science for a changing world

Prepared in cooperation with Washington State Division of Geology and Earth Resources, U.S. National Park Service, and U.S. Forest Service

Geologic Map of the North Cascade Range, Washington

By Ralph A. Haugerud and Rowland W. Tabor

Technical pamphlet to accompany

Scientific Investigations Map 2940

Looking south from the North Klawatti Glacier [Mbse]. In the right foreground, the glacier breaks into a heavily crevassed icefall where it descends steeply. Rock in the foreground knob is Eldorado Orthogneiss (unit TKgo), a 90 million-year-old stitching pluton, which here includes numerous dikes of light-colored pegmatite. Mount Buckner on the left skyline and Mount Forbidden hidden in clouds are also eroded from the Eldorado Orthogneiss (photographed in 1987).

2009

U.S. Department of the Interior
U.S. Geological Survey

CONTENTS

Introduction

The North Cascade Range, commonly referred to as the North Cascades, is the northern part of the Cascade Range that stretches from northern California into British Columbia, where it merges with the Coast Mountains of British Columbia at the Fraser River. The North Cascades are generally characterized by exposure of plutonic and metamorphic rocks in contrast to the volcanic terrain to the south (fig. 10). The rocks of the North Cascades are more resistant to erosion, display greater relief, and show evidence of more pronounced uplift and recent glaciation. Although the total length of the North Cascade Range, extending north from Snoqualmie Pass in Washington, is about 200 mi (320 km), this compilation map at 1:200,000 scale covers only that part (~150 mi) in the United States. The compilation map is derived mostly from eight 1:100,000-scale quadrangle maps that include all of the North Cascade Range in Washington and a bit of the mostly volcanic part of the Cascade Range to the south (fig. 1, sheet 2). Overall, the area represented by this compilation is about 12,740 mi^2 (33,000 km^2).

The superb alpine scenery of the North Cascade Range and its proximity to major population centers has led to designation of much of the area for recreational use or wilderness preservation. A major part of the map area is in North Cascade National Park. Other restricted use areas are the Alpine Lakes, Boulder River, Clearwater, Glacier Peak, Henry M. Jackson, Lake Chelan-Sawtooth, Mount Baker, Noisy-Diobsud, Norse Peak, and Pasayten Wildernesses and the Mount Baker, Lake Chelan, and Ross Lake National Recreation Areas. The valleys traversed by Washington State Highway 20 east of Ross Lake are preserved as North Cascades Scenic Highway.

The map area is traversed by three major highways: U.S. Interstate 90, crossing Snoqualmie Pass; Washington State Highway 2, crossing Stevens Pass; and Washington State Highway 20, crossing Washington Pass. Major secondary roads, as well as a network of U.S. Forest Service roads and a few private roads mainly used for logging, are restricted mostly to the flanks of the range. Although much of the mountainous core is inaccessible to automobiles, numerous trails serve the foot or horse traveler.

Using This Report

We designed this map for two audiences: those who visit the North Cascades (fig. 1) and want to have a feeling for the rocks around them, and those who have geologic training, are familiar with North Cascade geology, and want a geologic overview of the range. In the pamphlet accompanying this map, we present text and rock descriptions in plain terms, with as little jargon as possible. The Description of Map Units for the nonspecialist emphasizes how the rocks are formed and their geologic history. Much of the nonspecialist text in the pamphlet is drawn from our book, The Geology of the North Cascades: A Mountain Mosaic (published in 1999 by The Mountaineers, Seattle). The technical pamphlet is a summary of material presented in the eight 1:100,000-scale geologic maps and other technical sources and heavily references them. Both technical user and nonspecialist may want to refer to both versions of the pamphlet for the complete story.

Because the geologic map is large and complex, we appended location codes in brackets after geographic place names and geologic unit and feature names where needed. The eight 1:100,000-scale quadrangles are outlined on the map, and quadrangle names and their abbreviations are labeled along the edges of the map, as well as in figures 1 and 5, sheet 2. The quadrangle maps may be further subdivided into quadrants indicated by compass directions. The location code may consist of the quadrangle(s) abbreviation or a combination of the quadrangle and quadrant abbreviations. Thus, the location code "[MBnw]" following a place name, unit name, or geologic feature name indicates a location in the northwest quadrant of the Mount Baker quadrangle.

Figures are numbered consecutively in the nontechnical pamphlet for the nonspecialist; however, the same figures are necessarily cited out of sequence in this technical pamphlet.

Additional photographs may be accessed at the publication website (http://pubs.usgs.gov/sim/2940).

Map Preparation

We compiled the map electronically from digital databases for eight 1:100,000-scale geologic quadrangle maps of the North Cascades (fig. 1). We and our colleagues mapped and compiled the geology of the eight maps from 1975 through 2003: Chelan (Tabor and others, 1987a), Mount Baker (Tabor and others, 2003), Robinson Mountain (R.A. Haugerud and R.W. Tabor, unpub. field maps), Sauk River (Tabor and others, 2002), Skykomish River (Tabor and others, 1993), Snoqualmie Pass (Tabor and others, 2000), Twisp (R.A. Haugerud, J.B. Mahoney, and R.W. Tabor, unpub. field maps), and Wenatchee (Tabor and others, 1982). The predominant sources of the geology are revealed on each of the individual 1:100,000-scale maps. Except to correct minor drafting errors in the original source maps, we have not moved contacts or faults shown on the published 1:100,000-scale maps, but we have changed the interpretation of a few structures based on insights gained during this compilation, new published work, and (or) new field data. References are sparse for a map of this size and complexity. In the Description of Map Units, we cite one or more of the 1:100,000-scale geologic maps most appropriate for more information about the unit. We tried to include references to more current work, some that may directly conflict with our interpretations.

Major Sources of New Data

We compiled the geology of the Robinson Mountain quadrangle from a new 1:100,00-scale map that is nearing completion. Sources of data for this quadrangle, other than the authors' field maps, are Barksdale (1975), Hawkins (1963,

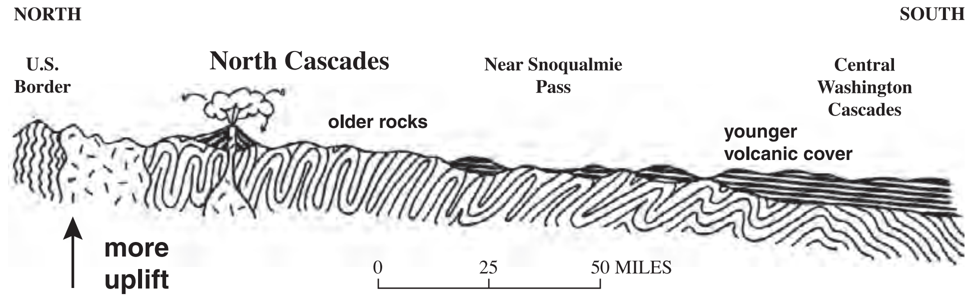

Figure 10. Sketch showing a north-south cross section of the Cascade Range in Washington. Erosion removed more of the volcanic deposits in the north than in the south, because uplift is greater in the north. Contact between volcanic deposits and underlying, folded older rocks is an angular unconformity.

1968), McGroder and others (1991), Riedell (1979), Staatz and others (1971), Tabor and others (1968), Tennyson (1974 plus written commun., 1990), Todd (1995a, 1995b plus written commun., 1990), and White (1986).

The northeastern third of the Twisp quadrangle represents new compilation based on extensive field work by R.A. Haugerud, J.B. Mahoney, and R.W. Tabor, mostly in 1993–96. Quaternary deposits in this area were largely interpreted by Haugerud from aerial photographs and published 1:24,000-scale topography.

Ongoing work by R.B. Miller, his students, and their collaborators, mostly in the southern part of the map area, continues to improve our understanding of Cascade geology. We include some of their new ages for metamorphic rocks.

We also incorporate some of the continuing work of C.A. Hopson (written commun., 2005; Hopson and Mattinson, 1994) along the southwest margin of the Twisp quadrangle (fig. 2, sheet 2) and in the Lake Chelan area of the Chelan quadrangle.

Locally, considerable large-scale geologic mapping was completed since publication of the 1:100,000-scale quadrangles, in particular at 1:24,000 scale near and west of Darrington by J.D. Dragovich and his colleagues with the Washington Division of Geology and Earth Resources. We did not compile directly from this new mapping, but we mention specific areas where their maps differ from our compilation; little of this new detailed data effects this 1:200,000-scale compilation.

Acknowledgments

For a project this big and inclusive that has taken a long time to complete, we must acknowledge that, although we continually tried to keep up with new work and ideas, our pursuit has been imperfect. We greatly appreciate the help of reviewers, blessed in current information, and their discussions: Joe Dragovich, Robert Miller, and Richard Waitt. Richard Waitt, in particular, vigorously improved our syntax. Clifford Hopson and Brian Mahoney provided unpublished map data and critical information for the Twisp quadrangle. Jon Riedel contributed to our understanding of the Cordilleran Ice Sheet extent and provided unpublished data.

Geology of the North Cascade Range

Geologic events recorded in the North Cascades include (fig. 6)

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; Haugerud and others, 1994), including an exception, the Swakane terrane, which was deposited and emplaced in the Late Cretaceous (Matzel and others, 2002);

2. middle to Late Cretaceous thickening by thrusting and pluton accumulation (Misch, 1966; McGroder, 1991; Brown and Walker, 1993; Haugerud and others, 1994; Miller and others, 2000; Matzel, 2004), accompanied by and followed by regional metamorphism;

3. Eocene strike-slip faulting, extensional faulting, rapid unroofing of deeply buried metamorphic rocks, basin development, and locally continued metamorphism and plutonism (Johnson, 1984, 1985; Brown, 1987; Miller and Bowring, 1990; Haugerud and others, 1991; Miller, 1994; Valley and others, 2003);

4. growth of the Cascade Magmatic Arc (fig. 3, sheet 2) in Oligocene to Holocene time (Vance and others, 1987; Smith, 1993; Tabor and others, 1989); and

5. Quaternary glacial erosion, drainage derangement, and deposition of glacially derived sediments (Booth, 1987; Booth and Goldstein, 1994; Waitt and Thorson, 1983; Riedel and others, 2007).

Brown and Dragovich (2003) present a useful summary of the tectonic elements and their kinematic history.

Major Faults

From west to east, five major faults or fault zones (fig. 4, sheet 2) define the structural framework of North Cascades geology: the Darrington-Devils Mountain Fault Zone, the Straight Creek Fault, the Entiat Fault, the Ross Lake Fault Zone (Ross Lake Fault System of Miller, 1994), and the Pasayten Fault. The blocks between these faults are clearly defined, but Tertiary cover obscures much of the older terranes in the southwestern part of the North Cascades; the exact history and even the identification of the Straight Creek Fault, the younger(?) Darrington-Devils Mountain Fault Zone, and the structural blocks and or terranes they define are uncertain. Similar uncertainty surrounds the south ends of the Ross Lake and Pasayten Faults where the distinction between the Chelan and Okanogan blocks is obscure (Hopson and Mattinson, 1994; Tabor and Haugerud, in press).

Darrington-Devils Mountain Fault Zone

The Darrington-Devils Mountain Fault Zone (DDMFZ) separates the thrust-faulted stack of Mesozoic and Paleozoic terranes, the Northwest Cascade System, from a second stack of thrust-joined mélange terranes, the western and eastern mélange belts and the Helena-Haystack mélange (Tabor and others, 1993, 2002; Tabor, 1994). The northwestern part of the DDMFZ appears to remain seismically active (Zollweg and Johnson, 1989; Johnson and others, 2001; Dragovich and others, 2003a,b, 2004; Dragovich and DeOme, 2006).

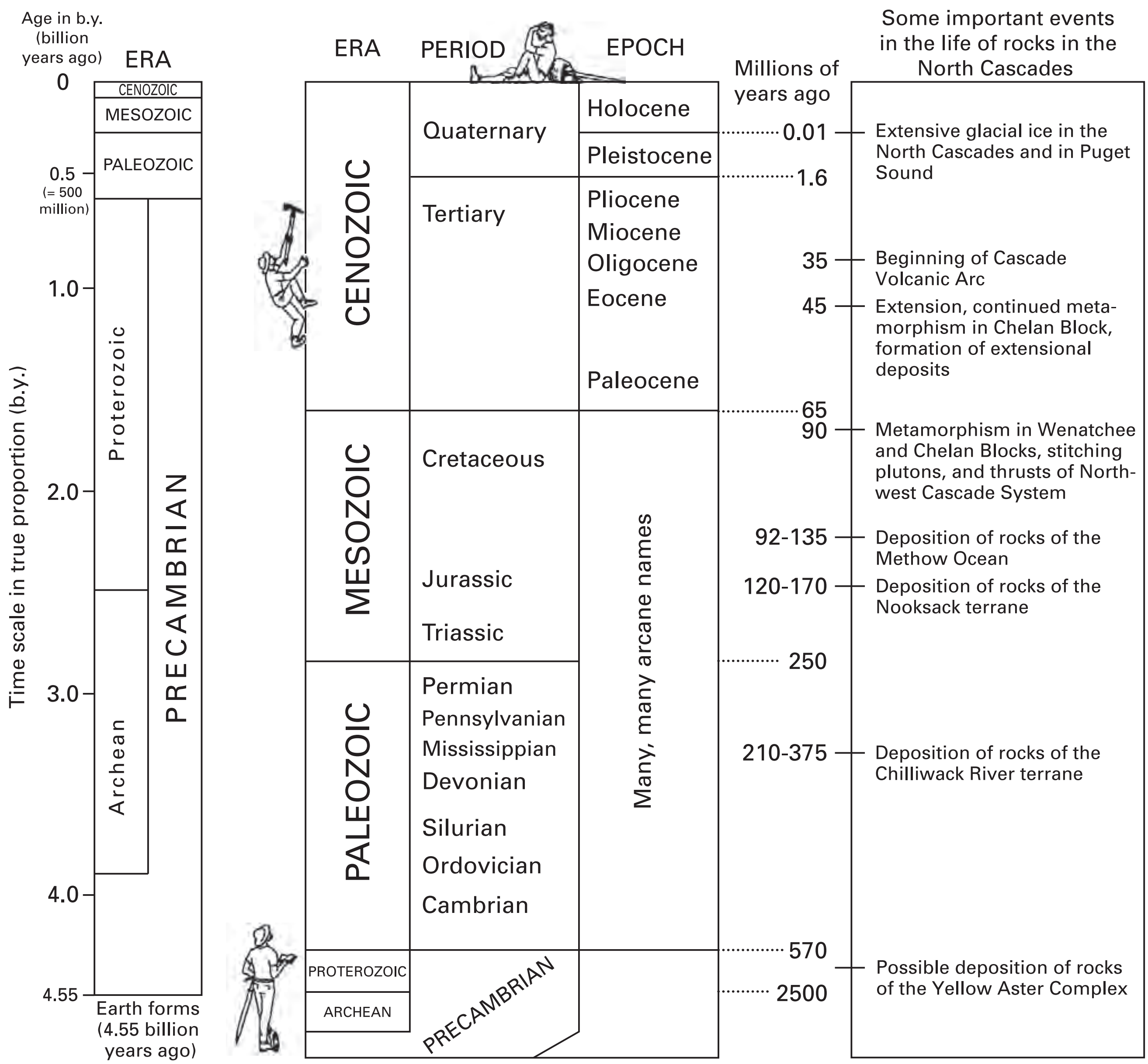

Figure 6. Geologic time scales relative to some geologic events in North Cascades, Washington.

Straight Creek Fault

The Straight Creek Fault [MB, SR] and its northern continuation, the Fraser Fault, extend 500 km from British Columbia to central Washington, where it meets the DDMFZ and (or) disappears under Tertiary cover. Tertiary arc plutons obliterate parts of the Straight Creek Fault in Washington and southernmost British Columbia, but in the northern part of the map area the fault clearly separates low-grade metamorphic rocks of the Northwest Cascade System of Brown and others (1987) on the west from highly metamorphosed rocks in the Wenatchee and Chelan blocks on the east. Estimates of right-lateral strike slip on the Straight Creek Fault range from about 90 to 190 km (Misch, 1977a; Vance and Miller, 1981, 1992; Vance, 1985; Monger, 1985; Kleinspehn, 1985; Coleman and Parrish, 1991; McGroder, 1991; Miller, 1994).

Ross Lake Fault Zone

The Ross Lake Fault Zone mostly separates highly metamorphosed rocks of the Chelan block from unmetamorphosed rocks of the Methow block. Kriens (1988) and Kriens and Wernicke (1990a,b) suggest 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 metamorphic core to the unmetamorphosed marine and terrestrial fore-arc deposits of the Methow block to the east. However, Miller and Bowring (1990) describe structural evidence for an early period of strike slip on the Ross Lake Fault, and Haugerud (1985) and Miller and others (1994) describe the strong discontinuity in metamorphic grade and metamorphic history across the zone. In general, rocks in the metamorphic core of the range were uplifted 15–25 km relative to rocks on either side. Nevertheless, Miller and others (1994) and Dragovich and others (1997) describe rocks of the Methow block that were locally metamorphosed with the core rocks. The history of the Ross Lake Fault Zone is complex.

Pasayten Fault

The Pasayten Fault also has an enigmatic history. For much of its mapped trace, it clearly separates unmetamorphosed Mesozoic strata of the Methow block on the west from deep-seated metamorphic and intrusive rocks of the Okanogan block. Long recognized as a major regional structure, the Pasayten Fault was interpreted as a significant dextral plate-bounding fault (Davis and others, 1978; Hamilton, 1978), an Early Cretaceous sinistral strike-slip fault (Greig, 1989; Hurlow, 1993), and a large-displacement Late Cretaceous dextral strike-slip fault (Wynne and others, 1995). At its north end in Washington, the fault is clearly composite, including a younger segment that offsets Eocene volcanic rocks (R.A. Haugerud and R.W. Tabor, unpub. field maps).

South of lat 48°30' N. near Twisp, the Pasayten Fault appears to end. Farther south, the Vinegar Fault [Tse] (figs. 4 and 5) juxtaposes strongly contrasting rock units and is associated with significant mylonite and cataclasite. Poor exposure and complex geology in the intervening area make interpretations uncertain, but any probable fault has pre-Late Jurassic Okanogan gneiss and Jurassic Methow plutons on both sides, arguing against large displacement (Tabor and Haugerud, in press).

Geologic Map Units

Orogenic And Pre-Orogenic Rocks Mostly West of the Straight Creek Fault

Rocks southwest of and in the Darrington-Devils Mountain Fault Zone (DDMFZ)

Blocks between the major fault zones comprise numerous terranes. Southwest of the DDMFZ, the eastern mélange belt (unit TKeb; including the Trafton terrane of Whetten and others, 1988), which contains oceanic marine and mafic volcanic components ranging from Mississippian to Early Jurassic in age, is in thrust contact with the western mélange belt (unit TKwb) of mostly marine sedimentary rocks ranging from Late Jurassic to Early Cretaceous in age (fig. 5). Both belts contain Permian olistostromal marble; some marble in the western belt is as old as Pennsylvanian. And both belts contain meta-ultramafic rocks, weakly metamorphosed gabbro, diorite, tonalite, and migmatite (unit TKebg). A metatonalite block in the Trafton yields a Pennsylvanian U-Pb age (Whetten and others, 1980). The mélange belts contain metamorphic prehnite and pumpellyite but no high-pressure minerals except aragonite(?), which occurs in veins.

In the map area, the DDMFZ is mostly coincident with the Helena-Haystack mélange (units TKhm, TKhg), which contains pieces of both the eastern mélange belt and rocks of the Northwest Cascade System, as well as exotic metavolcanic blocks derived from an arc. West of the map area, Dragovich and others (1999a,b) mapped klippe of the Helena-Haystack mélange over rocks of the Easton Metamorphic Suite far north of the Devils Mountain Fault (the main continuation of the DDMFZ). Tabor (1994) and Tabor and others (2002) proposed that the mélange belts were thrust over rocks of the Northwest Cascade System in the Late Cretaceous to early Eocene prior to probable late Eocene faulting along the DDMFZ.

We include the Lookout Mountain Formation of Stout (1964) [SPse] in the western mélange belt. It is mostly mica schist and amphibolite; its probable pre-Middle Jurassic protolith age discussed by Tabor and others (2000) is older than most of the sedimentary components in the western mélange belt. The Lookout Mountain Formation crops out at the south end of the North Cascades, where extensive Tertiary cover and poorly understood faulting make correlation difficult. The unit is intruded by the slightly metamorphosed Quartz Mountain stock, which yields Middle Jurassic U-Pb ages (Miller and others, 1993; MacDonald, 2006). Miller (1989) and, more recently, Cowan (2003) discussed regional correlations of parts of the western mélange belt.

Rocks Northeast of the Darrington-Devils Mountain Fault Zone

Northwest Cascade System

Northeast of the DDMFZ, rocks of the Northwest Cascade System are exposed in a well-developed regional thrust stratigraphy (fig. 11). Three nappes (fig. 5) that rest on a probable autochthonous basement are, from structurally highest to lowest (Misch, 1966; Brown and others, 1987; Tabor, 1994; Tabor and others, 2003), (1) the Shuksan Nappe [MB, SR] made up of the Easton terrane composed largely of the Easton Metamorphic Suite, (2) the Welker Peak Nappe [MB] composed of the Bell Pass mélange, and (3) the Excelsior Nappe made of the Chilliwack River terrane composed of the Chilliwack Group of Cairnes (1944) and the Cultus Formation of Brown and others (1987). The autochthon is the Nooksack Formation [MBnw] including the Wells Creek Volcanic Member.

Convincing correlations of nappes in the North Cascades with nappes in the San Juan Islands (fig 1; Brown and Dragovich, 2003) demonstrate the wide extent of the Northwest Cascade System. Based on Ar-Ar dating of minerals that they related to overthrust structures in the San Juan Islands, Brown and Lapen (2003) suggested that thrusting took place 125 m.y. ago (mid-Cretaceous). More recent study of detrital zircon ages from nappes of the Northwest Cascade System indicate thrusting is younger than 110–114 Ma (Brown and Gehrels, 2007; Brown and others, 2007).

Some workers (Brown, 1987; Dragovich and others, 1999a,b) included the Helena-Haystack mélange and the mélange belts in the Northwest Cascade System, but we exclude these units because they generally lack high-pressure minerals, except possible aragonite, and may have been emplaced on rocks of the Northwest Cascade System long after its nappes were in place in the mid-Cretaceous (Tabor, 1994; Tabor and Haugerud, in press).

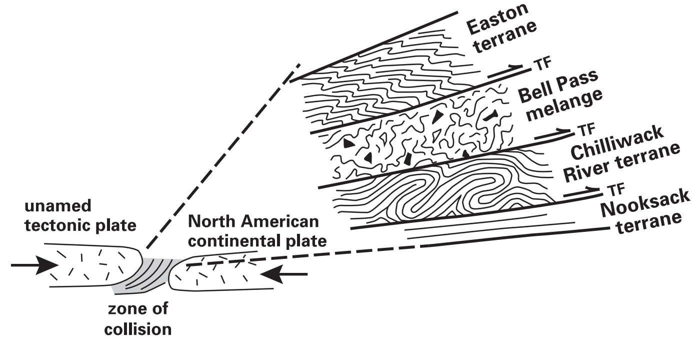

Figure 11. Sketch of cross section showing how terranes (nappes) became stacked in Northwest Cascade System along thrust faults (TF) during collision between tectonic plates. Half arrow (⟶) shows direction of movement along faults.

Shuksan Nappe

The Easton Metamorphic Suite, or the Easton terrane, includes the Shuksan Greenschist (unit Kes) and Darrington Phyllite (unit Ked). Shuksan Greenschist is a fine-grained but well-recrystallized metamorphic rock, commonly containing sodic amphiboles. Its oceanic-basalt protolith formed in the Middle and Late Jurassic and metamorphosed into greenschist and local blueschist in the Early Cretaceous (Brown, 1986). The Shuksan protolith was overlain by oceanic shale and sandstone that metamorphosed to the Darrington Phyllite. Most of the Darrington Phyllite is well-recrystallized, fine-grained, graphitic quartz-albite-muscovite schist, but it commonly cleaves along a secondary foliation coated with finer grained minerals and has a phyllitic appearance. Locally, it has albite porphyroblasts and well-developed lawsonite. West of the Baker River [MBsw], Tabor and others (2002, 2003) mapped extensive, partly recrystallized sandstone and minor shale (the semischist and phyllite of Mount Josephine [MBsw]), but we include these rocks in the Darrington Phyllite.

On the west edge of the map, south of the Skagit River between Iron Mountain [SRnw] and Gee Point, epidote amphibolite, barroisite schist, quartz-muscovite schist, hornblende-garnet rocks, and rare eclogite crop out in the Shuksan Greenschist. Most of these schists are considerably coarser grained than schist typical of the Shuksan Greenschist. The coarser grained rocks are especially abundant as blocks in the serpentinite matrix of the Helena-Haystack mélange near Iron Mountain, but they also occur as scarce isolated masses with rare serpentinite in the Shuksan Greenschist exposed east of Iron Mountain. Many of the hornblende-bearing, coarser grained rocks have an overprint of blueschist metamorphism (Brown and others, 1987. Brown (1986) suggests that amphibolite and barroisite schist were thermally metamorphosed when the original protolith basalt and oceanic sediments were overthrust by hot mantle rocks in a subduction zone, prior to the blueschist metamorphism that recrystallized the Easton in general.

We include the tonalite gneiss of Hicks Butte (unit Ket) [SPse] in the Easton terrane, because its metamorphic history seems intimately, if controversially, related to the Shuksan Greenschist (Miller and others, 1993; Tabor and others, 2002).

The Shuksan Nappe (fig. 5) overlies the Welker Peak Nappe along the Shuksan thrust.

Welker Peak Nappe

Much of the Bell Pass mélange (unit KJb), exposed in the Welker Peak Nappe (fig. 5), 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. Ultramafic rocks, various blocks of gneiss and schist, and granitoid rocks ranging from granite to gabbro in composition crop out in association with the Elbow Lake Formation. The largest outcrops of these exotics are mapped as the Twin Sisters Dunite of Ragan (1963) (unit KJts), the Vedder Complex of Armstrong and others (1983) (unit KJv), and the Yellow Aster Complex of Misch (1966) (unit KJya). Ages of radiolaria from chert blocks in the Elbow Lake Formation range from Pennsylvanian to Jurassic, but detrital zircon grains are as young as 110 m.y., indicating a Cretaceous component (Brown and Gehrels, 2007). Gneiss and schist of the Vedder Complex yield K-Ar and Rb-Sr ages that indicate Permian metamorphism. Individual detrital zircon grains from paragneiss in the Yellow Aster Complex are mostly older than 1,800 m.y., indicating erosion from a Proterozoic terrane (Brown and Gehrels, 2007). Zircons from orthogneiss in the complex yield middle Paleozoic ages. The Bell Pass mélange overlies the Excelsior Nappe along the Welker Peak thrust.

Excelsior Nappe

Chilliwack River terrane

The Chilliwack Group of Cairnes (1944) (unit PDc) is composed of weakly metamorphosed basaltic and andesitic volcanic rocks, sandstone, siltstone, shale, and minor limestone or marble that formed in an arc setting. The limey rock 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 subhorizontal. Lawsonite and aragonite are common metamorphic minerals but generally are very fine grained.

Triassic to Early Jurassic marine sedimentary rocks and dacitic volcanic rocks of the Cultus Formation of Brown and others (1987) (unit JTrc) depositionally overlie the Chilliwack Group.

The Chilliwack Group and Cultus Formation make up the Chilliwack River terrane. The Excelsior Nappe contains significant internal thrusts; rocks of the Chilliwack Group and Cultus Formation are regionally overturned and have penetrative fabrics in most locales, suggesting a pre-mid-Cretaceous, possibly pre-Late Jurassic, tectonic event not seen in the underlying Nooksack Formation.

Rocks of Autochthon

At the bottom of the exposed stack of nappes, beneath the Excelsior Ridge thrust, the Middle Jurassic-Early Cretaceous Nooksack Formation (unit KJn) consists of marine clastic rocks that overlie and interfinger stratigraphically with the Middle Jurassic Wells Creek Volcanic Member (unit Jnw). Sondergaard (1979) considered the Nooksack Formation to be a submarine fan deposit associated with a volcanic arc. The Nooksack Formation is generally not strongly penetratively deformed or recrystallized, although in many areas it has slaty cleavage and has been partially recrystallized in subgreenschist facies (Tabor and others, 2003). We consider the Nooksack Formation to be autochthonous, but the base of the Wells Creek Volcanic Member is not exposed, leaving the possibility that this autochthon is yet another nappe as Misch (1966) suggested.

Orogenic and Pre-Orogenic Rocks East of the Straight Creek Fault

Rocks Unique to the Wenatchee block

Ingalls Terrane

A large part of the Jurassic Ingalls terrane (units Jis, Jbi, Jbs), also known as the Ingalls Tectonic Complex (Tabor and others, 1982), Ingalls ophiolite, or Ingalls Ophiolite Complex (Metzger and others, 2002; Harper and others, 2003; MacDonald and others, 2005: MacDonald, 2006), is ultramafic rock, in part, lherzolite and harzburgite formed in an oceanic fracture zone (Miller and Mogk, 1987) and sheared serpentinite derived from the mantle rocks. Harper and others (2003) also describe Early Jurassic metasedimentary and metavolcanic rocks, schist of DeRoux Creek of Miller (1985), and sea-mount basalt on Iron Peak [Wnw], as well as Late Jurassic oceanic basalt. Most major components of the Ingalls terrane are separated by faults; serpentinized ultramafic rock surrounds tectonically mixed sandstone and argillite, radiolarian chert, pillow basalt, and ultramafic rock throughout much of the terrane (Southwick, 1974; Miller, 1985). Miller (1985), Whetten and others (1980), and Vance and others (1980) describe tectonic emplacement of the Ingalls terrane over higher grade metamorphic rocks of the North Cascade crystalline core (our Nason terrane) along the Windy Pass Thrust.

Some geologists (Brandon, 1989) consider the Ingalls terrane to be another nappe of the Northwest Cascade System, an interpretation supported by relations in the San Juan Islands west of the North Cascades (fig. 1), where the Fidalgo Complex has been correlated with the Ingalls terrane and overlies rocks of the Northwest Cascade System. Garver (1988) proposes that the Fidalgo Complex is part of the exotic Decatur terrane that correlates with the Coast Range ophiolite and Great Valley sequence of California. A recent geochemical study of the volcanic components of the Ingalls terrane by Metzger and others (2002) and MacDonald (2006) suggests that the Ingalls terrane was formed in a back-arc setting and correlates more closely with the Klamath terrane to the south, such as the Josephine ophiolite of southern Oregon and northern California. Based on lithologic and geochemical differences, Miller and others (1993, 2003), MacDonald and others (2003), Harper and others (2003), and MacDonald (2006) consider the schist of DeRoux Creek of Miller (1985), mapped as unit Jbs on the south side of the Ingalls terrane, to be unrelated to the Ingalls igneous and metamorphic mélange but still a component of the Klamath terrane. In contrast, Brown and Dragovich (2003) correlate the schist of De Roux Creek of Miller (1985) with the western mélange belt and believe it was thrust over the Ingalls terrane.

Nason Terrane

The Nason terrane (fig. 5) is composed predominantly of the Chiwaukum Schist (unit Kncs) that is largely aluminum silicate mineral-bearing metapelite, as well as some metasandstone, metabasite, and minor metaperidotite. The protolith of the Chiwaukum Schist was predominantly marine clastic strata with minor oceanic basalt, perhaps deposited in a distal arc setting (Magloughlin and Edwards, 1993). The protolith age of the Chiwaukum Schist has been uncertain; it has long been considered equivalent to the Settler Schist of Lowes (1972), offset from the Chiwaukum Schist along the Straight Creek Fault in Canada. The protolith of the Settler Schist may be Late Jurassic to early Cretaceous based on correlation with the Cayoosh Assemblage of Mahoney and Journeay (1993) in British Columbia (Monger and Journeay, 1994). More recently Brown and Gehrels (2007) have determined U-Pb ages of detrital zircons from the Tonga Formation of Yeats (1958), a less metamorphosed correlative of the Chiwaukum Schist (Duggan and Brown, 1994), and their analyses indicate that the protolith age of the unit is no older than 125 m.y. (Early Cretaceous). The Nason Ridge Migmatitic Gneiss (unit Knmg) evolved from the Chiwaukum Schist by more advanced recrystallization and probable igneous injection. In its age and mode of formation, the Nason Ridge Migmatitic Gneiss is analogous to terrane-overlap units in the Chelan block to the northeast.

Rocks in the Wenatchee and Chelan Blocks

Terrane Uncertain

The Chelan Migmatite Complex of Hopson and Mattinson (1994) (unit Kcxm) is predominantly metaplutonic mafic migmatite derived from Early Cretaceous tonalitic intrusive material. Hopson (1955), Hopson and Mattinson (1971), and Tabor and others (1987a) called much of this unit the Chelan Complex, but Hopson and Mattinson (1994) excluded migmatitic rocks rich in country rock remnants, repatriating them to their protolith units, namely the Cascade River Schist (amphibolite and schist of Twentyfive Mile Creek of Tabor and others, 1987a) and the metamorphosed Triassic Marblemount plutons (Dumbell plutons of Cater and Wright, 1967).

Chelan Mountains Terrane

The Chelan Mountains terrane (fig. 5) includes the Napeequa Schist (units TKns, Kns), the Cascade River Schist (units TKcs, Kcs), and the Marblemount plutons (units TKmd, Kmd). The Napeequa Schist is mostly fine-grained hornblende-mica schist. Micaceous quartzite and schistose amphibolite derived from a protolith of oceanic chert and basalt are prominent. Minor marble and small bodies of metamorphosed ultramafic rock are also characteristic. Typical of Napeequa Schist elsewhere, well-layered gneiss that is locally migmatitic but also rich in fine-grained hornblendic schist is included in the Napeequa Schist, which was mapped previously by Tabor and others (2002) as banded gneiss associated with the tonalitic gneiss of Bench Lake.

The 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. Clasts of the Marblemount plutons are prominent in the metaconglomerate, indicating that the Cascade River Schist protolith was deposited on or near eroded Marblemount plutons. Minor constituents of the Cascade River Schist are silicic schist (metatuff), marble, and amphibolite. U-Pb analysis of zircons from a dacitic metatuff yielded an age of about 220 Ma (Late Triassic). In the Holden area [Tsw], metasedimentary and metavolcanic rocks, on strike with and almost continuous with the Cascade River Schist and the Napeequa Schist exposed in the Chelan terrane to the northwest, have some components unlike either the Cascade River Schist or the Napeequa Schist; we concur with Miller and others (1994) and correlate the schist around Holden with the Cascade River Schist. Based on the above discussion, re-evaluation of the lithologies, and discussion with C.A. Hopson (written commun., 2005), we correlate the rocks of Twentyfive Mile Creek, on strike farther to the southeast, with the Cascade River Schist as well, although they were once correlated with the Napeequa Schist (Tabor and others, 1987a).

Although the overall lithologies of the Napeequa Schist and Cascade River Schist are generally distinct and suggest disparate depositional settings, the two units are locally thoroughly imbricated or interfolded and may not be mappable as separate terrane units. We consider the Napeequa Schist to be a part of the Chelan Mountains terrane; for a discussion of this problem see Miller and others (1994).

The Marblemount plutons form the Marblemount-Dumbell plutonic belt (fig. 7, sheet 2) that extends about 70 km southeast from the Straight Creek Fault in the Mount Baker quadrangle. The crystallization age of the Marblemount pluton protolith is also 220 Ma, which is similar to the depositional age of the Cascade River Schist. The similar ages suggest deposition of the Cascade River Schist protolith in a forearc or intra-arc basin, where intrusion of arc-root plutons was followed by rapid unroofing and further deposition of arc volcanic rocks.

The Magic Mountain Gneiss (unit TKmm) overlying the Cascade River Schist is an unusually well layered rock of low-grade mafic schist, metaconglomerate, and metatonalite sills. It appears to be a thick, metamorphosed lit-par-lit complex of Marblemount sills in the Cascade River Schist (Dougan and Brown, 1991; Dougan, 1993; Allen, 2002; Allen and Schermer, 2002). For further discussion of the origin of this rock, see Allen (2002) and Tabor and others (2003).

Terrane Overlap Units and Stitching Plutons

During Late Cretaceous and earliest Tertiary metamorphism, most of the units between the Pasayten and Straight Creek Faults were invaded by large tonalite to granodiorite plutons. Plutons in the metamorphic core of the range were deep seated and synmetamorphic. Isotopic ages of these plutons suggest intrusion from about 96 to 50 m.y. (Michels and others, 2007). Plutons in the Methow block were more shallowly emplaced and appear to be entirely early Late Cretaceous (~90 m.y.). In the Sauk River quadrangle, Tabor and others (2002) divided the synmetamorphic plutons into a tonalitic group and a granodioritic group based on modal and normative mineralogy and $\delta^{18}O$ values. Both igneous and metamorphic features characterize most plutons in the tonalitic group;

analysed plutons have $\delta^{18}O$ values less than 10 (White and others, 1986). The granodioritic plutons commonly contain muscovite, have fewer relict textures and structures revealing their probable igneous origin, and have $\delta^{18}O$ values greater than 10 (White and others, 1986). Granodioritic plutons also contain zircons with discordant ages, suggesting inherited lead. All granodioritic plutons are in the Napeequa Schist. Plutons of both groups lack static thermal aureoles and are generally elongate parallel to the regional foliation.

We assigned many plutons to these two groups based on their mineralogy alone, but further chemical and isotopic analyses are needed to validate the assignments. We used evidence of apparent Tertiary metamorphism (fig. 4) to further subdivide the tonalitic group into tonalitic orthogneiss (unit TKto) and tonalite plutons (unit Kt). Similarly, the granodioritic group is mapped as granodioritic orthogneiss (unit TKgo) and granodioritic plutons (unit Kg).

In the Mount Baker quadrangle (Tabor and others, 2003) and part of the Twisp quadrangle, the division between tonalitic plutons and granodioritic plutons is not well established. The tonalitic group (units TKto, Kt) probably contains the orthogneisses of Haystack Creek, Marble Creek, and Mount Triumph [MBse]. The granodioritic group (units TKgo, Kg) definitely includes the Hidden Lake stock and probably contains the orthogneiss of Alma Creek pluton. We also include the Eldorado Orthogneiss in the granodioritic group because of its composition, although it has much in common with the tonalitic group. Elsewhere, we include the light-colored gneiss of the Mad River terrane (Napeequa Schist) for its granodioritic composition and predominantly Late Cretaceous but discordant zircon ages. However, Miller and others (2000) and Miller and Patterson (2001a,b) include this gneiss in their sheeted-dike phase of the Entiat pluton, which we include in the tonalitic group. The Excelsior pluton and the Mount Stuart and Black Peak batholiths and associated plutons appear to be in the tonalite group.

Migmatite of the Chelan Migmatite Complex of Hopson and Mattinson (1994) surrounds several large masses of tonalite to granodiorite (unit Kt) that, unlike other stitching plutons of the North Cascades, appear to have gradual and diffuse contacts with adjoining older rocks. Previous workers (Hopson, 1955; Hopson and Mattinson, 1971; Mattinson, 1972; Tabor and others, 1987a) included these bodies and the Entiat pluton and associated granodiorite plutons within the Chelan Complex of Hopson and Mattinson (1971), but we include them with the stitching plutons, a designation confirmed by more recent mapping (Hopson and Mattinson, 1994; Miller and Patterson, 2001a) and U-Pb zircon ages (Matzel, 2004).

Dawes (1993, 1996) studied the chemistry of several stitching plutons and concluded that the Tenpeak and Chaval plutons of the tonalitic group were derived from "mantle-derived, subduction-related basaltic magmas" formed in the lower and middle crust. He feels that the Sulphur Mountain, Bench Lake, and Downey Creek plutons of the granodioritic group, however, are composed of lower crustal melt derived from "plagioclase- and lithic-rich graywacke," altered basalts, or both. Dawes noted their similarity to Archean plutons of the craton but considered their common chemical signature to be process related. Tabor and others (2002) suggested that magmas of the granodioritic group may have assimilated material from ancient rocks underlying the Chelan Mountains terrane, presumably the Swakane Biotite Gneiss of the Swakane terrane. Considering that the Swakane Biotite Gneiss may be younger than the plutons (Matzel, 2004), this suggestion is probably wrong, though the inference of assimilated older crustal material may still be valid.

We include the Skagit Gneiss Complex (unit TKsg) with the stitching plutons because it consists mainly of Late Cretaceous orthogneiss bodies, although it also contains considerable metamorphosed supracrustal material derived from rock units of the Chelan Mountains terrane. Most of the large orthogneiss bodies (unit TKso) included with the Skagit Gneiss Complex are tonalitic, and tonalitic pegmatitic dikes are common throughout the unit. Dikes and irregular bodies of middle Eocene granitic and granodioritic orthogneiss also permeate the complex. From the area of the Stehekin River [Tnw] southeast to about Railroad Creek [Tsw], the contact between complex and locally migmatitic orthogneiss bodies (unit TKso) and orthogneiss sills separated by septa of paragneiss (unit TKsg) is located on the basis of our reconnaissance studies and those of Miller and others (1994) and Dragovich and Norman (1995). Mapped separately, the orthogneiss of The Needle (unit TKsn) is a probable Late Triassic tonalitic pluton similar to the Marblemount plutons but thoroughly metamorphosed in the Late Cretaceous through Eocene Skagit event. By analogy, the Nason Ridge Migmatic Gneiss could also be considered a stitching pluton, but we described it separately.

Swakane Terrane

The Swakane Biotite Gneiss (unit Kswg) is the sole component of the Swakane terran (fig. 5). It is notable for its uniformity in structure and lithology. Early isotopic and geochemical studies indicated its derivation from either a Precambrian dacitic volcanic accumulation (Mattinson, 1972; Cater, 1982; Tabor and others, 1987a,b) or a younger detrital rock derived from Early Proterozoic and younger source terranes (Waters, 1932; Cater, 1982; Rasbury and Walker, 1992; Whitney and others, 1999). Recent work (Matzel, 2004) identifies the Swakane protolith as Late Cretaceous and postulates that it was emplaced beneath the Napeequa Schist of the Chelan Mountains terrane along a regional thrust. The Swakane was likely exhumed by Eocene extensional faulting.

Rocks Unique to the Ross Lake Fault Zone

The protolith of a small intrusion of tonalite orthogneiss (unit TKmo) on Elija Ridge [RMsw] intruded rocks of the Pasayten Group of Kiessling and Mahoney (1997) prior to metamorphism of both. A U-Pb zircon age of 103 Ma (Albian; S. Bowring, written commun., 1993) for this body seems anomalous, because it intrudes metaconglomerate that we correlate with the Virginian Ridge Formation of probable Turonian age (93.5–99.6 m.y.), preserved farther east in the Methow block.

A zone of igneous intrusions parallels faults in the Ross Lake Fault Zone (fig. 5) from west of Ross Lake [MB] to Granite Creek [RMsw]. Misch (1966) called this the Ruby Creek Heterogeneous Plutonic Belt (unit TKrb) [RMsw] and its significance has been much debated (Haugerud and others, 1994). The country rock invaded by the plutons appears to be phyllite and schist of Little Jack Mountain of Tabor and others (2003) that we include in the metamorphosed rocks of the Methow block. Most of the igneous bodies in the belt are tonalite or granite. The tonalites resemble the tonalitic stitching plutons, in particular the Black Peak batholith, and the granite resembles the Golden Horn batholith. A U-Pb zircon age from a single light-colored tonalite body is 48 Ma. We include the Skymo Complex of Wallace (1976) (unit TKsx) in the Ruby Creek Belt. The Skymo unit is a mafic igneous complex with a probable polymetamorphic history including granulite-facies metamorphism (Wallace, 1976; Baldwin and others, 1997).

Metamorphosed rocks of Methow Ocean (units TKm, Km) include various rock types (fig. 18). Metaconglomerate, mostly rich in quartzose clasts; pyroxene metaporphyry; hornblende schist; metamorphosed siltstone; weakly metamorphosed gabbro; and rare mica schist in the vicinity of Easy Pass [RMsw] correlate with the Virginian Ridge Formation and mafic intrusive rocks within it. Correlation of the phyllite and schist of Little Jack Mountain (Tabor and others, 2003) with rocks of the Methow block is less certain, but the Little Jack

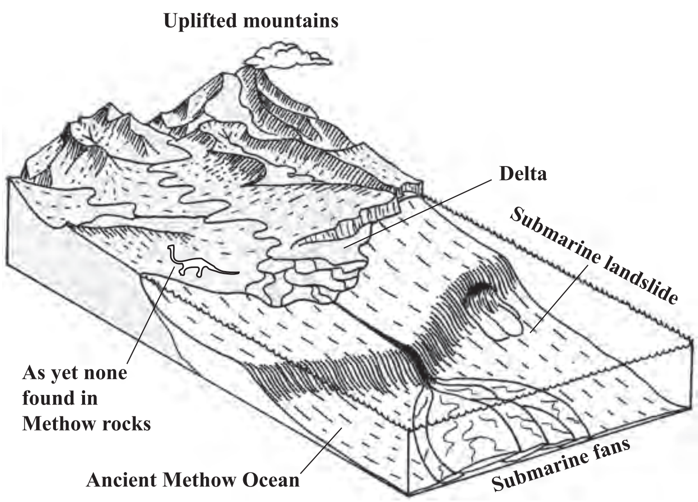

Figure 18. Sketch showing Cretaceous setting for accumulation of sediments that became rocks of Methow Ocean and younger deposits (after a drawing by David G. Howell).

rocks appear to grade into less metamorphosed rocks of the Three Fools sequence southeast of Crater Mountain [RMsw]. Ultramafic rocks in the Little Jack unit are not present in rocks of the Methow block. Haugerud and others (2002) suggest these ultramafic blocks slid into the Mesozoic Methow basin as its sediments were overthrust by the encroaching Hozomeen terrane in the Early Cretaceous.

Rocks in the Methow Block

Rocks of the Methow block (fig. 5) record a Jurassic and Cretaceous, mostly marine basin that became subaerial during the Late Cretaceous. We infer that the basin was floored by the Hozomeen Group (unit MzPzh) and island arc volcanic rocks of the Early to Middle Jurassic Ladner Group of Mahoney (1993) (unit Jl), near and north of lat 49° N., and the Late Jurassic Newby Group of Mahoney and others (2002) (unit Jnb), in the eastern and southern part of the Methow Block (figs. 4, 5). Thin Early Cretaceous shallow-marine and terrestrial strata are locally present. Mid-Cretaceous marine turbidites of the Three Fools sequence of Haugerud and others (2002) (unit Ktf) are thick and extensive. These deposits are overlain by mostly terrestrial deposits of the early Late Cretaceous Pasayten Group of Kiessling and Mahoney (1997) (units Kps, Kpv) and intruded by coeval tonalite stitching plutons (unit Kt). Mid-Cretaceous to Late Cretaceous (~105–90 Ma) east-vergent thrusting raised the Hozomeen floor of the basin at its west edge and depressed the central basin floor to provide a trap for plutonic detritus from the east and chert-rich debris from the west.

The Hozomeen Group (unit MzPzh) of the Hozomeen terrane comprises greenstone, chert, clastic sedimentary rocks, gabbro, limestone, and ultramafic rocks in Canada. Greenstones and associated marine sedimentary rocks (fig. 20, sheet 2) are exposed in a continuous north- to northwest-trending belt 132 km long, from Crater Mountain, near lat 48°45' N., to the Fraser River Fault in British Columbia. Chert and some limestone beds yield fossils ranging in age from Pennsylvanian to Late Jurassic. Ray (1986) thought that the ultramafic rock in British Columbia was derived from oceanic mantle and considered the Hozomeen to be a dismembered ophiolite with volcanic rocks that include both arc tholeiite and oceanic island-seamount subalkaline basalt. Haugerud (1985) showed that the uppermost greenstone unit of the Hozomeen Group had an alkali-basalt protolith that erupted as an intraplate seamount(s). Tabor and others (2003) discuss regional correlations.

South of lat 49º N., the Ladner Group of Mahoney (1993) (unit Jl) comprises sedimentary rocks rich in volcanic-arc debris. Farther north, in Manning Park, British Columbia, Coates (1974) and Mahoney (1993) describe proximal volcanic rocks in the Ladner.

Distinctly younger than the Ladner, the Newby Group of Mahoney and others (2002) (unit Jnb) comprises black argillite, volcanic sandstone, and extensive tuff and breccia, much of which is rhyolitic. Geochemistry indicates that the Newby Group has little or no contamination by older continental crust (Mahoney and others, 2002). Locally, the Newby Group recrystallized into the metamorphic rocks of McClure Mountain (unit Jnbm), schistose rocks with steep foliation cut by the undeformed 142 Ma Alder Creek stock (Mahoney and others, 2002). U-Pb zircon ages indicate that deposition of the Newby, intra-arc deformation, and postdeformation intrusion all took place over a span of about 16 m.y. in the Late Jurassic to earliest Cretaceous. Dragovich and others (1997) discuss the regional implications of Late Jurassic metamorphism. The Button Creek stock, the Alder Creek stock, and other small plutons, which were probably deeper parts of the Newby magmatic arc, are mapped as Early Cretaceous and Late Jurassic tonalitic intrusions (unit KJi).

Kriens (1988) and Kriens and Wernicke, (1990a,b) considered the Newby Group to be the protolith of the Napeequa Schist, but the Napeequa is clearly an older deep oceanic assemblage that contains little volcanic arc material.

The oldest undisputed rocks of the Methow Ocean, the older sedimentary rocks (unit KJos), are Early Cretaceous-Late Jurassic coarse clastic strata deposited in a shallow marine environment (Haugerud and others, 2002). Succeeding units of the mid-Cretaceous Three Fools sequence of Haugerud and others (2002) (unit Ktf; fig. 19, sheet 2) record a deep ocean gradually becoming shallow and mostly filled with sand and clay eroded from granitic terrain to the east (DeGraaff-Surpless and others, 2003). By the time sediments of the Pasayten Group of Kiessling and Mahoney (1997) (unit Ktf) were deposited, the ocean was essentially filled. Lowermost sedimentary rocks (unit Kps) of the Pasayten Group are rich in chert pebbles and other debris derived from the uplifted Hozomeen Group to the west. Higher in the section, coarsely crossbedded, east-derived, fluvial feldspathic sandstones predominate. Late Cretaceous volcanic rocks (unit Kpv) of the Pasayten Group are mostly andesitic breccia and tuff.

Tonalitic plutons (unit Kt) invaded the sedimentary and volcanic rocks of the Methow Ocean in the mid-Cretaceous. These plutons may have been magma chambers for the Late Cretaceous volcanic rocks in the Methow block. Presence of similar plutons in the Wenatchee block suggests that the Methow, Wenatchee, and intervening blocks were essentially adjacent to each other by about 95 Ma.

Rhyolite-rich conglomerate and sandstone of the Pipestone Canyon Formation (unit Kpc) are late Late Cretaceous in age (Peterson and others, 1997; Peterson, 1999). The tectonic setting during their deposition is unknown but may have been regional strike-slip faulting.

Rocks in the Okanogan Block

Okanogan Terrane

In the North Cascades, the defining geologic event for the Okanogan terrane was the intrusion of multiple plutons making up the Early Cretaceous Remmel batholith (unit Kor) and the older tonalite (unit Kot) bodies at about 110 Ma. Daly (1912) first named some of these rocks the Remmel batholith; later workers (Hawkins, 1964, 1968; Staatz and others, 1971; Todd, 1995) applied other names. We use Remmel batholith to emphasize the fundamentally igneous character of this unit. Older igneous bodies invaded by these plutons are Jurassic and Cretaceous mylonitic granodiorite, gneissic trondhjemite, and banded gneiss (unit KJog). Older units with supracrustal material intruded by the Remmel batholith and older tonalite are the Spanish Camp Gneiss of Hawkins (1964) (unit KJh), Ashnola gabbro of Daly (1912) (unit KJh) and the Leecher metamorphics of Barksdale (1975) (unit KJh). The Leecher is mostly metasedimentary and metavolcanic materials.

A younger episode of intrusion produced granite and granodiorite (unit Kog) of the 100 Ma Cathedral batholith of Daley (1912) and similar bodies. Tonalite of the Texas Creek stock (unit Ktd) appears to belong to a still younger intrusive suite, probably a stitching pluton.

Rocks of Late- and Post-orogenic Transtension

The North Cascades deformed transtensionally from Late Cretaceous to earliest Oligocene time through considerable strike slip along major faults, unroofing along extensional faults, extensional subsidence of local depositional basins, local compression, and ductile stretching at depth. This deformational pattern is particularly evident in thick sequences of middle and late Eocene sedimentary and volcanic strata that appear to have accumulated in local extensional(?) basins. We group these strata with coeval plutons as “Rocks of late- and post-orogenic transtension.” Throughout most of the map area, these transtensional features are superimposed on deep-seated Cretaceous metamorphism and deformation, but Eocene magmatism and deformation in the upper Skagit River region appear to be a continuation of deep-seated Cretaceous orogeny.

Extensional Deposits

The Raging River Formation (unit Trr) is not clearly related to this transtensional episode except for its age. Exposed near the west edge of the map area southwest of North Bend [SKsw], it consists of middle Eocene marine sandstone, shale, and conglomerate that is locally rich in chert clasts. These rocks are conformably overlain by terrestrial sandstone of the Puget Group, which clearly belongs to the extensional episode. Raging River rocks are the youngest and last evidence of marine deposition in the map area, although younger marine rocks crop out to the west.

Early extensional deposits (unit Tees, locally unit Tes) are mostly thick bedded fluvial feldspathic sandstone and conglomerate of the Swauk and Chuckanut Formations (fig. 13, sheet 2), deposited by streams in rapidly sinking, locally fault-bounded basins (Johnson, 1985). The Silver Pass Volcanic Member of the Swauk Formation (unit Teev) is interbedded with sandstone of the Swauk Formation and overlies it locally. Bimodal volcanic rocks, mostly basalt and rhyolite, interbedded with fluvial feldspathic sandstone unconformably overlie these older Eocene deposits in the southern part of the map area. Most of the extensional volcanic rocks (unit Tev) and extensional sedimentary rocks (unit Tes) are middle to upper Eocene in age. During this time plutons of granite and granodiorite intruded older rocks of the North Cascades. Granitic dikes in the deeply buried north end of the Chelan block have pronounced lineation parallel to the regional strike and record the transtensional episode (Haugerud and others, 1991). West of Lake Chelan [Tsw], large elongate granite to granodiorite plutons, such as the Duncan Hill and Railroad Creek plutons, are composed of lineated sills at their north ends (Dellinger, 1996). At its high-level south end, the Duncan Hill pluton grades into a swarm of strike-transverse dikes. The Cooper Mountain batholith, which grades into a complex dike-rich intrusive zone on its northwest side near South Navarre Peak [Tse], is presumably a high-level equivalent of the lineated sill swarm on the deep-seated north ends of the elongate Railroad Creek and Duncan Hill plutons of the same episode (Hopson and Mattinson, 1999). Some geologists (Ewing, 1980; Brown and Dragovich, 2003) have considered the Eocene intrusive rocks to be arc related and (or) the product of subduction-related melting. Cowan (2003) suggests that the Mt. Pilchuck stock and Bald Mountain batholith on the west side of the map area, east of Granite Falls [SRsw], are products of a subducted oceanic spreading center and correlate with similar peraluminous plutons on Vancouver Island, Canada, and in the Chugach-Prince William terrane of Alaska. Many of these volcanic rocks have been considered part of the Challis volcanic arc or episode (Armstrong, 1978; Heller and others, 1987; Haugerud and others, 1994; Brown and Dragovich, 2003) that extends across much of the northern Cordillera from north-central British Columbia to southern Idaho.

Flood Basalt and Associated Deposits

The huge flood basalt field of the Columbia Plateau underlies much of southeastern Washington and adjacent Oregon and Idaho. It extends into the map area as the Yakima Subgroup of the Columbia River Basalt Group. The Yakima Basalt Subgroup (Swanson and others, 1979) is divided into three formations: in ascending order, the Grande Ronde, Wanapum, and Saddle Mountains Basalts. Only the Grande Ronde (unit Tyg) and Wanapum (unit Tyw) Basalts occur within the map area (Swanson and others, 1982). K-Ar and paleontologic data (Swanson and others, 1979) indicate that the Grande Ronde Basalt is mostly or wholly late early Miocene (16.5–14 Ma) and the Wanapum Basalt is middle Miocene.

All of the basalt erupted from vents southeast of the North Cascades. Measurements of foreset bedding in lava deltas show that lava flowed to the west and northwest. Sedimentary rocks of the Ellensburg Formation are interbedded in the basalt. Northeast of the Kittitas Valley [Wse], the Ellensburg Formation is mostly micaceous feldspathic sandstone and siltstone, largely lacking in volcaniclastic material. In and southwest of the valley, it is dominantly tuffaceous sandstone, siltstone, and conglomerate that, in part, are lahar deposits (Swanson and others, 1982).

Rocks of the Cascade Magmatic Arc

Intrusive Rocks of the Arc

Eruptive rocks of the Cascade magmatic arc dominate the southern reaches of the North Cascade Range, reflecting lesser uplift of the southern part of the map area. In the northern part of the map area, erosion cut into plutons that fed the arc volcanoes (fig. 10; fig. 12, sheet 2). These plutons range from gabbro to alaskite in composition and from 32 to about 1 Ma in age. Tabor and others (1989) 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, 35–29 Ma; Snoqualmie family, 28–22 Ma; and Cascade Pass family, less than 20 Ma.

Although many of the larger plutons have been dated by K-Ar or U-Pb methods, many smaller plutons have not been dated. We placed undated plutons into intrusive families by their association with dated plutons on the assumption that they are satellites of the larger bodies, although we know in some cases that this assumption is incorrect. For instance, south of Snoqualmie Pass [SPne], the southern part of the Snoqualmie batholith is about 17 Ma and is in the Cascade Pass family of plutons, but a small stock (incorrectly called the Three Queens stock in table 2, Tabor and others, 2000) at Meadow Mountain [SPne] to the south is about 24 Ma and is in the Snoqualmie family. In the area between the southern part of the Snoqualmie batholith and the Carbon River stock (unit QTcp; southwest corner of map), we classified many small granitic bodies with the Cascade Pass family. Many of these small bodies intrude the 20–22 Ma Fifes Peak Formation (unit Tcaf), supporting the younger family assignment. To the east of this area, south and east of the Meadow Mountain stock, we classified the small intrusions in the Snoqualmie family (unit Tcas).

Volcanic Rocks of the Arc

The oldest rocks of the Cascade magmatic arc, the Oligocene volcanic rocks of the Ohanapecosh episode, consist mostly of colorful, highly altered, well-bedded andesite to dacite breccia, volcaniclastic sedimentary rocks, and locally abundant altered basalt and andesite flows. Relatively fresh basalt and andesite flows, breccias, subordinate rhyodacite ash-flow tuff and breccia, and volcanic sedimentary rocks of the early Miocene volcanic rocks of the Fifes Peak episode unconformably overlie rocks of the Ohanapecosh episode. In the southwestern part of the map area, most rocks of the Ohanapecosh and Fifes Peak episodes (units Tcao, Tcaf) are Ohanapecosh Formation and Fifes Peak Formations, respectively. North of the South Fork Snoqualmie River [SPnw], similar rocks of like ages are assigned to the aforenamed episodes, but we eschew correlation with the formally named formations to the south. Because of their early Oligocene age, we include the quartzose sandstone, minor paleosols, shale, and rare tuffs of the Wenatchee Formation in the Ohanapecosh episode despite their generally nonvolcanic character.

Most of the caldera deposits (unit QTcc) crop out in three eroded Pliocene-Pleistocene calderas (fig. 5): Kulshan caldera, northeast of Mount Baker [MBnw] (Hildreth, 1996; Hildreth and others, 2004), Hannegan caldera (fig. 12), and Gamma Ridge caldera (Tabor and others, 2002; Lanphere and Sisson, 2003). A recent study by Tucker (2004) and Tucker and others (2007) details the eruptive units and history of Hannegan caldera. A few Pliocene volcanic remnants included with this unit have not been studied enough to establish their caldera origin. Most are dacitic except for the basalt of Dalles Ridge.

Rocks of the young Cascade volcanoes (unit Qcav) include flows and breccias of Glacier Peak and Mount Baker (fig. 7 and fig. 8, sheet 2), a remnant of a flow from Mount Rainier that reached the south edge of the map in Huckleberry Creek [SPsw], and a few isolated patches of Pleistocene and (or) Holocene andesitic rocks.

Unconsolidated Deposits

Glacial and Nonglacial Deposits

The older gravel (unit QTog) is a disparate collection of weakly consolidated to unconsolidated deposits. All older gravel deposits are considerably eroded, leaving most of them as erosional remnants on ridge tops. Some of the deposits shown in the Wenatchee River drainage contain mostly angular clasts of volcanic rock similar to the volcanic rocks (unit Tcaf) at Sugarloaf Peak [Cse] and on Burch Mountain [Cse], suggesting debris flows from a highly eroded volcanic edifice deposited in valleys of a much older, probably Pliocene, drainage system (Waitt, 1987). Deposits southwest of Wenatchee [Wne], similar but rich in basalt clasts, are included in the older gravels.

Nonglacial and glacial sedimentary deposits older than Fraser Glaciation (unit Qpf) are locally exposed along the west side of the range.

Glacial Deposits

Alpine glacial deposits (unit Qag) floor most mountain valleys and veneer lower valley walls. These beds were deposited by local, alpine glaciers and consist of locally derived clasts. The stratigraphy of extensive alpine glacial deposits in the upper Yakima River valley [SPne] was studied in detail (Porter, 1976; Booth and Waitt, 2000). Most of this unit was probably deposited during the Evans Creek Stade of the Fraser Glaciation of Armstrong and others (1965), about 22,000–18,000 years ago, but a portion of the unit is younger. Over much of the map area, alpine glacial deposits are generalized and locally include other unconsolidated deposits.

The northern third of the North Cascades was overidden by the Cordilleran Ice Sheet (fig. 9, sheet 2) during the Vashon stade of the Fraser glaciation of Armstrong and others (1965), about 18,000–14,000 years ago. Some of the resulting deposits contain far-travelled debris and some do not. The same area was locally glaciated both prior to the Vashon stade (Evans Creek stade) and after the Vashon stade (Younger Dryas or younger). Throughout most of the northern third of the range, local alpine glacier deposits and deposits of the Cordilleran Ice Sheet have not been differentiated, and we map them as deposits of alpine glaciers and the Cordilleran Ice Sheet (unit Qga). These deposits are particularly evident in the main branches of the Pasayten River [RMnw] and the Ashnola River [RMne], in the area around Cathedral Peak [RMne], and in the upper reaches of Early Winters Creek [RMsw].

Upland deposits (unit Qud) occur mostly on the east side of the range. Loess is an important constituent and, in the southeastern part of the map area, makes up most of the deposit. Upland deposits are mapped without a solid contact to emphasize their gradual and indistinct boundaries.

Deposits of glacial outburst floods (unit Qgf) were emplaced by scores of catastrophic floods from glacial Lake Missoula. In the Columbia River valley, these deposits are commonly coarse gravels. The oldest and highest of these bedload flood deposits occur as much as 245 m above the present river. Near Leavenworth [Csw], fine-grained, slack-water flood deposits reach an elevation 250 m above the Columbia River at Wenatchee (Waitt, 1980, 1985).

Deposits of the Vashon stade of the Fraser glaciation of Armstrong and others (1965) consist of three units: advance outwash deposits (unit Qva), till (unit Qvt), and recessional outwash deposits (unit Qvr). On the west side of the map area these units were associated with the Puget lobe of the Cordilleran Ice Sheet (Booth and others, 2004). Similar but more limited deposits occur along the Methow River [Tse], where Cordilleran ice extended downvalley to the confluence with the Columbia River and beyond (fig. 9).

Nonglacial Deposits

Landslide deposits (unit QTl) include a wide range of rock types from catastrophic rock-fall avalanches to incipient block slides; the latter mostly occur in relatively strong rocks. Incipient block slides were recognized by deep fissuring in the rocks, generally above precipitous valley walls. Most landslides in the map area are postglacial, but some of the larger ones predate the last glaciation. The most extensive area of landsliding is along the edge of the Columbia River Basalt (units Tyw, Tyg) where weak interbeds failed beneath massive basalt flows, causing wide areas of collapse.

We distinguish broadly defined alluvium (unit Qu) from the deposits of flat-floored, mostly major valleys that we call alluvium of valley bottoms (unit Qa). Alluvium includes alluvial fans and other valley-side deposits that commonly have noticeable slopes. Alluvium of valley bottoms comprises the most recent flat-bedded sands and gravels of streams and rivers, as well as some slightly older terrace deposits that make up the valley floors. Because alluvium was mapped differently on many of the source maps, we reassigned it into these two units on the basis of topography in some quadrangles. There is a large conceptual overlap between these units.

Lahars (unit Qlh) fill valleys near Glacier Peak [SRse] and in parts of the White River [SPsw] that drain Mount Rainier, off the map to the south. In the drainages west of Glacier Peak, Dragovich and others (2002a) recognize three major events at about 11–13 ka, 5.1–5.4 ka, and 1.8 ka. Lahars are interbedded with alluvial-fan material on the east side of Mount Baker and probably are present under alluvium in other river valleys that head on Mount Baker.

Talus deposits (unit Qt) are prominent in all the alpine areas but are most widely mapped (from aerial photographs) in the Twisp and Robinson Mountain quadrangles where the drier climate has suppressed vegetation growth. Many of the previously mapped (Tabor and others, 1993, 2000, 2002, 2003) areas of alpine glacial deposits in the western part of the range probably include heavily vegetated talus.

DESCRIPTION OF MAP UNITS

[Age in parenthesis after unit name is age of assemblage or metamorphism for mélange and metamorphic units. The eight 1:100,000-scale quadrangles are outlined on the map, and quadrangle names and their abbreviations are labeled along the edges of the map, as well as on figures 1 and 5. Location codes in brackets that follow place names, unit names, geologic feature names, or unit descriptions may consist of a quadrangle abbreviation or a combination of quadrangle and quadrant abbreviations; for example, [MBnw] indicates a location in the northwest quadrant of the Mount Baker quadrangle]

UNCONSOLIDATED DEPOSITS

NONGLACIAL DEPOSITS

Qa **Alluvium of valley bottoms (Holocene and Pleistocene)**—Moderately sorted to well-sorted deposits of cobble gravel to sand along rivers and streams and local lacustrian deposits. Includes some older fluvial deposits in terraces above present rivers and streams. In Wenatchee River drainage [Wne], includes terrace gravels associated with alpine drift. Locally includes small side-stream fans and other unconsolidated deposits

Qu **Alluvium (Holocene and Pleistocene)**—Alluvium, colluvium, soil, steep alluvial fans, and landslide debris with indistinct morphology. Mapped where sufficiently continuous and thick to obscure underlying units

Qt **Talus deposits (Holocene and Pleistocene)**—Nonsorted angular gravel to boulder diamict. At lower elevations, gradational with unit Qu. 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

QTl **Landslide deposits (Holocene, Pleistocene, and Pliocene?)**—Diamict composed of angular clasts of bedrock and surficial deposits derived from upslope. Commonly unlabeled on map. Includes both transported material and unstable scarp area, if present. Older landslides are generally large and have somewhat subdued hilly topography. Includes older diamict southwest of Wenatchee [Wne] (Tabor and others, 1982)

Qlh **Lahars (Holocene and Pleistocene)**—Nonsorted muddy boulder diamict to moderately sorted or well-sorted sand and gravel. In drainages around Glacier Peak [SRse], contains distinctive clasts of pumice and volcanic rocks from Glacier Peak. For more details on distribution of lahars near Darrington [SRsw] and to the west, see Dragovich and others (2000a,b; 2002a,b, 2003a,b). In White River valley [SPsw] and adjacent lowlands at south edge of map, includes deposits of numerous Holocene mudflows from Mount Rainier volcano south of the map area (Tabor and others, 2000, 2002)

GLACIAL DEPOSITS

Qag **Alpine glacial deposits (Holocene and Pleistocene)**—Deposits ranging from boulder till in uplands and upper valleys 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. Includes older Pleistocene (pre-Vashon) deposits, especially in southern part of map area

Qga **Deposits of alpine glaciers and Cordilleran Ice Sheet (Holocene and Pleistocene)**—Deposits ranging from boulder till in uplands and upper valleys 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. Includes drift deposited by Cordilleran Ice Sheet that enveloped most of the range north of Glacier Peak [SRse] (fig. 9), drift deposited by coeval alpine glaciers that were confluent with north-derived Cordilleran ice, and deposits of older (pre-Vashon) and younger (latest Pleistocene and Holocene) discrete alpine glaciers in region overridden by Cordilleran ice. Areas of thin, sparse drift not distinguished from bedrock. May include unvegetated late Holocene moraine at higher elevations in central and northern part of map area

Deposits of Vashon stade of Fraser glaciation of Armstrong and others (1965) (Pleistocene)

Qvr **Recessional outwash deposits**—Stratified sand and gravel, moderately sorted to well-sorted and well-bedded silty sand to silty clay. Formed predominantly in outwash-plain and valley-train environments in lowland areas. South of North Bend [SKsw], includes morainal embankment and ice-marginal lake deposits elsewhere mapped as unit Qva (Tabor and others, 1993, 2000, 2002). In Darrington area, includes small areas of advance outwash deposits (Dragovich and others, 2002b)

Qvt **Till**—Mainly compact diamict with rounded and lesser subangular clasts, glacially transported and deposited. In ice-marginal areas or where covered by thin layer of recessional outwash, contact with unit Qvr is approximate. In Lake Chelan area, includes outwash deposits

Qva **Advance outwash deposits**—Well-bedded gravel, sand, and silt, generally firm and unoxidized. Deposited by streams and in lakes in front of the advancing glacier. Includes extensive, ice-marginal, morainal embankment and lake deposits in western valleys that were originally mapped as ice-contact deposits (Tabor and others, 1993, 2002)

Qud **Upland deposits (Holocene and Pleistocene)**—Mostly upland glacial deposits of Fraser glaciation age or older, but locally contains material elsewhere mapped as unit Qu. Most contacts approximately located or gradational with other unconsolidated deposits. Loess deposits in southeastern part of map (Tabor and others, 1987a)

Qgf **Deposits of glacial outburst floods (Pleistocene)**—Bedded silt, sand, and gravel in Wenatchee and Columbia River drainages [Cse, Wne] related to jökulhlaups along Columbia River (Waitt, 1980, 1985; Tabor and others, 1987a). Includes some bedded terrace deposits of nonflood origin

GLACIAL AND NONGLACIAL DEPOSITS

Qpf **Nonglacial and glacial sedimentary deposits older than Fraser glaciation (Pleistocene)**—Moderately to deeply weathered clay, stratified sand, and gravel of various depositional settings, as well as some pre-Fraser-glaciation alpine glacier deposits (Tabor and others, 1993)

QTog **Older gravel (Pleistocene, Pliocene, and Miocene?)**—Weakly cemented to uncemented boulder to pebble gravel, locally with tuffaceous interbeds. Includes diamict with angular volcanic clasts. Generally caps ridges or is deeply incised by modern drainage. Includes Thorp Gravel (Waitt, 1979) [Wsw], the conglomerate of Brays Landing of Waitt (1987) [Cse], the Summit Conglomerate of Page (1939) on Natapoc Mountain [Csw], debris-avalanche deposits of Wenatchee Heights [Wne], and cemented terrace gravel along Wenatchee River near Sunnyslope [Wne] (Tabor and others, 1982)

ROCKS OF CASCADE MAGMATIC ARC

Qcav **Rocks of young Cascade volcanoes (Holocene and Pleistocene)**—Broadly consists of active stratovolcanoes (Glacier Peak [SRse], Mount Baker [MBnw]; figs. 7, 8), older highly eroded volcanoes (Black Buttes [MBnw]), and scattered volcanic deposits erupted from independent vents (Table Mountain [MBnw], White Chuck Cinder Cone [SRse], Basalt of Canyon Creek [SPsw], and other small occurrences. Predominantly andesite but composition ranges from dacite to basalt (Tabor and others, 2002; Hildreth and others, 2003)

QTcc **Caldera deposits (Pleistocene, Pliocene, and Miocene)**—Caldera deposits, such as those from Kulshan (east of Mount Baker [MBnw]), Hannegan [MBnw], and Gamma Ridge [SRse] calderas (fig. 5); mostly dacite and rhyodacite tuff and breccia. Includes some isolated volcanic centers of andesite and basalt, which may not have been calderas (Tabor and others, 1996; Hildreth, 2003; Hildreth and others, 2004; Tucker and others, 2007)

QTcp **Intrusive rocks of Cascade Pass family (Pleistocene, Pliocene, and Miocene)**—Tonalite, granodiorite, and granite; rare gabbro. Includes intrusive breccias associated with plutons of this family. Includes parts of Chilliwack [MBne] and Snoqualmie [SPnw] batholiths, Cascade Pass dike [SRne], Carbon River stock, and minor intrusive bodies (Tabor and others, 1993, 2000, 2002, 2003). Youngest dated body is a small early Pleistocene stock (~1 m.y. or less; Hildreth and others, 2003) in Bar Creek [MBnw], associated with the Kulshan Caldera. [SRne]

Tcaf **Volcanic rocks of Fifes Peak episode (Miocene)**—Predominantly basaltic andesite and basalt flows and breccias, as well as rhyolitic ash-flow tuffs. Includes mapped Fifes Peak Formation [SP] and smaller accumulations such as breccia of Kyes Peak [SKne] and Eagle Tuff of Yeats (1977) [SKne]. Includes minor mafic intrusions (Tabor and others, 1993, 2000)

Tcas **Intrusive rocks of Snoqualmie family (Miocene and Oligocene)**—Tonalite, granodiorite, and granite; rare gabbro. Includes parts of Chilliwack, Cloudy Pass [SKse] (fig. 7, sheet 2), Grotto [SKse], and Snoqualmie batholiths and minor intrusive bodies. [MB, SK, SP, SR]

Tcao **Volcanic and sedimentary rocks of Ohanapecosh episode (Oligocene)**—Mostly basalt and andesite but ranges from basalt to rhyolite. Includes mapped Ohanapecosh Formation [SP] (Tabor and others, 2000) and deposits of isolated volcanic centers (Tabor and others, 2003), such as volcanic rocks of Mount Rahm, volcanic rocks of Big Bosom Buttes [MBnw], breccia of Round Lake [SRse], and minor hypabyssal intrusive rocks. Includes areas of numerous dikes and sills west of Wenatchee [Wne]. Also includes predominantly feldspathic sandstone of Wenatchee Formation and poorly consolidated unnamed sandstone and conglomerate north and northwest of Monroe [SKnw]

Tcai **Intrusive rocks of Index family (Oligocene)**—Tonalite, granodiorite, and granite; rare gabbro. Includes parts of Chilliwack batholith, Index batholith [SKnw], Squire Creek stock [SKsw], and minor intrusive bodies. [SKnw]

FLOOD BASALT AND ASSOCIATED DEPOSITS

Te **Ellensburg Formation (Miocene)**—Weakly indurated sandstone and minor conglomerate; feldspathic to volcanic rich. Includes volcanic tuff and breccia in southeast corner of map. Mostly interbedded with and overlying basalt of the Yakima Basalt Subgroup (Tabor and others, 1982, 1987a). [Wsw]

Yakima Basalt Subgroup of Columbia River Basalt Group (Miocene)

Tyw **Wanapum Basalt**—Fine- to medium-grained basalt flows with sparse olivine and plagioclase phenocrysts. Includes several members with reversed and transitional magnetic polarity (Tabor and others, 1982, 1987a). [W, C]

Tyg **Grand Ronde Basalt**—Fine- to medium-grained aphyric to slightly plagioclase porphyritic basalt flows. Includes several named flows with normal and reversed magnetic polarity (Tabor and others, 1982, 1987a). [W, C]

ROCKS OF LATE- AND POST-OROGENIC TRANSTENSION

EXTENSIONAL DEPOSITS

Tes **Extensional sedimentary rocks (early Oligocene and Eocene)**—Mostly fluvial sandstone and conglomerate with subordinate shale, volcanic rocks, and minor coal. Includes mostly sedimentary parts of the Naches Formation, Barlow Pass [SRse] Volcanics of Vance (1957a,b), and Puget Group. Also includes Roslyn [Wsw], Chumstick [Csw], and Chuckanut Formations (Tabor and others, 1982, 2003); new work includes Evans (1994) and Evans and Johnson (1989). For some recent work on fossils in Chuckanut Formation, see Mustoe and Gannaway (1997). Locally, mapped as early extensional sedimentary rocks or Silver Pass Volcanic Member of Swauk Formation

Tees **Early extensional sedimentary rocks (middle and early Eocene)**—Mostly fluvial sandstone and conglomerate of Swauk Formation (fig. 13, sheet 2; Tabor and others, 1984). [Wnw]

Teev **Silver Pass Volcanic Member of Swauk Formation**—Mostly dacite and andesite flows and pyroclastic rocks. Small diamond-shaped areas of unit Teev shown in unit Tees represent outcrops too small to show at map scale. [SPne]

Tev **Volcanic rocks (early Oligocene and Eocene)**—Mostly basalt and rhyolite flows, breccia, and tuff. Includes mostly volcanic parts of Naches Formation, Barlow Pass Volcanics of Vance (1957a,b), and Puget Group. Includes Teanaway Formation [Wnw] (Tabor and others, 1982, 2000) and volcanic rocks of Mount Persis [SKnw] (Tabor and others, 2000), Island Mountain [RMne], and Storey Peak [Tne] (Haugerud and Tabor, unpub. field maps). Rocks on Rattlesnake and Lookout Mountains [SPnw] south of North Bend are included in the extensional volcanic deposits, but Tim Walsh (written commun., 2001) mapped these rocks with the younger Cascade Magmatic Arc (see Dragovich and others, 2002c). Includes some small bodies of mafic intrusive rocks

OTHER ROCKS

Tei **Intrusive rocks (middle Eocene)**—Mostly granite and granodiorite; rare tonalite and diorite. Includes Golden Horn [RMsw] and Cooper Mountain [Tse] batholiths, Railroad Creek [Tsw] and Duncan Hill [Tsw] plutons, Monument Peak stock [RMne], Pilchuck stock [SRsw], Bald Mountain batholith [SRsw], and smaller masses. Dellinger (1996) completed a detailed study of Duncan Hill pluton, and we incorporated his mapped appinite in the Duncan Hill pluton northwest of Chelan [Cne]. Hopson and Mattinson (1994) suggest that two gabbro bodies with surprisingly pristine igneous textures, mapped by Tabor and others (1987a) in the Chelan Complex of Hopson and Mattinson (1971) and in the Cretaceous Entiat pluton, are middle Eocene intrusions. Includes some large or thick swarms of rhyolite dikes

Trr **Raging River Formation (middle and early? Eocene)**—Mostly shallow-marine and fluvial sandstone and shale (Tabor and others, 2000). [SPnw]

OROGENIC AND PRE-OROGENIC ROCKS MOSTLY WEST OF STRAIGHT CREEK FAULT

ROCKS SOUTHWEST OF DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

TKwb **Rocks of western mélange belt (middle Eocene to Late Cretaceous)**—Mostly pervasively foliated sandstone and semischist. Minor fine- to medium-cobble conglomerate, locally stretched. Commonly interbedded with argillite or phyllite. Includes chert, marble, greenstone, sheared greenstone, diabase, gabbro, metatonalite, and very rare serpentinized peridotite and dunite (Tabor and others, 2002). Locally highly disrupted and mixed (fig. 14, sheet 2). Includes metamorphosed Lookout Mountain Formation of Stout (1964) [SPse]; intruded by Quartz Mountain stock (unit TKwg)

TKwg **Quartz Mountain stock (Middle Jurassic)**—Slightly metamorphosed tonalite and granodiorite. MacDonald (2006) mentions a pervasive greenschist-facies metamorphic overprint and confirms an intrusive age of 157 Ma. [SPse]

TKeb **Rocks of eastern mélange belt (middle Eocene to Late Cretaceous)**—Mostly mafic volcanic rocks and chert with subordinate graywacke and foliated graywacke, argillite and phyllitic argillite, and marble. Includes large masses of gabbro, metatonalite, and gneissic amphibolite. Local serpentinite and serpentinized peridotite (Tabor and others, 2002). More recent studies of these rocks are by Dragovich and others (2002a,b; 2004)

TKebg **Migmatitic gneiss**—Fine-grained schistose amphibolite to medium- and coarse-grained massive quartz diorite with layered hornblende gneiss, gneissose quartz diorite, trondhjemite, and replacement breccia and minor serpentinized ultramafic rock (fig. 15, sheet 2; Tabor and others, 1993)

ROCKS IN DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Helena-Haystack mélange (middle Eocene and (or) Late Cretaceous)—Described in detail by Tabor (1994). For more recent work on Helena-Haystack mélange, see Dragovich and others (1999a,b, 2000b, 2002a,b,c, 2003a,b, 2004, 2006). [SRnw, SRsw]

TKhm **Serpentinite**—Locally includes peridotite where matrix has been thermally metamorphosed, probably by a subjacent pluton of the Cascade arc

TKhg **Blocks of resistant rock**—Greenstone including basalt, uralitic metadiabase and metagabbro, rare chert, graywacke, phyllitic argillite, semischist, foliated metavolcanic rocks, amphibolite, and tonalite (Tabor and others, 2002). Some blocks are tectonic fragments of eastern mélange belt or Shuksan Greenschist (fig. 16, sheet 2)

ROCKS NORTHEAST OF DARRINGTON-DEVILS MOUNTAIN FAULT ZONE

Northwest Cascade System

[Includes units that are offset across Straight Creek Fault [SRse] and, in southern part of map, lie east of it]

Rocks of Autochthon

KJn **Nooksack Formation (Early Cretaceous to Middle Jurassic)**—Massive to laminated black argillite; thick-bedded volcanic-lithic sandstone and pebble conglomerate. We describe unit as sedimentary rock, although much of it is incipiently recrystallized (Tabor and others, 2003). [MBnw]

Jnw **Wells Creek Volcanic Member**—Incipiently recrystallized dacite, dacite breccia, dacitic tuff, and andesite with some argillite interbeds. [MBnw]

Welker Peak and Excelsior Nappes

KJb **Bell Pass mélange (Cretaceous to Late Jurassic)**—Disrupted argillite, slate, phyllite, sandstone, semischist, ribbon chert, and basalt of Elbow Lake Formation of Brown and others (1987) [MBsw] with tectonic blocks of meta-igneous rocks, gneiss, schist, ultramafic rocks, and marble. In northwestern part of map, includes conglomerate of Bald Mountain [MBnw] and blueschist of Baker Lake [MBsw] (Tabor and others, 2003). Locally divided into Yellow Aster Complex of Misch (1966), Twin Sisters dunite of Ragan (1961), and Vedder Complex of Armstrong and others (1983). [MBsw]

KJya **Yellow Aster Complex of Misch (1966) (Paleozoic or older protolith age)**—Medium- to coarse-grained feldspathic and calc-silicate gneiss and associated weakly deformed plutonic rock. Includes local serpentinite and partially serpentinized dunite and harzburgite. [MBnw]

KJts **Twin Sisters Dunite of Ragan (1961, 1963)**—Dunite, pyroxenite, and harzburgite, locally serpentinized (fig. 8; Ragan, 1963). [MBsw]

KJv **Vedder Complex of Armstrong and others (1983) (pre-Permian protolith age)**—Amphibolite, blueschist, micaceous quartzite, and mica-quartz schist. Metamorphosed in Permian

Chilliwack River Terrane

J₸c **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 dacite and associated tuffaceous sedimentary rocks

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, which are largely recrystallized to greenstone. Also includes gabbro and diabase, some of which may be younger. Mapped unit includes Slate of Rinker Ridge [SRnw] (Tabor and others, 2002), which Dragovich and others (2002b,c) include in the Darrington Phyllite

Shuksan Nappe

Easton Terrane

Ket **Tonalite gneiss of Hicks Butte (Early Cretaceous)**—Lineated, medium-grained hornblende tonalite and tonalite gneiss, locally porphyroclastic and mylonitic. In least-deformed rock, green hornblende and labradorite are subhedral with intergranular quartz, opaque minerals, and minor biotite. Patchy alteration of plagioclase and hornblende to epidote and late microcrystalline pumpellyite. Includes tectonic zone of Tabor and others (2002). [SPse]

Easton Metamorphic Suite

Ked **Darrington Phyllite (Early Cretaceous)**—Predominantly black, highly fissile sericite-graphite-albite-quartz phyllite, typically with abundant quartz veinlets; commonly complexly folded. Locally interlayered with greenschist. Mapped unit includes semischist and phyllite of Mount Josephine [MBsw] (Tabor and others, 2003). For additional, more recent studies see Dragovich and others (1999a,b, 2000b, 2002a,b,c). [SRsw]

Kes **Shuksan Greenschist (Early Cretaceous)**—Predominantly fine grained greenschist, sodic actinolite-bearing greenschist, and blueschist. Locally interlayered with sericite-quartz phyllite. Locally includes garnet amphibolite and muscovite-quartz schist, barroisite schist, hornblende-garnet rocks, and rare eclogite commonly surrounded by greenschist (Tabor and others, 2003). [MBnw]

OROGENIC AND PRE-OROGENIC ROCKS EAST OF STRAIGHT CREEK FAULT

ROCKS UNIQUE TO WENATCHEE BLOCK

Ingalls Terrane

Jis **Ingalls terrane (Jurassic)**—Predominantly ultramafic rocks; lherzolite and hartzburgite on northwest, foliated and massive serpentinite and serpentinized metaperidotite on south and east (Tabor and others, 1982, 2000). Recently studied by Metzger and others (2002), Harper and others (2003), and MacDonald (2006). [Wnw]

Jbi **Resistant blocks of igneous and meta-igneous rocks**—Gabbro, diabase, and greenstone. Mapped unit includes amphibolite

Jbs **Resistant blocks of sedimentary rocks**—Argillite, phyllite, metasandstone, conglomerate, greenstone, and minor chert, metachert, and marble. Includes schist of DeRoux Creek of Miller (1985)

Nason Terrane

Knmg **Nason Ridge Migmatitic Gneiss (Late Cretaceous)**—In southern part of outcrop area, mostly heterogeneous, light-colored tonalitic to granodioritic gneiss, interlayered with mica schist and amphibolite similar to Chiwaukum Schist. Crosscutting sills, dikes, and irregular bodies of light-colored, fine-grained to pegmatitic tonalite and gneiss are also abundant in migmatitic phases (Tabor and others, 1987a, 2002). Grades northward into more uniform, mostly medium grained garnet-biotite-quartz-oligoclase (andesine) gneiss (with aluminum silicate minerals locally) that is difficult to distinguish from Chiwaukum Schist. [Cnw]

Kncs **Chiwaukum Schist (Late Cretaceous)**—Mostly well laminated, graphitic garnet-biotite-quartz schist. Locally contains cordierite, staurolite, or kyanite; rare sillimanite. Minor to locally abundant schistose amphibolite. Local dikes and sills of tonalite and granodiorite. Rare marble and calc-silicate rocks. Includes Tonga Formation of Yeats (1958) [SKse], shown by Duggan and Brown (1994) to be a low-grade correlative of Chiwaukum Schist (Tabor and others, 1987a, 2002). For more recent work on Chiwaukum Schist, see Miller and others (2000) and Miller and Paterson (2001b). Jensen (2004) details structural history of Tonga Formation. [Csw]

ROCKS IN WENATCHEE AND CHELAN BLOCKS

Terrane Overlap Units and Stitching Plutons

TKsg **Skagit Gneiss Complex (middle Eocene to Late Cretaceous)**—Heterogeneous complex of supracrustal schist, amphibolite, and rare marble and ultramafic rocks intruded in lit-par-lit fashion by mostly hornblende-biotite and biotite tonalite orthogneiss. Orthogneiss bodies range from a few centimeters thick in banded gneisses to several kilometers thick in mapped orthogneiss. Abundant deformed dikes and sills of light-colored pegmatitic tonalite and lineated granite. Commonly migmatitic (Tabor and others, 2003). Locally shown as orthogneiss and orthogneiss of The Needle. [MBse]

TKso **Orthogneiss**—Gneissic hornblende-biotite tonalite. Relatively uniform crystalloblastic granitoid gneiss. Locally migmatitic with concordant and crosscutting light-colored dikes of foliated, lineated, fine-grained to pegmatitic leucotonalite

TKsn **Orthogneiss of The Needle**—Gneissic hornblende tonalite to granodiorite orthogneiss with distinctive texture of ~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. [MBse]

TKto **Tonalitic orthogneiss (middle Eocene to Late Cretaceous)**—Mostly tonalitic to granodioritic gneiss, mostly with both hornblende and biotite (Tabor and others, 1987a, 2002, 2003). Textures range from massive to flaseroid. Includes orthogneisses of Haystack Creek, Marble Creek, and Mount Triumph [MBse]; Le Roy Creek [Tsw], Mount Benzarino [Tnw], and Cardinal Peak [Tsw] plutons; Seven Fingered Jack plutons [Tsw]; and parts of Bearcat Ridge plutons [Tsw]. Also includes Oval Peak batholith [Tne], western part of Black Peak batholith [RMsw], and minor bodies. For more recent studies of some of these plutons, see

Paterson and others (1996), Paterson and Miller (1998a,b), Dragovich and others (1997), Miller and Paterson (2001a,b), Valley and others (2003)

TKgo **Granodioritic orthogneiss (middle Eocene to Late Cretaceous)**—Mostly granodioritic orthogneiss but ranges to tonalite. Textures are massive to flaseroid. Includes Hidden Lake [SRne] and Foam Creek [SRse] stocks, Eldorado Orthogneiss [MBse] (fig. 17, sheet 2), and orthogneiss of Alma Creek [MBse] (Tabor and others, 2002, 2003)

Kt **Tonalitic plutons (Late Cretaceous)**—Mostly tonalite, gneissic tonalite, and tonalitic to granodioritic gneiss; mostly with both hornblende and biotite; some bodies have magmatic epidote. Includes tonalitic gneiss of Bench Lake [SRne]; Sloan Creek [SRse], Excelsior [SKne], Chaval [SRne], Tenpeak [SRse], Dirty Face [Cnw], and parts of Bearcat Ridge [Tsw] and Entiat [Cne] plutons; Clark Mountain [Tsw] and Grassy Point [SRse] stocks; Mount Stuart batholith [Wnw]; Beckler Peak stocks [SKse]; eastern part of Black Peak batholith [RMsw] and minor bodies. (Tabor and others, 1987a, 2002, 2003). Also includes mostly undeformed hornblende gabbro of Riddle Peaks pluton and Wenatchee Ridge pluton [Cnw] that is predominantly an entanglement of light-colored tonalite dikes and sills. Excelsior pluton, once thought to be Jurassic based on discordant zircon ages (Tabor and others, 1993), has been shown by Matzel (in Jensen, 2004) to be 96 m.y. old, placing it squarely in the Late Cretaceous. Based on intrusive relations of plutons and mapping by C.A. Hopson (written commun., 2005), some gneissic tonalite bodies along lower Lake Chelan [Cse] include Early Cretaceous tonalite. Recent studies of Entiat [Cse] and Tenpeak plutons are reported in Miller and others (2000), Paterson and Miller (1998a), Miller and Patterson (2001), and Matzel (2004). For more recent studies of Mount Stuart batholith consult Paterson and others (1994), Paterson and Miller (1998b), and Miller and others (2000) and for Black Peak batholith, Dragovich and others (1997)

Kg **Granodioritic plutons (Late Cretaceous)**—Mostly granodiorite and granodioritic orthogneiss but ranging to tonalite. Plutons are mostly massive. Includes Cyclone Lake [SRne], Jordan Lakes [SRne], Sulphur Mountain [SRse], and High Pass [Tsw] plutons; Downey Creek sill complex [SRne]; light-colored gneiss of Mad River terrane of Tabor and others (1987a; now Napeequa Schist); and smaller bodies (Tabor and others, 2002, 2003)

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, minor hornblende-zoisite schist, hornblende garbenschiefer, calc-silicate schist, marble, and ultramafic rocks (Tabor and others, 2002, 2003). Includes Heterogeneous gneiss and schist unit of Tabor and others (1987a) and Twisp River Schist of Barksdale (1975). Miller and others (2000), Miller and Paterson (2001b), and Valley and others (2003) report more recent studies. Locally mapped as ultramafic rocks. [Tsw]

TKnu, Knu **Ultramafic rocks**—Serpentinite, talc-magnesite schist, talc schist, tremolite-talc schist, and olivine-talc rocks

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, leucogreenschist, hornblende-biotite-andesine schist, garbenschiefer, fine-grained amphibolite, and fine-grained paragneiss. Prominent highly strained metaconglomerate (fig. 17, sheet 2; Tabor and others, 2002). Includes Holden schist of Miller and others (1994) [Tsw] and schist of Twentyfive Mile Creek of Tabor and others (1987a) [Cne] (C.A. Hopson, written commun., 2002). [MBse]

TKmd, Kmd **Marblemount plutons (middle Eocene to Late Cretaceous)**—Meta-quartz diorite, metatonalite, and tonalitic gneiss; light-colored metatonalite dikes. Includes Marblemount meta-quartz diorite of Misch (1966) and Dumbell Mountain plutons of Crowder (1959) and Cater and Crowder (1967) [Tse]. Recently determined zircon dates (Matzel, 2004) indicate that some elongate mafic plutons, mapped as unit TKto west of Seven Fingered Jack [Tsw], are Marblemount plutons. West of Entiat River [Tsw], well-layered migmatitic rocks rich in igneous material that were included in the Chelan Complex of Hopson and Mattinson (1971) by Tabor and others (1987a) are here included in the Marblemount plutons, based on mapping of Cater and Wright (1967) and Hopson and Mattinson (1994). [MBse]

TKmm **Magic Mountain Gneiss (middle Eocene to Late Cretaceous)**—Light-colored chlorite-muscovite-epidote-plagioclase gneiss or flaser gneiss interlayered with Cascade River Schist lithologies (Allen and Schermer, 2002; Allen, 2002). [SRne]

Swakane Terrane

Kswg **Swakane Biotite Gneiss (Late Cretaceous)**—Biotite-oligoclase-quartz gneiss with varying amounts of muscovite and garnet. Very rare amphibolite, hornblende schist, calc-silicate schist, and marble. Locally, thin layers rich in mica. Mostly with very uniform planar gneissic fabric; commonly granoblastic, locally strongly mylonitic (Tabor and others, 1987a, 2002). For more recent studies, see Miller and others (2000), Miller and Paterson (2001b), Valley and others (2003), Matzel (2004), Matzel and others (2002), and Matzel and Bowring (2004). [Cse]

Terrane Uncertain

Kcxm **Chelan Migmatite Complex of Hopson and Mattinson (1994) (Cretaceous)**—Metatonalite, metabasite, and metaplutonic migmatite. Characterized by tonalitic paleosome with abundant metabasite and ultramafic bodies and pervasive trondhjemitic leucosomes and disrupted synplutonic mafic dikes injected by leucosomes (adapted from Hopson and Mattinson, 1994). [Cne]

ROCKS UNIQUE TO ROSS LAKE FAULT ZONE

TKrb **Ruby Creek heterogeneous plutonic belt of Misch (1966) (middle Eocene to Late Cretaceous)**—Numerous massive to gneissic granitic to gabbroic plutonic masses in the phyllite and schist of Little Jack Mountain (Tabor and others, 2003). Includes rocks similar to Golden Horn and Black Peak batholiths. [RMsw]

TKsx **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 (Tabor and others, 2003). Unit is highly faulted and cut by mylonitic zones. [MBne]

TKm, Km **Metamorphosed rocks of Methow Ocean (middle Eocene to Late Cretaceous)**—Includes phyllite and schist of Little Jack Mountain (Tabor and others, 2003) and Elijah Ridge Schist of Misch (1966, 1977b) [RMsw]. Of particular interest are metaconglomerate in rocks near Easy Pass [RMsw] and conglomerate of South Creek (Dragovich and others, 1997), which appear to correlate with conglomerate in Virginian Ridge Formation of Barksdale (1975) [RMse]

TKmo **Tonalitic orthogneiss (middle Eocene to Late Cretaceous)**—Gneissic light-colored biotite tonalite. Mostly mylonitic with rectangular plagioclase porphyroclasts set in matrix of fine-grained quartz and biotite (Tabor and Haugerud, in press)

ROCKS IN METHOW BLOCK

Kpc **Pipestone Canyon Formation (Late Cretaceous)**—Conglomerate, feldspathic sandstone, and rare interbedded tuff and breccia (Haugerud and others, 1994; Kriens and others, 1995; Peterson, 1999). [Tne]

Onlap assemblage and stitching plutons

Ktm **Tonalite plutons in Methow block (Late Cretaceous)**—Biotite-hornblende tonalite and granodiorite; medium grained, hypidiomorphic granular. Makes up large Pasayten dike [RMne] and Fawn Peak [RMse], Lost Peak [RMne], Rock Creek [RMnw], Chancellor [RMnw], and Barron [RMnw] stocks, as well as unnamed plutonic bodies. Includes smaller masses of diorite and local gabbro

Pasayten Group of Kiessling and Mahoney (1997) (Late Cretaceous)

Kpv **Volcanic rocks**—Predominantly andesitic breccia and tuff; locally fluvial maroon siltstone, sandstone, and conglomerate. Includes Ventura Member of Midnight Peak Formation of Barksdale (1975) [Tne]. [RMnw]

Kps **Sedimentary rocks**—Mostly fluvial and estuarine lithic biotite arkose and siltstone and chert-lithic sandstone and pebble conglomerate. Includes Winthrop Formation of Kiessling and Mahoney (1997) [Tne], parts of the Virginian Ridge Formation of Barksdale (1975) [RMse], Devils Pass Member of Virginian Ridge Formation of Trexler (1985) [RMnw], and other rocks

Rocks of Methow Ocean and Onlap Assemblages

Ktf **Three Fools sequence of Haugerud and others (2002) (Cretaceous)**—Predominantly thick bedded quartzofeldspathic marine sandstone with minor polymictic conglomerate and thin-bedded sandstone and argillite (fig. 19). Also chert-lithic conglomerate and sandstone. Mostly turbidites. Includes Harts Pass Formation of Barksdale (1975) [RMsw] and some strata previously mapped as Virginian Ridge Formation of Barksdale (1975). [RMnw]

KJos **Older sedimentary rocks (Early Cretaceous and Late Jurassic)**—Predominantly siltstone, minor sandstone, and conglomerate. Shallow-marine and fluvial, locally bioturbated, local shelly lags and coquina. Includes rocks previously mapped as Panther Creek Formation of Barksdale (1975) [RMse], much of Buck Mountain Formation of Barksdale (1975) [RMse], and Patterson Lake unit of McGroder and others (1991) [Tne] (Maurer, 1958; Trexler and Bourgeois, 1985)

Rocks of Methow Ocean Floor

KJi **Tonalite intrusions (Early Cretaceous and Late Jurassic)**—Biotite-hornblende tonalite. Includes the Button Creek [RMse] and Alder Creek [Tne] stocks. A U-Pb-zircon age for the Alder Creek stock is 142 Ma (Mahoney and others, 2002)

Jnb **Newby Group of Mahoney and others (2002) (Late Jurassic)**—Rhyolitic, andesitic, and basaltic volcanic breccia, tuff, and massive volcanic rock with interbeds of volcanic-lithic sandstone and argillite. Locally slaty argillite and sandstone. Includes Twisp Formation of Barksdale (1975). [Tne]

Jnbm **Metamorphic rocks of McClure Mountain**—Schist, mostly derived from rhyolite tuff of Newby Group of Mahoney and others (2002) (unit Jnb) in probable latest Jurassic deformational event (Mahoney and others, 1996; Hopkins, 1987). [Tne]

Jl **Ladner Group of Mahoney (1993) (Middle Jurassic)**—Thin-bedded volcanic-lithic sandstone and pelite. Appears to be marine

Hozomeen Terrane

MzPzh **Hozomeen Group (Mesozoic and Paleozoic)**—Greenstone, ribbon chert, and gabbro with rare siltstone, sandstone, and limestone (fig. 20, sheet 2). Seafloor and oceanic-island deposits. Much of unit is slump facies indicative of redeposition on or at foot of submarine slopes (Haugerud, 1985). Largely metamorphosed to prehnite-pumpellyite facies; metamorphic grade increases to west. [MBne]

ROCKS IN OKANOGAN BLOCK

Okanogan Terrane

Ktd **Tonalite and diorite (Late Cretaceous)**—Texas Creek stock [Tse]: biotite-hornblende granodiorite and quartz monzonite with reported Late Cretaceous K-Ar age (Bunning, 1992). Yockey Creek stock [Tse]: hornblende diorite that Bunning (1992) suggests might be as young as Eocene

Kog **Granite and granodiorite (Early Cretaceous)**—Medium- to coarse-grained biotite granite and granodiorite. Includes Cathedral batholith of Daly (1912) [RMne] and smaller bodies

Kor **Remmel batholith (Early Cretaceous)**—Light-colored biotite tonalite and gneissic tonalite; local garnet-biotite tonalite and granodiorite. Includes Todd's (1995) trondhjemite of Doe Mountain [RMse], Chewack River [RMse] and Lake Creek [RMne] Gneisses of Hawkins (1968), and Summit-Fraser Gneiss of Menzer (1983). [RMne]

Kot **Older tonalite (Early Cretaceous)**—Hornblende-biotite tonalite includes tonalite of Eight Mile Creek [RMne] (Todd, 1995), tonalite of Bob Creek [RMne], and Methow Gneiss of Barksdale (1975) [Tse]. Methow Gneiss is gneissic biotite tonalite with characteristic large splotchy biotite aggregates

KJh **Hornblendic metamorphic rocks (Early Cretaceous and Jurassic)**—Amphibolite, hornblende-biotite schist, and biotite schist with layers of quartzite, calc-silicate schist, and marble. Mapped unit includes extensive gneissic biotite and hornblende-biotite tonalite. Includes Leecher metamorphics of Barksdale (1975) (Bunning, 1992) in southeastern part of map area and, at northern margin of map area, migmatitic hornblende-rich gneiss with leucotonalite layers (Spanish Camp Gneiss of Hawkins, 1968) and Ashnola gabbro of Daly (1912). [RMne, Tse]

KJog **Mylonitic granodiorite, gneissic trondhjemite, and banded gneiss (Early Cretaceous and Jurassic)**—Includes gneissic trondhjemite of Tiffany Mountain (Reinhart, 1981). [RM]

REFERENCES CITED

Allen, M.E., 2002, Tectonic significance of the Magic Mountain Gneiss, North Cascades, Washington: Bellingham, Western Washington University, undergraduate thesis, 48 p.

Allen, M.E., and Schermer, E.R., 2002, Tectonic significance of the Magic Mountain Gneiss, North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 34, no. 5, p. A28.

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

Armstrong, R.L., 1978, Cenozoic igneous history of the U.S. Cordillera from lat 42° to 49° N., *in* Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir, v. 152, p. 265–282.

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

Baldwin, J.A., Whitney, D.L., and Hurlow, H.A., 1997, Metamorphic and structural evidence for significant vertical displacement along the Ross Lake fault zone, a major orogen-parallel shear zone in the Cordillera of western North America: Tectonics, v. 16, no. 4, p. 662–681.

Barksdale, J.D., 1975, Geology of the Methow Valley, Okanagan County, Washington: Washington Division of Geology and Earth Resources Bulletin 68, p. 72 p.

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

Booth, D.B., 1987, Timing and processes of deglaciation along the southern margin of the Cordilleran ice sheet, *in* Ruddiman, W.F., and Wright, H.O., Jr., eds., North America and adjacent oceans during the last deglaciation: Geological Society of America, v. K–3, p. 71–90.

Booth, D.B., 1990, Surficial geologic map of the Skykomish and Snoqualmie Rivers area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1745, scale 1:50,000.

Booth, D.B., and Goldstein, B., 1994, Patterns and Processes of Landscape Development, *in* Cheney, E.S., and Lasmanis, R., eds., Regional Geology of Washington State: Washington Division of Geology and Earth Resources Bulletin, v. 80, p. 207–218.

Booth, D.B., Troost, K.G., Clague, J.J., and Waitt, R.B., 2004, The Cordilleran Ice Sheet, *in* Gillespie, A.R., Porter, S.C., and Atwater, B.F., eds., The Quaternary Period in the United States: Amsterdam, The Netherlands, Elsevier, International, v. 1, p. 17–43.

Booth, D.B., and Waitt, R.B., 2000, Quaternary surficial deposits and landforms, *in* Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., and Waitt, R.B., 2000, Geologic map of the Snoqualmie Pass 30- x 60-minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series I–2538, scale 1:100,000, 57 p.

Brandon, M.T., 1989, Geology of the San Juan-Cascade nappes, northwestern Cascade Range and San Juan Islands, *in* Joseph, N.L., ed., Geologic guidebook for Washington and adjacent areas: Washington Division of Geology and Earth Resources Information Circular, v. 86, p. 137–162.

Brown, E.H., 1986, Geology of the Shuksan Suite, North Cascades, Washington, U.S.A., *in* Evans, B.W., and Brown, E.H., eds., Blueschists and eclogites: Geological Society of America Memoir 164, 423 p.

Brown, E.H., 1987, Structural geology and accretionary history of the Northwest Cascade System, Washington and British Columbia: Geological Society of America Bulletin, v. 99, no. 2, p. 201–214.

Brown, E.H., Blackwell, D.L., Christenson, B.W., and 12 others, 1987, Geologic map of the northwest Cascades, Washington: Geological Society of America Map and Chart Series MC–61, scale 1:100,000, 10 p.

Brown, E.H., and Dragovich, J.D., 2003, Tectonic elements and evolution of Northwest Washington: Washington Division of Geology and Earth Resources Geologic Map GM–52, scale 1:625,000, 9 p.

Brown, E.H., and Gehrels, G.E., 2007, Detrital zircon constraints and terrane ages and affinities and timing of orogenic events in the San Juan Islands and North Cascades, Washington: Canadian Journal of Earth Sciences, v. 44, p. 1375-1396.

Brown, E.H., Housen, B.A., and Schermer, E.R., 2007, Tectonic evolution of the San Juan Islands thrust system, Washington, *in* Stelling P., and Tucker, D.S., eds., Floods, Faults, and Fire—Geological field trips in Washington state and southwest British Columbia: Geological Society of America Field Guide, v. 9, p. 143–177.

Brown, E.H., and Lapen, T.J., 2003, Revised metamorphic history of the San Juan Islands: Geological Society of American Abstracts with Program, v. 35, no. 6, p. 113.

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

Bunning, B.B., 1992, Geologic map of the east half of the Twisp 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90–9, 51 p.

Cairnes, C.E., 1944, Hope Sheet, British Columbia: Geological Survey of Canada Map 737A, scale 1:253,440.

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

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

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

Coates, J.A., 1974, Geology of the Manning Park area, Cascade Mountains, British Columbia: Geological Survey of Canada Bulletin, v. 238, 177 p.

Coleman, M.E., and Parrish, R.R., 1991, Eocene dextral strike-slip and extensional faulting in the Bridge River Terrane, southwest British Columbia: Tectonics, v. 10, no. 6, p. 1222–1238.

Cowan, D.S., 2003, Revisiting the Baranof-Leech River hypothesis for Early Tertiary coastwise transport of the Chugach-Prince William terrane: Earth and Planetary Science Letters, v. 213, p. 463–475.

Cowie, J.W., and Bassett, M.B., 1989, International Union of Geological Sciences 1989 Global Stratigraphic Chart: Episodes, v. 12, no. 2, June supplement.

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

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

Davis, G.A., Monger, J.W.H., and Burchfiel, B.C., 1978, Mesozoic construction of the Cordilleran "Collage," central British Columbia to central California, *in* Howell, D.G., and McDougall, K.A., Mesozoic paleogeography of the western United States, Pacific Coast Paleogeography Symposium 2: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 1–32.

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

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

DeGraaff-Surpless, K., Mahoney, J.B., Wooden, J.L., and McWilliams, M.O., 2003, Lithofacies control in detrital zircon provenance studies—Insights from the Cretaceous Methow basin, southern Canadian Cordillera: Geological Society of America Bulletin, v. 115, no. 8, p. 899–915.

Dellinger, D.A., 1996, The geology, petrology, geochemistry, mineralogy, and diapiric emplacement of the Duncan Hill pluton, North Cascades, Washington: Santa Barbara, University of California, Ph.D. dissertation, 539 p.

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

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

Dragovich, J.D., and DeOme, A.J., 2006, Geologic map of the McMurray 7.5-minute quadrangle, Skagit and Snohomish counties, Washington, *with a discussion of* The evidence for Holocene activity on the Darrington-Devils Mountain Fault Zone: Washington Division of Geology and Earth Resources Geologic Map GM–61, scale 1:24,000, 18 p.

Dragovich, J.D., Gilbertson, L.A., Lingley, W.S., Jr., Polenz, M., and Glenn, J., 2002a, Geologic map of the Fortson 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington: Washington Division of Geology and Earth Resources Open-File Report 2002–6, scale 1:24,000.

Dragovich, J.D., Gilbertson, L.A., Lingley, W.S., Jr., Polenz, M., and Glenn, J., 2002b, Geologic map of the Darrington 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington: Washington Division of Geology and Earth Resources Open-File Report 2002–7, scale 1:24,000.

Dragovich, J.D., Logan, R.L., Schasse, H.W., and 7 others, 2002c, Geologic Map of Washington-Northwest quadrant: Washington Division of Geology and Earth Resources Geologic Map GM–50, 1:250,000, 72 p.

Dragovich, J.D., McKay, D.T.J., Dethier, D.P., and Beget, J.E., 2000a, Holocene Glacier Peak lahar deposits in the lower Skagit River Valley, Washington: Washington Geology, v. 28, no. 1/2, p. 19–21.

Dragovich, J.D., and Norman, D.K., comps., 1995, Geologic map of the west half of the Twisp 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open-File Report 95–3, scale 1:100,000, 63 p.

Dragovich, J.D., Norman, D.K., and Anderson, G., 2000b, Interpreted geologic history of the Sedro-Woolley North and Lyman 7.5-minute quadrangles, western Skagit County, Washington: Washington Division of Geology and Earth Resources Open-File Report 2000–1, 71 p.

Dragovich, J.D., Norman, D.K., Grisamer, C.L., Logan, R.L., and Anderson, G., 1999a, Geologic map and interpreted geologic history of the Bow and Alger 7.5-minute quadrangles, western Skagit County, Washington: Washington Division of Geology and Earth Resources Open-File Report 98–5, scale 1:24,000, 80 p.

Dragovich, J.D., Norman, D.K., Haugerud, R.A., and Miller, R.B., 1997, Geologic map of the Gilbert 7.5' quadrangle, Chelan and Okanogan Counties, Washington: Washington Division of Geology and Earth Resources Geologic Map GM–46, scale 1:24,000.

Dragovich, J.D., Norman, D.K., Lapen, T.J., and Anderson, G., 1999b, Geologic map of the Sedro-Woolley North and Lyman 7.5-minute quadrangles, western Skagit County, Washington: Washington Division of Geology and Earth Resources Open-File Report 99–3, 37 p.

Dragovich, J.D., Stanton, B.W., Lingley, W.S., Jr., Griesel, G.A., and Polenz, M., 2003a, Geologic map of the Mount Higgins 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington: Washington Division of Geology and Earth Resources Open-File Report 2003–12, scale 1:24,000.

Dragovich, J.D., Stanton, B.W., Lingley, W.S., Jr., Griesel, G.A., and Polenz, M., 2003b, Geologic Map of the Oso 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington: Washington Division of Geology and Earth Resources Open-File Report 2003b–11, scale 1:24,000.

Dragovich, J.D., Wolfe, M.W., Stanton, B.W., and Norman, D.K., 2004, Geologic map of the Stimson Hill 7.5-minute quadrangle, Skagit and Snohomish Counties, Washington: Washington Division of Geology and Earth Resources Open-File Report 2004–9, scale 1:24,000.

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

Evans, J.E., 1994, Depositional history of the Eocene Chumstick Formation—Implications of tectonic partitioning for the history of the Leavenworth and Entiat-Eagle Creek fault systems, Washington: Tectonics, v. 13, p. 1425–1444.

Evans, J.E., and Johnson, S.Y., 1989, Paleogene strike-slip basins of central Washington—Swauk Formation and Chumstick Formation, *in* Joseph, N.L., ed., Geologic guidebook for Washington and adjacent areas, Washington Division of Geology and Earth Resources, Information Circular 86, p. 215–237.

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

Fitzgibbon, T.T., 1991, ALACARTE installation and system manual (version 1.0): U.S. Geological Survey Open-File Report 91–587B.

Fitzgibbon, T.T., and Wentworth, C.M., 1991, ALACARTE user interface—AML code and demonstration maps (version 1.0): U.S. Geological Survey Open-File Report 91–587A.

Garver, J.L., 1988, Fragment of the Coast Range ophiolite and the Great Valley sequence in the San Juan Islands, Washington: Geology, v. 16, p. 948–951.

Greig, C., 1989, Deformation and plutonism in the Eagle Complex, Coquihalla area, southwest British Columbia—Implications for Late Jurassic deformation along the western margin of Quesnellia and constraints on mid-Cretaceous motion along the Pasayten fault: Geological Society of America Programs with Abstracts, v. 21, no. 5, p. 87.

Hamilton, W., 1978, Mesozoic tectonics of the western United States, *in* Howell, D.G., and McDougall, K.A., Mesozoic Paleogeography of the United States: Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 33–77.

Harper, G.D., Miller, R.B., MacDonald, J.H., Jr., Miller, J.S., and Mlinarevic, A.N., 2003, Evolution of a polygenetic ophiolite—The Jurassic Ingalls Ophiolite, Washington Cascades, *in* Swanson, T.W., ed., Field Guide—Western Cordillera and adjacent areas: Geological Society of America, v. 4, p. 251–265.

Haugerud, R.A., 1985, Geology of the Hozameen Group and the Ross Lake shear zone, Maselpanik area, North Cascades, southwest British Columbia: Seattle, University of Washington, Ph.D. dissertation, 263 p.

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

Haugerud, R.A., Tabor, R.W., and Mahoney, J.B., 2002, Stratigraphic record of Cretaceous tectonics in the Methow block, North Cascades, Washington [abs.]: Geological Society of America Abstracts with Programs, v. 34, no. 5, p. A–95.

Haugerud, R.A., van der Heyden, P., Tabor, R.W., Stacey, J.S., and Zartman, R.E., 1991, Late Cretaceous and early Tertiary plutonism and deformation in the Skagit Gneiss Complex, North Cascades Range, Washington and British Columbia: Geological Society of America Bulletin, v. 103, p. 1297–1307.

Hawkins, J.W., Jr., 1963, Geology of the crystalline rocks of the northwestern part of the Okanogan Range, north central Washington: Seattle, University of Washington, Ph.D. dissertation, 173 p.

Hawkins, J.W., Jr., 1968, Regional metamorphism, metasomatism, and partial fusion in the northwestern part of the Okanogan Range, Washington: Geological Society of America Bulletin, v. 79, no. 12, p. 1785–1819.

Heller, P.L., Tabor, R.W., and Suczek, C.A., 1987, Paleogeographic evolution of the United States Pacific Northwest during Paleogene time: Canadian Journal of Earth Sciences, v. 24, no. 8, p. 1652–1667.

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

Hildreth, W., Fierstein, J., and Lanphere, M., 2003, Eruptive history and geochronology of the Mount Baker volcanic field, Washington: Geological Society of America Bulletin, v. 115, no. 6, p. 729–764.

Hildreth, W., Lanphere, M.A., Champion, D.E., and Fierstein, J., 2004, Rhyodacites of Kulshan caldera, North Cascades of Washington—Postcaldera lavas that span the Jaramillo: Journal of Volcanology and Geothermal Research, v. 130, p. 227–264.

Hopkins, W.N., 1987, Geology of the Newby Group and adjacent units in the southern Methow Trough, Northeast Cascades, Washington: Calif., San Jose State University, M.S. thesis, 95 p.

Hopson, C.A., 1955, Petrology and structure of the Chelan batholith, near Chelan, Washington: Baltimore, Md., Johns Hopkins University, Ph.D. dissertation, 178 p.

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

Hopson, C.A., and Mattinson, J.M., 1994, Chelan migmatite complex, Washington—Field evidence for mafic magmatism, crustal anatexis, mixing, and protodiapiric emplacement, *in* Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest, Seattle, Washington, October 24–27: Geological Society of America Annual Meeting, v. 2, p. 2K2–2K21.

Hopson, C.A., and Mattinson, J.M., 1999, Birth of epizonal mid-Eocene granitoid plutons from the Late Cretaceous-Early Tertiary Skagit Gneiss Complex: Geological Society of America Abstracts with Programs, v. 31, no. 6, p. 63.

Hurlow, H.A., 1993, Mid-Cretaceous strike-slip and contractional fault zones in the western intermontane terrane, Washington, and their relation to the North Cascades-southeastern Coast Belt orogen: Tectonics, v. 12, no. 5, p. 1240–1257.

Jensen, L.A., 2004, Reinterpreting the tectono-metamorphic evolution of the Tonga Formation, North Cascades—A new prospective from multiple episodes of folding and metamorphism: Los Angeles, University of Southern California, M.S. thesis, 67 p.

Johnson, S.Y., 1984, Stratigraphy, age, and paleogeography of the Eocene Chuckanut Formation, northwest Washington: Canadian Journal of Earth Sciences, v. 21, no. 1, p. 92–106.

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

Johnson, S.Y., Dadisman, S.V., Mosher, D.C., Blakely, R.J., and Childs, J.R., 2001, Active tectonics of the Devils Mountain Fault and related stuctures, northern Puget Lowland and eastern Strait of Juan de Fuca region, Pacific Northwest: U.S. Geological Survey Professional Paper 1643, 45 p.

Kiessling, M.D., and Mahoney, J.B., 1997, Revised stratigraphy of the Pasayten Group, Manning Park, British Columbia: Geological Survey of Canada Paper 97–1A, p. 151–158.

Kleinspehn, K.L., 1985, Cretaceous sedimentation and tectonics, Tyaughton-Methow Basin, southwestern British Columbia: Canadian Journal of Earth Sciences, v. 22, no. 2, p. 154–174.

Kriens, B.J., 1988, Tectonic evolution of the Ross Lake area, northwest Washington-southwest British Columbia: Cambridge, Mass., Harvard University, Ph.D. dissertation, 214 p.

Kriens, B.J., Hawley, D.L., Chappelear, F.D., Mack, P., and Chan, A.F., 1995, Spatial and temporal relationship between early Tertiary shortening and extension in northwestern Washington, based on geology of the Pipestone Canyon Formation and surrounding rocks: Tectonics, v. 14, no. 3, p. 719–735.

Kriens, B.J., and Wernicke, B., 1990a, Characteristics of a continental margin magmatic arc as a function of depth—The Skagit-Methow crustal section, *in* Salisbury, M.H., and Fountain, D.M., eds., Exposed cross sections of the continental crust: Dordrecht, The Netherlands, Kluwer Academic Publishers, p.159–173.

Kriens, B., and Wernicke, B., 1990b, Nature of the contact zone between the North Cascades crystalline core and the Methow sequence in the Ross Lake area, Washington—Implications for Cordilleran tectonics: Tectonics, v. 9, no. 5, p. 953–981.

Lanphere, M.A., and Sisson, T.W., 2003, Episodic volcano growth at Mt. Rainier, Washington—A product of tectonic throttling?: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 644.

Libby, W.G., 1964, Petrography and structure of the crystalline rocks between Agnes Creek and the Methow Valley, Washington: Seattle, University of Washington, Ph.D. dissertation, scale 1:31,680, 171 p.

Lowes, B.E., 1972, Metamorphic petrology and structural geology of the area east of Harrison Lake, British Columbia, Canada: Seattle, University of Washington, Ph.D. dissertation, 162 p.

MacDonald, J.H., 2006, Petrology, petrogenesis, and tectonic setting of Jurassic rocks of the central Cascades, Washington, and Klamath Mountains, California-Oregon: Albany, State University of New York, Ph.D. dissertation, 415 p.

MacDonald, J.H., Jr., Harper, G.D., and Miller, R.B., 2003, The De Roux unit of the central Cascades, Washington—Geochemistry, tectonic setting, and possible correlations: Geological Society of America Abstracts with Program, v. 35, no. 6, p. 513.

MacDonald, J.H., Jr., Harper, G.D., Miller, R.B., Miller, J.S., Mlinarevic, A.N., and Schultz, C.E., 2005, The polygenetic Ingalls Ophiolite Complex and its relationsip to the Josephine and Coast Range ophiolites: Geological Society of America Abstracts with Programs, v. 37, no. 4, p. 85.

Magloughlin, J.F., and Edwards, R., 1993, Geochemistry of the Chiwaukum Schist, Washington—Evidence for a back-arc basin and island arc complex, the accretion of a juvenile oceanic terrane, and geochemical stability during metamorphism: Geological Society of America Abstracts with Programs, v. 25, no. 6, p. A321–A322.

Mahoney, J.B., 1993, Facies reconstructions in the Lower to Middle Jurassic Ladner Group, southern British Columbia, *in* Current research—Part A, Cordillera and Pacific margin: Geological Survey of Canada, Paper 93–1A, p. 173–182.

Mahoney, J.B., Haugerud, R.A., Friedman, R.M., and Tabor, R.W., 1996, Newby Group—An Upper Jurassic volcanic-arc assemblage in the southern Methow terrane, Washington: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 88.

Mahoney, J.B., Haugerud, R.A., Friedman, R.M., and Tabor, R.W., 2002, Late Jurassic terrane linkages in the North Cascades—Newby Group is Quesnellia? [abs.]: Geological Society of America Abstracts with Programs, v. 34, no. 5, p. A–95.

Mahoney, J.B., and Journeay, J.M., 1993, The Cayoosh Assemblage, southwestern British Columbia—Last vestige of the Bridge River Ocean, *in* Current Research, Part A: Geological Survey of Canada Paper 93–1A, p. 235–244.

Mattinson, J.M., 1972, Ages of zircons from the northern Cascade Mountains, Washington: Geological Society of America Bulletin, v. 83, no. 12, p. 3769–3784.

Matzel, J.E.P., 2004, Rates of tectonic and magmatic processes in the North Cascades continental magmatic arc: Boston, Massachusetts Institute of Technology, Ph.D. dissertation, 249 p.

Matzel, J.E.P. and Bowring, S.A., 2004, Protolith age of the Swakane Gneiss, North Cascades, Washington—Evidence of rapid underthrusting of sediments beneath an arc: Tectonics, v. 23, no. 6, p. 1–18.

Matzel, J., Bowring, S.A., and Miller, R., 2002, U-Pb geochronology evidence of a Late Cretaceous protolith age for the Swakane Gneiss, North Cascades, Washington: Geological Society of America Abstracts with Programs, v. 34, no. 6, p. 105.

Maurer, D.L., 1958, Biostratigraphy of the Buck Mountain member and adjacent units in the Winthrop area, Washington: Seattle, University of Washington, M.S. thesis, 110 p.

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

McGroder, M.F., Garver, J.L., and Mallory, V.S., 1991, Bedrock geologic map, biostratigraphy, and structure sections of the Methow basin, Washington and British Columbia: Washington Division of Geology and Earth Resources Open-File Report 90–19, scale 1:100,000, 32 p.

Menzer, F.J., Jr., 1983, Metamorphism and plutonism in the central part of the Okanogan Range, Washington: Geological Society of America Bulletin, v. 94, p. 471–498.

Metzger, E.P., Miller, R.B., and Harper, G.D., 2002, Geochemistry and tectonic setting of the ophiolitic Ingalls Complex, North Cascades, Washington—Implications for correlations of Jurassic ophiolites: Journal of Geology, v. 110, p. 543–560.

Michels, Z.D., Miller, R.B., and McLean, N., 2007, Structures of the central part of the Skagit Gneiss Complex, North Cascades, Washington: Geological Society of America Abstracts with Programs, v. 39, no. 4, p. 10.

Miller, J., Miller, R., Wooden, J., and Harper, G., 2003, Geochronologic links between the Ingalls Ophiolite, North Cascades, Washington, and the Josephine Ophiolite, Klamath Mountains, Oregon and California [abs]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 113.

Miller, R.B., 1985, The ophiolitic Ingalls Complex, north-central Cascade Mountains, Washington: Geological Society of America Bulletin, v. 96., no. 1, p. 27–42.

Miller, R.B., 1987, Geologic map of the Twisp River-Chelan divide region, North Cascades, Washington: Washington Division of Geology and Earth Resources Open-File Report 87–17, 2 pl., scale 1:24,000 and 1:100,000, 12 p.

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

Miller, R.B., 1994, A mid-crustal contractional stepover zone in a major strike-slip system, North Cascades, Washington: Journal of Structural Geology, v. 16, no. 1, p. 47–60.

Miller, R.B., and Bowring, S.A., 1990, Structure and chronology of the Oval Peak batholith and adjacent rocks—Implications for the Ross Lake fault zone, North Cascades, Washington: Geological Society of America Bulletin, v. 102, no. 10, p. 1361–1377.

Miller, R.B. Haugerud, R.A., Murphy, F., and Nicholson, L.S., 1994, Tectonostratigraphic framework of the northeastern Cascades; *in* Lasmanis, R., and Cheney, E.S., convenors, Regional geology of Washington State: Washington Division of Geology and Earth Resources Bulletin, v. 80, p. 73–92.

Miller, R.B., Mattinson, J.M., Funk, S.A.G., Hopson, C.A., and Treat, C.L., 1993, Tectonic evolution of Mesozoic rocks in the southern and central Washington Cascades, *in* Dunn, G., and McDougall, K., eds., Mesozoic Paleogeography of the Western United States, II: Society of Economic Paleontologists and Mineralogists, Pacific Section, Book 71, p. 81–98.

Miller, R.B., and Mogk, D.W., 1987, Ultramafic rocks of a fracture-zone ophiolite, North Cascades, Washington: Tectonophysics, v. 142, no. 3, p. 261–289.

Miller, R.B., and Paterson, S.R., 2001a, Construction of mid-crustal sheeted plutons—Examples from the North Cascades, Washington: Geological Society of America Bulletin, v. 113, no. 11, p. 1423–1442.

Miller, R.B., and Paterson, S.R., 2001b, Influence of lithological heterogeneity, mechanical anisotropy, and magmatism on the rheology of an arc, North Cascades, Washington: Tectonophysics, v. 342, p. 351–370.

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

Misch, P., 1966, Tectonic evolution of the northern Cascades of Washington State—A west-cordilleran case history, *in* Gunning, H.C., ed., A symposium on the tectonic history and mineral deposits of the western Cordillera in British Columbia and in neighboring parts of the U.S.A., Vancouver, 1964: Canadian Institute of Mining and Metallurgy Special Volume 8, p. 101–148.

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

Misch, P., 1977b, Bedrock geology of the North Cascades, *in* Brown, E.H., and Ellis, R.C., eds., Geological excursions in the Pacific Northwest: Geological Society of America field guide, p. 1–62.

Monger, J.W.H., 1985, Intermontane belt, in Price, R.A., Monger, J.W.H., and Roddick, J.A., Cordillerian cross section—Calgary to Vancouver, *in* Templeman-Kluit, D., ed., Field Guides to Geology and Mineral Deposits in the southern Canadian Cordillera, Trip 3, Geological Society of America Cordillera Meeting, Vancouver: Vancouver, B.C., Geological Association of Canada, p. 3-37–3-49.

Monger, J.W.H., and Journeay, J.M., 1994, Basement geology and tectonic evolution of the Vancouver region, *in* Monger, J.W.H., ed., Geology and Geological Hazards of the Vancouver Region, southwestern British Columbia: Geological Survey of Canada Bulletin, v. 481, p. 3–25.

Mustoe, G.E., and Gannaway, W.L., 1997, Paleogeography and paleontology of the Early Tertiary Chuckanut Formation, Northwest Washington: Washington Geology, v. 25, no. 3, p. 3–18.

Page, B.M., 1939, Geology of part of the Chiwaukum quadrangle, Washington: Calif., Stanford University, Ph.D. dissertation, 203 p.

Paterson, S.R., Fowler, T.K., Jr., and Miller, R.B., 1996, Pluton emplacement in arcs—A crustal-scale exchange process: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 87, p. 115–123.

Paterson, S.R., and Miller, R.B., 1998a, Mid-crustal magmatic sheets in the Cascades Mountains, Washington—Implications for magma ascent: Journal of Structural Geology, v. 20, no. 9, p. 1345–1363.

Paterson, S.R., and Miller, R.B., 1998b, Regional tilt of the Mount Stuart batholith, Washington, determined using aluminum-in-hornblende barometry—Implications for northward translation of Baja British Columbia, Discussion and Repy: Geological Society of America Bulletin, v. 110, no. 5, p. 685–690.

Paterson, S.R., Miller, R.B., Anderson, L., Lund, S., Bendixen, J., Taylor, N., and Fink, T., 1994, Emplacement and evolution of the Mt. Stuart batholith, *in* Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest: Seattle, University of Washington, v. 2, p. 2F2–2F45.

Peterson, J.J., 1999, Stratigraphy and sedimentology of the Pipestone Canyon Formation, north central Washington: Bellingham, Western Washington University, M.S. thesis, 122 p.

Peterson, J.J., Mahoney, J.B., and Haugerud, R.A., 1997, Constraints on Late Cretaceous movement on the Pasayten fault—The Pipestone Canyon Formation, Washington: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A–278.

Porter, S.C., 1976, Pleistocene glaciation in the southern part of the north Cascade Range, Washington: Geological Society of America Bulletin, v. 87, no. 1, p. 61–75.

Ragan, D.M., 1961, Geology of Twin Sisters dunite, northern Cascades, Washington: Seattle, University of Washington, Ph.D. dissertation, 98 p.

Ragan, D.M., 1963, Emplacement of the Twin Sisters dunite, Washington: American Journal of Science, v. 261, p. 549–565.

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

Ray, G.E., 1986, The Hozomeen fault system and related Coquihalla serpentine belt of southwestern British Columbia: Canadian Journal of Earth Science, v. 23, p. 1022–1041.

Riedel, J.L., Haugerud, R.A., and Clague, J.J., 2007, Geomorphology of a Cordilleran Ice Sheet drainage network through breached divides in the North Cascade Mountains of Washington and British Columbia: Geomorphology, v. 91, no. 12, p.1–18.

Riedell, K.B., 1979, Geology and porphyry copper mineralization of the Fawn Peak intrusive complex, Methow Valley, Washington: Seattle, University of Washington, M.S. thesis, 52 p.

Rinehart, C.D., 1981, Reconaissance geochemical survey of gully and stream sediments, and geologic summary, in part of the Okanogan Range, Okanogan County, Washington: Washington Division of Geology and Earth Resources, Bulletin 74, 3 pl., 24 p.

Smith, J.G., 1993, Geologic map of upper Eocene to Holocene volcanic and related rocks in the Cascade Range, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–2005, scale 1:500,000.

Sondergaard, J.N., 1979, Stratigraphy and petrology of the Nooksack Group in the Glacier Creek-Skyline divide area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 103 p.

Southwick, D.L., 1974, Geology of the alpine-type ultramafic complex near Mount Stuart, Washington: Geological Society of America Bulletin, v. 85, no. 3, p. 391–402.

Staatz, M.H., Weiss, P.L., Tabor, R.W., and 4 others, 1971, Mineral resources of the Pasayten Wilderness Area, Washington: U.S. Geological Survey Bulletin 1325, 255 p.

Stout, M.L., 1964, Geology of a part of the south-central Cascade Mountains, Washington: Geological Society of America Bulletin, v. 75, no. 4, p. 317–334.

Swanson, D.A., Byerly, G.R., and Bentley, R.D., 1982, Columbia River Basalt Group, *in* Tabor, R.W., Waitt, R.B., Frizzell, V.A., and 3 others, Geologic map of the Wenatchee 1:100,000 quadrangle, central Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1311, p. 13–15.

Swanson, D.A., Wright, T.L., Hooper, P.R., and Bentley, R.D., 1979, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457–G, 59 p.

Tabor, R.W., 1961, The crystalline geology of the area south of Cascade Pass, northern Cascade Mountains, Washington: Seattle, University of Washington, Ph.D. dissertation, scale 1:31,680, 205 p.

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

Tabor, R.W., Booth, D.B., and Ford, A.B., 2002, Geologic map of the Sauk 30- x 60-minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series I–2592, scale, 1:100,000, 67 p.

Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., and Waitt, R.B., 2000, Geologic map of the Snoqualmie Pass 30- x 60-minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series Map I–2538, scale, 1:100,000, 57 p.

Tabor, R.W., Frizzell, V.A., Jr., Booth, D.B., Waitt, R.B., Whetten, J.T., and Zartman, R.E., 1993, Geologic map of the Skykomish 60-minute by 30-minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series Map I–1963, scale 1:100,000, 42 p.

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

Tabor, R.W., Frizzell, V.A., Jr., Whetten, J.T., and 6 others, 1987a, Geologic map of the Chelan 30-minute by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Map I–1661, scale 1:100,000, 29 p.

Tabor, R.W., and Haugerud, R.A., 1999, Geology of the North Cascades—A Mountain Mosaic: Seattle, Wash., The Mountaineers, 143 p.

Tabor, R.W., and Haugerud, R.A., in press, Geology of the North Cascades—Summary and Enigmas, *in* Cheney, E., ed., Geology of Washington: Seattle, University of Washington Press.

Tabor, R.W., Haugerud, R.A., Hildreth, W., and Brown, E.H., 2003, Geologic map of the Mount Baker 30- x 60-minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series Map I–2660, scale 1:100,000, 73 p.

Tabor, R.W., Haugerud, R.A., and Miller, R.B., 1989, Overview of the geology of the North Cascades, *in* Tabor, R.W., Haugerud, R.A., Brown, E.H., Babcock, R.S., and Miller, R.B., Accreted Terranes of the North Cascades Range, Washington: American Geophysical Union, International Geological Congress Field Trip T307, Washington, D.C., p. 1–33.

Tabor, R.W., Waitt, R.B., Frizzell, V.A., Jr., Swanson, D.A., Byerly, G.R., and Bentley, R.D., 1982, Geologic map of the Wenatchee 1:100,000 quadrangle, central Washington: U.S. Geological Survey Miscellaneous Investigations Map I–1311, scale 1:100,000, 26 p.

Tabor, T.W., Zartman, R.E., and Frizell, V.A., Jr., 1987b, Possible tectonostratigraphic terranes in the North Cascades crystalline core, Washington, *in* Schuster, J.E., ed., Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources, Bulletin 77, p. 107–127.

Todd, V.R., 1995, Geologic map of the Doe Mountain 15' quadrangle, Okanogan County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–2306, scale 1:62,500, 17 p.

Trexler, J.H., Jr., 1985, Sedimentology and stratigraphy of the Cretaceous Virginian Ridge Formation, Methow basin, Washington: Canadian Journal of Earth Sciences, v. 22, no. 9, p. 1274–1285.

Trexler, J.H., and Bourgeois, J., 1985, Evidence for Mid-Cretaceous wrench-faulting in the Methow Basin, Washington: Tectonics, v. 4, no. 4, p. 379–394.

Tucker, D.S., 2000, Pliocene Hannegan Caldera in the North Cascades, Washington [abs]: Geological Society of America Abstracts with Programs, v. 32, no. 6, p. 73.

Tucker, D.S., 2004, Geology and eruptive history of Hannegan Caldera, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 126 p.

Tucker, D.S., Hildreth, W., Ullrich, T., and Friedman, R., 2007, Geology and complex collapse mechanisms of the 3.72 Ma Hannegan caldera, North Cascades, Washington, U.S.A.: Geological Society of America Bulletin, v. 119, no. 3, p. 329–342.

Valley, P.M., Whitney, D.L., Paterson, S.R., Miller, R.B., and Alsleben, H., 2003, Metamorphism of the deepest exposed arc rocks in the Cretaceous to Paleogene Cascades belt, Washington—Evidence for large-scale vertical motion in

a continental arc: Journal of Metamorphic Geology, v. 21, no. 2, p. 203–220.
Vance, J.A., 1957a, The geology of the Swauk River area in the northern Cascades of Washington: Seattle, University of Washington, Ph.D. dissertation, 312 p.
Vance, J.A., 1957b, The geology of the Swauk River area in the northern Cascades of Washington: Dissertation Abstracts, v. 17, no . 9, p. 1984.
Vance, J.A., 1985, Early Tertiary faulting in the North Cascades: Geological Society of America Abstracts with Programs, v. 17, no. 6, p. 415.
Vance, J.A., Clayton, G.A., Mattinson, J.M., and Naeser, C.W., 1987, Early and middle Cenozoic stratigraphy of the Mount Rainier-Tieton River area, southern Washington Cascades, *in* Schuster, J.E., ed., Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin, v. 77, p. 269–290.
Vance, J.A., Dungan, M.A., Blanchard, D.P., and Rhodes, J.M., 1980, Tectonic setting and trace element geochemistry of Mesozoic ophiolitic rocks in western Washington: American Journal of Science, v. 280–A, p. 359–388.
Vance, J.A., and Miller, R.B., 1981, The movement history of the Straight Creek Fault in Washington State—The last 100 million years (mid-Cretaceous to Holocene) [abs]: Symposium on geology and mineral deposits in the Canadian Cordillera, Programme with Abstracts, p. 39–41.
Vance, J.A., and Miller, R.B., 1992, Another look at the Fraser River-Straight Creek fault [abs]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 88.
Waitt, R.B., Jr., 1972, Geomorphology and glacial geology of the Methow drainage basin, eastern North Cascade Range, Washington: Seattle, University of Washington, Ph.D. dissertation, 154 p.
Waitt, R.B., 1979, Late Cenozoic landforms, stratigraphy, and tectonism in Kittitas Valley, Washington: U.S. Geological Survey Professional Paper 1127, 18 p.
Waitt, R.B., 1980, About forty last-glacial Lake Missoula jökulhlaups through southern Washington: Journal of Geology, v. 88, no. 6, p. 653–679.
Waitt, R.B., 1985, Case for periodic colossal jökulhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, no. 10, p. 1271–1286.
Waitt, R.B., 1987, Erosional landscape and surficial deposits, *in* Tabor, R.W., Frizell, V.A., Jr., Whetten, J.T., and 6 others, Geologic map of the Chelan 30-minute by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–1661, p. 2–24.
Waitt, R.B., Jr., and Thorson, R.M., 1983, Cordilleran ice sheet in Washington, Idaho, and Montana, *in* Wright, H.E., Jr., ed., Late Quaternary environments of the United States—Volume 1, the Late Pleistocene: Minneapolis, University of Minnesota Press, p. 53–71.
Wallace, W.K., 1976, Bedrock geology of the Ross Lake fault zone in the Skymo Creek area, North Cascades National Park, Washington: Seattle, University of Washington, M.S. thesis, 111 p.
Waters, A.C., 1932, A petrologic and structural study of the Swakane gneiss, Entiat Mountains, Washington: Journal of Geology, v. 40, no. 6, p. 604–633.
Wentworth, C.M., and Fitzgibbon, T.T., 1991, ALACARTE user manual (version 1.0): U.S. Geological Survey Open-File Report 91–587C.
Whetten, J.T., Carroll, P.I., Gower, H.D., Brown, E.H., and Pessl, F., Jr., 1988, Bedrock geologic map of the Port Townsend quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Series I–1198–G, scale 1:100,000.
Whetten, J.T., Zartman, R.E., Blakely, R.J., and Jones, D.L., 1980, Allochthonous Jurassic ophiolite in northwest Washington: Geological Society of America Bulletin, v. 91, pt. 1, no. 6, p. 359–368.
White, L.D., Maley, C.A., Barnes, I., and Ford, A.B., 1986, Oxygen isotope data for plutonic rocks and gneisses of the Glacier Peak Wilderness and vicinity, northern Cascades, Washington: U.S. Geological Survey Open File Report 86–76, 36 p.
Whitney, D.L., Miller, R.B., and Paterson, S.R., 1999, P-T-t evidence for mechanisms of vertical tectonic motion in a contractional orogen, northwestern United States and Canadian Cordillera: Journal of Metamorphic Geology, v. 17, p. 75–90.
Wynne, P.J., Irving, E., Maxson, J.A., and Kleinsphehn, K.L., 1995, Paleomagnetism of the Upper Cretaceous strata of Mount Tatlow—Evidence for 3,000 km of northward displacement of the eastern Coast Belt, British Columbia: Journal of Geophysical Research, B, Solid Earth and Planets, v. 100, no. 4, p. 6073–6091.
Yeats, R.S., 1958, Geology of the Skykomish area in the Cascade Mountains of Washington: Seattle, University of Washington, Ph.D. dissertation, 249 p.
Yeats, R.S., 1977, Structure, stratigraphy, plutonism, and volcanism of the central Cascades, Washington, Part I—General geologic setting of the Skykomish Valley, *in* Brown, E.H., and Ellis, R.C., eds., Geological excursions in the Pacific Northwest: Geological Society of America Annual Meeting, Seattle, Wash., Field Guide, p. 265–275.
Zollweg, J.E., and Johnson, P.A., 1989, The Darrington seismic zone of northwestern Washington: Seismological Society of America Bulletin, v. 79, no. 6, p. 1833–1845.