This Chapter

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Geology of the Metamorphic Core of the North Cascades
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INTRODUCTION

Eocene faults segment the Cretaceous and earliest Tertiary North Cascades orogen into several blocks (Fig. 1) among which there are significant differences in stratigraphy, thermal history, and (or) deformational history. Medium- and high-grade regionally metamorphosed rocks of the orogen are restricted to the region between the Straight Creek fault and the Ross Lake fault zone—commonly referred to as the “metamorphic core” or “Skagit core”—and a narrow area along the northeast side of the Ross Lake and North Creek faults.

This paper contains a geologic overview and road log for a one-day field trip across the Ross Lake fault zone and metamorphic core along Washington State Route (SR) 20. The road log continues into the mildly metamorphosed rocks west of the Straight Creek fault; however, for an overview of the geology of of the western North Cascades, the reader should refer to the companion paper by Brandon (this volume).

Within the metamorphic core the Entiat fault is a significant boundary. Much of the block to the northeast of the fault was ductilely deformed in the Eocene, and a large fraction of K-Ar cooling ages there are Eocene (disregarding those ages associated with younger plutons of the Cascade arc). No Eocene ductile deformation has been recognized in the block southwest of the Entiat fault, where most cooling ages are Late Cretaceous (Engels and others, 1976; Haugerud, 1987). Discussion herein of the metamorphic core is, in general, applicable only to the region northeast of the Entiat fault.

GEOLOGIC OVERVIEW

The gross structural relations among major pre-Eocene lithologic units discussed here are summarized in Figure 2. The geology and geography of the field trip are sketched in Figure 3 (Ross Lake fault zone and metamorphic core) and Figure 4 (western North Cascades).

Fieldtrip stops emphasize three themes: (1) several pre-Late Cretaceous terranes that are the fundamental building blocks of this part of the range, (2) deformation and metamorphic recrystallization of these terrenes during Late Cretaceous and earliest Tertiary orogeny, and (3) Eocene reworking of the orogen and coeval magmatism of the “Challis” event. Oligocene and younger magmatic rocks of the Cascade arc are neglected, though they comprise much of this part of the range.

Pre-Late Cretaceous(?) Terranes Rocks within the Ross Lake Fault Zone

Three units of metamorphosed sedimentary and volcanic strata which crop out between the Hozameen fault and Ross Lake fault proper, within the Ross Lake fault zone, comprise two terranes. Below the Jack Mountain thrust, phyllite and semischist with minor amounts of interlayered ribbon chert, greenish tuffaceous schist, and scattered ultramafic pods constitute the Jack Mountain Phyllite of Misch (1966b) (Stop 2-2); associated with this unit is the higher grade, largely metavolcanic, Elijah Ridge Schist of Misch (1966b). The North Creek Volcanics of Misch (1966b) may be correlative with the Elijah Ridge Schist. Tabor and others (in press [a]) lump these units together as the Little Jack terrane. These units predate the Late Cretaceous Black Peak and middle Eocene Golden Horn batholiths.

Above the Jack Mountain thrust lies the Permian to Middle Jurassic Hozameen Group of Cairnes (1944)(Hozameen of other authors), composed of basaltic greenstone (metamorphosed pillow basalt, tuff, breccia, massive lava), chert, and argillite with minor amounts of limestone, gabbro, sandstone, and dacite(?) (McTaggart and Thompson, 1967; Tennyson and others, 1982; Haugerud, 1985; Ray, 1986).

North of 49°N, the Maselpanik schist unit of Haugerud (1985) is the along-strike metamorphic equivalent of the Elijah Ridge Schist and Jack Mountain Phyllite, although McTaggart and Thompson (1967) and
Figure 1. North Cascades area and significant Eocene features. Shaded areas. Eocene sedimentary and volcanic rocks; crosses, Eocene plutons (1, Granite Falls; 2, Mount Pilchuck; 3, Bald Mountain; 4, Duncan Hill; 5, Railroad Creek; 6, Cooper Mountain; 7, Golden Horn; 8, Ruby Creek; 9, Monument Peak/Lost Peak; 10, Castle Peak; 11, Needle Peak); wavy lines, regions of Eocene ductile deformation and(or) Eocene K-Ar regional-metamorphic cooling ages; DDMFZ, Danington-Devils Mountain fault zone; TLF, Thunder Lake fault. Eocene ages of some features are inferred.
Haugerud (1985) inferred that this unit has a Hozameen protolith.

**Rocks between the Ross Lake and Straight Creek Faults**

Tabor and others (in press [a]) assign schists and gneisses on the fieldtrip route between the Ross Lake and Straight Creek faults to four units. First is the Napeequa unit (Stop 2-6), which consists of metachert, amphibolite, calcareous and amphibolitic schist, rare marble, and scat-tered ultramafic bodies. The second unit, the Cascade River unit, consists of thick sections of granitoid-clast metaconglomerate as well as metasandstone, lesser metapelite, and some metavolcanic rock. Associated with these two units is the third, the tonalitic, 220 Ma Marblemount Meta Quartz Diorite of Misch (1966b) and related plutons. These three units are part of the Chelan Mountains terrane. (Nomenclature used here is that of Tabor and others, 1988, in press [a]). The Cascade River Schist of Misch, 1966, includes all of the Cascade River unit and parts of the Napeequa unit. Our work suggests that the Cascade River Schist should be restricted to the metatlastic schists and their interstratified metavolcanic rocks. As used here, the Chelan Mountains terrane in-cludes the Mad River terrane of Tabor and others (1987a).

Relations among these three units are not well under-stood. My preferred hypothesis is that the Marblemount plutons intruded the Napeequa unit and that the Cascade River unit once overlay both depositionally. A pre-metamorphic fault between the Napeequa and Cascade River units is also plausible. Constraints are: (a) boulders of Marblemount(?), tonalite occur in metaconglomerate of the Cascade River unit; (b) the oceanic, ribbon chert- and basalt-rich Napeequa unit and the coarse-clastic-rich Cascade River unit are incompatible depositional assemblages; (c) Mattinson (1972) interpreted a discordant U-Pb zircon age from meta-keratophyre of the Napeequa unit (collected in the Holden area) to indicate crystallization at about 265 Ma, before intrusion of the 220 Ma Marblemount plutons; and (d) the Cascade River unit is in part coeval with the Marblemount unit, as metatuff in the Cascade River unit has given a 219 Ma U-Pb zircon age (John Stacey, U.S. Geological Survey, written commun., 1988).

The fourth unit of the metamorphic core at this latitude, the Skagit Gneiss of Misch (1966b), is largely orthogneiss (Stop 2-5) with subsidiary banded gneiss which contains significant paragneiss (Stop 2-4). Both are commonly migmatitic. Near Big Devil Peak, south of Newhalem, schist of the Napeequa unit grades into banded gneiss of the Skagit Gneiss; similar schist reappears at the northeast margin of the Skagit Gneiss, on the upper slopes of Ruby Mountain. For these reasons Tabor and others (in press [a]) include all Skagit paragneisses in the Chelan Mountains terrane, though it is possible that other pre-metamorphic terrenes (for example, the Skymo unit, Stop 2-3) are hidden by the veil of high-grade metamorphism and migmatization in the Skagit.

Farther south, other pre-Late Cretaceous terranes lie within the metamorphic core of the North Cascades. These include the largely metapelitic Nason terrane, the meta-arkosic(?) Swakane terrane, and the (in part un-meta-morphosed) ophiolitic Ingalls Complex of Miller (1985). Descriptions of these terranes and further references are in Tabor and others (1987a).
Figure 3. Geologic map of the area along the fieldtrip route between the Hozameen and Straight Creek faults. Compiled from Tabor (1961), Staatz and others (1972), Barksdale (1975), Misch (1977), Miller (1987), Tabor and others (1988), and Tabor and Haugerud (unpublished USGS field maps). Absolute ages are primary intrusive or depositional ages interpreted from U-Pb zircon dating as reported by Mattinson (1972), Hoppe (1984), Miller and others (1988), Haugerud and others (1988), and J. S. Stacey (USGS, written commun., 1987, 1988). See facing page for explanation.
EXPLANATION

ROCKS OF THE CASCADE ARC

Tomg  Miocene and Oligocene granitoid rocks
Tomv  Miocene and Oligocene volcanic rocks

ROCKS OF THE “CHALLIS” EVENT

Teg  Eocene granite of the Golden Horn batholith-50 Ma

EOCENE TO LATE CRETACEOUS
OROGENIC ROCKS

Skagit Gneiss of Misch (1966)—Largely migmatitic. Divided into:
TKsb  Banded gneiss (metamorphic age)—derived from strata of the Chelan Mountains terrane
TKss  Skymo unit—Troctolite, norite, and gabbro
TKso  Orthogneiss—65 and 74 Ma, in part
TKsp  Pegmatite—At northeast border of Eldorado pluton

Orthogneiss—Divided into:
TKoa  Alma Creek pluton
TKom  Marble Creek pluton-75 Ma
TKoh  Haystack Creek pluton
TKog  Gabriel Peak Orthogneiss of Misch (1966)-65 Ma
T Koe  Eldorado Orthogneiss of Misch (1966)-90 Ma

Granitoid plutons—Little-deformed to undeformed. Divided into:
TKgr  “Ruby Creek Heterogeneous Plutonic Belt” of Misch (1966)-48 Ma, in part
TKghl  Hidden Lake pluton-75 Ma
TKgs  Snowking pluton
TKgbp  Black Peak batholith-90 Ma, in part

PRE-OROGENIC TERRANES

JPh  Hozameen Group of Cairnes (1944) (Middle Jurassic to Permian)
pKlj  Pre-Late Cretaceous rocks of the Little Jack terrane-Metamorphosed during Late Cretaceous to Eocene orogeny
Triassic (and older?) rocks of the Chelan Mountains terrane-Metamorphosed during Late Cretaceous to Eocene orogeny. Divided into:
TR cc  Cascade River unit—219 Ma, in part
TR cn  Napeequa unit—Pre(?)-220 Ma, in part
TR cm  Marblemount Meta Quartz Diorite of Misch (1966) and correlative tonalitic plutons-220 Ma

Rocks West of the Straight Creek Fault

Rocks west of the Straight Creek fault have close affinities with rocks of the San Juan Islands and are described by Brandon (this volume).

The discerning reader will note possible parallels between rock units east and west of the Straight Creek fault: for example, might the Elbow Lake Formation, Napeequa unit, and Hozameen Group be equivalent? What of the similarities between the Cultus Formation and Cascade River unit? Such correlations should be good fodder for the beer hour.
Figure 4. Geologic map of the area along fieldtrip route west of the Straight Creek fault Simplified from Brown and others (1987). Age assignments are from cited references and C. D. Blome (USGS, written commun., 1988). See facing page for explanation.
Late Cretaceous and Earliest Tertiary Orogeny

Most rocks within the metamorphic core of the North Cascades are schist or gneiss formed during Late Cretaceous recrystallization and deformation, which locally lasted into the early Tertiary. Roughly contemporaneous with this metamorphism was the intrusion of numerous plutons. Peak regional-metamorphic conditions along the fieldtrip route ranged from chlorite zone near the Hozameen-North Creek fault, to sillimanite zone in much of the Skagit Gneiss, back down to chlorite zone near Marblemount (Misch, 1966b, 1968, 1977, 1979). Thermobarometry suggests peak conditions of about 720°C and 9 kb in Skagit Gneiss having the highest metamorphic grade (Whitney and Evans, 1988).

Synorogenic plutons are mostly tonalitic. Mattinson (1972) demonstrated that one of the largest of these, the Eldorado Orthogneiss of Misch (1966b), is -90 Ma, thus part of a suite of mid-Cretaceous plutons that includes the Mount Stuart, Spuzzum, Pasayten, and several other bodies in the North Cascades and adjacent Coast Mountains. More recently, Miller and others (1988), Haugerud
and others (1988), and John Stacey (U.S. Geological Survey, written commun., 1988) have obtained U-Pb zircon ages of 60 to 75 Ma from several plutons in the Ross Lake fault zone and that part of the metamorphic core northeast of the Entiat fault (Stop 2-5). The younger plutons seem to be restricted to this region.

Ductile deformation in the metamorphic core and at the southwest edge of the Ross Lake fault zone postdates Upper Triassic and Middle Jurassic protoliths and locally lasted into (or was revived in) the middle Eocene (Stop 2-4). Within the Skagit Gneiss, early Tertiary deformation has obliterated most evidence of earlier phases of deformation. Xenoliths in a 64 Ma orthogneiss in the Skagit preserve an older, preintrusion foliation (Haugerud, 1985; Haugerud and others, 1988). An older fabric is also preserved in well-foliated schist which is intruded by the slightly deformed -75 Ma Hidden Lake Peak stock (Fig. 3). By analogy, all of the Skagit Gneiss was probably deformed before 75 Ma.

Along the fieldtrip route, the dominant fabric in rocks of the core is a northwest-trending subhorizontal lineation associated with steeply dipping northwest-striking foliation. These orientations largely reflect the youngest, Eocene, penetrative deformation.

Metamorphic recrystallization is not well dated, but must postdate Late Triassic strata of the Chelan Mountains terrane and Middle Jurassic Hozameen strata that grade into the Maselpanik schist unit of Haugerud (1985). Pre-kinematic porphyrobasts in schists adjacent to the Hidden Lake Peak stock demonstrate pre-75 Ma recrystallization. The -75 Ma tonalitic Marble Creek pluton (Fig. 3) contains magmatic epidote, indicating pressures >6 kb at that time (Zen and Hammarstrom, 1984). The 65 Ma pluton at Nehalem (Stop 2-5) has participated in migmatization. Most metamorphic recrystallization within the Skagit Gneiss predates middle Eocene dikes and sills; these dikes and sills cross-cut the main metamorphic fabric and have igneous textures modified only by mylonitic grain-size reduction.

Eocene Orogeny

The North Cascades lie at the junction of two Eocene tectonic regimes. To the east, west-east extension of the Omineca belt in the early and middle Eocene was accompanied by low-angle normal faulting; basin development; ductile deformation, unroofing, and cooling of mid-crustal rocks; and by the extensive and intense Challis magmatic event (Ewing, 1980; Parrish and others, 1988). To the west, parts of the continental margin were transported northward on a network of north- to northwest-trending steep faults at about the same time (for example, Cowan, 1982; Johnson, 1984).

Eocene deformation of the North Cascades seems to reflect the interaction of these regimes: The few K-Ar ages from the Skagit Gneiss and adjacent schists (Engels and others, 1976; Richards and McTaggart, 1976) indicate unroofing and consequent cooling in the middle Eocene, apparently during or shortly after post-46 Ma ductile extension (Stop 2-4). Challis-age magmatic rocks are present in much of the range (Stops 2-1 and 2-4), and sedimentary basins developed in the western North Cascades, in the central Cascades, and east of the metamorphic core. However, the extension direction in the Skagit Gneiss is northwest-southeast, subparallel to the continental margin, and associated faults are steep and dominated by dextral strike slip. Eocene features in the North Cascades are sketched in Figure 1.

Mylonitic fabrics, cooling at the same time as unroofing of metamorphic complexes in the Okanogan region to the east, and sharp changes in metamorphic grade at the northeast margin of the Skagit Gneiss all invite comparison with metamorphic core complexes elsewhere in the Cordillera, but the characteristic low-angle normal faults seem to be missing.

Unroofing of the Skagit Gneiss was accommodated by at least three mechanisms: (1) an unknown amount of erosion; (2) vertical thinning within the Skagit Gneiss, and presumably the once-overlying rocks, evidenced by uniaxial prolate strains in late lineated orthogneiss dikes—that is, horizontal extension with apparent shortening in all directions, including the vertical, at right angles to the extension direction; and, necessarily coupled with these mechanisms, (3) the dip-slip component of motion on the Ross Lake, Entiat, and Straight Creek faults (Haugerud, 1985). Along-strike depth changes in the Duncan Hill pluton (Fig. 1) (Hopson and others, 1970; Bellinger and Hopson, 1988) suggest up-to-the-northwest tilting at the southern margin of the Skagit Gneiss.

Seemingly contradictory evidence for timing of motion in the Ross Lake fault zone (Fig. 3) is reviewed by McGroder and Miller (this volume). Though one strand of the zone is plugged by the Black Peak batholith—dated at one locality at 90 Ma—and the 50 Ma Golden Horn batholith plugs another strand, other strands displace rocks as young as 48 Ma, and fault-associated fabrics affect 46 Ma orthogneiss north of 49°N. The contrast in metamorphic facies across the fault zone suggests significant dip-slip motion, whereas fabrics within the zone show both dextral strike slip and oblique slip (Haugerud, 1985; Tabor and others, in press [a]; McGroder and Miller, this volume). Kriens (1988) studied the Ross Lake fault proper near SR 20 and found no evidence for significant early Tertiary dextral displacement. Perhaps much of the Eocene motion documented by Haugerud (1985) to the north and Miller (Miller and others, 1985; McGroder and Miller, this volume) to the south is localized on faults or zones of distributed shear west of the region Kriens examined.
ACKNOWLEDGMENTS

My understanding of North Cascades geology has matured in the course of three summers mapping the Mount Baker 30 x 60 minute quadrangle with Rowland Tabor; the work and ideas presented here are in large part his. These ideas will undoubtedly grow further as this mapping is completed. Conversations with E. H. Brown, the late P. Misch, D. L. Whitney, G. J. Woodsworth, and others have been helpful. The road log draws heavily from guides by Misch (1977) and Tabor and others (in press [a]). Reviews by J. G. Evans, M. A. Korosec, R. E. Powell, R. W. Tabor, and J. A. Vance have helped improve the text. Special thanks to M. F. McGroder for organizing all of this.

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Editors Note:
This extra half-page is an artifact of re-formatting this reference section. These entries all occur on page 129 of the original document. For this reason, it has no page number.
Road Log

This log covers the second day of a three-day field trip. It includes more stops than we can comfortably make in one day. Depending on weather, snowpack, time, and the interests of the group, we will omit some of the following stops.

The road log begins on Washington State Route (SR) 20, several miles up-valley (northwest) of the communities of Winthrop and Twisp. For most of the day, mileage is referenced to the mileposts along SR 20 (milepost numbers are lower to the west), not to elapsed distance.

179.6 Turnoff to Mazama and Harts Pass.

167.6 STOP 2-1. Rapakivi (plagioclase mantling potassium feldspar) granite of the undeformed, high-level, ~50 Ma Golden Horn batholith.

   Look carefully for miarolitic cavities at this stop. Elsewhere, granite of the Golden Horn batholith bears arfvedsonite (Boggs, 1984; earlier workers considered the sodic amphibole to be riebeckite) and aegirine. Because the batholith has intruded the Hozameen-North Creek fault, motion on this stretch of the fault must be older than 50 Ma.

   The Golden Horn batholith is the best known (Misch, 1966a; Stull, 1969; Engels and others, 1976; Hoppe, 1984; Boggs, 1980, 1984) of a suite of middle Eocene granite and granodiorite plutons that extends across much of the range. The suite also includes the late lineated dikes of the Skagit Gneiss (Stop 2-4) and the Castle Peak, Monument Peak, Cooper Mountain, Duncan Hill, Railroad Creek, Bald Mountain(?), and Mount Pilchuck plutons. Most older and younger plutons in the North Cascades are tonalite.

162.4 Washington Pass (5,477 ft), where the Chelan and Methow Rivers divide; both streams flow into the Columbia River.

160.0 Roadcuts are in undeformed tonalite of the Black Peak batholith. Samples from near here have yielded -90 Ma U-Pb zircon and K-Ar ages (Hoppe, 1984; Engels and others, 1976).

157.5 Rainy Pass (4,840 ft) on the Skagit-Chelan divide. For the next 16 mi we travel northwest along the Ross Lake fault zone, here totally obliterated by the younger Golden Horn batholith.

141.2 STOP 2-2. Jack Mountain Phyllite at Canyon Creek trail head.

   Park on the right (north).

   Roadcuts on the south side of SR 20 are in Jack Mountain Phyllite (Little Jack terrane). They display typical biotite porphyroblasts and deformed leucocratic sills, all with a gently southwest-plunging lineation. Across the valley to the north, the lower two-thirds of the hillside is also Jack Mountain Phyllite. The upper slopes are greenstone of the Hozameen Group.

139.9 Northwest of the Golden Horn batholith the Ross Lake fault zone has been invaded by numerous granitoid intrusions, some of which are foliated. These range in composition from granite to hornblende diorite. The intrusions are the “Ruby Creek Heterogeneous Plutonic Belt” of Misch (1966b). The complicated intrusive relations and large amounts of included country rock are probably the result of intrusion into an active fault zone (Misch, 1977). At this location, Ruby Creek agmatites range from varieties with equant and angular inclusions to varieties with elongate, rounded, foliated fragments. The latter are Misch’s “pol-lywog agmatite”. Most inclusions are probably Jack Mountain Phyllite or Elijah Ridge Schist. The trondhjemite matrix of the pollywog agmatite has given a 48 Ma U-Pb zircon date (Miller and others, 1988).

138.5 Panther Creek bridge.


   Park in the large turnout on the right.

   Across the road are complex migmatites of the Skagit Gneiss (Chelan Mountains terrane, see Stop 2-6). Good views to the north of (right to left) Little Jack, Jack, and Hozomeen Moun-tains, Ross Lake, and Mount Prophet, highest point on the left. Mount Prophet (7,650 ft) is carved from marble, paragneiss, and orthogneiss of the Skagit Gneiss. One of the few sillimanite localities in the Skagit Gneiss is on its southern slope. Ridges to the right of Mount Prophet are underlain by the Skymo unit of Wallace (1976): trondhjemite and olivine norite intruded by medium- to coarse-grained gabbro. Brittle, north- and northwest-trending faults separate the Skymo unit from the Skagit Gneiss, but Skymo gabbro is intruded.
by pegmatite of the Skagit Gneiss (Staatz and others, 1972). Rocks of the Skymo unit extend southeast to the shore of Ross Lake.

To the northeast, but on the west side of the lake, are schists, semischists and phyllites of the Little Jack terrane, in which metamorphic grade decreases to the east. Farther to the northeast are greenstone and chert of the Hozameen Group. In the distance, beyond the head of the lake in Canada, is Silvertip Mountain. Closer to the overlook, the sharp horns to the right are Hozameen Mountain (8,066 ft). Small stocks of the Chilliwack batholith are present on both Silvertip and Hozomeen Mountains and their contact-metamorphic effects have helped produce rugged mountains out of otherwise less competent chert, argillite, and greenstone of the Hozameen Group.

The massive peak to the right is Jack Mountain (9,066 ft). On its lower slopes, near timber-line, the gently northeast-dipping Jack Mountain fault places the Hozameen Group above semi-schist, phyllite, tect schist, and metamorphite of the Little Jack terrane. Little Jack Mountain (6,745 ft) is the grassy ridge below and to the right of Jack Mountain.

Although the Little Jack terrane here is in fault contact with the Hozameen Group and the Skymo unit of the Chelan Mountains terrane, it displays a steep metamorphic gradient from the high-grade rocks to the southwest to the slightly metamorphosed Hozameen Group. A similar but less faulted gradient occurs north of 49°N, though in rocks probably correlative with the Hozameen Group (McTaggart and Thompson, 1967; Haugerud, 1985).

The Hozameen Group and Little Jack terrane most likely overlay the Skagit Gneiss during Late Cretaceous to early Tertiary phases of the Chil-liwack batholith and do not offset the early Oligocene phases of the Chil-liwack batholith to the north. Sourdough Creek (which drains toward us on the south face of Sourdough Mountain), Thunder Lake, and a large notch on the east ridge of Colonial Peak are located on the Thunder Lake fault, the most conspicuous of these structures.

133.5 Horsetail Creek and John Pierce Falls. East of the bridge are spectacular roadcuts of banded migmatitic gneiss, locally with layers of metamorphosed ultramafic rock.

131.8 Diablo Lake overlook. Stop here (though not today) to admire the view southwest across Thunder Arm of Diablo Lake to Colonial Peak (7,771 ft) and neighboring summits. To the north, across Diablo Lake, peaks made of Skagit Gneiss are (left to right) Davis Peak (7,051 ft), Elephant Butte (7,380 ft) and Sourdough Mountain (6,106 ft), on which is a fire lookout that was manned by poet Gary Snyder during the mid-1950s.

The outcrop across the highway is massive biotite-hornblende quartz diorite orthogneiss, veined by extensive light-colored dikes. From this point to beyond the turnoff to Diablo, outcrops are dominantly paragneiss.

130.5 Bridge across Thunder Arm of Diablo Lake.

129.5 Thunder Lake. The valleys of Stetattle Creek and Thunder Creek are localized along strands of a group of north- and NNW-trending brittle faults. These faults must be of late Eocene or earliest Oli-gocene age because they cut Skagit Gneiss with its ductile middle Eocene fabric and do not offset the early Oligocene phases of the Chil-liwack batholith to the north. Sourdough Creek (which drains toward us on the south face of Sourdough Mountain), Thunder Lake, and a large notch on the east ridge of Colonial Peak are located on the Thunder Lake fault, the most conspicuous of these structures.

127.4 STOP 2-4. Skagit Gneiss at the Diablo Dam turnoff.

Roadcuts here display migmatitic banded gneiss with both older, pegmatitic, main-phase leucosomes and finer grained, cross-cutting late lineated dikes. There is no consensus on the petrogenesis of Skagit migmatites. Plagioclase compositions in most leucosomes and their wall rocks do not dif-fer substantially (Misch, 1968; Yardley, 1978), indicating that the leucosomes are not injected melts. The wide range of leucosome plagioclase composi-tions, lack of K-feldspar, common lack of nearby melanosomes, and estimated metamorphic temperatures of 600°C led Misch (1968) to infer that the leucosomes are not segregated partial melts. Misch (1968) and Bab-cock (1970) favored large-scale metasomatism at sub-solidus conditions to generate the leucosomes. Yardley (1978) agreed that the mig-matites formed without melting but favored...
local metamorphic differentiation.

More recently, Whitney and Evans (1988) estimated peak metamorphic conditions of ~720°C and ~9 kb. Given these conditions, parts of the Skagit must have been partially molten, yet the pegmatitic texture of most leucosomes suggests that their constituent grains grew in a hydrous fluid, not a melt. Melts at 9 kb are very effective H2O reservoirs. Magmas intruding the Skagit could have arrived with substantial dissolved H2O, and in-situ melts would have trapped any water passing through the crustal pile. Perhaps most leucosomes in the Skagit are pegmatites formed by protracted exsolution of this H2O during regional uplift. Slow exsolution would favor collection of fluid into scattered large bubbles (Godinot, 1988). Besides carrying substantial dissolved solids, such fluid would speed grain-size coarsening in the regions it wetted.

Late lineated dikes have a range of compositions, but most common are cream-colored granites, commonly with minor biotite, locally with garnet and(or) muscovite. The granitic composition is distinctive: along the Skagit River most older parts of the Skagit Gneiss lack potassium feldspar. The dikes commonly crosscut foliation in the host gneiss, yet are themselves lineated parallel to the northwest-trending low-angle lineation in the gneiss. Locally the dikes are foliated. These relations indicate that the dikes were intruded after most regional metamorphism but while the gneiss complex was still hot. They were subsequently stretched northwest-southeast along with the rest of the complex. Whole-rock Rb-Sr analyses of a suite of these dikes from along SR 20 define a 45 ± 3 Ma isochron (Babcock and others, 1985). U-Pb dates from a structurally and lithologically similar pluton a few kilometers north of 49°N (Haugerud, 1985) indicate intrusion at about 46 Ma (Peter van der Heyden, University of British Columbia, written commun., 1987, 1988). Along with the ~64 Ma age of the more strongly migmatized Custer ortho-gneiss unit of Haugerud and others (1988) north of 49°N, these dates demonstrate that deformation and migmatization of the Skagit Gneiss are in part Tertiary.

As we leave Newhalem and cross Goodell Creek, look to the right (north) for a view of the southern Picket Range, eroded out of Skagit orthogneiss.

118.2 First outcrops of the Oligocene and younger Chilliwack composite batholith.

114.9 Light-colored waterlaid volcanic ash in roadcuts. This deposit must be postglacial, yet present-day Skagit River is an unlikely agent to deposit such fine-grained material. Landslide(s) farther downstream probably dammed the Skagit and these beds were laid down in the resulting lake.

114.6 STOP 2-6. Schist of the Napeequa unit of the Chelan Mountains terrane, with sills of late-metamorphic orthogneiss.

Park on the river side of the road.

At the upstream end of the outcrop are intricately folded quartz-rich biotite schists—with thicker quartzite and thinner biotite-rich laminae—typical of metacherts in the Napeequa unit. The intricate fold style is common in much lower grade ribbon chert, and by analogy it is likely that these folds largely predate amphibolite-facies metamorphism.

For the next 2 mi outcrops of schist of the Napeequa unit are in the toes of large landslides. Rapids in this stretch of the Skagit River are formed by blocks of landslide debris. Rock types in the roadcuts include biotite schist, two-mica schist, quartzose schist, amphibole-bearing schist, and chlorite-rich mafic schist. Less abundant are pods and layers of talc and talc-carbonateschists, locally with forsterite, tremolite, and anthophyllite. All are metamorphosed in amphibolite fades (Misch, 1977). Vein quartz is locally extensive enough to have been mined to make glass.

110.7 Bridge over Bacon Creek.

110.4 Marblemount Meta Quartz Diorite of Misch (1966). Here the Marblemount is
predominantly a muscovite-chlorite-epidote-albite-quartz gneiss. From these outcrops Mattinson (1972) obtained a 220 Ma (Late Triassic) zircon U-Pb age. The Marblemount and its equivalent Late Triassic plutons form a belt extending from the Straight Creek fault, only about 1 km to the west of here, southeast for 150 km before they are covered by the Miocene Columbia River Basalt Group.

106.1 Town of Marblemount. The broad valley junction here is eroded out along two strands of the Eocene Straight Creek fault. Lookout Mountain looming up to the east is underlain by Marblemount Meta Quartz Diorite. Forested bluffs to the west are Shuksan Greenschist of the Easton terrane.

Refer to the paper by Brandon (this volume) for an overview of lithologies and tectonics relevant to the following part of the road log.

103.0 Cotkindale Creek. To the north, east of Corkindale Creek, steep wooded hillsides are underlain by Shuksan Greenschist. West of the creek are greenstones and low-grade metasedimentary rocks of the upper Paleozoic Chilliwack Group of Cairnes (1944), and high on the ridge are thick chert beds and greenstone of the Permian (?) to Jurassic (?) Elbow Lake formation of Brown and others (1987).

97.7 Junction with SR 530, the Darrington-Rockport road. Roadcuts to the east are in basaltic greenstone and associated sedimentary rocks of the Chilliwack Group.

89.6 At the east edge of the town of Concrete, before crossing the bridge over the Baker River, turn right onto Everett Avenue, then left onto East Main Street. Just before crossing the old Baker River bridge, turn uphill (right) onto East Lake Shannon Road. Follow this road up the hill, turn left onto the road to the top of Lower Baker Dam, and then take the right fork at “Y”. Stop at the gate and walk around the corner into the abandoned quarry.

STOP 2-7. Quarry in limestone of the Chilliwack Group of Cairnes (1944).

Mount Shuksan, Mount Baker, and Grandy Ridge can be seen from here on a clear day, and this stop is convenient for orienting ourselves amidst the controversy and confusion of northwest Cascades tectonics.

Age-definitive fossils have not been reported from this quarry, but on the basis of large crinoid columnals (present in some talus blocks on the east side of the quarry), Danner (1966) correlated these beds with limestone of his Lower Pennsylvanian Red Mountain sequence, which was reinterpreted by Liszak (1982) to be Late Mississippian in age. Like much of the remainder of the Chilliwack Group, this limestone lens has been technically dismembered: the upper and lower contacts are faults, and the limestone cannot be traced along strike. Similar, though smaller, fault-bounded lenses of Devonian to Permian limestone are scattered throughout the Chilliwack Group. North of 49°N, Monger (1966, 1970) used such lenses to trace a coherent stratigraphy. Such stratigraphy is only locally recognizable south of the border.

The Chilliwack Group also contains arc volcanic rocks and volcanioclastic sedimentary rocks. Felsic and intermediate Permian (?) volcanic rocks of the Chilliwack Group and associated volcanioclastic strata are difficult to distinguish from similar Triassic rocks in the Cultus Formation of Monger (1970) (Blackwell, 1983). The Cultus Formation probably was deposited on the Chilliwack Group, though we have not seen the contact. Younger than most of the Cultus are dacitic tuffs and flows of the Middle Jurassic Wells Creek Volcanics of Misch (1966b) and the overlying, Upper Jurassic to Lower Cretaceous argillite and sandstone of the Nooksack Group of Misch (1966b). The base of the Wells Creek Volcanics is not exposed, but I believe the unit overlies the Cultus Formation. Tabor and others (in press [a]) lump all these units together as the Grandy Ridge terrane.

Return to East Main Street, turn right, cross the old bridge over the Baker River, and follow the road up hill to the stop sign. Turn right onto Main Street and continue west through downtown Concrete to the stop sign at Main and Superior. Turn right on Superior, go uphill, and turn left onto the Burpee Hill Road. Follow the Burpee Hill Road past outcrops of glacial out-wash deposits (note collapse features) about 4 mi to:

1.7 The low hill in the foreground is of young, but pre Vashon age (latest continental glaciation), olivine basalt (see Stop 2-10).

5.8 Rocky Creek bridge; at the north end of the bridge, turn left onto U.S. Forest Service Road (FSR) 12 and follow signs to Schreibers Meadow.

-8 Cross Sulphur Creek. Beyond here the road is on top of olivine basalt flows. Morphology and vegetative cover suggest that flows of at least two ages, both postglacial, erupted from the cinder cone south of Schreibers Meadow. The oldest flows extend almost to Upper Baker Dam. These flows overlie the
glacial-outwash deposits that fill the lower Baker River valley.

-10 Junction of FSR 12 and FSR 13. Keep right on FSR 13 past three hairpin turns, to:

-12 STOP 2-8. Yellow Aster Complex of Misch (1966b). Park near the road-metal quarry on the right side of the road. The Yellow Aster Complex is a hodge-podge of fault-bounded igneous and metamorphic rock fragments in the northwest Cascades. Radiometric dating (Mattinson, 1972) indicates that some gneisses and granitoid rocks of the complex crystallized at ~415 Ma; these plutons intrude older clinopyroxene-bearing gneisses which Misch and Mattinson interpreted as metamorphosed 1,400 Ma plutons. Younger mafic intrusions, mostly diabase, intrude the gneisses and granitoid rocks.

This outcrop is in the >6-km-long Park Butte slab of imbricated gneiss of the Yellow Aster Complex and volcanic rock of the Chilliwack Group, which caps ridges on the south side of Mount Baker. Hornblende diorite and gneissic diorite here are typical of the younger elements of the Yellow Aster Complex. The cross-cutting mafic dikes are also typical.

Older clinopyroxene-plagioclase-quartz gneiss, calc-silicate gneiss, and marble are present at the west end of this slab; the lithologic association strongly suggests that the older gneisses are metasedimentary. Good talus exposures of these older gneisses can be reached via a short (~1 mi) walk from the end of FSR 13 to the base of Survey Point, immediately west of Schreibcrs Meadow.

Retrace the route 1/4 mi back down FSR 13 to:

STOP 2-9. Low-angle fault zone beneath Park Butte slate of the Yellow Aster Complex. Park at the blocked spur road (on the left, or north, side of FSR 13) adjacent to the stream culvert 100 m west of the margin of a recent clear-cut.

Below FSR 13 the stream has carved a broad, steep gully which exposes the low-angle fault zone beneath the Yellow Aster Complex. Walk through logging slash and brush along the east margin of the washout until you can descend into the gully to reach excellent exposures of the fault zone, which extends to the base of the hillside some 200 m below. Most rock is tecone/ed shale, siltstone, and sandstone of the Nooksack Group. Imbricated with the Nooksack are blocks of greenstone (Chilliwack Group?) and, on the east side of the gully, a 1 m x 2 m lozenge of light-colored, poorly cemented, chert-lithic sandstone and granule conglomerate with thin coaly seams. This last lithology is common in early Tertiary sandstones in the northwest Cascades. Simi-larly, poorly cemented sandstone, commonly with abundant quartz grains and minor detrital muscovite, is present at several other localities in low-angle fault zones south and east of Mount Baker. Low-angle faults in the northwest Cascades have been considered mid-Cretaceous thrusts (Misch, 1966b; Brandon and Cowan, 1985; Brown, 1987; Smith, 1988), and the low-grade, lawsonite-argonite metamorphism of the northwest Cascades has been thought a consequence of burial by these thrusts (Brandon and others, 1988). Yet some sandstones in the low-angle fault zones appear unmetamorphosed! Do these sandstones owe their unmetamorphosed appearance to leaching by ground water, or are the Tertiary tectonics of the foothills more complicated than previously realized?

Return to the junction with the Baker Lake highway.

0.0 At the junction, reset odometer and turn right, toward Concrete.

0.9 STOP 2-10. Nooksack Group. Park on the left side of the road at this long roadcut.

One of the more frustrating aspects of mapping in the northwest Cascades is that volcaniclastic strata such as those here can reasonably be assigned to the Paleozoic (Chilliwack Group), Triassic (Cultus Formation), or Jurassic and Cretaceous (Wells Creek Volcanics and Nooksack Group). Misch (1966) considered rocks at this outcrop to be part of the Nooksack Group; Brown and others (1987) mapped them as Chilliwack Group. I think these outcrops are Nooksack because they are structurally conformable with fine-grained, chocolate-weathering, locally marly strata in which I have recently found belemnites and one ammonite, all characteristic of Nooksack strata south of Mount Baker. However, green-gray to black strata here are richer in coarse-grained volcanic detritus than most of the Nooksack south of Mount Baker.

At the north end of the roadcut, Nooksack Group rocks are overlain by Quaternary deposits of (in ascending stratigraphic order) unconsolidated gravel, basaltic agglomerate, olivine basalt with poorly formed columns, and clay-rich till. The basalt is similar to—but must be older than—the postglacial Sulphur Creek flows. Two small hills immediately to the east, possibly the dissected vent, are composed of olivine basalt, basaltic agglomerate, and bedded cinders.
Return to Concrete via the Burpee Hill Road (about 9 mi). [If Stop 2-11 is to be skipped in a rush to reach Interstate Highway 5 (1-5), do not turn left onto Burpee Hill Road at Lake Tyee, but follow the Baker Lake highway down Grandy Creek to SR 20, turn right onto SR 20, and follow SR 20 to 1-5. Blocky-weathering, siliceous, volcanic siltstones in roadcuts near Grandy Lake, 1.8 mi beyond the Burpee Hill Road junction, belong to the Cultus(?) Formation.]

At the intersection of Superior and Main Streets in Concrete (stop sign), continue straight ahead (south) 0.1 mi to SR 20.

0.0 At junction with SR 20 reset odometer and turn right.

0.4 Turn left onto the South Skagit highway.

1.3 Bridge over the Skagit River. At the south end of the bridge, follow the South Skagit highway to the right. Darrington Phyllite of the Easton Metamorphic Suite crops out at the south abutment.


The Easton Metamorphic Suite (Tabor and others, in press [b]), commonly referred to as the Shuksan Metamorphic Suite of Misch (1966b) and also known as the Shuksan terrane of Silberling and others (1987), includes the Darrington Phyllite and Shuksan Greenschist. Protoliths of the Darrington and Shuksan were marine shale and minor sandstone and MORB-type submarine basalt which probably underlay the shale (Haugerud and others, 1981; Dungan and others, 1983; Brown, 1986). From their isotopic studies, Brown and others (1982), Brown (1986), and Armstrong and Misch (1987) suggest that the protolith age of the Easton Metamorphic Suite is Jurassic and metamorphism is Early Cretaceous (pre-120 Ma). Metamorphic assemblages testify to metamorphism at 7 to 9 kb and 300° to 400°C (Brown, 1986). Regionally extensive blueschists with very similar metamorphic history and lithologies occur in northern California (Brown and Blake, 1987).

While the Shuksan Greenschist is in blue-schist facies, most of the unit is (obviously) greenschist, with subordinate blueschist. The stability of actinolite (greenschist) versus glaucophane or crossite (blueschist) depends on the bulk composition of the rock, especially the Fe2+/Fe3+ ratio.

Thorough recrystallization and a well-developed metamorphic fabric distinguish rocks of the Easton Metamorphic Suite from most other rocks in the western North Cascades. You may see small knots of epidote with foliation wrapping around them. These are relics from an earlier, static metamorphism which predates synkinematic blueschist-facies metamorphism. This earlier event was probably sea-floor hydrothermal alteration (Haugerud and others, 1981).

The Easton Metamorphic Suite is bounded by post-metamorphic faults. Though most of these faults are high angle, some evidence suggests that the Easton is structurally high, above the Grandy Ridge terrane and the overlying Elbow Lake unit.

End of trip.

To reach 1-5, continue west on the South Skagit highway:

25.0 The South Skagit highway passes beneath an overpass and loops left to join SR 9.


26.4 First of two railroad crossings in the town of Clear Lake.

29.7 Junction of SR 9 with SR 538 (at mile 49.8 of SR 9). Turn right on SR 538.

33.5 Intersection of SR 538 (Clear Lake Road) with 1-5, milepost 227.

To continue west on SR 20 to Anacortes for the Day 3 trip, take 1-5 north to exit 230, exit onto SR 20 and turn west (left).