposits (unit Qbbb) dip radially away from the hydrothermally altered core, which has been glacially gutted and occupied by the west cirque of Deming Glacier. Thunder Glacier [32] has excavated the northwest flank of the dissected cone. The east and northeast flanks are largely concealed by Mount Baker, but they emerge distally at upper Sandy Creek, below the Squak Glacier. Proximal flows are typically 1–15 m thick, and more than 30 flows are exposed on each side of Thunder Glacier and more than 60 flows on the west slope of Black Buttes. Local relief is 600 m on walls of Deming Glacier, but total thickness of the surviving pile exceeds 1,200 m. A few much thicker flows (50–300 m; 59–64 percent SiO_2) of pyroxene andesite extend radially outward, capping Heliotrope [31] and Marmot [33] Ridges and the divide between Wallace and Rankin Creeks [35]. The lowest lava flow on the southwest side of the Black Butte cone gives a K-Ar age of 495±18 ka. On the basis of numerous K-Ar ages, much of the edifice seen today was built between 400 ka and 300 ka, and the youngest flow yet dated gives 288±15 ka. Accounting for erosion, a minimum eruptive volume of 30 km^3 is estimated, roughly double that of the active cone of Mount Baker.

Additional thick stacks of contemporaneous andesite make up **Forest Divide** (unit Qbfd), **Bastille Ridge** [25] (unit Qbbr) and **Lava Divide** [37] (unit Qbld), southeast, north, and northeast of Mount Baker, respectively. These were emplaced during the active lifetime of the main Black Buttes cone, but they appear to be glaciated remnants of separate peripheral eruptive centers, each once a substantial andesitic cone in its own right. The stack of andesite lava flows on Forest Divide is bracketed by ages of 455±9 ka and 366±10 ka. The remnant on Bastille Ridge has a K-Ar age of 322±12 ka. The stack of flows at Lava Divide is largely bracketed by ages of 460±13 ka and 296±15 ka. It is the only remnant of a once-substantial andesite volcano and has a maximum preserved thickness of about 550 m. The unit is the main source of Holocene debris-avalanche deposits along Rainbow Creek [36].

In addition to the peripheral andesite vents at Forest Divide, Lava Divide, and Bastille Ridge, three substantial andesitic suites were erupted on the site of Kulshan Caldera during the middle Pleistocene. Several thick lava flows of olivine-pyroxene andesite (unit Qblr) erupted from an obscure vent at the upper end of **Lasiocarpa Ridge** [16], flowing northward across the caldera's northwest margin. The ridge-capping tongue 3 km north of the vent is a single lava flow 200 m thick that once filled a northwest-trending paleovalley. The flow has a K-Ar age of 515±8 ka, and as a whole, the suite is richer in K_2O than andesites of all other Quaternary units in the Mount Baker area except the andesite of Coleman Pinnacle (unit Qbcp). In contrast to the propylitized andesite dikes that intrude the directly subjacent intracaldera ignimbrite and sediments, the comminuted matrix of the basal breccia of the Lasiocarpa andesite pile is virtually unaltered, suggesting that the caldera's hydrothermal system was by then extinguished.

A voluminous effusion of hornblende-andesite lavas, the **andesite of Coleman Pinnacle** (unit Qbcp), took place from a fissure system now marked by a 2-km-long set of northeast-trending dikes on Ptarmigan Ridge [22]. The unit yields a K-Ar age of 305±6 ka. At about the same time, a set of pyroxene-andesite lava flows, the **andesite of Table Mountain** (unit Qbtm), which interstratified with the hornblende andesite, erupted from vents along Ptarmigan Ridge. Thick stacks of these flows make up Table Mountain [17] and Kulshan Ridge, and glaciated remnants of their glassy columnar zones floor much of the Heather Meadows ski area. The flows have K-Ar ages that range from 309±13 ka to 301±5 ka.

The **andesite of Pinus Lake** (unit Qbpl) represents remnants of three intracanyon flows with unknown source vents. The largest remnant east of the mouth of Wells Creek has a K-Ar age of 202±9 ka; a 60-m cliff just below it consists of hornblende dacite (not shown separately on the map), dated at 149±5 ka. The third remnant is olivine pyroxene andesite south of Nooksack Falls [7].

In the late Pleistocene, two new satellite vents were active briefly, and growth of the still-active stratovolcano Mount Baker was initiated on the northeast flank of the by-then inactive Black Buttes cone. A pile of basaltic hyaloclastite, the **basalt of Lake Shannon** (unit Qbls) erupted, probably in part subglacially, at 94±21 ka. A few kilometers northeast of the Black Buttes, a thick stack of pyroxene-andesite lava flows, the **andesite of The Portals** (unit Qbtp) erupted at 70±7 ka, probably before inception of Mount Baker, and flowed far northward down a paleovalley. The consistently glassy and polygonally jointed lavas suggest ice contact during emplacement.

The age of inception of **Mount Baker** itself has not been well established, but, lacking major internal unconformities, the main cone is unlikely to predate the last Pleistocene glaciation and most of it is probably younger than 43±5 ka. An older package of andesite-dacite lava flows exposed in Park and Boulder Creeks is 80-90 k.y. old, but its relationship to Mount Baker remains uncertain. On several sides of the modern cone, basalt lava flows yield K-Ar ages of 14±9 ka. Eruptive volume of the stratocone is estimated to be about 15 km^3. Like the Black Buttes cone before it, all Mount Baker's magmatic products appear to have issued from a single, now ice-filled, central vent at the summit. The 600-m-wide Sherman Crater, fumarolically active and conspicuous on the south slope just below the summit, was created in the Holocene by nonmagmatic (phreatic or hydrothermal) explosions, the youngest of which may have taken place in 1843 (Harris, 1988; K.M. Scott, written commun., 1995). Mount Baker (unit Qbv) is mostly made up of lava flows (and associated flow breccias) of pyroxene andesite, with or without olivine. Agglutinate and scoria deposits of similar composition are important within about 1 km of the summit, and a few andesitic pyroclastic-flow deposits crop out between lavas on the flanks. Debris flows are an important hazard and have probably been volumetrically significant, but nearly all such material funnels into river valleys and is rapidly reworked by fluvial or glacial processes. A few modest summit eruptions of juvenile andesite took place as recently as 12 ka and 6.5 ka but left no deposits representable at 1:100,000 scale. The only Holocene eruption that did so issued from a new vent on **Sulphur Creek**, 8 km south of the summit, producing a small scoria cone and a 12-km-long lava-flow fan, which is zoned from basalt to andesite (unit Qbsc). Although no late Holocene activity on or near Mount Baker is known to have been magmatic, future eruptions should not be unexpected.

UNCONSOLIDATED DEPOSITS

By R.A. Haugerud and R.W. Tabor

[Bracketed numbers refer to locations shown on figure 6]

INTRODUCTION

Pleistocene glaciation has shaped the landscape of the Mount Baker quadrangle to such a degree that it is fundamentally different from the pre-Pleistocene stream-eroded mountains that preceeded glaciation. Almost all valleys are U-shaped, and thick accumulations of glacial drift blanket much of the western part of the quadrangle. Post-glacial processes have made slight modification. Talus, alluvial-fan, alluvial valley-bottom, and landslide deposits are only locally significant.

Glacial chronology and ice sources

During the last glaciation, glaciers existed at different times in the central Cascade Range and in the Puget Lowland. Glaciers local to the Cascades are conventionally known as “alpine”, whereas glaciers that flowed south from British Columbia and covered the Puget Lowland are called “Cordilleran”. Cary and Carlston (1937) and Mackin (1941) first recognized the asynchronous behavior of the Cordilleran and alpine glacial advances well south of the Mount Baker quadrangle where the temporal distinction between alpine and Cordilleran glaciations largely corresponds also to a change in provenance and, locally, transport direction, making the depositional record of these events relatively easy to decipher.

In the Mount Rainier area (fig. 1), Crandell (1963) identified several alpine ice advances and defined a stratigraphy of such glacial deposits. The latest of these major alpine advances is the Evans Creek stade of the Fraser glaciation of Armstrong and others (1965), which culminated at about 20,000 yr B.P. Relative extent and weathering characteristics have allowed Booth (in Tabor and others, 2002) to correlate equivalent deposits located immediately south of the Mount Baker quadrangle. The alpine source of glacial ice on ridges and cirques in the Cascade mountains is weakly echoed by the modern distribution of permanent snow fields and cirque glaciers.

At least six major Cordilleran ice-sheet advances are recognized in the Puget Lowland (Crandell and Mullineaux, 1958; Easterbrook and others, 1967); the latest advance, named the Vashon stade of the Fraser glaciation by Armstrong and others (1965), reached its maximum at about 15,000 yr B.P. Ice-flow indicators, evidence of the ice-surface slope, and drift lithologies all indicate a northern, Canadian, source for Vashon ice in the Puget Lowland. South of the Mount Baker quadrangle, the alpine glaciers of the Evans Creek stade had retreated prior to Vashon-stade Cordilleran glaciation. Tongues of Puget lobe ice advanced up trunk valleys an insufficient distance to meet any remnant or revitalized downvalley-flowing Cascade glaciers.

In the Mount Baker quadrangle, the distinctions are less evident. Evidence in the Puget Lowland for the northward rise of the Vashon stade ice-sheet surface—with predicted ice-surface elevation of about 1,500 m west of the quadrangle (Booth, 1987, p. 81)—and evidence in the Pasayten area to the east for the upper limit of Cordilleran ice (Waitt, 1972) indicate that Vashon stade ice blanketed the quadrangle. Geomorphology, clast provenance, and local paleocurrent indicators demonstrate that the thick drift accumulation in the lower Skagit and Baker River valleys was derived from Cordilleran ice. Nonetheless, glacial erratics at modest elevations in the Baker River drainage indicate an eastern, Cascade source. Numerous existing glaciers decorating the high peaks of the quadrangle suggest that in any colder climate the higher peaks of the quadrangle would also be ice source areas.

A near-continuous ice cap covered the map area during Vashon time, broken by numerous nunataks that projected above the ice surface. At least in the vicinity of the high peaks of Mount Redoubt above Redoubt Creek [76] and the Picket Range [92], Mount Shuksan, Mount Baker, and the Snowfield-Eldorado massif, the ice sheet was nourished by local cirque glaciers and thus must have sloped outward from these local sources. Precipitation on the high, extensive ice upwind to the west may have starved these local glaciers, minimizing this outward slope, and complex bed topography would have inhibited flow.

Drainage derangement

During Pleistocene time the Skagit River must have drained south via the Sauk and Stillaguamish Rivers, just south of the Mount Baker quadrangle (fig. 1). As described by D.B. Booth (in Tabor and others, 2002),

> “the Sauk River beheads a major west-trending spur of the Cascade Range and so links two major river valleys, the Skagit and the lower North Fork of the Stillaguamish Rivers, along a valley conspicuously athwart the regional drainage pattern. For most of the Vashon stade (and preceding Cordilleran ice advances), first subglacial and

> then proglacial meltwater from the upper Skagit River basin would have drained south along this channel, because the ice sheet thinned to the south. A plug of Vashon-age sediments, with an upper surface above 300-m elevation, blocked the Skagit valley just west of its confluence with the Sauk River (Heller, 1978; Tabor and others, 1994) and so maintained this diversion throughout ice occupation and well into the recessional history of the area."
>
> " The Skagit valley plug was eventually breached * * * near the town of Concrete, probably by incision by the Baker River and other local flows draining over the top of the sediments, together with piping on the steep downvalley face by emergent groundwater once the ice tongue had retreated farther west."

Booth (in Tabor and others, 2002) further explains drainage diversions near Darrington (fig. 1) that rerouted the Skagit and the Sauk Rivers northward again to drain out the modern Skagit Valley (see also Tabor and Haugerud, 1999).

The Skagit River Gorge between Newhalem and Diablo marks the former divide at the head of the lower Skagit River. The north-flowing upper Skagit drained into the Fraser River via Klesilkwa River and Silverhope Creek, through a pass that has a present elevation of about 520 m. Although this idea has been previously discussed briefly by Weiss (1969), it was discounted by Waitt (1977) who thought that the anomolous gorge could be explained by localization of alpine and Cordilleran ice sculpture. When the regional drainage pattern is considered, however, the early idea is once again attractive. Moderately sloping surfaces near Pyramid Lake [101], Happy Flat [100], and Roland Point [98] and descending east of Sourdough Mountain and complex ridge profiles above Diablo [97] appear to mark the former presence of a broad upland at the head of the upper Skagit. Capture of the upper Skagit by the lower Skagit and subsequent rapid downcutting has left hanging all tributaries to the Skagit between Newhalem and the Canadian border. The only exceptions are Stetattle Creek, Thunder Creek, and Big Beaver Creek, all of which drain heavily glaciated cirques that would have hosted active alpine glaciers whose downcutting kept up with rapidly lowering base levels.

Prior to the Pleistocene a roughly east-west drainage divide appears to have separated the north-flowing Chilliwack, upper Skagit, Pasayten, and Ashnola rivers from south-flowing Baker, lower Skagit, and Methow rivers, as hypothesized by Riedel and Haugerud (1994). Advancing Cordilleran ice blocked the north-flowing drainages and formed proglacial lakes that overflowed at the lowest saddles along the divide. The large discharges rapidly lowered the divides and moved them northward. Ice scour during maximum glaciation and fluvial erosion during ice recession broadened and further lowered the breaches in the divides. This cycle would have been repeated during each glaciation. The best evidence for this process is found east of the Mount Baker quadrangle; however, at Chilliwack Pass the divide appears to have moved at least 2 km north (Jon Riedel, written commun., 1994).

NON-GLACIAL DEPOSITS AND GLACIAL DEPOSITS

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

GLACIAL DEPOSITS

Deposits of Fraser glaciation of Armstrong and others (1965)

The Baker River valley and adjoining Skagit River valley provide the best record in the Mount Baker quadrangle of glacial deposits of the Puget lobe of Cordilleran ice sheet. **Advance outwash deposits, till, and recessional outwash deposits** (units Qva, Qvt, Qvr) are displayed in eroded terraces along the Skagit and Baker Rivers. Heller (1978, 1979) describes the deposits in detail. Most of our map data is adapted from his report. East-derived glacial erratics littering the ground surface on Grandy Ridge and the ridges north and south of Jackman Creek indicate that during Vashon time there was a significant contribution of North Cascades ice to the Puget lobe.

Alpine glacial deposits reflect occupation by ice originating from peaks and cirques in the local area. About 20,000 yr B.P., during the time of maximum alpine-ice advance, the regional snowline lay about 900 m below its present elevation (Porter, 1977). We distinguish alpine glacial deposits from those of the Cordilleran ice sheet on the basis of clast lithology, because the alpine deposits typically contain no clasts foreign to the up-glacier basin. On the north sides of the Silver Creek [74] and Perry Creek [77] valleys, morphologically distinct lateral moraines probably formed in the Evans Creek stade of the Fraser Glaciation of Armstrong and others (1965), but were later veneered with till of the Vashon Cordilleran ice.

In some areas glacial deposits are mapped on the basis of areal photo expression and scattered reconnaissance ground study. These areas are generally shown as **glacial deposits, undivided** (unit Qgu). Deposits in the Nooksack River drainages and along Ross Lake may contain debris carried by Cordilleran ice as well as locally derived material. Some of these deposits in the North Fork of the Nooksack River may be from the Sumas Stade of the Fraser glaciation of Armstrong and others (1965).

Alpine glacial moraine (unit Qam) is generally unvegetated and derived from present-day glaciers or, also probable, from glaciers of 19th century advances. We mapped moraine crests shown in such deposits and, locally, on underlying units where the extent of the deposit is too limited to show at map scale, from aerial photographs. Some crests may be protalus ramparts.

NON-GLACIAL DEPOSITS

A variety of non-glacial materials, deposited after the retreat of the Cordilleran ice sheet, fill the river valleys and mantle many of the hillsides of the quadrangle. Because most of the recessional river channels were graded to the level of ice-dammed lakes, the modern rivers, graded to sea level, have entrenched the recessional deposits. Where the resulting excavation has been extensive, wide surfaces underlain by valley-bottom **younger and older alluvium** (units Qyal, Qoal) are particularly prominent, such as along the Skagit River. Younger alluvium mapped in the North Fork of the Nooksack River includes lahar deposits derived from Mount Baker volcano (Cary and others, 1992b). Many alpine valleys are still choked with recessional glacial deposits, but in some younger materials prevail. **Alluvial-fan deposits** (unit Qf) are particularly prominent in valleys eroded from well-jointed granitic rocks of the Chilliwack composite batholith; they merge with **talus deposits** (unit Qt), which may be barren. The broad alluvial fans at the mouths of creeks draining the east and south side of Mount Baker contain laharic deposits (Hyde and Crandall, 1978). We have mapped from aerial photographs alluvial fans and talus deposits in many remote valleys. Terraces mapped as older alluvium along the Middle Fork of the Nooksack River may contain glacial outwash deposits of the Fraser glaciation of Armstrong and others (1965).

Unstable hillsides have collapsed into the valleys forming **landslide deposits** (unit Ql) that range in age from about 10 ka to the present. Heller and Dethier (1981) describe landslides in the lower Skagit River valley (many derived from unconsolidated glacial deposits), the large Bear Creek [45] landslide west of Lake Shannon, and the role of the Bear Creek slide in the formation of Vashon recessional deposits.

The age of extensive landslides in the Skagit River below Damnation Creek can be deduced from the age of fine volcanic ash exposed in roadcuts along the Skagit River above the landslide (see Haugerud and others, 1994, p. 2E–38). The deposits, too small to show at map scale, were laid down in a lake dammed by the landslides (Riedel and others, 2001). The ash, Mount Mazama ash, has an age of about 6.7 ka (Hallet and others, 1997). The landslides are composed of various materials, but failure may have been facilitated by talc lenses in the Napeequa Schist.

On the North Fork of the Nooksack, the Church Mountain landslide (Cary and others, 1992a; Carpenter, 1993; Carpenter and Easterbrook, 1993) covers about 9 km^2 of valley floor. As outlined by Carpenter (1993), the size, disposition, morphology, and internal stratigraphy of the deposit suggest that it records a single catastrophic failure of the steep south face of Church Mountain. Radiocarbon ages from logs buried beneath the deposit led her to infer deposition at about 2.7 ka. Engebretson and others (1996) suggest shallow-focus earthquakes are responsible for this slide and others.

DESCRIPTION OF MAP UNITS

[Bracketed numbers refer to locations shown on figure 6]

SURFICIAL DEPOSITS

Non-glacial deposits

Ql **Landslide deposits (Holocene)**—Diamictons composed of angular clasts of bedrock and surficial deposits derived from upslope. Commonly shown on map without unit label; arrows denote downslope direction of movement. Includes both transported material and unstable scarp area if present. Locally includes:

Qlo **Older landslide deposits (Holocene and Pleistocene)**—Similar to diamictons (Ql) described above but with data to show age. Generally large and with somewhat subdued hilly topography. Church Mountain landslide in the North Fork of the Nooksack, the Bear Creek [45] landslide, and landslides in the Skagit River valley south of Damnation Creek [102]

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

Qt **Talus deposits (Holocene)**—Non-sorted angular gravel to boulder diamicton. At lower elevations gradational with unit Qf. At higher elevations includes small rock-avalanche deposits as well as some Holocene moraines, rock glaciers, and protalus rampart deposits that lack characteristic morphology. Surfaces generally unvegetated. Mostly mapped from aerial photos in alpine valleys. Grades into unit Qf

Qf **Alluvial-fan deposits (Holocene)**—Poorly sorted cobble to boulder gravel, deposited either as a discrete lobe at the intersection of a steep stream with a valley floor of lower gradient or as a broad apron on steep sideslopes. Gradational with unit Qt, especially in granitic terrane where fans along major valleys commonly merge with talus. Mostly mapped from topography and aerial photos in alpine valleys

Qyal **Younger alluvium (Holocene)**—Moderately sorted deposits of cobble gravel to pebbly sand along rivers and streams. Generally unvegetated surfaces; gradational with both units Qf and Qb

Qb **Bog deposits (Holocene)**—Peat and alluvium. Poorly drained and intermittently wet. Grades into unit Qyal

Qoal **Older alluvium (Holocene and Pleistocene)**—Deposits similar to unit Qyal, but standing above modern flood-plain level and generally separated from it by a distinct topographic scarp. Age of deposits presumed younger than that of unit Qvr, but relations are ambiguous in some localities. In Middle Fork of the Nooksack River valley, may include lahar deposits from Mount Baker (Easterbrook and Kovanen, 1996)

Glacial deposits

Qam **Alpine glacial moraine (Holocene)**—Boulder till; sparsely vegetated to unvegetated. Also shown as symbolized moraine crest on bedrock unit

Qag **Alpine glacial deposits (Holocene and Pleistocene)**—Deposits ranging from boulder till in uplands and upvalley to gravel or sand outwash on broad valley floors. On valley sides and uplands, includes areas veneered with drift but also includes subordinate areas of 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

Qgu **Glacial deposits, undivided (Holocene and Pleistocene)**—Mostly morainal deposits or vegetated talus deposits similar to unit Qag or Qt, but includes outwash. May include considerable debris deposited from the Cordilleran ice sheet, especially in the North Fork of the Nooksack River and along Ross Lake. As mapped, includes deposits in part belonging to units Qyal, Qf, and Qmw

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

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

Qvt **Till**—Mainly compact diamicton with subangular to rounded clasts, glacially transported and deposited. In ice-marginal areas or where covered by a thin layer of recessional outwash, contact with unit Qvr is gradational. As mapped, also includes deposits of units Qf, Qmw, and Qyal too poorly exposed or too small to show at map scale

Qva **Advance outwash deposits**—Well-bedded gravelly sand, fine-grained sand, and bedded silt, generally firm and unoxidized; deposited by proglacial streams and in proglacial lakes

Non-glacial and glacial deposits

Qpf **Non-glacial and glacial sedimentary deposits older than Fraser Glaciation (Pleistocene)**—Moderately to deeply weathered, moderately sorted sand with volcanic clasts. Exposed only in the western part of the quadrangle along the south boundary

ROCKS OF THE CASCADE MAGMATIC ARC

Rocks of the Mount Baker volcanic center (Holocene and Pleistocene)—Broadly consists of (1) the active stratovolcano (Mount Baker itself); (2) Black Buttes [34] stratovolcano, a middle Pleistocene edifice now deeply eroded but once larger than modern Mount Baker; and (3) several volcanic units that erupted from vents peripheral to the stratovolcanoes. Divided into:

Qbsc **Basalt of Sulphur Creek (Holocene)**—Plagioclase-rich olivine-pyroxene basalt to andesite lava flows and scoria cone produced by a monogenetic eruption near the head of Sulphur Creek in the early Holocene. Lava complex dominantly basaltic but consists of basaltic andesite medially and andesite proximally, zoned 51–59% SiO_2. Lavas flowed 12 km eastward to Baker River, where a remnant survives on the east shore of Baker Lake. Scoria cone indicated by pattern

Qbv **Andesite of present-day Mount Baker stratovolcano (Holocene and late Pleistocene)**—Plagioclase-rich pyroxene andesite (56–64% SiO_2; commonly olivine bearing) lava flows and flow breccia with subordinate agglutinate, scoria, and pyroclastic-flow deposits—all erupted from the central vent of the modern stratovolcano. Consists dominantly of about 200 lava flows, nearly all emplaced radially and sector confined. About 25 flows exposed between elevations of 2,500 m and 3,200 m make up the steep ridge west of the summit of Mount Baker. Debris flows derived from the cone have moved far down Park [38], Boulder [42], Sandy [43], Sulphur, Rocky, Bar [15], and Glacier [12] Creeks and the Middle Fork of the Nooksack River, but deposits have largely been reworked as alluvium or till. Unit includes andesite lava remnants along Kulshan [28], Heliotrope [27], and Glacier Creeks

Qbm **Miscellaneous lava-flow remnants (Pleistocene)**—Isolated andesite and dacite lava flows largely removed by erosion; source vents unknown but presumed to have erupted in the Chowder Ridge-Mount Baker area in postcaldera time. Includes (1) reversely magnetized, olivine-pyroxene andesite lava-flow (55.5% SiO_2) remnant in upper Thompson Creek [9], K-Ar dated at 878±18 ka; (2) reversely magnetized, olivine-bearing pyroxene andesite lava-flow (60% SiO_2) remnant on southwest slope of Lookout Mountain [19], K-Ar dated at 859±14 ka; (3) undated, hornblende-pyroxene-plagioclase andesite (59% SiO_2) lava-flow remnant on lower north slope of Slate Mountain [8], 400 m east of Anderson Creek, about 370 m above the modern valley floor; (4) undated, plagioclase-rich hornblende-pyroxene andesite (57.5% SiO_2) dike cutting south slope of Mount Herman [11] (at 1,525 m elevation; but too small to show at map scale); and (5) rhyodacite lava-flow remnant on distal nose of Boulder Ridge, north of Boulder Creek, K-Ar dated at 199±5 ka. Locally shown as:

Qbsw **Andesite of Swift Creek (late Pleistocene)**—Plagioclase-rich, olivine-pyroxene basaltic andesite (54–56% SiO_2); isolated eroded remnants of lava flows along the floor of Swift Creek or banked against its east wall as high as 110 m above the floor. Vent unknown, probably farther north within Swift Creek drainage. Yields K-Ar determined age of 48±18 ka. Lava flows were emplaced after downcutting of Swift Creek gorge to approximately its present depth

Qbtp **Andesite of The Portals (late Pleistocene)**—Pyroxene andesite lava flows (57–62% SiO_2) distinguished by abundant small (<1 mm) plagioclase; erupted from a glacially eroded vent exposed on east face of Landes Cleaver (east of Mazama Glacier [30]). A few thick flows form a proximal stack still more than 500 m thick and an intracanyon tongue more than 200 m thick that caps the divide between Sholes [21] and Bar [15] Creeks. Most exposures are glassy and polygonally jointed, owing to ice-contact emplacement. Different flows yield K-Ar ages of 76±7 ka and 70±7 ka

Qbls **Basalt of Lake Shannon (late Pleistocene)**—Plagioclase-olivine basalt (51–52% SiO_2), hyaloclastite tuff and thin lava flows, making up two glaciated knobs and a roadcut remnant 1–2 km west of upper Lake Shannon. Poorly sorted and poorly stratified deposit, as thick as 150 m. Vesicular fragments 1–15 cm across make up only 5–10% of glassy deposit dominated by sand- and silt-sized particles, which are locally palagonitized and indurated. Intercalated lava tongues, probably spatter-fed, are 1–3 m thick; one gave an age of 94±21 ka

Qbcd **Andesite of Cougar Divide (middle Pleistocene)**—Plagioclase-rich pyroxene andesite and olivine-pyroxene andesite lava flows (56–63% SiO_2) capping the northern part of Cougar Divide [14] and forming smaller remnants near upper Dobbs Creek

Qbpc **Andesite of Park Creek (late Pleistocene)**—Stack of five pyroxene andesite lava flows (57–61% SiO_2) on south wall of Park Creek. Source vent concealed beneath modern Mount Baker. Middle flow gives K-Ar age of 140±55 ka

Qbpl **Andesite of Pinus Lake (middle Pleistocene)**—Plagioclase-rich pyroxene andesite (59–62% SiO_2; sparse olivine) intracanyon lava flow, surviving only as a 1-km^2 remnant 100 m thick, 1–2 km east of the confluence of Wells Creek with the North Fork of the Nooksack River. Base of flow 120 m above present-day river. Not distinguished separately on map is a second intracanyon flow remnant of glassy hornblende dacite (65% SiO_2) that supports a 60-m cliff below the northwest face of the andesite. Another remnant of yet a third intracanyon flow is present 1.5 km farther west; consisting of olivine-pyroxene andesite (59% SiO_2), its base is 225 m above the river junction

Qbbb **Andesite of Black Buttes (middle Pleistocene)**—Olivine-pyroxene andesite (mostly 55–59% SiO_2) lava flows, flow breccia, and near-vent fragmental deposits of Black

Buttes stratovolcano. Plagioclase small and sparse in the dominant mafic lavas and ejecta but abundant in thicker flows of silicic andesite. Unit also includes sparse thin flows of olivine-plagioclase basalt (52% SiO_2). A fragmental vent complex interfingers radially with thick stacks of thin (1–15 m) proximal flows and flow breccia. The fragmental core, extensively altered by fumarolic-hydrothermal fluids, has been glacially gutted to provide the west cirque of Deming Glacier. A few much thicker lava flows of pyroxene andesite (59–64% SiO_2) extend outward from the edifice, today supporting several high divides. Separate vents active during Black Buttes time include Forest Divide (unit Qbfd), Lava Divide (unit Qbld), and Lasiocarpa Ridge (unit Qblr)

Qbcp **Andesite of Coleman Pinnacle (middle Pleistocene)**—Hornblende-plagioclase andesite (59–63% SiO_2; pyroxene sparse to absent) lava flows and dikes, capping much of Ptarmigan Ridge [22]. Erupted from dike-fed fissure system that extends more than 2 km northeasterly along Ptarmigan Ridge. Glacially sculptured remnants are as thick as 200 m

Qbtm **Andesite of Table Mountain (middle Pleistocene)**—Plagioclase-rich pyroxene andesite lava flows (59–62.5% SiO_2) that form stacks as thick as 150 m at Table Mountain [17] and 250 m at nearby Kulshan Ridge [18]. Glacially scoured remnants, mostly glassy and polygonally jointed, make up much of the surface in the Heather Meadows ski area

Qbld **Andesite of Lava Divide (middle Pleistocene)**—Plagioclase-rich pyroxene andesite (58–63% SiO_2) lava flows, chaotic and stratified breccias, and vent-filling intrusion. Some flows olivine bearing. Vent plug is conical peak, fumarolically altered and laced with sulfides, forming western prow of cleaver between Park and Rainbow Glaciers. Most lavas bracketed between 460 and 296 ka, but a basal flow on Park Creek gives 743±72 ka

Qbbr **Andesite of Bastille Ridge (middle Pleistocene)**—Plagioclase-rich pyroxene andesite (59–63% SiO_2) lavas that form a 200-m stack of about 14 west-dipping flows that cap Bastille Ridge [25]. Top and bottom flows both yield ages of 322 ka. Remnant of two other flows on north side of Smith Creek [24] are indistinguishable

Qbfd **Andesite of Forest Divide (middle Pleistocene)**—Olivine-bearing pyroxene andesite (58–61% SiO_2). Stack of about 10 lava flows capping Forest Divide. Vent buried by Mount Baker. Basal and top flows yield K-Ar ages of 455±9 ka and 366±10 ka

Qblr **Andesite of Lasiocarpa Ridge (middle Pleistocene)**—Plagioclase-rich olivine-pyroxene andesite (58–62% SiO_2) lava flows and thick flow breccia. K-Ar age of 515±8 ka

Qbpb **Basalt of Park Butte (and associated rocks) (middle Pleistocene)**—Plagioclase-olivine basalt (50% SiO_2) lava flow capping east ridge of Park Butte; yields K-Ar age of 716±45 ka. Nearby remnants of basaltic andesite lavas (52.5–56% SiO_2; mapped as Qbm), containing clinopyroxene as well as olivine and plagioclase, cap Cathedral Crag, the ridge north of Baker Pass, and the small plateau just east of Park Butte [41]. These yield K-Ar ages between 333 and 203 ka and have no recognizable source vent

Rocks of Kulshan caldera (early Pleistocene)—Divided into:

Qkrl **Rhyodacite lava flows, domes, dikes, and shallow intrusions**—At least seven separate eruptive units of biotite-hypersthene-hornblende plagioclase rhyodacite (69–72% SiO_2) intrude and overlie intracaldera ignimbrite or sedimentary deposits. Five more intrude and overlie unit KJna on Cougar Divide (where three are shown on the geologic map), and at least one dike (30 m thick, but not shown on the map) of similar rhyodacite cuts unit Pcmv on the divide between Swift and Rainbow [36] Creeks just south of the caldera. Compositionally, the lavas and dikes are similar to the dominant pumice in the ignimbrite or slightly less evolved. Phenocryst contents range widely, from 5 to 25%. Like the ignimbrite, the lavas and dikes contain plagioclase, hypersthene, hornblende, biotite, FeTi oxides, apatite, and zircon, although one or more of these may be missing in some flows; sanidine is lacking, and clinopyroxene and quartz are absent or very rare. Lithologically, the lavas and dikes are massive or flow-banded felsite; glacial erosion has stripped all but sparse remnants of glassy external zones, which tend to be altered where they survive. The felsite is pale to medium grey where fresh but is largely tan to orange brown owing to pervasive oxidation and ferruginous films on joints and vugs. In areas of hydrothermal alteration, especially where brecciated, the lavas are pale green, cream, or white, commonly stained and streaked ochre to rusty brown due to decomposition of disseminated pyrite

Qkls **Caldera-lake sedimentary deposits**—Laminated to thin-bedded ashy mudstone, ash-dominated debris-flow deposits, and intercalated sheets of rockfall breccia. Ashy sediments that originally consisted predominantly of vitric shards are mostly well lithified and rich in calcite, clays, and pyrite. Colors range from pale grey or tan to black, or, where altered, ochre to rusty brown. Debris-flow deposits are diamictic massive or graded beds 0.1–7 m thick, containing pumice, caldera-wall lithics, and mudstone intraclasts in an ashy matrix. Sheets of lithic breccia, poor in ash, 0.1–5 m thick, largely made up of angular clasts of argillite, sandstone, and conglomerate, alternate with ash-rich laminated mudstone. Unit has been widely stripped by erosion. Surviving sections dip gently toward middle of caldera or are locally disrupted by intrusive rhyodacite and andesite

Qkig **Ignimbrite of Swift Creek**—Intracaldera rhyodacite ignimbrite (ash-flow tuff) filling Kulshan caldera. Mostly massive, but crudely stratified in top 100 m and near walls where myriad sheets of wall-collapse breccia are intercalated. Largely nonwelded but firmly indurated by groundwater and hydrothermal fluids. White to pale grey except where hydrothermally altered ochre to orange brown. Pumice clasts are rarely larger than 10 cm and mostly smaller than 2 cm; nearly all are rhyodacite (72% SiO_2) containing 10–15 wt % phenocrysts (plagioclase >> hypersthene   hornblende > biotite > FeTi oxides > rounded quartz > apatite   zircon). Andesitic pumice is also present but very sparse. Ignimbrite matrix is crystal enriched (relative to pumice) and is poor in lithic fragments except near walls, where they are abundant. In addition to feeders for the postcaldera rhyodacite lavas (unit Qkrl), the ignimbrite is cut by at least 60 andesitic dikes and irregular intrusions, none of which are known to extend out of the caldera into surrounding wall rocks

Qkmb **Caldera-collapse megablocks**—Partly shattered and sheared but quasi-coherent 0.1- to 1-km slide blocks of caldera-wall rock surrounded by intracaldera ignimbrite. Examples shown on map consist of Nooksack Formation (unit KJna) in upper Wells Creek and Lake Ann stock (unit Tcla) in upper Swift Creek

Hannegan Volcanics (Pliocene)—Divided into:

Thb **Volcanic breccia**—Mostly clinopyroxene-hornblende andesite clasts along with many clasts of older rocks in andesite tuff matrix. Many andesite dikes, sills, and (or) flows

Thmb **Monolithologic breccia**—Angular debris of older rocks, probably talus, and (or) debris-flow deposits. Mapped on north side of Ruth Mountain [58] and above Sulphide Creek [63]. The latter occurence includes volcanic breccia, is outside the caldera, and may be of different origin

Tht **Tuff**—White to light-brown dacite tuff and welded tuff, some rhyolite tuff, and rare andesite tuff and flow rocks, commonly highly altered. Bedding obscure

Other volcanic rocks

Tvr **Volcanic rocks of Mount Rahm (Oligocene)**—Dacitic to less commonly andesitic breccias, tuffs, and flows with some feldspathic sandstone and conglomerate interbeds. Welded dacite tuff common

Volcanic rocks of Big Bosom Buttes (Oligocene)—Divided into:

Tvbb **Breccia**—Predominantly dacite breccia; minor tuff beds. Forms massive cliffs. Scattered clasts of older rocks, including light-colored granitic rocks

Tvbd **Dacite tuff**—Biotite dacite tuff, commonly ash-flow tuff and bedded fine-grained tuff. Also includes dacite on Middle Peak [51]

Tvbm **Monolithologic granite breccia**—Angular blocks of biotite granite from a few cm to several meters across in a granitic sand matrix. Scattered volcanic fragments. Derived from granite of Pocket Peak phase (unit Tcp)

Volcanic rocks of Pioneer Ridge (Oligocene)—Divided into:

Tvpd **Dacite flows**—Plagioclase- and quartz-phyric dacite. Mafic minerals altered to smectites

Tvpb **Mudflow breccia**—Clasts of dacitic volcanic rocks and abundant clasts of underlying metamorphic rocks. Also includes volcanic-lithic sandstone. Locally strongly thermally metamorphosed

INTRUSIVE ROCKS OF THE CASCADE PASS FAMILY

Tdt **Tonalite of Cascade Pass dike (Miocene)**—Medium-grained hornblende-biotite tonalite, hypidiomorphic granular with small glomeroporphyrocrysts of mafic minerals. CI=7–26 (Tabor, 1961, p. 175; Ford and others, 1988, p. 34), mostly CI=15–17. Massive and coarsely jointed, with local areas of disseminated sulfide minerals. The dike has finer-grained, porphyritic, chilled margins; contact lit-par-lit complexes are common, and alteration is locally pervasive. Exposed in southeast corner of map

Rocks of the Chilliwack composite batholith (Pliocene and Miocene)—Divided into:

Tcla **Lake Ann stock (Pliocene)**—Medium-grained hypersthene-clinopyroxene quartz monzodiorite and quartz monzonite, locally with biotite and very minor hornblende. Normatively some is granodiorite; CI=12–19 (James, 1980). Euhedral biotite common near roof above Lake Ann

Tcmi **Miscellaneous granodiorite intrusions (Pliocene and (or) Miocene)**—Biotite granodiorite, micrographic, commonly altered, with much chlorite. As mapped comprises lithologically similar stocks cropping out on the north side of Hagan Mountain [66], in Sulphide Creek [63], and in upper Noisy Creek [68]. Also includes fine-grained biotite pyroxene amphibole granodiorite stock on Bar Creek [15], which may be as young as middle Pleistocene (Hildreth and others, 2003)

Tcnm **Quartz monzonite and granite of Nooksack cirque (Pliocene)**—Quartz monzonite and granite with minor granodiorite and quartz monzodiorite. Predominantly with uralitic hornblende and relict clinopyroxene. CI=7–15

Tcrg **Granite of Ruth Mountain (Pliocene)**—Biotite granite and granodiorite, commonly with large twinned perthite crystals. Minor hornblende. CI=4–17

Tcid **Quartz diorite and quartz monzodiorite of Icy Peak (Pliocene)**—Biotite-clinopyroxene quartz diorite to quartz monzodiorite with minor hypersthene and uralite. Some rock is plagioclase porphyritic. CI=15–32

Tcgp **Granite porphyry of Egg Lake (Pliocene)**—Hornblende and biotite granite and granodiorite porphyry with phenocrysts of quartz, plagioclase, and hornblende in a xenomorphic matrix of K-feldspar, quartz, and plagioclase. Compositionally heterogeneous and commonly altered

Tcrgd **Ruth Creek pluton (Miocene)**—Biotite granodiorite, some granite and quartz monzodiorite, locally with quartz eyes as large as 1 cm in diameter; CI=3–7 (Tepper, 1991, p. 78), but mostly 4–5. Rare blocky hornblende with pyroxene cores

Tcm **Mineral Mountain pluton (Miocene)**—Biotite granite. CI=3–7. Characterized by conspicuous quartz eyes several centimeters across, which are glomerocrysts of rounded quartz grains with K-feldspar in the curved triangular interstices. Micrographic intergrowths of K-feldspar and quartz common. Conspicuous chloritic alteration

Tcwb **Granite of western Bear Mountain (Miocene?)**—Biotite granite and granodiorite, some with hornblende. Rock is heterogeneous; CI=2–12. Quartz eyes conspicuous. Rock is cut by numerous aplitic dikes (Tepper, 1991, p. 79)

Tcdcg **Granite of Depot Creek (Miocene)**—Biotite-hornblende granite with relict clinopyroxene cores in hornblende. Forms a small stock below the Redoubt Glacier [73]

Tcrq **Quartz monzodiorite of Redoubt Creek (Miocene)**—Biotite-pyroxene-hornblende quartz monzodiorite, quartz monzonite, granite, granodiorite, and diorite, commonly altered, with pinkish cast. CI=3–20, but most CI=11–17. Some rocks are porphyritic allotriomorphic and vermicular; micrographic quartz is common (Tepper, 1991, p. 68)

INTRUSIVE ROCKS OF THE SNOQUALMIE FAMILY

Rocks of the Chilliwack composite batholith (Miocene and Oligocene)—Divided into:

Tcbx **Intrusive breccia (Miocene and (or) Oligocene)**—On north ridge of Mount Blum [64], unit consists of alaskite and other intermediate plutonic rocks mixed with hypabyssal rocks in altered porphyroclastic xenomorphic and cataclastic matrix of rhyolitic composition; rocks are thermally metamorphosed. Breccia is cut by or marginal to a variety of silicic dike rocks. Above Luna Lake [88], gneiss, hypabyssal dike rocks, mafic schist, and country rock gneiss clasts with vuggy quartz, pyrite, and radial amphibole bursts. Near Tapto Lakes [83], mafic plutonic-rock clasts, such as diorite, are mixed with andesite clasts in an altered dacitic matrix (Moore, 1972, p. 49–50)

Tcsg **Mount Sefrit Gabbronorite of Tepper and others (1993) (Miocene)**—Mostly olivine-bearing gabbronorite with minor two-pyroxene diorite, hornblende diorite, and quartz diorite. Rocks are dark, partly because of swarms of minute dark inclusions in calcic plagioclase (Tepper, 1985)

Tcpc **Perry Creek phase (Miocene and Oligocene)**—Mostly biotite-hornblende tonalite and granodiorite, commonly with relict clinopyroxene. Minor quartz monzodiorite and quartz diorite. Hornblende or biotite may predominate. Quartz is typically mesostasic. CI=8–22, but most are CI=12–19. As mapped, probably includes several plutons. Locally includes:

Tcpct **Tectonized tonalite**—Shattered and locally cataclastic to mylonitic, highly altered tonalite and granodiorite; mafic minerals chloritized. Also includes hornfels and shattered and recrystallized plutonic and hypabyssal rocks, with biotite, amphibole, plagioclase and quartz mosaics

Tcbg **Biotite granodiorite of Little Beaver Creek (Oligocene)**—Mostly hornblende-biotite granodiorite and minor granite, locally quartz and plagioclase phyric; CI=3–10

Tccv **Chilliwack valley phase (Oligocene)**—Biotite-hornblende tonalite, granodiorite, and minor quartz diorite, commonly with subhedral plagioclase prisms in quartz mesostasis. Minor clinopyroxene, locally. CI=7–30, but mostly CI=15–20. As mapped, probably includes several plutons. Locally includes:

Tccvt **Dark tonalite**—Pyroxene-hornblende tonalite with distinctive dark vitreous appearance in outcrop

Tcig **Indian Mountain phase (Oligocene)**—Biotite-hornblende granodiorite and granite, with minor quartz monzonite and quartz monzodiorite. CI=3–19, most CI=12–19. Texturally heterogeneous, some quartz or K-feldspar pheoncrystic but these minerals are generally mesostasic; locally granophyric. Rock is commonly pinkish with chloritized hornblende and biotite. As mapped, probably includes several plutons

INTRUSIVE ROCKS OF THE INDEX FAMILY

Rocks of the Chilliwack composite batholith (Oligocene)—Divided into:

Tcbr **Baker River phase (Oligocene)**—Mostly biotite hornblende granodiorite with some tonalite and quartz diorite, locally with clinopyroxene and hypersthene. Subhedral plagioclase in quartz mesostasis common. CI=7–25, but for most rocks in southern part CI=13–18 and, in Skagit Range [52], CI=17–20. Mostly tonalite, quartz diorite, and rare diorite in Skagit Range and in small pluton on American Border Peak [47]; some diorite is hornfelsic. As mapped, probably includes several plutons. Locally includes:

Tcbrp **Price Glacier pluton**—Biotite-hornblende quartz diorite with mesostasic quartz. CI=16-18. Tepper (1991) describes some of the rock making up this unit as part of his granodiorite of Ruth Mountain [58]. Specific age uncertain

Tcml **Tonalite of Maiden Lake**—Biotite-hornblende metatonalite and metaquartz diorite with highly altered plagioclase and biotite. Hypidiomorphic granular. Metamorphic minerals are chlorite, epidote, prehnite, pumpellyite, sericite, and carbonate

Tcsp **Silesia Creek pluton (Oligocene)**—Biotite-hornblende granodiorite, quartz monzodiorite and quartz diorite with inclusions and layers of biotite granodiorite and granite; some granitic xenoliths as long as 200 m. CI=5–20. Quartz diorite displays prominent magmatic alignment of feldspar and mafic minerals

Tcba **Biotite alaskite of Mount Blum (Oligocene)**—Medium-grained biotite alaskite (granite) with prominent perthite prisms, rare hornblende, locally quartz phyric. CI=1–4

Tcp **Pocket Peak phase (Oligocene)**—Biotite granite. Medium grained, hypidiomorphic granular. Commonly with quartz eyes, which are glomerocrysts of rounded quartz grains with K-feldspar in the curved triangular interstices. CI=1–5, mostly CI=3–5. As mapped, probably includes several plutons

Tcht **Heterogeneous tonalite and granodiorite of Middle Peak (Oligocene?)**—Quartz diorite to biotite granite, mostly mafic-poor. Many rocks hornfelsic. Also includes amphibolite of unknown origin

Tcdg **Granodiorite of Mount Despair (Oligocene)**—Biotite-hornblende granodiorite with minor tonalite, quartz diorite, and quartz monzodiorite. Conspicuous quartz eyes, which are glomerocrysts of rounded quartz grains with K-feldspar in the curved triangular interstices. CI=7–20, but mostly CI=10–12;

hornblende usually predominates. Locally includes:

Tcdga **Agmatite**—Swarms of dark rounded inclusions from 0.25 m to several meters across composed of mafic biotite-hornblende quartz diorite and fine-grained tonalite in a lighter colored granodiorite and tonalite matrix

Tcmg **Miscellaneous gabbros and diorites (Oligocene?)**—Pyroxene-hornblende gabbro, diorite, and quartz diorite. Rocks contain much uralite. Mafic hornblende gabbro near Mount Spickard is mixed with granitic rocks. A small body of pyroxene gabbro at Chilliwack Pass [59] is not shown on the map. Locally includes:

Tcmge **Inclusion-rich diorite of Ensawkwatch Creek**—Layered hypersthene hornfels inclusions in diorite and quartz diorite. East of Pocket Peak [50]

Tcclg **Gabbro of Copper Lake (Oligocene)**—Oikocrystic hornblende gabbro surrounded by equigranular hornblende diorite. Some pyroxene in the diorite which is also zoned to quartz and biotite-bearing varieties. CI=25–40. Cumulous textures throughout. Description adopted from Tepper (1991, p. 20–27)

LATE OROGENIC AND POSTOROGENIC DEPOSITS

Tc **Chuckanut Formation (Eocene)**—Mostly fluvial, plagioclase arkose, biotite-rich with minor muscovite, buff-weathering, medium- to thick-bedded, and minor interbeds of siltstone, mudstone, and very fine grained sandstone. Also includes minor pebble to cobble conglomerate. Conspicuous crossbeds, convolute bedding, and plant fossils. Sandstone is locally thinner bedded and more lithic. Ochre-colored silty beds near base of unit may be paleosols. Basal beds, where exposed, commonly include bull-quartz pebble conglomerate which appears to have been derived from the underlying Easton Metamorphic Suite

Tys **Younger sandstone and conglomerate (middle Eocene or younger)**—West of lower Bacon Creek, mostly coarse cobble conglomerate with clasts derived from the Marblemount pluton

Tos **Older sandstone and conglomerate (age uncertain)**—Thick- to thin-bedded fluviatile arkosic sandstone and interbedded argillite, siltstone, and very fine grained sandstone. Locally has conspicuous crossbeds, fossil leaves, and fossil logs. Basal beds commonly rich in angular fragments derived from underlying rocks. Southeast of Berdeen Lake [65], unit includes conglomerate with clasts of granitic rock, greenstone, gneiss, schist, phyllite, abundant well-rounded cobbles of quartzite, and minor sandstone and limestone. On Mount Despair, unit includes pebble to cobble conglomerate with clasts of gneiss, metachert, and minor pegmatite; intruded by granodiorite of Mount Despair, indicating unit age here is early Oligocene or older. Converted to biotite hornfels, commonly with cordierite and (or) andalusite, in proximity to younger plutons

ROCKS WEST OF THE STRAIGHT CREEK FAULT

Northwest Cascades System

Welker Peak and Excelsior nappes

bc **Conglomerate of Bald Mountain (Age uncertain)**—Coarse polymictic conglomerate, chert-pebble conglomerate, grey lithic sandstone, and phyllitic black to silvery argillite. Polymictic conglomerate includes clasts of chert, argillite, green metatonalite, dacite, buff-weathering calcite-cemented quartzose sandstone, and rare bedded lithic sandstone. Clast supported, pebbles and boulders well rounded. Clasts in conglomerates locally flattened and boudinaged. Rare siltstone and shale interbeds. East of Goat Mountain [46] unit contains abundant fossil plant material. Locally includes:

bcs **Sandstone and argillite**—Highly indurated, thin- to medium-bedded sandstone; beds generally disrupted. Sandstone poorly sorted, rich in chert clasts. Black argillite, flaky to slaty. Minor chert-pebble conglomerate beds

Rocks of the Bell Pass mélange (Cretaceous to Late Jurassic)

KJb **Bell Pass mélange, undivided**—Disrupted argillite, slate, phyllite, sandstone, semischist, ribbon chert, and basalt of the Elbow Lake Formation of Brown and others (1987), with tectonic blocks of meta-igneous rocks, gneiss, schist, ultramafic rocks, and marble. Sandstone commonly lithic subquartzose, either volcanic rich and (or) chert rich; argillite is mostly scaly, and grades into slate and phyllite. Greenstones are recrystallized basalt, mafic tuff, diabase, and gabbro and commonly make the most prominent outcrops. Metamorphic minerals in greenstones and metasedimentary rocks are chlorite, epidote, albite, pumpellyite, rare actinolite, carbonate minerals, and indistinct masses of pumpellyite and (or) lawsonite. Locally includes as tectonic blocks:

bb **Blueschist of Baker Lake (Cretaceous to Jurassic metamorphic age)**—Metabasaltic rocks, meta-ribbon chert, and marble characterized by distinctive (for the Northwest Cascades System) high-pressure/low-temperature crossite, lawsonite, some aragonite metamorphism. Metabasaltic rocks range from very fine grained schistose metatuff to incipiently recrystallized basalt

Yellow Aster Complex of Misch (1966) (Paleozoic protolith age)—Medium- to coarse-grained feldspathic gneisses and associated weakly deformed plutonic rocks. Divided into:

byan **Non-gneissic rocks**—Predominantly massive metagabbro, metadiabase, metatonalite; locally includes minor gneissic igneous rocks. May include late Paleozoic or Mesozoic intrusive rocks similar to units MzPzg and MzPzt

byag **Gneissic rocks**—Layered siliceous gneiss, quartz-rich pyroxene gneiss, gneissic megacrystic granite, and minor marble, as well as associated metagabbro, metadiabase, and metatonalite. Gneissic granite with K-feldspar megacrysts known only from Kidney Creek [4]. Includes areas lacking siliceous gneiss, but with strongly mylonitic quartz-rich meta-igneous rocks. Talus blocks east of Park Butte [41] grade from graphitic marble to quartz-rich pyroxene gneiss. Most rocks are highly strained and recrystallized in amphibolite or upper-greenschist facies. Locally, intruded by associated metagabbro, metadiabase, and metatonalite

bu **Ultramafic rocks**—Serpentinite and partially serpentinized dunite and harzburgite. Outcrops too small to show at map scale shown with asterisk symbol. Locally includes:

but **Twin Sisters Dunite of Ragan (1961, 1963)**—Dunite and harzburgite, locally serpentinized

bup **Pyroxenite**—Massive pyroxenite consisting of mostly enstatite and minor olivine and serpentine minerals

bv **Vedder Complex of Armstrong and others (1983) (Permian metamorphic age)**—Amphibolite, blueschist, micaceous quartzite, and mica-quartz schist. Some garnet. Amphiboles are hornblende, actinolite, and barroisite. Some amphibolites contain albite porphyroblasts

bm **Marble**—Coarsely crystalline marble. Outcrops near Anderson Creek [67] too small to show at map scale shown as cyan diamond

KJrs **Slate of Rinker Ridge (Cretaceous to Late Jurassic)**—Slate and semischist similar to the semischist of Mount Josephine, but less thoroughly recrystallized. Metamorphic minerals are chlorite and sericite. Exposed only in lower Skagit River valley

MzPzg **Gabbroic intrusions (Mesozoic and Paleozoic)**—Metagabbro, metadiabase, and minor mafic metatonalite. Generally highly cataclastically deformed and altered to chlorite, epidote, albite, pumpellyite, and carbonate minerals. Many rocks with very fine grained high-relief minerals replacing plagioclase, probably pumpellyite and (or) lawsonite

MzPzt **Tonalitic intrusions (Mesozoic and Paleozoic)**—Metatonalite, commonly strongly cataclastically deformed. Metatonalite in the Cultus Formation of Daly (1912) consists of albitic plagioclase and quartz, commonly in micrographic intergrowths, with less than 10% chlorite, epidote, and opaque ore minerals, which have replaced hornblende and (or) biotite

MzPzcc **Chilliwack Group of Cairnes (1944) and Cultus Formation of Brown and others (1987) undivided (Mesozoic and Paleozoic)**

JTRc **Cultus Formation of Brown and others (1987) (Early Jurassic and Late Triassic)**—Tuffaceous siltstone, sandstone, and argillite, mostly thin bedded to finely laminated. Also includes much rhythmite. Medium-bedded sandstone on Loomis Mountain. Locally includes:

JTRcd **Dacite and associated tuffaceous sedimentary rocks**—Generally light green vitreous metadacite with microphyric plagioclase

PDc **Chilliwack Group of Cairnes (1944) (Permian, Carboniferous, and Devonian)**—Mostly well bedded gray to brown and black argillite and volcanic subquartzose sandstone with minor pebble conglomerate, marble, and rare chert. Also basalt, andesite, dacite, volcanic breccia, and tuff. In sedimentary rocks, graded beds, scour structures, and load casts locally prominent; also includes some rhythmite. Locally sandstone beds strongly disrupted in argillite matrix. Rocks grade rapidly from little-deformed to phyllitic with a pronounced foliation generally subparallel to bedding. Most rocks partially recrystallized in sub-greenschist facies. Locally divided into:

Pcmv **Volcanic rocks of Mount Herman (Permian)**-Breccia, pillows, pillow breccia, and associated volcanic sandstone of basalt or basaltic andesite composition. Most volcanic rocks are plagioclase-phyric, some are amygdaloidal. Unit weathers orange brown; dark- to light-green on fresh surfaces

Pcms **Sedimentary rocks of Mount Herman (Permian)**—Volcanic sandstone, siliceous siltstone, argillite, and limestone. Generally well bedded and with little foliation

PDcv **Volcanic rocks (Permian, Carboniferous, and Devonian)**—Mostly basaltic greenstone, with subordinate andesite and rare dacite or rhyolite. Breccia and tuff predominate. Mafic volcanic rocks commonly with relict plagioclase and clinopyroxene in a chlorite-epidote matrix, commonly with carbonate minerals. Plagioclase is mostly recrystallized as albite. Also includes some gabbro and diabase

PDcl **Limestone and marble (Permian, Carboniferous, and Devonian)**—Mostly coarsely crystalline, gray to black, and petroliferous limestone and marble; occurs in small isolated pods and blocks; locally fossiliferous. Outcrop too small to show at map scale shown by cyan diamond

Rocks of the Autochthon

Kg **Gabbroic intrusions (Early Cretaceous?)**—Metagabbro with relict clinopyroxene. Altered to chlorite, epidote, albite, carbonate minerals, and montmorillonoids after olivine(?). Intrudes the Nooksack Formation at the toe of the Roosevelt Glacier [29]. Lithologically similar dikes (unmapped) form swarm southeast of intrusion

Nooksack Formation (Early Cretaceous to Middle Jurassic)—Described here as sedimentary rocks, although much of the unit is incipiently recrystallized (Brown and others, 1981, 1987). Divided into:

KJna **Argillite and sandstone**—Predominantly massive to laminated black argillite. Locally with thin to medium beds of mostly lithic-volcanic sandstone. Also includes minor limy siltstone and limestone. Some beds heavily bioturbated. Local detrital muscovite. Cleavage weakly developed north of Mount Baker, but pronounced to south. Argillite near top of the Wells Creek Volcanic Member rich in pyrogenic plagioclase and quartz phenocrysts. Belemnite molds characteristic

KJnt **Thick-bedded sandstone and argillite**—Volcanic lithic sandstone with minor interbeds of argillite

KJng **Grit and thick-bedded sandstone**—Poorly rounded to angular small pebble conglomerate and volcanic-lithic sandstone. Minor interbeds of argillite

KJnv **Volcanic-rich conglomerate and sandstone**—Massive to locally well bedded pebble to boulder conglomerate rich in dacite and tonalite clasts. Boulders as large as 1 m diameter. Also includes some well-bedded volcanic sandstone and tuff. Belemnite fragments common

Jnw **Wells Creek Volcanic Member**—Incipiently recrystallized dacite, dacite breccia and tuff, and andesite, with some argillite interbeds. Metamorphic pumpellyite, chlorite, epidote, and albite

Shuksan nappe

Kjs **Semischist and phyllite of Mount Josephine (Early Cretaceous?)**—Graphitic sericite-plagioclase-quartz phyllite and semischistose lithic-volcanic subquartzose sandstone. Protolith sediments thin to medium bedded. Locally highly contorted, but generally lacks prominent multiple crenulations characteristic of the Darrington Phyllite. Locally includes:

Kjsu **Ultramafic rocks**—Serpentinite and silica-carbonate rock

Easton Metamorphic Suite (Early Cretaceous)—Divided into:

Ked **Darrington Phyllite (Early Cretaceous)**—Silvery to black quartzose graphitic phyllite, with minor greenschist, metachert, and muscovite-quartz-albite schist. Commonly with multiple foliations and crenulation lineations; abundant quartz veins. Dominant foliation is commonly second generation or later. Mineralogy is quartz-albite-white mica-chlorite, + lawsonite, garnet, and margarite. Thin sections show well-crystallized white mica: fine grain size in hand sample reflects tendency of rock to break along post-peak metamorphic pressure-solution cleavage surfaces along which fine insoluble material has concentrated. Locally interlayered with unit Kes

Kes **Shuksan Greenschist (Early Cretaceous)**—Greenschist and lesser blueschist. Locally includes iron- and manganese-rich quartzite (metachert), greenstone, and graphitic phyllite. Rare relict clinopyroxene in some greenschist. Schist varieties include dark-green, fine-grained, muscovite-chlorite-epidote-actinolite schist with common knots and masses of epidote, quartz-albite-chlorite veins, and relict pillow or breccia structure, and well-layered light-green chlorite-rich schist that appears to be metamorphosed tuff. Well-layered, Fe^{3+}-poor metatuffs with conspicuous patches of albite relict after plagioclase phenocrysts are locally abundant. Blueschist bears Na-amphibole (crossite-soda actinolite-riebeckite) + hematite (Brown, 1986). Locally interlayered with unit Ked

Keu **Ultramafic rock (Early Cretaceous)**—Serpentinite, silica-carbonate rock, and forsterite-enstatite-tremolite-chlorite rock on Mount Sefrit (Tepper, 1985) and west of Grandy Creek. Shown as asterisk only

ROCKS BETWEEN THE STRAIGHT CREEK FAULT AND ROSS LAKE FAULT ZONE

Terrane overlap units and stitching plutons

Skagit Gneiss Complex

Skagit Gneiss Complex (Middle Eocene to Late Cretaceous)—Heterogeneous complex of supracrustal schist, amphibolite, and rare marble and ultramafic rocks intruded in a lit-par-lit fashion by mostly hornblende-biotite and biotite-tonalite orthogneiss. Orthogneiss bodies range from a few centimeters thick in the banded gneisses to several kilometers thick in the mapped orthogneiss. Abundant deformed dikes and sills of light-colored pegmatitic tonalite and lineated granite. Divided into:

TKsgp **Granite pegmatite**—Granite pegmatite (associated with unit TKeb) in mostly layer-parallel sills and dikes; country rock sparse to absent between multiple intrusions. Quartz in pegmatite generally highly strained, mylonitic to blastomylonitic

TKsbg **Banded gneiss, mostly biotite gneiss**—Biotite schist, biotite-garnet schist, biotite paragneiss (some garnet, cummingtonite), hornblende-biotite paragneiss, gneissic hornblende-biotite tonalite, and tonalite gneiss. Strongly layered rocks with minor amphibolite gneiss, and hornblende schist. Commonly strongly migmatitic with concordant and crosscutting light-colored dikes of foliated, lineated, fine-grained to pegmatitic leucotonalite and lineated granite and granodiorite

TKsbga **Banded gneiss, mostly amphibole gneiss and amphibolite**—Hornblende and biotite-hornblende paragneiss, gneissic amphibolite, hornblende schist, biotite schist and paragneiss, and tonalite gneiss. Rare marble. In some mapped areas, hornblendic rocks are conspicuous but may not be dominant. Commonly strongly migmatitic with concordant and crosscutting light-colored dikes of foliated, lineated, fine-grained to pegmatitic leucotonalite and lineated granite and granodiorite

TKso **Orthogneiss**—Gneissic hornblende-biotite tonalite. Relatively uniform crystalloblastic granitoid gneiss with rare relict euhedral oscillatory-zoned plagioclase crystals. Hornblende or biotite may predominate. Garnet locally. Quartz and biotite commonly moderately to highly strained. Locally migmatitic with concordant and crosscutting light-colored dikes of foliated, lineated, fine-grained to pegmatitic leucotonalite. Locally includes:

TKsom **Mafic orthogneiss**—Garnet-hornblende diorite orthogneiss above Diablo Lake. Also includes amphibolite and hornblendite

TKsoa **Mafic migmatite**—Heterogeneous hornblende tonalite migmatite and orthogneiss rich in slivers of hornblendite and amphibolite east of Snowfield Peak. Cross-cutting dikes of light-colored, fine-grained to pegmatitic, foliated and lineated tonalite and lineated granite and granodiorite

TKsn **Orthogneiss of The Needle**—Hornblende tonalite to granodiorite orthogneiss with distinctive texture of approximately 1-mm equant crystals forming centimeter-size patches rich in quartz, plagioclase, hornblende, or biotite. Dominant foliation locally axial-planar to small folds of an earlier foliation

TKsu **Ultramafic rocks**—Harzburgite tectonite, talc-tremolite schist, anthophyllite-talc-tremolite schist, chlorite-rich blackwall, and retrograde serpentinite. Common relict chromite attests to igneous origin. Small outcrops shown with asterisk symbol only

TKsm **Marble and calcsilicate rocks**—Shown with cyan diamond where outcrop too small to show at map scale

Plutons of the tonalitic group

TKho **Orthogneiss of Haystack Creek (Middle Eocene to Late Cretaceous)**—Hornblende biotite gneiss with blotchy patches of aggregate mafic minerals

TKmo **Orthogneiss of Marble Creek (Middle Eocene to Late Cretaceous)**—Biotite tonalite to granodiorite gneiss with minor hornblende, muscovite, and well-formed igneous(?) epidote. Ranges from granitoid gneiss with intergranular quartz and relict euhedral oscillatory zoned plagioclase to highly strained flaser gneiss with anastomosing mylonite with quartz and biotite. Pluton is rich in screens and rafts of supracrustal schists and pods of ultramafic rocks

TKto **Orthogneiss of Mount Triumph (Tertiary and Late Cretaceous)**—Gneissic medium-grained biotite-hornblende tonalite. Epidote locally intergrown with hornblende and biotite. Weak foliation and lineation and common cataclasis. Contact metamorphism by adjacent Chilliwack batholith has annealed some textures of earlier deformation

Plutons of the granodioritic group

TKeb **Eldorado Orthogneiss (Middle Eocene to Late Cretaceous)**—Biotite-hornblende monzodiorite to biotite granodiorite gneiss, rare tonalite and quartz diorite (Ford and others, 1988, p. 107–108). Medium-grained subhedral to euhedral sodic plagioclase commonly filled with epidote or clinozoisite and set in a crystalloblastic to mylonitic matrix of quartz, K-feldspar, hornblende, biotite, and epidote; accessory sphene, apatite, zircon, and opaque oxides; commonly well aligned prismatic aggregates of hornblende and biotite, but in many rocks mafic minerals are aligned in a streaky planar fabric. Common mafic enclaves locally define strong flattening and weak strike-parallel elongation. Gradational over several hundred meters into unit TKef. Locally includes:

TKef **Flaser gneiss border zone**—Fine- to medium-grained biotite-hornblende metatonalite and metagranodiorite flaser gneiss, with augen of quartz and plagioclase or simple sodic plagioclase mosaic and rare filled plagioclase crystals set in mylonitic fabric of finer grained quartz, plagioclase, and mafic minerals

TKhl **Hidden Lake stock (Middle Eocene to Late Cretaceous)**—Biotite metatonalite with relict hypidiomorphic granular texture. Rocks are granodiorite based on CIPW normative minerals and $\delta^{18}O$ values greater than 10 (Ford and others, 1988, p. 26). Plagioclase mostly filled with well-crystallized metamorphic epidote and muscovite; some grain margins have recrystallized and quartz is sutured. Some K-feldspar is microcline. Rock is massive and sharply intrusive

TKao **Orthogneiss of Alma Creek (Middle Eocene to Late Cretaceous)**—Biotite leucogranodiorite and leucotonalite gneiss, with minor muscovite. Hypidiomorphic granular with highly strained quartz; biotite commonly decussate. CI<10. Local 2- to 4 -cm-diameter orbicules are biotite which tangentially rims quartzofeldspathic cores. Some small irregular bodies northwest of Skagit River are not shown

Chelan Mountains terrane

TKns, Kns **Napeequa Schist (Middle Eocene to Late Cretaceous)**—Predominantly fine-grained hornblende-mica schist, mica-quartz schist, hornblende schist, amphibolite, garnet-biotite schist, and minor hornblende-zoisite schist, hornblende garbenschiefer, calc-silicate schist, marble, and ultramafic rocks. In the Cascade River area and in the Straight Creek Fault zone, phyllitic muscovite-chlorite-quartz schist predominates. Rocks are mostly white, tan, brown to black, locally greenish with conspicuous compositional banding. Fine lamellar foliation, locally blastomylonitic. On outcrop scale the schist is isoclinally folded, commonly crenulated; small crinkle folds on prominent foliation surfaces. Locally includes:

TKnm **Marble and minor amphibolite**—Small outcrops shown with cyan diamond or line symbol only

TKnu, Knu **Ultramafic rocks**—Serpentinite, talc-magnesite schist, talc schist, tremolite-talc schist, and olivine-talc rocks. Shown with asterisk symbol where too small to show at map scale

TKcs, Kcs **Cascade River Schist (Middle Eocene to Late Cretaceous)**—Mostly fine grained, highly fissile, green, brown, and black micaceous schist ranging from phyllitic sericite-quartz schist to granoblastic biotite- and muscovite-biotite-quartz-albite schist, hornblende-biotite-andesine schist, garbenschiefer, fine-grained amphibolite, and fine-grained paragneiss. Many rocks have garnet, less commonly staurolite and kyanite. Rare chloritoid. Calcareous mica schist locally. Hornblende is commonly blue green. Relict clastic textures common in metasandstone; unit also includes small-pebble metaconglomerate. Locally includes:

TKcc, Kcc **Metaconglomerate**—Gray to dark-green rocks ranging from boulder conglomerate with weak foliation to highly schistose rocks in which clasts are so highly attenuated that they are only visible on surfaces cut perpendicular to fabric lineation. Identifiable clast protoliths are quartzite, volcanic rocks, and granitoid rocks, including rocks derived from the protolith of the Marblemount pluton

Kcmv **Metavolcanic rocks**—Fine-grained leucogreenschist, commonly with relict highly flattened phenocrysts of plagioclase or mafic minerals

Kmd **Marblemount pluton (Late Cretaceous)**—Metaquartz diorite and metatonalite and tonalitic gneiss; light-colored metatonalite dikes. Locally includes unmetamorphosed hornblende tonalite north of Skagit River. Rocks have CI =16–54 (Ford and others, 1988), are medium grained, pale green, have numerous anastomosing zones rich in chlorite, epidote, and actinolitic hornblende, and vary from massive with relict hypidiomorphic granular texture to highly foliate and mylonitic. Plagioclase commonly transformed to unzoned, complexly twinned albite filled with epidote and (or) white mica. Locally includes:

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

ROCKS IN THE ROSS LAKE FAULT ZONE

TKhr **Ruby Creek Heterogeneous Plutonic Belt of Misch (1966) (Middle Eocene to Late Cretaceous)**—Heterogeneous gabbro to granodiorite in small masses and dikes. Grain size and composition varies considerably on an outcrop scale. Some rocks cataclastically foliated. Plutons of the belt intrude the phyllite and schist of Little Jack Mountain and are commonly rich in inclusions of the country rock. Also includes much medium-colored fine- to medium-grained, locally cataclastic, hornblende-biotite tonalite and abundant light-colored hornblende-biotite tonalite to granodiorite. Locally includes:

TKhri **Prominent inclusions of mafic metagabbro and ultramafic rocks**—Similar to TKhr, with prominent inclusions of mafic and ultramafic components of the Skymo Complex of Wallace (1976)

TKhrd **Diorite**—Pyroxene metadiorite, highly altered, locally cataclastic

TKs **Skymo Complex of Wallace (1976) (Middle Eocene to Late Cretaceous)**—Metamorphosed troctolite, gabbronorite, and anorthosite intruded by irregular patches and veins of lighter colored medium- to coarse-grained gabbro and rare tonalitic pegmatite. Gabbronorite locally grades to pyroxenite. Troctolite and gabbronorite weather orange-brown. Oikocrystic orthopyroxene in gabbronorite. Troctolite, gabbronorite, and anorthosite weakly layered; cumulate origin is probable. Unit is highly faulted and cut by mylonitic zones. Locally includes:

TKsf **Fine-grained granulites**—Interlayered calc-silicate gneiss, garnet plagioclase schist, hypersthene-plagioclase gneiss, and orthogneiss (Baldwin and others, 1997)

TKsfm **Marble**—Small outcrops shown as cyan diamond only

Little Jack terrane

TKlp **Phyllite and schist of Little Jack Mountain (Middle Eocene to Late Cretaceous)**—Mostly quartz-mica phyllite and biotite schist with local staurolite, garnet, andalusite, and sillimanite. Rare ribbon chert, local marble, and ubiquitous pods of metapyroxenite, talc-bearing metaperidotite, and serpentinite. Local amphibolite and hornblende-biotite schist. Biotite commonly porphyroblastic. Intruded by dacite porphyry dikes ranging from undeformed to mylonitic with strong, mostly northwest-trending, stretching lineation. Locally includes:

TKlu **Ultramafic rocks**—Metaperidotite and metapyroxenite. Small outcrops shown by asterisk symbol only

Hozomeen terrane

Hozomeen Group (Mesozoic and Paleozoic)—Divided into:

JŦhgs **Greenstone, clastic sedimentary rock, limestone, and chert (Middle Jurassic to Late Triassic)**—Heterogeneous discontinuously bedded greenstone, graywacke, argillite, marble, and ribbon chert. Local chaotic mixing suggestive of deposition by submarine landslides. Greenstones commonly derived from Ti-rich basalt, locally with well-developed pillows. Partially recrystallized to prehnite-pumpellyite facies. Limestones mostly coarsely recrystallized, grey, and in 0.1- to 10-m pods. Deformational fabric ranges from none to (mostly) incipient slaty cleavage. Description modified from Haugerud (1985). Unit JŦhgs corresponds to the uppermost of four units described by McTaggart and Thompson (1967)

Ŧhc **Chert (Late and Middle Triassic)**—Mostly ribbon chert and slaty argillite with minor greenstone and marble. Probably equivalent to third highest of four units described by McTaggart and Thompson (1967)

Pzhg **Greenstone with minor argillite, chert, and limestone (Permian and Pennsylvanian)**—Mostly pillow basalt, pillow breccia, flows, and minor basaltic tuff, with minor argillite, volcanic lithic sandstone, ribbon chert, and limestone. Partially recrystallized to prehnite-pumpellyite facies. Probably corresponds to second highest of four units described by McTaggart and Thompson (1967). Locally includes:

Pzhgl **Limestone, chert, and minor greenstone and metatuff**—Mostly grey, well-recrystallized limestone

ROCKS EAST OF THE ROSS LAKE FAULT ZONE

Methow Terrane

Js **Sandstone and argillite (Late Jurassic)**

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Table 1. *Nomenclature of terrane and structural elements in the Northwest Cascade System*

Misch, 1966	Tabor and others, 1989	Brandon, 1989	This map
			Gold Run Pass Nappe made up of parts of lower nappes
			Gold Run Pass thrust
Shuksan thrust plate composed of the Shuksan Suite of Misch (1966) made up of the Shuksan Greenschist and Darrington Phyllite	**Easton terrane** composed of the Easton Metamorphic Suite made up of the Shuksan Greenschist and Darrington Phyllite	**Easton terrane** composed of the Easton Metamorphic Suite	**Shuksan Nappe** composed of Easton terrane made up of Easton Metamorphic Suite
Shuksan thrust			*Shuksan Thrust*
Imbricate zone included the Yellow Aster Complex of Misch (1966) and other highly faulted rocks	**Elbow Lake terrane** **Yellow Aster terrane**	**Deadman Bay and related terranes** including the Elbow Lake Formation of Brown and others (1987)	**Welker Peak Nappe** composed of the Bell Pass Melange which is made of the Elbow Lake Formation of Brown and others (1987), Yellow Aster Complex of Misch (1966), and other units
Shuksan thrust			*Welker Peak Thrust*
Church Mountain thrust plate composed of the Cultus Formation and Chilliwack Group of Cairnes (1944) [in which Misch (1966) included rocks now referred to the Elbow Lake Formation of Brown and others, 1987]	**Grandy Ridge terrane** composed of the Cultus Formation of Brown and others (1987), Chilliwack Group of Cairnes (1944), Nooksack Group of Danner (1958), and Wells Creek Volcanics of Misch (1966)	**Chilliwack terrane and overlying clastic sequence** includes the Nooksack Group of Danner (1958), Wells Creek Volcanics of Misch (1966), Cultus Formation of Brown and others (1987), and Chilliwack Group of Cairnes (1944), as well as the Yellow Aster Complex of Misch (1966)	**Excelsior Nappe** composed of the Cultus Formation of Brown and others (1987) and Chilliwack Group of Cairnes (1944)
Church Mountain thrust			*Excelsior Thrust*
Autocthon composed of the Nooksack Group of Danner (1958) and Wells Creek Volcanics of Misch (1966)			**Nooksack Formation**

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington*

[Map number in parentheses not on this map]

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
				Conglomerate of Bald Mountain		
1f	SJ88-BM1	48°58.13'	121°57.18'	Pollen from mudstone	Late Cretaceous-early Tertiary	E. Leopold, written commun. to S.Y. Johnson, 1980
2f	RH88-139a	48° 57.61'	121°56.50'	Radiolarians in chert clasts in conglomerate	Triassic?	C.D. Blome, written commun., 1990
3f	RH88-106a	48°36.08'	121°49.23'	Radiolarians in sandstone and chert granules in conglomerate	Late Triassic	Do.
				Cultus Formation		
4f	91-115	48°40.79'	121°50.26'	Coral and spongiomorph in limestone	Triassic	W.R. Danner in Blackwell, 1983, p. 701
5f	RWT 309-87	48°40.83'	121°50.26'	Radiolarians in limey argillite	Triassic?	C.D. Blome, written commun., 1988
6f	1502-517	48°59.8'	121°56.7'	Ammonites and belemnites in argillite	Jurassic (originally reported as Triassic, but fossil since reclassified as Jurassic)	T.W. Stanton in Daly, 1912, p. 517; Hillhouse, 1956
7f	JM91-82	48°59.86'	121°51.0'	Radiolarians in chert pods	Late Triassic?	C.D. Blome, written commun., 1994
8f	RWT 244-90	48°57.2'	121°39.0'	Radiolarians in cherty argillite	Middle or Late Triassic??	C.D, Blome, written commun., 1995
9f	RWT 133-88	48°59.98'	121°56.14'	Radiolarians in chert	probably Middle or Late Jurassic	C.D. Blome, written commun., 1990
10f	KA 90-89	48°39.5'	121°39.5'	Radiolarians in chert	Jurassic?	C.D. Blome, written commun., 1995
11f	RWT 65-90	48°34.91'	121°39.79'	Radiolarians in thinly laminated chert	Triassic?	Do
12f	RH90-38	48°35.3'	121°37.6'	Radiolarians in argillite	probably Triassic (Ladinian or Carnian)	Do
				Chilliwack Group		
13f	101-234	48°59.65'	121°54.97'	Fusulinids in limestone	Permian	Jones, 1984, p. 25 and 27
14f	D248	49°00.0'	121°55.7'	Fusulinid in limestone	Permian	Danner, 1966, p. 248; Hillhouse, 1956, p.19-20
(15f)	M58	49°00.19'	121°59.16'	Fusulinids in limestone; off quadrangle to north	Early Permian	Monger, 1966, p. 173
16f	1509-1511	48°59.9'	121°51.0'	Corals, gastropods, trace fossils	Paleozoic	George H. Girty in Daly, 1912, p. 510-511, 515; Will Elder, written commun., 1994
17f	101-109	48°59.59'	121°51.35'	Crinoids in limestone	Mississippian (?)*	Jones, 1984, p. 25

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
18f	1506	48°59'	121°52'	Crinoidal fragments	Mississippian (?)*	Daly (1912, p. 510)
19f	101-311	48°59.64'	121°50.82'	Carbonized plant debris in clastic rocks	probably Pennsylvanian	Rouse, in Jones, 1984, p. 32
20f	D255	48°54.75'	121°55.08'	Coral in limestone	Devonian	Danner, 1966, p. 255-256
21f	D257	48°43.24'	121°53.15'	Crinoids in limestone	Mississippian*	Danner, 1966, p. 257
22f	101-188	48°58.17'	121°54.22'	Corals in limestone	probably Devonian	W.R. Danner, in Jones, 1984, p. 22
23f	D263	48°39.3'	121°46.1'	Large crinoid stem fragments	Mississippian*	Danner, 1966, p. 263
24f	RH90-43	48°38.2'	121°48.8'	Fine plant hash and stem impression	Paleozoic	S.H. Mamay, written commun., 1991
25f	D264	48°37.81'	121°49.69'	Crinoids, bryozoans, and brachiopods in limestone	probably Mississippian*	Danner, 1966, p. 264-268
26f	RH 90-46	48°37.66'	121°48.66'	Stem casts in fine-grained sandstone	Pennsylvanian-Early Permian	S.H. Mamay, written commun., 1991
27f	RH 90-47	48°37.43'	121°48.95'	Conodont from limestone	Middle Pennsylvanian (Atokian-Desmorian)	A.G. Harris, written commun., 1991
28f	CO 121-85	48°35.55'	121°39.95'	Conodonts in crinoidal limestone	Late Mississippian, Chesterian	R.T. Lierman and K.S. Schindler, written commun., 1986
29f	D271	48°33.10'	121°44.05'	Crinoids in limestone	Mississippian*	Danner, 1966, p. 271-275
30f	D271	48°33.15'	121°43.12'	Crinoids in limestone	Mississippian*	Do.
31f	D276	48°33.22'	121°39.16'	Coral in limestone	Devonian	Danner, 1966, p. 277
32f	D281	48°32.87'	121°38.49'	Corals and stromatoporoids in limestone	Devonian(?)	Danner, 1966, p. 281-282
33f	D289	48°30.01'	121°35.63'	Brachiopods in limestone	Silurian-Devonian	Danner, 1966, p.289-292
				Volcanic rocks of Mount Herman		
34f	RH90-138	48°48.78'	121°42.94'	Radiolarians in siliceous siltstone	Late Permian (Guadalupian)?	C.D. Blome, written commun., 1991
				Bell Pass melange		
35f	RWT 120-88	48°59.68'	121°59.87'	Radiolarians in cherty argillite	Jurassic?	C.D. Blome, written commun., 1990
36f	RH88-141a	48°58.90'	121°57.13'	Radiolarians in chert	Late Jurassic (undifferentiated)	Do.
37f	RH88-142a	48°58.86'	121°56.30'	Radiolarians in black chert	Permian (undifferentiated)	Do.

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
37f (cont.)	RH88-142b			Radiolarians in grey chert	Early Permian	Do.
	MR0922			Radiolarians in chert; location inferred	Late Pennsylvanian to Early and Middle Permian	D. L. Jones and B. Murchey, written commun. to W.R. Danner, 1980
38f	RH88-138a	48°57.19'	121°56.29'	Radiolarians in chert	Mesozoic	Do.
39f	RH88-136	48°56.93'	121°56.04'	Radiolarians in chert	Late Triassic?	Do.
(40f)	RH88-150	48°56.81'	122°00.89'	Radiolarians in chert; off quadrangle to west	Permian?	Do.
(41f)	RH88-153	48°57.98'	122°01.69'	Radiolarians in red chert	Permian	Do.
42f	RWT 100-88	48°49.32'	121°58.91'	Radiolarians in black chert	Mesozoic	C.D. Blome, written commun., 1989
(43f)	B871	48°46.70'	122°03.40'	Radiolarians in chert; off quadrangle to west	Mesozoic, probably Jurassic	B. Murchey, written commun., 1986
44f	RH88-116	48°46.03'	121°58.13'	Radiolarians in chert	Late Triassic	C.D. Blome, written commun., 1990
45f	RH88-114b	48°45.91'	121°58.52'	Radiolarians in chert	Late Triassic	C.D. Blome, written commun., 1989
46f	KD 43-87	48°39.82'	121°47.43'	Radiolarians in chert in probable fault zone. Possible Cultus Fm.	Late Triassic?	C.D. Blome, written commun., 1988
47f	RWT 84-90	48°56.47'	121°41.63'	Highly deformed chert	probably Middle or Late Triassic??	C.D. Blome, written commun., 1995
48f	RWT 82-90	48°56.11'	121°41.61'	Highly deformed chert	Late Triassic (probably Carnian)	Do.
	RWT 83-90	48°56.11'	121°41.61'	Highly deformed chert	Triassic (Ladinian or Carnian)	Do.
49f	RH90-66	48°50.49'	121°39.12'	Highly deformed chert	Mesozoic	C.D. Blome, written commun., 1991
50f	RH88-35	48°43.52'	121°36.26'	Radiolarians in chert	Jurassic?	C.D. Blome, written commun., 1990
51f	RH86-153	48°45.1'	121°37.3'	Radiolarians in chert	Triassic (Late Triassic?)	C.D. Blome, written commun., 1993
52f	RH86B-141a	48°41.7'	121°37.8'	Radiolarians in chert	Probably Early Permian	Do.
53f	DM91-29	48°38.58'	121°35.22'	Radiolarians in sheared chert and argillite	Late Triassic?	C.D. Blome, written commun., 1994
54f	JM91-87	48°35.46'	121°34.74'	Radiolarians in sheared chert and argillite	Late Triassic?	Do.
55f	RH91-225	48°33.96'	121°32.64'	Radiolarians in chert pod in argillite	possibly Late Triassic or Early Jurassic	Do.
				Nooksack Group		
56f	101-108	48°56.74'	121°49.84'	Belemnite in siltstone	Late Jurassic to Early Cretaceous	Jones, 1984, p. 40,43
57f	101-98	48°55.88'	121°51'	Pelecypod in volcanic arenite	Late Jurassic to Early Cretaceous	Jones, 1984, p. 40-41

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
58f	RWT 163-88	48°56.05'	121°47.35'	Radiolarians in cherty argillite and siltstone	Mesozoic (Jurassic?)	C.D. Blome, written commun., 1990
59f	RH91-216	48°56.04'	121°48.54'	Radiolarians in concretion in argillite	Late Triassic to Late Jurasic	C.D. Blome, written commun., 1994
60f	RH91-213	48°55.68'	121°50.34'	Pelecypods, belemnites	Late Jurassic	Will Elder, written commun., 1994
61f	RH91-212	48°55.68'	121°50.52'	Pelecypod	Jurassic (late Kimmeridgian to early Tithonian)	Do.
62f	RH91-214	48°55.50'	121°49.86'	Pelecypod	Jurassic (Oxfordian to Early Kimmeridgian)	Do.
63f	no number	48°57'	121°50'	Pelecypods, belemnites (location uncertain)	Upper Jurassic	T.W. Stanton in Smith and Calkins, 1904, p. 27
64f	9.22.52.2	48°55.77'	121°49.04'	Belemnites	Jurassic-Lower Cretaceous	J.A. Jeletzky, GSC Report no. K-9-1954/1955 and PMA**
65f	9.22.52.15	48°55.67'	121°50.33'	Pelecypods and belemnites	mid-Late Jurassic	Do.
66f	9.22.52.14	48°55.51'	121°49.70'	Belemnites	Jurassic-Lower Cretaceous	Do.
67f	8.29.54.27	48°55.10'	121°51.35'	no fossils cited	mid-Late Jurassic (Lower Kimmeridgian)	authority unknown, PMA**
68f	10.4.54.1	48°54.69'	121°47.54'	no fossils cited	Middle Jurassic (Early Cretaceous)	Do.
69f	101-256	48°55.04'	121°53.11'	Pelecypod in siltstone	Late Jurassic to Early Cretaceous	Jones, 1984, p. 40-41
70f	9.23.52.5	48°54.34'	121°52.61'	Pelecypods	mid-Late Jurassic (Oxfordian to lower Kimmeridgian)	J.A. Jeletzky, GSC Report no. K-9-1954/1955 and PMA**
71f	9.23.52.4	48°54.30'	121°53.38'	Belemnite in float	Jurassic-Lower Cretaceous	Do.
72f	9.23.52.7	48°54.30'	121°51.43'	Pelecypods and belemnites in float	mid-Late Jurassic (Oxfordian to lower Kimmeridgian)	Do.
73f	9.15.77.3	48°54.19'	121°52.99'	no fossils cited	Early Cretaceous (upper Valanginian)	authority unknown, PMA**
74f	9.17.77.4	48°54.19'	121°52.41'	no fossils cited	Late Jurassic (Oxfordian-Kimmeridgian)	Do.
75f	Misch 77	48°53.83'	121°53.74'	no fossils cited	Early Cretaceous (upper Valanginian)	Do.
76f	9.23.52.1	48°53.76'	121°54.92'	Belemnite	Jurassic-Lower Cretaceous	J.A. Jeletzky, GSC Report no. K-9-1954/1955 and PMA**
77f	9.3.54.6	48°53.37'	121°51.85'	no fossils cited	Early Cretaceous (middle or upper Valanginian)	authority unknown, PMA**
78f	9.3.54.7	48°53.36'	121°51.92'	in float(?)	Early Cretaceous (middle or upper Valanginian)	Do.
79f	JM91-73a,c	48°53.28'	121°53.10'	Belemnites	Berriasian to Hauterivian	Will Elder, written commun., 1994
80f	RH88-180c	48°52.87'	121°56.22'	Radiolarians in argillite concretions	Middle Jurassic?	C.D. Blome, written commun., 1990

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
81f	RH92-272	48°52.66'	121°54.3'	Bivalves and inocerimid	Jurassic-Cretaceous	Will Elder, written commun., 1992
82f	9.21.52.8	48°52.44'	121°45.91'	Pelecypods	mid-Late Jurassic (Oxfordian to lower Kimmeridgian)	J.A. Jeletzky, GSC Report no. K-9-1954/1955 and PMA**
83f	9.2.54.10	48°50.71'	121°51.22'	no fossils cited	Latest Jurassic (Purbeckian-upper Tithonian)	authority unknown, PMA**
	9.2.54.11	48°50.71'	121°51.22'	in float?	Late Jurassic (Portlandian to Purbeckian)	Do.
84f	9.2.54.1	48°49.60'	121°50.72'	no fossils cited	mid-Late Jurassic (upper Oxfordian or lower Kimmeridgian)	Do.
85f	7.10.49.1	48°48.66'	121°49.32'	Pelecypods in thin limestone	earliest Cretaceous (middle or upper Valanginian(?))	J.A. Jeletzky, GSC Report no. K-9-1954/1955 and PMA**
86f	KA90-205A	48°47.09'	121°53.09'	Radiolarians in concretions in argillite	middle or Late Cretaceous	C.D. Blome, written commun., 1995
87f	KA90-207	48°46.7'	121°53.5'	Argillite	questionable Cretaceous	Do.
88f	RH88-96b	48°45.65'	121°42.85'	Radiolarians in slaty, phyllitic argillite	Early Jurassic to Cretaceous	C.D. Blome, written commun., 1990
89f	RWT 303-85	48°41.76'	121°43.56'	Radiolarians in concretions in slaty argillite	Mesozoic or younger	C.D. Blome, written commun., 1986
90f	RWT 305-85	48°41.64'	121°43.32'	Radiolarians in concretions in slaty argillite	possibly Late Jurassic	Do.
91f	RWT 297-92	48°57.42'	121°39.06'	Belemnite in argillite; in float	Early Jurassic to Early Cretaceous	W. Elder, oral commun., 1993
				Hozomeen Group		
92f	RWT310-91	48°59.71'	121°00.39'	Conodonts m (CAI=chiefly 6, one at 3 or 4; contact met. at >200°C but probably <400°C)	Early to Middle Pennsylvanian	B.R. Wardlaw, written commun., 1991
93f	RH91-260	48°55.08'	121°05.10'	Radiolarians in chert	Triassic (probably late middle Norian to Hettangian)	C.D. Blome, written communn., 1994
94f	RH91-261	48°55.08'	121°04.68'	Radiolarians in chert	Triassic (probably Norian)	Do.
95f	RWT 293-91	48°54.54'	121°05.70'	Radiolarians in ribbon chert	Triassic (Ladinian or Carnian)	Do.
96f	RH81-D28a	48°55.77'	121°04.09'	Radiolarians in chert	Late Triassic (Karnian-Norian)	E.A. Pessagno, written commun., in Haugerud, 1985

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
97f	RH91-349	48°52.32'	121°03.96'	Radiolarians in ribbon chert	Late Triassic?	C.D. Blome, written commun., 1994
98f	RH91-348	48°52.08'	121°04.02'	Radiolarians in ribbon chert	Late Triassic (probably mid-late Norian)	Do.
99f	RH91-347	48°51.84'	121°03.84'	Radiolarians in ribbon chert	Late Triassic (early to late middle Norian)	Do.
100f	RH91-346	48°51.86'	121°04.08'	Radiolarians in ribbon chert	Triassic?	Do.
101f	RH91-343	48°51.54'	121°04.62'	Radiolarians in ribbon chert	Triassic (Ladinian or early Carnian)	Do.
102f	RH91-342	48°51.54'	121°04.74'	Radiolarians in ribbon chert	Jurassic; Early Jurassic (Sinemurian or Toarcian)	C.D. Blome, written commun., 1994, 1995
103f	RH91-339	48°51.42'	121°05.04'	Radiolarians in ribbon chert	Late Triassic?	Do.
104f	RH91-338	48°51.42'	121°05.10'	Radiolarians in ribbon chert	Triassic or younger	Do.
105f	RH91-337	48°51.42'	121°05.28'	Radiolarians in ribbon chert	Triassic or younger	Do.
	RH91-336	48°51.42'	121°05.28'	Radiolarians in ribbon chert	Triassic?	Do.
106f	RH 81-D14a	48°55.15'	121°05.85'	Radiolarians in chert	Late Triassic (upper Karnian? lower to upper middle Norian)	E.A. Pessagno, written commun., in Haugerud, 1985
107f	KD 94-87	48°51.47'	121°05.06'	Radiolarians in chert	Jurassic and younger	C.D. Blome, written commun., 1988, 1995
(108f)	RH81-D59b	49°04.72'	121°06.62'	Radiolarians in chert; off quadrangle to north	Middle Triassic (Ladinian)	E.A. Pessagno, written commun., in Haugerud, 1985
(109f)	RH81-D72b	49°04.54'	121°14.02'	Radiolarians in chert; off quadrangle to north	Jurassic (Sinemurian or younger)	Do.
(110f)	RH81-D73b	49°04.54'	121°14.10'	Radiolarians in chert; off quadrangle to north	Middle Jurassic (Aalenian to upper lower Bajocian)	Do.
(111f)	RH81-D75g	49°04.18'	121°13.21'	Radiolarians in chert; off quadrangle to north	Late Triassic (upper Karnian(?); lower to upper middle Norian)	Do.
(112f)	RH82-E19b	49°04.73'	121°14.02'	Radiolarians in chert; off quadrangle to north	Late Triassic (upper Karnian(?); lower to upper middle Norian	Do.
(113f)	RH82-E20b	49°02.31'	121°11.56'	Radiolarians in chert; off quadrangle to north	Late Triassic (upper middle Norian)	Do.

Table 2. *Fossils and fossil locations in the Mount Baker 30- by 60-minute quadrangle, Washington—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Description	Age	Reference
(114f)	RH82-E36b	49°03.85'	121°13.22'	Radiolarians in chert; off quadrangle to north	Late Triassic (upper Karnian(?); lower to upper middle Norian)	Do.
(115f)	no number	48°45'	120°51'	Radiolarians in chert; off quadrangle to east	Permian	Tennyson and others, 1981
				Sandstone and argillite		
(116f)	RWT275-91	48°56.2'	120°58.5'	Ammonites and brachiopods in argillite; off quadrangle to east	Late Jurassic (Oxfordian-Valanginian)	Will Elder, written commun., 1992

* These samples of coarse crinoidal limestone were identified by the cited authors as Pennsylvanian by lithologic correlation with the Red Mountain limestone unit of Danner (1966), which is now known to be late Visean (Mississippian) in age (Liszak, 1982). See text for discussion

** PMA = unpublished map of Mount Baker 15' quadrangle by Peter Misch, in archives, Suzallo Library, University of Washington, Seattle

Table 3. *Summary of fission-track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; except for Map Nos. 1 and 2, mostly obtained prior to 1995; for additional more recently obtained ages, see text.*

[nn=no sample number available. Map numbers in parentheses are not on this map. All fission-track ages calculated with F=7.03x10^{-17}/yr. All U.S. Geological Survey K-Ar ages calculated on basis of 1976 IUGS decay and abundance constants. K-Ar ages from Engels and others (1976) and earlier reports are corrected by use of table in Dalrymple (1979). Errors on single new K-Ar ages of this report based on an empirical function relating the coefficient of variation in the age to percent radiogenic argon (Tabor and others, 1985). U-Th-Pb isotope ages reported in following order $^{206}Pb/^{238}U$; $^{207}Pb/^{235}U$; $^{207}Pb/^{206}Pb$; $^{208}Pb/^{232}Th$ (--, no age). Constants: ^{238}U=1.55125x10^{-10}/yr; ^{235}U=9.8485x10^{-10}/yr; ^{232}Th=4.9475x10^{-11}/yr; $^{238}U/^{235}U$=137.88]

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
					Deposits of Mount Baker volcanic center			
1	MB632	48°48.4'	121°53.1'	K-Ar	whole rock	0.014±0.009	Mount Baker strato-volcano; see text for more ages	Hildreth and others (in press)
2	MB10	48°51'	121°41.8'	K-Ar	whole rock	0.309±0.013	Andesite of Table Mountain; see text for more ages	Do.
					Volcanic deposits Kulshan Caldera			
3	RH90-122	48°48.7'	121°43.9'	FT	zircon	1.46±0.15	Biotite rhyodacite dome	J.A. Vance (written commun., 1992)
					Hannegan Volcanics			
4	RWT469A-67	48°51.8'	121°31.4'	K-Ar	hornblende	3.6±1.0	Andesite clast	Engels and others (1976)
	RWT469B-67	48°51.8'	121°31.4'	K-Ar	hornblende	3.3±1.0	do.	Do.
5	TG90-64	48°53.2'	121°31.7'	FT	zircon	4.4±0.5	Biotite vitrophyre	J.A. Vance (written commun., 1992)
					Chilliwack composite batholith			
6	RWT 480-67	48°49.6'	121°37.8'	K-Ar	biotite**	2.7±0.3	Lake Ann stock	Engels and others (1976)
7	DFC 1-69	48°50'	121°38'	K-Ar	biotite	2.5±0.1	Hornfels adjacent to Lake Ann stock	Do.
8	RWT 269-87	48°50.2'	121°27.2'	FT	zircon	6.5±1.3	Mineral Mountain pluton	J.H. Tepper and J. Garver (written commun, 1995)
				U-Pb	nm [+102]	7.5;7.4;14.3;--		J.S. Stacey (written commun.
					nm [-63]	7.4;8.1;225.6;--		1988)
					m [-63]	7.3;7.5;44.3;--		
9	CB87(JT)-120	48°53.8'	121°33.6'	FT	zircon	8.7	Ruth Creek pluton	J.A.,Vance cited in Tepper (1991)
10	CB82-074	48°53.8'	121°34.7'	Rb-Sr	biotite-wr	8.7	do.	Tepper (1991; written commun., 1993)
11	RWT 500-66	48°56.4'	121°18.2'	K-Ar	hornblende	10.8±0.9	Quartz monzodiorite of Redoubt Creek	Engels and others (1976)
(12)	nn	49°00.7'	121°12.3'	K-Ar	biotite	12.1±0.4	Just north of quadrangle	Mathews and others (1981)
13	CB88-038	48°53.0'	121°34.6'	Rb-Sr	biot-cpx-plag-wr isochron	22.85±0.05	Mount Sefrit Gabbronorite of Tepper and others (1993)	Tepper (1991; written commun., 1993)
14	PM 27	48°54.6'	121°11.8'	K-Ar	hornblende	25.2±0.7	Biotite granodiorite of Little Beaver Creek	Engels and others (1976)
				K-Ar	biotite	22.6±0.7		

Table 3. *Summary of fission track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; mostly obtained prior to 1995—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
15	RWT 474-67	48°51.6'	121°18.4'	K-Ar	hornblende	21.6±0.7	Perry Creek phase	Do.
				K-Ar	biotite	21.9±0.7		
16	RWT 501-66	48°57.2'	121°10.4'	K-Ar	hornblende	23.0±0.7	do.	Do.
				K-Ar	biotite	25.3±0.7		
17	PM 7	48°57'	121°10'	K-Ar	biotite	31.8	Perry Creek phase, location uncertain	Do.
18	75R-66	48°58.6'	121°0.4'	K-Ar	biotite	23.8±0.7	Perry Creek phase on Mount Hozomeen	Do.
19	RH90-194	48°55.25'	121°27.3'	K-Ar	hornblende	23.8±1.7	Chilliwack valley phase	table 4
20	RWT 475-67	48°59.4'	121°28.7'	K-Ar	biotite	25.7±0.8	do.	Engels and others (1976)
				K-Ar	amphibole	27.1±3.0		
21	RWT 298-90	48°54.5'	121°23.7'	K-Ar	hornblende	26.5±1.3	Indian Mountain phase	table 4
				K-Ar	biotite	23.4±0.6		
22	RH90-228	48°48.1'	121°40.3'	U-Pb	zircon		Tonalite of Maiden Lake	W. C. McClellan (written commun., 1996)
					(fraction 1)	29.0;29.0;29.0±5; --		
					(fraction 2)	33.2;34.2;103±4; --		
					(fraction 3)	68.1;71.5;184±5; --		
23	RWT 206-91	48°59.2'	121°36.2'	K-Ar	hornblende	30.3±1.2	Silesia Creek pluton	table 4
				K-Ar	biotite	30.7±0.9		
24	R-212	48°45'	121° 29'	K-Ar	biotite	29.4, 30.8 (average 30.1±0.7)	Biotite alaskite of Mount Blum; location uncertain	J.A. Vance (written commun., 1986)
				Rb-Sr	biotite-wr	30.3±0.6		
25	RWT 476-67	48°59.6'	121°33.1'	K-Ar	biotite	30.9±0.9	Pocket Peak phase	Engels and others (1976)
				K-Ar	muscovite	29.5±1.2	do.	
26	RWT 482-67	48°51.7'	121°28.8'	K-Ar	hornblende	32.5±2.1	Dike cutting Pocket Peak phase	Do.
27	JV 290	48°40.4'	121°19.5'	K-Ar	biotite	29.5±0.6	Granodiorite of Mount Despair	table 4
				K-Ar	hornblende	32.9±3.1		Do.
				FT	zircon	33.1		J.A. Vance (written commun., 1986)
				U-Pb	zircon			Vance and others (1986)
					fine	--;--;31.9;--		
					coarse	--;--;31.8;--		
				U-Pb	zircon	--;--;34.8;--		W. Hoppe, in Vance and others (1986)
28	827-7I	48°38.3'	121°19.1'	K-Ar	hornblende	29.4±0.6	Granodiorite of Mount Despair	R. Fleck (written commun., 1993)
					biotite	30.1±0.2		
29	PM 14	48°39.6'	121°17.7'	K-Ar	biotite	30±1	do.	Engels and others (1976)

Table 3. *Summary of fission track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; mostly obtained prior to 1995—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
30	RWT 471-67	48°44.7'	121°25.0'	K-Ar	hornblende	31.1±1.4	do.	Do.
31	PM 13	48°39'	121°18.4'	K-Ar	biotite	32±1	do.	Misch (1963b, 1964)
32	PM 4	48°38'	121°20'	K-Ar	biotite	34.9	do.	Do.
33	PM 6	48°38'	121°19'	K-Ar	biotite	50±1	Ages for this sample suspect	Do.
				K-Ar	biotite	40±1	Rerun of above	Do.
				K-Ar	hornblende	51±1	Contamination?	Do.
	PM 12	48°38'	121°19'	K-Ar	biotite	33±1	do.	Do.
34	CB88-23	48°54.8'	121°27.3'	Rb-Sr	biot-hbl-plag-wr isochron	34±0.9	Gabbro of Copper Lake	Tepper (1991; written commun., 1993)
					Volcanic rocks of Mount Rahm			
35	nn	48°59.8'	121°11.2'	K-Ar	wr	12.6±0.4	Tuff; age probably reset by granite of Redoubt Creek	Mathews and others (1981)
(36)	nn	49°00.7'	121°13.3'	K-Ar	plagioclase	13.1±0.5	Volcanic dike; age probably reset by granite of Redoubt Creek; just off quadrangle to north	Do.
					Younger sandstone and conglomerate			
37	JV-x	48°36'	121°25'	FT	zircon	~45	Clast of Marblemount pluton in conglomerate; location uncertain	J.A. Vance (written commun., 1989)
					Unnamed sandstone in fault zone along west side of Twin Sisters Mountains			
(38)	KD 17-87	48°41.5'	121°00.8'	FT	zircon	>60, <73	Off quadrangle to west; probable stratigraphic age	J.A. Vance (written commun., 1992)
					Dikes			
39	2-268c	48°57.0'	121°37.8'	K-Ar	hornblende	58.2±2.3	Foliated dioritic dike in Welker Peak Thrust Fault	Brown (1986, p. 208), R.L. Armstrong (written commun., 1983)
40	nn	48°59.5'	121°56.2'	K-Ar	hornblende	51.1±1.8	hornblende-pyroxene porphyry dike cutting byan	W. D. Danner (written commun., 1995)
					Alma Creek pluton			
41	MO 272-85	48°36.0'	121°21.4'	K-Ar	biotite	38.8±1.8		table 4
				K-Ar	muscovite	49.3±0.7		
					Haystack pluton			
42	RWT 421-85	48°34.1'	121°15.6'	K-Ar	biotite	44.4±0.6		table 4
				K-Ar	muscovite	48.0±0.6		
43	RWT 338-85	48°34.1'	121°13.9'	K-Ar	hornblende	53.3±1.7	mafic gabbro	Do.

Table 3. *Summary of fission track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; mostly obtained prior to 1995—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
					Marble Creek pluton			
44	RWT 434-85	48°34.0'	121°16.7'	K-Ar	biotite	45.0±1.9		table 4
				U-Pb	zircon			Haugerud and others (1991)
					nm [63-102]	75.6;75.9;83±7;--		
					m [63-102]	75.7;76.3;94±7;--		
					nm [-63]	75.1;76.4;116±11;--		
					m [-63]	74.7;73.4;33±16;--		
45	MO 107-85	48°31.9'	121°16.1'	K-Ar	biotite	43.8±1.1		table 4
				K-Ar	muscovite	49.6±1.7		
					Hidden Lake stock			
46	827-6D	48°30.0'	121°12.0'	K-Ar	biotite	37.6±0.3		R.J. Fleck and A.B. Ford (written commun., 1992)
47	RH86-B127A	48°30.6'	121°12.3'	U-Pb	zircon			Haugerud and others (1991)
					(-60+140)	75.4;75.5;80±12;--		
					(-140)	72.9;73.1;79±12;--		
					Skagit Gneiss Complex			
48	PM 1	48°42'	121°12'	K-Ar	biotite	44±2	Biotite schist septum in orthogneiss	Misch (1963b, 1964)
	PM 2	48°42'	121°12'	K-Ar	biotite	45±2	do.	Do.
49	PM 20	48°34'	121°02'	K-Ar	hornblende	57±2	Amphibolite	Do.
50	RWT 428-85	48°36.3'	121°17.9'	K-Ar	biotite	44.2±0.8	Orthogneiss	table 4
51	RWT 179-86	48°40.5'	121°14.8'	U-Pb	zircon		Orthogneiss	Haugerud and others (1991)
					nm [63-102]	64.8;65.0;74±11;--		
					nm [-63]	63.3;63.9;84±13;--		
	827-8C	48°40.5'	121°14.8'	K-Ar	biotite	30.2±0.1	do.	R.J. Fleck and A.B. Ford (written commun., 1992)
				K-Ar	hornblende	42.9±0.2		
52	68-16	48°42.5'	121°05.6'	U-Pb	zircon	66;67;79±10;--	Mafic orthogneiss	Mattinson (1972)
	827-8J	48°42.5'	121°05.6'	K-Ar	biotite	42.5±0.2	do.	R.J. Fleck and A.B. Ford (written commun., 1993)
				K-Ar	hornblende	42.5±3.3		
	827-8H	48°42.5'	121°05.6'	K-Ar	biotite	41.2±0.3	Biotite granodiorite dike intruding mafic orthogneiss	Do.
	NE			Ar-Ar	hornblende	47.1±1.3	Exact location uncertain;	Wernicke and Getty (1997)
				Ar-Ar	biotite	45.2±0.2	see original reference	
				Sm-Nd	plag, hbl, apatite, and garnet	60.0±1.2		

Table 3. *Summary of fission track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; mostly obtained prior to 1995—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
53	RWT 97-86	48°39.71'	121°15.05'	U-Pb	zircon		Orthogneiss	Haugerud and others (1991)
					nm [+102]	74.1;74.7;92±4;--		
					nm [-63]	72.5;72.1;61±11;--		
54	69-12	48°42.4'	121°10.2'	U-Pb	zircon		Pegmatite gneiss	Mattinson (1972)
					coarse	90;--;--;--		
					fine	57;--;--;--		
55	RWT 211-86	48°37.73'	121°08.14'	U-Pb	zircon		Orthogneiss of the Needle	Haugerud and others (1991)
					nm[63-103]	116.9;122.0;221±13;--		
					nm [-63]	112.9;117.7;242±6;--		
56	69-10	48°41.4'	121°13.7'	U-Pb	zircon	98;112 ;428±10;--	Biotite gneiss	Mattinson (1972)
					apatite	46;--;--;--		
Eldorado Orthogneiss								
57	RWT-204-86	48°31.1'	121°08.5'	U-Pb	zircon			Haugerud and others (1991)
					(-60+140)	87.7;88.2;102±6;--		
					(-140+200)	88.3;88.7;99±4;--		
Cascade River Schist								
58	RWT-42-85	48°32.1'	121°18.2'	K-Ar	muscovite	45.8±0.8	Clast of Marblemount pluton in metaconglomerate	table 4
59	118-15G	48°32.6'	121°19.7'	U-Pb	zircon		Metatuff	J.S. Stacey (written commun., 1987)
					(-150)	219;221;240;--		
Napeequa Schist								
60	RWT 426-85	48°35.4'	121°15.5'	K-Ar	hornblende	54.8±1.7	Amphibolite	table 4
61	PM 3	48°37'	121°22'	K-Ar	biotite	49±2	Biotite schist	Misch (1963b, 1964)
Marblemount pluton								
62	RWT-39-85	48°31.1'	121°21.8'	K-Ar	muscovite	94.0±1.5		table 4
63	68-18	48°34.8'	121°24.4'	U-Pb	zircon	222;221;214±30;--		Mattinson (1972)
Wells Creek Volcanic Member of the Nooksack Formatin								
64	F64F	48°52.6'	121°49.8'	U-Pb	zircon		Dacite tuff	J.M. Mattinson, in Franklin (1985)
					coarse	174.5;175.3;187±5;--		
					fine	173.2;173.7;181±5;--		
Semischist and phyllite of Mount Josephine								
65	PM 16	48°49'	121°56'	K-Ar	whole rock	113±3	Sericite phyllite	Misch (1963b, 1964)

Table 3. *Summary of fission track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; mostly obtained prior to 1995—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
					Easton Metamorphic Suite			
66	RH78-E69	48°39.4'	121°33.7'	K-Ar	whole rock	122±4	Micaceous blueschist	Haugerud (1980); Armstrong and Misch (1987)
67	27Q	48°30.9'	121°58.4'	K-Ar	muscovite	130±5	Muscovite schist	Brown and others (1982)
					Blueschist of Baker Lake			
68	887E	48°44.0'	121°37.1'	K-Ar	whole rock	127±5	Meta-ribbon chert	Brown and others (1987)
					Bell Pass melange, Vedder Complex of Armstrong and others (1983)			
69	RH78-D61	48°41.7'	121°38.2'	K-Ar	muscovite	196±7	Quartz-mica semischist	Haugerud (1980)
70	PM 24	48°47'	121°58'	K-Ar	whole rock	259±8	Crossite schist	Armstrong (1980), Armstrong and others (1983)
71	Baker 10B	48°47.2'	121°57.0'	K-Ar	whole rock	219±9		Do.
	Baker 10D	48°47.2'	121°57.0'	K-Ar	whole rock	221±8		Do.
72	PL90-8	48°45.0'	121°36.7'	K-Ar	muscovite	274±9	Albite-muscovite schist	Armstrong and Misch (1987)
				Rb-Sr	musc-wr	273		
73	NR-311	48°44.8'	121°57.2'	K-Ar	muscovite	277±9		R.L. Armstrong, in Rady (1980), Armstrong and Misch (1987)
				K-Ar	barrosite	279±9		
74	PM 101	48°45.1'	121°36.9'	K-Ar	muscovite	283±9	Albite-muscovite-amphibole schist	Armstrong and Misch (1987)
				K-Ar	amphibole	259±9		
				Rb-Sr	musc-amph-wr isochron	280±39		
					Bell Pass melange, Yellow Aster Complex of Misch (1966)			
75	69-8	48°57.3'	121°40.2'	U-Pb-Th	zircon	64;75;427±75;248	Pegmatite gneiss	Mattinson (1972)
76	80-100	48°41.85'	121°38.3'	U-Pb-Th	zircon	320;329;393;305	Phacoid in Bell Pass mélange	R.E. Zartman (written commun. to Peter Misch, 1983)
77	69-7	48°57.3'	121°40.2'	U-Pb	zircon		do.	Mattinson (1972)
					coarse	370;376;411±15;--		
					fine	368;374;412±15;--		
78	69-9	48°56.3'	121°40.4'	U-Pb	zircon	711;912;1452±20;--	do.	
				U-Pb	sphene	415;415;410±85;--		
79	TR91-83	48° 56.7'	121°41.4'	U-Pb	8 single zircon xtals		Pyroxene gneiss phacoid in Bell Pass mélange	E.T. Rasmusen and N.W. Walker (written commun., 1995)
					coarse	1082;1129;1212±23;--		
					fine	524;536;587±69;--		
				Sm-Nd		1800		

Table 3. *Summary of fission track (FT) and isotope age analyses of rocks in and near the Mount Baker 30- by 60-minute quadrangle, Washington; mostly obtained prior to 1995—continued*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Method	Material*	Age (m.y.)	Map unit, comment	References
79 (cont.)	TR91-81A	48° 56.7'	121°41.4'	U- Pb	4 single zircon xtals		Pegmatite in pyroxene gneiss	Do.
					coarse	631;895;1621±2;--		
					fine	357;491;1181±3;--		
80	TR91-59	48°42.4'	121°49.7'	U -Pb	4 single zircon xtals		Pyroxene gneiss	Do.
					coarse	1379;1857;2443±4;--		
					fine	256;267;360±10;--		
				Sm-Nd		2090		
81	YAC91-61	48°41.61'	121°46.9'	Sm-Nd		1740	Metagabbro	Do.

* Abbreviations: amph, amphibole; biot, biotite; cpx, clinopyroxene; hbl, hornblende; musc, muscovite; plag, plagioclase; wr, whole rock; c, coarse; f, fine; m, magnetic; nm, nonmagnetic; xtals, crystals. Mesh sizes in parentheses, size range in microns in brackets

** Sample erroneously reported by Engels and others (1976) to be from hornfels

Table 4. *New K-Ar ages from the Mount Baker quadrangle and vicinity, Washington, obtained prior to 1995*

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

Map No.	Sample No.	Mineral	K_2O (percent)	^{40}Ar Rad moles/gm x10^{-10}	^{40}Ar Rad (percent)	Age (Ma)
19	RH90-194	hornblende	0.311, 0.306	0.1062	20.7	23.8±1.7
21	RWT 298-90	hornblende	0.585, 0.568	0.2213	29.3	26.5±1.3
23	RWT 206-91	hornblende	0.618, 0.614	0.2708	31.7	30.3±1.2
		biotite	8.28, 8.26	3.687	53.3	30.7±0.9
		biotite	8.28, 8.24	2.805	57.8	23.4±0.6
27	JV 290	hornblende	0.495, 0.491	0.2357	14.6	32.9±3.1
		biotite	8.39, 8.41	3.594	63.3	29.5±0.6
41	MO 272-85	biotite	8.85, 8.85	5.000	59.5	38.8±1.8
		muscovite	10.87, 10.79	7.788	79.2	49.3±0.7
42	RWT 421-85	biotite	9.21, 9.20	1.257	17.4	44.4±0.6
		muscovite	10.61, 10.60	7.422	87.2	48.0±0.6
43	RWT 338-85	hornblende	0.667, 0.667	50.267, 53.569	35.4, 74.5	53.3±1.7
44	RWT 434-85	biotite	9.14, 9.17	6.000	62.4	45.0±1.9
45	MO 107-85	biotite	9.24, 9.23	5.894	57.1	43.8±1.1
		muscovite	10.97, 10.93	7.922	69.0	49.6±1.7
50	RWT 428-85	biotite	8.73, 8.74	5.631	74.3	44.2±0,8
58	RWT-42-85	muscovite	9.94, 9.97	6.646	71.1	45.8±0.8
60	RWT 426-85	hornblende	0.666, 0.665	53.301	46.9	54.8±1.7
62	RWT-39-85	muscovite	8.62, 8.64	11.786, 12.182	88.9, 74.1	94.0±1.5