Northwest Geological Society

Society Field Trips in Pacific Northwest Geology

The Northwest Cascades System

In the Baker River and North Fork
Nooksack River Drainages

September 16 - 17 1995

Led By:

Ralph Haugerud, USGS

GUIDE FOR A 2-DAY EXCURSION THROUGH THE

NORTHWEST CASCADES SYSTEM

IN THE BAKER RIVER AND NORTH FORK NOOKSACK RIVER DRAINAGES

NORTHWEST GEOLOGICAL SOCIETY
SEPTEMBER 16-17,1995

Ralph A. Haugerud, U.S. Geological Survey
c/o Dept. of Geological Sciences. University of Washington, Box 351310. Seattle. WA 98195-1310
email: rah @geology. Washington, edu

GUIDE FOR A 2-DAY EXCURSION THROUGH THE

NORTHWEST CASCADES SYSTEM
IN THE BAKER RIVER AND NORTH FORK NOOKSACK RIVER DRAINAGES

Table of Contents

DISCLAIMER: This guide has not been reviewed. Not for consistency, nor completeness, nor conformance with U.S. Geological Sunvey editorial standards or the Code of Stratigraphic Nomenclature. Indeed, it is in part derived from a manuscript that is currently in review. It contains a few significant revisions to prior Stratigraphic nomenclature, revisions that may themselves be revised during USGS review. *This is gray literature: Use it with caution*!

INTRODUCTION

This report is a guide to a two day excursion through that part of the North Cascade Range that lies west of the Straight Creek fault between the Skagit River and the 49th parallel. The excursion examines pre-Tertiary rocks that were structurally stacked during mid-Cretaceous orogeny, overlying Eocene continental sedimentary rocks of the Chuckanut Formation, poorly-understood post-Chuckanut deformation, late Cenozoic glacial and volcanic history, and a catastrophic Holocene landslide.

What is the Northwest Cascades System?

Early Tertiary faults divide the North Cascade Range into several structural blocks, or domains (Fig. 1). The best known of these faults is the Straight Creek fault, which separates little-metamorphosed rocks in the western foothills from schist and gneiss in the heart of the range.

West of the Straight Creek fault, the North Cascades appear to be composed of two fundamental blocks separated by a complex tectonic belt and high-angle faults. The northeastern structural block, exposed primarily in the western half of the Mount Baker 30x60 minute quadrangle, is mostly composed of Paleozoic and Mesozoic volcanic arc and associated clastic wedge deposits along with more thoroughly metamorphosed oceanic rocks, thrust in the mid-Cretaceous into a series of nappes. Misch (1966, p. 128) defined the “mid-Cretaceous Northwest Cascades System” as a structural unit consisting of the nappe-bounding thrusts and associated structures. The overall structure was likened to a regional melange by Brown (1987), who expanded the Northwest Cascades System (NWCS) to include the rocks involved in these structures. In this guide, I follow Haugerud and others (1994) and also use NWCS to refer to the region in which these structures and rocks are exposed.

The NWCS is a triangular region bounded on the east by the Straight Creek fault, on the southwest by the Darrington-Devils Mountain fault zone, and on the northwest by the lower Fraser River, which roughly follows inferred faults of the Vedder discontinuity. The San Juan Islands appear to be within the NWCS, though there are unresolved questions regarding the correlation of rocks and structures on the mainland with those in the islands. The San Juans also contain lithologic units which have no correlatives in the area to the east.

How to use this guide

Some of the material in this guide is repeated and some of it is quite detailed and heavily referenced. The reader’s way may be smoother if she starts by completing this INTRODUCTION, looks at fig. 4 (a tectonostratigraphic

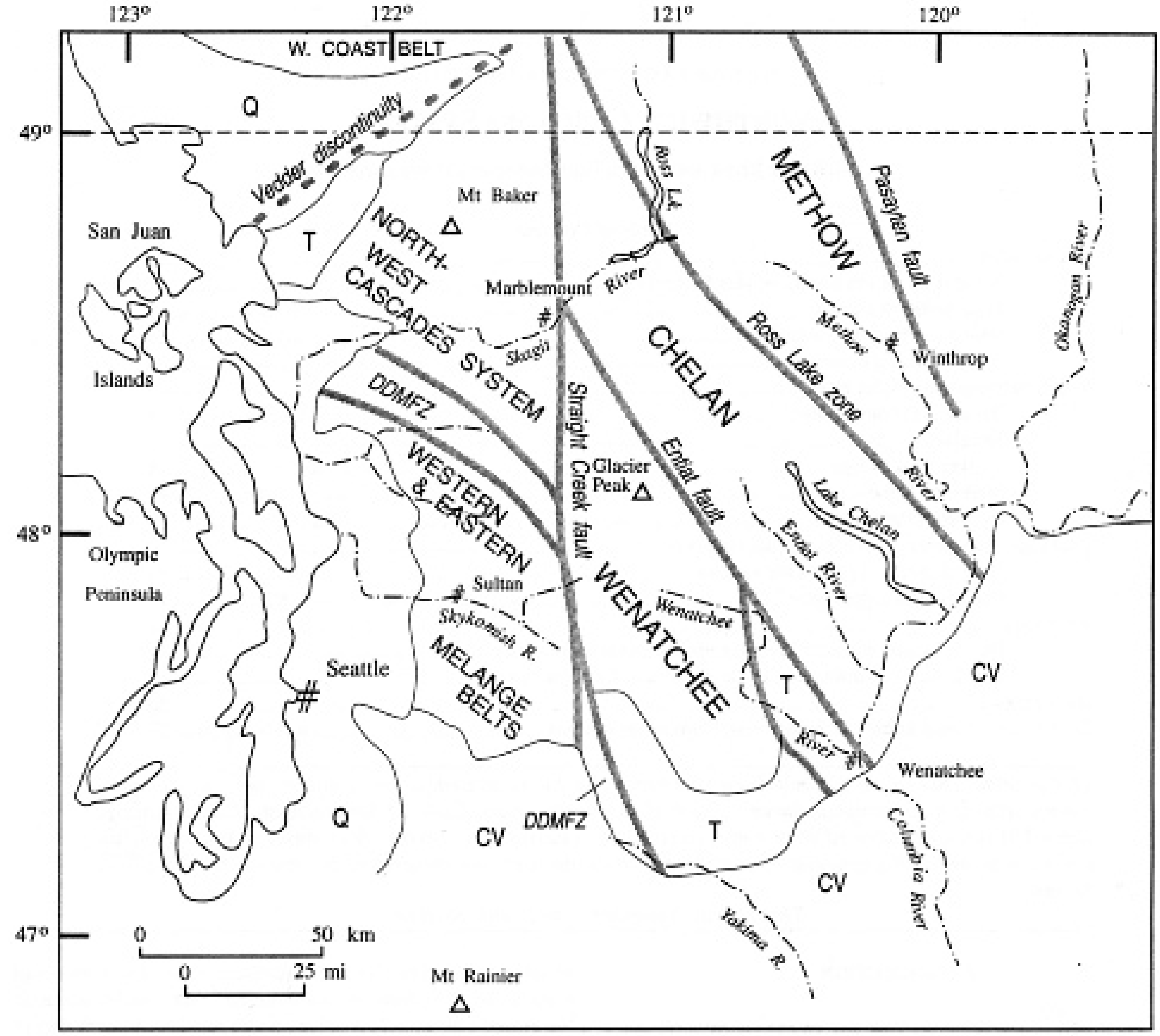


FIGURE 1. Map of Washington portion of North Cascades showing domains of contrasting lithology, metamorphism, and (or) structural style. T, early Tertiary continental sediments and associated volcanic rocks; Q, Quaternary deposits; CV, Cenozoic volcanic rocks of Cascade arc and Columbia River Basalt Group. DDMFZ, Darrington-Devils Mountain fault zone

column for the NWCS),and then reads the ROAD LOG, consulting the geologic map as needed. At such time as lithologic details, extensive references to other work, or speculations on geologic history are desired, consult DESCRIPTION OF MAP UNITS, TECTONOSTRATIGRAPHY OF THE NWCS, and LATE CENOZOIC HISTORY AND NON-VOLCANIC DEPOSITS.

Sources and acknowledgments

This guide includes much material from other works. TECTONOSTRATIGRAPHY OF THE NWCS is modified from Tabor and others (in preparation). The road log for Day 1 is slightly modified from Haugerud and others (1994). I have borrowed heavily from Misch (1977) in preparing the road log for Day 2. The geologic map and DESCRIPTION OF MAP UNITS are direct reproductions from Tabor and others (1994).

Wes Hildreth of the U.S. Geological Survey has been mapping and analyzing the volcanic rocks of Mount Baker during much of the last five years. Few results are reported here, as he has only published a preliminary abstract (Hildreth, 1994), but this work will significantly deepen our understanding of the late Cenozoic evolution of this area.

My knowledge of the NWCS, and the North Cascades as a whole, stems largely from a decade's work with Rowland Tabor, also with the U.S. Geological Survey. He has spent the last twenty years mapping the geology of the North Cascades at a scale of 1:100,000. The status of this effort is shown in figure 2. Many of the ideas and words in this guide are his, and he would be a co-author but that he has no responsibility for how I have mangled his prose. The authorial we of this guide is Tabor and Haugerud.

I would also like to acknowledge a great debt to Ned Brown, who taught my first geology course and started me working in the NWCS when I was a student of his at Western Washington University. The late Peter Misch, whose concepts still underlie much of our thinking about the range, taught me much (though perhaps not enough) about thinking widely and

writing carefully while I was a doctoral student at the University of Washington.

A brief geologic history

Pre-mid-Cretaceous rocks of the NWCS belong to several terranes. Incompatible environments recorded in Late Triassic oceanic (Elbow Lake Formation of Brown and others, 1987) and island-arc (Cultus Formation of Brown and others, 1987) rocks and Early Cretaceous arc-margin sediments (Nooksack Fm) and subduction zone (Easton Metamorphic Suite) are compelling demonstrations of allochthoneity. The NWCS also seems to contain fragments of three Middle Jurassic strati-graphic columns, in the Nooksack Formation, Cultus Forma¬tion, and Elbow Lake Formation.

Haugerud and others (1992) speculated that units within the Bell Pass melange, and perhaps the Bell Pass melange and the Chilliwack Group of Cairnes (1944) cum Cultus Formation of Brown and others (1987) were juxtaposed by Middle to Late Jurassic orogeny, but the evidence for this within the NWCS is circumstantial.

During mid-Cretaceous time—after deposition of Valanginian (Early Cretaceous, -138-131 Ma) Nooksack strata, after -120 Ma metamorphism of the Easton Metamorphic Suite, ‘before Eocene deposition of the Chuckanut Formation, and perhaps before deposition of Turonian (early Late Cretaceous, -90 Ma) and younger strata of the Nanaimo Group—disparate terranes were stacked by thrusting to produce the NWCS. Thrusting within the NWCS was part of late Mesozoic orogeny that thickened the crust throughout what is now the northern Cordillera.

Misch (1966) first described the thrust stratigraphy of the NWCS and attributed thrusting to west-verging shortening. Since his pioneering work, other workers (for instance, Brandon and Cowan, 1985; McGroder, 1991) have defended east-west or northeast-southwest shortening. Brown (1987) first proposed that the units were stacked by northwest-southeast shortening. Haugerud and others (1994) summarize evidence and arguments for these opposing views. Thrusting has been interpreted to be a second-order effect of major northwards translation (Brown, 1987), to reflect margin-normal shortening within a complex continental margin composed of various terranes previously juxtaposed by along-margin translation (Brandon and others, 1988), and to record accretion of the Insular terrane (McGroder, 1991).

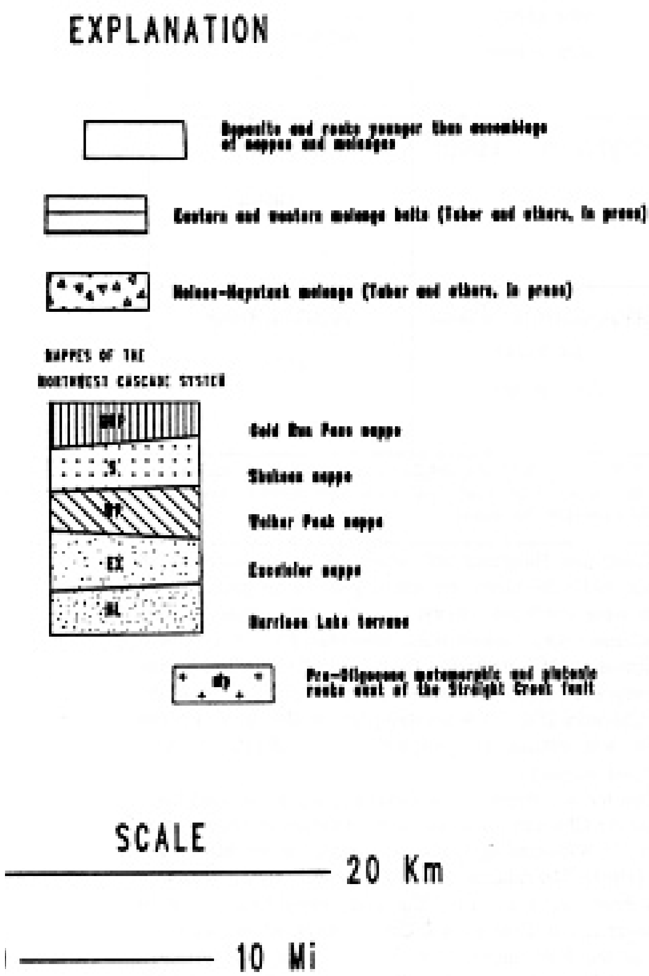
During the Eocene (especially the middle Eocene, 52-43 Ma) the over-thickened crust of the late Mesozoic orogen collapsed. Collapse seems to have been at the same time as, or slightly before, an episode of dextral translation along the continental margin. There is no agreement as to the relative importance of gravity, a change in plate interactions along the continental margin, and thermal softening by the early Tertiary magmatic arc in driving this collapse, but the results were striking. Within the North Cascades, the northeastern part of the crystalline core was rapidly unroofed (Haugerud and others, 1991), there was significant dextral strike-slip on the Ross Lake, Entiat, Straight Creek, and Darrington-Devils Mountain.fault zones (see Haugerud and others, 1994, for summary of evidence and references), numerous granitic to granodioritic plutons were emplaced, coeval volcanic rocks were erupted, and pull-apart basins subsided and filled rapidly with continen¬tal sediments that became the Chumstick, Swauk, Puget, and Chuckanut units (Johnson, 1985). The domainal structure of the North Cascades (Fig. 1) was established at this time. Eocene orogeny was almost as profound in its effects • as mid-Cretaceous orogeny.

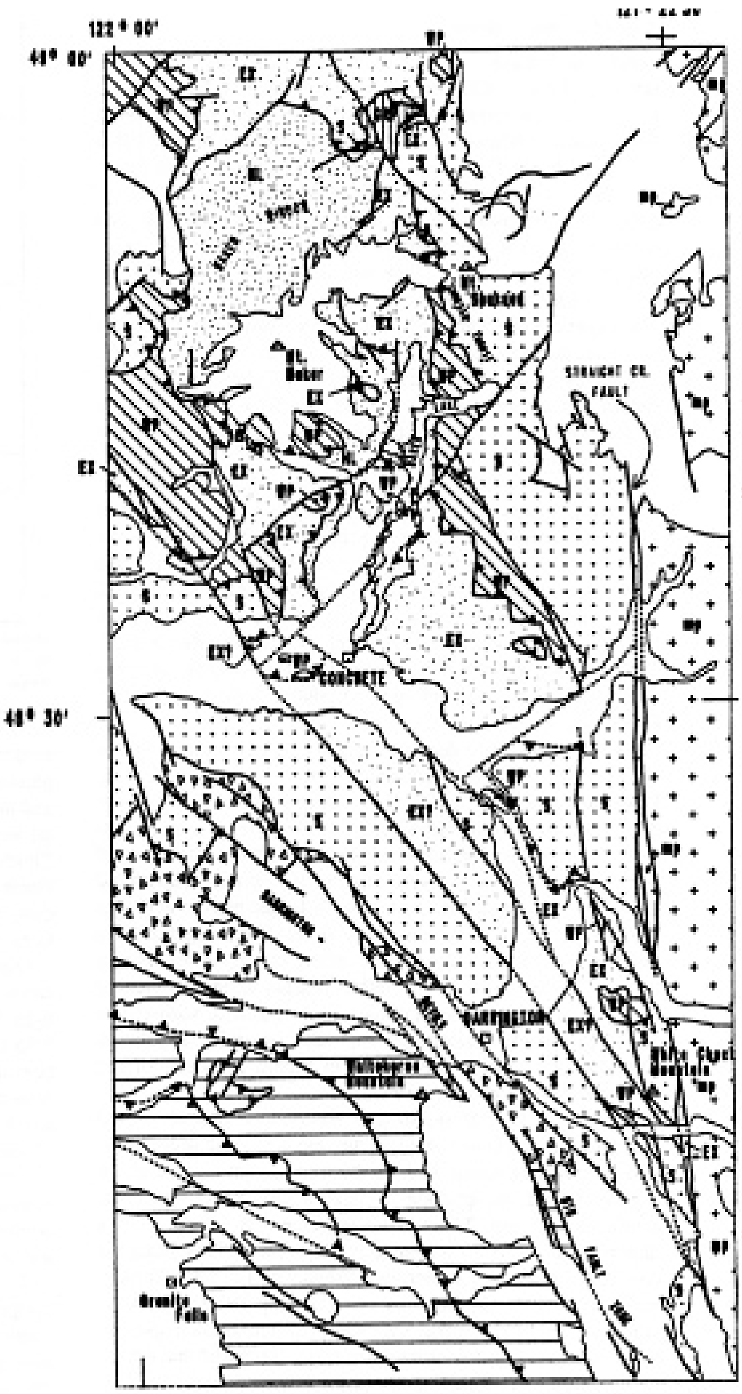
Figure 2. Status of U.S. Geological Survey 1:100,000-scale mapping in the North Cascades. I-maps are published Miscellaneous Investigations maps, OFR are open-file reports.

During the late stages of the Eocene event, or perhaps later, strata of the Chuckanut Formation were deformed into open to tight N- to NW-trending folds, best described by Miller and Misch (1963). The folds may have been mechanically linked to coeval thrust faults, as in the Cowichan thrust belt of eastern Vancouver Island (England and Calon, 1991), which lies along strike to the NW, though this has not been demonstrated. Miller and Misch (op. cit.) described evidence that most folding predates the Late Eocene Huntingdon Formation, though subsequent workers (e.g. Johnson, 1982, 1985) have not confirmed the existence of an angular unconformity at all the locales described by Miller and Misch.

The Chuckanut is also involved in a significant extensional faulting; see Stop 2-4. The tectonic context of this fault is unknown. Its age is poorly constrained, but probably middle Tertiary (Late Eocene to Oligocene). Down-to-the-SE high-angle normal faults control the present distribution of the Chuckanut Formation; it is preserved in the hanging walls of the Boulder Creek and Anderson faults and in the hanging wall of an unnamed fault along the Skagit valley NE of Rock-

3 The NWCS may have been at the latitude of southern Mexico during mid-Cretaceous time; we are within (or outboard of) that pan of the Cordillera tor which there is sound paleomagnetic evidence for -3000 km of northwards translation since about 90 Ma (Wynne and others, 1995)





ure 3. Generalized map of nappes of the Northwest Cascade System and melange belts to the southwest

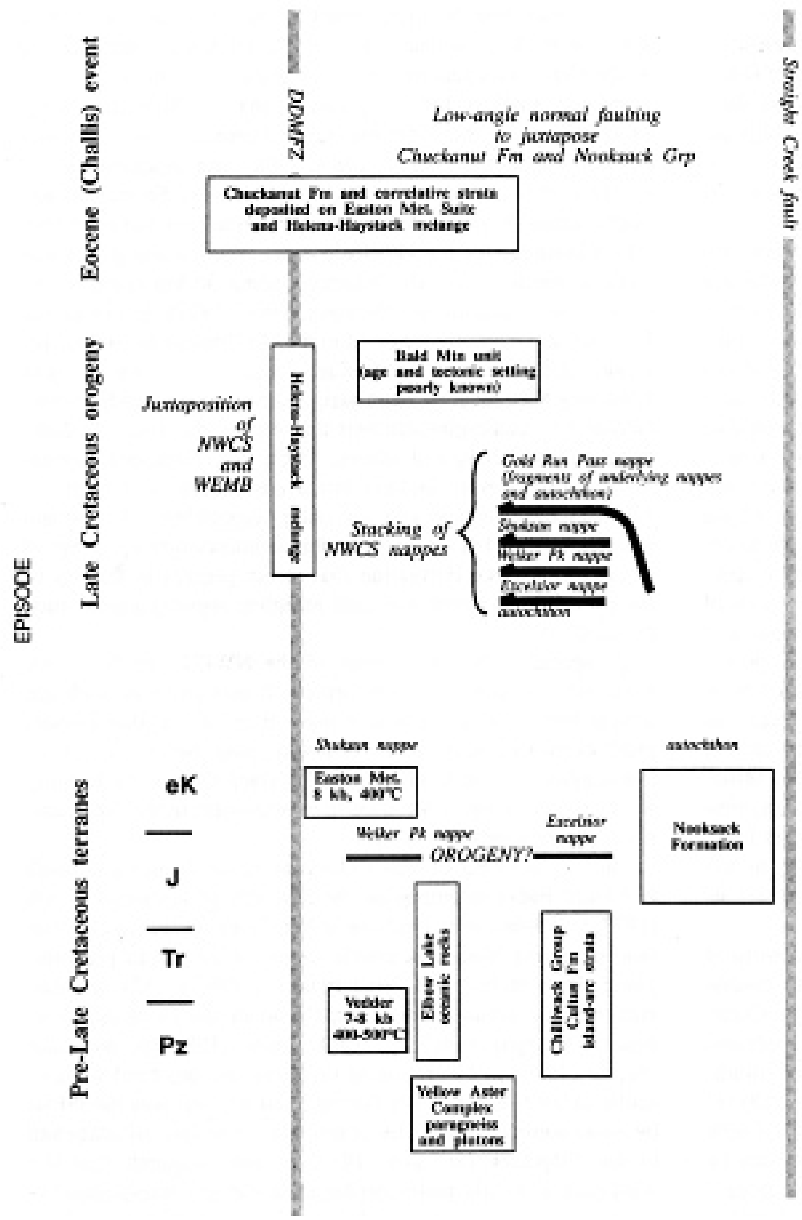


Figure 4. Tectonostratiographic column for the Northwest Cascades.

probably reflects the operation of arc processes (magmatic and tectonic underplating, thermal expansion, etc.) on crust with previously-established differences in composition. Late Cenozoic tectonism within the NWCS is not evident, perhaps largely because of the lack of suitable marker horizons. Land forms within the NWCS must reflect repeated glaciation during the Pleistocene, but no depositional record has been recognized for any glaciation older than the last, Fraser, event.

TECTONOSTRATIGRAPHY OF THE NWCS

Four major nappes, stacked along folded thrusts, and their probably autochthonous footwall comprise the pre-Tertiary NWCS (Fig. 3, 4). The structural stratigraphy of the NWCS appears to be consistent over a wide area of northwest Washington. The rocks in the three lowermost nappes and the autochthon differ enough in lithology, structure, and metamorphic history to warrant consideration as separate terranes (Tabor and others, 1989; Haugerud and others, 1994), whereas the highest and youngest nappe consists of slices of the lower nappes and autochthon.

Rocks of the autochthon

The Nooksack Formation (revised nomenclature) and its basal and interfingering Wells Creek Volcanic Member (revised nomenclature) comprise the lowest structural package in the NWCS. The Middle Jurassic to Early Cretaceous Nooksack Formation characteristically varies from thick, massive black argillite beds with minor lithic subquartzose sandstone interbeds to predominantly thick sandstone and (or) conglomeratic beds with minor black argillite interbeds. The argillite interfingers with and overlies a thick sequence of Middle Jurassic dacitic tuffs and flows. Argillite in the interbedded zone above the volcanic rock is rich in feldspar and quartz phenoclasts of probable pyrogenic origin.

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

We include in the Nooksack Formation Middle and Late Jurassic and Early Cretaceous clastic rocks and associated Middle Jurassic dacitic volcanic rocks exposed in the Nooksack and Baker River drainage. We designate the type area of the Nooksack Formation to be the valley walls of the North Fork Nook-sack River in the vicinity of 48°54' N, 121°53' W

port. Similar faults controlled emplacement of phases of the Chilliwack batholith that range in age from 26 to 12 Ma.

The Cascade magmatic arc fired up at about 36 Ma (Vance and others, 1986, 1987; Smith, 1993). Within the region of the NWCS, the arc is mostly represented by the Chilliwack composite batholith and volcanic rocks associated with Mount Baker. Plutons of the batholith range from gabbro to alaskite in composition and from 32 to 2.5 Ma (Oligocene to Pliocene) in age. Plutons of the batholith with ages of about 30 Ma and older appear to belong to the Index family of arc-root plutons as defined by Tabor and others (1989). Those in the range of about 30 to 20 Ma are in the Snoqualmie family. Plutons <20 Ma are in the Cascade Pass family, including the 2.5 Ma Lake Ann stock.

Significant relief in a region of high precipitation and the general lack of young deposits indicate that the range is actively rising. Gross topography of the North Cascades

(Glacier 7.5' quadrangle). We propose that the volcanic rocks be called the Wells Creek Volcanic Member of the Nooksack Formation. We designate the type area of the Wells Creek Volcanic Member to be lower Wells Creek, in the vicinity of 48°54' N, 12T48' W (Bearpaw Mountain 7.5' quadrangle).

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

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

The clastic part of the Nooksack Formation exposed north of Mount Baker contains a fairly rich fossil record with assemblages of definite Late Jurassic (Oxfordian) and Early Cretaceous (Valanginian) ages. Except for a few belemnite casts and radiolaria, fossils have not been found on the western, southern, and eastern sides of Mount Baker. Misch (1966, p. 118) reported Middle Jurassic or younger fossils in the Wells Creek Volcanic member. The Middle Jurassic age is corroborated by mildly discordant U-Pb ages of 173-187 Ma obtained from a dacitic tuff (J.M. Mattinson, in Franklin, 1985). The distribution of the youngest, Early Cretaceous fossil assemblages in the Nooksack near the town of Glacier requires faulting to bring relatively low dipping relatively younger strata into the valley bottom (Tanked by older strata on the canyon sides. Based on the fossil ages and bedding attitudes as well as consideration of the principle style of faulting in the NWCS, we have inferred an intraformational thrust fault bringing older Nooksack over younger, but high-angle faults could also be present.

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

At the top, the Nooksack Formation is bounded by the Excelsior Ridge Thrust. The base of the Wells Creek Volcanic Member is not exposed. Sondergaard (1979, p. 7) estimated the clastic part of the Nooksack to be between 5800 and 7300 m thick, but did not allow for folding or repetition by faulting.

We estimate that the clastic part of the Nooksack is at least 4300 m thick as exposed across Glacier Creek and that the Wells Creek Volcanic Member is at least 700 m thick. Misch (1966, p. 118-119) thought that his Nooksack Group correlated with the Harrison Lake Formation of Crickmay (1930). Tabor and others (1989, 1994) and Nockleburg and others (1995) included rocks of the Nooksack Formation and Wells Creek Volcanic Member in the Harrison Lake terrane, which is named for the Mesozoic strata exposed along Harrison Lake in southern British Columbia, some 30 km north of the Mount Baker quadrangle (Monger, 1986, 1993).

Rocks of the Harrison Lake terrane range from middle Triassic to middle Jurassic. Late Jurassic and early Cretaceous rocks of the Harrison Lake area have recently been assigned to the Gravina-Nutzotin-Gambier volcanic-plutonic belt that onlaps the Harrison Lake terrane (Nockleberg and others, 1995). The Nooksack Formation would seem to include strata correlative with both the Harrison Lake terrane and the onlap assemblage. Arthur and others (1993, p. 14) report a possible unconformity at the top of the Harrison Lake Formation that is not present at the top of the coeval Wells Creek Volcanic Member, arguing against such correlations.

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

The development of slatey cleavage varies from weak north of Mount Baker to strong on the east side of the peak. Misch (1977, p. 59-60) described the Wells Creek Volcanic Member (and overlying Nooksack clastic rocks) as altered in prehnite-pumpellyite facies, and Sondergaard (1979, p. 52) reported metamorphic prehnite and pumpellyite in the Nooksack Formation. Sevigny (1983, p. 104), Jones (1984, p. 47), and Ziegler (1986, p. 59) reported incipient development of law-sonite as well, but the very fine-grained mineral was identified by x-ray methods which are unreliable . The lack of aragonite in the Nooksack (Sevigny, 1983, p. 104) suggests that the Nooksack was only metamorphosed in the

---

^Brandon and Vance (1992, p. 597) and Brandon (written comm., 1991) have shown that even very rigorous x-ray and electron microprobe determinations of calcium aluminum silicates in fine-grained metamorphic rocks do not adequately discriminate between lawsonite and pumpellyite.

rehnite-pumpellyite facies in contrast to overlying nappes which contain lawsonite and aragonite indicative of higher pressures (see below). Brown and others (1981) discuss metamorphic assemblages in the Nooksack Formation.

Excelsior Nappe

Structurally overlying the Nooksack Formation along the Excelsior Thrust Fault (the Church Mountain thrust of Misch, 1966) is the Excelsior Nappe, consisting of rocks of the Paleozoic Chilliwack Group of Cairnes (1944) and the early Mesozoic Cultus Formation of Brown and others (1987). The Excelsior Nappe contains significant internal thrusts; rocks of the Chilliwack Group and Cultus Formation are regionally overturned, and they have penetrative fabrics in most locales, suggesting a pre-mid-Cretaceous, possible pre-Late Jurassic tectonic event not seen in the underlying Nooksack Formation.

A unit with similarities to the clastic facies of the Chilliwack Group, as well as other units in NWCS is the **slate of Rinker Ridge.** It is poorly exposed in the lower Skagit River valley of the Mount Baker quadrangle. Good exposures in the Sauk River quadrangle to the south (Tabor and others, in press) indicate that the slate of Rinker Ridge appears to be a fault bounded block within extensive outcrops of Easton Metamorphic Suite. Tabor and others (op. cit.) discuss the possible protoliths for the slate of Rinker Ridge and tentatively assign it to the Chilliwack Group.

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

Misch (1952; 1966, p. 116; 1979) included chert, some greenstone, argillite, and lithic graywacke in the Chilliwack Group which we include in the Elbow Lake Formation of Brown and others (1987) (see description of Bell Pass melange below). Within the Chilliwack Group we have mapped separately areas of predominantly mafic volcanic flows and breccias. In addition we show separately the volcanic rocks and sedimentary rocks of Mount Herman. Bedding is generally obscure in the volcanic rocks of Mount Herman, but where found is steeper than much of the bedding in other rocks of the Chilliwack Group.

Fossils are locally abundant in calcareous rocks of the Chilliwack Group and range from Silurian-Devonian to Permian in age. Distinctive 1- to 3-cm-diameter crinoid columnals led Danner (1966) to correlate many marble outcrops with his Red Mountain limestone unit, exposed west of the Mount Baker quadrangle, which he considered to be Pennsylvanian in age. Lisak (1982) restudied the Red Mountain fauna and determined a Mississippian (late Visean) age for it, which we adopt for all the large-crinoid limestones of the Chilliwack Group. Single crystal U-Pb ages of detrital zircons from Chilliwack clastic rocks in the Jackman Creek area suggest Late Devonian deposition of the original sediments (McClelland and Mattin-son, 1993). The irregular distribution of Devonian, Mississippian, Pennsylvanian, and Permian fossils substantiates the complex structure shown by bedding features and suggests that few Intact stratigraphic sections remain.

The youngest rocks of the Chilliwack Group are the well-bedded sedimentary rocks of Mount Herman. However, the kinship of rock that bears fossils with the volcanic rocks of Mount Herman is not unassailable. Guadalupian (Late Permian)(?) radiolaria were found in a small block of well-bedded siliceous siltstone that overlies Pliocene ignimbrites of the Kulshan Caldera and to the southwest is in contact with meta-tonalite in the caldera wall, The siltstone is presumably a block that slid from the caldera wall, presumably from the nearby volcanic rocks of Mount Herman, but we found no similar sedimentary rocks with the nearby undisturbed Mount Herman strata. However, the distinctive strata of the block are identical to well-bedded siltstone that we have found southwest of Lake Ann as talus blocks below cliffs of hornfelsic sediment which we map as the sedimentary rocks of Mount Herman.

The rocks of the Chilliwack Group grade from little-deformed to strongly penetratively deformed with phyllitic foliation mostly parallel to bedding. Where metamorphosed the rocks are recrystallized to phyllite, semischist, greenstone, or greenschist, mostly in sub-greenschist facies. Lawsonite and aragonite occur throughout the Chilliwack Group and in the Cultus Formation of Brown and others (1987). Brown and others (1981, p. 172-173) and Smith (1986) describe metamorphic mineral assemblages of the Chilliwack Group. Bedding data and original top directions shown by graded beds, scour structures, and load casts indicate complex structure including large areas of terrane turned completely upside down. As the underlying Nooksack Formation appears generally less-recrystallized and has much simpler structure, we surmise that the Chilliwack was strongly deformed, although perhaps not metamorphosed, prior to formation of the mid-Cretaceous nappes (Haugerud and others, 1992). Smith (1986, p. 131-134) and Brown (1987, p. 209) suggest that the metamorphism was mid-Cretaceous.

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

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

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

In the Mount Baker quadrangle, radiolarians from several localities are Triassic in age, but in the area of Frost Creek, a chert layer yields probable Middle to Late Jurassic radiolarians. Chert pods in faulted rocks on the ridge north of Canyon Creek yield Triassic(?) radiolaria. The rocks at this site are well-bedded limestone with tuffaceous argillite and siltstone interbeds, typical of the Cultus. Unfortunately Daly (1912, p. 510, 515) reports a collection of Paleozoic fossils typical of the Chilliwack from very near this locality (as best as can be determined from the old descriptions). We have inferred a fault between the two fossil localities. Monger (1970, p. 12-13) reports fossil ages from Late Triassic to Late Jurassic in the Cultus of British Columbia. For further descriptions, see Monger (1966, p. 91-102; 1970, p. 11-14) and Blackwell (1983, p. 70-74).

Gabbroic and tonalitic intrusions—Several mappable metagabbro and metatonalite bodies intrude rocks of the Chilliwack Group and Cultus Formation. Some were mapped by previous workers as tectonic blocks of the Yellow Aster Complex of Misch (1966), but locally show good evidence of intrusion. See the description of the Bell Pass melange below for further discussion of this problem. The best examples are gabbro intruding Chilliwack north of Canyon Creek and the large meta-hornblende tonalite body southwest of Lake Ann; the latter is described by Ziegler (1986, p. 99-103). Blackwell (1993, p. 105-106, 213) describes and reports chemical data for a gabbroic body on the south side of Loomis Creek.

Welker Peak Nappe

The Chilliwack Group and Cultus Formation are overlain along the Welker Peak Thrust by the Bell Pass melange, much of which is comprised of the Elbow Lake Formation of Brown and others (1987), a melange-like assemblage of foliated sandstone, argillite (phyllite), ribbon chert, basalt, and very rare marble. Commonly in or associated with the Elbow Lake assemblage are ultramafic rocks, various blocks of gneiss and schist, and granitoid rocks ranging from granite to gabbro in composition. These rocks make up the Welker Peak Nappe. In part, the Bell Pass melange is coincident physically and in concept with the thick tectonic zone at the base of the mid-Cretaceous Shuksan Thrust Fault as described by Misch (1966, 1980), which separates more thoroughly metamorphosed rocks of the Easton Metamorphic Suite—equivalent to Misch's (1966) Shuksan Metamorphic Suite—from the structurally underlying Nooksack Formation, Chilliwack Group, and Cultus Formation. However, we suspect that some of the mixing and deformation within the Bell Pass melange predates mid-Cretaceous tectonism and is unrelated to the Shuksan Thrust. Some parts of the Bell Pass in which tectonic mixing is more severe were mapped as melange by Brown and others (1987). Although all contacts of the exotic blocks are probably faults, we show them as unfaulted except in the case of very large phacoids such as the Twin Sisters Dunite and the large slabs of Yellow Aster Complex at Yellow Aster Meadows and at Park Butte.

The Elbow Lake Formation of Brown and others (1987) consists of highly disrupted lithic subquartzose sandstone, argillite, wispy mafic tuff and argillite, ribbon chert, and greenstone. The latter two lithologies dominate locally. Small marble phacoids are also present. Clastic rocks grade rapidly to slate, phyllite, and semischist. Within the Mount Baker quadrangle there are no areas free of outcrop-scale disruption; we cannot describe an undisturbed stratigraphic section of the Elbow Lake Formation.

Most earlier workers included rocks of the Elbow Lake Formation in the Chilliwack Group (Misch, 1966, p. 116, 1979; Vance, 1957, p. 200-210; Rady, 1980, p. 86-88). Haugerud (1980, p. 62-87) recognized the fragmented, mixed character of some of these rocks, and Blackwell (1983, p. 81-86), Sevigny (1983, p. 93-97), Jones (1984, p. 63-69), Ziegler (1986, p. 66), and Leiggi (1986, p. 45-46), distinguished these rocks as the Elbow Lake unit, the chert-basalt unit, or the Haystack Mountain unit.

Greenstone in the Elbow Lake Formation is derived from Ti-rich oceanic basalt, including, mafic tuff, diabase, and gabbro. Based on lithology and some basalt chemistry, several workers (Sevigny, 1983, p. 93-97; Blackwell, 1983, p. 85-86; Jones, 1984, p. 69; Leiggi, 1986, p. 45^48) correlated the lithologies of the Elbow Lake Formation with the Haystack unit of Cruver (1983), exposed near Haystack Mountain about 9 km southwest of the Mount Baker quadrangle. There are some chemical differences as discussed by Tabor (1994) who also suggested that the Haystack unit is part of the Helena-Haystack melange, a tectonic unit younger than the Bell Pass melange, characterized by a very different tectonic assemblage.

Sevigny and Brown (1989) report chemical characteristics of the high-Ti metabasalts of the Elbow Lake Formation of Brown and others (1987).

Ribbon chert of the Elbow Lake Formation, commonly highly deformed and locally occurring as resistant knockers, yields mostly Triassic and Jurassic radiolarians; a few late Paleozoic forms have been identified. Late Jurassic radiolarians sampled in the northwest corner of the Mount Baker quadrangle are anomalously young and, based on correlations with rocks in the San Juan Islands and structural arguments, may be from the otherwise-undated clastic portion of the Elbow Lake Formation.

Metamorphism in rocks of the Elbow Lake Formation is generally sub-greenschist facies, locally with pumpellyite and lawsonite (Blackwell, 1983, p. 80). Very fine-grained blueschist crops out locally within the Elbow Lake Formation. This rock, the **blueschist of Baker Lake** (Baker Lake Blueschist of Brown and others, 1987), is characterized by dis¬tinctive high-pressure/low-temperature crossite + lawsonite + aragonite metamorphism. The protolith assemblage for the blueschist—especially basalt with high-Ti clinopyroxene—ap¬pears correlative with the chert-basalt association within the Elbow Lake unit, which appears to be largely Triassic and older, thus suggesting that metamorphism is post-Late Triassic. Brown and others (1987) report a 127 Ma whole-rock K-Ar age of uncertain significance from the Baker Lake unit. Leiggi (1986, p. 113-136), Ziegler (1986, p. 85-92), and Brown and others (1987) describe petrographic, mineralogic, and chemical aspects of the blueschist of Baker Lake

Misch (1960, 1966, p. 104-105, 1963) described pyroxene gneiss, variously deformed and metamorphosed tonalitic to gabbroic intrusions, and ultramafic rocks as his **Yellow Aster Complex**, which he thought was basement to the volcanic and sedimentary rocks of the NWCS. Since Misch's mapping, we have identified other lithologies in the Yellow Aster Complex, including definite supracrustal materials such as marble and associated calc-silicate gneiss. Gneissic megacrystic granite crops out on Kidney Creek, northeast of Church Mountain. The association of gneiss and mostly-mafic igneous rocks is typical of the Yellow Aster, but in many areas distinguishing younger (that is upper Paleozoic and (or) Mesozoic) intrusions from older intrusive material that was emplaced tectonically is difficult. We have separated crystalline rocks, all of which were formerly mapped as Yellow Aster Complex, into 4 units:

1) Gneissic rocks of the Yellow Aster Complex of Misch (1966). Well-layered pyroxene gneiss, calc-silicate gneiss and associated marble and meta-igneous rocks. Strongly mylonitic quartz-rich tonalites are distinctive members of this association, and thus, even where we have not identified layered gneisses we have mapped these tonalites as part of the gneissic rocks of the Yellow Aster.

2) Non-gneissic rocks of the Yellow Aster Complex of Misch (1966). Meta-igneous rocks, not associated with layered gneiss, with no evidence of preserved intrusive contacts with supracrustal units that would indicate a late Paleozoic or younger age. We observe or infer their structural setting to be comparable with that of nearby layered gneisses of the Yellow Aster Complex.

3)Mesozoic and Paleozoic intrusions which we divide into subunits of tonalitic and gabbroic intrusions. These rocks generally show direct evidence of intrusion into Chilliwack Group or younger units or their structural position suggests that they are intrusions, not tectonically emplaced slivers. They may be deformed and metamorphosed, but are not conspicuously mylonitic.

4)Ultramafic rocks. These are serpentinite or serpentinized harzburgite, described by Sevigny (1983, p. 84-92) and Leiggi (1986, p. 49-84).

Rocks of the Yellow Aster Complex of Misch (1966) have a sub-greenschist-facies metamorphic overprint, with pumpelly-ite and prehnite (Brown and others, 1981). Misch (op. cit.) suggested that, although one could only say with certainty that the age of the Yellow Aster was pre-Devonian, the evidence of a long history of multiple metamorphism and intrusion in the complex suggested that the older components might be Precambrian. With recognition that elements of the NWCS may constitute distinctly unrelated terranes, even the certainty that the Yellow Aster is pre-Devonian has evaporated. Discordant U-Pb ages of zircon and sphene from pyroxene gneisses range from 64 to 912 Ma. Mattinson (1972) interpreted a 1.4 Ga (Proterozoic) Pb-Pb age for pyroxene gneiss, thought to be orthogneiss, to represent a minimum protolith age for rocks metamorphosed at about 400 Ma (Devonian) and perhaps at about 270 Ma (Permian) as well. Rasbury and Walker (1992) report similar analyses of single zircon grains from similar gneiss, but interpret the zircons to be detrital relicts of 1.85 Ga crust, nevertheless deposited in the Proterozoic (Rasbury and Walker, written commun. 1995). Zircons from a metatonalite block in the Bell Pass melange above Anderson Creek yield discordant U-Pb ages of about 330-390 Ma, suggesting igneous crystallization in the mid-Paleozoic.

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

Scattered irregularly throughout the Bell Pass melange are outcrops of the **Vedder Complex** of Armstrong and others (1983). Most of the Vedder is well-recrystallized siliceous schist and amphibolite metamorphosed in high-pressure albite-epidote amphibolite facies. In the Mount Baker quadrangle, K-Ar ages range from 196 to 283 Ma. On Vedder Mountain, Rb-Sr ages of minerals and rocks are in the

229- to 285-Ma range (Armstrong and others, 1983). Petrographic, chemical, and isotopic data are in Armstrong and others (1983).

Conglomerate of Bald Mountain—Coarse bouldery conglomerate rich in chert cobbles holds up the steep slopes of Bald Mountain, northwest of Glacier. Highly strained sandstone and slatey argillite associated with the conglomerate indicates the unit has participated in Mesozoic orogeny; lack of penetrative deformation in the main mass of the conglomerate is probably due to its strength. Poorly preserved pollen from a mudstone interbed in the massive conglomerate suggests a Late Cretaceous to early Tertiary age (E. Leopold, written comm. to S.Y. Johnson, 1980). We consider its age to be Late Cretaceous.

Misch (1996, p. 103) thought that the Bald Mountain rocks were possibly correlative with the Late Triassic to Early Jurassic Cultus Formation of Daly (1912), but the unit is unlike the Cultus lithologically. Two chert clasts yield possible Triassic and Late Triassic radiolarians, indicating derivation of the chert clasts from the nearby Elbow Lake unit, and supporting a post Cultus age. Based on similarity to nearby Tertiary conglomerate and the ambiguous age call on pollen (see above), Johnson (1982, p. 50-54) considered these rocks to be part of the Eocene Chuckanut Formation. See Johnson (op. cit.) for further descriptions.

We correlate a small outcrop of chert pebble conglomerate in a fault zone east of Goat Mountain with the conglomerate of Bald Mountain. If the correlation is correct, the faulted sliver indicates latest Cretaceous movement on some thrust faults of the NWCS. Just off the Mount Baker quadrangle, another sliver of conglomeratic sandstone caught up in high angle faults west of the Twin Sisters Dunite of Ragan (1963) may be a correlative of the Bald Mountain rocks. The rock is a lithic subquartzose sandstone with up to 10% K-feldspar and abundant chert grains. The rock is not penetratively deformed but locally highly sheared and imbricated with low-grade metavolcanic rocks. A FT age of detrital zircon is between 60 and 73 Ma (J.A. Vance, written comm. to R.W. Tabor, 1992) suggesting a depositional age of Late Cretaceous.

The structural position of the Bald Mountain rocks is uncertain. They appear to be part of the Welker Peak nappe, but alternately may have been deposited on top of the NWCS stack after it was imbricated and partly eroded.

Shuksan Nappe

The **Easton Metamorphic Suite**, also referred to as the Easton terrane (Tabor and others, 1989), is composed of the Shuksan Greenschist and the Darrington Phyllite. This unit has been referred to by many workers as the Shuksan Metamorphic Suite of Misch (1966) and (or) the Shuksan Suite of Brown (1986). It generally overlies lower nappes along the Shuksan Thrust Fault. The Easton Metamorphic Suite within the NWCS extends about 88 km southeast of the Mount Baker quadrangle and is exposed east of the Straight Creek Fault in the vicinity of the upper Yakima River. The Easton records a more thorough episode of high P/T metamorphism than most other units in the NWCS.

Much has been written about the Shuksan Greenschist and Darrington Phyllite, beginning with the pioneering work of Vance (1957, p. 12-60) and Misch (1959, 1966, p. 109-112). Brown (1974, 1986), Morrison (1977), Haugerud (1980), Haugerud and others (1981), Street-Martin (1981), Brown and others (1982), Dungan and others (1983), Armstrong and Misch (1987), and Owen (1988), report petrologic, chemical and isotopic data and describe the Easton Metamorphic Suite. Brown and Blake (1987) discuss the correlation of the rocks of the Easton Metamorphic Suite with similar units in Oregon and Washington. We summarize briefly here.

Shuksan Greenschist is predominantly well-recrystallized, but fine-grained, epidote-chlorite-amphibole-quartz albite schist. The amphibole is typically crossite, Na-actinolite, or actinolite, depending mostly on the bulk-rock Fe’+ content. Epidote balls, knots, and masses formed during early static hydrothermal metasomatism; the balls are vesicle fillings (Haugerud, 1980; Haugerud and others, 1981; compare with Misch, 1965). Co-occurrence of abundant white mica, Na-amphibole, and hematite suggest oxidation and incorporation of potassium during submarine weathering. Haugerud and others (1981, p. 380) and Brown (1986, p. 151) indicate that the Easton Metamorphic Suite crystallized at T = 330-400° C and P = 7-9 Kb.

Chemistry and relict textures indicate that the Shuksan Greenschist was derived from mid-ocean-ridge basalt (MORE) (Dungan and others, 1983). Relict textures indicate that much of the protolith was pillows or breccia; well-layered, Fe^{3+}-poor metatuff with conspicuous patches of albite relict after plagioclase phenocrysts are locally abundant.

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

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

Armstrong (1980) and Brown and others (1982, p. 1095) proposed that the protolith age of the Easton

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

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

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

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

Gold Run Pass Nappe

Distinctive belemnite-bearing argillite of the Nooksack Formation, Chilliwack Group rocks, chert of the Elbow Lake unit, Yellow Aster Complex, and Darrington Phyllite are stacked on top of Darrington Phyllite in the Winchester Mountain-Yellow Aster Meadows area. This is the evidence for existence of the Gold Run Pass nappe, which must have formed after the underlying nappes were assembled, though perhaps during the same deformational episode.

LATE CENOZOIC HISTORY AND NON-VOLCANIC DEPOSITS

Glacial chronology and ice sources

During the last glaciation, glaciers existed at different times in the central Cascade Range and in the Puget Lowland. Glaciers local to the Cascades are conventionally known as “alpine”, whereas glaciers that flowed south from British Columbia and covered the Puget Lowland are called “Cordilleran.” The latest major alpine advance was the Evans Creek stade of the Fraser glaciation of Armstrong and others (1965), which culminated at about 20,000 yr. B.P. The latest major Cordilleran ice advance, named the Vashon stade of the Fraser glaciation by Armstrong and others (1965), reached its maximum after about 15,000 yr. B.P. Ice-flow indicators, evidence of the ice-surface slope, and drift lithologies all indicate a northern, Canadian, source for Vashon ice in the Puget Lowland. South of the Mount Baker quadrangle, the alpine glaciers of the Evans Creek stade had retreated prior to Vashon-stade Cordilleran glaciation. Tongues of Puget lobe ice advanced up trunk valleys an insufficient distance to meet any remnant or revitalized downvalley-flowing Cascade glaciers.

In the Mount Baker quadrangle, the distinction between alpine and Cordilleran ice is less obvious. Evidence in the Puget Lowland for the northward rise of the Vashon ice-sheet surface—with predicted ice-surface elevation of about 1500 m west of the quadrangle (Booth, 1987, p. 81)—and evidence in the Pasayten area to the east for the upper limit of Cordilleran ice (Waitt, 1972; Haugerud and Tabor, in preparation) make it clear that Vashon ice blanketed the quadrangle. Geomorphology, clast provenance, and local paleocurrent indicators demonstrate that the thick drift accumulation in the lower Skagit and Baker River valleys was derived from Cordilleran ice. Nonetheless, glacial erratics at modest elevations in the Baker River drainage indicate an eastern, Cascade source. Numerous glaciers decorating the higher peaks of the North Cascades at present suggest that in any colder climate the higher peaks would also be ice source areas.

We propose that at least in the vicinity of the high peaks of Mount Redoubt, the Picket Range, Mount Shuksan, Mount Baker, and the Snowfield-Eldorado massif, the Cordilleran ice sheet must have been nourished by local cirque glaciers and thus must have sloped outward from these local sources. Precipitation on the high, extensive ice upwind to the west may have starved these local glaciers, minimizing the outward slope.

Evolution of topography

We know little about how the topography of the North Cascades evolved. The present land surface cuts across middle and late Eocene strata, and thus must be younger, though in the vicinity of Vancouver, B.C. the southern slope of the Coast Mountains is conformable with late

Eocene strata and may be essentially a dissected, warped late Eocene surface.

The topography around Mount Shuksan is strongly discordant to the 2.5 Ma Lake Ann stock, indicating that present land forms were eroded after that time. Present topography is also discordant to the Kulshan caldera, suggesting that cutting of present ridges and valleys is largely younger than -1.0 Ma. Rainbow Divide and Forest Divide radiate from Mount Baker and are capped by valley-filling lava flows whose form is reminiscent of the present landscape. This suggests that a drainage pattern which approximates the present pattern was established by the time the ridge-capping flows were erupted. The bases of the ridge-capping flows are typically several hundred meters above the adjacent valleys and the rate of erosion in this area could be determined if the ridge-capping flows were dated.

Drainage derangement—After the Vashon ice maximum the Skagit River must have drained south via the Sauk and Stillaguamish Rivers, just south of the Mount Baker quadrangle. As described by D.B. Booth (in Tabor and others, in press), "the Sauk River beheads a major west-trending spur of the Cascade Range and so links two major river valleys, the Skagit and the lower North Fork of the Stillaguamish Rivers, along a valley conspicuously athwart the regional drainage pattern. For most of the Vashon stade (and preceding Cordilleran ice advances), first subglacial and then proglacial meltwater from the upper Skagit River basin would have drained south along this channel, because the ice sheet thinned to the south. A plug of Vashon-age sediments, with an upper surface above 300 m elevation, blocked the Skagit valley just west of its confluence with the Sauk River (Heller, 1978; Tabor and others, 1994) and so maintained this diversion throughout ice occupation and well into the recessional history of the area: "The Skagit valley plug was eventually breached near the town of Concrete, probably by incision by the Baker River and other local flows draining over the top of the sediments, together with piping on the steep downvalley face by emergent groundwater once the ice tongue had retreated farther west". Booth (in Tabor and others, in press) further explains drainage diversions near Darrington that rerouted the Skagit and the Sauk Rivers northward again to drain out the modern Skagit Valley.

Prior to the Pleistocene a roughly east-west drainage divide appears to have separated the north-flowing Chilliwack, upper Skagit, Pasayten, and Ashnola rivers from south-flowing Baker, lower Skagit, and Methow rivers, as hypothesized by Riedel and Haugerud (1994). Advancing Cordilleran ice blocked the north-flowing drainages and formed proglacial lakes which overflowed at the lowest saddles along the divide. The large discharges rapidly lowered the divides and moved them northward. Ice scour during maximum glaciation and fluvial erosion during ice recession broadened and further lowered the breaches in the divides. This cycle would have been repeated during each glaciation. The Skagit River Gorge between Newhalem and Diablo marks the former divide at the head of the lower Skagit River. The north-flowing upper Skagit drained into the Fraser River via Klesilkwa River and Silver-hope Creek, through a pass that has a present elevation of about 520 m. This idea was earlier discussed briefly by Weis (1969) and discounted by Waitt (1977), who thought that the anomalous gorge could be explained by localization of alpine and Cordilleran ice sculpture. When the regional drainage pattern is considered, however, the early idea is once again attractive.

ROAD LOG

Day 1. Seattle to Sedro Woolley via the Baker Lake area

Mileage

Leave Seattle and drive north on 1-5 to Burlington, exit and go east on Washington State Route 20 (SR 20). Log begins about 45 miles north of Seattle. Total driving distance for day I is about 180 miles. Mileage below corresponds to mileposts on 1-5

216.0 Mount Vernon 10 miles.

Surrounding area is underlain by Vashon till and minor recessional outwash, with low-relief N-S flutes. This fluted till plain forms most of the Puget Lowland south of a line extending approximately from Port Townsend to Mount Vernon. Till is a thin (a few meters in most places) mantle to an extensive, locally thick blanket of lacustrine and fluvial sediments laid down during the advance of the Vashon ice sheet. The constructional surface of the advance outwash deposit, graded to its discharge via the Chehalis River, forms a low-relief upland at an elevation of 60-180 m that is the dominant landform in the central and southern Puget Lowland. In the short time between advance of the Vashon lobe after -15 ka and its retreat by -13 ka, sub-glacial meltwater cut Puget Sound, Hood Canal, Lake Washington, and similar north-south troughs into the advance outwash deposit (Booth, 1994).

Farther north, much of the Puget Lowland is mantled by a smooth blanket of glaciomarine drift, depos¬ited beneath a floating ice shelf late in the Vashon stade. **2.5**

218.5 Begin descent into Skagit valley.

The lower Skagit valley must have been cut into the Puget Lowland by the Skagit River after the Vashon lobe melted, after sufficient isostatic rebound to bring this area above sea level, and while global sea level was still low enough for base level to be lower than at present (Fig. 5). The valley has subsequently been filled with Holocene Skagit River alluvium. 2.5

221.0 Exit for Conway and La Connor. **1.4**

222.4 Notch to east is trace of southern strand of the Devils Mountain fault. This east-west fault is part of the regional Darrington-Devils Mountain fault zone, which separates the NWCS to the north from the western and eastern melange belts to the south. Outboard of the melange belts are the Olympic Mountains, composed of Tertiary clastic marine rocks and submarine basaltic rocks of the Coast Range basalt (sometimes called Siletzia terrane), emplaced against the North American continent in middle Eocene time, at about 50 Ma.

The Darrington-Devils Mountain fault may continue west via the Leech River fault to the West Coast fault on

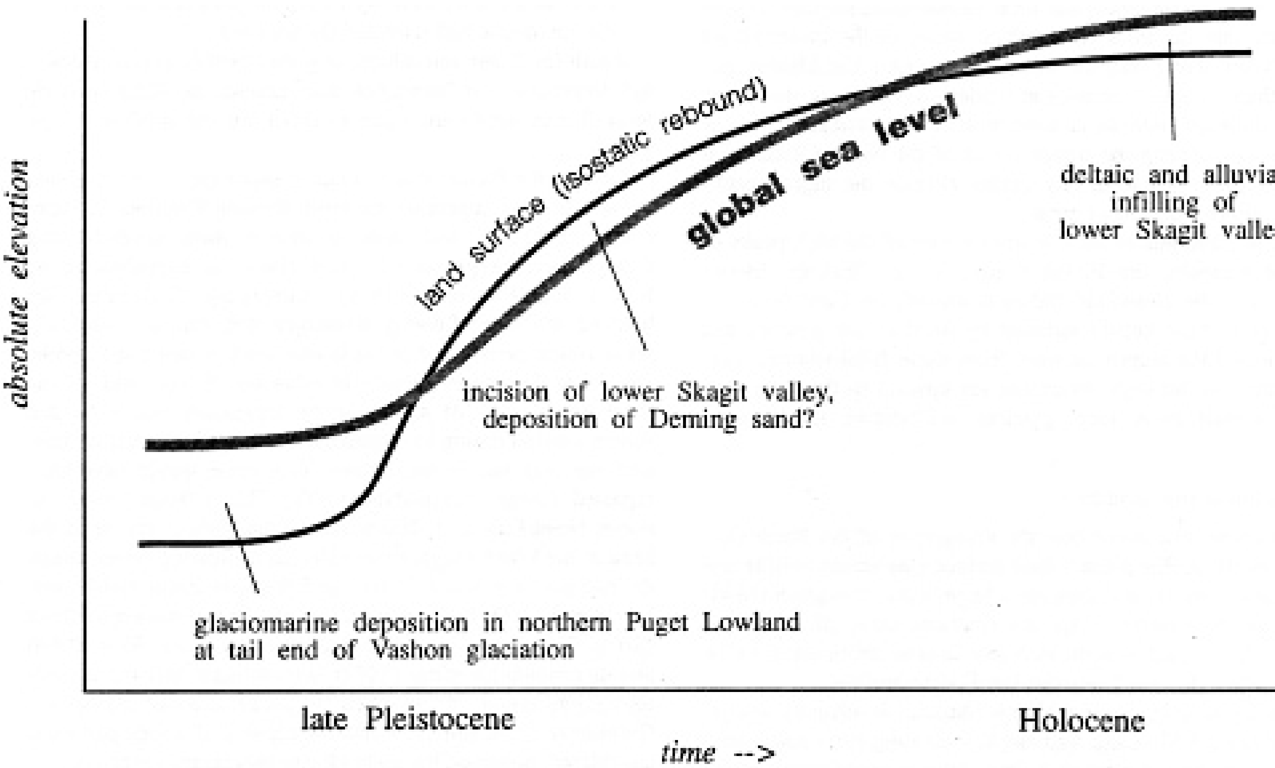


Figure 5. Schematic diagram illustrating likely interaction between local isostatic rebound, increased global ocean volume, local sealevel, and events in the northern Puget Lowland at and after the end of Vashon glaciation.

Vancouver Island, and may have truncated the Straight Creek fault in Eocene time. Dextral strike slip brought rocks of the melange belts northwesterly at least as far as the Pacific Rim Complex on western Vancouver Island. Present consensus is that Oregon-Washington Coast Ranges (Siletzia) basalts were erupted in a margin-parallel pull-apart basin during oblique plate convergence (Wells and others, 1984; Babcock and others, 1994; Suczek and others, 1994). Ray Wells (personal comm., 1992) has suggested that if subsequent rotation of the southern Cascades and Coast Ranges is undone, the Coast Ranges are parallel to the Darrington-Devils Mountain and West Coast faults, which may have formed the northeastern margin of the Siletzia pull-apart. **3.6**

226.0 Exit 226, Kincaid Street and downtown Mount Vernon, "city of the soft petal..." 2.4 228.4 Bridge over Skagit River. Hills to west at 9:00-10:00 are San Juan Islands. **1.5**

229.9 Exit 230 to SR 20, Burlington and Anacortes. Exit 1-5 and turn right, following signs for North Cascades Highway. In !/2 mile turn left at light, then go another l/i mile and turn right. **1.6**

Mileage below corresponds to mileposis on SR 20

61.0 Buried hill on right is one of several knobs of green¬stone, chert, and metagraywacke in the lower Skagit valley that we interpret to be resistant knockers in the Helena-Haystack melange (HHM).

The serpentinite-matrix HHM is probably a terrane-bounding fault zone that formed in latest Cretaceous to early Tertiary when the western and eastern melange belts were obducted onto rocks of the NWCS (Tabor and others, 1989; Tabor, 1994). The melange was further deformed by mid-Tertiary motion on the Darrington-Devils Mountain fault zone3 (DDMFZ), after deposition of sandstone, conglomerate, argillite, and volcanic rocks of the Eocene Barlow Pass unit. Barlow Pass strata are infaulted into the HHM, and con¬glomerate clasts are locally stretched parallel to the NW-SE strike of the DDMFZ.

HHM underlies much of the lumpy upland south of the Skagit valley and east of 1-5. **2.7**

63.7 Sedro Woolley city limit. **0.9**

64.6 North Cascade National Park headquarters. Baker Ranger District of the U.S. Forest Service, public information center, and restrooms on left. **0.2**

64.6 Stoplight at junction with SR 9 south. **1.2**

65.8 Three Rivers Inn and restaurant on right. **0.3**

66.1 Stoplight at junction with SR 9 north on the east margin of Sedro Woolley. **4.9**

71.0 Scattered outcrops of Chuckanut Fm sandstone con tinue for next Vi mile. Outcrops are in NE limb of NW-trending syncline. **3.1**

74.0 Lyman turnoff. **3.2**

77.3 Hamilton turnoff. Cliffy slopes on south side of Skagit valley are underlain by Chuckanut Fm, southern continuation of syncline mentioned above. Chuckanut arkose rests unconformably on Shuksan Greenschist which underlies smoother slopes to the left. **2.6**

---

3 A note on the confusing nomenclature here. The HHM is a lithoilogic unit that is interpreted to record latest Cretaceous tectonism, whereas the DDMFZ is a set of structures that were active in later Eocene or earliest Oligocene time. The two are spatially coincident, which has led to numerous discussions between Tabor and I as to whether there really was pre-Barlow Pass deformation

77.9 Near here route leaves the Mount Baker 30x60 minute quadrangle. **3.8**
81.7 Intermittent views at 3:00 of Mount Josephine. **0.4**
82.4 Views to south of hills in Easton Metamorphic Suite, mostly Shuksan Greenschist. **1.2**
83.6 Junction with Grandy Creek Road to Baker Lake. Continue east on SR 20 to Concrete. **5.0**
88.6 Turn left on Superior Street and start odometer.

Mileage for rest of day is measured from junction of SR 20 and Superior Street

0.0 Abandoned silos on right recall Concrete's youth as a cement-manufacturing center. Limestone came from large lenses in the Chilliwack Group. **0.1**
0.1 Stop sign. Go straight, crossing main street of Concrete. **0.2**
0.3 Turn left towards Baker Lake. Burpee Hill Road climbs through coarsening-upwards sequence of Vashon advance outwash. Glaciolacustrine clay and silt at base of sequence are responsible for widespread landsliding (Heller and Dethier, 1981). Roadcuts farther up the hill expose faults in bedded sand. **1.5**
1.8 **Stop 1—1. Vashon drift.** A thin layer of till at top of the outwash cliff demonstrates that this is advance, not recessional, outwash. **0.4**
2.2 Emerge onto till-covered plain. **2.0**
4.2 Turn right at junction with Baker Lake road. Hills above road are capped with NE-facing alluvial fan of Vashon recessional outwash (Stop 1-9). **2.8**
7.0 View at 12:00 of now-dissected volcano active before or during Vashon glaciation. **1.8**
8.8 Outcrop on left of probable Nooksack Formation, at north end overlain by (in ascending stratigraphic order) gravel, olivine basalt and agglomerate, and till. **0.9**
9.7 Bridge over Rocky Creek, then straight past junction with road to Schreibers Meadow (FS 12). Begin long roadcuts in deformed argillite of Nooksack Formation. **0.7**
10.4 **Stop 1-2. Nooksack Formation.** This stop is near the lowest exposed level of a several-km-thick pile of thrust nappes that constitute the Northwest Cascades System (NWCS). Jurassic and Lower Cretaceous clastic rocks of the Nooksack Formation overlie and locally interfinger with Middle Jurassic arc .volcanic rocks of the Wells Creek Volcanic Member; both units are commonly upright, with shallow to moderate dips, and (north of Mount Baker) a NW-striking steep slatey cleavage. Many workers have considered these rocks correlative with the Harrison Lake Volcanics and overlying strata exposed north of 49°N in the central Coast belt. Perhaps these units are autochthonous.

Slatey argillite here is typical of rocks south of Mount Baker that have been assigned to the Nooksack Formation. Locally this argillite bears metamorphic lawsonite. North of Mount Baker, relatively abundant Buchia establish Tithonian and Valanginian ages for the unit. Questionably Middle Jurassic radiolaria occur in siltstone NW of Mount Baker (Tabor and others, 1994). **0.8**

Turn right to Baker Dam. Road runs along surface of postglacial Sulphur Creek basalt flow. **1.2**
Kulshan Campground, run by Puget Power Co. Facilities ahead on left. **0.3**

Outcrops of Wells Creek Volcanic Member leading around to the top of Baker Dam. Cross the dam (one¬way traffic). **0.3**
Outcrop of Nooksack slatey argillite. **0.4**

Turn left on Anderson Creek Road towards Watson Lakes and East Bank (Baker Lake) trail. Somewhere in the next mile of no outcrop we cross the trace of the Excelsior thrust (the Church Mountain fault of Misch, 1966, renamed by Tabor and others, 1994, because it is not exposed at Church Mountain), which places Paleozoic and early Mesozoic volcanic arc rocks above the Nooksack Formation. 2.9
32.9 **Stop 1-3. Felsic volcanic rocks of Chilliwack Group or Cultus Formation**. Outcrops are well-foliated felsic metavolcanic rocks, mostly derived from lapilli tuff and breccia. The rocks have a weak, north-trending, flat lineation, interpreted to be stretching line-ation, but when it formed is poorly known.

The Chilliwack Group is generally composed of partly metamorphosed basaltic and andesitic volcanic and volcaniclastic rocks, sandstone, siltstone, shale and minor limestone; penetrative deformation is common. Marble in the Chilliwack contains fossils ranging in age from Silurian(?) and Devonian to Permian but most are Mississippian (Danner, 1966; Liszak, 1982). Lawsonite and aragonite are common metamorphic minerals (Christianson, 1981; Blackwell, 1983). Smith (1986) reported rare glaucophane.

The Cultus Formation comprises Triassic and Jurassic fine-grained marine clastic and dacitic volcanic rocks (Daly, 1912; Monger, 1970; Blackwell, 1983). Where age-diagnostic fossils are lacking, as in the vicinity of this stop, we have found it impossible to distinguish between Chilliwack dacite and Cultus dacite.

Monger (1970), Christianson (1981), Blackwell (1983), and Sevigny and Brown (1989) inferred that the Chilliwack formed in a volcanic-arc. Strong deformation in Chilliwack and Cultus rocks, including regional overturning, penetrative deformation, and in-traformational thrusting, suggest a pre-mid-Cretaceous, possibly Middle to Late Jurassic, tectonic event not seen in the underlying Nooksack Formation (Haugerud and others, 1992).

Look west for a view of the broad fan coming out of a wide-floored valley southeast of Mount Baker. The valley floor and fan are held up by the Sulphur Creek flow, a Holocene olivine basalt flow erupted from a small cinder cone on the south side of Mount Baker volcano (Stop 1-7). **1.8**
34.7 First outcrops of strongly deformed argillite, mafic tuff, greenstone, and chert of the Elbow Lake Formation of Brown and others (1987) in the Bell Pass melange. We have crossed the Welker Peak thrust. **0.6**
35.3 Cross Anderson Creek on bridge. Bell Pass melange here is further tectonized along the Anderson Creek fault, a southeast-side-down normal fault of middle Tertiary age. **2.4**
37.7 Along a south-trending switchback, look for view ahead of Welker Peak, capped by east-dipping slab of Elbow Lake chert, the Welker Peak nappe, lying above the Welker

Peak thrust. **0.7**

38.4 Junction at top of grade. Turn left on spur road. **0.5**

38.9 **Stop 1-4. Chert of the Elbow Lake unit, Bell Pass melange**. Park at large borrow pit at road intersection. Radiolarians from here are probably early to mid-Permian. Faunas from other Elbow Lake locales are mostly Permian and Triassic, with some as young as late Middle to Late Jurassic and possibly as old as Pennsylvanian (Tabor and others, 1994).

The Elbow Lake unit appears to be mostly correla¬tive with the Permian, Triassic, and Lower Jurassic Deadman Bay terrane of the San Juan Islands (Brandon and others, 1988). Similar oceanic units in the western Cordillera—including the Cache Creek and Bridge River complexes of British Columbia, the Hozameen Group of the eastern Cascades, the Elkhorn Ridge Argillite of northeastern Oregon, and parts of the Triassic and Paleozoic belt of the Klamath Mountains—are Middle Jurassic and older. Pelagic chert and greenstone deposition in many oceanic terranes now preserved within the Cordillera seems to have ended in the Middle Jurassic. (The Franciscan Complex of California represents a younger suite.)

Abundant clastic rocks within the Elbow Lake unit, which are not well represented here east of Baker Lake, may be equivalent to the Upper Jurassic and Lower Cretaceous Constitution Formation of the San Juan Islands. A single late Middle to Late Jurassic age obtained from the Elbow Lake unit could be from strata equivalent to the Constitution. The contact between the Constitution and underlying rocks of the Deadman Bay and Garrison terranes in the San Juans has been described as an unconformity (Vance, 1977, and oral comm., 1993) and as a fault-modified unconformity (Brandon and others, 1988). Inference of a similar unconformity within the Elbow Lake unit is further argument for a Middle to Late Jurassic orogenic event not recorded in the underlying Wells Creek-Nooksack sequence. Retrace route to Anderson Creek road. **0.5**

Stop 1-5. **Bell Pass melange**. Park at junction with Anderson Creek road. Much chert and argillite of the Elbow Lake unit has a scaly fabric like that seen here. In many areas where there are extensive exposures of the Elbow Lake unit there are tectonic slivers of crystalline rocks, including old gneiss of the Yellow Aster Complex of Misch (1966); Permian high-P schist of the Vedder Complex of Armstrong and others (1983), the low-T, high-P blueschist of Baker Lake; and the Twin Sisters Dunite of Ragan (1963), a high-T mantle tectonite. For these reasons Tabor and others (1994) mapped all of the Welker Peak nappe as the Bell Pass melange, a regionally-developed tectonic melange.

Formation of the melange probably occurred at several times. Some mixing by submarine landsliding while the Elbow Lake unit was still in its oceanic home is possible. Haugerud and others (1992) proposed tectonic mixing associated with Jurassic orogeny. Most likely there was further mixing associated with mid-Cretaceous emplacement of the Excelsior, Welker Peak, and Shuksan nappes above the Nooksack Formation.

Walk 50 m up Anderson Creek road, left, to small borrow pit in dense amphibolite of the Vedder Complex. Most rock is barroisitic amphibolite; inclusion-rich albite porphyroblasts may be visible on weathered surfaces. Elsewhere this unit includes green amphibolite, fine-grained blueschist, and quartzose garnet-mica schist (metachert). Armstrong and others (1983) demonstrated that the Vedder underwent epidote-amphi-bolite facies metamorphism at P > 7-8 kb in Permian to Triassic time. Amphibolite here also records subsequent lower-T metamorphism, with partial recrystallization to fine-grained Na-amphibole, pumpellyite, and aragonite (Haugerud, 1980).

The Vedder Complex is correlative with the Garrison Formation of the San Juan Islands. It may be the same tectonic element as blueschists at Pinchi Lake, British Columbia; near Mitchell, Oregon; and in the Stuart Fork terrane in the Klamath Mountains.

Continue left up Anderson Creek road, crossing trace of the Shuksan fault. **0.6**

40.0 Road junction in Darrington Phyllite. Turn left on spur, following signs to Watson Lakes trail. 1.1

41.0 **Stop 1-6. Easton Metamorphic Suite**. Park at Watson Lakes trailhead. Walk out gated spur road about 1 mile to end at outcrop of Shuksan Greenschist. Along the way, admire outcrops of tectonized Darrington Phyllite, beautiful drift boulders of isofacial greenschist and blueschist of the Shuksan Greenschist, and occasional erratics of granitic rocks (Chilliwack batholith?), gneissic tonalite (Coast Plutonic Com¬plex? Skagit Gneiss Complex?), and rare blocks of sandstone (Chuckanut Formation?).

Shuksan Greenschist, Darrington Phyllite, and semischist of Mount Josephine make up the Easton Metamorphic Suite, the sole constituent of the Shuksan nappe, which overlies Welker Peak and Excelsior nappes. Bulk compositions indicate a basaltic, largely mid-ocean-ridge basalt, protolith for the Shuksan Greenschist (Street-Martin, 1981; Dungan and others, 1983). Most workers interpret the protolithic shale and local sandstone of the Darrington Phyllite to have been deposited on the ocean floor basalt protolith of the Shuksan Greenschist (Brown, 1986; Dungan and others, 1983; Haugerud and others, 1981), but in some areas phyllite and greenschist are clearly interlayered, suggesting depositional interfingering.

Isotopic analyses led Brown and others (1982) and Armstrong and others (1983) to suggest a Middle to Late Jurassic (about 150-160 Ma) depositional age for the Easton. Rb-Sr and K-Ar ages suggest metamorphism of most of the Easton Suite at 120-130 Ma, with local earlier metamorphism (Brown and others, 1982). Thrust emplacement of the Easton above less-metamorphosed rocks of lower nappes must be younger.

Greenschist and blueschist of the Shuksan unit dif¬fer in bulk composition, not metamorphic grade: blueschists bear sodic amphibole instead of actinolite because they are richer in Fe^{3+} (Brown, 1974). Shuksan mineralogy indicates metamorphism at -8 kb and 400°C (Brown, 1986). Blueschist-facies minerals are strongly synkinematic.

Knots of grass-green epidote characterize much of the Shuksan Greenschist here. Some of the epidote overprints undeformed plagioclase lath-work of the basalt protolith, indicating it crystallized without penetrative strain. Millimeter-diameter epidote balls, discerned with difficulty in hand specimen, are relict amvedules. Locally, epidote knots are fractured and extended, with sodic amphibole in the fractures. The epidote appears to have formed prior to blueschist-facies metamorphism. Haugerud and others (1981) inferred the epidote to have formed during submarine hydrothermal alteration.

Easton schist is not present north of -49°15'N. In lithology and age it closely resembles the South Fork Mountain Schist of northern coastal California (Brown and Blake, 1987), lending support to tectonic models that propose mid- or Late Cretaceous northwards translation in the NWCS and associated domains.

Return to cars and retrace route over Baker Dam to Baker Lake road.

13.4 54.5 Junction with Baker Lake Road. Turn left. **1.5**

56.0 Junction with FS 12. Turn right towards Schreibers Meadow. **2.2**

58.2 Milepost 2. We are on the post-glacial Sulphur Creek flow; its blocky aa surface is exposed along the road. **1.6**

59.8 Junction with FS 13. Turn right, following sign to Mount Baker recreation area (Schreibers Meadow).**0.1**

59.9 Cross pipeline for hydroelectric power plant and climb valley wall, above surface of Sulphur Creek flow. **0.6**

60.5 Junction with road to right. Stay straight. **1.4**

61.9 Switchback and well-signed junction. Keep left to Schreibers Meadow on FS 13. *0.5*

62.4 View ahead of Loomis Mountain, eroded from marine sandstone and argillite of Cultus Formation. **1.0**

63.4 Borrow pit in isotropic to weakly deformed quartz diorite of Yellow Aster Complex. **0.8**

64.2 Tephra in roadcut presumably was erupted from the cinder cone at Schreibers Meadow. Note view ahead of Mount Baker lavas holding up ridge west of Easton Glacier. **0.9**

65.1 **Stop 1-7. Oldest and youngest rocks in the North Cascades**. End of road and parking for Schreibers Meadow-Park Butte trail.

The parking lot and the first part of the trail are on the Holocene Sulphur Creek basalt flow. The low, heavily-timbered hill immediately south of the parking lot is a cinder cone (with central crater) that appears to have been the vent for the flow. The ridges east and west of here are underlain by the Park Butte slab of the Yellow Aster Complex, a fault-bounded >4 x 9 km lens that is the largest fragment of Yellow Aster Complex in the NWCS.

Walk trail about 2/3 mile to where it begins to parallel Rocky Creek and is opposite toe of talus facing east off Surveyor Point. Leave trail and crash through brush to creek. Hop boulders or ford creek, depending on water level, to reach talus on west side. CAUTION: *At high water the creek may be unsafe to cross. Use your judgment!* Allow at least an hour for the round-trip hike and examination of the rocks.

Talus blocks of Yellow Aster Complex show marble, calcsilicate gneiss, amphibolite, clinopyroxene gneiss, and pegmatitic leucotonalite, all with mylonitic deformation, and cross-cutting dikes of plagioclase porphyry and nondescript basaltic rock. Some dikes have well-developed reaction zones where they cut marble, suggesting that they have been metamorphosed to some extent.

Gradational contacts between marble, calcsilicate gneiss, and quartz-rich clinopyroxene gneiss in these talus blocks show that at least some clinopyroxene gneiss in the Yellow Aster Complex is paragneiss. Gneiss is intruded by plutonic rocks that include gab-bro, quartz diorite, and tonalite, with rare K-feldspar-porphyritic granodiorite. Discordant zircon dates from the plutonic rocks suggest mid-Paleozoic intrusion (Mattinson, 1972; R.E. Zartman, in Tabor and others, 1994). Amphibolite-facies metamorphism of paragneiss is older, though perhaps not much older; Mat¬tinson (1972) obtained concordant U-Pb sphene dates of 415 Ma. The zircons from which Mattinson (1972) obtained a 1.4 Ga Pb-Pb date, and interpreted a 2.0 Ga age, were probably detrital and from paragneisses.

Many of these rocks have a mylonitic fabric that has no equivalent in other elements of the Bell Pass melange (except some of the Vedder Complex), and thus predates late Mesozoic assembly of the melange. The fabric is probably also Paleozoic. Rare lawsonite in some metaplutonic rocks is probably Cretaceous.

Return to vehicles and retrace route down FS 13 to **2.5**

67.6 **Stop 1-8. (Optional) Fault beneath Park Butte slab of Yellow Aster Complex**. Park on left at beginning of abandoned spur road. Walk down FS 13 to two-armed snag and descend through brush into scar at head of debris-flow chute. Footing is poor; an ice ax may be of use for maintaining footing and clearing outcrops.

Fault breccia with a pronounced sub-horizontal scaly fabric crops out in the stream bed and adjoining slope. Slopes above the road are underlain by Yellow Aster Complex. A large greenstone block at the head of the landslide scarp may be a fragment of Chilliwack Group. Tabor and others (1994) assigned sandstone and shale below here to the Nooksack Formation.

Questions one might ask of this outcrop, but which so far have eluded answers, include: what was the transport direction? Is the fabric Cretaceous, or largely Tertiary? Under what confining pressure and strain regime did the fabric develop? Continue retracing route down FS 13. **7.2**

73.8 Junction of FS 12 and paved Baker River Road. Turn right (south). **4.0**

78.3 **Stop 1-9. (Optional) Late Vashon-age alluvial fan**. Fragments of a gently NE-sloping surface that top foreground hills both right and left of the Baker Lake road are remnants of an alluvial fan formed during recession of Vashon ice. There is no till on top of these hills, they are formed of fluvial gravel, and pebble imbrication in roadcuts near the top of the hill to the east show paleocurrents flowed to the NE. The fan must have been formed when an east-flowing stream confined between the ice in the lower Skagit valley and Grandy Ridge to the north spilled out onto the outwash plug that filled the lower Baker River valley. **1.5**

79.3 Junction with road to Concrete on left. Keep right on Baker Lake road - Grandy Creek road. **1.5**

80.8 On the left is Grandy Lake, a small pond dammed by an alluvial fan from the north. **3.3**

84.1 Grandy Creek bridge. Vashon advance outwash forms impressive hill across the valley to the right. **1.9**

86.0 Junction with SR 20. Turn right to motels in Sedro Woolley (17 miles) or left to state and county campgrounds near Rockport (13 miles). Camping is also available at Puget Power's Kulshan Campground near Baker Dam and USFS campgrounds in the North Fork Nooksack valley, east of Glacier.

Day 2. Sedro Woolley to Seattle via Mount Baker ski area

Log begins at junction of SR 9 and SR 20 on the east margin of Sedro Woolley. Total driving distance for day 2 is about 120 miles, plus return from Deming to Seattle. Mileage below corresponds to mileposts on SR 9.

57.2 Junction SR 9 and SR 20. Go north on SR 9. **0.8**
57.9 Washington Department of Natural Resources offices. **5.8**
63.7 Bridge over Samish River. **2.8**
66.5 Outcrop of Darrington Phyllite of Misch (1966). 0.4 66.9 Whatcom Co. line. First views of Twin Sisters Range at 1:30. Roadcut on left mantled with rip-rap of white and gray Paleozoic marble, quarried from the Chilliwack Group north of here near the Canadian border. **1.0**
67.9 Junction with Park Road, left, to Lake Whatcom. Continue north on SR 9. **2.9**
70.8 Roadcuts on left, from here to Acme, are in rocks mapped as Darrington Phyllite by Miller and Misch (1963).

We have found that rocks mapped by earlier workers as Darrington Phyllite can be profitably subdivided. Some of the rocks here are contorted, shiny, quartz-veined black phyllite, identical in most respects to typical Darrington. Nonetheless, the dominant foliation (at least at milepost 71.0) is S,—as is typical of the semischist and phyllite of Mount Josephine, not a secondary pressure-solution cleavage as in most Darrington sensu stricto. **1.0**
71.8 Enter Acme. **0.6**
72.4 Leave Acme. Bridge over South Fork Nooksack River. **1.6**
74.0 Railroad crossing. Somewhere near here the route crosses the basal contact of the north-dipping Chuckanut Fm, here buried beneath valley-bottom alluvium **1.4**
75.4 White outcrop on valley wall at 9:00 is arkose of Eocene Chuckanut Fm. **2.4**
77.4 Van Zandt and railroad crossing. **1.5**
78.9 Bridge over North Fork Nooksack River, below con¬fluence with Middle Fork. **0.3**
79.2 Outcrops on both sides of road of moderately N-dip-ping Chuckanut Fm. 0.2
79.4 Junction with Mount Baker Highway, SR 542. Turn right. **0.1**

Mileage below corresponds to mileposts on SR 542

14.5 **Stop 2-1. Geologic overview**: sub-Eocene uncon¬formity, Chuckanut Fm structure, Sumas Mountain, late Vashon glaciomarine drift. Pull into large graveled area on right.

Our route has taken us north from Early Cretaceous schist, semischist and phyllite of the Easton Metamorphic Suite, through the sub-Eocene unconformity, into Eocene arkose of the Chuckanut Fm. Here we are near the middle of the Chuckanut outcrop, which extends from Bellingham on the west to Glacier, north of Mount Baker, on the east. The southern contact is an unconformity on top of the Easton Metamorphic Suite, locally modified by faulting, which we drove through north of Acme. Overall, the Chuckanut forms a north-dipping homocline, truncated on the north by the east-to northeast-striking Boulder Creek fault. Superimposed on this homocline, or carried within it, are N- to NW-trending open to tight folds with wavelengths measured in kilometers, best described by Miller and Misch(1963).

Across the road to the north is the southern toe of Sumas Mountain, the northern and western parts of which are underlain by that part of the NWCS most in need of modern geologic mapping.

See Easterbrook (1994) for a description of glacial deposits at this stop. We are near the type localities of the Bellingham (upper) and Kulshan (lower) glaciomarine drifts, which are separated by fluvial Deming sand; all are of late Vashon age. Shells in Kulshan drift near here have been dated by 14C at 12,970 ± 280 yr. B.P. Rapid change in the late Pleistocene local sea level from submergence (deposition of Kulshan glaciomarine drift), to emergence (deposition of Deming sand) during or after deglaciation, to resub-mergence during the early Holocene, is a predictable consequence of isostatic rebound consequent upon deglaciation and the rise of global sea level (e.g. Fig. 5). However, it is not clear how this area could have been resubmerged, during late Vashon time to deposit Bellingham glaciomarine drift. Easterbrook (op. cit., p. IJ-23) suggests that tectonism is indicated. **1.0**
15.5 Carol's Coffee Cup. **1.3**
16.8 Mosquito Lake Road on right. Access to Middle Fork Nooksack River area. **0.8**
17.6 Bells Creek. **0.6**
18.2 Near here the route enters the north half of the Van Zandt 15' quadrangle, mapped by Moen (1962). **2.4**
20.6 Coal Creek. **1.5**
22.1 Heading north after second right-angle corner. Views of Red Mountain (1:00, underlain by Chilliwack Group and, perhaps, Bell Pass melange). Black Mountain (1:30, with Chilli wack Group on crest and western slope, backslope underlain by Bell Pass melange), Bald Mountain (2:00, underlain by conglomerate of Bald Mountain; lower area to right is Chuckanut Fm), and Church Mountain (2:45, capped by Chilliwack Group). Farther to right is Slide Mountain, underlain by Chuckanut Fm. Northern Sumas Mtn, left of the road, is underlain by Chilliwack Group and, perhaps, Bell Pass melange. **0.7**
22.8 Junction with SR 547, north and west to Sumas. Stay right. **0.1**
22.9 Kendall. Last gas station. **3.0**
25.9 Maple Falls and junction with Silver Lake Rd on left. **2.5**
28.4 Boulder Creek. For most of its length the creek flows along the Boulder Creek fault, a NE-trending down-

to-the SE fault of post-Chuckanut age, similar to the Anderson Creek fault (crossed between stops 1-3 and 1-4) SE of Mount Baker.

Debris flows down Boulder Creek have repeatedly destroyed the bridge here and blocked SR 542. Landslides in weak rock along the Boulder Creek fault may have contributed to the debris flows. One wonders to what extent reactivation of these landslides and initiation of the debris flows have been caused by wholesale clear-cutting of the upper Boulder Creek drainage. 0.8

29.2 **Stop 2-2. Chuckanut Fm**. Pull over on right. If there is insufficient parking, continue 0.4 miles to overgrown viewpoint and sign for Mount Baker. Admire the view of Mount Baker, then carefully cross SR 542 to examine north-dipping beds of Chuckanut Fm with well-preserved palm fossils.

The Chuckanut Formation consists of fluviatile feldspathic sandstone, conglomerate, argillite, and coal. Johnson (1982, p. 12, 1984) reports an aggregate thickness of about 6 km. In the Mount Baker quadrangle, we have restricted the Chuckanut Formation to rocks continuous with mapped Chuckanut to the west. Chuckanut beds in this area have been referred to the Bellingham Bay, Slide, and Warnick Members by Johnson (op. cit.) who considered these rocks to range from early to late(?) Eocene in age. J.A. Vance (oral commun., 1993) reports that detrital zircon populations separated from numerous samples of the Chuckanut Formation throughout the section each show an age peak of ca. 56 Ma, implying that most of the unit is younger than this. 0.8

30.0 Near here route enters Mount Baker 30x60 minute quadrangle. **1.0**

31.0 Bridge over North Fk Nooksack River. East abutment founded on Chuckanut Fm, which an outcrop in river-cut to NE shows to be south-dipping. 2.4

33.4 Downtown Glacier. Phone, lodging, and food; no gasoline.

For an interesting side-trip, turn right at stop sign on east side of Graham's Store and follow a DNR logging road south towards Coal Pass. At 0.2 miles: piles of anthracite mined from test pits at Coal Pass. At 0.8 miles: brushy, slippery exposures of Nooksack Formation in the bed of Little Creek. Continue several miles to where the road is blocked north of Coal Pass, at the fault contact between Nooksack Fm and the Easton Metamorphic Suite (semischist of Mount Josephine), then walk to prospect pits in strongly deformed coal seams above the depositional contact of the Chuckanut Formation on the semischist of Mount Josephine. **0.1**

33.5 Bridge over Gallop Creek, then bridge over Glacier Creek. **0.2**

33.7 Glacier Public Service Center, U.S. Forest Service. In¬formation and bathrooms. **0.1**

33.8 Poor outcrops for next '/i mile are in debris of the Church Mountain mega-landslide (Stop 2-6). **0.6**

34.4 Turn right on Glacier Creek road, FS 37. Continue south **0.6** miles to long, mossy roadcut on left.

Stop 2-3. **Nooksack Fmn**. These outcrops of steeply-dipping argillite and calcareous sandstone are the westernmost easily accessible outcrop of Nooksack in this area. This is the base of the NWCS structural stack.

Clastic rock of the Nooksack is quite varied. Most is homogenous thick-bedded black argillite, but we have also noted heavily bioturbated, pyritic, sandy siltstone in thick beds; calcarenite; feldspathic, volcaniclastic sandstone; well-bedded turbidite; and muddy olistostromes. Some sandstone bears detrital muscovite. Typically bedding has low dips (unlike here) and is cut by a steep, NW-striking slatey cleavage. We have not noted fossils here, though they are relatively common in Nooksack argillite. The most common forms are pelecypods of the genus Buchia and belemnites. Age determinations on fossils from the North Fk Nooksack drainage are permissive of the interpretation that only two fossiliferous horizons are present, of Valanginian (Early Cretaceous) and Kim-meridgian (Late Jurassic) ages.

Turn around, return to Mount Baker Highway (milepost 34.4) and turn right. **1.0**

35.4 Bridge over North Fk Nooksack River. 0.2 35.6 Turn left on Canyon Creek Rd, FS 31.

At 0.3 miles, begin outcrops of volcanic and sedimentary rocks of the Chilliwack Group.

At 1.5 miles, after switchbacks, cross Hurst Creek (unsigned), pull into gravel spur road on left, and park. Walk up Canyon Creek road -200 m to

Stop 2-4. **View of Glacier fault**. Rubble in the roadcut here is arkose of the Eocene Chuckanut Fm. East of here bedrock is Chilliwack Group, overlying Nooksack Fm at the base of the slope. Hurst Creek Hows over a landslide along the fault contact between the Chuckanut and pre-Tertiary rocks. This fault, the Glacier fault, continues SW, crossing the North Fk Nooksack River near Glacier, and then trends SSE to near Coal Pass. The V-shaped trace across the North Fk Nooksack valley indicates a 30° dip to the west.

Hanging wall of the Glacier fault is Chuckanut Fm and its Easton Suite basement. From Glacier south these units are juxtaposed with a Nooksack Fm foot-wall. Missing are most of the Shuksan nappe, the Welker Peak nappe, and the Excelsior nappe. The fault also cuts across the entire preserved thickness of the E-W striking, mostly north-dipping Chuckanut Fm. Lacking good thickness estimates for the NWCS nappes in this area and not knowing how the Chuckanut was deformed prior to movement on the Glacier fault, displacement on the fault is not well constrained, but 4—10 km of tectonostratigraphic section seems to be omitted.

Misch (1966, p. 137) recognized this fault and its moderate west dip but interpreted it as minor east-vergent "shearing-off' at the Chuckanut basal contact.

Return to cars, turn around, and retrace route to Mount Baker Highway. Turn left and continue upvalley. **1.5**

37.1 Begin roadcuts in Nooksack Fm. **1.5**

38.6 Fossil Creek. **0.1**

38.7 Church Mtn road on left. **0.2**

38.9 Stream-gauging station and outcrops of dacitic tuff in Wells Creek Member of Nooksack Fm. Across the river from this point. Franklin (1985) collected a sample of dacite tuff from which J.M. Mattinson (in Franklin, op. cit.) obtained mildly discordant 173-187 Ma U-Pb dates. **1.7**

40.6 Junction with road to Nooksack Falls on right. **0.4**

41.0 Excelsior Pass trailhead and parking. **0.1**

41.1 Begin outcrops of dacite, dacitic breccia, and slatey argillite of the Wells Creek Volcanic Member, here orange- and yellow-weathering because of sulphide mineralization.

Across the Nooksack River is a remnant of an intra-canyon flow of columnar Mount Baker andesite. **5.2**

46.3 Snowplow sheds. Junction with Swamp Creek Rd on left; access to Yellow Aster Meadows, Gold Run Pass, Twin Lakes, Winchester Mtn, and Silesia Creek. **0.2**

46.5 Junction with Ruth Creek Rd on left; access to south side Goat Mtn, Hannegan Pass, and Nooksack Cirque. There are good outcrops 0.1-0.2 miles up Ruth Creek Rd of coarse breccias in the greenstone of Mount Herman (Chilliwack Group). **0.1**

46.6 Bridge over North Fk Nooksack River. For the next several miles outcrops along road are Permian green¬stone of Mount Herman (Chilliwack Group) and overlying Quaternary volcanic rocks of Mount Baker volcanic center. **4.7**

51.3 Razerhone Creek. **0.1**

51.4 Covered contact between Mount Herman greenstone and Darrington Phyllite. **0.8**

52.2 Recross Razerhone Creek and re-enter Mount Herman greenstone. **2.2**

54.4 Before reaching ski lodge, turn right on road to Austin Pass and Artists Point. **-1**

-55 Road crosses unconformity between Permian greenstone (on north), here cooked by nearby Lake Ann stock, and Quaternary lavas of the Mount Baker volcanic center. -1

-56 Stop 2-5. Views of Mount Baker, topographic inversion, Kulshan caldera, Lake Ann stock, and views of NWCS. Park at end of road at Artists Point, and walk about for views in all directions. Starting with the view to the northwest and moving clockwise, one sees:

Table Mountain is a classic example of inverted topography. It is part of a family of lavas spatially associated with Mount Baker but older than, and not erupted from, the current cone.

The peak immediately west of the Baker ski area, north of Table Mountain, is Mount Herman, eroded from altered breccias, pillow lavas, and volcanic sandstone of the Chilliwack Group. These rocks form a distinctive unit that can be traced from near the snow-plow sheds at the Swamp Creek road turnoff south to the north shore of Baker Lake. The Mount Herman greenstone is the youngest known part of the Chilliwack, with a Guadalupian age (discussed below). On a clear day one can look north to Tomyhoi Peak, American and Canadian Border Peaks, Mount Larrabee, and the Pleiades, carved from the stacked nappes of the NWCS. Farther to the right is Goat Mountain, entirely underlain by Darrington Phyllite.

Rusty peaks of Mount Sefrit, immediately north of Mount Shuksan, are underlain by rocks of the Cenozoic Chilliwack batholith, including local olivine gabbro, that intrude Darrington Phyllite to the west. The batholithic rocks on Sefrit, particularly the mafic ones, were recently studied by Tepper (1985, 1991; Tepper and others, 1993).

The long ridge extending east from here to Mount Shuksan is Shuksan Arm. One can follow a way-trail along the crest of Shuksan Arm to Lake Ann, with excellent exposures of Mount Herman greenstone and associated sediments, the Welker Peak thrust, and deformed siliceous rocks of the Elbow Lake Formation. Such good exposures of Elbow Lake Fm are rare; here they reflect contact metamorphism by the underlying Lake Ann stock. The outcrops provide fodder for discussion of the relative importance of soft-sediment and tectonic deformation in the melanging of the Elbow Lake, the origin (chert ribbons? thin sand layers? veins?) of siliceous layers, deformation mechanisms, and the direction of tectonic transport. One can descend south into the Lake Ann stock and return via the Lake Ann trail. The hike is best in early September, when most winter snow is melted and the huckleberries are ripe. Allow a full day.

The 2.5 Ma **Lake Ann stock** was studied by James (1980). who presents petrographic and chemical data. It intrudes Mount Herman greenstone (Chilliwack Group), Bell Pass melange, and Easton schists at the foot of the west face of Mount Shuksan. The Lake Ann stock may be continuous at depth with a zoned pluton that intrudes the -4 Ma Hannegan Volcanics in Nooksack Cirque on the east side of Mount Shuksan. The extensive gossan visible on the south side of Shuksan Arm is developed in sedimentary rocks associated with the Mount Herman greenstone. Mount Ann, south of Lake Ann, is underlain by Mount Herman rocks.

The rocks of Kulshan Caldera (earlier named the Swift Creek volcanics by James, 1980) erupted at about 1.0 Ma (Wes Hildreth, personal communication) and unconformably overlie the 2.5 Ma granodiorite of the Lake Ann stock, demonstrating that the stock was emplaced and unroofed within l'/2 million years.

Guadalupian (Permian) radiolaria, the youngest fossils found in the Chilliwack Group, were recovered from a diagenetic chert layer in limestone associated with Mount Herman greenstone in landslide block within Kulshan caldera on a western tributary to upper Swift Creek, about 4 km south of here.

Massive white rocks visible in the valley walls to the SW beneath this point are rhyolitic tuff that fills Kulshan caldera (Hildreth, 1994). Massive tuff that forms the bulk of the caldera fill is overlain by lacustrine beds and all is intruded by a small plug of rhyolite vitrophyre. The lacustrine beds have intercalated landslide deposits with Nooksack Fm debris, and are folded with dips as steep as 30°. Hildreth (oral communication) reports radiometric ages and a distinctive phenocryst assemblage which demonstrate that Kulshan caldera was the source of the 1 Ma Lake Tapps tephra, corroborating evidence from within the caldera fill that it developed while this area was overridden by Cordilleran ice. Much of this geology is well-exposed in the area south of Coleman Pinnacle. A daylong hike into this area, mostly on good trail, is a rewarding excursion.

Retrace route back towards Glacier. -20

Bridge over North Fk Nooksack River. **0.8**

Stop 2-6a. Church Mountain mega-landslide. Turn right into Snowline vacation-home development. Turn left and follow loop road(s) through the development, noting lumpy microtopography and the predominance of angular boulders removed from foundation excavations. The boulders are largely greenstone of the Chilliwack Group, not the Nooksack Fm clastic rocks appropriate for this locale. This housing development, along with the rest of the built-up area around Glacier, sits on the debris of a large Holocene rockfall derived from the south face of Church Mountain.

The rockfall has been independently recognized several times. Wayne Moen (1969, p. 85) noted the landslide-like topography. In the mid-1970s Eric Cheney (oral communication, 1994) found massive sulphide mineralization on the south face of Church Mountain after realizing that prospects on the valley-floor east of Glacier were in landslide debris. Rowland Tabor and I, working in the North Fork Nooksack valley in 1990, realized that this area was underlain by catastrophic rockfall debris and presumed that collapse was late Pleistocene, consequent upon deglaciation. Carla Gary (Gary and others, 1992a), studying debris flows in Glacier Creek, recognized that this was a landslide deposit and then was informed by Don Easterbrook that he had known of it for some time.

Carpenter (1993; Carpenter and Easterbrook, 1993) studied the deposit and identified it as a catastrophic mega-landslide, or sturzstrom, that covers about 9 krrr of valley floor. The size, disposition, morphology, and internal stratigraphy of the deposit suggested to Carpenter (op. cit.) that it records a single catastrophic failure of the steep south face of Church Mountain.

Return to Mount Baker Highway and turn right. **0.2**

Glacier Creek Rd. **0.2**

Stop 2-6b. Church Mountain mega-landslide. Turn left into Mount Baker Rim development. Note: access to Mount Baker Rim is by permission only! Follow roads south to clubhouse on northeast bank of Glacier Creek. Park at clubhouse, follow path to creek-bed, and walk downstream (right) to end of marble rip-rap.

A stream-cut bank exposes fluvial sand and gravel, mostly with clasts of Mount Baker andesite, which overlies uncemented breccia composed of angular fragments of Nooksack argillite. The breccia overlies several large logs. The breccia is part of the Church Mountain landslide deposit, and this outcrop is evidence that collapse of the south face of Church Mtn did not occur immediately upon deglaciation, as Tabor and I had assumed when we first recognized the landslide. See the discussion of this event above (Stop 2-6a).

This appears to be one of the locales from which Carpenter (1993) obtained wood for I4C dating. The resulting ages led her (op. cit.) to infer deposition at about 2.7 ka.

Return to cars, retrace route to Mount Baker Highway, and return to Seattle.

From the junction of SR 542 and SR 9 it is about 90 miles to north Seattle via SR 9 to Sedro Woolley and 1-5, or about 100 miles via SR 542 west to Bellingham and 1-5.

REFERENCES

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

Armstrong. R.L., 1980, Geochronology of the Shuksan Metamorphic Suite. North Cascades, Washington: Geological Society of America Abstracts with Programs, v. 12., n. 3, p. 94.

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

Armstrong. R.L., and Misch, P., 1987, Rb-Sr and K-Ar dating of mid-Mesozoic blueschist and late Paleozoic albite-epidote-amphibolite and blueschist facies metamorphism in the North Cascades, Washington and British Columbia, and fingerprinting of engeosynclinal rock assemblages, in Schuster, J.E., editor. Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin??, p. 85-105.

Arthur, A.J., Smith, P.J., Monger, J.W.H. and Tipper, H.W., 1993, Mesozoic stratigraphy and Jurassic paleontology west of Harrison Lake, southwestern British Columbia: Geological Survey of Canada Bulletin, v. 441, p. 62.

Babcock, R.S., Suczek. C.A., and Engebretson, D.C., The Crescent "terrane", Olympic Peninsula and southern Vancouver Island, in Lasmanis, R., and Cheney, E.S., convenors. Regional geology of Washington State: Washington Division of Geology and Earth Resources, Bulletin 80, p. 141-157.

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

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

- **1994**, Glaciofluvial infilling and scour of the Puget Lowland,Washington, during ice-sheet glaciation: Geology, v. 22, p. 695-698.

Brandon, M.T. and Cowan, D.S., 1985, The late Cretaceous San Juan Islands - northwestern Cascades thrust system: Geological Society of America Abstracts with Programs, v. 17, n. 6, p. 343

Brandon, M.T. and Vance, J.A., 1992, Tectonic evolution of the Cenozoic Olympic subduction complex, Washington state, as deduced from fission track ages for detrital zircons: American Journal of Sci¬ence, v. 292. p. 565-636.

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

Brown. E.H.. 1974, Comparison of the mineralogy and phase relations of blueschists from the North Cascades, Washington, and greenschists fom Otago, New Zealand: Geological Society of America Bulletin, v. 85, n. 3, p.333-344.

- **1986**, Geology of the Shuksan suite. North Cascades, Washington,U.S.A., in Evans, B.W., and Brown, E.H., editors, Blueschists and eclogites: Geological Society of America Memoir 164, p. 143-153.
- **1987**. Structural geology and accretionary history of the Northwest Cascade System of Washington and British Columbia: Geological Society of America Bulletin, v. 99, p. 201-214.
Brown, E.H. and Blake, M.C., Jr., 1987, Correlation of Early Cretaceous blueschists in Washington, Oregon, and northern California: Tectonics, v. 6, p. 795-806.
Brown, E.H., Bernardi, M.L., Christiansen, B.W., Cruver, J.R., Haugerud, R.A., and Rady, P.M., 1981, Metamorphic facies and tectonics in part of the Cascade Range and Puget Lowland of northwestern Washington: Geological Society of America Bulletin, v. 92, pt. 1, p. 170-178 and pt. 2, p. 515-553.
Brown, E.H., Wilson, D.L., Armstrong, R.L., and Harakal. J.E., 1982. Petrologic, structural, and age relations of serpentinite, amphibolite, and blueschist in the Shuksan Suite of the Iron Mountain-Gee Point area. North Cascades, Washington: Geological Society of America Bulletin, v. 93, n. 11, p. 1087-1098.
Brown, E.H., Blackwell, D.L., Christiansen, B.W., Frasse, F.I., Haugerud, R.A., Jones, J.T., Leiggi. P.L., Morrison. M.L., Rady, P.M., Reller, G.J., Sevigny, J.H., Silverberg, D.L., Smith, M.T., Sondergaard, J.N., and Zielger, C.B., 1987, Geologic map of the northwest Cascades, Washington: Geological Society of America Map and Chart Series MC-61, scale 1:100,000. I Op.
Caimes, C.E., compiler, 1944, Hope, Yale, and New Westminster Districts, British Columbia: Geological Survey of Canada Map 737A, 1 sheet, scale 1:253,400.
Carpenter, M.R., 1993, The Church Mountain sturzstrom (mega-landslide) near Glacier, Washington: Bellingham, Western Washington University, M.S. thesis, 71 p.
Carpenter, M.R., and Easterbrook, D.J., 1993, The Church Mountain sturzstrom (mega-landslide). Glacier, Washington: Geological Society of America Abstracts with Programs, v. 25, n. 5, p. 18.
Cary, CM., Easterbrook, D.J., and Carpenter, M.R., 1992, Post-glacial mega-landslides in the North Cascades near Mt. Baker, Washington: Geological Society of America Abstracts with Programs, v. 24, p. 13.
Christensen, N.I., 1971, Fabric, seismic anisotropy, and tectonic history of the Twin Sisters dunite, Washington: Geological Society of America Bulletin, v. 81, p. 2181-2202.
Christiansen, B.W., 1981, Structure, petrology and geochemistry of the Chilliwack Group near Sauk Mountain, Washington: Bellingham, Western Washington University M.S. thesis, 181 p.
Crickmay, C.H., 1930, The structural connection between the Coast Range of British Columbia and the Cascade Range of Washington: Geological Magazine, v. 67, p. 482—491.
Cruver, J.R., 1983. Petrology and geochemistry of the Haystack Mountain unit, lower Skagit valley, Washington [M.S. thesis): Bellingham, Western Washington University, 149 p.
Daly, R.A., 1912, Geology of the North American Cordillera at the forty-ninth parallel: Geological Survey of Canada Memoir, v. 38, 857 p.
Danner, W.R., 1957, A stratigraphic reconnaissance in the northwestern Cascade Mountains and San Juan Islands of Washington State: Seattle, University of Washington, Ph.D. thesis, 561 p.
1958, A stratigraphic reconnaissance in the northwestern Cascade Mountains and San Juan Islands of Washington State: Dissertation Abstracts, v. 18, n. 1, p. 195.
1966, Limestone resources of western Washington: Washington Division of Mines and Geology, Bulletin 52, 474 p.
Dungan, M.A., Vance, J.A., and Blanchard, D.P., 1983, Geochemistry of the Shuksan greenschists and blueschists. North Cascades, Washington: variably fractionated and altered metabasalts of oceanic affinity: Contributions to Mineralogy and Petrology, v. 82, p. 131-146.
Easterbrook, D.J., 1994, Stratigraphy and chronology of early to late Pleistocene glacial and interglacial sediments in the Puget Lowland, Washington, in D. A. Swanson and R. A. Haugerud, Geologic field trips in the Pacific Northwest: Published in conjunction with the Geological Society of America Annual Meeting in Seattle, October 24-27, by the Department of Geological Sciences. University of Washington, Seattle, Washington, v. l,p. 1J-1-38.
England, T.D.J., and Calon, T.J., 1991, The Cowichan fold and thrust system, Vancouver Island, southwestern British Columbia: Geological Society of America Bulletin, v. 103. p. 336-362.
Franklin, R.J., 1985, Geology and mineralization of the Great Excelsior Mine, Whatcom County, Washington: Bellingham, Western Washington University, M.S. thesis, 118 p.
Franklin, W.E., 1974, Structural significance of meta-igneous fragments in the Prairie Mountain area. North Cascade Range, Snohomish County, Washington: Corvallis, Oregon State University, M.S. thesis, 109 p.
Gallagher, M.P., 1986, Structure and petrology of meta-igneous rocks in the western pan of the Shuksan Metamorphic Suite, northwestern Washington, U.S.A.: Bellingham. Western Washington University M.S. thesis, p. 59.
Gallagher, M.P., Brown, E.H., and Walker, N.W., 1988, A new structural and tectonic interpretation of the western part of the Shukson blueschist terrane, northwestern Washington: Geological Society of America Bulletin., v. 100, p.1415-1422.
Gulick, C.W., 1994, Industrial Minerals: Washington Geology, v. 22, n. l,p. 19-22.
Haugerud, R.A., 1980, The Shuksan Metamorphic Suite and Shuksan thrust, Mt. Watson area. North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 125 p.
Haugerud, R.A., and Tabor, R.W., in preparation. Preliminary geologic map of the Robinson Mountain 30' x 60' quadrangle, Washington: U.S. Geological Survey Open File Report.
Haugerud, R.A., Morrison, M.L.. and Brown, E.H., 1981, Structural and metamorphic history of the Shuksan Metamorphic Suite in the Mount Watson and Gee Point areas. North Cascades, Washington: Geologi¬cal Society of America Bulletin, v. 92, Part 1, p. 374-383.
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 Cascade Range. Washington and British Columbia: Geological Society of America Bulletin, v. 103, p. 1297-1307.
Haugerud, R.A., Tabor, R.W., and Blome, C, D., 1992, Pre-Tertiary stratigraphy and multiple orogeny in the western North Cascades. Washington: Geological Society of America Abstracts with Programs, v.24, n. 5, p. 32.
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 D. A. Swanson and R. A. Haugerud, Geologic field trips in the Pacific Northwest: Published in conjunction with the Geological Society of America Annual Meeting in Seattle, October 24-27 by the Department of Geological Sciences, University of Washington, Seat¬tle, Washington, v. 2, p. 2E1-2E51.
Heller, P.L., 1978, Pleistocene geology and related landslides in the lower Skagit and Baker Valleys, North Cascades, Washington: Bel¬lingham. Western Washington University, M.S. thesis, 154 p.
Heller, P.L., and Dethier, D.P., 1981, Surficial and environmental geology of the lower Baker Valley, Skagit County, Washington: Northwest Science, v. 55, n. 2, p. 145-155.
Heller, P.L., Tabor, R.W., and Suczek, C.A., 1987, Paleogeographic evolution of the United States Pacific Northwest during Paleogene time: Canadian Journal of Earth Sciences, v. 24, p. 1652-1667.
Hersch, J.T., 1974, Origin of localized layering in the Twin Sisters dunite. Washington: Seattle, Univeristy of Washington, M.S. thesis, 65 p.
Hildreth, W., 1994, Ignimbrite-filled Quaternary caldera in the North Cascades, Washington: Eos. Transactions of the American Geophysical Union, v. 75, n. 16, p. 367-368.
James, E.W., 1980, Geology and petrology of the Lake Ann stock and associated rocks: Bellingham, Western Washington University, M.S. thesis, 57 p.
Jett, G.A., 1986, Sedimentary petrology of the western melange belt, north Cascades, Washington: Laramie, University of Wyoming, M.S . thesis, 85 p.
Jett, G.A. and Heller, P.L., 1988, Tectonic significance of polymodal composition in melange sandstone, western melange belt. North Cascades Range, Washington: Journal of Sedimentary Petrology, v. 58, n. 1, p. 52-61.
Johnson, S.Y., 1982, Stratigraphy, sedimentology, and tectonic setting of the Eocene Chuckanut Formation, northwest Washington: Seattle, University of Washington, Ph.D. thesis, 221 p.
1984, Stratigraphy, age, and paleogeography of the Eocene Chuckanut Formation, northwest Washington: Canadian Journal of Earth Sciences, v. 21, p. 92-106.
1985, Eocene strike-slip faulting and nonmarine basin formation in Washington, in K. T. Biddle and N. Christie-Blick editors.. Strike-slip deformation, basin formation and sedimentation: Society of Economic Paleontologists and-Mineralogists Special Publication 37. p. 283-302.
Jones, J.T., 1984, The geology and structure of the Canyon Creek-Church Mountain area. North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 125
Leiggi, P.A., 1986, Structure and petrology along a segment of the Shuksan thrust fault. Mount Shuksan area. Washington: Bellingham, Western Washington University, M.S. thesis, 207 p.
Levine, C.A., 1981, Internal structures of the northwestern portion of the Twin Sisters dunite. North Cascades, Washington: Seattle, University of Washington, M.S. thesis, 82 p.
Liszak, J.L., 1982, The Chilliwack Group on Black Mountain, Washington: Bellingham, Western Washington University, M.S. thesis, 104 p.
Mackin, J. H., 1941, Glacial geology of the Snoqualmie-Cedar area, Washington: Journal of Geology, v. 49, p. 449-481.
Mattinson, J.M., 1972, Ages of zircons from the Northern Cascade Mountains, Washington: Geological Society of America Bulletin, v. 83, p. 3769-3784.
McClelland. W.C., and Mattinson, J.M., 1993. Devonian single detrital zircon ages from the Chilliwack terrane, Washington: Geological Society of America Abstracts with Programs, v. 25, n. 6, p. A173.
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. n. 2, p. 189-209.
McKee, E., D., 1956, Paleotectonic maps, Jurassic System: U.S. Geologi¬cal Survey Miscellaneous Investigations Map, 1-175, 6 p.
Miller, G.M., 1979, Western extent of the Shuksan and Church Mountain thrust plates in Whatcom, Skagit, and Snohomish Counties. Washing¬ton: Northwest Science, v. 53, n. 4, p. 229-241.
Miller, G.M., and Misch, P., 1963, Early Eocene angular unconformity at western front of Northern Cascades, Whatcom County, Washington: American Association of Petroleum Geologists Bulletin, v. 47, p. 163-174.
Misch, P., 1952, Geology of the northern Cascades of Washington: The Mountaineers, v. 45, p. 3-22.
1959, Sodic amphiboles and metamorphic facies in Mount Shukan belt, northern Cascades, Washington [abstract]: Geological Society of America Bulletin, v. 70, p. 1736-1737.
1960, Large overthrusts in the northwestern Cascades near the 49th parallel [abstract]: Geological Society of America Bulletin, v. 71, p. 2069.
1963, Crystalline basement complex in northern Cascades of Washington [abstract]: Geological Society of America Special Paper, v. 76,p. 213-214.
1965, Radial epidote glomeroblasts formed under conditions of synkinematic metamorphism—a new mechanism of collective crystal-loblastesis: Geologisches Rundschau, v. 54, pt. 2, p. 944-956.
1966, Tectonic evolution of the northern Cascades of Washington State—a west-cordilleran case history, in 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, Cana¬dian Institute of Mining and Metallurgy, Special Volume 8, p. 101-148.
1977. Bedrock geology of the North Cascades, in Brown, E.H., and Ellis, R.C., editors, Geological excursions in the Pacific Northwest: Geological Society of America Annual

Meeting, Seattle, p. 1-62.
1979, Geologic map of the Marblemount Quadrangle, Washington: Washington Division of Geology and Earth Resources, Map GM-23, scale 1:48,000.
1980, Involvement of ancient continental basement and of alpine peridotite in complex imbricate zone beneath blueschist facies Shuk¬san thrust plate. Northwest Cascades, Washington: Geological Society of America Abstracts with Programs, v. 12, n. 3, p. 142.
Moen, W.S., 1962, Geology and mineral deposits of the north half of the Van Zandt quadrangle, Whatcom County, Washington: Washington Division of Mines and Geology Bulletin 50, 129 p.
—— **1969**, Mines and mineral deposits of Whatcom County, Washington: Washington Division of Mines and Geology Bulletin 57, 133 p.
Monger, J.W.H., 1966, The stratigraphy and structure of the type area of the Chilliwack Group, southwestern British Columbia: Vancouver, University of British Columbia. Ph.D. thesis, 173 p.
1970, Hope map-area, west half, British Columbia: Geological Survey of Canada Paper 69-47, 75 p.
1977, Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran evolution: Canadian Journal of Earth Science, v. 14, p. 1832-1859.
1986, Geology between Harrison Lake and Fraser River, Hope map area, southwestern British Columbia, in Current Research, Part B: Geological Survey of Canada Paper 86-1 B. p. 699-706.
- **1993**. Canadian Cordilleran tectonics: from geosynclines to cruslal collage: Canadian Journal of Earth Sciences, v. 30, p. 209-231.
- **1989**, Geology, Hope, British Columbia, Map 41-1989 Sheets 1-4, scale 1:250.000.
Morrison, M.L., 1977, Structure and stratigraphy of the Shuksan meta-morphic suite in the Gee Point-Finney Park area. North Cascades: Bel-lingham. Western Washington State College. M.S. thesis, 69 p.
Nokleberg, WJ., Parfenov, L.M., Monger, J.W.H., Baranov, B.V., Byalobzhesky, S.G., Bundtzen, T.K., Feeney, T.D., Fujita, K., Gordey, S.P., Grantz. A., Khanchuk, A.I., Natal'in, B.A., Natapov, L.M., Nor¬ton, I.O., Patton, W.W., Jr., Plafke'r, G., Scholl, D.W., Sokolov, S.D.. Sosunov, G.M.. Stone, D.B.. Tabor, R.W., Tsukanov, N.V., Vallier, T.L. and Wakita, K., 1994, Circum-North Pacific tectono-stratigraphic terrane map: U.S. Geological Survey Open-File Report 94-714, p. 433.
Owen, C, 1988, The petrogenesis of blueschist facies ironstones in the Shuksan and Easton schists. North Cascades, Washington: Seattle, University of Washington, Ph.D. thesis, 290 p.
Rady, P.M., 1980, Structure and petrology of the Groat Mountain area, North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis, 132 p.
Ragan, D.M.. 1961, Geology of Twin Sisters dunite, northern Cascades, Washington: Seattle, University of Washington, Ph.D. thesis, 98 p.
- **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 Srn-Nd mdodel ages and single grain U-Pb zircon geochronology for the age and heritage of the Swakane Gneiss, Yellow Aster Complex, and Skagit Gneiss, North Cascades, Wash.: Geological Society of America Ab¬stracts with Programs, v. 24, n. 7, p. A65.
Riedel, J.L. and Haugerud, R.A., 1994, Glacial rearrangement of drainage in the northern North Cascade Range, Washington: Geological Society of America Absracts with Programs, v. 26, n. 7, p. A-307.
Sevigny, J.H., 1983, Structure and petrology of the Tomyhoi Peak area, North Cascades Range, Washington: Bellingham, Western Washington University, M.S. thesis, 203 p.
Sevigny, J.H., and Brown, E.H., 1989, Geochemistry and tectonic interpretations of some metavolcanic rock units of the western North Cascades, Washington: Geological Society of America Bulletin, v. 101, p.
Smith. J.G., 1989, Geologic map of upper Eocene to Holocene volcanic and related rocks in the Cascade Range, Washington: U.S. Geological Survey Miscellaneous Investigations Map 1-2005, 19 p., scale 1:500,000.
Smith, M.T., 1986, Structure and petrology of the Grandy Ridge-Lake Shannon area. North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis. 103 p.
- 1988, Deformational geometry and tectonic significance of a portion of the Chilliwack Group, northwestern Cascades, Washington: Canadian Journal of Earth Science, v. 25. p. 433-441 .
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.
Street-Martin, L.W., 1981, The chemical composition of the Shuksan Metamorphic Suite in the Gee Point-Finney Peak area. North Cascad¬es, Washington: Bellingham, Western Washington University, M.S. thesis, 91 p.
Suczek, C.A., Babcock, R.S., and Engebretson, D.C., 1994, Tectonostratigraphy of the Crescent terrane and related rocks, Olympic Peninsula, Washington, in D. A. Swanson and R. A. Haugerud, Geologic field trips in the Pacific Northwest: Published in conjunction with the Geological Society of America Annual Meeting in Seattle, October 24-27, by the Department of Geological Sciences, University of Washington, Seattle, Washington, v. 1. p. 1H-I-1 1.
Tabor, R.W., 1994, Late Mesozoic and possible early Tertiary accretion in Western Washington State: the Helena-Haystack melange and the Darrington-Devis Mountain fault zone: Geological Society of America Bulletin, v. 106, n. 2, p. 217-232.
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, n. 1, p. 26-44.
Tabor, R.W., Haugerud, R.H., 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, Washington, D.C., International Geological Congress Field Trip T307, p. 1-33.

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 Miscellaneous Investigations Map 1-1963. scale 1:100.000.

Tabor, R.W., Haugerud, R.A.. Booth, D.B., and Brown, E.H., 1994, Preliminary geologic map of the Mount Baker 30- by 60-minute quadrangle: U.S. Geological Survey Open-File Report 94-403, 43 p., scale 1:100,000.

Tabor, R.W., Booth, D.B., Vance, J. A., and Ford. A.B., in press. Geologic map of the Sauk River 1/2 by 1 degree quadrangle, U.S. Geological Survey Miscellaneous Investigations Map, scale 1:100,000.

Tabor, R.W.. Haugerud, R.A., Hildreth, E.W., and Brown. E.H.. in preparation. Geologic map of the Mount Baker 30- by 60-minute quadrangle: U.S. Geological Survey Miscellaneous Investigations map. scale 1:100,000.

Tepper, J.H., 1985, Petrology of the Chilliwack composite batholith, Mt. Sefritarea, North Cascades, Washington: Seattle, University of Wash¬ington, M.S. thesis, 102 p.

1991, Petrology of mafic plutons and their role in granitoid genesis, Chilliwack balholith. North Cascades, Washington: Seattle, University of Washington, Ph.D. thesis, 307 p.

Tepper. J.H., Nelson, B.K., Bergantz, G.W., and Irving, A.J.. 1993, Petrology of the Chilliwack batholith. North Cascades, Washington: generation of calc-alkaline granitoids by melting of mafic lower crust with variable water fugacity: Contributions to Mineralogy and Petrology, v. 113. p. 333-351.

Thompson, G.A., and Robinson, R., 1975, Gravity and magnetic investigation of the Twin Sisters dunite, northern Washington: Geological Society of America Bulletin, v. 86, 1413-1422.

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

Vance, J.A.. 1977, The stratigraphy and structure of Orcas Island, San Juan Islands, in Brown, E.H.. and Ellis, R.C., editors. Geological excursions in the Pacific Northwest: Geological Society of America field guide. Annual Meeting, Seattle, p. 170-203.

Vance, J.A., Walker. N.W., and Mattinson, J.M., 1986, U/Pb ages of early Cascade plutons in Washington State: Geological Society of America Abstracts with Programs, v. 18, n. 2, p. 194.

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 J. E. Schuster, editor. Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77. p. 269-290.

Vance. J.A., and Miller, R.B., 1992, Another look at the Fraser River-Straight Creek fault (FRSCF): Geological Society of America Ab¬stracts with Programs, v. 24. n. 5, p. 88.

Vonheeder, E.R., 1975, Coal reserves of Whatcom County, Washington: Washington Division of Geology and Earth Resources Open-file Report 75-9, 86 p.

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., p. 154.

Waitt, R.B.. Jr., 1977, Evolution of glaciated topography of upper Skagit drainage basin, Washington: Arctic and Alpine Research, v. 9, n. 2, p. 183-192.

Weis. P.L., 1969, Glacial drainage divide in the Skagit Valley, Washing¬ton: U.S. Geological Survey Professional Paper 650-C, p. C71-C74.

Wells, R.E., Engebretson, D.C., Snavely, P.O., Jr., and Coe. R.S.. 1984, Cenozoic plate motions and the volcano-tectonic evolution of western Oregon and Washington: Tectonics, v. 3, p. 275-294.

Ziegler, C.B., 1986, Structure and petrology of the Swift Creek area. North Cascades, Washington: Bellingham, Western Washington University, M.S. thesis. 191 p.