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Geology of the Methow Block

September 5 - 8 1996

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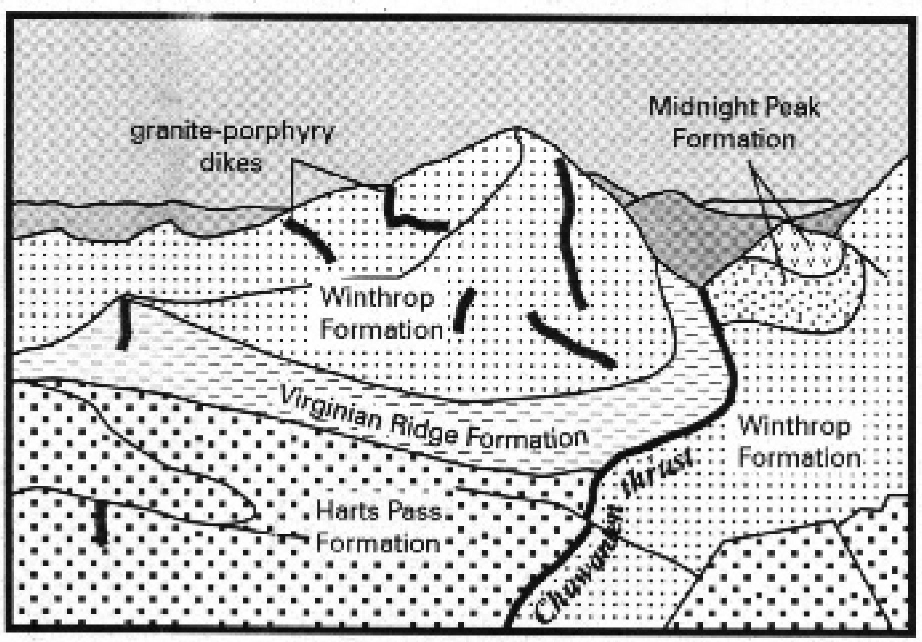
GEOLOGY OF THE METHOW BLOCK

A guide to a 4-day excursion in the Methow valley, Okanogan County, Washington, focussing on the stratigraphy, internal structure and bounding faults of the Methow block, with comments on the evolution of the landscape

by

Ralph A. Haugerud, J. Brian Mahoney, and Joe D. Dragovich



Northwest Geological Society Fall Field Trip
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Prepared for the Northwest Geological Society Fall field trip
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Cover: View of the Chuwanten thrust on Osceola Peak, looking north-east from the summit of Mount Rolo.

TABLE OF CONTENTS

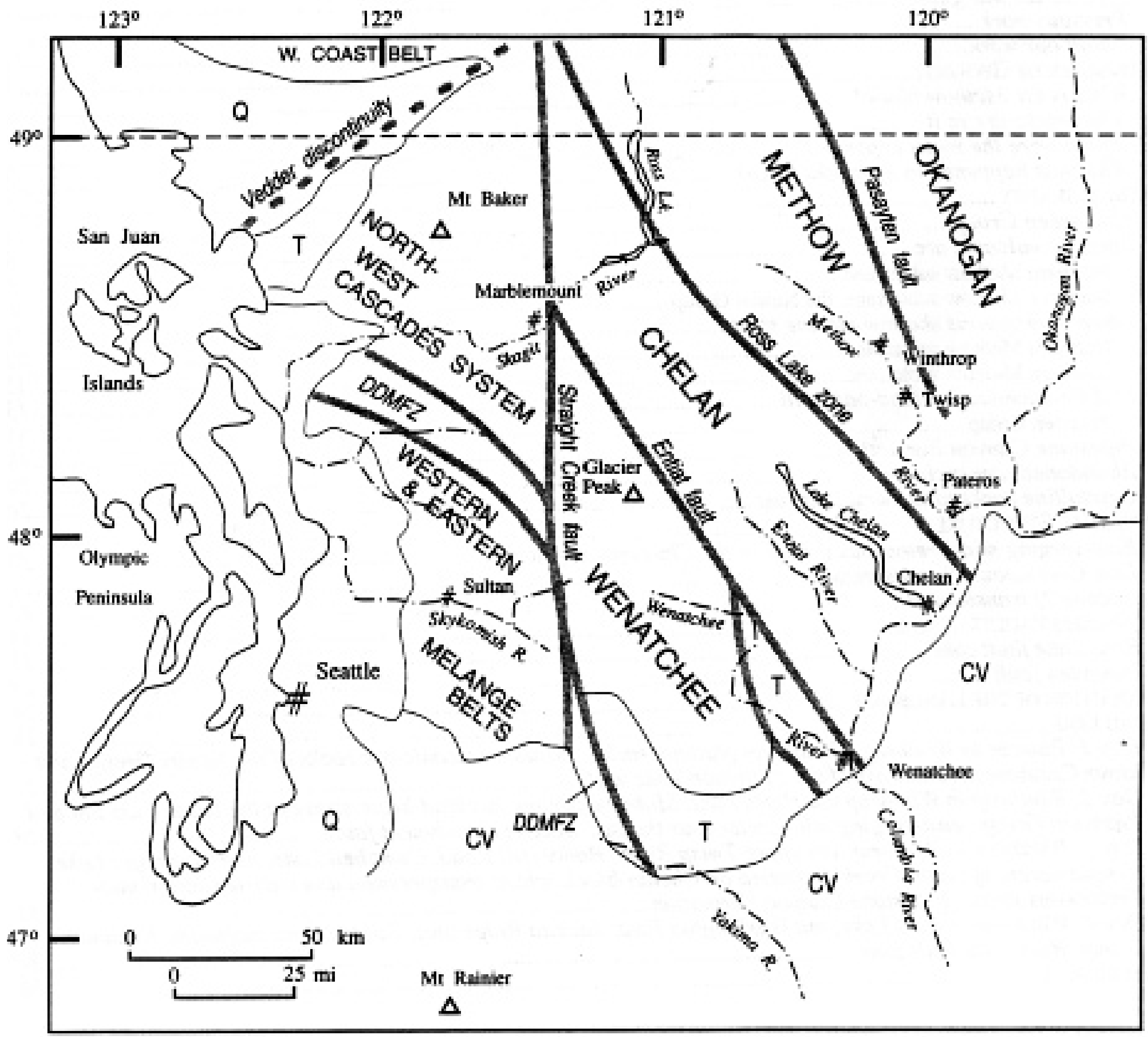


Figure 1. Blocks of the North Cascades Range. CZ = Cenozoic volcanic rocks of Cascade Arc and Columbia Plateau. DDMFZ = Darrington-Devils Mountain fault zone. Q = unconsolidated Quaternary deposits of Puget Lowland. T = early Ternary continental sedimentary rocks.

INTRODUCTION

The Methow block (Fig. 1) is friendly to geologists. Drier climate, stratified rocks, and abundant high country conspire to make it THE place in the North Cascades to easily see the bones of the land. The tongue need not trip over words like leucotrondhjemite and lithodemic: rocks here sport simple, everyday names like sandstone and shale. With thick Mesozoic terrestrial strata, one might even find dinosaur fossils.

But these days the Methow is not only friendly, it is exciting! New ages lead us to restack the stratigraphic column. Improved stratigraphic resolution and more mapping are writ¬ing a structural story with multiple chapters, details we could not hope to decipher a decade ago. Paleomagnetism suggests displacements on the Pasayten fault, at the northeast margin of the Methow block, that are 10 times greater than most geologists believe probable. Years of looking at the landscape, consideration of the Pleistocene history, and computer visualization of the regional topography have reawakened questions about the topographic evolution of the North Cascades, questions that were first and best asked by Bailey Willis almost a century ago.

Much our work has been driven by three questions: When, exactly, was Cretaceous orogeny in the North Cascades? (Did it start before the end of the Albian (98 Ma)? Was it over by 90 Ma?) What was the structural style? (Strike-normal contraction? Transpression?) And where did it happen? (Right here? Somewhere to the south in the Columbia Embayment? Or off the coast of southern Mexico?)

HOW TO USE THIS GUIDE

Please read the SUMMARY OF GEOLOGY as background to the ROAD LOG. Finish this INTRODUCTION if you wish to learn some of the history of geologic study. Read the other chapters as you need details on specific geologic points.
The answers to our three questions come, mostly, from stratigraphy, and so stratigraphy forms the bulk of this guide. Our work leads us to revise the existing stratigraphic frame¬work, and these revisions are not yet formalized. In direct violation of the North American Stratigraphic Code, we here introduce new stratigraphic names and revise old ones without adequate documentation and in an illegitimate context (this guide.) Beware! If the concepts embodied in these names survive the discussion we expect on this excursion, we intend to formalize our nomenclature in future publications.

PREVIOUS WORK

Israel C. Russell, a professor in the temporary employ of the U.S. Geological Survey, visited the Methow valley in 1898 (Russell, 1900). George Otis Smith (later to become Director of the USGS) and Frank Calkins surveyed the US-Canada boundary in 1903 (Smith and Calkins, 1904). Reginald A. Daly, a professor at Harvard, mapped the geology of the boundary strip for the Geological Survey of Canada (Daly, 1912).

Julian Barksdale, then a new faculty member at the University of Washington, was introduced to the Methow by Aaron Waters in 1938. He published first on the glacial geol¬ogy of the region (1941) but worked on all aspects of the geologic history. The stratigraphic framework he established (Barksdale, 1948, 1975) remains the basis of our geologic knowledge of the area. In the mid-1960s the U.S. Geological Survey assessed the mineral resources of the region that became the Pasayten Wilderness Area (Staatz and others, 1971). Several Methow plutons were dated in the course of this effort (Tabor and others, 1968). Several generations of student research, mostly at the University of Washington, have provided both details and overall synthesis. Relevant theses are cited below, but we are especially conscious of our debts to Marilyn Tennyson (1974) and Michael McGroder (1988).

The faults that bound the Methow have been the subject of several studies, including those of Lawrence (1978) and Hurlow (1993; Hurlow and Nelson, 1993) on the Pasayten fault, and that of Miller and coworkers on the Ross Lake fault system (Miller and Bowring, 1990; Miller and others, 1993, 1994).

ABOUT OUR WORK

Joe D., with the help of Dave Norman, mapped the Gilbert 7.5' quadrangle (Fig. 2) in 1995. Brian M. started working on rocks of the Newby Group in 1991, as part of a Ph.D. project at the University of British Columbia, under the guidance of the late Dick Armstrong. Brian is currently studying Albian-Cenomanian conglomerates along the Insular-Intermontane boundary (including those in the Methow) to provide geologic constraints on the -1700 km of translation that paleomagnetic data suggest for this boundary. Ralph H. is wrapping up 6 summers (starting in earnest in 1991) of l:100,000-scale mapping in the Robinson Mountain and Twisp 30'x60' quadrangles (Fig. 2)
.

We have not worked alone. Rowland Tabor (formerly of the U.S. Geological Survey) participated fully in the mapping and has been mentor and inspiration to all of us. Will Elder (also formerly of the U.S. Geological Survey) has provided extremely helpful fossil identifications and discussions of the significance and certainty of his calls. Joe Vance (University of Washington) and, especially, Rich Friedman (University of British Columbia) have provided radiometric ages. Phil Royce (Royce, 1995) and Jim Peterson (work in progress at Western Washington University) have focussed their thesis projects on questions of interest to us. We are grateful to a small army of summer interns, student volunteers, and friends and relations who have served as field assistants. Discussions with numerous colleagues have been invaluable. We thank Lori Snyder for critically reading this guide.

We have discussed preliminary results in several abstracts (Haugerud and others, 199la, 1992; Mahoney and others, 1996), a paper on the tectonostratigraphy of the eastern North Cascades (Miller and others, 1994), and an earlier field guide

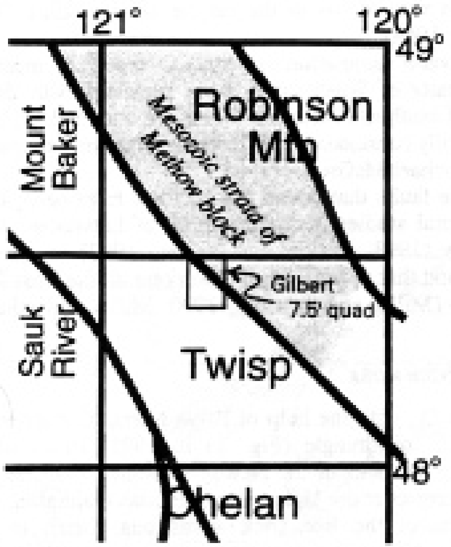


Figure 2. Thirty- by sixty-minute map sheets for the eastern North Cascades, published by the U.S. Geological Survey as 1:100.000-scale maps. Tabor and others (I987a. 1988. 1994) have completed 1:100.000-scale geologic maps for the the Chelan, Mount Baker, and Sauk River quadrangles. Similar maps for the Robinson Mountain and Twisp quadrangles are in preparation; see also Bunning (1990) and Stoffel and McGroder (1990). A 1:24.000-scale map of the Gilbert 7.5' quadrangle by Dragovich and others is in press.

(Haugerud and others, 1994).

SUMMARY OF GEOLOGY

WHAT IS THE METHOW BLOCK?

The Methow block is that region of the North Cascades that is bounded on the east by the Pasayten fault and on the west by the strands of the Ross Lake fault zone. It is characterized by a thick, little-metamorphosed succession of Jurassic and Cretaceous rocks, both sedimentary and volcanic, terrestrial and marine. We include late Paleozoic and early Mesozoic greenstone and ribbon chert of the Hozameen Group in the Methow block, as these rocks are also little metamorphosed and are part of the Methow story since the mid-Cretaceous, if not earlier.

On the southwest the Methow block adjoins the plutonic rocks of the Chelan block, comprising the migmatitic Skagit Gneiss Complex, various schist units, and gneissic plutons. One of the new things we have learned is that this boundary is not everywhere a fault. On the northeast, the Methow block adjoins plutonic rocks of the Okanogan region, mostly 110-120 Ma (Early Cretaceous) plutons and their older metamorphic wallrocks. We have learned that this boundary, also, is not faulted everywhere.

To the north, the Methow block extends through Manning Park and continues north to about latitude 50°N, where the Pasayten fault and Fraser fault converge. Correlative strata underlie the Tyaughton region farther NW. To the south, the Pasayten fault ends near Beaver Creek, a few miles southeast of Twisp. The unexposed and little-understood NE-trending Methow River fault and the N-striking Vinegar fault separate Methow from Okanogan between Beaver Creek and the middle Eocene Cooper Mountain batholith. Methow rocks are absent south of the Cooper Mountain batholith.

WHA T ROCKS ARE IN IT?

Rocks of the Methow can be divided into 6 categories (Fig. 3,4):

- Middle Eocene (55 to 45 Ma) granitic plutons and associated volcanic rocks: the Golden Horn, Monument Peak, and Cooper Mountain batholiths, Island Mountain volcanics, and numerous dikes. These rocks are part of the Challis suite, which forms a wide swath that extends across much of the northern Cordillera, from Wyoming to the Yukon. Formation of the Challis suite has been attributed to (1) an episode of low-angle subduction, (2) melting of lower crust and upper mantle following thickening by late Mesozoic orogeny, and(or) (3) melting of lower crust when it came in contact with hot asthenosphere after foundering of the lithospheric mantle.

- Mid-Cretaceous (-90 Ma) tonalitic plutons and associated sills: the Black Peak batholith, Pasayten stock,

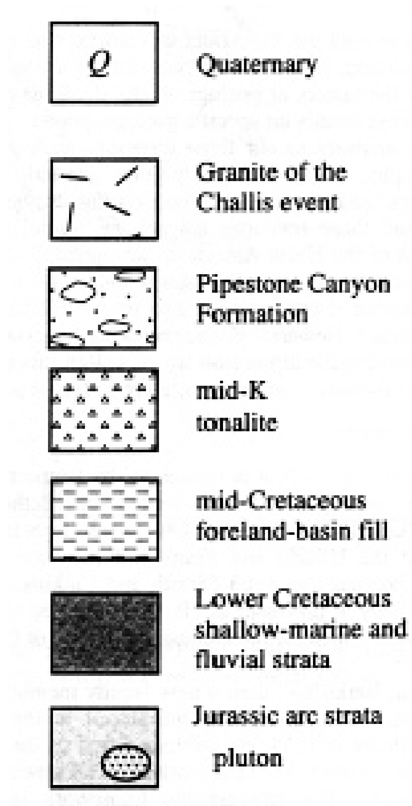
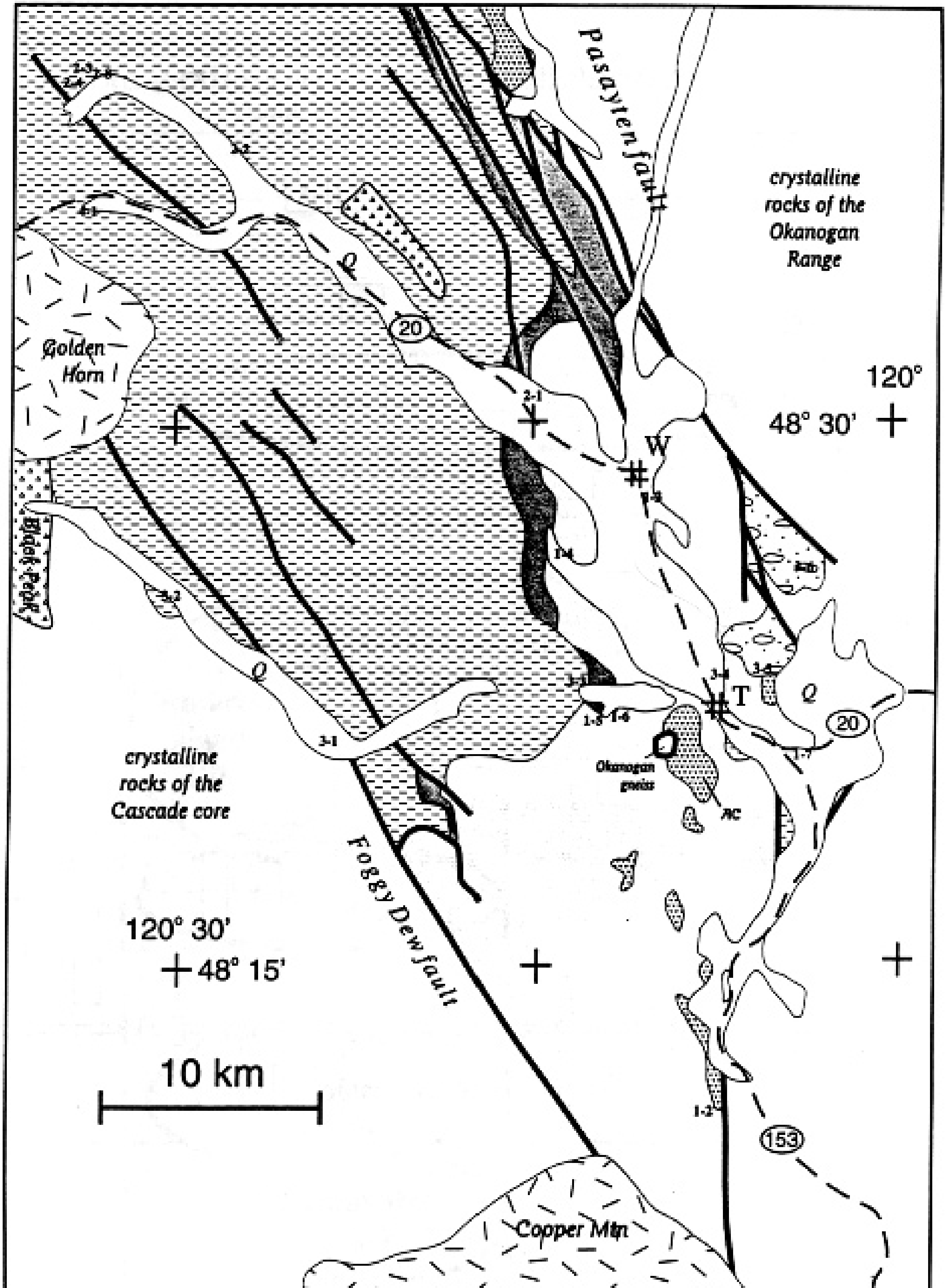


Figure 3. Simplified geologic map of the southern portion of the Methow block, showing locations of field-trip stops. Pre¬pared from new 1:100,000 and 1:24,000-scale mapping by Haugerud, Tabor, Mahoney, and Dragovich as of early 19%. Stop 1-1 is south of the area shown; stops 4-2, 4-3, and 4-4 are northwest of map area.



Pasayten fault
crystalline rocks of the Okanogan Range
Golden Horn
Q
20
2-1
W
120°
48° 30'
Black Peak
T
crystalline rocks of the Cascade core
Okanogan gneiss
AC
Foggy Dew fault
120° 30'
48° 15'
10 km
153
1-2
Copper Mtn

Correlation of units of the Methow block
and surrounding areas

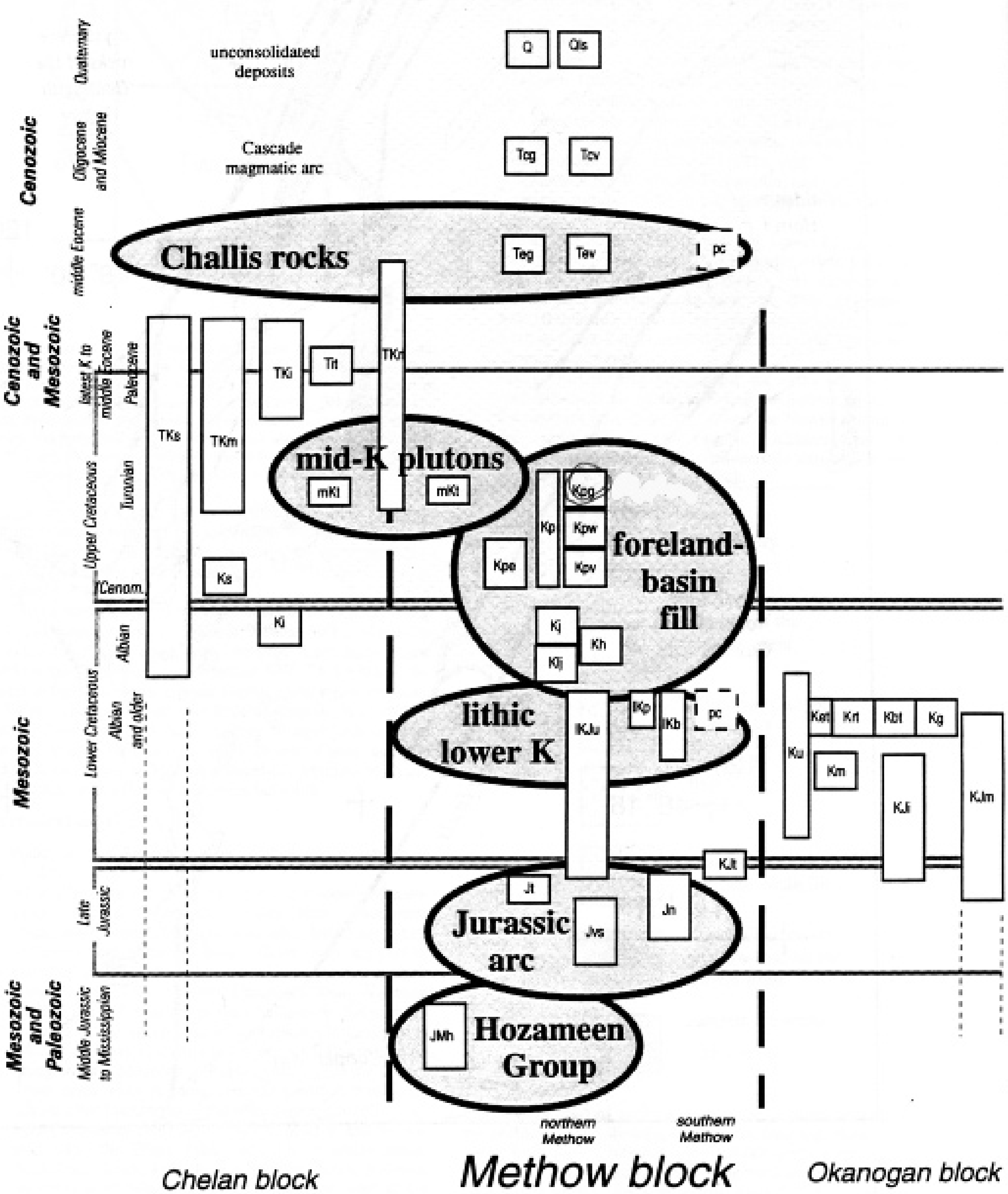


Table 1. SUMMARY OF GEOLOGIC UNITS, METHOW BLOCK AND SURROUNDING AREAS

UNCONSOLIDATED DEPOSITS

Q — **Quaternary, undifferentiated (Quaternary)**—Includes alluvium, colluvium, talus, extensive alpine and Cordilleran glacial deposits, bog deposits, etc.

Qls — **Landslides (Quaternary)**—Landslides, both deep-seated and not

ROCKS OF THE CASCADE ARC

Tcv — **Cascade volcanic rocks (Miocene and Oligocene)**—Includes volcanic rocks of Mount Rahm, at 49th parallel west of Skagit River

Tcg — **Cascade granitoid rocks (Miocene and Oligocene)**—Includes mid-Oligocene Perry Creek phase of the Chilliwack batholith and Miocene granitoid rocks in vicinity of Silver Lake and Mount Redoubt

ROCKS OF THE CHALLIS SUITE

Tev — **Eocene volcanic rocks (middle Eocene)**—Includes volcanics of Island Mountain (Staatz et al., 1971; White, 1986); silicic volcanic rocks that overlie the Skagit Gneiss Complex and are intruded by Cooper Mountain batholith; and unnamed, undated, volcanic rocks on west shoulder of North Twentymile Peak

Teg — **Eocene granite (middle Eocene)**—Includes Golden Horn batholith, Monument Peak stock, Castle Peak stock, Cooper Mountain

TKri — **Ruby Creek intrusions (middle Eocene and mid-Cretaceous)**—Ruby Creek Heterogenous Plutonic Belt of Misch (1966). Youngest phases dated at 48 Ma (U-Pb, Miller and Bowring). Oldest phases similar to 90-Ma Black Peak batholith

ROCKS OF THE CHELAN BLOCK

TKs — **Schist (Tertiary and Cretaceous)**—Mostly amphibolite-facies biotite schist, hornblendic schist, amphibolite, metachert, meta-ultramafite, etc. Locally greenschist facies. Includes Napeequa Schist of Tabor and others (in press), Twisp Valley Schist of Adams (1961) and Miller and others (1993), and Holden unit of Miller and others (1994)

TKm — **Migmatite (Tertiary and Cretaceous)**—Migmatitic orthogneiss and banded (interlayered ortho- and para-) gneiss. Includes Skagit Gneiss Complex and Chelan Complex

TKi — **Intrusive rocks (earliest Tertiary and latest Cretaceous)**—Cardinal Peak pluton, Mount Benzarino pluton (*née* Gabriel Peak Orthogneiss of Misch and Kriens), Tuckaway Lake, Lake Juanita, and Battle Mountain gneisses of Miller and Bowring. Compositions range from tonalite to (rarely) granodiorite. Mostly leucocratic. Mostly deformed and somewhat recrystallized in amphibolite facies

Tit — **Intrusive rocks (earliest Tertiary)**—Oval Peak pluton. NE part is massive biotite tonalite; SW part is foliated. Intrusive age is 65 Ma

mKt — **Tonalite (mid-Cretaceous)**—Includes Bearcat Ridge pluton and Black Peak batholith, both intruded at ~90 Ma (early Late Cretaceous). Moderately calcic biotite-hornblende tonalite to granodiorite

Ks — **Skymo complex (Cretaceous?)**—Gabbro, troctolite, norite, and anorthosite. Has undergone Skagit metamorphism but mostly retains primary igneous fabric. Perhaps a metamorphosed plutonic equivalent of volcanic and subvolcanic rocks of the Pasayten Group? (E.g. igneous component of Easy Pass assemblage; Midnight Mountain volcanic rocks)

Ki — **Intrusive rock (Cretaceous)**—Leucocratic biotite tonalite pluton on western Elijah Ridge; intrudes Napeequa schist (TKs) and dated by Bowring (U-Pb, personal communication) at ~102 Ma

ROCKS OF THE METHOW BLOCK

--northern Methow sub-terrane--

Kp — **Pasayten Group (Cretaceous)**—Undifferentiated Pasayten Group strata; mapped on Robinson Mtn and in vicinity of North Creek (North Creek Volcanics of Misch, 1966). Mostly mapped as:

Kpg — **Goat Wall Formation**—Plagioclase-phyric andesitic flows, breccias, and tuffs, with minor associated volcaniclastic sedimentary rocks. Overlies Winthrop Formation; part of Midnight Peak Formation of Barksdale (1975)

Locally mapped as:

Kpgv — **Volcanic rocks**

Kpgr — **Ventura member (redbeds)**

Kpw — **Winthrop Formation**—Mostly trough cross-bedded biotite arkose and associated siltstone and pelite. In places includes volcanic sandstone, volcanic siltstone, and volcanic breccias and flows. Paleocurrents indicate most of unit is east-derived.

Intruded by 90 Ma plutons; same age as or younger than Turonian(?) strata of Virginian Ridge Formation.

Locally mapped as:

Kpwm — **Three AM Mountain member**—Clinopyroxene-phyric volcanic breccia, tuff, and (probably) flows, with associated volcanic sandstone and volcanic argillite, locally with interbedded arkose. Included by Barksdale in his Midnight Peak Formation. Largely equivalent to the 'volcanic member of the Winthrop Sandstone' of McGroder and others (1991)

Kpwy — **Yellowjacket member**—Volcanic-lithic sandstone and subquartzose volcanic-lithic sandstone, locally with minor volcanic rocks

Kpv — **Virginian Ridge Formation**—Argillite (overbank deposits) with lesser chert-grain sandstone and chert-pebble conglomerate (channels and crevasse-splay sands). Fluvial with rare estuarine to shallow-marine beds. Turonian? fossils at one locality. Paleocurrents and facies relations indicate derivation from west

Locally mapped as:

Kpvd — **Devils Pass member**—Dominantly thick-bedded conglomerate. Appears to be fluvial

Kpvs — **Slate Peak member**—Heavily bioturbated argillite and siltstone, with resistant beds of chert-grain

Table 1. SUMMARY OF GEOLOGIC UNITS, METHOW BLOCK AND SURROUNDING AREAS

sandstone, chert-pebble conglomerate, and cross-bedded biotite arkose identical to that in the Winthrop Formation. Mostly fluvial

Kpvsc **South Creek member**—Metachert- and greenschist-cobble conglomerate, sandstone, and siltstone. Conglomerate clasts derived from underlying Twisp Valley Schist. Probably fluvial

Kpe **Easy Pass assemblage**—Chert-pebble conglomerate, siltstone, pelite, and associated metamorphosed dikes and sills rich in clinopyroxene and hornblende phenocrysts, all metamorphosed. Well-exposed at Easy Pass; similar, though unmetamorphosed, rocks occur within Virginian Ridge Formation near Devils Pass and at the head of Wolf Creek

Kj **Jackita Ridge Formation (Cretaceous)**—Chert-grain sandstone, siltstone, and shale. Turbidite. Overlies and interfingers with Albian Harts Pass Formation. West-derived

Kh **Harts Pass Formation (Cretaceous)**—Massive biotite arkose, lesser fine sandstone, siltstone and shale. Below-wave base turbidite. Paleocurrents indicate derivation from east

Klj **Little Jack unit (Cretaceous?)**—Siltstone, sandstone, shale, ultramafic rock, and rare limestone and ribbon chert. Now metamorphosed to phyllite, semischist, and schist. Hypothesized to be Albian, coeval with the lower Harts Pass Formation, and to be pelagic material and sediment derived from submarine slumps prior to emergence of Hozameen Group as sediment source at beginning of Jackita Ridge time

lKJu **undifferentiated strata (Lower Cretaceous and Jurassic)**—Includes Albian lithic sandstone, conglomerate, and argillite at Dead Lake, Panther Creek Formation of Barksdale (1975), and Jurassic strata in Lightning Creek drainage

Jt **tonalite (Jurassic)**—Button Creek stock. Biotite-hornblende tonalite. K-Ar dates indicate Late Jurassic intrusive age

Jvs **volcanic and sedimentary strata (Jurassic)**—

--southern Methow sub-terrane--

pc **Pipestone Canyon Formation (age poorly known)**—Monolithologic leucotonalite fanglomerate, heterolithologic cobble conglomerate, chert-, volcanic- and plutonic-pebble to small cobble conglomerate, sandstone, tuffaceous sandstone, siltstone, and minor basaltic flows and breccia. Sedimentary rocks mostly fluvial. Volcanic debris largely rhyolitic

lKp **Patterson Lake unit (Lower Cretaceous)**—Conglomerate, lithic sandstone, siltstone, and argillite. Conglomerate clasts mostly argillite, volcanic sandstone, and tuff reworked from underlying Newby Group. Fluvial to shallow-marine. Albian trigoniid clams. Brachiopods at many localities

lKb **Buck Mountain unit (Lower Cretaceous)**—Volcanic sandstone, volcanic- and granitoid-cobble conglomerate, and siltstone. Shallow-marine and fluvial. No proximal volcanic rocks. Probably includes strata equivalent to Patterson Lake unit. Albian and Hauterivian-Barremian fossils (including ammonites, *Inoceramus*). No *Buchia*

KJt **tonalitic rocks (Cretaceous to Jurassic)**—Includes Alder Creek stock, Carleton stocks, McFarland Creek stock, and western part of Fraser Creek complex of Barksdale (1975). Mostly calcic biotite-hornblende tonalite; locally deformed. U-Pb age of Alder Creek stock is 142 Ma

Jn **Newby Group (Late Jurassic)**—Arc volcanics and associated sedimentary rocks. Mostly andesitic and rhyolitic. Lower Newby Group is (Twisp Formation of Barksdale, 1975). Upper Newby includes Lookout Mountain unit (greenschist-facies proximal volcanics and associated sedimentary rocks) and Bear Creek unit (more distal zeolite-facies breccia and tuff). Includes schist of McClure Mountain unit, derived from upper Newby rocks in late Newby time

JMh **Hozameen Group (Middle Jurassic to Mississippian)**—Greenstone, ribbon chert, argillite, gabbro, rare sandstone and limestone. Mostly altered in prehnite-pumpellyite facies. Late Triassic seamount and older ocean floor locally overlain by Middle Jurassic clastic rocks

ROCKS OF THE OKANOGAN BLOCK

Ku **undifferentiated plutonic rocks (Cretaceous)**—Includes mylonitic gneiss of Todd (personal communication), contact complex NE of Island Mountain, Yockey Creek stock, and Texas Creek stock

Ket **Eightmile Creek tonalite (Cretaceous)**—Biotite-hornblende tonalite, CI=10–15, with conspicuous 1–2 cm hornblende prisms

Krt **Remmel batholith (Cretaceous)**—Relatively homogenous, light-colored, biotite (± muscovite, garnet) tonalite. Conspicuous large quartz grains common. Parts of unit have been known as the Lake Creek Gneiss (Hawkins), Summit-Fraser Gneiss (Menzer), and Doe Mountain and Lamb Butte plutons (Todd), but all are lithologically similar to and continuous with rocks which Daly (1912) called the Remmel batholith

Kbt **Bob Creek tonalite (Cretaceous?)**—Biotite-hornblende tonalite. Undated, little-deformed

Kg **granitic rocks (Cretaceous)**—Includes Cathedral Granite (Daly, 1912) and similar granite to the west. Biotite K-Ar ages of ~100 Ma, probable late Early Cretaceous intrusive age. Little-deformed

Km **Methow Gneiss (Cretaceous)**—Gneissic epidote-biotite tonalite to granodiorite, most with conspicuous splotchy biotite aggregates. Early Cretaceous U-Pb age

JKo **older intrusive rocks (Cretaceous? and Jurassic)**—Includes trondhjemitic gneiss of Tiffany Mountain, of Late Jurassic age

JKm **metamorphic rocks (Cretaceous? and Jurassic?)**—Includes Spanish Camp gneisses of Hawkins, high-grade portion of the Leecher Metamorphics of Barksdale, and Antoine Creek gneiss of Raviola. Protolith includes probable Late Triassic rock—Ashnola Gabbro of Spanish Camp complex appears to have been a mafic to ultramafic arc-root pluton of the Nicola Arc)

Rock Creek stock, and a host of smaller bodies. Volcanic equivalents of these plutons form the upper part of the mid-Cretaceous foreland-basin fill (below). Mid-Albian (perhaps as old as -106 Ma—the Albian extends from 112 to 98 Ma) to 87 Ma-old (Coruacian) sedimentary and volcanic rocks of a mid-Cretaceous foreland basin fill. The foreland-basin fill is divided into the below-wave-base marine Harts Pass Formation, the conformably overlying (and interfingering?) Jackita Ridge unit, and the shallow marine to (mostly) fluvial sedimentary rocks and associated volcanic strata of the Pasayten Group. Included in the Pasayten Group are fluvial and locally shallow-marine argillite, sandstone, and chert-pebble conglomerate of the Virginian Ridge Formation; fluvial quartzofeldspathic sandstone with lesser volcanic tuff, volcanic breccia, and volcaniclastic sandstone of the Winthrop Formation; and redbeds and andesitic volcanic rocks of the Midnight Peak Formation.

Albian and older (145 to -104 Ma; Lower Cretaceous) shallow-marine and fluvial strata, mostly rich in volcanic detritus, with local volcanic rocks. This category includes the Patterson Lake unit, the Buck Mountain unit (restricted), some rocks previously assigned to the Panther Creek Formation and, potentially, the Pipestone Canyon Formation.

Middle to Late Jurassic volcanic arc rocks and associ¬ated volcaniclastic strata, including the Ladner Group in the northern part of the block, and the Newby Group in the south. The Late Jurassic (Kimmeridgian to Tithonian) Newby Group is extensively exposed in the southern end of the Methow block.

- Late Paleozoic and early Mesozoic (Mississippian to Middle Jurassic) ribbon chert and greenstone of the Ho-zameen Group. The Hozameen is a remnant of paleo-Pacific Ocean floor and one or more oceanic islands. Hozameen Group rocks may constitute part of the basement to younger strata of the Methow block. During mid-Cretaceous time the Hozameen Group formed the hinterland of the foreland basin: it occupies the hanging wall of the highest and westernmost thrust fault, its weight depressed the crust to form the basin, and erosion of the Hozameen Group provided chert-rich sediment which filled the west side of the basin. We will only see this unit from afar.

This picture is complicated by the possibility, discussed below, that Albian and older rocks of the Methow block may belong to two distinct stratigraphies, one that lies on top of the Newby Group and a different set of rocks that underlie the mid-Cretaceous foreland basin fill.

WHERE WERE THE ROCKS DEPOSITED?

We don't know. Paleomagnetic data, obtained both from farther west within the North Cascades and from Methow-equivalent rocks far to the northwest in central British Columbia, suggest that mid-Cretaceous rocks of the Methow and regions to the west were deposited some 3000 km farther south, at the latitude of southern Mexico. Paleomagnetic data also suggest that rocks of the Okanogan region to the east were deposited 1300 km south of their present position, thus indicating some 1700 km of post-mid-Cretaceous (post-90 Ma) dextral strike slip on the Pasayten fault or its precursor (Wynne and others, 1995; Irving and others, 1995).

The paleomagnetic data and the story told from them are not universally accepted. Many geologists are sympathetic to fairly compelling stratigraphic and structural arguments that tie Methow rocks to terranes east of the Pasayten fault, but these arguments need substantiation. We are currently collaborating on a direct test of the large-displacement hypothesis that examines stratigraphic linkages of Albian-Cenomanian clastic rocks across the proposed terrane boundary.

The great amount of pluton-derived sand in the mid-Cretaceous foreland-basin fill sequence indicates these rocks were formed at or within the North American continental margin, rather than far out at sea.

WHAT HAS HAPPENED TO THE ROCKS SINCE?

The earliest recognized tectonism within the Methow block is the formation of schist of the McClure Mountain unit in Late Jurassic-Early Cretaceous time. We interpret this to reflect intra-arc deformation within the Newby Group Laterally discontinuous volcanic cobble to boulder conglomerates (Patterson Lake unit and (possibly) the Pipestone Canyon Formation), north to northwest-trending normal faults that cut the Newby Group and associated strata, probable 106 Ma volcamsm and the lack of detritus from the roof of the Okanogan Complex lead us to speculate that there was an early Albian extensional event along the eastern margin of the Methow block. Although conjectural, documentation of this extensional event would represent an early link between the Methow strata and rocks of the Okanogan complex to the east.

The vast majority of rocks within the Methow block are mid-Albian and younger strata of the mid-Cretaceous foreland-basin fill. Structures within these rocks seem to fall into three systems. Foreland-basin deposition was presumably accompanied by, and certainly was followed by, eastward-verging thrust faulting of the mid-Cretaceous Chwwanten fault system. These faults may be inferred to have been active from mid-AIbian (the time foreland-basin deposition was initiated) to about 90 Ma (the age of the youngest, Midnight Peak, strata involved in the thrusting.)

A major fold associated with Chuwanten thrusting is cut by the oblique-slip Slate Creek fault system. Small thrusts that verge outwards from this fault, to the north on the northeast side and to the south on the southwest side, demonstrate its dextral, transpressive nature. This deformation is younger than the Virginian Ridge Formation (which is not well dated!) and older than the 48 Ma Golden Horn batholith. For the sake of discussion we assign a Late Cretaceous age to this event.

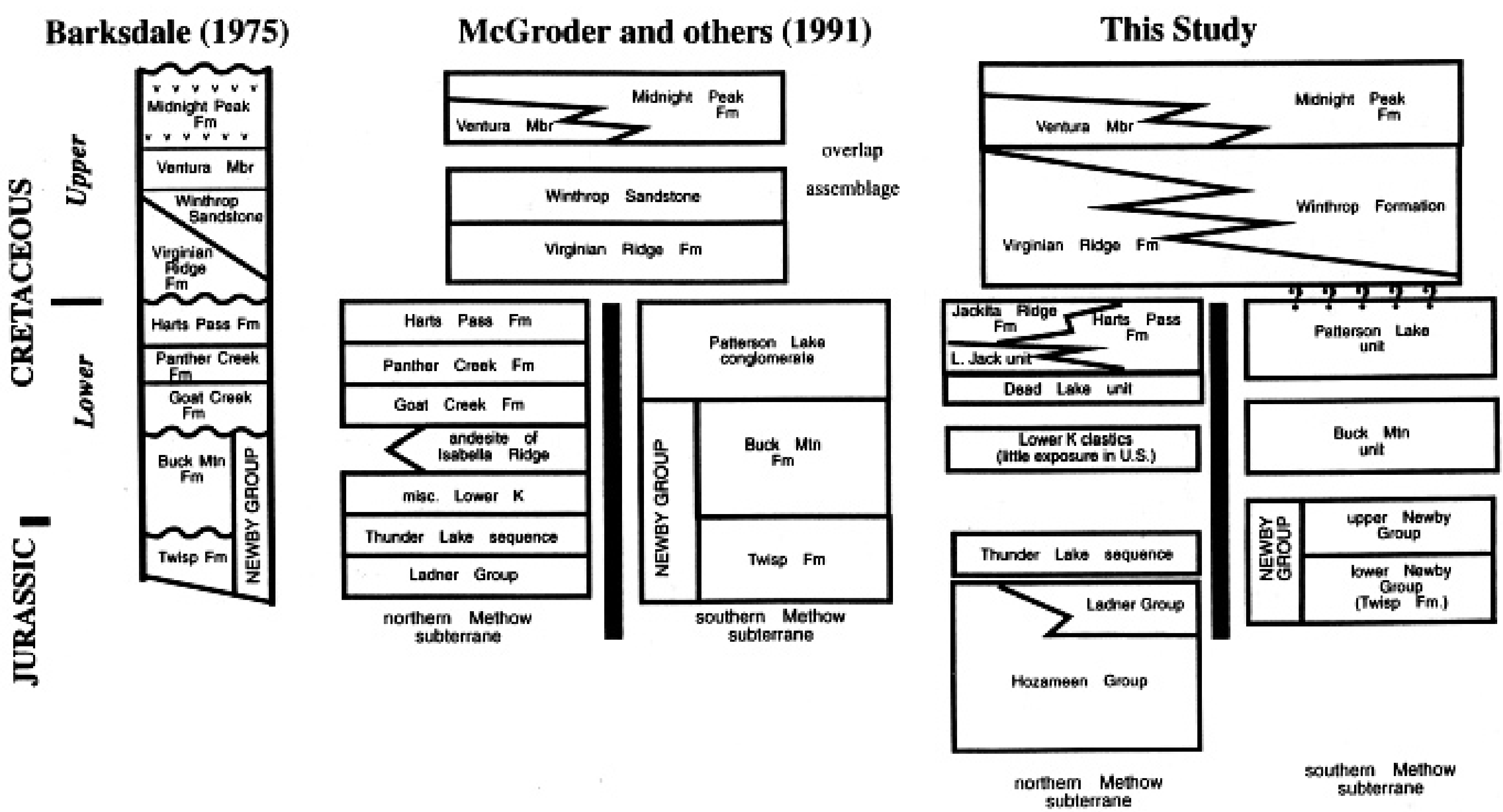


Figure 5. Methow block stratigraphy as seen by different workers.

Middle Eocene transtensional faults, including the Devils Mountain detachment, cut the 90 Ma Pasayten stock and the 46 Ma Island Mountain Volcamcs, and apparently are intruded by the 48 Ma Monument Peak stock. Total slip on this system appears to be on the order of 5 km.

STRATIGRAPHY

Stratigraphic columns for the Methow block, as proposed by different workers, are shown in Fig. 5. Barksdale (1948, 1975) saw a coherent Jurassic? to Cretaceous stratigraphy and formally named numerous units.

McGroder (1989; McGroder and others, 1991) correlated strata in the U.S. part of the Methow with similar rocks in Manning Park, British Columbia and presented a revised stratigraphy. Differences in Lower Cretaceous stratigraphy led him to propose that Albian and older strata of the Methow constitute two subterranes, with a northern subterrane extending across most of the Methow block northwest of Winthrop and southern subterrane extending southeast from Winthrop.

We also see Stratigraphic differences from north to south within the Methow, and a major goal of our work is devel¬opment of a basin model that reconciles these differences. The northern (roughly northwest of Winthrop and into British Columbia) and southern (roughly southeast of Winthrop) subterranes differ in three significant ways:

1) Basement in the north consists of Lower to Middle Ju¬ rassic rocks of the Ladner Group (O'Brien, 1986, Mahoney, 1993, 1994); basement in the south is the Upper Jurassic Newby Group.

2) The northern subterrane contains a thick succession of lower to mid-AIbian marine strata (Dead Lake unit. Harts Pass Formation, Jackita Ridge Formation); Albian strata in the southern subterrane are thin, shallow-marine to fluvial strata of the Patterson Lake unit.

3) The northern subterrane contains -4 km of lower Up¬ per Cretaceous clastic strata and overlying andesitic volcanics of the Pasayten Group (Virginian Ridge, Winthrop and Mid¬ night Peak Formations). Pasayten Group strata are absent in the south.

The cause of the Stratigraphic differences between the northern and southern subterranes is uncertain. The two subterranes meet at a fault that in most places is at the Virginian Ridge-Patterson Lake contact. Sub-isoclinal folding of Virginian Ridge Formation and imbrication of Virginian Ridge and Patterson Lake conglomerates along this contact suggest displacement is significant, but we cannot estimate its magnitude.

Conversely, Stratigraphic differences between the north-em and southern Methow subterranes may be due to differences in original Stratigraphic thicknesses coupled with erosion at the sub-Virginian Ridge Formation, sub-Eocene(?) and modem unconformities. Pervasive faulting of the Virginian Ridge-Patterson Lake contact may simply reflect the relative weakness of this stratigraphic level.

For purposes of discussion we divide stratified rocks of the Methow block into four sequences: 1) Hozameen Group, 2) Jurassic volcanogenic strata, 3) Lower Cretaceous shallow marine to fluvial strata, and 4) mid-Cretaceous foreland-basin fill. Coarse clastic strata of the Pipestone Canyon Formation possibly represent a fifth sequence of post-thrusting fluvial strata; we treat it separately, but we are uncertain about the age of this unit. Given our uncertainty as to the significance of northern and southern Methow subterranes, we conservatively discuss Jurassic arc strata and Lower Cretaceous shal¬low-marine and fluvial strata of the northern and southern Methow subterranes separately.

Many of the rocks in the Methow were deposited during a fairly short period of time in the middle of the Cretaceous.

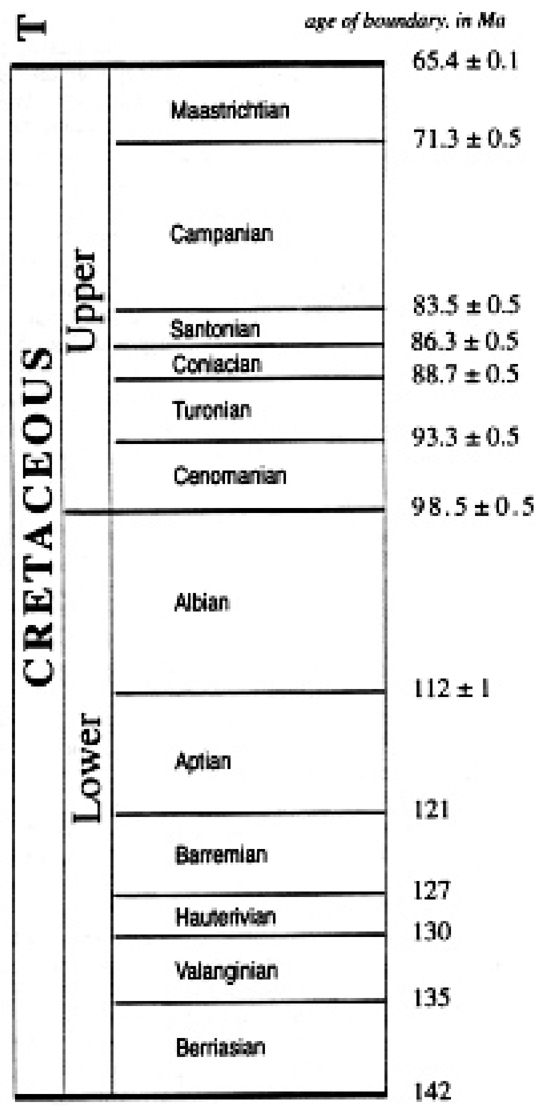


Figure 6. Absolute ages for subdivisions of the Cretaceous period, after Obradovich (1994).

These rocks are intruded by early Late Cretaceous plutons that have been dated radiometrically, and which provide a constraint on the youngest possible age of several units. To relate the radiometric constraints to fossil ages we use the time scale suggested by Obradovich (1994; Fig. 6).

NOTE: The following descriptions contain abundant ref¬erences to geographic locales not shown on the maps in this guide. Geographic locales may be found by consulting U.S. Forest Service maps or standard U.S. Geologic Survey topographic maps.

HOZAMEEN GROUP

The late Paleozoic to Middle Jurassic Hozameen Group (Daly, 1912; McTaggart and Thompson, 1967; Haugerud, 1985; Ray, 1990) is mostly greenstone (altered basalt of various textures and forms: flows, pillows, breccia, tuff, etc.), ribbon chert, and argillite with minor sandstone, limestone, and gabbro. Most of the Hozameen south of the 49th parallel is partially recrystallized in the prehnite-pumpellyite facies. Fossils, mostly radiolarian ribbon cherts, from the Hozameen are Mississippian, Permian, Middle and Late Tnassic, and Middle Jurassic (Haugerud, 1985; Tabor and others, 1994).

Compositions of relict igneous clinopyroxene in Hozameen greenstone indicate that much of the Late Triassic lava was alkaline oceanic-island basalt (Haugerud, 1985). Analyses of late Paleozoic clinopyroxenes indicate tholeiitic basalt not indicative of any particular tectonic setting. Middle Jurassic cherts in the Hozameen Group are intercalated with fine-grained clastic rocks.

Ages, lithologies, and inferred basalt compositions suggest that the Hozameen Group represents Late Paleozoic ocean crust and Late Triassic seamounts that were in proximity to a continent (probably North America) by Middle Jurassic time. The Hozameen Group is correlative with the Bridge River Group exposed to the north in British Columbia. There, thin-bedded clastic strata of the Lower Jurassic to Lower Cretaceous Cayoosh Assemblage conformably overlie oceanic sediments of the Bridge River Group (Joumeay and Northcoate, 1992, Mahoney and Joumeay, 1993). Cayoosh Assemblage strata are interpreted to be the distal equivalents of Methow strata, and to represent a stratigraphic linkage between the Bridge River and Methow terranes. We therefore suggest that the Hozameen Group may be basement to the western part of the northern Methow subterrane.

JURASSIC VOLCANIC ARC

Northern Methow subterrane

Lower and Middle Jurassic volcanic-arc strata of the Ladner Group (O'Brien, 1986; Mahoney, 1993, 1994) and Upper Jurassic shallow-marine clastic strata of the Thunder Lake sequence (O'Brien, 1986) underlie Cretaceous strata in Manning Park. We have found Jurassic fossils in the Lightning Creek drainage, adjacent to the Hozameen fault in the northwest comer of the Robinson Mountain quadrangle, but know little about these rocks.

Pre-latest Jurassic (pre -155 Ma) volcanic rocks crop out west of the Pasayten fault from near the Chewuch River to the 49th parallel. Most of the rocks are coarse breccias and flows indistinguishable from the Late Cretaceous breccias and flows that locally overlie them—we can confidently distinguish the two packages only where the older volcanics are intruded by the Button Creek stock (-152 Ma), which is overlain unconformably by the younger volcanics. The older rocks are mostly plagioclase-phyric andesite or basalt; hornblende is locally present. Included in the older volcanics are small amounts of massive rhyolite and rhyolite breccia. These older volcanic rocks may be correlative to the eastern facies of the Dewdney Creek Formation of the Ladner Group (Mahoney, 1993). The older volcanics host sub-economic mineralization near Copper Glance Lake.
Southern Methow subterrane: the Newby Group

The Late Jurassic Newby Group has suffered a long and tortuous nomenclatural history. The "Newby Formation" was described by Barksdale (1948) as a series of strongly folded, faulted, and altered andesitic breccias, flows and associated volcaniclastic sediments exposed primarily in two areas, east of the Methow River between Twisp and Winthrop, and south of the Twisp River (Fig. 3). He designated Lookout Ridge, the long west ridge of Lookout Mountain on the divide between the Twisp River and Libby Creek, as the type locality. Barksdale (1975) raised the unit to Group status, and subdivided it into the Twisp and Buck Mountain Formations. He defined the Twisp Formation as a strongly deformed accumulation of black argillite and interbedded lithic sandstone, which he and many others have speculated may be of Jurassic age. Barksdale (1975) described the overlying Buck Mountain Formation as a sequence of interlayered volcanic and volcaniclastic rocks of Hauterivian to Barremian age. He described the contact between the Twisp and Buck Mountain Formations as an unconformity that is well exposed on the southern end of the hill between Winthrop and lower Bear Creek. Barksdale (1975) was not able to subdivide all of the Newby Group into the Twisp and Buck Mountain Formations, and mapped a great deal of "Newby Group, undifferentiated."

W.M. Phillips and H.W. Schasse of the Washington Division of Geology and Earth Resources mapped an area of undifferentiated Newby Group south of the Twisp River and subdivided the unit into a number of lithofacies (Bunning, 1990). They recognized that the volcanic and volcaniclastic rocks of the Newby Group in this area were intruded by the Early Cretaceous (K-Ar age -137-139 Ma) Alder Creek Stock, and therefore were demonstrably older than the type section of the Buck Mountain Formation. Bunning (1990) thus excluded much volcanic and volcaniclastic rock in the Twisp 1:100,000 quadrangle from the Buck Mountain Formation, and mapped it as various facies of the Newby

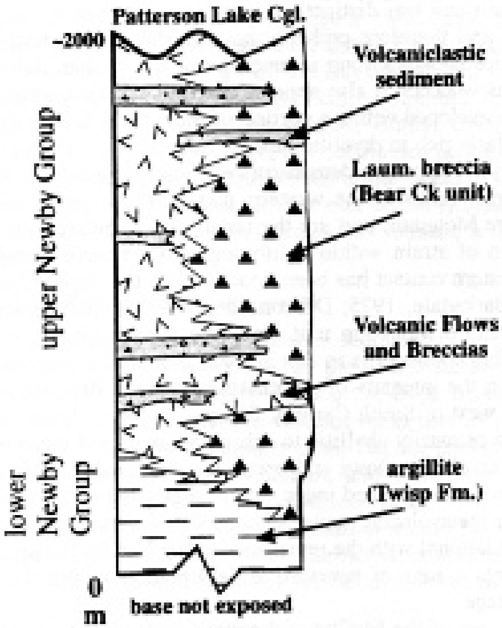


Figure 7. Schematic stratigraphic section of the Newby Group. Note intertingenng relationship of laumontitic breccias and associated units (Bear Creek unit) with volcanic flows and breccias (Lookout Mountain unit). Note also gradational relationship between the lower Newby Group (Twisp Formation) and upper Newby Group strata. Actual percentage of volcaniclastic sediments and fragmental rocks is much higher than shown.

Group.

Kriens (1988; Kriens and Wemicke, 1990a, 1990b; see also Stop 3-2 in Haugerud and others, 1994), working along the Ross Lake zone at the western edge of the Methow block, adopted a most generous view of the range of lithologies in the Newby and described many of the metasedimentary and metavolcanic rocks in the Skagit Gneiss Complex and associated schist units as metamorphosed Newby Group.

Early in our mapping we were surprised to find that the fossiliferous Lower Cretaceous sedimentary rocks on Buck Mountain are separated by faults from the volcanic rocks that had been included in the Buck Mountain Formation, and that these volcanic rocks are significantly older (pre-latest Jurassic), and younger (Late Cretaceous) than rocks formally assigned to the Buck Mountain Formation. We restrict the Buck Mountain unit to sedimentary strata exposed in the vicinity of Buck Mountain.

We redefine the Newby Group as volcanic breccias, flows, tuff, and associated volcaniclastic sedimentary rocks, including extensive black argillite, of Jurassic age that crop out in a roughly north-trending belt that extends from the South Fork of Gold Creek to the Pasayten fault northeast of Buck Mountain. Rocks typical of this suite crop out on Newby Ridge. Barksdale's type locality, the long west ridge of Lookout Mountain, is as good as any. The thickness, area! extent, and lithologic variety within the Newby suggest that is fully deserving of group status, but because we have not satisfactorily resolved the stratigraphic and structural complexities evident within the unit we do not propose to formally subdivide it.

With three exceptions, the map extent of our Newby does not significantly differ from that of Barksdale's (1975) Newby. The exceptions are: 1) We exclude volcanic rocks on Isabella Ridge and farther north, adjacent to the Pasayten fault, from the Newby. 2) We also exclude rocks in the North Creek drainage (the North Creek Volcanics of Misch, 1966) which are mostly sedimentary and which we believe to be Cretaceous. 3) Barksdale assigned low-grade schist on the southern ridges of McClure Mountain to the Leecher Metamorphics; however, the protolith of the schist is similar to parts of the Newby Group and the contact between schist and little-metamorphosed rocks of the Newby Group to the west is gradational We include these rocks—the McClure Mountain unit of DiLeonardo (1987) and Hopkins (1987)—in the Newby Group.

Our mapping, coupled with geochronologic, geochemical and isotopic analyses of Newby Group rocks provides a rela¬tively complete picture of the areal distribution, lithoiogies, and stratigraphic character of the Newby Group. It consists of two distinct parts (Fig. 7): the lower Newby Group, consisting of thin-bedded black argillite, siltstone, lithic sandstone and minor calcarenite, and the upper Newby Group, containing andesitic to rhyolitic flows, hypabyssal rocks, volcanic breccias, lapilli tuff, and volcaniclastic conglomerate, sandstone, and argillite. The lower Newby Group corresponds to the Twisp Formation of Barksdale (1975), and the upper Newby Group corresponds to the undifferentiated Newby Group of Bunning (1990). We also include the McClure Mountain unit within the Newby Group; it is low-grade schist and metaplutonic rock that we believe was derived from upper Newby Group strata and associated intrusions by intra-arc deformation during late Newby time.

The lower Newby Group (Twisp Formation of Barks-dale, 1975) is primarily exposed in a 5-6 km wide belt cen¬tered on the Methow River between the Twisp and Chewuch Rivers. The best exposures occur in road cuts along SR 20 between Twisp and Winthrop, Washington; elsewhere, the unit is recessive and poorly exposed. The Twisp Formation along SR 20 is atypical, being much more deformed than the unit elsewhere. The unit locally contains tight to isoclinal folds, and displays a prominent cleavage absent in overlying rocks. Poor exposure and a lack of discernible marker beds make the recognition of stratigraphic succession within the unit difficult, although lithologic variations do suggest a relative stratigraphic sequence. The lowest visible portion of the Twisp Formation is dominated by thin bedded black argillite, with subordinate dark gray siltstone, thin to medium bedded lithic sandstone, and minor sandy limestone (Stop 1-3). Beds are laterally continuous and graded bedding and partial Bouma sequences are locally recognized. The upper portion of the Twisp Formation contains thin light gray to yellow tuf-faceous beds and thin- to medium-bedded coarse volcanic sandstone. It does not contain limey horizons. TufTaceous in-terbeds are most common on the west side of the Methow River, especially on Patterson Mountain (Stop 1—4). Zircon derived from a tuffaceous interval on the south side of Patter¬son Mountain yields a U-Pb age of 151.0 +8.7/-0.3 Ma.

The base of the Twisp Formation is not exposed. At the top of the Twisp Formation, we do not see the unconformity between it and the overlying volcanic strata which Barksdale (1975) described. The proximity of tuffaceous interbeds to overlying volcanic rocks of the upper Newby suggests a gra-dational contact between the Twisp Formation and the upper Newby Group. This gradational contact is supported by the occurrence of thick (>10 m) successions of tuflaceous black argillite intercalated with coarse breccias, tuffs and flows of the upper member. At the place where Barksdale (1975) identified his unconformity we find Twisp-like argillite and fine sandstone interbedded with andesitic tuff and breccia of the Bear Creek unit of the upper Newby Group.

The upper, volcanic-rich part of the Newby Group is widely exposed, albeit poorly, from Gold Creek to east of Buck Mountain, north of Winthrop. The upper Newby Group comprises the majority of the Group, and is at least 1300 meters thick (an estimate based on topographic relief). Lateral variations in lithofacies and, more importantly, differences in metamorphic alteration lead us to differentiate two units within the upper member 1) the Lookout Mountain unit, a series of andesitic to rhyolitic flows, hypabyssal plugs, breccias, lapilli tuffs, and volcaniclastic sediments character¬ized by greenschist-facies alteration; and 2) the Bear Creek unit, a sequence of tuff breccias, lapilli tuffs and associated volcaniclastic sediments displaying pervasive laumontitic alteration

The Lookout Mountain unit is primarily exposed between the Twisp River and Gold Creek, on the west side of the Methow River. Lithologic variations within the unit result in an outcrop pattern characterized by north-trending lenticular belts that alternate between flow- and breccia-dominated and sediment-dominated. Volcanic flows and associated breccias form massive, resistant cliffs of dark green- to gray-weathenng plagioclase-phvnc andesite and dacite (Stop 1-6) intercalated with lesser lapilli tuff and volcaniclastic sediments. Silicic alteration is common, plagioclase is commonly albitized with fuzzy grain boundaries, and chloride alteration of mafic minerals (mostly hornblende ± pyroxene?) is pervasive. Sediment-dominated successions are characterized by thick (>200 m) sequences of volcanic breccia, conglomerate, medium to coarse sandstone, siltstone and shale. Conglomerate beds primarily consist of poorly sorted, angular to sub-rounded volcanic clasts set in a matrix of coarse volcanic sand and silt. Sandstone intervals contain medium- to coarse¬grained lithic feldspathic wacke intercalated with laminated fine sandstone, siltstone and shale. Sedimentary beds are laterally continuous, and contain graded bedding, partial Bouma sequences, planar laminations, basal scour features and soft-sediment deformation. Beds are commonly arranged in cyclic fining- and thinning-upward sequences that are 1 to 20 meters thick. The recessive character of the fine-grained intervals results in ribs of conglomerate and breccia standing in bold relief.

The Lookout Mountain unit is spatially associated with plugs, dikes, sills and flows(?) of yellow- to light gray-weathering sparsely-phyric rhyolite. Rhyolite intrusions commonly cut older flows and sediments, and probable flows appear to overlie more mafic flows and breccias. This relationship is well-exposed on the eastern slope of McClure Mountain, where rhyolite intrusions, including a probable rhyolite dome, cut the Lookout Mountain unit. On the west-em face of the ridge immediately north of Twisp on the east side of the Methow River, a dike that cuts flows and breccias of the Lookout Mountain unit yields a U-Pb age of 152.8 ± 0.9 Ma, which overlaps in age with the tufiaceous interval dated from the upper portion of the lower member. However, it must be noted that the abundance of rhyolite in the area south of Twisp is unusual, and we cannot discount the possibility of a younger, post-Newby Group, rhyolitic volcanic event in the region.

The Bear Creek unit is primarily exposed on the east side of the Methow between the Balky Hill Road and Buck Mountain, and west of the Methow River between the Twisp River and Thompson Creek. It consists primarily of tuff breccia, lapilli tuff, conglomerate, sandstone, siltstone and shale. Volcanic flows, coarse breccias and associated hypabyssal intrusions are rare. Coarse-grained intervals tend to be thick-bedded to massive and appear structureless; pebble conglomerate, sandstone, siltstone and shale tend to be thin-to medium-bedded and display crude, commonly planar, laminations. Laumontitic alteration is pervasive and leads to light brown, chalky exposures, commonly with extensive veining. Original sedimentary features are commonly masked outcrops are friable, and resulting regolith is crumbly.

The Lookout Mountain and Bear Creek units probably represent laterally contiguous, interflngehng lithofacies that differ in original lithology and subsequent alteration. The Lookout Mountain unit contains flows, coarse breccia, and andesitic to rhyolitic hypabyssal rock formed on or immediately adjacent to a volcanic edifice, whereas the Bear Creek unit contains finer-grained tuff breccia, lapilli tuff and vol-caniclastic rock deposited in a more distal setting. The differences in alteration are best attributed to differing proximity to hydrothermal fluids associated with the magmatic system; rocks closer to the magmatic system (Lookout Mountain unit) are more altered than those distal to the system (Bear Creek unit). Probable laterally contiguity and fundamentally gradational contacts between these units will make it difficult to formalize our nomenclature.

The lower contact of the upper Newby Group is a gradational contact with the underlying lower Newby (Twisp Formation). The upper contact is a moderately angular uncon¬formity with the Pipestone Canyon Formation and Patterson Lake unit.

Our mapping and geochronologic analyses indicate that the upper portion of the lower Newby Group (Twisp Formation) and the upper Newby Group are Late Jurassic (Kimmeridgian to Tithonian) in age. Zircon derived from a tuffaceous interbed in the upper portion of the lower Newby Group yielded a U-Pb age of 151.0 +8.7/-0.3 Ma. A rhyolite dike cutting breccias east of the Methow River yields a U-Pb age of 152.8 ± 0.9 Ma. Mylonitic quartz diorite within the McClure Mountain unit (metamorphosed Newby Group; see below) provides a U/Pb age of 142.8 -KJ.9/-0.3 Ma. The Alder Creek Stock, which we interpret to be syn- to post-kinematic with respect to deformation of the McClure Mountain unit, yields a U-Pb zircon age of 141.6 +1.0/-0.3 Ma. We therefore conclude that Newby Group volcanism lasted from 153 Ma to 142 Ma, with the later stages of magmatism characterized by intra-arc deformation (formation of McClure Mountain Unit) and emplacement of sub-volcanic plutons (Alder Creek and possibly Carleton stocks). We note that the lower portion of the Twisp Formation could be significantly older.

The McClure Mountain unit (Stop 1-2) consists of m-terlayered siliceous phyllite, chloritic quartz-rich schist, dioritic gneisses, and lesser mylonite. The unit crops out south of McClure Mountain between Smith Canyon and the Methow River. Purple to green, fine-grained phyllite and chloritic schist dominate the unit, with coarse-grained gneiss and metavolcanic rocks forming elongate lenses (1-250 m in length) set in a schistose matrix. Foliation is steep. Lineation directions vary from place to place, being both steep and gently north-plunging. Metamorphism appears to be largely in greenschist facies, though Hopkins (1987) described amphibolite-facies assemblages.

Barksdale (1975) included these low-grade rocks in his Leecher Metamorphics, which, east of the Methow River, are metamorphosed in upper amphibolite facies. He attributed the low metamorphic grade west of the Methow River to retrograde metamorphism and recrystallization during faulting. DiLeonardo (1987) noted significant compositional differences between the low-grade rocks and the Leecher Metamorphics, and defined the former as the McClure Mountain unit, which he interpreted to mostly be metamorphosed quartzofeldspathic sedimentary rocks. Hopkins (1987) described the unit as intercalated quartzose sandstone, shale, and silicic and intermediate volcanic rocks metamorphosed to schist, homfels and quartzite.

We think the McClure Mountain unit was derived from a Newby protolith. DiLeonardo (1987) and Hopkins (1987) noted similarities between the McClure Mountain unit and the adjacent Newby Group, but both thought the McClure Mountain unit was distinctly richer in quartz than the Newby Group, and therefore probably not correlative. We note that the entire Newby Group is much more silicic than noted by previous workers. It also appears that the McClure Mountain unit is developed within a portion of the Newby Group that is particularly rich in rhyolitic tuffs.

Our mapping demonstrates that apparently-sharp lithologic breaks at the western and northern limits of the McClure Mountain unit are the result of inhomogeneous dis¬tribution of strain within a lithologically variable protolith. The western contact has been described as the Smith Canyon fault (Barksdale, 1975; DiLeonardo, 1987), which separates the McClure Mountain unit from the Newby Group to the west. This boundary is in fact gradational, with a gradual decrease in the intensity of deformation across a distance of 1 -1.5 km west of Smith Canyon. Sharp lithologic breaks occur between primarily phyllitic to schistose zones and more mas¬sive metavolcanic flows and breccias. Ductile deformation is common in fine-grained units; brittle shattering is common in massive metavolcanic units. The McClure Mountain unit is thus gradational with the remainder of the Newby Group, and represents a zone of penetrative deformation within the arc assemblage.

The age of the McClure Mountain unit is constrained by the age of the protolith (Newby Group; 153-142 Ma) and by the age of intrusions within and cross-cutting the unit. A mylonitic quartz diorite within the McClure Mountain unit yields a U-Pb age of 142.8 +0.9/-0.3 Ma, providing a maxi¬mum age of deformation. The McClure Mountain unit is cut and contact metamorphosed by the magmatically foliated Alder Creek stock (141.6 +1.0/-0.3 Ma; U-Pb zircon) on its northern boundary, and by the southern Carleton stock (129.6 ±1.1 Ma; K-Ar hornblende) on its southern boundary. The Alder Creek stock appears to be syn- to post-kinematic, and the southern Carleton stock is post-kinematic. We therefore conservatively estimate deformation and formation of the McClure Mountain unit to be bracketed between 143 and 130 Ma. This deformation is the oldest recognized tectonism in the Methow block.

LOWER CRETACEOUS SHALLOW-MARINE STRATA

Northern Methaw subterrane

There is little exposure of older Lower Cretaceous (sub-Harts Pass) strata in the U.S. part of the northern Methow subterrane, and what there is we have not examined closely. Lithic sandstone, argillite, and pebble- to cobble conglomerate crop out at Dead Lake, west of the lower Pasayten River. Fossils, especially trigoniid clams, indicate an Albian age (D.L. Jones, cited in Staatz and others, 1971; W. Elder, written communication, 1993). The rocks are depositionally overlain by the middle Albian Harts Pass Formation. Extensive bioturbation and fossil hashes (storm lags?) suggest shallow-marine deposition.

Similar rocks crop out in upper Panther Creek, where Barksdale (1975) designated them the Panther Creek Formation. He reported a probable middle Aptian age. Fossils we have collected from the Panther Creek area are Valanginian(?) (W. Elder, written communication, 1992). There- is sufficient outcrop in this area to infer that the conglomerate forms lenticular bodies of limited lateral extent.

Many outcrops of Lower Cretaceous strata are characterized by conglomerate with abundant, well-rounded, granitoid clasts. Lithologic correlation of these rocks is uncertain, as similar granitoid-cobble conglomerates occur at several different horizons: within the Albion Harts Pass Formation, in sub-Harts Pass rocks of Albian age at Dead Lake, in Valanginian(?) strata at the head of Panther Creek, and in Hauterivian-Barremian strata of the Buck Mountain unit of the southern Methow subterrane. Coarse granitoid cobble conglomerate overlies the Late Jurassic Button Creek stock in upper Ortell Creek drainage, but has yielded no fossils.

Lithic sandstone, siltstone, and minor calcarenite crop out west of Spratt Mountain, not far east of the Hozameen fault. Abundant *Inoceramus* shell fragments indicate a Cretaceous age.
Southern Methow subterrane

We identify lower Cretaceous sedimentary strata on and adjacent to Buck Mountain as the Buck Mountain unit. Barksdale (1975) formally defined the Buck Mountain Formation to include extensive volcanic rocks that we now know to be both older and younger than, but not coeval with, the clastic strata on Buck Mountain, and which are separated from the clastic strata by significant faults. We think that Barksdale's Buck Mountain Formation should be abandoned but are not prepared to offer alternative nomenclature. The Buck Mountain unit includes several distinctive rock assemblages, including:

1) Interlayered green volcanic-lithic sandstone, black argillite, and pebble to cobble conglomerate with conspicuous granitoid clasts. This unit contains abundant fossilized plant material, including logs, and large palmate leaves or fronds which can be seen in a roadcut along the West Chewuch Road south of Cub Creek.Stacked fossilized fern-fronds, with the spore buttons still preserved and all facing the same direction, indicate at least part of this unit is fluvial. South of Cub Creek this unit grades up into

2) black calcareous siltstone punctuated by shell mounds. Most of the shells are an unusually fat *inoceramid.*

3) Conglomerate, similar to that in the first unit, which contains granitoid clasts but also contains scattered limestone pebbles.

4) Pale green volcaniclastic sandstone with scattered shelly horizons and intervening poorly exposed argillite.

W.P. Elder (written communication, 1994) has examined several fossil collections from the Buck Mountain unit, including some of the collections at the Burke Museum. The *inoceramids* in unit 2 are "*Inoceramus " colonicus* Anderson of Hautcn vian to early Barremian age; these are the fossils which McGroder and others (1991) reported as Buchia of probable Jurassic age. They occur with belemnites that suggest a Hauterivian age. Probable Shasticrioceras in other collections indicates an early Barremian age. Ammonites recovered from unit 4, on the south slopes of Buck Mountain, indicate a probable Albian age, perhaps equivalent to the Patterson Lake unit. Poor outcrop and a resulting lack of structural data make it difficult to unravel the Buck Mountain unit, but we suspect that it includes strata which elsewhere we have mapped as Patterson Lake unit, and that the Buck Mountain unit is internally imbricated.

The Albian Patterson Lake unit is a laterally variable succession of volcanic- and sedimentary-clast pebble to cobble conglomerate that overlies the Newby Group. The unit is exposed primarily in two north-trending panels that flank the main exposure of the Newby Group on either side of the Methow River. The Patterson Lake conglomerate was named by Maurer (19S8), but was considered the basal member of the Virginian Ridge Formation by Barksdale (1975) and Trexler (198S). The conglomerate was again recognized as a distinct, mappable unit by McGroder and others (1991; Stotfel and McGroder, 1990; Bunning, 1990).

The conglomerate is generally dark brown to dark grey, thick-bedded to massive and matrix- to clast-supported. Clasts within the conglomerate are poorly sorted, subrounded to rounded, and are primarily intermediate volcanic rocks, volcaniclastic sandstone, siltstone and argillite. Plutonic debris, including granitic clasts, is locally evident. Chert is rare or absent. Clasts are set in a dark grey to dark brown, fine- to medium-grained sandstone matrix. Sedimentary structures are limited to crude stratification and poorly developed imbrication. Conglomerate is locally interbedded with medium-to thick-bedded, dark grey to brown, medium-to coarse¬grained volcanic lithic sandstone. Much of the Patterson Lake unit northwest of Winthrop is pink- to orange-weathering massive lithic sandstone with scattered pebble stringers. Shelly horizons are relatively common (at least in comparison to other Methow rocks) and usually are thin coquinas of dis¬articulated shells, suggesting beach deposits or shallow-water storm lags. Much of the unit may be fluvial. The unit tends to weather recessively, and is commonly recognized through rounded volcanic clasts found in dark, sandy regolith. The Patterson Lake unit is laterally variable, with distinct variations in thickness, clast content, and grain size along strike.

The Patterson Lake unit overlies both upper and lower Newby Group strata with angular unconformity. This contact is well exposed west of Elbow Coulee, between the Twisp River and Patterson Lake. Earlier workers (Trexler, 1985, Bunning, 1990; McGroder and others, 1991) interpreted the upper contact to be a probable disconformity with the adjacent Virginian Ridge Formation. However, our mapping shows that the Patterson Lake-Virginian Ridge contact is commonly faulted and comprises a zone of tectonic interleaving between the two units. We do not know if faulting has disrupted a depositional contact, or if this is a thrust fault of unknown, potentially significant, displacement. This contact is the boundary between the northern and southern Methow subterranes (see introduction to STRATIGRAPHY, above)

The trigoniid-bearing Albian faunas described by Barksdale (1975, page 41) as being from the Virginian Ridge Formation are from the Patterson Lake unit. W.P. Elder (written communication, 1994) examined fossils in the Burke Museum collection and new collections by us from the Patterson Lake unit and identified trigoniid Yaadia whiteavesi (Packard) of late early Albian to middle Albian age.

MID-CRETACEOUS FORELAND-BASIN FILL

Thick—more than 6 km—middle Albian to Turanian or Comacian strata of the northern Methow subterrane constitute a shallowing-upward sequence that we interpret as the fill of a foreland basin, deposited in the structural depression in front of, and overridden by, an east-verging allochthon now represented by the Hozameen Group. Units of the foreland-basin fill are, from the bottom up, the Little Jack unit, the Harts Pass Formation, the Jackita Ridge Formation, and the Pasayten Group, the latter comprising the Virginian Ridge Formation, the Winthrop Formation, and the Midnight Peak Formation.

The Albianf?) Little Jack unit consists of shale, silt-stone, sandstone, tuffaceous rock, and minor ultramafic rock, and rare limestone and ribbon chert. The name is from Little Jack Mountain, which lies southwest of Jack Mountain and forms the divide between Crater Creek and Ross Lake. Some of the fine sandstone, particularly south of Canyon Creek, is relatively quartzose. Much of the Little Jack is metamorphosed, ranging from sub-biotite-zone phyllite and semischist in the Canyon Creek drainage, to biotite schist at the Canyon Creek trailhead on SR 20, to gamet-sillimanite schist west of Ross Lake. Misch (1966, 1977) included much of this unit in his Jack Mountain Phyllite; Tabor and others (1989) included much of this unit in their Little Jack terrane.

Neither the base nor the top of the Little Jack has been identified; indeed, we have little sense of its internal structure. Where outcrop is good (Stop 4-3), isoclinal folding is evident. Age control, beyond intrusion by the Black Peak ba-tholith (- 90 Ma), is absent. Most of the unit lies structurally beneath the Jack Mountain thrust on Jack and Crater Mountains. Tennyson (1974) proposed that the Hozameen fault, extends southeast through Boulder Pass, near the northern edge of the Golden Horn batholith, and separates rocks we call Little Jack from Methow strata. Misch (oral communications, 1981-1985) was adamant that his Jack Mountain Phyllite was transitional into undeformed Methow strata. After finding clean arkosic sandstone typical of the Harts Pass Formation west of Boulder Pass, we are inclined to agree with Misch that large displacement on a fault through Boulder Pass is not likely.

We hypothesize an Albian age for the Little Jack unit entirely on the basis of inferences drawn from our foreland-basin model for the Harts Pass and overlying formations. In this model, the Little Jack unit represents deep water pelagic and distal hemipelagic sediment deposited in a developing intra-oceanic foreland basin. We infer that the Little Jack unit is the west-derived equivalent of the east-derived Harts Pass Formation (see below). We also infer that the Little Jack unit is gradiationally overlain by the west-derived Jackita Ridge Formation, and that this transition records the emergence of a sediment source (the Hozameen allochthon) at the west margin of the basin.

Coversely, the Little Jack unit could be correlative with the Lower Jurassic-Lower Cretaceous Cayoosh Assemblage of the southeastern Coast Mountains (Joumeay and Northcoate, 1992, Mahoney and Journeay, 1993). The quartzose siltstone and fine sandstone and structural association with the Hozameen (=Bridge River) Group are similar. Another possibility (or is it the same one?) is that the Little Jack unit is correlative with parts of the Twisp Formation of Barksdale (1975) (see Stop 3-2 in Haugerud and others, 1994).

The middle Albian Harts Pass Formation comprises gray- to white-weathering medium-grained plagioclase arkose interbedded with subsidiary thin-bedded fine sandstone and argillite, with local conglomerate. Barksdale (1975) designated the area occupied by the formation within three miles of Harts Pass as the type area. Almost all of the unit is turbidite, though we have seen coarsely cross-bedded sandstone at one location. Fresh surfaces are commonly greenish: Coates (1974) reports that similar sandstone in Manning Park is albitized, though Pierson (1972) found calcic plagioclase in the vicinity of Harts Pass. Most sand beds lack internal bedding, though trains of argillite intraclasts and stringers of pebbles are locally present. Scour marks and load casts are common at bases of sand beds and finer-grained tops of some sand beds are ripple cross-laminated. Sand beds are commonly amalgamated and fine-grained intervals fail to crop out, leading to hillsides of blocky sandstone outcrop with no measurable bedding. Detrital grains are mostly plagioclase (-55%), quartz (30%), and lithic fragments (15%) (Pierson, 1972). Lithic fragments are mostly felsic plutonic and metamorphic rock fragments. Minor detrital biotite is conspicuous in most hand samples; fairly abundant (1-3%) coarse epidote appears to be detrital, and detrital muscovite is obvious under the microscope. Sandstones typically contains less than a few percent K-feldspar. Rare conglomerates are dominated by granitoid cobbles.

In the vicinity of Harts Pass the formation is uncon-formably overlain by the Virginian Ridge Formation (Fig. 14) and the lower contact is probably faulted. A complete section is preserved near the Cascade Crest on Mount Winthrop, several km south of the 49th parallel. There, the poorly exposed base appears transitional with shallow-water Albian strata at the southwest comer of The Parks, and the top is apparently conformable with the overlying Jackita Ridge Formation (Three Fools facies) at Castle Pass. Total thickness on Mount Winthrop is about 2.5 km. Mappable (at 1:100,000 scale) lenses of conglomerate occur within the Harts Pass Formation at and north of Holman Peak, on Center Mountain north to Three Fools Peak, and on Devils Dome and Spratt Mountain. We also mapped sepa¬rately a unit of massive siltstone with scattered 1-3 decimeter-thick arkose beds and Albian fossils which crops out beneath ordinary Harts Pass arkose in upper Freezeout Creek.

Crowley (1993) reports a middle Albian age for the Harts

Pass Formation on the basis of its ammonite fauna. The age of the Harts Pass Formation is further constrained by (1) Albian (undivided) fossils from shallow-water deposits at Dead Lake, beneath the Harts Pass Formation, and (2) Turonian(?) fossils from the Virginian Ridge Formation, which lies uncontbrmably above the Harts Pass. The Harts Pass Formation is intruded by the 88-90 Ma Rock Creek and Pasayten stocks.

The Harts Pass Formation is correlative with the upper part of the Jackass Mountain Group of southern British Columbia as described by Coates (1974), though the Jackass Mountain includes shallow-water Lower Cretaceous strata that correlate with units beneath the Harts Pass.

The Harts Pass Formation is marine. Massive sand beds, scoured and loaded bases, common amalgamation, restriction of cross-bedding to fine-grained tops of beds and fine sandstone layers within pelitic interbeds, and common intraclasts all indicate deposition by turbidity currents. The nearly-universal lack of storm lags and bioturbation (the fossil locale 2/3 mile southeast of Harts Pass is a rare exception) indicate deposition at depths below storm-wave base. The conglomeratic unit noted above, which crops out intermittently from Holman Peak to Devils Dome, is probably a large submarine-fan channel-fill complex. This channel-fill unit and the sand-rich character of the remainder of the unit suggest deposition in the middle reaches of a fan. The massive siltstone facies in upper Freezeout Creek may record the onset of arkose deposition during initial basin subsidence early in Albian time.Paleocurrent indicators (Cole, 1973) indicate an eastern source for Harts Pass sediment.

Thin-bedded dark gray argillite and sandstone turbidite with abundant graded beds, load casts, and flames constitute the Albian (and younger?) Jackita Ridge Formation. Typically more than half of the outcrop is finer than medium-grained sandstone. Where sands are sufficiently coarse one can see that many grains are chert fragments. Thick coarsening-upwards sequences culminate in chert-pebble conglomerate which is commonly matrix-supported. The unit generally coarsens upwards, though conglomerate is locally present at the base of unit. Much of the Jackita Ridge Formation has well-developed slatey cleavage. We suggest Jackita Ridge, and particularly the long spur ridge extending east from the Devils Park trail towards Ana-cortes Crossing, as the type area of the unit. Exposures along the Boundary Trail west of Castle Pass are also informative, appear less complicated structurally, and have less lithologic variety.

The base of the Jackita Ridge Formation appears to be conformable with the underlying Harts Pass Formation at Castle Pass, though the contact is not well exposed. A conformable basal contact is also evident north of Welcome Basin, where it is drawn at the change from sand-dominated (Harts Pass) to fine-dominated (Jackita Ridge) strata. On Majestic Mountain, south of Canyon Creek, one finds probable Jackita Ridge chert-pebble conglomerate interbedded with Harts Pass-like arkose. We have not closely observed the top of the Jackita Ridge Fm. On Jackita Ridge the unit crops out in the west limb of a complex syncline, in the core of which lies Virginian Ridge Formation, but the contact between the two units is commonly faulted. This contact is also present in at least two locales west and southwest of Storey Peak.

Tennyson (1974) and, following her lead, Trexler (1985) and McGroder and others (1991) divided the strata we call Jackita Ridge Formation amongst the Harts Pass Formation and the Virginian Ridge Formation.

W.P. Elder (written communication, 1994) has tentatively assigned late Albian-Cenomanian and early-middle Albian ages to inoceramid fossils collected at three localities in the Jackita Ridge Formation.The Jackita Ridge Formation contains the oldest west-derived strata in the Methow, and records the emergence of the Hozameen Group as a sediment source.

Pasayten Group

The Pasayten Group was defined in Manning Park, British Columbia (Daly, 1912; Coates, 1974), where Coates (1974) described it as predominantly arkosic, fluvial sandstone that overlies marine strata of the Jackass Mountain Group. The upper parts of the Jackass Mountain appear to be equivalent to the Harts Pass Formation. We extend the Pasayten Group south across the 49th parallel to include the Virginian Ridge, Winthrop, and Midnight Peak Formations.

Figure 8 summarizes the nomenclature, age constraints, and physical stratigraphy of the Pasayten Group.

The Turonian? and probably Cenomanian Virginian Ridge Formation comprises argillite, siltstone, chert-grain sandstone, chert-pebble conglomerate, and biotite arkose. The unit is characterized by expanses of featureless argillite and siltstone punctuated by 1- to 10-m thick coarser-grained beds. Most argillite and siltstone is dark gray to black, olive brown, or blue-gray. Coarser beds commonly have undulating bases and internal cross-bedding. Barksdale (1948, 1975) described a type section along the lower part of Virginian Ridge, between Wolf Creek and the Methow River about 5 miles west of Winthrop. At the Virginian Ridge type section the base of the formation is faulted and the top of the section is not well exposed.

The basal contact is preserved in upper Rattlesnake Creek, off the Harts Pass Road (Stop 2-5), on the southeast ridge of Mcl.eod Mountain, and elsewhere in the northeast-em part of the Methow block, where it commonly is a low-angle unconformity on top of the Harts Pass Formation, hi the western Methow block, where the Virginian Ridge Formation overlies the Jackita Ridge Formation, the basal contact is locally omitted by faulting and we have not examined it closely. The upper contact is commonly gradational with the Winthrop Formation.

Barksdale's (1975) Virginian Ridge Formation included the

Patterson Lake unit, which he referred to as “basal conglomerate derived from Newby Group rocks.” Trexler (1985) retained Barksdale’s conception of the Virginian Ridge Formation and defined a Slate Peak, Devils Pass, and Patterson Lake members. We follow McGroder and others (1991) and exclude the Patterson Lake unit from the Virginian Ridge: depositional contacts between the two units cannot be identified, there are very few, if any transitional lithologies, and fossil ages suggest that i/the Virginian Ridge and Patterson Lake units are part of the same stratigraphic succession, the Harts Pass Formation is missing.

Except that we exclude the Patterson Lake unit and include the South Creek metaconglomerate of Dragovich and others (in press) (below), our conception of the Virginian Ridge Formation remains similar to Barksdale’s (1975) We note that much of the unit, including the type section, contains beds of cross-bedded biotite arkose identical to that which is typical of the Winthrop Formation. We follow Trexler (1985) and recognize Devils Pass and Slate Peak members, though some finer-grained strata west of the Cascade crest, which Trexler included in the Slate Peak member, we place in the Jackita Ridge Formation.

Fossils of marine snails, including a new Actaeonella species similar to *Actaeonella oviformis* Gabb, from Slate Peak and along strike to the north, suggest a Turonianf .’ age to Will Elder (written communications, 1992, 1994). The Virginian Ridge Formation unconformably overlies middle Albian Harts Pass Formation and overlies the Albian Jackita Ridge Formation with an unknown relationship. We thus suggest a Turonian(?) and probably Cenomanian age for the Virginian Ridge. Barksdale’s (1975) suggestion of an Albian age for part of the unit was based on excellent Albian fossil collections from several locales that are within the Patterson Lake unit

The Slate Peak Member makes up the majority of the Virginian Ridge Formation, including the type section. It is predominantly argillite and siltstone, with lesser sandstone and conglomerate. Outcrops in the vicinity of Slate Peak are atypical, with better-preserved bedding in fine-grained rocks, abundant flaser bedding, common plant debris, and local brackish-water to marine fossils. Relatively accessible outcrops of rocks more typical of the Slate Peak Member are present on the slopes above the Harts Pass Road along Rattlesnake Creek, on Sandy Butte, and at some locales high on Thompson Ridge.

The Slate Peak Member is predominantly fluvial. Lenticular coarse-grained beds are channel deposits, whereas the featureless argillite and siltstone typical of the unit are bio-turbated overbank deposits. This interpretation is supported by the observation of in-situ stump molds at the bases of some chert-pebble conglomerate beds and interbedding with cross-bedded arkose typical of the fluvial Winthrop Formation. The fossil beds at Slate Peak, and the associated flaser-bedded fine sandstone and siltstone, are an exception: these beds are estuarine to shallow-marine.

The Devils Pass Member comprises thick-bedded chert-pebble conglomerate and minor fine-grained beds. Maximum chert-clast size is typically about 10 cm, which presumably reflects the maximum thickness of ribbon-chert beds in the source terrain. Most outcrops contain a few clasts of mafic greenstone. Casts of sticks and logs are locally evident. The Devils Pass Member is restricted to the western part of the Methow block.

Low-angle cross-stratification and gradational contacts with the Slate Peak Member suggest that the Devils Pass is also alluvial, perhaps deposited in an alluvial-fan environment. Trexler (1985) inferred a fan-delta environment for the Devils Pass Member, though we suspect no marine beds are present.

We consider the South Creek metaconglomerate unit of Dragovich and others (in press) to be a basal member of the Virginian Ridge Formation. The South Creek Member comprises approximately 600 m of pebble to boulder conglomerate and lesser medium- to fine-grained sandstone and minor siltstone with rare fossilized wood debris. Conglomerate is clast-supported and poorly sorted, with subangular to subrounded ciasts dominated by metamorphosed ribbon chert and lesser greenschist and intermediate volcanic rocks. The unit is characterized by abundant angular white pebbles and cobbles of metamorphosed ribbon chert.

The South Creek Member was deposited on metamorphosed ribbon chert of the Twisp Valley Schist. The contact is exposed on the southwest wall of the Twisp River valley north of Reynolds Creek. The upper contact is not well exposed, but appears to be, in the vicinity of Reynolds Creek, gradational with argillite of the Slate Peak Member. Farther north, the South Creek Member may be directly overlain by sandstone and siltstone of the

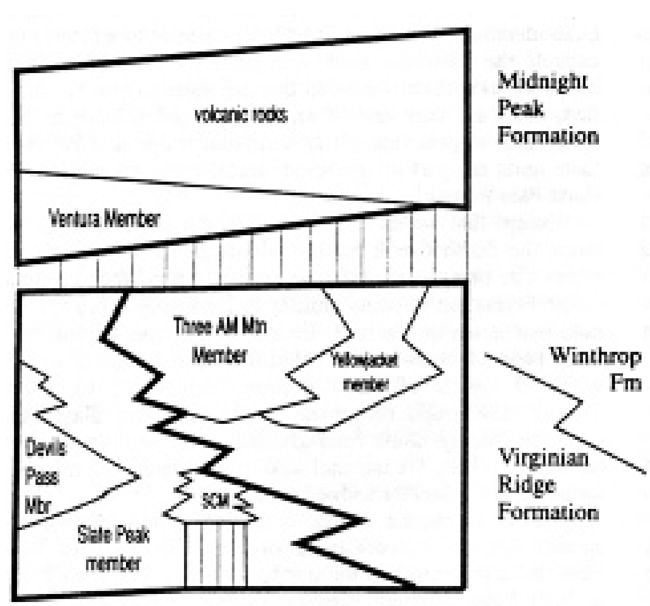


Figure 8. Schematic stratigraphic section for the Pasayten Group, not to any scale, showing interfmgering relations—some observed, some inferred—and our nomenclature. Vertical-ruled areas indicate non-deposition and (or) erosion.

Winthrop Formation.

Very poorly-sorted massive conglomerate at the base of the South Creek Member contains some angular material and is commonly clast-supported, suggesting debris flow deposition in an alluvial fan to alluvial environment. The clast composition reflects local derivation from the uplifted Twisp Valley Schist basement as evidenced by the transition from a basal fanglomerate to an overall upward-fining and upward-thinning sequence with interspersed massive, clast-supported debris flow deposits. The South Creek Member is metamorphosed in the greenschist facies. Metamorphic minerals, some of which may be recrystallized detrital grains, include albite (An2), epidote, zoisite, chlorite, and white mica. Conglomerate ciasts are now elongate and fine-grained beds have phyllitic foliation.

Correlation of the South Creek unit with the Virginian Ridge Formation is based in part on its stratigraphic position below the Winthrop Formation. More importantly, the dis¬tinctive metamorphosed ribbon chert clasts that comprise much South Creek conglomerate also occur within unquestioned Virginian Ridge conglomerate on the northeast wall of the Twisp River valley south of Mystery Camp.2 Pierson (1972) noted minor metamorphic detritus in sandstone of the Slate Peak Member, perhaps this detritus is a distal reflection of the Twisp Valley Schist source for the South Creek Member. South Creek conglomerate clearly lies above a significant unconformity and it seems parsimonious to identify this with the sub-Virginian Ridge unconformity seen elsewhere in the Methow. Alternately, the South Creek could be significantly older.

Paleocurrent measurements by Cole (1973) and Trexler (1985) demonstrate west-to-east transport in the Virginian Ridge Formation, in accord with the restriction of thick, proximal conglomerates (Devils Pass Member) to the western part of the Methow block. Tennyson (1974) identified ribbon chert and greenstone of the Hozameen Group as the probable source of most Virginian Ridge sediment.

The Winthrop Formation, of probable Turanian and Cenomanian age, is mostly cross-bedded biotite arkose, with lesser lithic sandstone, siltstone, and shale. The east face of Osceola Peak, a ~500-m cliff, displays a gently-dipping section that is more than 75% sandstone. Sandstone is white- to buff-weathering, commonly weathers to rounded forms, and locally has an irregular carbonate cement. Laumontitic alteration is common. Plant fossils are locally abundant and some fine-grained beds contain coal. The formation is charac¬terized by abundant trough cross-stratification. Locally the Winthrop contains significant volcanic breccia, tuff, flows, and associated volcaniclastic sedimentary rocks. Most arkosic sandstone contains several percent K-feldspar and quartz-feldspar composite grains demonstrating that this is first-cycle debris from a plutonic source.

The name dates back to I.C. Russell (1900) who called continental sandstone northwest of Winthrop the “Winthrop sandstone”. Barksdale (1975) formally defined the Winthrop Sandstone as nearly white, massive, arkosic sandstone and light-gray shale with a type area along the northeast side of SR 20, near Boesel Canyon, between 5 and 6 miles northwest of Winthrop.

McGroder (McGroder and others, 1991) recognized that volcanic rocks on Midnight Mountain3 and Three AM Mountain, which Barksdale (1975) included in his Midnight Peak Formation, are time-equivalent to the Winthrop. We have revised some of McGroder’s map boundaries in this area, but are in agreement with him that there is a significant volcanic pile within Winthrop-age strata that is most usefully described as pan of the Winthrop. We have also found that much of the Barksdale’s Winthrop is not arkose, but volcanic-lithic sandstone. We thus redefine the Winthrop Formation to include these volcanic rocks and associated volcaniclastic strata.

Perhaps the best-exposed section of the Winthrop is located west of Lucky Jim Bluff, in the Little Boulder Creek drainage, where both the top and base of the unit are pie-served. There is volcaniclastic sandstone in this section, but no volcanic rock. The base of the Winthrop is gradational with the Virginian Ridge Formation; we find it most useful to draw this contact at the change from predominant argillite (Virginian Ridge Formation) to predominant sandstone. McGroder and others (1991) apparently mapped Winthrop wherever sandstone beds were arkosic, thus including much argillite-nch strata that we call Virginian Ridge Formation.

The top of the Winthrop is locally a disconformity (as at Lucky Jim Bluffs) or an angular unconformity (e.g. Last Chance Point).

Barksdale (1975) reported thicknesses for the Winthrop that range from 2,000’ (600 m) to 13,500’ (4 km). This thick¬ness variation is also evident from our mapping, though the maximum thickness is in the poorly-exposed east limb of the Goat Peak syncline, where inconclusive evidence suggests the possibility of structural repetition.

In some locales we have mapped non-arkosic strata within the Winthrop as distinct members. The Yellow jacket Member (after exposures in the Yellowjacket Creek drainage, east of the lower Lost River) is predominantly volcaniclastic sandstone. Some sandstone is pale gray whereas other is pale to brilliant green, and either color sandstone may bear scattered red lithic grains. Most Yellowjacket sandstone is quartzose. Yellowjacket sandstone commonly lacks the strong trough cross-bedding typical of the arkosic Winthrop.

Dark green to very dark maroon mafic volcanic breccias with conspicuous dark green to black clinopyroxene crystals, along with flows4, tuffs, and associated dark volcaniclastic sediments, are interbedded with arkose along Canyon Ridge, southeast of Three AM Mountain. Three AM Mountain and Midnight Mountain are composed of massive breccias with similar clinopyroxene-phyric lithology. We include all of these rocks—clinopyroxene-phyric volcanics, associated dark volcaniclastic rocks, and interbedded arkose—in the Three AM Mountain Member of the Winthrop Formation.

The exact age of the Winthrop Formation has not been clear. An Albian age has been proposed on the basis of Al-bian ammonites found in "Pasayten Group" strata in Manning Park, but this age is suspect: marine fossils are an unlikely component of a fluvial sandstone. The ammonite-bearing strata are probably equivalent to the Harts Pass Formation, which in some respects is lithologically similar to Winthrop arkose. Plant fossils have been used to suggest an Albian age, both for the Winthrop proper (Crabtree, cited in Rau, 1987) and for correlative strata in the Pasayten Group in Manning Park (Bell, cited in Coates, 1974). The floral-age assignment follows from comparison with fossils found in the Alberta basin, at a higher latitude and on the other side of a major climatic barrier. The lack of a reference section for low-elevation, maritime, mid-Cretaceous floras in this part of the world causes us to suspect the Albian floral age.

Dragovich and others (in press) report a 97.5 +2/-3 Ma (early Cenomanian) U-Pb age for a sill that intrudes Winthrop Formation, and a 100 +3/-5 Ma U-Pb age for a tuffaceous sandstone in the lower part of the Winthrop Formation in the westernmost part of the Methow block. We are uncertain whether the zircons derived from the tuffaceous sandstone are detrital or the product of syndepositional volcanism.

We suggest that the Winthrop is Turonian and Cenomanian, as it lies well above middle Albion Harts Pass Forma¬tion, contains latest Albian or earliest Cenomanian detritus, interfingers with and overlies Turonian(?) strata of the Virginian Ridge Formation, and is intruded by 88-90 Ma plutons.

Barksdale (1975), Tennyson (1974), Rau (1987), and others all interpret a fluvial origin for the Winthrop. Paleocurrents reported by Cole (1973) and Rau (1987) indicate transport of arkosic sand from an eastern source. Volcanic sandstone is probably of intrabasinal origin.

We restrict the Midnight Peak Formation to maroon, green, and gray andesitic volcanic and volcaniclastic rocks and underlying red-beds that are exposed in the Goat Peak synclme and on Isabella Ridge, and correlative rocks in the Little Bridge Creek drainage and south of the Twisp River. The rocks at Midnight Mountain are not in the Midnight Peak Formation—see the discussion of the Winthrop Formation, above. The Midnight Peak Formation is so firmly en¬trenched in the literature that we feel it would only add to the confusion to propose a new name for these rocks. Thus we propose to continue calling these Upper Cretaceous andesitic volcanic rocks and associated red-beds the Midnight Peak Formation, but redefine the type section to be Goat Wall (Stop 2-2).

The volcanic rocks are mostly plagioclase-phyric andesitic breccias, tuff, and flows. Some lavas, particularly on Isabella Ridge, bear large, waxy, brown clinopyroxene phe-nocrysts. Hornblende is rare, though not absent, in eruptive rocks. Most hornblende-bearing volcanic rocks within the Midnight Peak Formation appear to be cross-cutting dikes that may be significantly younger. Locally, for example in Black Pine Basin at the north end of Goat Wall, the volcanic rocks grade to laumontitic lapilli tuffs identical in most respects to the Bear Creek unit of the Newby Group. Volcani¬clastic rocks are dark, indistinctly-bedded volcanic sandstone and siltstone. Volcanic sandstone commonly bears scattered dark red lithic grains.

Multicolored homblende-plagioclase andesite breccias occur on Storey Peak and at one point on the divide between Newby Creek and Buttermilk Creek. We have mapped these breccias as Midnight Peak Formation, though the lithology is atypical. Both locations are Eocene structural lows, and it seems possible that these rocks might prove to be younger than the rest of the Midnight Peak.

Veining and epidote-quartz-calcite alteration are extensive in the volcanic rocks of the Midnight Peak Formation. Bedding in the volcanic and volcaniclastic rocks is typically difficult to see on the outcrop and is commonly more easily observed from across the valley: with distance the weak competency contrasts in thick-bedded strata are more evident.

Barksdale (1975) formally named red-beds which underlie these volcanic rocks the Ventura Member, and identified the type section as Lucky Jim Bluff (seen from Stop 2-1). Russell (1900) had earlier named the Ventura for outcrops near the long-gone mining camp of Ventura, north of Mazama. The color led Russell to speculate that these strata might be Triassic!

The Ventura Member includes poorly-sorted red silt-stones with scattered white calcareous nodules, sandstone, and conglomerate. Sandstone and conglomerate are typically thin-bedded, though conglomerate layers are commonly amalgamated. Abundant trough cross-stratification and fine-grained beds that we interpret as paleosols because of their extensive bioturbation and calcareous nodules suggest that the Ventura Member is fluvial.

Coarse-grained beds in the Ventura Member are commonly gray or green. Gray-green rims surrounding red cores on clasts in some conglomerates suggest that these beds were oxidized when deposited and then reduced by interaction with groundwater: The color contrast between fine-grained and coarse-grained beds thus follows the permeability contrast.

Clasts in Ventura conglomerates in the Goat Peak syncline and on Isabella Ridge are predominantly chert, perhaps derived from erosion of the Virginian Ridge Formation. Farther west, in outcrops extending from Gardner Mountain into Little Bridge Creek, clasts are dominantly red, gray, and pale green siltstone, with lesser volcanic rock, limestone, and granitoid rock.

Most of the Ventura is extensively slumped, so that structural data are difficult to obtain. Nonetheless, the red-beds are the only widespread rock-type in the Methow that preserves a stable remanent magnetization, making them a focus of paleomagnetic investigation.

Haugerud and others (1993) reported an 87.0 ± 0.4 Ma K-Ar age for hornblende from an andesitic breccia in the Midnight Peak Formation at the south end of Isabella Ridge. In the Goat Peak syncline, the Midnight Peak Formation is intruded by the 88 Ma (K-Ar biotite; K.B. Reidell, written communication, 1994) Fawn Peak stock. The data are precise enough to infer that volcanic rocks of the Midnight Peak Formation differ slightly in age from place to place. These ages are near the Turonian-Coniacian boundary on the time scale of Obradovich (1994).

PIPESTONE CANYON FORMATION

Chert-, volcanic-, and grantoid-clast bearing conglomerate, with lesser sandstone and shale exposed along the walls of a Pleistocene meltwater channel on the eastern side of the Methow Valley were named the Pipestone Canyon Formation by Barksdale (1948). Ryason (1959) mapped the areal extent of the formation, described its stratigraphy and was the first to infer an eastern (Okanogan) source for the conglom¬erate. Kriens and others (1995) described the geology of the Pipestone Canyon area and interpreted its structure as reflecting mid-Cretaceous and early Tertiary regional shortening.

The obvious implications for regional tectonics and ter-rane linkages suggested by the coarse-grained character, poorly constrained age, and provenance of the Pipestone Canyon Formation have led to a detailed re-examination of the unit by James Peterson, currently working on a graduate thesis at Western Washington University. We describe preliminary results of his work below.

The Pipestone Canyon Formation is exposed in a limited geographic area roughly bounded on the west by the Methow River, on the east and south by Beaver Creek, and on the north by Bear Creek. This area is cut by N- to NNW-trending high angle faults, including the Pasayten and Fuzzy Canyon faults. The Pasayten fault separates the Pipestone Canyon Formation from the Okanogan complex to the east. The Fuzzy Canyon fault separates the Pipestone Canyon into two areas with different stratigraphies and different basements. We refer to Pipestone Canyon rocks in the western block as the Banner Lake section, and to those in the eastern block as the Campbell Lake section (Fig. 9). Within each of these sections, conglomeratic strata are mostly contained in relatively simple, northeast-dipping homoclinal successions.

The western edge of the Campbell Lake section is foldedf?) to near-vertical dips adjacent to the Fuzzy Canyon fault. East of Bonner Lake itself, the Bonner Lake section appears to be hyper-extended, with homoclinal, steeply-dipping strata lying above a low-angle normal fault. This interpretation contrasts with that of Kriens and others (1995), who described all structures in the unit as compressional.

The type area (Barksdale, 1948, 1975) of the Pipestone Canyon Formation is contained in the Campbell Lake section (Fig. 9) (Stop 3-6). Strata in this section can be subdivided into four distinct lithofacies: 1) basal monolithologic granitoid-boulder conglomerate, 2) tuffaceous lithic feldspathic wacke; 3) chert-, granitoid-, and volcanic-cobble conglomerate; and 4) chert- and volcanic-pebble conglomerate and chert-lithic sandstone.

The basal conglomerate is spectacularly exposed at the mouth of Pipestone Canyon, where it consists of over 60 m of unsorted, subangular to subrounded, matrix-supported bi-otite-bearing light-colored tonalite clasts up to 1.5 m in diameter. This conglomerate is gradationally overlain by forty-plus meters of medium- to thick-bedded, dark purple, fine- to coarse-grained, poorly sorted, tuffaceous lithic feldspathic wacke. The wacke contains abundant granitic detritus float¬ing in a tuffaceous matrix. Tuffaceous wacke is sharply overlain by thick-bedded to massive cobble conglomerate containing 1-15 cm clasts of varicolored chert, foliated and non-foliated plutonic rocks, and intermediate volcanic rocks. The conglomerate comprises 1-5 m thick fining-upward sequences capped by thin- to medium-bedded fine- to medium-grained sandstone. The base of each sequence is commonly erosional, and rare basal lag deposits contain plutonic clasts up to 1.5 m in diameter. These conglomerate beds fine and thin upward into overlying chert- and volcanic-pebble conglomerate and associated sandstone.

Chert clasts comprise up to 70% of the pebble conglomerate, volcanic clasts are volu-metncally more significant than in the subjacent unit, and plutonic clasts decrease in size and abundance upward. Sandstone beds locally form 40% of the section. The upper portion of the conglomerate is contained in lenticular channels, is locally cross-stratified, organic debris is locally abun¬dant, and rare in situ tree stumps may be found.

The Campbell Lake section rests nonconformably on mafic hornblende diorite (the Redshirt gabbro of some workers), gneissic tonalite, and banded gneiss of the Okanogan block. The contact is irregular, we infer a buttress unconformity between the mafic hornblende diorite and the basal conglom¬erate and lower portion of the tuffaceous wacke. This steep contact is onlapped by the upper portion of the tuffaceous wacke and the overlying chert-bearing units. An unconformable contact is suggested by the presence of boxwork, con¬cretions, and strong alteration indicative of a weathered zone in the upper portions of the diorite, below unaltered Pipestone Canyon strata. The top of the section is the modem erosion surface.

The Bonner Lake section is thinner and lithologically less varied than the Campbell Lake section (Fig. 9). The Bonner Lake section is well exposed on the west face of the north-trending ridge west of Bonner Lake, where a prominent cliff of coarse conglomerate, above the Methow River directly north of Twisp (Stop 3—4), exposes over 140 m of sub-rounded to rounded, matrix- to clast-supported boulder conglomerate. The conglomerate (Stop 3-5) contains clasts of foliated and non-foliated

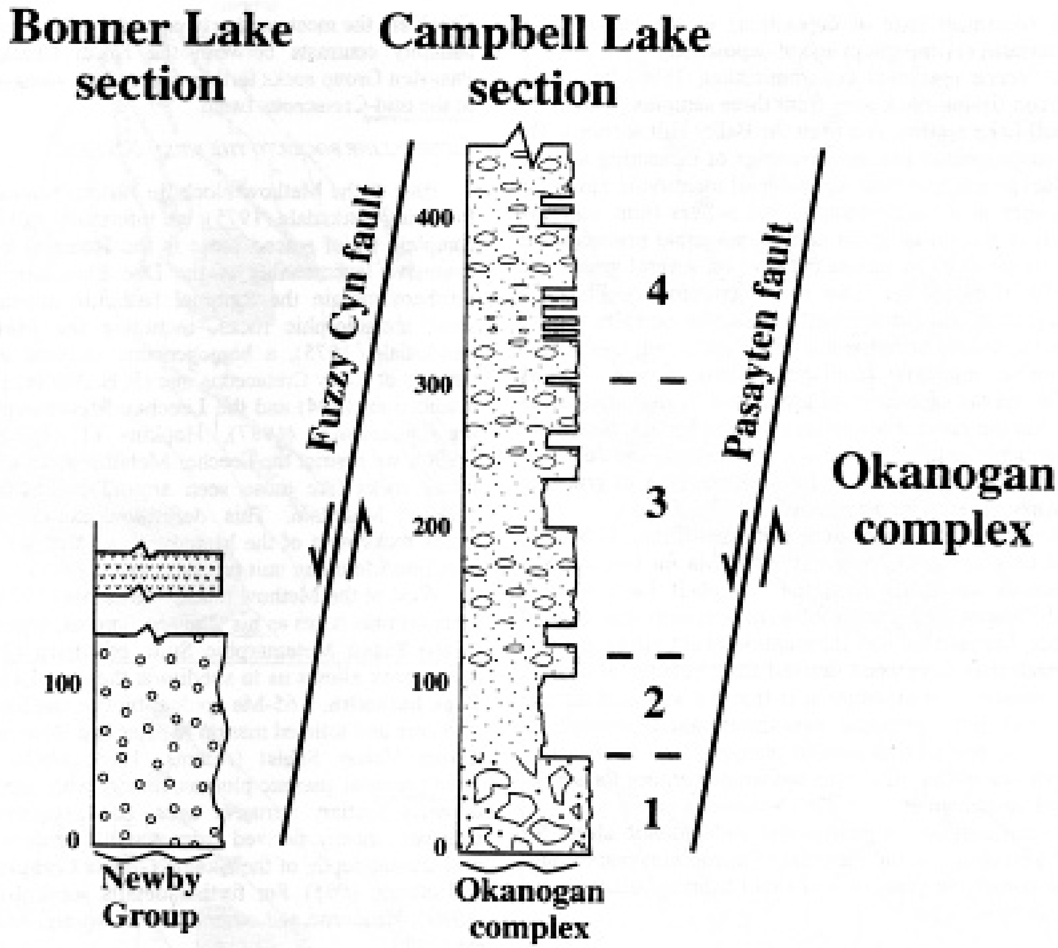


Figure 9. (left) Generalized stratigraphic columns for the Pipestone Canyon Formation. Numbers adjacent to Campbell Lake section refer to lithofacies discussed in text. Volcanic unit shown an unknown stratigraphic distance above Bonner Lake section conglomerate is basalt flows and breccias. Faults shown are schematic, and no inference as to timing of movement is intended (except that they cut the Pipestone Canyon Formation). Some of the motion on these faults may be out of the plane of the section.

plutonic rock (40%), rhyolite (45%), intennediate volcanic rock (10%), and minor chert (5%), and is thick-bedded to massive. Crude stratification, displayed by remnants of laminated to thin-bedded sandstone, is locally evident. Sand beds are rarely more than 30 cm thick with the exceptional bed approaching 1 m. The sands do not extend laterally for more than a few meters. Poor exposure and several high-angle faults make documentation of strata above the massive boulder conglomerate difficult. Little-altered basalt flows and breccia are exposed southeast of Bonner Lake, are homoclinal with adjacent conglomerate, and we interpret them to lie at the top of the Bonner Lake section (Fig. 9).

The Bonner Lake section nonconformably overlies andesite and rhyolite of the Newby Group. The unconformity is well-exposed on the west side of the ridge west of Bonner Lake, where tuff and breccia of the Newby Group are intruded by a rhyolite dike that is truncated by the unconformity. Similar quartz-phyric rhyolite lies beneath Pipestone Canyon conglomerate NW of Bonner Lake. Aphyric rhyolite lies beneath the Bonner Lake section in several other locales. The top of the Bonner Lake section is the modem erosion surface.

The age of the Pipestone Canyon Formation is poorly constrained. Ryason (1959) and Royce (1965) reported a loosely constrained Late Cretaceous to Tertiary, probably Paleocene, age based on plant macrofossils (Dunning, 1990). Our quest for an accurate age for the Pipestone Canyon is driven by three conflicting lines of thought concerning the character of the formation: If it is latest Cretaceous to Eocene m age, and was deposited during a time of active tectonism that post-dates east-vergent compression along the Chmvan-ten thrust system, why does the formation not contain clasts of the uplifted mid-Cretaceous rocks (Harts Pass, Virginian Ridge, Winthrop, Midnight Peak Formations) of the Methow block? Alternately, if the Pipestone Canyon is mid- to early Late Cretaceous in age, and contains detritus from -105-115 Ma (Hurlow and Nelson, 1993) plutons of the Okanogan complex to the east, with K-Ar uplift ages of -95-105 Ma (Dunning, 1990), as previously inferred by Ryason (1959) and Kriens and others (1995), final unroofing of the Okanogan complex must have been very rapid. Such rapid unroofing probably requires extensions! tectonism, which could also explain the lack of volcanic detritus (Okanogan complex volcanic cover) in Methow strata. A third possibility is presented by paleomagnetic data which suggest that the Methow and Okanogan blocks were widely separated during Late Cretaceous time. We need accurate ages for the Pipestone Canyon Formation to constrain the tectonic evolution of the region.

Existing radiometric age data provide similarly loose constraints. The Balky Hill section unconformably overlies the Newby Group (U-Pb age of 152.8 ± 0.9 Ma; R. Friedman, personal communication, 1996). We also have radiometric ages from several samples of tuffaceous sandstone. These ages are inherently ambiguous, as they may record syndepositional volcanism (age of deposition) or the age of older source terrane(s) (maximum age of deposition).

J.A. Vance (personal communication, 1996) has measured zircon fission-track ages from three samples (2 from the Campbell Lake section, one from the Balky Hill section). The fission-track method has the advantage of measuring ages on individual grains, and thus is capable of identifying zircons of several ages in a single sample, but suffers from very low precision of individual grain ages. Reasonable precision can usually be obtained by measuring ages on several grains that appear to all record the same event (eruption, cooling) and averaging them. All three Pipestone Canyon samples yielded fairly broad spectra of individual grain ages, with Late Cretaceous median ages and small populations of early Tertiary ages. The spread of individual grain ages in each sample indicates that the zircon fission-track system has not been reset by subsequent heating. How much significance should be attached to early Tertiary ages of a small number of grains in each sample is yet to be determined.

Richard Friedman (personal communication, 1996) has obtained bulk zircon U-Pb ages of-106 Ma for two samples of tuffaceous sandstone from the Campbell Lake section. These U-Pb ages have greater inherent precision than fission-track ages, but provide less information about zircon populations which may have been derived from sources of diverse ages. A conservative assumption is that the analyzed zircons were detrital, thus providing a maximum age of deposition. However, the presence of altered pumice clasts in thin sections from one of the tuffaceous sandstones argues for synde-positional volcanism at -106 Ma.

We have sampled large volcanic and plutonic clasts for further U-Pb dating of the Pipestone Canyon provenance, and have submitted samples of leaf-fossil-bearing siltstone for palynological analysis.

ABANDONED NOMENCLATURE

Barksdale (197S) assigned arkosic sandstone and shale at the head of Goat Creek to the Goat Creek Formation of probable Aptian age. Changes in facing direction through the section at the head of Goat Creek indicate that it cannot be a continuous stratigraphic section as indicated by Barksdale. We have mapped the strata in the Goat Creek Formation type area as Harts Pass Formation and Winthrop Formation. We consider most other outcrops that have previously been as¬signed to the Goat Creek Formation to be within the Harts Pass Formation. Misch (1966) called volcanic, volcaniclastic, and sedimentary rocks in the North Creek drainage, at the head of the Twisp River, the North Creek Volcanic*. Barksdale later labelled the same rocks 'Newby Group, undifferentiated.' We find that: (1) The percentage of eruptive rocks within the North Creek section has been overemphasized: most of the flow-like rocks appear to be hypabyssal sills. (2) The North Creek section is a northeast-dipping homocline and appears to be entirely upright. (3) Rock low in the section is arkosic sandstone with stringers of chert-pebble conglomerate; the middle of the section contains cross-bedded arkose; and the top of the section are clinopyroxene-phyric breccia, tuff, and volcaniclastic sedimentary rocks similar to those on Midnight and Three AM Mountains. (4) Tuffaceous sandstone low in the section yields a 100 +3/-S Ma U-Pb age. These observa¬tions lead us to abandon the name North Creek Volcanics and identify the constituent parts as Winthrop Formation and Three AM Member of the Winthrop Formation. If probable dextral displacement on the North Creek, Slate Lake, and other faults farther east is considered, the rocks at North Creek are the most southerly part of the Pasayten Group. Presumably contrasts between the North Creek section and Pasayten Group rocks farther east reflect along-strike changes in the mid-Cretaceous basin.

CRYSTALLINE ROCKS TO THE WEST AND EAST

East of the Methow block lie various plutonic rocks that, following Barksdale (1975), we informally call the Okanogan complex. Chief among these is the Remmel batholith with extensive leucotonalite of the Doe Mountain phase. At its southern margin the Remmel batholith appears to intrude older metamorphic rocks, including the Methow Gneiss (Barksdale, 1975), a homogeneous gneissic epidote-biotite tonalite of Early Cretaceous age (R.B. Miller, personal communication, 1994) and the Leecher Metamorphics. Following DiLeonardo (1987), Hopkins (1987), and Bunning (1990), we restrict the Leecher Metamorphics to amphibolite-facies rocks like those seen around the Minnie Mine on Leecher Mountain. This definition excludes greenschist-facies rocks west of the Methow River that we assign to the McClure Mountain unit (cf. Barksdale, 1975).

West of the Methow block, Barksdale (1975) lumped the metamorphic rocks as his Chelan complex, equivalent in part to the Skagit Metamorphic Suite of Misch (1966). Subsequent work allows us to subdivide these rocks into the Oval Peak batholith, a 65-Ma epidote-biotite tonalite with a mas¬sive core and foliated margin (Miller and Bowring, 1990); the Twisp Valley Schist (Adams, 1964; Miller and others, 1994); several gneissic plutons, mostly with latest Cretaceous or early Tertiary intrusive ages; and extensive migmatitic gneisses, mostly derived from tonalite magma intruded at mid-crustal depth, of the Skagit Gneiss Complex (Haugerud and others, 1991). For further details see Tabor and others (1989), Haugerud and others (1991a, b) and Miller and others (1994).

INTERNAL STRUCTURE

We have largely not resolved structure within the Newby Group. Within the mid-Cretaceous foreland-basin fill, structure is more straightforward. We have divided structures in the Robinson Mountain quadrangle portion of the Methow block into several groups which are summarized in Figure 10.

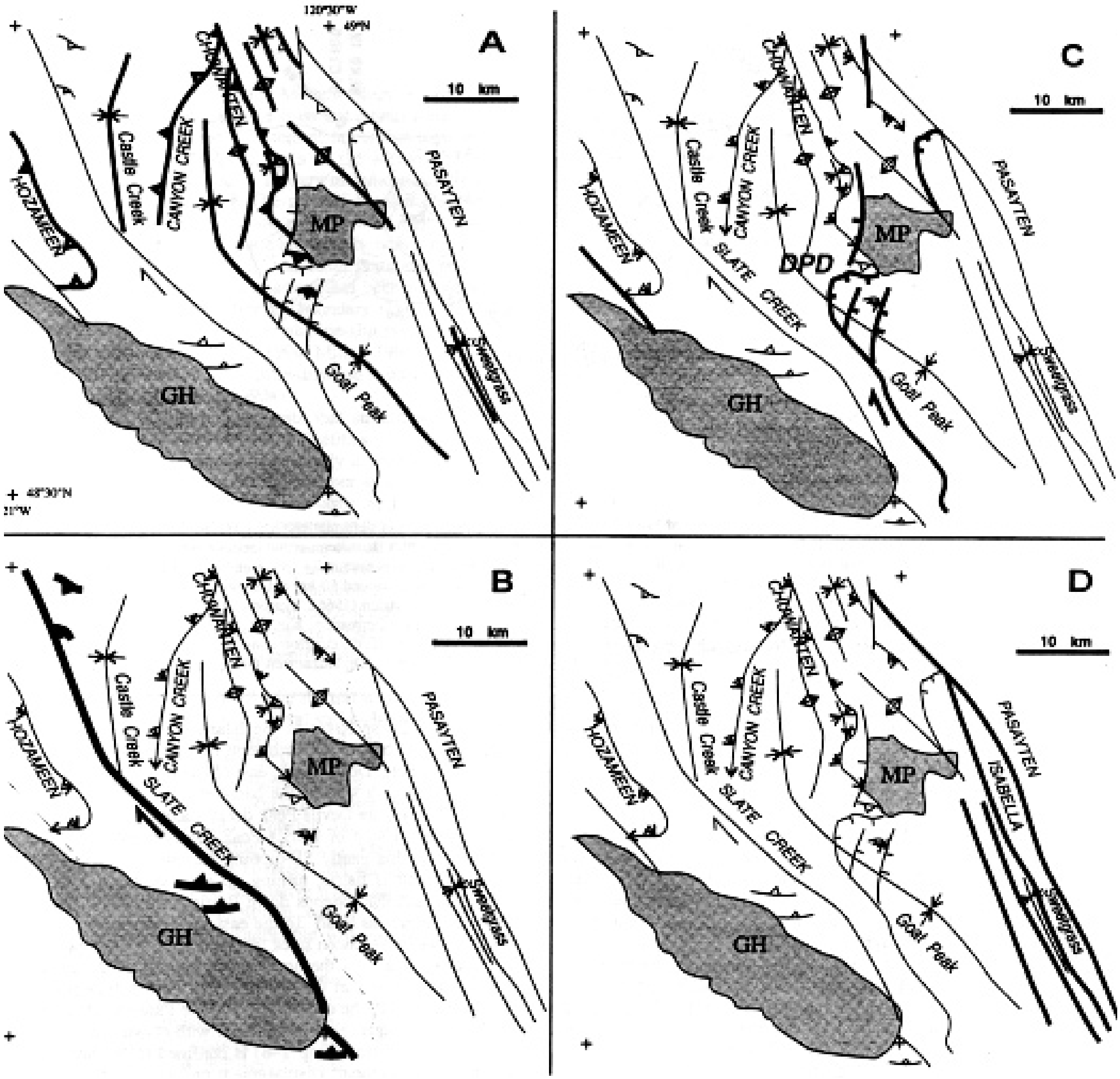


Figure 10. Simplified maps of faults and folds in the Methow block within the Robinson Mountain 30'x60' quadrangle. GH = Golden Horn ba-tholith. MP = Monument Peak stock. A. Mid-Cretaceous Chuwanten fold-and-thrust system. FAULTS in upper case. Fold Names in upper and lower case. B. Late Cretaceousf?) faults of the dextral-transpressive Slate Creek fault system. C. Eocene faults, including the Devils Peak de¬tachment (DPD). E. Faults associated with the Pasayten fault, post-87 Ma in age.

EAST-VERGING MID-CRETACEOUS THRUSTS OF THE CHUWANTEN SYSTEM

The major structures in the Methow block are N- to NNW-trending tight folds and thrust faults (Fig. lOa), the largest of which is the west-dipping Chuwanten thrust. McGroder (1989) recognized that the geometry of the Chuwanten and associated faults is similar to that of classic thrust systems in which transport is approximately normal to strike. The E-verging Chuwanten, Cascade Crest, and Jack Mountain faults are the most obvious elements of a family of structures that constitute a fold-and-thrust belt. We infer that the thrusts, in their early stages, controlled the deposition of mid-Cretaceous strata of the northern Methow subterrane.

Initiation of thrusting corresponds to the infra-Albian initiation of deep-water deposition at the beginning of Harts Pass time. At first the basin was starved on its western margin, as the Hozameen allochthon was not emergent and did not supply abundant sediment. Continued shortening led to emergence of the Hozameen allochthon, development of a western sediment source, and deposition of the Jackita

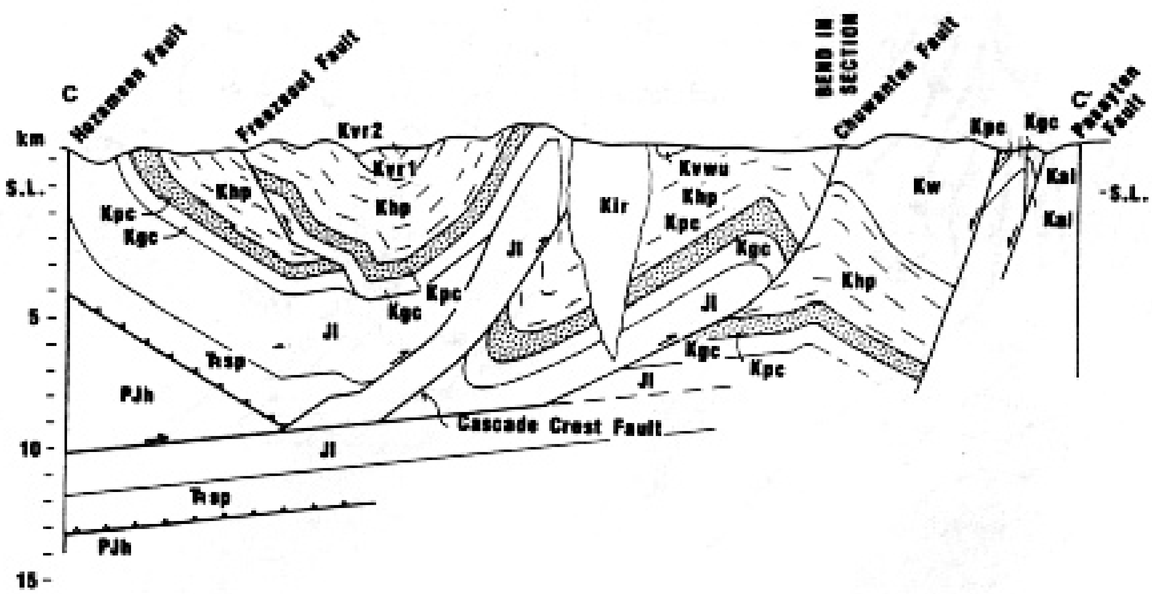


Figure 11. Cross-section through northeastern pan of Methow block, showing inferred style of deformation. After McGroder (1991). The major structures are three east-vergent thrusts. The westernmost of these thrusts forms the base of a Hozameen-cored tectonic wedge and dies upward into the antithetic Freezeout fault, which forms the lid of the tectonic wedge. The wedge sits structurally above and was carried piggyback on the Cascade Crest and Chuwanteen thrusts. Maximum cumulative shortening in the basin exceeded 50 km (McGroder. 1989). The fault at -10 km adjacent to the Hozameen fault is probably equivalent to the Jack Mountain thrust of Misch (1966). Symbols: Jl. Ladner Group; Kai. an-desite of Isabella Ridge; Kgc. Goat Creek Formation of Barksdale (1975): Khp. Harts Pass Formation; Kir. Rock Creek stock: Kpc. Panther Creek Formation of Barksdale (1975); Kvrl. conglomerate-poor Virginian Ridge Formation: Kvr2. conglomerate-rich Virginian Ridge Forma¬tion: Kvwu. Virginian Ridge and Winthrop formations, undivided: Kw, Wimhrop Sandstone: PJh. Hozameen Group: TRsp. Spider Peak For-mation (Ray. 1990). Faults with open barbs are probably pre-mid-Cretaceous in age.

Ridge Formation. The basin filled in, either by sedimentation or tectonism; was locally folded, uplifted, and eroded; and Virgmian Ridge deposition commenced. By this time the basin was largely subaerial. Thrusting continued until, at the eastern edge of the thrusts, the youngest (Midnight Peak) strata in the northern Methow subterrane were involved, suggesting mo-tion until at least 90 Ma. The Rock Creek pluton intrudes the Cascade Crest fault, demonstrating that it, at least, had stopped moving by —90 Ma.

Balanced cross-sections developed by McGroder (e.g. Fig. 11) indicate about 40 km of E-W shortening at 49°N. If we assume this amount of shortening, and that contraction commenced in early or middle Albian time (110-105 Ma) and continued until about 90 Ma, we get a shortening rate of 2-2.5 mm/yr.

LATE CRETACEOUS(?) TRANSPRESSION

The Slate Creek fault system (Fig. lOb) consists of NNW-trending oblique-slip faults and associated minor thrusts that splay out of the oblique-slip zone. Lineations and scaly fault-fabrics within the fault zone at several locales indicate dextral oblique (W side up) displacement. The Slate Creek fault itself cuts the Castle Creek syncline, part of the Chuwanten fold-and-thrust belt. Separation of the syncline axis is hard to estimate because of the acute intersection of two structures, but it is on order of a few km. The intersection also demon¬strates that the Slate Creek system is younger than at least part of the Chu-wanten system. Minor thrusts associated with the Slate Creek system, particular in upper Freezeout Creek, verge to NE on the east side of fault; folds associated with thrusts at the head of Wolf Creek are on the SW side of the fault system and verge south.

The Slate Creek system is thus transpressive and younger than the Chuwanten system. Slate Creek-like faults are intruded by the Golden Horn batholith, establishing that the system is older than 49 Ma. For the sake of discussion we suggest a Late Cretaceous age to this deformation.

Cascading W-verging folds on Thompson Ridge may be coeval with the Slate Creek. The Boesel fault (Stop 2-1) is small-displacement structure in the hinge of one of these folds.

At the southern edge of the Robinson Mountain quad¬rangle, Gardner Mountain lies in the core of a spectacular W-verging refold of the E-verging Gardner nappe. The refold is an anti-formal syncline, with younger beds in the center and a hinge in the sky, and has a half-wavelength of several km. This structure is younger than the Chuwanten system and older than Eocene transtension, and we assign it to the transpres-sive episode.

EOCENE(?) TRANSTENSION

A set of right-stepping, NW-trending strike-slip faults, linked by extensional stepovers, traverses the Methow block, trans-ferring displacement NE from the Foggy Dew fault, south of the Twisp River to the Island Mountain area and then probably north to the Princeton half-graben in southern Brit-ish Columbia. Devils Peak, east of Slate Peak (Stop 2-7) lies in the hanging wall of the best-developed of the exten-sional stepovers, the Devils Peak detachment. Midnight Peak strata on the N side of Devils Peak dip NW into, and are truncated by, this gently SE-dipping structure. To the west the detachment is listric, turning up and becoming a steep strike-slip fault that extends down Rattlesnake Creek, parallel to the Harts Pass Road. To the east the detachment can be traced across the Pasayten stock, and produces minor, oposed, across-strike offsets of the northeastern contact of the stock, thus demonstrating that the slip direction on the detachment was SE, parallel to the overall trend of the Pasayten stock. A family of high-angle, N-striking faults with consistent down-to-the-E displacement (Stop 2-8) is confined to the hanging wall of the detachment. Displacement on the fault is on the order of 5 km, estimated from inferred separation of cutoffs of a tongue of Winthrop Formation arkose that occurs in both hanging wall and foot wall,

East of the Pasayten stock the Devils Peak detachment is intruded by the Monument Peak stock, which appears to hgave come in along the fault, as the roof of the pluton is in the plane of the detachment.

Another stepover lies across the Newby Creek-Buttermilk Creek divide, south of the Twisp River, which is the site of a modest extensional fan. Deformation seems to sole into a) arkose low in the Winthrop Formation and b) the Patterson Lake unit, reactivating the northern-southern Methow subterrane contact. The duplex transfers displacement west towards the Foggy Dew fault; details of the last west step have yet to be worked out amongst the sub-timberline exposures of Mission Peak.

BOUNDING FAULTS

ROSS LAKE FAULT ZONE

The western edge of the Methow block is largely coincident with strands of the the Ross Lake fault zone of Misch, (1966), a >170 km-long system of faults that separate little-metamorphosed Mesozoic strata of the Methow block from Late Cretaceous and early Tertiary metamorphic rocks of the Chelan block (Fig. 12). The zone is braided on a scale of many km; some strands are entirely within little-metamorphosed Methow strata, some are entirely within metamorphic rocks of the Chelan block, and some juxtapose units of the two domains. The Ross Lake zone has been interpreted as a pre-90 Ma strike-slip terrane boundary (Davis and others, 1978), a major post-orogenic oblique-slip system (Haugerud, 1985; Miller and Bowring, 1990; Miller, 1994), and a collection of tectonized but little-displaced intrusive contacts (Kriens and Wemicke, 1990a). Available evidence suggests that structures in the Ross Lake zone have had at least six identities:

1) An original boundary—probably a depositional contact, but it could also be a fault, either accretionary or trans¬form—between terrigenous clastic strata of the Methow basin and oceanic rocks beneath or to the southwest.

2) A mid-Cretaceous, NE-verging thrust that separated the Pasavten Group foreland from the Hozameen allochthon.

3) A SW-side down, post-90 Ma dip-slip structure that accommodated deep burial of rocks of the Chelan block.

4) A latest Cretaceous and (or) early Tertiary dip-slip structure along which deeply-buried rocks of the Chelan block were unroofed.

5) A middle Eocene and older dextral strike-slip fault.

6) A belt of post-45 Ma dextral strike-slip that may be confined to the northern part of the Ross Lake zone.

Identity 2 corresponds to the mid-Cretaceous Chuwanten thrust system. The depositional contact of the South Creek Member of the Virginian Ridge on Twisp Valley Schist dates from this period, and probably records out-of-sequence thrusting, where a hanging-wall block was transferred to the footwall, depressed and covered with sediment, and overriden. Identity 3 may be correlative with Late Cretaceous tran-spressive structures identified within the Methow block. Identities 4 and 5 are compatible with Eocene transtension within the Methow.

The Ross Lake zone has also been the locus of extensive plutonism, which has obliterated much of the evidence for identities 1 through 5. Where the traces of identities 1 through 5 mostly coincide (west and north of Ross Lake, southeast of the Twisp River) the Ross Lake zone is relatively simple. Elsewhere it is not.

PASAYTEN FAULT

If we define the Pasavten fault as the western limit of plutonic rocks of the Okanogan complex, it is probably composite. We can identify 4 segments extending south from 49°N, each with different characteristics.

The northernmost segment, extending from the 49th parallel to east of Pearrygin Lake, is a brittle fault that, for the most part, separates volcanic rocks of the Midnight Peak Formation, the latest Jurassic Button Creek stock, and older volcanic rocks from gneissic to massive Early Cretaceous plutonic rocks of the Remmel batholith and the Eightmile to-nalite. The plutonic rocks locally carry a weakly to strongly-developed mylonitic foliation; associated streaking lineations and S-C fabrics indicate oblique, sinistral displacement, down to the SE. Lawrence (1978) and Hurlow (1993) identifled this ductile fabric with the Pasavten fault and concluded that the most significant displacement on the fault was sinistral and of modest amount. This conclusion ignores three points: 1) The fault itself is brittle and must have moved after 87 Ma, the age of the rocks it bounds on the west, 2) The ductile fabrics must have developed between -110 Ma, when the plutonic rocks crystallized, and -100 Ma, when they cooled below about 300°C, the closure temperature for Ar diffusion and biotite and a plausible lower temperature limit for mylonitic deformation of such quartzose rocks. 3) The ductile fabrics lie in a zone that trends more westerly than the fault itself, and is truncated by the fault. We conclude that these fabrics are irrelevant to the Late Cretaceous history of the Pasavten fault.

The Isabella fault locally contains penetratively-deformed rock with moderately-plunging lineations. hi its southern extant several faults link it to the Pasavten, and it seems likely that collectively these faults constitute a braided fault system (Fig. lOd). When mapping the northern limit of the Eocene volcanics of Island Mountain, which Staatz and others (1971) and White (1986) had inferred to overlap the Pasavten fault, we found that the northeastern contact of the volcanics with rocks of the Remmel batholith is everywhere faulted. We suspect that this faulting is part of the Eocene transtensive event described above, and on a grander scale cross-cuts the Pasavten fault, but we cannot rule out the possibility of extensive Eocene displacement on much of this segment of the Pasavten.

The second segment of the Pasavten fault extends from near Pearrygin Lake south to Beaver Creek. Here we find that if the Pasavten fault is the western limit of plutonic rocks of the Okanogan complex, it has previously been mislocated. The Campbell Lake section of the Pipestone Canyon Formation sits on Redshirt gabbro, gneissic tonalite, and banded gneiss that appear identical to Okanogan rocks farther east. The western limit of these rocks is the NNW-trending Fuzzy Canyon fault of Kriens and others (1995), which at its north-em end is truncated by a N-trending fault which traverses the west face of Bowen Mountain. The age of most recent motion on this segment of the Pasavten fault clearly depends on the age of the Pipestone Canyon Formation, which we do not know. If the Bonner Lake and Campbell Lake sections of the Pipestone Canyon Formation are closely correlative, the contrasting metamorphic facies of rocks beneath the Pipestone Canyon (amphibolite facies Okanogan complex on the east, low greenschist and zeolite facies Newby Group on the west) demands significant pre-Pipestone Canyon displacement The third segment of the Pasayten fault extends NE-SW beneath the southeastern edge of the Beaver Creek fan towards Carleton. This segment was called the Methow River fault by Frey and Anderson (1987), who inferred it to dip to the SE. Outcrop in this area is mostly absent, and we hesitate to draw any conclusions about the geometry of this structure. Extensive mylonite, brecciated mylonite, breccia, and altered pseudotachyiitef?), all apparently developed from the McClure Mountain unit, crop out a few km north of Carleton on the west wall of the Methow River valley. Trends in these mangled rocks are mostly ME, suggesting that they are in some way related to the Methow River fault.

The fourth segment of the Pasayten fault extends down the Methow River Valley from near Carleton to the Cooper Mountain batholith. This is the Vinegar fault of Hopkins (1987), and is a steep, brittle, poorly-exposed structure that predates the 48-Ma Cooper Mountain batholith.

In summary, the western edge of the Okanogan complex is not a single structure. Displacement on this boundary need not be limited to the several 10s of km of late Early Creta¬ceous sinistral slip, as previously postulated. The present ge¬ometry is not conducive to interpretations of 1700 km of Late Cretaceous and earliest Tertiary dextral strike slip, but the present geometry could reflect later modification of straighter boundary—we cannot adequately restore evidently complex structure in the vicinity of Twisp.

As is the case with most other brittle faults, meaningful discussion of the displacement history of the Pasayten fault must begin and end with stratigraphic arguments. These arguments either depend on data we do not have (e.g. the age of the Pipestone Canyon Formation) or are regional and beyond the scope of this guide.

EVOLUTION OF THE LANDSCAPE

Most of us study geology because, in part, we appreciate scenery. But widespread absence in the northeastern Cascades of deposits older than the last glaciation and younger than early Late Cretaceous leaves us with little evidence for the evolution of the present landscape. The only place left to look is at the erosional landscape itself. Here we are treading on thin ice: the lack of deposits means nothing we can readily examine to examine to test our hypotheses. A colleague tells us that 'all the geomorphologists I know are frustrated novelists.'

But how was the scenery made? Making the rocks that underlie it is only part of the story. We draw inspiration from Bailey Willis, who almost a century ago began by riding a horse around the ridges that separate the Methow from the Chelan drainage and finished with an estimate for the depth to decollement for the late Cenozoic deformation that built these mountains (Willis, 1903). His methods are now questionable, victims of changing fashions in peneplains and oro-genic structure. But his questions are very current, and no one has done better since.

We have no coherent story to tell, only fragments.
The oldest landform we see is probably the high plateau that surmounts much of the eastern Pasayten Wilderness at elevations of -7,000' (2.2 km). This surface extends north into British Columbia where, a few km across the border, it is capped by middle Eocene volcanic rocks. A small cap—the map pattern suggests a fragment of an old valley-filling flow—of undated volcanic rock sits high on the west shoulder of North Twentymile Peak, north of Winthrop, and may also be middle Eocene. By analogy with the Columbia Plateau, we might suppose that preservation of this surface was aided by the tendency of the capping volcanics to be highly fractured, draining by sub-surface flow and inhibiting the development of streams that might effectively erode the area.

Somewhat younger is the Entiat surface of Willis (1903; see also Waters, 1939 and Waitt in Tabor and others, 1987). This surface is cut across the middle Eocene Cooper Mountain batholith, so must be younger than the eastern Pasayten surface. From many places in the Methow block one can look west or south to see accordant ridges rising gently up towards the Sawtooth Range divide. These appear to be remnants of the Entiat surface. Oval Peak and other high summits of the Sawtooth Range appear to be remnants of monadnocks that protruded from the Entiat surface. At and south of the summit of Cooper Mountain, the ridge-enveloping surface merges with extensive moderate-elevation ridge-top flats which slope gently to the SE until they pass over (Willis, 1903), pass beneath (Waters, 1939; Gresens, 1981) or merge with (Waitt, in Tabor and others, 1987) the middle Miocene flood basalts of the northwestern comer of the Columbia Plateau.

The Pasayten Wilderness extends east-west along a re¬gional divide that separates the south-flowing Methow from the Pasayten and Ashnola Rivers, which drain north into the Similkameen. Jon Reidel (National Park Service) and Haugerud have speculated that the east-west divide, at least in this region, reflects drainage off of volcanoes erupted above the Monument Peak stock. Perhaps the divide between the SE-flowing Chelan and Methow drainages and NW-flowing streams now tributary to the Skagit reflects the past presence of volcanoes above the Golden Horn batholith.

The east-west divide was modified, in places severely, by the Cordilleran ice sheet (Reidel and Haugerud, 1994). South-advancing Cordilleran ice dammed streams flowing north. The ponded meltwater overflowed to the south at low points on the divide (Holman Pass, Hidden Lakes, Eightmile Pass, Ashnola Pass, etc.), cutting the divides down moving them northwards. Subsequent erosion by the overriding ice, by sub-glacial meltwater, and by pro-glacial meltwater ponded during ice retreat furthered the process. Most places the effects were noteworthy: at Ashnola Pass, Andrews Pass, and Remmel Lake the valleys which descend south into the Chewuch are dried-up rocky riverbeds where pack-animals scrabble for footing on rough trails that wend there way over the water-worn bedrock and between large rounded boulders. The north-descending valleys, tributary to the Ashnola, are beset with mudholes developed in the sediments deposited in proglucial lakes.

At other places the effects were more spectacular. The Lost River Gorge is the biggest (though negative) topographic feature in the Robinson Mountain 30- by 60-minute quad¬rangle. It was appar-

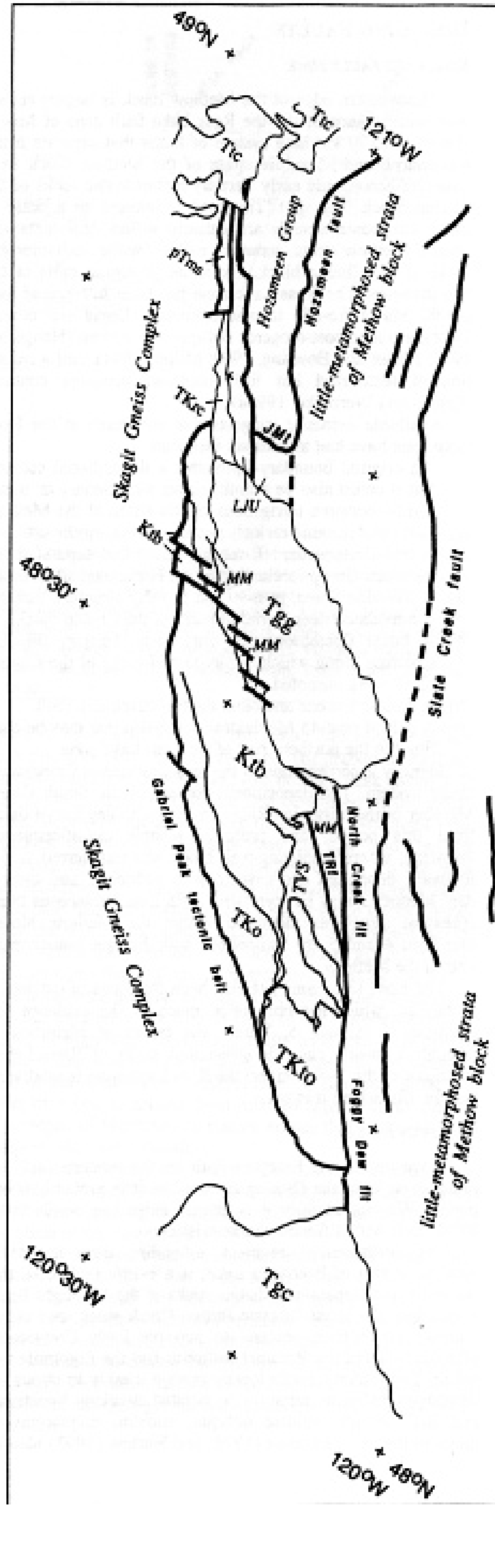


Figure 12. Map of the Ross Lake fault system south of 49°N. Lifted from Haugerud and others (1994). Plutonic rocks include: Ttc. 25 Ma Chilliwack lonalite: pTms. pre-Tertiary Skymo mafic complex: TKrc. 48 Ma and older Ruby Creek Heterogeneous Plutonic Belt of Misch (1966); Tgg. 49 Ma Golden Horn granite; Ktb, 90 Ma Black Peak to-nalite; TKo, orthogneisses of Gabriel Peak tectonic belt of Miller and Bowring (1990; cf. Kriens and Chappelear, 1993). including 65 Ma Benzarino pluton: TKto. 65 Ma Oval Peak tonalite; Tgc. 48 Ma Coo¬per Mountain granite. Supracrustal rock units include LJU. Little Jack unit; TVS. Twisp Valley Schist: MM. metamorphosed strata of Methow domain (mostly Pasayten Group). Faults include JUt. Jack Mountain thrust: Tftf. Twisp River fault. Note that we no longer be¬lieve the Twisp River fault exists.

ently carved by glacial meltwater breaching the former drainage divide and cutting back to the current divide, several miles north at Hidden Lakes. The present-day Skagit River appears to have had a similar origin. Prior to the Pleistocene, the Cascade crest appears to have been somewhere between Newhalem and Diablo. With the aid of ice-diverted drainage from much of southwestern British Columbia, the lower Skagit cut through the divide, carved the Skagit Gorge, and captured a large part of the north-draining upper Skagit.

Other than erosion in meltwater channels, a thin veneer of glacial drift, and extensive outwash deposits in the Methow valley and other low areas, Cordilleran ice had sur¬prisingly little effect on the landscape. As noted by Waitt (1972), valleys in the Methow region are commonly U-shaped in their upper reaches, as a result of local (alpine) glaciation, and V-shaped in their lower reaches, despite the fact that it was Cordilleran ice that last covered the entire drainage. The northeast-trending drainages that head in the high peaks of the Sawtooth Range are a particularly good place to see relicts of alpine glaciation, with extensive moraines in Buttermilk Creek and Libby Creek. Morphology and position of the moraines suggest they formed during at least two episodes of alpine glaciation. Farther north, alpine-glacial moraines are rare, but rounded relicts are preserved in a few drainages surrounded by divides at or above the upper limit of the Cordilleran ice. In these drainages there was little Cordilleran ice flow, and consequently little erosion.

ROAD LOG

From Seattle, reach Pateros via US 2 over Stevens Pass— or 1-90 over Snoqualmie Pass to Cle Elum and then US 97 north over neo-Blewett (nte Sauk) Pass to the Big Y and then east on US 2—to Wenatchee, then north on US 97. Allow at least 3’/j hours for the drive.
Distances in the log are given in miles.

A note on lodging: There are numerous hotels, motels, and rental cabins available in Winthrop, as well as a couple of fee campgrounds, including Pearrygm Lake State Park. Lodging in the Winthrop area can be difficult to obtain during the summer and early fall. Make reservations early! The nearest free camping is many miles out of town—try U.S. Forest Service campgrounds on Eightmile Creek, the upper Chewuch River, the upper Twisp River, and at Early Winters, or the Washington DNR campground on Beaver Creek, northeast of Twisp.

Figure 13, a road map showing the location of most of the stops, is at the end of the guide.

DAY 1. PATEROS TO WINTHROP. OKANOGAN PLUTONIC ROCKS, JURASSIC VOLCANIC-ARC ROCKS OF THE NEWBY GROUP, AND LOWER CRETACEOUS SEDIMENTS OFTHE PATTERSON LAKE UNIT

0.0 Turn right from US 97 onto State Route (SR) 153, towards Twisp, Winthrop, and the North Cascades Highway.

0.5 Stop 1-1. Overview of Methow block. Turn right into public river access area, across road from fruit stand.

This part of north-central Washington runs on orcharding, tourism, electric power generation, ranching, and—less importantly of late—logging. Mining, or rather the hope of mining, drove much early white settlement, but is not important at present.
We are in the slack water behind Wells Dam on the Columbia River. The nice houses across the water were built by the Public Utility Districts (PUDs) that operate Wells Dam when the dam flooded old Pa¬teros. The parking lot, boat ramp, and vault toilet here were also funded by the PUDs.

Look upvalley along the highway to Alta Moun¬tain. Flat-topped hills in the foreground are dissected glacial-outwash terraces. High peaks at 1:00 are in crystalline rocks of the Sawtooth Range, southwest of the Foggy Dew fault. Low flat skyline at 5:00 is underlain by Miocene Columbia River Basalt.
Walk back along road to look at large cuts in the Alta Lake migmatite of Raviola (1988). Raviola reported a 10415 Ma hornblende K-Ar age from an amphiholite in this unit. This is significantly older than hornblende ages of the Chelan Complex (maximum 84 Ma; Tabor and others, 1987) and suggests affinity with gneissic rocks of the Okanogan Ranges to the east.

1.8 Left turn to Alta Lake State Park, 2 miles. 6.6 Black Canyon Creek.

10.9 Unincorporated town of Methow. Historical marker states that in 1888 the Robinson brothers, early trappers, planted the first orchard in the Methow across the river- from here; after the Squaw Creek mining boom collapsed in 1899, W.A. Boliger moved his store to this site.

11.8 Bridge over Methow River.

12.3 Outcrop on comer is of the Noname stock (Bunning, 1990), also known as the Methow stock (Barksdale, 1975), a granodiorite of Eocene age.

14.0 Bridge over Methow River, followed by parking lot and river access point on left. A good place to stop and look at the Methow Gneiss, either in boulders in parking lot or in outcrops across river to south.

16.8 Turn left on Gold Creek Road.

17.7 Turn left on USFS 1084.

18.7 Junction with South Fork Gold Creek Road on left
Proceed straight ahead.

20.1 **Stop 1-2**. McClure Mountain unit Park on left shoulder at beginning of 0.3-mile roadcut.
Rocks here are mostly metamorphosed andesitic to rhyolitic breccias with layers (dikes or sills?) of dark-green metamorphosed mafic rock. Foliation is steep and stretching lineations plunge gently to the north. The outcrop is dominated by chloritic schists with a distinct phyllitic sheen; competent andesite and rhy-olite form elongate boudms Mylomtic fabrics are locally evident. Our mapping demonstrates that the McClure Mountain unit has a gradational contact with the Newby Group, and represents metamorphosed volcanic and volcaniclastic strata.

Following Barksdale’s (1975) example, DiLeonardo (1987) and Hopkins (1987) referred to this exposure as the “Gold Creek Shear Zone” and interpreted it to be part of a discrete shear zone. We find that this zone is indistinguishable from widely distributed schistose rocks of the McClure Mountain unit, and do not choose to map it as a discrete shear zone. Deformation within the McClure Mountain unit is strongly lithologically controlled, with volcaniclastic sediments and tuffs forming well-developed schists, and more competent volcanic flows and breccias acting as structural buttresses and deforming brittlely. The gentle plunge of stretching lineations and steep foliation planes at this locale suggest deformation occurred in a transpressional setting (DiLeonardo, 1987).

Turn around and retrace route to beginning of Gold Creek road. 22.5 Stop sign at Gold Creek loop road (mile 17.7, above).

Turn left.

24.1 Stop sign at junction with Highway 153. Turn left. 25.0 View at 12:00 of grassy hillside on west side of Methow River that is underlain by large landslide. Libby Creek.

Begin outcrop of altered Methow Gneiss. Enter Carlton. Benson Creek Road on right.

Rocks on the right are metamorphic and plutonic rocks of the Okanogan region: Methow Gneiss, Leecher Metamorphics, and various plutons that intrude the Leecher. On left, across the river, are little-metamorphosed rocks of the Newby Group and the low-grade McClure Mountain unit, derived from the Newby.

McClure Mountain itself is at 9:00—the steep east face is mostly massive dacite or rhyolite with plagioclase and rare quartz phenocrysts, probably a dome or hypabyssal intrusion. The yellow stain on the left side of the east face is altered felsic breccia and tuff. These lithologies are erratically foliated, as is appropriate for Newby rocks on the boundary of the McClure Mountain unit domain.

33.5 Historical marker which states that development of the Methow began when the Chief Moses reservation was opened to white settlement in 1886; the town of Silver was founded near here in 1887, washed away in the great flood of 1894, and was then relocated on higher ground; the nearby Redshirt mine closed in 1900; and Silver was abandoned in 1904.

35.8 Junction with SR 20. Continue straight on SR 20 to Twisp and Winthrop.

37.2 Enter Twisp. View of Midnight Mountain at 12:30.

37.7 Turn right on road to Davis Lake, just before SR 20 bridge over Methow River.

37.8 Cliffs ahead, and roadcuts for next mile, are Bear Creek unit of Newby Group: andesitic breccia, lapilli tuff, and volcanic sandstone with conspicuous laumontitic alteration, locally interbedded with thin-bed¬ded shale, siltstone, and sandstone.

38.7 Cliffs ahead are Bonner Lake section of the Pipestone Canyon Formation.

40.0 Balky Hill Road on right.

42.8 Inter-City Airport Road on left.

43.2 Wilson Road on left. Go down it, some other time, about l/i mile to good outcrops of Bear Creek unit.

43.4 Bluffs ahead are Bear Creek unit. This locale was identified by Barksdale (1975) as a place where his Buck Mountain Formation unconformably overlies the Twisp Formation. The laumontitic Bear Creek rocks are separated from the sedimentary strata on Buck Mountain by a major fault, hence we exclude them from the Buck Mountain unit. The contact here between the breccias and the underlying (and intercalated) Twisp Formation argillite appears conformable.

44.7 Bear Creek Road on right.

45.9 **Stop 1-3**. Twisp Formation. Park on left shoulder. We interpret the Twisp Formation to underlie the main portion of the Newby Group. The lower portion of the Twisp Formation consists of thin to medium-bedded lithic sandstone, sandy limestone, siltstone, and shale. Primary volcanic material is absent. Sedimentary structures include graded bedding, scour features, convolute laminae, and partial Bouma sequences. Fossils are rare in the Twisp Formation, although ammonite fragments are locally evident.

The age of the formation is therefore poorly constrained. Previous workers have correlated the Twisp Formation with the Lower to Middle Jurassic Boston Bar Formation of the Ladner Group (Barksdale, 1975; O'Brien, 1986; Mahoney, 1993), but the existence of Late Jurassic zircons in the upper portion of the formation make that correlation questionable.

Typical exposures of the Twisp Formation may be seen in the sagebrush covered hills to the west. Exposures along SR 20 suggest the unit is at least in part strongly deformed. Cleavage at this outcrop is at a high angle to bedding, frustrating the ongoing search for fossils.

46.1 Enter Winthrop.

46.3 Turn left at bottom of dip.

46.4 Turn right.

46.7 Stop sign and junction with SR 20 Turn left and cross Methow River.

46.8 Turn right on Twin Lakes Road.

47.2 Winthrop National Fish Hatchery on right.

47.6 Begin readout in Twisp Formation.

48.1 Wolf Creek Road on right.
Big Twin Lake on left. Twin Lakes are kettles, ensconced in a mass of stratified and unstratified drift deposited during a late Eraser deglaciation still-stand. Turn right on Patterson Lake Road. Stop 1-4. Twisp Formation, radiometric age locale. Park on left shoulder and carefully exit cars and cross road to outcrop.

Note the altered, friable nature of the fine-grained rocks of the Newby Group, which contrasts with the well-indurated argillite and sandstone from the previous stop. Poor exposure and structural complexity make accurate stratigrapmc analysis of the Twisp Formation difficult. However, isolated outcrops of the Twisp Formation indicate that it is characterized by a gradual increase in volcanic detritus, including tuffaceous zones and volcanic lithic sandstone, adjacent to the volcanogenic upper Newby Group. Near the base of the volcanic unit, lapilli tuff, tuff breccia, and breccia are interbedded with volcanogenic sandstone, siltstone and shale. This outcrop consists of yellow-brown tuff intercalated with dark brown to dark gray argillite and siltstone. U-Pb dating of zircons derived from the tuff yields an age of 151.0 +8.7/-0.3 Ma (R. Friedman, personal communication, 1995). This age, coupled with the gradational contact between the Twisp Formation and overlying volcanic units, allows us to suggest a Kimmeridgian to Tithonian age for the initiation of volcanism in the Newby Group. Turn left onto unpaved Elbow Coulee Road. Newby Group lapilli tuff on left. Twisp Formation on left. Entrance to Pine Forest development on right. Steep slopes of colluvium here are worked for road metal. Bedrock is Bear Creek unit of the Newby Group. Cattleguard; road rums to left.

We are crossing the basal unconformity of the Patterson Lake unit, well-exposed on the hillside north of here. The Patterson Lake unit dips west. Virginian Ridge Formation underlies the upper west wall of Elbow Coulee (on right, after turning). Farther west the Virginian Ridge also dips west, but near this contact it is folded into a near-isoclinal anticline. Chert-pebble conglomerate of the Virginian Ridge Formation and argillite cum volcanic pebble conglomerate of the Patterson Lake unit are intermixed in a zone about 100 meters wide along this contact; the mixing is probably tectonic. Road crosses bottom of small gully. Patterson Lake conglomerate in roadcut on right. Out¬crops across valley on left are Virginian Ridge chert-pebble conglomerate in tectonically-mixed zone. Stop sign. Turn left on Twisp River Road. Begin roadcuts, on left, of Virginian Ridge Formation. See Stop 3-3.

Begin outcrops of Patterson Lake unit. Road crosses irrigation ditch. Turn right on Poorman Creek Cutoff Road. Cross bridge over Twisp River and go left at fork. Cross Poorman Creek. Junction with Poorman Creek Road.
Turn right.

Stop 1-5. Sedimentary strata of Newby Group; Patterson Lake unit conglomerate. Park on right.

Volcaniclastic sedimentary rock comprises the majority of the Newby Group; this exposure is typical. Outcrops are restricted to coarse sandstone and conglomerate. Fine-grained interbeds are commonly recessive. The outcrop here consists of thin- to medium-bedded fine- to medium-grained volcanic lithic sandstone, siltstone, and shale interbedded with medium- to thick-bedded volcanic lithic feldspathic sandstone. Sedimentary structures include graded bedding, poorly developed cross-beds, sharp basal contacts, rip-up clasts, parallel laminae, and partial Bourna sequences. Fining and thinning upward sequences (1-3 m) are evident. Note that the section is right side up.

Laterally continuous bedding, cyclic depositional sequences, and both complete and partial Bouma se¬quences within sedimentary rocks of the Newby Group suggests submarine deposition by turbidity currents. Pillow features and hyaloclastites are locally, albeit rarely, recognizable, and it is possible that at least a portion of the proximal volcanism was subaerial. Note the several small faults, at both high and low angles to bedding, visible at the south end of the outcrop. Poor exposure and lack of distinct marker beds make it hard to discern structure in the majority of the unit. What little we can see leads us to infer that the structure of the Newby Group is considerably more complex than can be documented.

Brownish-weathering volcanic cobble conglomerate crops out in the low exposure at the north end of this roadcut. This is a typical outcrop of the Patterson Lake unit, which unconformably overlies the Newby Group, hi this locale, however, the units are separated by a north-dipping normal fault. Bedding in the Patterson Lake unit on the ridge to the west dips 30° south, into the contact. We infer the Patterson Lake strata to have been rotated by slip on a northeast-trending normal fault.

Turn around and proceed to intersection of Poor-man Creek Road and Twisp River Road. 60.0 Junction with Poorman Creek Cutoff Road. Go straight and begin paved road.

60.3 Outcrops of rhyolite on right.

60.8 Outcrops of Newby Group rocks and younger(?) rhyolite dikes. Glacial drift at top of roadcut.

62.3 Begin large borrow pit on right.

62.4 **Stop 1-6**. Volcanic rocks in upper Newby Group. Park on right at east end of borrow pit.

Altered andesite, andesitic breccia and tuff breccia typical of the upper Newby Group may be examined in outcrop to the west, or 'fresh' rocks may be found among the large boulders scattered throughout the borrow pit. Volcanic flows and breccias constitute about 20-25% of the entire Newby Group. Volcanic flows, breccias, other proximal deposits, and inferred subvolcanic intrusions are concentrated south of the Twisp River and west of the Methow River, suggesting this area contains former vents for Newby volcanism.

We are approximately 1 km west of the Alder Creek stock. Greenschist-facies metamorphism like that here is characteristic of the Lookout Mountain unit of the upper Newby Group.

62.4 Stop sign at junction with Twisp River Road. Turn right.

63.7 Stop sign at SR 20 in Twisp. Turn right.

64.0 Twisp Ranger Station, U.S. Forest Service, on left.

64.3 Bridge

66.3 Junction SR 20 and SR 153. Turn left, following SR 20 towards Omak and Okanogan.

66.6 Stop 1-7. Rhyolite and felsic volcaniclastic rock of Newby Group. Rock here is feldspar and quartz-phyric rhvolitic breccia and tuff, locally with rather large fiamme. This rhyolite is similar in its crystal-rich character to the rhyolite that supports the east face of McClure Mountain, visible to the southwest across the Methow valley. Sulfide mineralization extends north from here along a minor fault ornamented with several prospect pits. Walk back down SR 20 a few hundred feet to look at more typical volcanic breccias of the Newby. If you are lucky you may find an nicely preserved belemnite end-section on one outcrop face. Please don't bang on it. Retrace route back to SR 20

66.9 Stop sign at junction SR 20 and SR 153. Turn right towards Twisp and Winthrop.

68.3 Enter Twisp.

68.8 Bridge over Methow River.

69.4 Twisp River Road on left.

69.5 Twisp River.

71.4 Begin outcrops of shattered Bear Creek unit.

72.1 South-facing slope at 3:00, across river, is exhumed fault at north end of western Pipestone Canyon Formation outcrop.

72.8 Outcrops of black argillite and pink rhvolitic sandstone that probably belong to the Patterson Lake unit.

75.0 Twin Lakes Road on left.

75.5 Begin outcrops of battered Twisp Formation.

76.8 Winthrop Post Office on right.

77.5 Bridge over Methow River.

78.1 Four-way stop in downtown Winthrop.

78.2 Winthrop Brew Pub on left. Finest beer in town

DAY 2. WINTHROP TO WINTHROP VIA HARTS PASS. MID-CRETACEOUS FORELAND-BASIN STRATA OF THE HARTS PASS FM AND PASAYTEN GROUP; EAST-VERGING MID-CRETACEOUS THRUSTS; EOCENE DETACHMENT FAULT

0.0 Four-way stop in downtown Winthrop. Follow SR 20 west across Chewuch River.

0.2 North Cascades Scenic Highway Visitor Center on left.

2.5 Begin long road cut in glacial outwash gravel.

4.1 Bluffs on right are diabasic intrusions into Twisp Formation.

4.7 Milepost 188.

5.5 Turn right and drive to remnants of old dam on left side of road.

5.7 Stop 2-1. Overview of mid-Cretaceous stratigraphy, Boesel fault, and introduction to Goat Peak syncline Outcrop on northeast side of road is fluvial sandstone, siltstone, and shale of the Winthrop Formation, on the NE limb of the Goat Peak syncline. We are not far from Barksdale's (1975) type section, located less than a kilometer to the northeast. Up-valley are the big flatirons of Lucky Jim Bluff, type section of the Ventura Member of the Midnight Peak Formation.

Across the valley on the left are NW-dipping beds of Virginian Ridge Formation (dark-weathering -sills with minor resistant layers) overlain by light-weathering arkose of the Winthrop. On the right are beds that strike parallel to the valley and dip towards us. The discordance between these attitudes is primary evidence for the Boesel fault. Minor stratigraphic mismatch across the discordance rules out the possibility that this is a fold with an exceedingly angular hinge.

Barksdale (1975) projected the Boesel fault ME to the Pasayten fault. McGroder (1989) suggested the Boesel fault separated a northern Methow subterrane that contains thick Albian turbidites of the Harts Pass Formation and a southern subterrane that lacks these strata. New mapping by Haugerud and Tabor shows that the Harts Pass Formation thins to the south beneath a sub-Pasayten Group unconformity to the north of the Boesel fault, is still present south of Barks-dale's projected Boesel fault, and where missing is absent because of complete erosion beneath the sub-Pasayten unconformity. Measuring from the base of the Winthrop Formation in the west limb to the base of the Winthrop in the NE limb, the Goat Peak syncline is about 10 km across, and at an elevation of 6500' is sub-isoclinal: strata on the SW limb dip about 50° to the ME and, above an elevation of about 6,000', strata in the NE limb are overturned and dip 65-80° to the NE. At lower elevations and farther NW the NE limb is upright. The tightness and complex fold profile suggest the Goat Peak syncline is polygenetic, a suggestion corroborated by Riedell (1979), who noted that the Fawn Peak stock probably was intruded after folding, and that it was subsequently tilted 45° down to the WSW.

6.1 Winthrop Formation in type section visible on right.

6.7 Milepost l86.

7.1 Cross Boesel fault.

7.6 Winthrop Formation, cooked by the Fawn Peak stock, followed by roadcuts in glacial outwash gravel.

8.0 Goat Creek road on right, followed by Weeman Bridge over Methow River.

8.3 View at 12:00 of type section of Ventura Member of the Midnight Peak Formation, along Lucky Jim Bluffs.

8.5 Wolf Creek Road on left.

8.6 View at 10:00 of Ventura (low) - Winthrop (high) contact.

8.9 View at 12:00 of Goat Peak. Summit is carved from plagioclase-phyric volcanic rocks of the Midnight Peak Formation 9.9 Midnight Peak Formation low on hill at 9:00

10.7 Mazama Community Church on left.

12.0 Early Winters Outfitters on left.
We did much of our work in the Pasayten Wilderness (which forms the northern half of the Robinson Mountain quadrangle) with a hired mule string, wrangler, and cook. It was expensive but cheaper than paying geologists to backpack camp. And, there is nothing finer than working in the wilderness with enough to eat, a BIG tent to eat in, and cold mornings with a pot of coffee on the wood-fired sheepherders stove.

13.2 Turn right on Lost River Road to Mazama. Stop after turn to admire view across axis of Goat Peak syncline.

The lower cliffs are formed of volcanic rocks of the Midnight Peak Formation, which here dip gently away from us, to the northeast. Crude sub-horizontal layering is probably bedding (flow and breccia boundaries), though such layering is typically extremely hard to identify on the outcrop.

The summit of Goat Peak is carved from the same strata in the far limb of the Goat Peak syncline, where they are vertical to overturned, facing towards us and dipping steeply to the northeast.

13.4 Cross Methow River.

13.6 Turn left at T intersection

13.7 Mazama country store, once a one-room gas station, general store, and post office, then demolished and rebuilt into what Rowland Tabor (in Haugerud and others, 1994) described as “an upscale yuppie moun¬tain boutique.”

16.6 Stop 2-2. Midnight Peak Formation. Park on left side of road. Outcrops here are maroon and green silt-stones of the Ventura Member of the Midnight Peak Formation, with abundant talus of volcanic breccia and tuff from cliffs of Midnight Peak volcamcs above. Walk south to see talus of Ventura conglomerate, coming from a bed at the top of the outcrop. Don’t climb to this bed with a large group below! Outcrop is cut by dikes and sills of several flavors.

View to northwest of Scramble Point, underlain by-Midnight Peak Formation, both volcanics and red-beds, traversed by orange-weathering granite-porphyry dikes (see Stop 2-4). View to southwest, across Methow River and behind Sandy Butte, of Gardner and North Gardner Mountains. The summit of Gardner Mountain (on left) is Ventura Member. In the Gardner Mountain area conglomerates of the Ventura lack the abundant chert pebbles seen here. They contain clasts of banded argillite, volcanic sandstone, andesite, and minor granitoid rocks and limestone. The east ridge of Gardner Mountain and North Gardner Mountain are underlain by volcanic breccia, tuff, and tuffaceous sandstone and shale of the Three AM member of the Winthrop Formation, stratigraphically beneath the Ventura. Beds are folded into a tight to isoclinal anti-formal syncline: beds top towards the fold axis and dip away from the axis. We infer this antiformal syncline to have formed by west-verging refolding of the overturned limb of a large E-verging fold (see Internal Structure, above). Cross Goat Wall Creek (unsigned). Outcrops of redbeds. More red-bed outcrops.

Great view at 12:00 of Last Chance Point. Summit is volcanic rocks of Midnight Peak Formation, overlaying Ventura redbeds, unconformably above Winthrop Formation, all traversed by orange-weathering granite-porphyry dikes (see Stop 2-4). Yellowjacket Sno-Park on right. Roadcut on left in colluvium derived from Ventura redbeds. Cross Lost River. Pavement ends.

Monument trailhead and U.S. Forest boundary sign. Robinson Creek, followed by tumoff to Robinson Creek trailhead. Ballard Campground on left.

Junction with road to Riverbend Campground on left. Take switchback to right. Poor outcrop on left of Winthrop Formation. Switchback, followed by sporadic outcrops of arkosic sandstone (Winthrop Formation), then black argillite of the Virginian Ridge Formation.

24.6 Stop 2-3. Virginian Ridge Formation. Park on left and walk back to look at pencil-cleaved slate and sparse chert-pebble conglomerate.

25.2 Granite-porphyry dike.

26.0 **Stop 2-4**. Eocene dikes; Winthrop Formation; view of Harts Pass Formation. Park at far end of cliffs at Deadhorse Point and walk back. BE VERY CAREFUL ALONG THIS ROAD - THE CLIFF IS VERY STEEP AND THE DRIVERS PASSING YOU ARE WINNEBAGO OWNERS FROM IOWA

North- to NNE-trending dikes here come in at least 3 flavors: dark brown, spheroidally-weathering basalt; light-grey dacitef?) with large plagioclase phenocrysts, and cream- to orange-weathering rhyolite with quartz, plagioclase, and K-feldspar phenocrysts (granite porphyry). Intermingling and common trends suggest the 3 varieties are roughly coeval. They are especially abundant in this region, between the 48—49 Ma Golden Horn and Monument Peak plutons, and appear to be offshoots of these plutons.

Winthrop Formation sandstone is micaceous (biotite and lesser muscovite) feldspathic arenite. Siltstones commonly have multiple cleavages which form shallowly-plunging pencils. Sedimentary structures in the Winthrop Formation include graded beds, scour surfaces, trough crossbeds, tool marks, climbing ripples, aligned wood fragments, convolute bedding, flames, and ripples. These outcrops of Winthrop Formation underlie the Virginian Ridge Formation exposed at Stop 2-3. Either the two units deposi-tionally intertongue, or in this region they are repeated by layer-parallel faulting.

Steep beds to the south, across the upper Methow valley, are E-facing Harts Pass Formation. Low-amplitude folds appear to be fault-bend folds associated with layer-parallel faulting. Brownish slopes at the right side of the buttress which carries the Harts Pass are underlain by massive argillites of the "Panther Creek Formation"; forested slopes to the left of the Harts Pass, directly south of this stop, are underlain by Virginian Ridge argillite. Total thickness of the Harts Pass here is about 1.2 km.

27.1 Cache Creek crossing. Winthrop Formation here is upside down.

27.6 Roadcut in glacial till.

28.8 Stop 2-5. Angular unconformity at Harts Pass -Virginian Ridge contact Pull over on left shoulder for view across valley at 9:00. Grey, horizontal rib across the valley, near the base of the slope, is a chert-pebble conglomerate bed at the base of the Virginian Ridge Formation. It dips towards us more steeply than the slope. Upslope from the grey rib, irregular, off-white ribs that trend down to the right across the slope are massive sandstone of the Harts Pass Formation, also dipping towards us but with a slightly more northerly strike and slightly steeper dip than the overlying Virginian Ridge Fm. (Fig. 14)

This unconformity is also evident on the east limb of the Goat Peak syncline, where the Harts Pass thins significantly to the southeast, and appears to be responsible for the absence of Harts Pass in the area around Winthrop. Northwest of here, where the basal Virginian Ridge is a fine-grained basinal facies, the contact appears conformable, or even interfingering.
30.4 Abandoned borrow pit on right, then road enters woods.

30.6 Road crosses (unexposed) contact of Virginian Ridge Formation with Harts Pass Formation.

32.4 Low argilhte outcrops on right are best-known fossil locale in Harts Pass Formation. Various ammonites found here, and elsewhere in the unit, indicate a mid-Albian age (Crowley, 1993). Massive character of these argillites is atypical.

33.0 Stop 2-6. Harts Pass Formation. Park at Harts Pass and walk back down road looking at outcrops of quartzofeldspathic turbidites.

33.5 Stock-loading ramp on left.

33.6 Road is along Harts Pass - Virginian Ridge contact. Next several outcrops are argilhte of the Virginian Ridge Formation.

34.3 Switchback and trailhead, Pacific Crest Trail—North.

35.3 Gate and parking lot. Stop 2-7. Anomalous Virgin¬ian Ridge Formation; views of Hozameen allochthon and Devils Peak detachment; discussion of structure of Methow block. Park at gate and walk up road to the summit.

Dikes and sills of orange-weathering quartz porphyry are part of swarm that extends between the Eocene Golden Horn and Monument Peak plutons. Country rock is the Slate Peak member (Trexler, 1985) of the Virginian Ridge Formation, comprising slatey argilhte and siltstone, lithic sandstone, arkosic sandstone, and chert-pebble conglomerate.

Beds along the road are rich in fossils of a snail that has previously been identified as *Actaonella cf. A. packardi*, though Will Elder (written communications, 1992, 1994) tells us it is better described as *Actaeonella n*. sp. similar to *Actaeonella oviformis Gabb*, and which elsewhere in the Pasayten Group occurs in an assemblage of probable Turonian age. Extensive woody debris, bioturbation, (laser bedding, cross-bedding in some conglomerate beds, and inter-bedded cross-bedded biotite arkose (some of which crops out at the comer of the summit platform) similar to that in the Winthrop Formation indicate shallow-marine, perhaps locally even fluvial, deposition.

Paleocurrent indicators show transport to the southeast and northeast (Cole, 1973) or northeast (Trexler, 1985). Tennyson and Cole (1978) noted that chert pebbles in the Virginian Ridge are the first west-derived detritus evident in Cretaceous Methow strata and record emergence of oceanic rocks of the late Paleozoic and early Mesozoic Hozameen Group, which if is is clear can be seen on Jack Mountain in the distance, some 15 km west of here.
Fades patterns in the chert-lithic Virginian Ridge and Jackita Ridge Formations suggest deposition in a foreland basin developed in front of, and cannibalized by, an E-verging thrust. Farther west the Jackita Ridge is deep-marine turbidite with graded beds, lit¬tle bioturbation, and no sign of wave reworking. These marine facies conformably overlie arkose of the Harts Pass Formation. Chert pebbles in the Slate Peak member of the Virginian Ridge Formation could not have been transported across a deep-marine basin into shallow water, and one can thus reason that the beds here are younger than the Jackita Ridge Forma¬tion. This is corroborated by Albian inoceramids (W.P. Elder, oral comm., 1994) in the

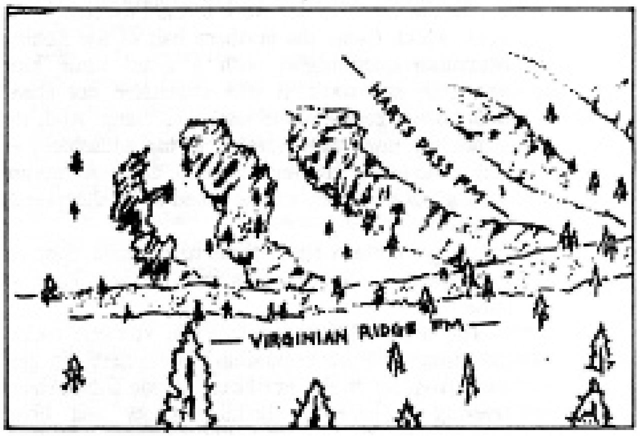


Figure 14. View west across Rattlesnake Creek of the sub-Virginian Ridge unconformity at Stop 2-5. Sketch by Josh Dialer.

western facies. The Jackita Ridge-Virginian Ridge basin seems to have migrated eastwards and become shallower with time. Migration was presumably in response to eastward movement of the Hozameen allochthon.

From the summit one looks north down the broad glacial troughs of the West and Middle Forks of the Pasayten River. These valleys were shaped by continental ice flowing south, up-valley, and over the high passes around Slate Peak. The massive mountain to the southeast is Robinson Mountain, largely underlain by Midnight Peak Formation in the hanging wall of the Eocene, down-to-the-SE, Devils Peak detach¬ment. On a clear day one looks west to (amongst a myriad of peaks) peaks of the southern and northern Pickets, carved from Skagit Gneiss Complex and, farthest west, the Quaternary volcanic cone of Mount Baker, sitting on top of the Northwest Cascade System.

Most of the area visible to the west, north, and east is within the Pasayten Wilderness. There are no roads and it is illegal to use a helicopter. The geologist must return to the 19th century, carrying camp on her back or (if well-funded) hiring a mule string.

Walk back to cars and retrace route down Harts Pass road to Switchback below Stop 2-3

Stop 2-8. View down Methow valley; normal faults in Devils Peak extensional allochthon. Stop here to admire a view considered by early visitors to be as fine as any in Yosemite. The nearby cliffs on the left are buff-weathering sandstone of the Winthrop Formation. Behind them are red-beds of the Ventura Member of the Midnight Peak Formation, brought down the same level by down-to-the-E displacement on N-trending normal faults. These faults are quite conspicuous on the ground and on air photos, are easily mapped, and are present only in the hanging wall of the Devils Peak allochthon, in the region between Devils Peak and the Lost River. Continue retracing route to Four-way stop in downtown Winthrop.

DAY 3. WINTHROP TO WINTHROP VIA UPPER TWISP RIVER, BALKY HILL ROAD, CAMPBELL LAKE, AND PEARRYGIN LAKE. CONGLOMERATE OF SOUTH CREEK DEPOSITED ON CHELAN-BLOCK SCHIST; TRANSPRESSION AND TRANSTENSION IN MID-CRETACEOUS STRATA; PIPESTONE CANYON FORMATION

0.0 Four-way stop in downtown Winthrop. Proceed south on SR 20 towards Twisp.

0.5 Follow SR 20 to right over Methow River.

0.6 Wolf Creek Road on nght; stay left on SR 20.

1.3 Winthrop Post Office on left.

3.1 Twin Lakes Road on right.

8.1 Milepost 201. Enter Twisp.

8.6 Cross Twisp River.

8.7 Turn right on Twisp River Road.

8.9 Lookout Mountain Road on left.

9.6 Outcrop on left of aphyric rhyolite followed by volcanic rocks of Newby Group.

9.9 Poorman Creek Road on left, followed by Twisp River bridge.

10.3 Outcrops on right are Bear Creek unit of Newby Group.

10.4 Outcrops of aphyric rhyolite that intrudes Bear Creekunit; sample collected ~’/j mile north of here failed to yield sufficient zircon for an accurate U-Pb age.

10.7 View of Reynolds Peak at 12:00.

11.5 Frost Road on right.

11.9 View up Poorman Creek (on left) to Raven Ridge, eroded from 65-Ma Oval Peak Batholith on southwest side of Foggy Dew fault.

12.4 Poorman Creek Cutoff Road on left.

12.6 Begin outcrops of Patterson Lake unit; dark siltstone interbedded with conglomerate bearing pebbles of argillite and volcaniclastic rocks.

12.8 Road crosses irrigation ditch.

14.0 Elbow Coulee Road on right.
14.6 Salmon acclimatization pond on left.

15.2 Outcrop of Winthrop Formation.

15.4 Outcrop of Winthrop Formation; most conspicuous 'bed' is an igneous sill.

15.5 Newby Creek Road on left.

15.8 Outcrop of volcanic rocks.

16.2 Outcrop of volcanic and volcaniclastic rocks of Three AM Member of Winthrop Formation.

16.7 Little Bridge Creek Road on right.

18.3 U.S. Forest Service information kiosk on right.

19.0 View at 10:00 up Buttermilk Creek.

19.4 West Buttermilk Creek Road on left.

19.5 Canyon Creek.

19.9 Lime Creek Road on right.

20.2 Hillside in middle distance is underlain by Twisp Valley Schist.

20.7 Lime Creek.

21.6 Okanogan National Forest sign.

22.2 Gilbert Mountain in distance at 12:00. 22.9 War Creek campground.

23.1 Turn left on gravel road, USFS 4430, towards War Creek trail.

23.2 Cross Twisp River.

23.3 At Y, go right towards War Creek trail.

23.6 Stop 3-1. Foggy Dew fault. Park on right shoulder. Mylomte here is associated with the Foggy Dew fault, buried beneath alluvium to the east, which separates Methow strata from metamorphic rocks of the Chelan block. The fault zone consists mainly of mylomtic gneiss, gamet-biotite schist, and deformed porphyry.

The latter may have been intruded into the fault zone and became the lineated mylonite exposed here. My-lonitic tonalitic gneiss bearing a greenschist-facies mineral assemblage, plagioclase porphyroclasts, and prominent quartz ribbons crops out a few tens of me¬ters southwest of the road.

Steep northwest-striking foliation and subhorizontal lineation at this point are most compatible with strike-slip motion, though substantial vertical displacement is indicated by the contrast between garnet-bearing schist to the west and little-metamorphosed Methow strata to the east. Scarce kinematic indicators are dextral. Sub-parallel faults of the Slate Creek fault zone that may also be splays of the Foggy Dew lie within Methow strata farther northeast. Continue northwest.

23.7 Keep right at junction.

26.3 Outcrop of metapelite in Twisp Valley Schist.

26.9 Williams Creek.

27.1 Williams Creek trailhead.

27.3 T intersection with USFS 4435. Turn left.

27.9 Reynolds Creek.

•28.3 Switchback.

28.4 Road to Reynolds Creek trailhead on right.

28.6 View of Gilbert Mountain at 12:00.

29.0 Milepost 2.

29.5 **Stop 3-2.** South Creek conglomerate, discussion of the 'Twisp River fault'. Pull into open area on right and park.

An hour's climb up the hill are excellent exposures of the basal contact of the South Creek Member of the Virginian Ridge Formation, where it overlies the metamorphosed ribbon chert of Twisp Valley Schist. We will content ourselves with examining boulders of the conglomerate that have fallen from above. Look around for poorly-sorted conglomerate with banded white clasts of metamorphosed ribbon chert. Some clasts contain tight, irregular metamorphic folds that clearly demonstrate the ribbon chert was metamorphosed before it was eroded and redeposited to form the conglomerate. The conglomerate itself has been metamorphosed: compare clast outlines on different faces of a single boulder. This is classic evidence for multiple metamorphism in the Twisp Valley Schist

See STRATIGRAPHY for discussion of our reasons for correlating the South Creek conglomerate with the Virginian Ridge Formation, and correlating the overlying North Creek Volcanics (Misch, 1966) with the Winthrop Formation.

The South Creek conglomerate also is the best possible evidence for pre-mid-Cretaceous metamorphism in the core of the North Cascades.

South Creek metaconglomerate is upright and dips northeast, lying conformably beneath Pasayten Group strata on the lower part of the far valley wall. There is no obvious break in lithology, degree of metamorphism, or orientation of bedding, foliation, or lineations to suggest a fault along the Twisp

River valley here, and we don't think there is one.

Without a Twisp River fault, interpretation of the Ross Lake fault zone becomes easier and more interesting. Miller and Bowring (1990; see also Tabor and others, 1989; Haugerud and others, 1994) struggled to explain how an Eocene fault (Stop 3-1) could be intruded by a 90 Ma pluton (the Black Peak batholith. which extends across the head of the Twisp River and underlies the upvalley part of Gilbert Mountain, barely visible through the trees to the north of here.) If there is no Twisp River fault, the mylonites at Stop 3-1 can be attributed to deformation on the Foggy Dew-North Creek fault, or(and) splays off this trend that trend more northerly and dissect Methow block strata farther to the east. The deformation passes east of the Black Peak batholith; some strands may bypass the 49 Ma Golden Horn batholith.

The South Creek conglomerate is a depositional tie between the Methow and the Chelan block. It is good evidence against very large strike-slip displacements on eastern strands of the Ross Lake fault zone— displacement on the North Creek fault can be no more than the strike length of the mid-Cretaceous foreland basin.

Retrace route to 31.1 Reynolds Creek.

31.7 Junction (mile 27.3 above). Go left and cross Twisp River on one-lane bhdge.

31.8 Outcrops of stretched rocks.

31.9 Begin pavement.

32.0 Junction with Twisp River Road (USFS 44). Tuni right.

32.8 Road to Slate Lake trailhead on right.

37.1 Leaving Okanogan National Forest sign.

37.5 Rocks ahead in middle distance dip south.

39.1 Canyon Creek.

39.2 West Buttermilk Creek Road on right.

39.4 Volcanic conglomerate and sandstone on river bank, below road to right, dip south.

42.0 Little Bridge Creek road on left.

43.2 Newby Creek Road on right.

43.5 Park on right for optional stop to examine Winthrop Formation.

44.7 Elbow Coulee Road on left.

4S.2 Stop 3-3. Eastern limit of Virginian Ridge Forma¬tion. Park on right at far end of outcrop.

Walk back along the entire outcrop, looking at steeply-dipping beds of chert-pebble conglomerate and interlayered fine-grained rock. Keep an eye out for evidence of facing direction. We hope you find that the beds in this outcrop form a tight anticline.

Outcrops east of here are all conglomerate and siltstone of the Patterson Lake unit. With the exception of fault-bounded inliers near Twisp, this is the easternmost extent of the Pasayten Group at this latitude.

Is the fault that juxtaposes Virginian Ridge conglomerate with the Patterson Lake unit a zone of weakness within a single depositional sequence, or are we just west of a terrene boundary with significant displacement?

50.1 Stop sign at SR 20 in Twisp. Turn right.

50.7 Bridge over Methow River. Turn left at far end of bridge, towards Davis Lake.

51.5 Begin outcrops of fractured and faulted volcanic and volcaniclastic rocks of the Bear Creek unit. Note laumontitic alteration.

51.9 View at 11:00 of Pipestone Canyon Formation (Bonner Lake section) overlying green tuff and brec¬cia of the Newby Group.

53.0 Turn right on Balky Hill Road (gravel) and park for

Stop 3—1. Overview of Pipestone Canyon Fm
The Campbell Lake section contains four distinct lithofacies (Fig. 9): 1) basal monolithologic granitoid-boulder conglomerate; 2) tufTaceous lithic feldspathic wacke; 3) chert-, granitoid-, and volcanic-cobble conglomerate; and 4) chert- and volcanic-pebble conglomerate and chert-lithic sandstone. We interpret the basal contact as a buttress unconformity with underlying hornblende diorite of Okanogan Complex affinity. The basal conglomerate/breccia consists entirely of angular clasts of coarse-grained, light-colored biotite tonalite and gneissic tonalite that strongly resemble the Rommel batholith of the Okanogan complex. Overlying the basal conglomerate is a series of purple, medium to thick bedded tuffaceous lithic feldspathic wacke. The sandstone contains abundant plutonic debris, but also appears to contain primary volcanic detritus. The tuffaceous beds are gradationally overlain by thick-bedded, crudely stratified, pebble to cobble chert-, volcanic- and granitoid-clast conglomerate in-terbedded with coarse-grained lithic sandstone and minor parallel-laminated siltstone. The polymict conglomerate fines upward into a chert- and volcamc-clast pebble to cobble conglomerate containing lenticular channels and trough cross-stratification.

The Campbell Lake section may be interpreted as a basal fanglomerate overlain by alluvial fan to fluvial deposits, with minor lacustrine interbeds in the lower middle portion of the section. We think anomalous white-weathering tuffaceous sandstone in the chert-and volcanic-clast conglomerate lithofacies records syndepositional volcanism.

At cars, return to 66.5 Junction (64.0, above) with Lester Road. Turn left.

67.8 Pipestone Canyon rubble.

67.9 Wide shoulder on left. Gneissic biotite tonalite of the Okanogan complex crops out 70 m up gully to right, apparently as sliver in fault (or basement to Bowen Mountain Pipestone Canyon?)

68.3 Switchback.

68.8 Junction with Bear Creek Road. Turn right.

69.3 Road crosses beneath power lines. Outcrop here is massive argillite, sandstone, and conglomerate of the Patterson Lake unit.

69.7 Junction with gated road to left. View of Pearrygin Lake at 10:00. Foreground (10-11:00) is Newby Group; farther in the distance is Pasayten Group.

70.5 Methow Wildlife Area (Washington Department of Fish and Wildlife) headquarters.

70.6 Junction. Go left.

71.3 Outcrop of Bear Creek unit.

72.5 Junction with road on right. Go straight.

72.7 Junction with paved road. Go right. Entrance to Pear¬rygin State Park is to left.

74.3 Stop sign at junction with East Chewuch Road. Turn left.

74 4 This and next outcrop are Bear Creek unit, with inter-bedded argillite like that of the Twisp Formation.

75.6 Thin-bedded argillite of Twisp Formation on left.

76.0 Four-way stop in downtown Winthrop.

DAY 4. WINTHROP TO ROSS LAKE, VIA WASHINGTON PASS. JACKITA RIDGE UNIT, GOLDEN HORN BATHOLITH, HOZAMEEN GROUP, ROSS LAKE FAULT ZONE

0.0 Four-way stop in downtown Winthrop. Take SR 20 west across Chewuch River.

13.2 Lost River Road to Mazama on right. Go straight ahead on SR 20. 14.8 U.S. Forest Service facility at Early Winters.

15.0 Early Winters Creek.

16.8 Milepost 176. Bridge over Early Winters Creek, followed by outcrop on left of chert-pebble conglomerate and argillite of the Virginian Ridge Formation.

20.1 Late Cretaceous(?) quartz diorite on left.

21.6 Stop 4-1. Jackita Ridge Formation. Park on right and walk across road to look at outcrop just down val¬ley from Silver Star Creek. Outcrops along this part of Early Winters Creek are not very exciting, but are the only place one can drive to see the Jackita Ridge Formation. Look for gray chert grains in coarser-grained sandstone and evidence for turbidite deposition. Outcrops are much better if one makes the 2-day (each way) trek to Jackita Ridge.

23.6 On right, first outcrops of Golden Horn batholith.

30.4 Washington Pass, elevation 5477.

30.5 Turn right to Washington Pass overlook.

30.8 **Stop 4-2**. Washington Pass overlook. Golden Horn batholith. Park and walk short trail to viewpoint. The Golden Horn batholith is a distinctive low-Ca granite, part of a suite of Eocene granites that, in the North Cascades, includes the Mount Pilchuck stock and Bald Mountain pluton west of the Straight Creek fault; the Duncan Hill, Railroad Creek, and Cooper Mountain plutons within the Chelan block, and the Golden Horn, Monument Peak, Castle Peak, and Needle Peak (located north of the Manning Park) plutons in the Methow block. Much of the Golden Horn is conspicuously miarolitic, rapakivi feldspar (white plagioclase mantling pink K-feldspar cores) is common, and the central phase contains a sodium-rich, dark blue amphibole that has been described as riebeckite (Misch, 1977) or arfvedsonite (Boggs, 1984).

The origin of these middle Eocene granites, and similar rocks throughout the northern Cordillera, from Idaho to northern British Columbia, has been much debated. One of the more unusual and interesting hypotheses is that they are melts produced when the sub-crustal lithosphere detached, sank into the mantle, and exposed the base of the crust directly to the asthenosphere. In essence, these granitoid magmas would be crustal melts produced by massive underplating of basalt.

Early Winters Spires, Lexington and Concord Towers, and Liberty Bell are blocked out of Golden Horn granite by ENE-trending faults—not joints— that pass through the notches between them. Unusually complete outcrop along the deep roadcut below the spires shows significant hrecciation along these fractures. The Wine Spires, on the north ridge of Silver Star Mountain east of here, are on strike with these faults and appear also to have been blocked out by them.

Return to vehicle and return to 31.0   Stop sign at SR 20. Turn right.

31.7 View ahead of orange Golden Horn granite dikes cut¬ting gray Black Peak batholith on Whistler Mountain.

33.9 Continuous outcrop of tonalite of Black Peak ba¬tholith on right side of road. Rock here is sick, with pervasive chlonte-epidote alteration. Black Peak to¬nalite nearby is not; we suspect this alteration is related to the ENE-trending minor faults discussed at Stop 4-2.

35.7 Rainy Pass.

37.0 Porcupine Creek.

41.9 Turnoff to left for Easy Pass trailhead.

45.4 Milepost 148. View ahead of Crater Mountain, carved from Hozameen Group greenstone in hanging wall of Jack Mountain thrust.

46.7 Stop 4-3. Deformed Golden Horn batholith; views of Crater Mountain and deformed Little Jack unit on McKay Ridge. Sign and pullout for view down valley of Crater Peak [sic], eroded from pillow basalt and gabbro of the Mississippian to Jurassic Hozameen Group, in the upper plate of the Jack Mountain thrust. Little of the north-dipping thrust is visible from here. On Crater Mountain the Hozameen Group is partially recrystallized in the prehnite-pumpellyite facies, without the development of penetrative fabric. Below the Jack Mountain thrust lie semischistose sandstone, phyllite, talc-bearing ultramafic schist, rare marble and ribbon chert, and abundant deformed dikes of porphyritic dacite. Tabor and others (1989) noted that these lithologies do not necessarily correlate with any of the adjacent tectonostratigraphic assemblages (Napeequa, Cascade River, Hozameen, Methow), and treated them as a separate, Little Jack, unit. Kriens and Wemicke (1990a, 1990b) correlated the Little Jack with the Hozameen Group and strata of the Methow domain. Near the Jack Mountain thrust, the Little Jack unit lacks biotite, though metamorphic grade increases to the west.

Look to McKay Ridge at 1:00-2:00 for views of strongly folded phyllitic siltstone and sandstone of the Little Jack unit, intruded by Black Peak biotite-hom-blende tonalite and Golden Horn granodiorite (Fig. 15). Cordiente-spotted homfels is locally abundant, reminiscent of contact aureoles around mid-Cretaceous intrusions farther east in the Methow block..

Note roadcut exposure of shattered Golden Horn granodionte with local chlorite-epidote alteration. Brecciation is important as an indication of post-Golden Horn tectonism, necessary to accommodate the contrast in strain between rocks southeast of here—undeformed since —49 Ma—and rocks to the northwest and west that were penetratively deformed after 46-45 Ma (Haugerud and others, 1991b). 49.4 Milepost 144. North contact of Golden Horn batholith.

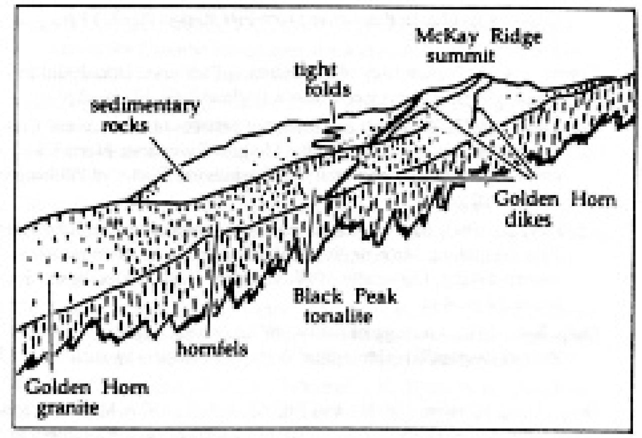


Figure 15. Sketch of McKay Ridge from Stop 4-3

52.0 Optional stop; park in front of sign "Canyon Creek trail 1/4 mile" to look at schistose metasedimentary rocks in Ross Lake zone.

52.2 Canyon Creek trailhead on right.

53.6 Begin outcrops of Ruby Creek heterogeneous plutonic belt.

53.7 Pollywog agmatite, an exposure favored by the late Peter Misch. See Stop A-24 in Misch (1977). Good swimming hole in Ruby Creek in woods to right.

54.9 Bridge over Panther Creek, followed by East Bank (Ross Lake) trailhead.

55.6 Western margin, Ruby Creek intrusions. 56.4   Cross western margin of the Robinson Mountain 30"x60' quadrangle.

58.3 **Stop 4—4.** Hozameen Group, Ross Lake fault. Park in overlook area on right.

Look up Ross Lake and right for views of Mount Hozameen, Desolation Peak, and Jack Mountain, all probably carved from late Paleozoic ocean-floor greenstone of the Hozameen Group, incipiently recrystallized in the prehnite-pumpellyite facies. Lower mountains on the west side of Ross Lake are, at least locally, Late Thassic alkali basalts and associated slump deposits formed at a seamount Farther west, the snowy slopes and multiple summits of Mount Prophet are carved of earliest Tertiary sillimarute-grade migmatitic orthogneiss and paragneiss of the Skagit Gneiss Complex, with a variably-developed Eocene mylorutic overprint. In between are gabbro, norite, troctolite, and anorthosite of the Skymo mat ic-ultramafic igneous complex. The contrasts in lithology, metamorphic grade, deformational history across this view constitute the Ross Lake fault zone.

We are also looking downstream along the pre-Pleistocene upper Skagit River. Reidel and Haugerud (1994) inferred that south-flowing Cordilleran ice dammed the north-flowing river to form a lake in this valley. The lake spilled over the lowest point in the drainage divide to the west, thus beginning incision of the Skagit Gorge.

To return to Seattle, proceed west, downvalley, on SR 20. The shortest route is via SR 530—which leaves SR 20 at Rockport, 37 miles west of this point—through Darrington to Arlington and then south on 1-5. Allow at least 2J/« hours for the drive. About Vt hour more is required to drive SR 20 through Sedro Woolley and Burlington and thence south on I-5. Gas, food, and phones are available in Marblemount, about 30 miles west of this point.

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