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FIELD TRIP GUIDEBOOK #053
FLOODS, FLOWS, FAULTS, GLACIERS,
GOLD, AND GNEISSES
FROM QUINCY TO CHELAN TO
WENATCHEE

May 18-20, 2018

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NWGS FIELD TRIP GUIDEBOOK SERIES

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NORTHWEST GEOLOGICAL SOCIETY FIELD GUIDEBOOK SERIES
Field Trip Guidebook #053

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I. PREFACE

The first edition of this NWGS field guide was for a trip on 13 and 14 May 2009. Since then, the rocks and sediments at each stop probably have not changed significantly, but our appreciation of some of them has. Rather than rewrite the entire 2009 guidebook, the simpler alternative was to correct a few topographic errors, provide addenda for some stops, and compile an annotated list of references published subsequent to the 2009 guidebook. In this second edition all of the addenda follow the original list of References.

To alert readers of addenda, a pound sign (#) marks relevant field stops in the text.

II. INTRODUCTION

The purpose of this NWGS field trip is to leave soggy Pugetopolis to examine some of the outstanding features of the diverse geology of sunny central Washington. Most field stops are roadside ones. Only two stops in the Wenatchee gold belt require moderate hikes.

On Day One we will drive from the Seattle area to the Quincy area via I-90 (**Fig. 1**). There, we will view Missoula flood sediments. Then we will drive up Moses Coulee (ogling the thrust fault in CRBG en route) to US-2. North of the US-2 we will do the Withrow moraine (twice) before descending scenic McNiel Canyon to Chelan Falls to marvel at the pre-Cenozoic Chelan Migmatite Complex. On the way back to Wenatchee we will stop at the pre-Cenozoic Entiat Orthogneiss at Earthquake (1872) Point and at the Swakane Biotite Gneiss at Rocky Reach.

On Day two we will do Stop 2-1 before breakfast. This allows us to utilize the early morning sun from atop Pangborn bar to enjoy the view of the entire Wenatchee district. After returning to the motel and after breakfast, we concentrate on the Chumstick Formation in the Wenatchee gold belt along the regional Eagle Creek reverse fault. We will see precious little ore. However, we will compare the reclamation at the L-D mine (closed 1967) with that of the Cannon mine (closed 1994). A scenic overview on Wenatchee Heights is along the Eagle Creek fold and thrust belt) at. We will return to Seattle via US-97 (Blewett Pass) and I-90. If time permits, along US-97 we may make optional stops in Cenozoic strata (Eocene Swauk and Chumstick formations, Miocene CRBG, and deformed Pliocene Thorp Gravel).

We will make extensive use of part of Margolis' 1994 field guide of the Wenatchee gold belt (Appendix I). The extensive list of references is slightly modified from Cheney and Hayman, 2007, 2009).

Wherever possible, the road logs utilize mile posts on highways, for example MP 23.2 of SR-28

III. REGIONAL SETTING AND TECTONIC HISTORY

General

Miocene and younger uplift of the Cascade Range largely governs the regional geology of central Washington (Mackin and Carey, 1965; Cheney, 1997; Cheney and Sherrod,

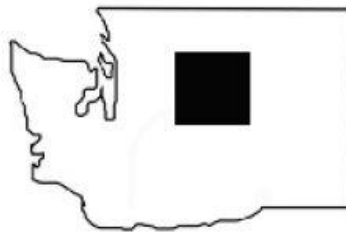
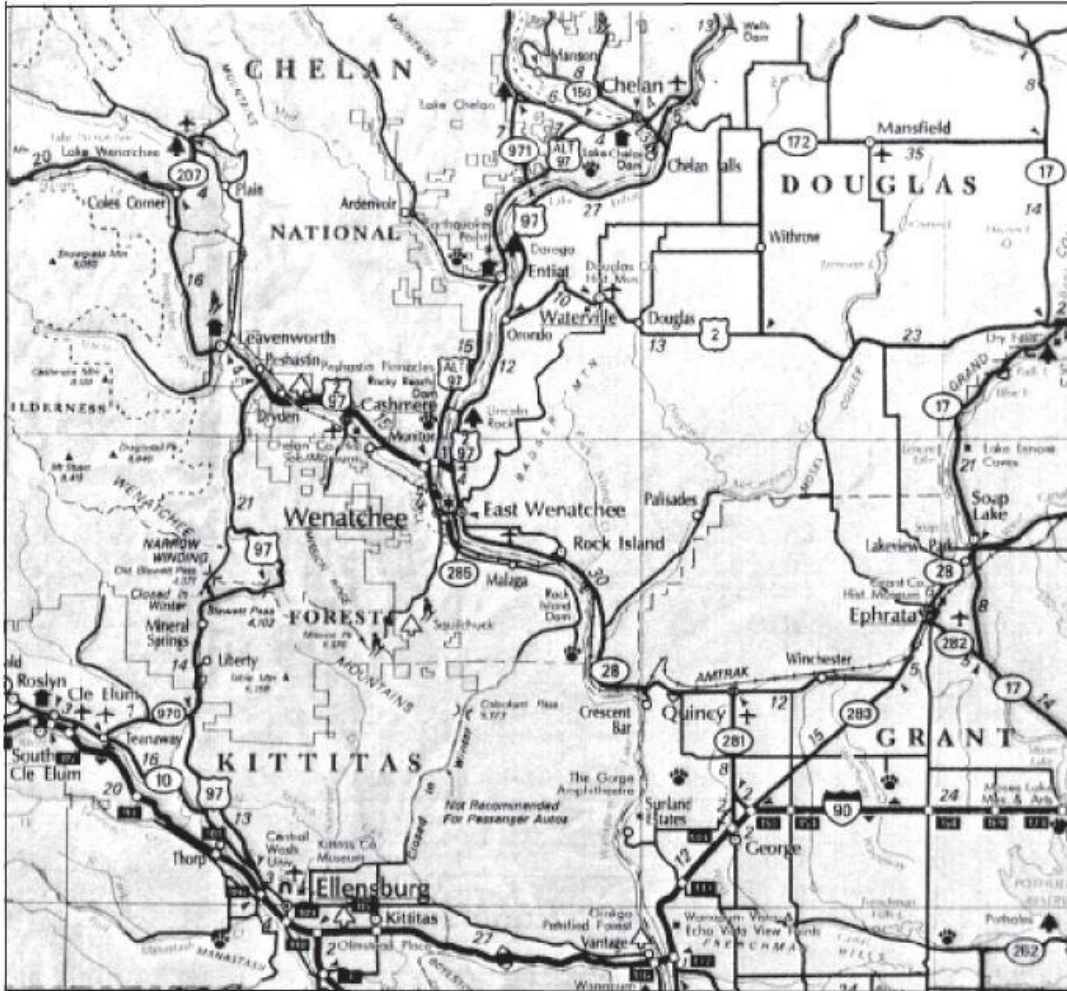


Figure 1. Washington Official Highway Map 2008-2009 (scale, 1' = 13.3 miles or 1:842,000). WA DOT.

1999; Reiners et al., 2002; Mitchell and Montgomery, 2006). The stratigraphy of the range includes four major Cenozoic unconformity-bounded cover sequences (Fig. 2) (Cheney, 1994). The southerly plunge of the Cascade Range anticline causes pre-Cenozoic crystalline rocks to dominate the northern part of the range; whereas, Cenozoic

sedimentary and volcanic rocks are generally younger and more extensive southward. The Wenatchee area is in the transition zone into the Cenozoic rocks (Fig. 3). Pleistocene volcanoes, such as Mt. Rainier, discontinuously cap the Cascade Range.

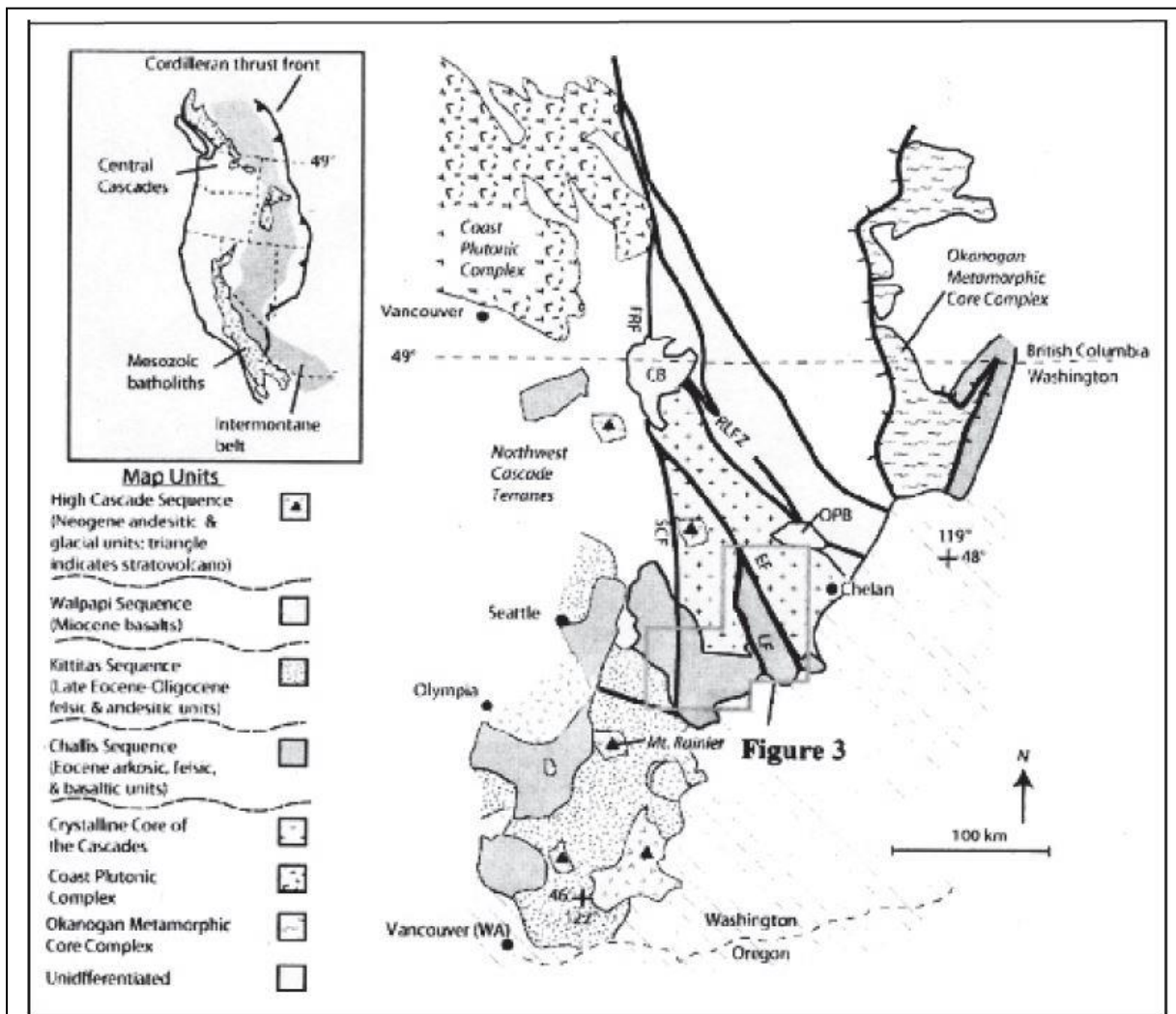


Figure 2. Geologic map of central Washington State, showing extent of the four major Cenozoic unconformity-bounded sequences mentioned in the text (Cheney and Hayman, 2009, fig. 1). Wavy lines in the explanation are regional unconformities. This field trip is on both sides of eastern margin of the area labeled Figure 3. Abbreviations are: SCF, Straight Creek Fault; EF, Entiat Fault; LF, Leavenworth. Fault. Triangles mark the locations of Cascade volcanoes, of which Mt. Rainier is the highest.

The crystalline rocks of the northern Cascade are terranes that amalgamated by the late Cretaceous. Three amphibolite-facies terranes along the Columbia River from Chelan to Wenatchee (Fig. 4) are Chelan Mountains, Mad River, and the Swakane Biotite gneiss (Stops 1-7, 1-8, 1-10 and 1-11) The Swakane Biotite Gneiss (Stop 1-11) is the youngest (about 73 Ma) and structurally deepest (Paterson et al. 2004) terrane in the range. It and other terranes were exhumed from depths of 40 km by 50 to 45 Ma (Miller

and Bowring, 1990; Haugerud et al., 1991; Wernicke and Getty, 1997; Valley et al., 2003; Paterson et al., 2004; McLean et al., 2006; Whitney et al., 2008).

The Eocene formations represent the Challis sequence of dominantly clastic and volcanoclastic lithologies (**Table 1; Fig. 1**). The key formation in the Wenatchee area is the arkosic Chumstick Formation. This formation was originally interpreted to fill the Chiwaukum “graben” (Willis, 1953;

Name with precedence	Synonymous names	Composition	Age (Ma)
Wenatchee	Nahahum Canyon	Predominantly shaley with arkosic sandstone	~42
Roslyn	Chumstick	Predominantly arkosic	43 to 46
Teanaway	Basalt of Frost Mountain	Basalt with some felsite, felsic volcanoclastic rocks and minor arkose	46 to 48
Taneum	Silver Pass, Peoh Point, Mount Catherine	Felsite and felsic volcanoclastic rocks	50 to 52
Swauk	Manastash, Guve	Predominantly arkosic	53 to 57

Table 1. Unconformity-bounded formations of the Eocene Challis sequence on the eastern flank of the Cascade Range (after Cheney and Hayman, 2009, Table 1). *Notes:* Stratigraphically upward is up in the table. Data are from Cheney (1994, 1999), except that the Nahahum Canyon correlation is this study. Ages are imprecise because they are K-Ar and fission-track dates.

Gresens et al., 1981, 1983; Tabor et al., 1982, 1987; Johnson, 1985; Evans, 1994). The graben was proposed to be a pull-apart basin between strike-slip faults (Gresens et al., 1981; Gresens, 1983). One reason was that major faults in the northern part of the range (Fig.1) dextrally offset pre-Cenozoic units by tens to hundreds of kilometers (Umhoefer, 1987; Umhoefer and Miller, 1996). Some of these faults, and the Ross Lake fault in particular (**Fig. 1**), underwent mid-Eocene slip with a dip-slip (normal) component (Miller and Bowring, 1990).

The volcanogenic formations of the Kittitas sequence originated from Oligo-Miocene plutons along the present Cascade crest. This was the Farallon magmatic arc, not the present Cascade arc (Cheney, 1997). Formations of this sequence are abundant in the southern Cascade Range but not in the Wenatchee area. A probable representative is the tuffaceous upper part of the Wenatchee Formation at Blue Grade (Stop 1-12) on the eastern side of the Columbia River.

The most voluminous lithostratigraphic unit of the Walpapi sequence is the 17 to 6 Ma Columbia River Basalt Group (Stop 1-1). In central Washington, the basalts occupy a

large regional syncline known as the Pasco Basin. The basalts issued from dikes in the common corner of Oregon, Washington, and Idaho. The major unconformity below the basalts and several within them (Stop 1-1) show that contemporaneous topography at the site of present Cascade Range was minimal. Thus, the basalts flowed westward to the sea (Cheney, 1997). Well known examples of folding of the basalts are the northwesterly trending Yakima fold belt, the southeastern part of Figure 3, and the Cascade Range anticline.

The High Cascade sequence consists of volcanogenic, glacial (Stops 1-4 and 1-5), and alluvial deposits (Stop 2-14). Of particular interest in the Wenatchee area are the deposits of the Missoula floods (Stops 1-2, 2-1, and 2-7).

Chiwaukum structural low

The ruling hypothesis of a Chiwaukum graben was based on the idea that clastic Eocene formations were deposited syntectonically in local basins. In contrast, Cheney and Hayman (2009) stressed that these formations are preserved in fault-bounded, regional synclines, not in separate

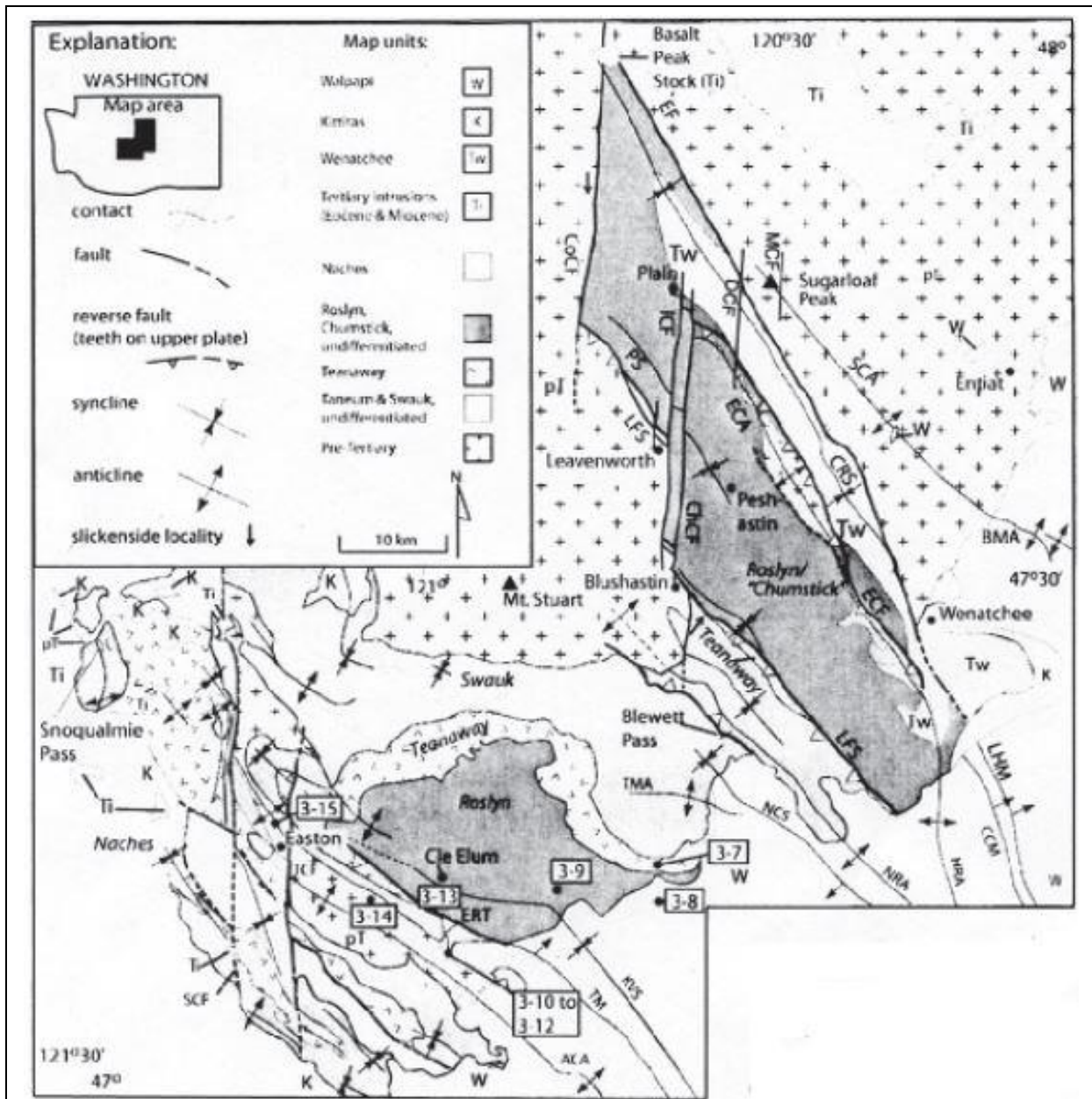
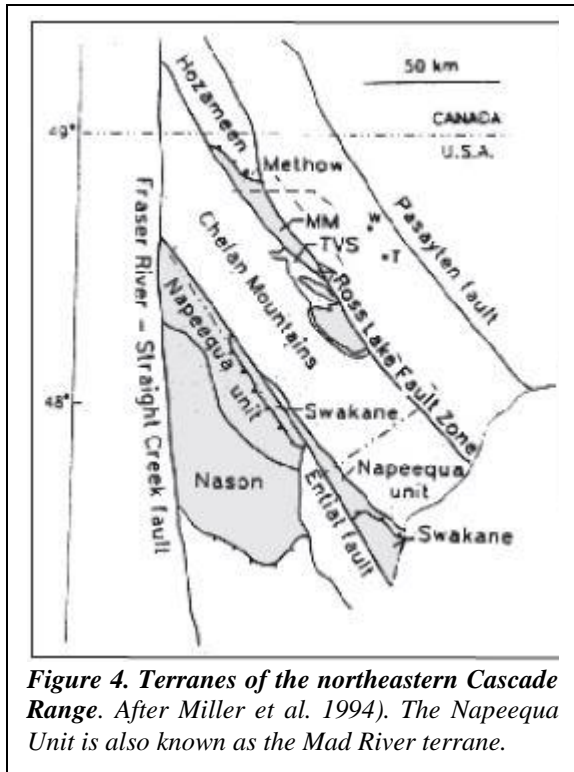


Figure 3. Regional geology. After Cheney and Hayman, 2009, fig. 2). For sources of data see Cheney and Hayman (2009), Abbreviations are: ACA, Ainsley Canyon anticline; BMA, Badger Mountain anticline; ChCF Chumstick Creek fault; CCM, Colockum Creek monocline; CoCF, Coulter Creek fault; CRS, Chiwawa River syncline; DCF, Dry Creek fault; ECA, Eagle Creek anticline; ECF, Eagle Creek fault; EF, Entiat fault; ERT, Easton Ridge thrust; HRA, Hog Ranch anticline; ICF, Icicle Creek fault; KVS, Kittitas Valley syncline; LFS, Leavenworth fault system; LHM, Laurel Hill monocline; MCA, Medicine Creek fault; NCS, Naneum Creek syncline; NRA, Naneum Ridge anticline; SCA, Swakane Creek anticline; SCF, Straight Creek fault; TCF, Tucker Creek fault; TM, Taneum monocline, and TMA, Table Mountain anticline.

depositional basins. Thus, Cheney and Hayman (2009) renamed the Chiwaukum graben the Chiwaukum Structural Low. Cheney and Hayman (2009) cited the following evidence for the Chiwaukum

Structural Low. The Eocene arkosic Chumstick Formation, which was thought to have been syntectonically deposited in the graben, is the proximal equivalent of the Roslyn Formation 25 km southwest of the



graben. Additionally, parts the Chumstick Formation probably are parts of the older Swauk Formation and the younger Wenatchee Formation. The southwestern boundary of the Chiwaukum Structural Low includes the Leavenworth fault zone, which consists of post-depositional, northwest striking reverse faults with adjacent northwest striking folds. The reverse faults place the regionally extensive Early-Eocene, arkosic Swauk Formation over the mid-Eocene, arkosic Chumstick Formation. A diamictite, which previously was placed in the Chumstick Formation and was inferred to have been syntectonically derived from the Leavenworth fault zone, is part of the older arkosic Swauk Formation. A conglomerate-bearing sandstone is a robust marker unit in the Chumstick Formation (**Fig. 5**). **Figure 6** is the explanation for **Figure 5**. Instead of being spatially related to the bounding faults, this conglomerate-bearing sandstone (Tcri and Tcru of **Figs. 5 and 6**) has a > 30 km strike length along the limbs of the Peshastin syncline and Eagle Creek anticline in the

structural low. The unit is 0.6 to 1 km thick (Cheney and Hayman, 2009, Table 4).

The northwesterly trending reverse faults and fold hinges in the Chumstick Formation are cut by northerly striking strike-slip faults (**Fig. 5**). These faults probably are satellites of the regional Straight Creek fault, which is late Eocene to Oligocene. These faults partially bound the structural low. Repetition of the stratigraphy by the north-south faults within the structural low probably contribute to the apparent very great thickness (>6 km) of the Chumstick Formation.

The Eocene folds and faults were reactivated by deformation of the Miocene Columbia River Basalt Group; this younger folding largely defines the regional map pattern on the eastern flank of the central Cascade Range. Thus, the Eocene-to-Recent history of the central Cascade region is, broadly speaking, characterized not by crustal extension, but by alternating episodes of folding with related reverse faults, and strike-slip faulting.

IV. REGIONAL EOCENE STRATIGRAPHY

Formation of the Challis sequence

On the eastern flank of the Cascade Range, the Eocene Challis sequence contains five unconformity-bounded formations (Table 1). In the Chiwaukum Structural Low, the most widespread unit is the mid-Eocene arkosic Chumstick Formation (**Fig. 5**).

Table 2 indicates that the early Eocene arkosic Swauk Formation and the middle Eocene arkosic Chumstick Formation usually can be distinguished by the size and composition of clasts in conglomerates, thickness and color of beds of sandstone, and

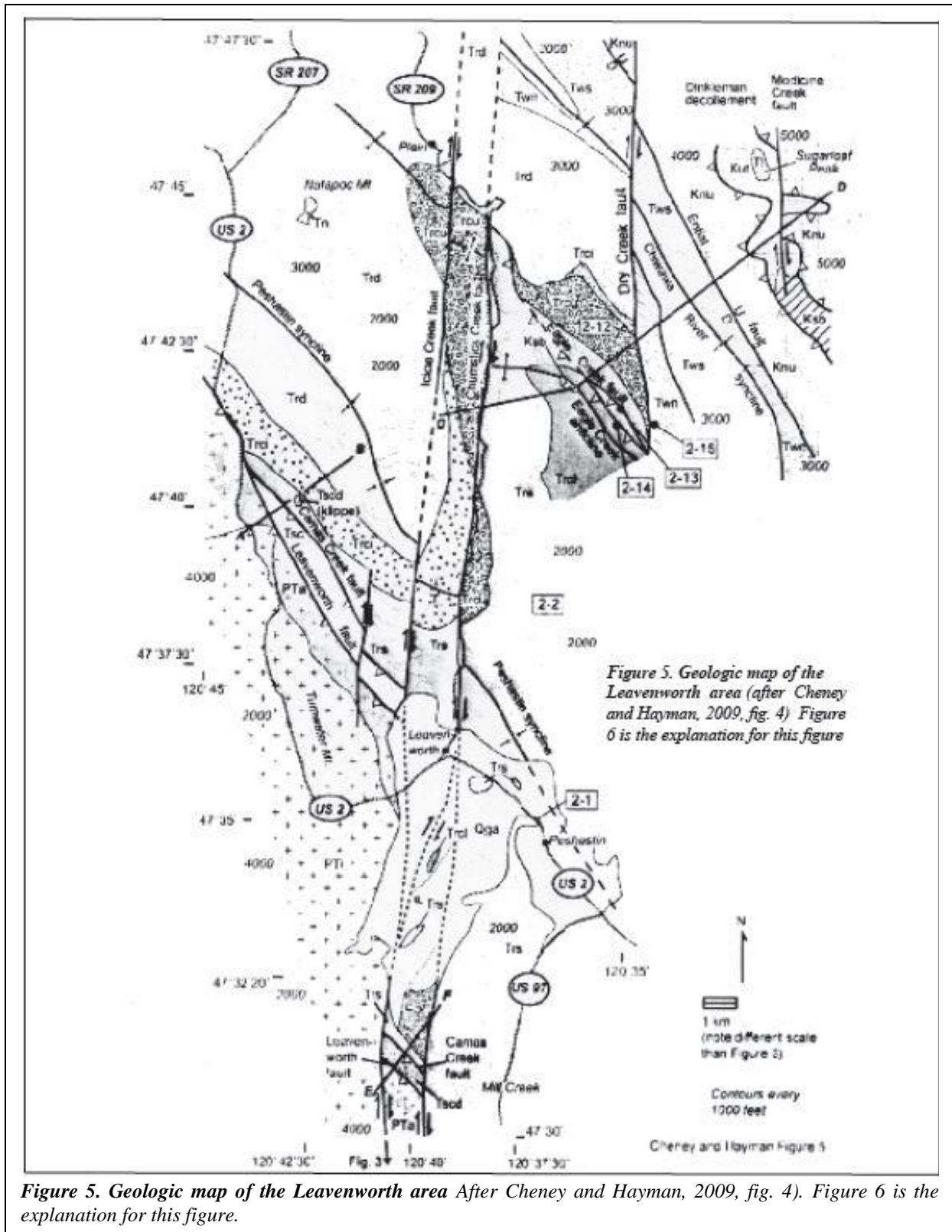


Figure 5. Geologic map of the Leavenworth area After Cheney and Hayman, 2009, fig. 4). Figure 6 is the explanation for this figure.

the presence or absence of dikes of Teanaway basalt, abundant lags of pebbles in

sandstones, coal, tuff, and diamictite. The smaller amount of conglomerate in the

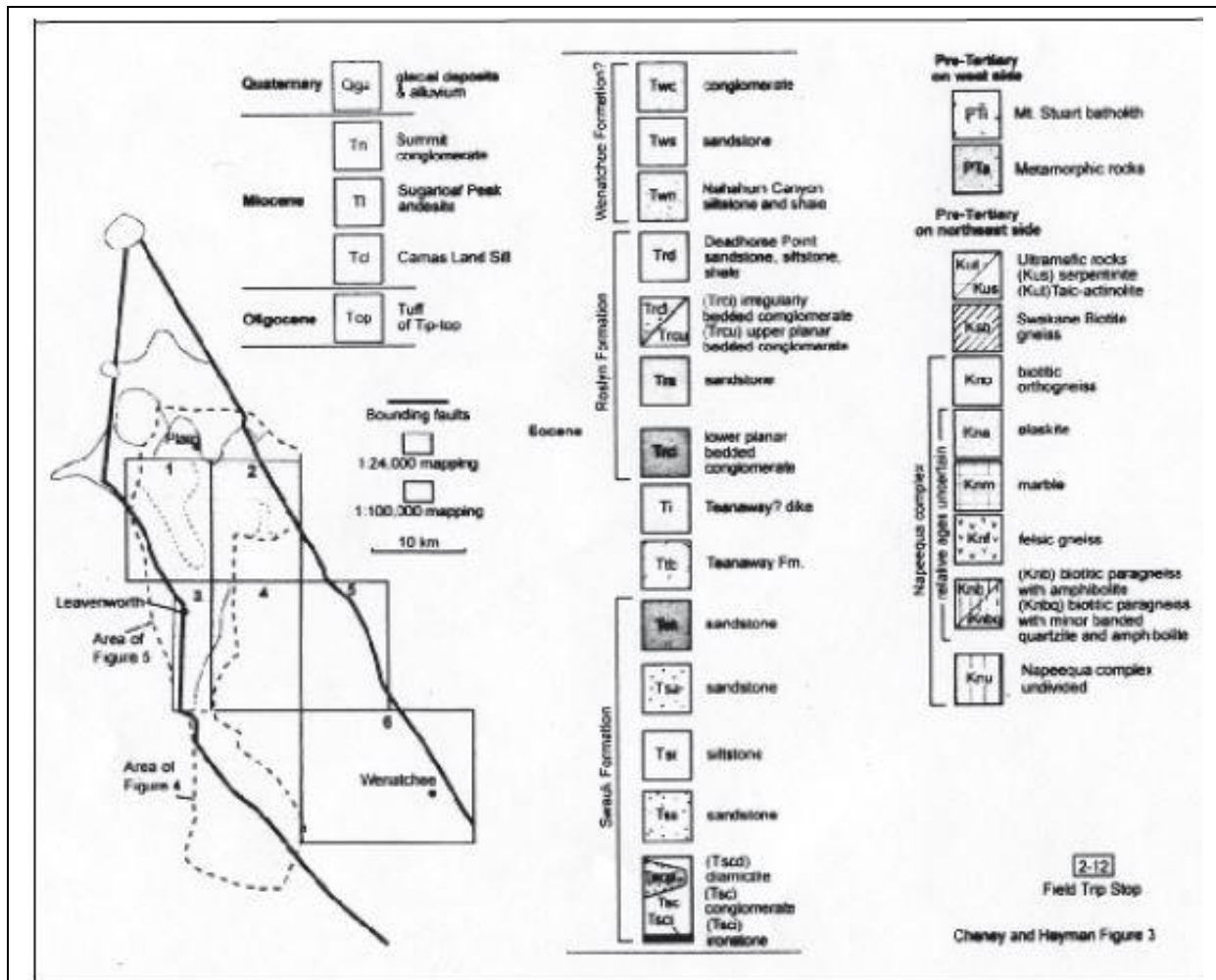


Figure 6. Index to 1:24,000 geologic mapping and lithologic units in and adjacent to the Chiwaukum Structural Low. This figure also is the explanation for Figure 5. Areas of previous geologic mapping are: 1) Whetten (1980a), 2) Whetten and Laravie (1976), 3) Whetten (1980b), 4) Whetten 1980c), 5) Whetten and Waitt (1978), and 6) Gresens (1983). Mapping by Cheney and Hayman (2009 and their subsequent mapping) are the irregular areas labeled 1:24,000 and 1:100,000 mapping.

Roslyn Formation (3% according to Bressler, 1951) and other characteristics in Table 2 suggest that the Chumstick Formation is a more proximal equivalent of the Roslyn Formation.

V. REGIONAL STRUCTURE

The major structures in the Wenatchee area are the Entiat fault and the Eagle Creek anticline and reverse fault (Figure 3). The Entiat fault is the northeastern bounding fault of the Chiwaukum Structural Low. It is a

high-angle fault that cuts the Chumstick Formation (Cheney and Hayman, 2009). If the Nahahum Canyon Member is equivalent to the Wenatchee Formation, the fault also cuts the Wenatchee Formation. Quaternary sediments obscure the Entiat fault in the Wenatchee area. The fault probably extends southeastward beneath downtown Wenatchee. It may be responsible for the faults on the northern end of Wenatchee Heights (Margolis, 1989).

The Eagle Creek anticline is the major fold in the northeastern portion of the Chiwaukum

Characteristics	"Chumstick" Fm.	Roslyn Fm.	Swauk Fm.
Type areas (no designated type sections)	Eagle Creek east of Leavenworth (Gresens et al. 1981)	Roslyn to Cle Elum (Tabor et al. 1982)	Swauk Creek south of Fig. 4 (Tabor et al., 1982)
Youngest underlying formation	Swauk Fm. (Gresens, 1983)	Teanaway Fm. (Walker, 1980)	Pre-Tertiary crystalline rocks (Tabor et al., 1982)
Oldest overlying formation	Wenatchee Fm. (Gresens 1983) ; age < 43-46 Ma	Naches Fm. (Cheney, 1999), age ≈ 39 to 40 Ma	Teanaway Fm. (Tabor et al. 1982)
Teanaway dikes	None (too young)	None (too young)	many
Palynology	Middle to Late Eocene (Evans, 1988, 1994)	Late Eocene pollen (Newman, 1981)	Middle Eocene pollen (Newman, 1981)
Estimated thickness	~ 2 km (Silling, 1979) ~ 8 km (Gresens et al., 1981) ~ 12 km (Evans, 1994)	~ 2900 m (Walker, 1980)	> 4.8 km (Taylor et al, 1988)
Outcrops of thick sandstone	White (Gresens et al. 1981)	White (Bressler, 1951; Tabor et al., 1982)	Dark (Tabor et al., 1982)
Thickness of most sandstones	Many > 8 m (this study)		Mostly < 8 m (this study)
Paleocurrent direction of most of the formation	From NE and E (Buza, 1979; Evans and Johnson, 1989; Evans, 1994)	From E (Walker,1980)	Mostly from N and E (Taylor et al., 1988)
Paleocurrent direction of Tsc of Swauk Formation	NA	NA	From W (Taylor et al., 1989)
Felsic volcanic clasts in conglomerates	3 to 70% (Evans and Johnson, 1989; Evans, 1994, fig. 13)	~ 15 % in sandstones but locally 50% (Bressler, 1951)	≤ 10% (Evans, 1994 table 3) 26% (Taylor et al., 1988, table 2)
Maximum size of clasts in polymict conglomerate	≤ 0.5 m (Gresens et al, 1981; Table 4 this study)	< 0.08 m (Bressler, 1951)	Mostly < 0.4 m but in some outcrops > 1 m (Table 3 this study)
Lags of pebbles and scattered pebbles < 7 cm	much more common than interbedded conglomerate (this study)		Much less common than interbedded conglomerate (this study)
Volcanoclastic units	Multiple felsic tuffs 1 to 12 m thick; FT ~ 45 ± 3Ma (Gresens et al., 1981)	Basal 500 m has rhyolite flows and tuffs and minor andesitic material (Walker, 1980)	Andesitic, up to 100s m thick; FT > 49 Ma ± 5 Ma (Cheney,1994, fig.8)
Organic matter	None (Hunting, 1943), but the uppermost member (Trd of Table 4) does have siltstones with 1.5 to 4.3 % total organic carbon (Evans, 1988, table 3.2)	Multiple seams in upper 750 m; 6 were mined from 1882 to 1963 (Walker, 1980)	None in this area, but the correlative Manastash Fm. to the south does contain minor coal (Walker, 1980).
Uppermost 1 to 2 km of formation	Abundant shale and siltstone but lacks conglomerate and tuff (Whetten, 1980a; Evans, 1994)	Abundant shale or silt-stone, but lacks conglomerate and tuff (Bresler, 1956; Walker, 1980)	Abundant shale and siltstone, but Tsa of Table 3 contains conglomerate
Red beds	Only a basal conglomerate, 0 to 200 m thick (Gresens et al. 1981)	Only a basal sandstone, < 60 m thick (Bressler, 1951)	None
Monomict diamictite	None (this study)	None described by Bressler (1951)	Tscd of Figs. 3 and 8A has mostly tonalitic clasts

Table 2. Characteristics of predominantly arkosic, non-marine, Eocene formations on the eastern flank of the Cascade Range (after Cheney and Hayman, 2009, Table 2). *Notes:* FT is fission track age from zircon in cited reference. NA is not applicable.

Structural Low. Swakane Biotite Gneiss is exposed in its core northwest of Wenatchee (Fig. 3; Tabor et al. 1987). The sedimentary rocks exposed in its core in the Wenatchee

area are either Swauk Formation (Gresens, 1983) or Chumstick Formation (Tabor et al., 1982). The Eagle Creek anticline is merely one of several major, northwesterly trending

Number	Method	Dates Ma	Sample	Reference
10	Fission-track zircon	41.9 \pm 6.8 to 48.8 \pm 7.2	Tuffs in <u>Chumstick</u>	Evans in Margolis (1994)
10	Fission-track zircon	47.7 \pm 7.7 to 66.4 \pm 3.9	Detrital in <u>Chumstick</u> sandstone	Evans in Margolis (1994)
1	K-Ar biotite	47.3 \pm 1.8	Tuff in Eagle Creek fault zone	Margolis (1989)
1	Fission-track zircon	51.4 \pm 2.8		Evans in Margolis (1994)
3	K-Ar whole rock	50.9 \pm 3.5 to 42.9 \pm 1.9	Intrusions in Eagle Creek Fault zone	Evans in Margolis (1994)
4	K-Ar mineral	40.1 \pm 2.5 to 45 \pm 1.8		Evans in Margolis (1994)
2	K-Ar biotite Wenatchee dome	43.2 \pm 0.4 42.5 \pm 1.6		Tabor et al., 1982
1	K-Ar biotite	46.2 \pm 1.8		Margolis (1989)
6	K-Ar adularia	43.6 \pm 2.0 to 45.5 \pm 2.0		Au mineralization

Table 3. Radiometric ages in the Wenatchee area.

folds in Eocene and older rocks on the eastern flank of the Cascade Range (Table 4, Fig. 3). Several of the anticlines, including the Eagle creek anticline) have steep reverse faults on their steeper northeastern limbs (Table 4). The Seattle fault (Pratt, 2008) is a similar feature.

The regional anticlines pass southeasterly down plunge into more gentle folds in the Miocene Columbia Basalt Group (Fig. 3). Cheney and Hayman documented two major episodes of folding. The Eocene rocks were folded along northwesterly axes about 40 Ma and are offset by north-south strike slip faults (Table 4, Fig. 3). The folding of the Columbia River Basalt Group occurred along the same northwesterly axes. Whereas the

Eocene folds have kilometers of structural relief, the younger folding only has hundreds of meters of structural relief (Cheney and Hayman, 2009). However, the younger folding governs the regional map pattern of all rocks, including the basement and Eocene formations, and is largely responsible for the Chiwaukum Structural Low (Cheney and Hayman, 2009).

VI. ECONOMIC GEOLOGY

Mineralization in the Wenatchee gold belt is in silicified and pyritized arkosic sandstones in the Eagle Creek fault zone. The L-D mine



Schematic drawing depicting age relationships and structural styles of dark-colored rocks of the Chelan Migmatite Complex. Encircled note the five main classes and variants of metabasite and basalt listed in Table 1. Small white bodies are leucosomes. Left-hand two-thirds of 1 shows features that typify the migmatite facies of CMC, and the right-hand one-third depicts typical metatonalite facies. The drawing is not to scale; i.e., the scale is internally variable with large-scale and small-scale features normalized to similar size.

TABLE 1. Mafic Magma Stages and Corresponding Rocks

Agmatite Blocks. Metaperidotite, metapymxenite, hornblendite, metagabbro.	3M	Mafic Synplutonic Dikes with Intermingled Silicic Rock. Microamphibolite (metagabb., metadior.) + trondhjemitic blebs, etc.
Layered Migmatite and Concordant Mafic Bodies Amphibolite (metagabbro, metadiorite, metatonalite) layers, schlieren.	3A	Appinitic Intrusive Bodies Appinitic hb gabbro, hornblendite, hb diorite, bi-hb tonalite.
Migmatitic Metabasite with intermingled Silicic Rock. Metagabbro, metadiorite + trondhjemitic blebs, marbling, etc.	STAGE 4	Late Synplutonic Dikes (less deformed, cut all leucosomes). Microamphibolite (metagabbro, metadiorite, metatonalite).
Mafic Layers and Schlieren in Metatonalite. Amphibolite (metagabbro, metadiorite).	4M	Late Synplutonic Dikes with Intermingled Silicic Rock. Microamphibolite + trondhjemitic blebs (etc.).
Early Synplutonic Dikes (disrupted, cut by leucosomes). Microamphibolite (metagabbro, metadiorite, metatonalite).	STAGE 5	Lamprophyre Dikes (post-metamorphic). Chiefly spessartite; some kersantite.

Figure 7. Schematic representation of the age relations in the Chelan Migmatite complex (Hopson and Mattinson, 1994, fig.5 and table 1).

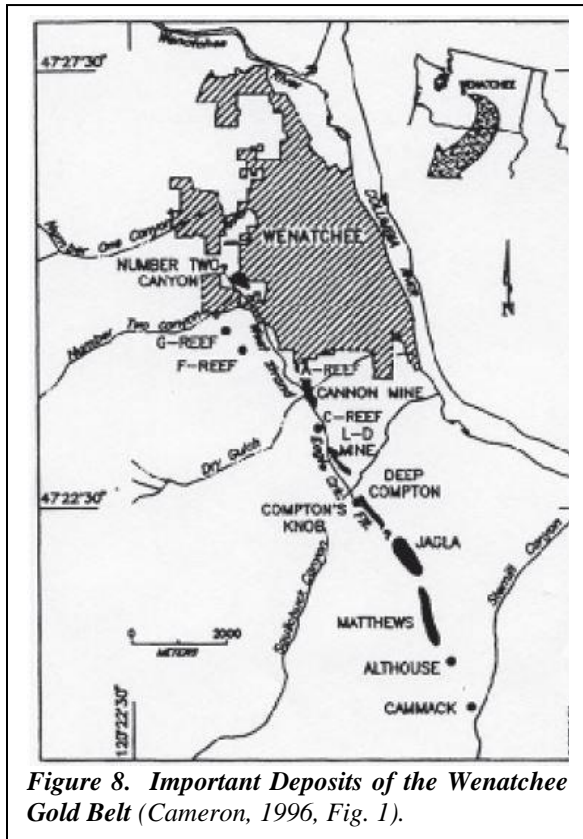
Folds	Rocks in core of fold	High-angle reverse fault on steeper NE limb	Cut by N-S faults	Maximum altitude of base of CRBG	Folds down plunge to SE in CRBG
<u>Swakane Creek anticline</u>	Pre-Tertiary crystalline	Unnamed fault (Gulick, 1990)		1450 m	Badger Mountain anticline, Moses Stool anticline (Gulick, 1990)
<u>Chiwawa River syncline</u>	“ <u>Chumstick</u> ” Formation		Coulter Creek fault (this study)	CRBG absent	
<u>Eagle Creek anticline</u>	Pre-Tertiary crystalline	Eagle Creek fault, but low angle to south (Patton and Cheney, 1971)	<u>Chumstick Creek & Icicle Creek faults</u> (this study); Wenatchee area (Patton and Cheney, 1971)	CRBG absent	Laurel Hill monocline, <u>Colockum Creek monocline</u>
<u>Peshastin syncline</u>	“ <u>Chumstick</u> ” Formation		<u>Chumstick Creek & Icicle Creek faults</u> (this study)	CRBG absent	
<u>Naneum Ridge anticline</u>	Pre-Tertiary crystalline	Camas Creek & Leavenworth faults (Cheney, 2003)	<u>Chumstick Creek fault</u> (this study)	2000	<u>Naneum Ridge anticline</u>
<u>Naneum Creek syncline</u>	<u>Swauk Formation</u>			1700	<u>Naneum Creek syncline</u>
<u>Table Mountain anticline</u>	<u>Swauk Formation</u>		Table Mountain anticline	1750	
<u>Kittitas Valley syncline</u>	Roslyn Formation			750	<u>Kittitas Valley syncline</u>
<u>Ainsley Canyon anticline</u>	Pre-Tertiary crystalline (Cheney, 1999)	Easton Ridge fault (Walker, 1980)		1450	<u>Ainsley Canyon anticline</u>

Table 4. Major northwesterly striking folds on the eastern flank of the Cascade Range.

(Fig. 8) produced 1.0 million tons of ore averaging 0.396 ounces of gold and 0.607 ounces of silver per ton (Patton and Cheney, 1971). The Cannon mine (1985 to 1994) to the north produced 4.1 million tons of ore

averaging 0.304 ounces of gold and 0.507 ounces of silver per ton (Cameron, 1996).

Mineralization consisted of disseminations in sandstone and individually mineable veins in the L-D mine (Patton and Cheney, 1971). At



the Cannon mine mineralization was disseminations in sandstones (especially brecciated sandstones) and in banded veins (mostly only centimeters wide) of fine-grained quartz-adularia-calcite (Cameron, 1996). The principle ore mineral is electrum (a native gold/native silver alloy). This type of mineralization is called epithermal.

Mineralization in the gold belt is confined to silicified arkose in the Eagle Creek fault zone on the northeastern limb of the Eagle Creek anticline. In the silicified arkose, mineralization consists of discrete veins, closely spaced veinlets, and disseminations (the latter two were bulk-mined). Gold grades are erratic. Blocks of silicified arkose are bounded by faults, which are septa of scaly (sheared), carbonaceous siltstone/mudstone. Individual siltstone/mudstone units vary significantly in thickness.

Margolis (1989, 1994) was impressed by the apparently coeval nature of (1) the arkosic rocks, (2) felsic plugs and tuffs, and (3) mineralization (Table 3). He also stressed the seemingly stratabound nature of alteration (especially silicification) and mineralization. Thus, he believed that the epithermal mineralization accompanied volcanism in the Chumstick Formation.

The restriction of veinlets and veins to the Eagle Creek fault zone suggests that it had an active role. Furthermore, Cameron (1996) noted that adjacent to faults, intersections of faults, or jogs in faults silicification is more intense and veinlets are more closely spaced. Thus, Cameron (1996) believed that the faulting focused the mineralizing solutions and generated sites for silicification and the deposition of ore.

In either case, the scaly mudstones/siltstones acted as aquitards for the mineralizing solutions (Margolis, 1989, 1994; Cameron, 1996).

Dating of adularia in the veinlets (Table 3) suggest that mineralization is about 44 Ma. Ore bodies and the Eagle Creek fault zone are dextrally offset by north-south faults (Patton and Cheney, 1971; Cameron, 1996). The Wenatchee Dome rhyodacite (Stop 2-5) is post-ore (Cameron, 1996) and is cut by the north-south faults (Patton and Cheney, 1971; Cameron, 1996). The rhyodacite is about 43 Ma (Table 3).

VII. MISSOULA FLOODS

Most of the floods were caused by jökulhlaups from the glacial ice damming glacial Lake Missoula. Evidence now exists for hundreds of such floods (Waite, 1994). The floods crossed the Columbia Plateau (mostly underlain by the Miocene Columbia River Basalt Group) of eastern Washington

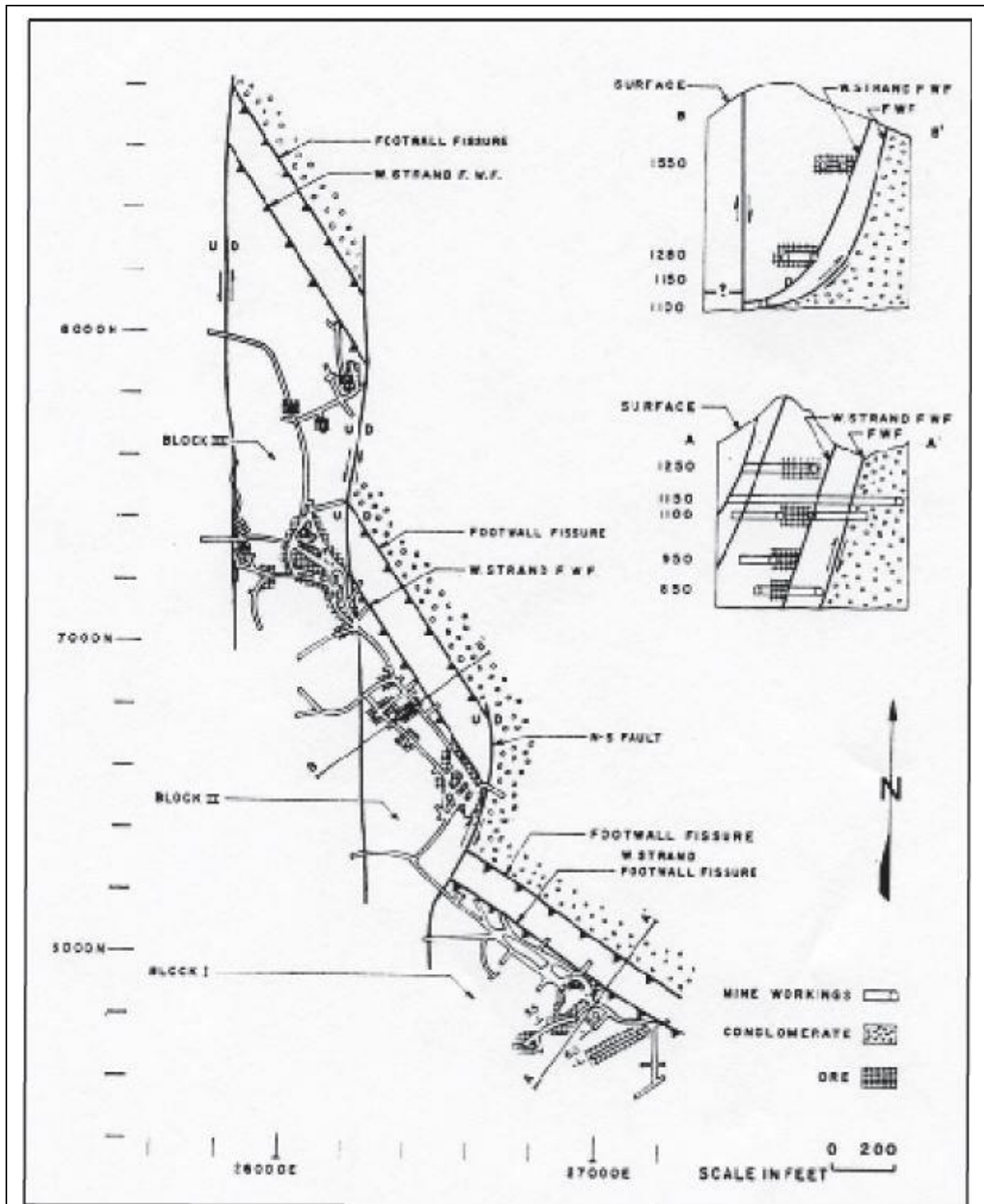


Figure 9. Generalized geology of the 1250 level of the L-D mine. Patton and Cheney (1971, fig.4). Ores in Block I and II are northwesterly dipping veins.

and adjacent Idaho and Oregon, hydraulically ponded at Wallula Gap on the Columbia River (at the Washington/Oregon border),

and surged up valleys tributary to the Columbia River. Present research in the Walla Walla valley suggests that similar

floods may have occurred during earlier Pleistocene ice ages (P. K. Spencer, May 2009, personal communication).

Where the floods crossed eastern Washington they caused the "channeled scabland". Examples of channeled scabland occur between Spokane and Grand Coulee. Bedrock exposures, predominantly of the Columbia River Basalt Group, are the channels. The intervening scabs are erosional remnants of loess on the basalt. The loess supports grasslands (both natural and wheat). The deepest channels are spectacular Grand Coulee and Moses Coulee (Stop 1-3).

According to Waitt (2009) the earliest flood, about 15,500 yr BP, down the Columbia River built the huge Pangborn bar at East Wenatchee (Stop 2-1). When the advancing Okanogan lobe of Cordilleran ice blocked the Columbia valley, several floods descended Moses Coulee and back flooded through Wenatchee. Once the Okanogan lobe blocked Moses Coulee, floods carved Grand Coulee and emptied into the Quincy basin; these floods also flowed up the Columbia River to Wenatchee (Stop 1-2); they ceased before 13,000 BP. The Okanogan lobe continued to block the Columbia valley until it failed about 12,700 BP. Late and smaller floods down the Columbia valley may have originated from glacial Lake Kootenay in British Columbia.

VIII. ROAD GUIDE

DAY 1#

From the Seattle area, drive eastward on I-90, cross the Columbia River at Vantage, and take Exit 149 (George) and SR 281 northbound to Quincy. At Quincy take SR 28 westbound (toward Wenatchee). At Milepost

25.1 of SR 28 is the WA DOT rest area at Babcock Bench. After using the rest rooms, continue on SR 28 toward Wenatchee.

At MP 23.3 park on the shoulder and walk downhill.

STOP 1-1: Contact and pinch-out of CRBG unit#

The Wanapum Basalt Formation is the middle unit of the CRBG. The Wanapum consists of several members. This is the Frenchman Springs member. Here (S.P. Reidel, personal communication, June, 2004) the Basalt of Sand Hollow (15.3 Ma) overlaps the basalt of Ginko (15.6 Ma). The Ginko flow has a well-developed basal zone of pillow/palagonite and an upper vesicular zone, which is partially oxidized. The Ginko flow is overlain by an arkosic interbed. The interbed is injected into the base of the Sand Hollow. Both the Ginko flow and the interbed are truncated by the Sand Hollow flow. The columnar jointing in the Sand Hollow flow is more closely spaced and inclined where the flow truncates the Ginko flow and the arkosic interbed.

Continue westbound on SR 28.

At Milepost 22.3 at Trinidad, turn west toward Crescent Bar. Continue downhill 0.9 miles to the T-junction and turn right. Proceed 0.1 mile to a small sand and gravel pit.

STOP 1-2: Rhythmic beds in Trinidad Bar & Giant Current Ripples of West Bar

Waitt's (1994).description is of this site is paraphrased here. The pit is near the top of Trinidad Bar, a gravel body 100 m thick. The pit originally exposed 19 rhythmic beds of gravel with silt tops. The mixed lithologies of the beds (white crystalline rocks and black

basalt) indicates a provenance from beyond and within the Columbia River Plateau. The systematic upward thinning and fining implies 19 separate and successively smaller floods, all of which were voluminous enough to flood this site 300 feet above the present valley floor. Foreset beds in the silts dip both up- and down-valley. This unusual combination apparently resulted from eddies in this alcove (Waite, 1994) when floods exiting the Quincy basin and backflowed upstream toward Wenatchee (Waite, 2009). In a now covered exposure 500 m to the east, Mount St. Helens “set S” tephra was near the top of fine gravel. This gives a date of approximately 13,000 ¹⁴C yr BP.

Across the valley the conspicuously asymmetric giant current dunes (ripples) on West Bar indicate down-valley flow. This bar and the lower, more riverward bar, which is studded with boulders, seem to be equivalent to bars at Malaga (downstream from Wenatchee) and at Chelan Falls (upstream from Wenatchee) (Waite, 1994).

Continue westbound (but now northward) on SR 28.

At MP 18, the mouth of Moses Coulee and the bar across it are visible ahead. The gravel in this bar is almost entirely basalt, indicating derivation from Moses Coulee, not from up the Columbia (Waite, 1994). Portions of the Trinidad bar overtop the Moses Coulee Bar (R.B. Waite, May 2009, personal communication).

At MP 14.2 turn right (east) on Palisades Road to drive up Moses Coulee. Pass “downtown” Palisades (11.2 miles), proceed another 1.5 miles, and stop opposite Trail End Road on the left. This side road is about 0.1 miles before the main highway beds to the left.

STOP 1-3: Thrust Fault in Moses Coulee

A northwest trending thrust fault cutting an anticline in the Columbia River Basalt Group is clearly visible on both sides of the coulee (Table 4). The importance of this stop is that it illustrates very young folding and thrusting (as does the Yakima fold and thrust belt 75 km to the southwest). The fault is a prime candidate for the 1872 earthquake (see Stop 1-10). Perhaps, future lidar surveys will indicate whether this fault is still active.

Continue up Moses Coulee. At 0.3 miles a gravel pit in a small flood bar on the right contains basaltic gravel with clasts ≤ 0.6 m in diameter and down-canyon dips. After rounding the bend at 1.0 miles, note the syncline in the basalts ahead. Continue about another 23 miles to the junction with US-2

The road joins US-2 on the top of a giant flood bar on the western side of upper Moses Coulee. The bar has a maximum height of 73 m, a maximum width of 1.2 km, and is 5.4 km long. The swale between it and on the west wall of the coulee is a maximum of 24 m deep.

Turn left (west) and follow US-2 about 8 miles to SR-172. Turn right (north) on SR-172 toward Withrow. At MP 6 is a potential photo-stop of Withrow and its moraine to the north. The moraine is 70 m high.

Continue 3.0 miles to just below the crest of the moraine and at MP 9.0 make a dangerous left turn into unimproved 9th NW Street. Before making this turn note the first appearance of “haystack rocks” to the west. Haystack rocks are erratics of the entablature of Columbia River basalts. Weathering along the many joints of the entablature generated talus around the erratics, so that from a distance, the erratics and their talus

commonly look like haystacks. However, haystack rocks can be the size of large houses.

STOP 1-4: Withrow Moraine

To the south and below the moraine is Withrow and the relatively flat surface of the Waterville Plateau. The ridge to the southwest is Badger Mountain, an anticline in CRBG on strike with anticline in Moses Coulee (Stop 1-3). Behind Badger Mountain in the distance (40 miles) is Mission Ridge south of Wenatchee. Mission Ridge is underlain by CRBG which dips easterly off the Cascade Range (Stop 2-1). To the west is the Cascade Range dominated by Mount Stuart (9415 feet).

Very carefully exit NW 9th Street and return southward toward Withrow. At MP 8.0, turn right (west) on NW 8th (Sprauer Road). Proceed 3.0 miles and turn right (north) on F NW Street. Proceed about 6.2 miles to a potential photo-stop of the Withrow moraine, which strikes N-S and is studded with haystack rocks. Continue another 0.5 miles around a curve and then another 0.3 miles to a gravel pit on the south side of the road. Walk to the south end of the pit.

STOP 1-5: Soft-sediment Deformation below the Withrow Moraine

An isoclinal fold, dipping gently eastward occurs in unconsolidated silt. The eastern wall of the pit is till capped by a haystack rock. Stratigraphically below the folded silt (to the west) is moderately dipping (eastward) and, apparently, unfolded cobble gravel (outwash).

Continue eastward 0.5 miles to the junction with McNiel Canyon Road. Turn left (westbound) toward Chelan. Proceed 1.3 miles to MP 7 where the road begins its

descent to the Columbia River. This is the western edge of the Waterville plateau. The hill south of the road has an altitude of 3191 feet. The altitude of the Columbia River is 770 feet.

STOP 1-6: Invasive Flow or Sill of Columbia River Basalt

Although subtle, Columbia River basalt here appears to be intrusive into overlying sedimentary rock, which implies that the basalt is a sill. Tabor et al. (1987) mapped the Hammond sill (invasive flow) of the Wenatchee area to within 13 km of this stop.

At Milepost 4.9, look for pullout and stop for a photogenic overview of Lake Chelan and the gorge of the Columbia River.

Continue 5.5 miles to the T junction with US 97. Turn right toward Chelan Falls, to cross the Beebe ridge over the Columbia River. At 0.6 miles at the junction with SR 150, continue north on US 97 for another 1.1 miles and park on the right (east) shoulder near a large road cut.

STOP 1-7: Cross cutting relations in the Chelan Migmatite #

The jargon for this stop is that migmatite is a rock with a mixture of igneous (or igneous appearing) and metamorphic materials. Leucosome is the light-colored part of a migmatite. Restite is the less mobile parts of a migmatite. Tonalite is a plutonic igneous rock with more than 20% quartz, in which the major mafic mineral is hornblende and 90% of the feldspar is plagioclase. Trondhjemite is a similar rock, but biotite is more abundant than hornblende. Lamoprophyres are fine-grained, dark-colored rocks with mafic phenocrysts but no feldspar phenocrysts. Lamoprophyre is an alkalic, not a mafic, rock.

Figure 7 is a schematic diagram and table from Hopson and Mattinson (1994) of the age relations and structural styles of the rocks of the Chelan Migmatite Complex. Not all relations can be seen at any one outcrop. Stops 1-7 and 1-8 are parts of the left-hand (migmatitic) portion of the schematic diagram. Hopson and Mattinson (1994) recognized five different ages of ultramafic to mafic rocks ranging from pre-migmatitic igneous bodies (former xenoliths) to post-migmatitic (Eocene) dikes. Although the field relations and petrographic evidence for the relations in Figure 7 appear convincing, isotopic and other geochemical supporting evidence has not yet been published.

Although foliations are locally variable, their overall orientation on the outcrop-scale defines domical and irregular protrusions with down-dip mineral lineations at moderate to steep angles, which Hopson and Mattinson, (1994) attributed to a huge, amphibolite-facies, mushy, ductily rising (protodiapiric) mass emplaced into mid-crustal rocks.

According to Hopson and Mattinson, the relative ages of the rocks on both sides of highway at Stop 1-7 are:

1. metatonalite derived from Triassic Marblemount/Dumbbell plutons,
2. xenoliths of metagabbro and biotitic hornblendite (remnant cumulates) = mafic episode 3M,
3. synplutonic dioritic dikes into anatectic tonalite = 3M or 4M,
- 3a. synplutonic mottled mafic dike of comingled dioritic and trondhjemitic melts = 3M or 4M,
4. leucotondhjemitic and granitic veins, patches, and dikelets of residual melt from anatectic tonalite,
5. biotitic granodioritic dikes from the nearby Arbuckle Mountain pluton (81 Ma K-Ar cooling date), and

6. lamprophyre dikes (5M) associated with the nearby 50- to 45-Ma Cooper Mountain and Duncan Hill plutons. Note hornblende (and look for biotite) in these dikes.

Turn around and return south on US 97 to the junction with SR 150. Turn right (west) on SR 150 and proceed up hill 1.3 miles and stop on the right shoulder opposite a very high road cut.

STOP 1-8: Swirly Chelan migmatite

This is the classic layered (and very photogenic) migmatite locality of Chelan Falls and Stop 3 of Hopson and Mattinson (1994). Refer again to Figure 7 for age relations and structural styles. According to Hopson and Mattinson, the relative ages of rocks here are:

1. metatonalitic to metadioritic orthogneiss derived from the tonalitic protolith,
2. former xenoliths of gabbro and pyroxenite = 1M,
3. layered dioritic to trondhjemitic migmatite = 2M plus leucosomes and restite,
4. synplutonic dioritic dikes = 3M,
5. trondhjemitic residual dikes and veins cutting 3M, and
6. lamprophyre dike = 5M, intruded during post-metamorphic cooling and uplift.

Continue up hill toward Chelan for 2.2 miles to the junction of SR 150 and Milepost 235 of US 97A. Turn left (west) to Chelan. At MP 236.1 of US 97A and junction with SR 150 turn right toward Manson. Continue 3.2 miles on SR 150 and turn around at Eldorado Road. Return 0.2 miles toward Chelan and park on the narrow shoulder.

STOP 1-9 (optional): Erratic of CRBG at Manson

Note the huge erratic of CRBG on the hillside above a house. Contemplate the potential societal impact of this erratic. The presence of this erratic indicates that the Okanogan lobe entered the eastern portion of the valley now occupied by Lake Chelan. Note the narrow valley above the southern shore of Lake Chelan. This valley, Knapp Coulee, was the outlet for the glacial lake when the Okanogan lobe blocked the eastern end of the valley (the present site of the Chelan River).

Return to downtown Chelan and take US 97A toward Wenatchee. From MP 229.0 (in migmatite) to MP 225.0 US 97A descends Knapp Coulee. At MP 218.3 at Earthquake Point below Ribbon Cliffs park on the right (west) next to the interpretive sign.

STOP 1-10: Entiat Orthogneiss at Earthquake Point #

The sign is no longer informative.

Climb to the first bench of the quarry to see blocks of the rockfall in the Columbia River (now Lake Entiat behind Rocky Reach dam) caused by the 1872 earthquake.

This is the tonalitic interior of the Entiat orthogneiss. Elsewhere this orthogneiss is intrusive into the Chelan Migmatite Complex and the Napeequa mafic schist of the Mad River terrane (Hopson and Mattinson, 1994; Miller and Paterson, 2001). The Entiat pluton is sheeted, zoned inward from mafic to felsic, 72 to 78 Ma, 80 by 8 km, and crystallized at 6.0 to 7.2 kbar (Miller and Paterson, 2001).

Mafic dikes form the ribbons of Ribbon Cliffs. Float containing hornblende suggests that the dikes may be equivalent to

lamprophyric dikes of 5M of Hopson and Mattinson (1994).

The 1872 earthquake has an interesting human history. Actually, because the population of central Washington was sparse at the time, little is known about the location and characteristics of the earthquake. Because aftershocks were felt, the earthquake was shallow. It was about 7.2M.

When the epicenter of the 1872 earthquake was assumed to be at Ribbon Cliffs, this was a problem in the 1970s for the utility (WPPSS) that proposed to build additional nuclear power plants on the Hanford Reservation. However, consultants for WPPSS concluded that the epicenter most likely was near Hope, BC. Because Hope is west of the crest of the Cascade Range, this epicenter became a major problem for the utility (Puget Power) that proposed to build two nuclear plants on the Skagit River near Sedro Woolley. The utilities subsequently convened a “blue ribbon panel” that placed the epicenter between Earthquake Point and Hope—east of the crest but sufficiently distant from Hanford. Malone and Bor (1979) recognized that the seismic velocities of the crusts of central and western Washington are different; they concluded, therefore, that an epicenter near Ross Lake best explains the distribution of the isoseismal lines. Ross Lake is between Sedro Woolley and Hope and is west of the Cascade crest.

An equally large (7.2 M) earthquake occurred on the eastern side of Vancouver Island in 1946. First motion studies showed that the causative fault had dextral movement. The earthquake was shallow, and ground rupture did occur.

At Earthquake Point we might ponder the greatest seismic risk for most of the population of Washington. The choices are:

1. a large to Great Earthquake offshore associated with the Cascadia subduction zone,
2. earthquakes 50 to 70 km deep beneath the Puget Lowland (such as 1949, 1965, and 2001),
3. shallow earthquakes on the Seattle or related faults,
4. shallow 1872- and 1946-like earthquakes that might be associated with dextral faults, or
5. other

In recent years interest has renewed as to the location of the 1872 earthquake. Prime candidates might be the Eagle Creek and Entiat faults (Figure 3). However, because it is demonstrably younger, the thrust fault in Moses Coulee is a better candidate. Several such folds and thrusts occur in the region (Table 4), including in Seattle (Pratt, 2009).

Continue south on US 97A

At MP 217 note the moderate northerly dip of the Swakane Biotite Gneiss. This is the northern limb of the Swakane Creek anticline (Fig. 3). The crest of the anticline is near MP 205.7. At MP 205.5 make a left turn into the viewpoint for Rocky Reach dam.

STOP 1-11: Swakane Biotite Gneiss

Examine the Swakane Biotite Gneiss with sillimanite (fibrolite) and boudinaged pegmatite.

According to Paterson and others (2004) the gneiss is a Cretaceous metaclastic assemblage ≥ 1.1 km thick and ≈ 73 Ma (U/Pb on zircons). It is so young that it contains none of Cretaceous arc-related plutons that are so common in the northeastern Cascade Range. Metamorphism induced pressures of 10 to 12 kbar and maximum temperatures of 640 to 750°C. Although the Swakane Biotite Gneiss is the

youngest terrane in the northeastern Cascade Range, it is structurally the lowest unit in the range and has undergone > 40 km of uplift (exhumation).

The island of Swakane Biotite Gneiss in Lake Entiat may be a landslide block. If so, from which side of canyon did it originate? Note that the island is studded by boulders related to the Missoula floods.

Continue south on US 97A. In 5.2 miles turn right (west) on Ohme Gardens Road. and proceed 0.9 miles. Park on the wide shoulder on the left (east).

STOP 1-12 (optional): Overview of Tertiary unconformity-bounded sequences

The trees on the ridge of Swakane Gneiss to the north are an important local attraction, Ohme Gardens. Two generations of Ohmes created and nurtured an oasis of alpine flora in the desert of Wenatchee. The State of Washington purchased the property in the mid-1990s and installed new toilets, handrails, and weeds. Nonetheless, the gardens, now a Chelan County park, are still worth a visit (on your next trip to Wenatchee) and do provide even better views of the relations seen at this stop.

The Entiat fault, which juxtaposes the Swakane Gneiss against the Eocene arkosic Chumstick Formation of the Challis sequence, is west of Ohme Gardens. On the southern edge of the city of Wenatchee the variable dips of the sandstones of the Chumstick Formation on the northern end of flat-topped Wenatchee Heights probably mark the southeastern continuation of the Entiat fault. Beyond Wenatchee Heights the fault passes below the hummocky topography of a large prehistoric landslide and below CRBG.

Across the Columbia River to the east are two major unconformities. Along the lower one, Wenatchee Formation is nonconformable upon Swakane Gneiss. The Wenatchee Formation apparently consists of two different units. Southwest of Wenatchee it has quartz pebble conglomerates and lignitic shales that have an Eocene flora (Stops 2-3 and 2-4) (Tabor and others, 1982). In contrast, at Blue Grade across the Columbia River from here, the formation is tuffaceous, has numerous paleosols, has been mined for clay, and yielded fission-track ages from zircon of 34.5 ± 1.2 and 39.8 ± 9.0 Ma (Tabor and others, 1982). The Blue Grade succession is interpreted (Cheney, 1997) to be the distal portion of the Kittitas sequence or synthem, proximal portions of which are exposed in the southern Cascade Range.

Along the upper unconformity near the skyline, flows of MSU R2 of the Grande Ronde Basalt of the Walpapi synthem unconformably overlie the Blue Grade succession.

The high ridge to the south above the city of Wenatchee is Mission Ridge (see Stop 2-1).

DAY 2

Use the inset in Figure 1 to access North Eastmont Avenue in East Wenatchee. Proceed uphill on North Eastmont Ave, which becomes Badger Mountain Road. Continue past a major switchback. Near the top of the hill, which is the top of the great Pangborn bar of East Wenatchee (Waitt, 1994), turn left (west) on Fancher Heights Boulevard. Proceed 0.2 miles and turn left on Grant Avenue. Continue 0.2 miles to the Pangborn-Herndon Memorial.

STOP 2-1: Overview from the Pangborn-Herndon Monument on Pangborn Bar #

First, reverse Pangborn and Herndon

Then reverse the Pangborn bar. It is the largest of Missoula flood bars and, perhaps, the largest in the world. The P-H monument is at an altitude of 1428 feet; the altitude of the Columbia River is 606 feet. The bar is capped by giant current dunes (mega-ripples) and a spectacular cache of Clovis artifacts (Waitt, 1994).

In the boulder field of Wenatchee/East Wenatchee, angular clasts of Swakane gneiss have a maximum intermediate diameter of 13 m (Waitt, 1994)! As Waitt (1994) noted, the Swakane Biotite Gneiss crops out south of the limit of glaciation by the Okanogan lobe; so these boulders were not ice-rafted. Perhaps, they were deposited by the causative flood of Pangborn bar.

Mission Ridge dominates the southern skyline. It is underlain by MSU N2 of the Grande Ronde Basalt. The basalt rises from an altitude of about 750 feet at Rock Island dam on the Columbia River to > 6000 feet. Clearly, the CRBG dips eastward off the Cascade Range. Thus, the present topography of the Cascade Range is younger than the Columbia River Basalt Group, < 5 Ma (also see Stop 2-14).

The CRBG of Mission Ridge unconformably overlies the Swauk, Chumstick, and Wenatchee formations. The break in slope at the base of the ski slope is the contact with the Swauk Formation.

The prehistoric Malaga landslide is at the eastern end of Mission Ridge.

To the west, Mount Stuart is west of the Chiwaukum Structural Low. Mount Stuart is the highest non-volcanic peak in the central Cascade Range. It is underlain by a Cretaceous tonalitic batholith. Assuming that

CRBG once passed over the top of Mount Stuart, the structural relief on the Cascade Range anticline is > 3.5 km

The variously dipping Chumstick strata on the northwest end of Wenatchee Heights (near Stop 2-2) probably mark the Entiat fault.

Knobs along the ridge southwest of the city of Wenatchee are various small intrusions, Rooster Comb (near the L-D mine, Stop 2-2), Wenatchee Dome (at the Cannon mine, Stop 2-5), Squaw Saddle, and Castle Rock. These intrusions are in or near the northwesterly trending Eagle Creek fault zone of Figure 3.

Return to Badger Mountain Road. An even more spectacular view than Stop 2-1 occurs at the base of CRBG up Badger Mountain Road (on the way to Waterville). Alas, this trip returns downhill to SR 28 (Sunset Highway). At the junction of SR-28 and SR-285 note the huge, angular boulders of Swakane Biotite Gneiss, but take SR 285 over the bridge to Wenatchee. On the bridge, manoeuvre into the left lane and exit on Mission Street (by following the signs to the Mission Ridge Ski Area). After Mission Street becomes Squilchuck Road (on the way to the Mission Ridge Ski Area), be alert for a right-hand turn onto Methow Street. Proceed to the former L-D mine in cliffs to the right.

STOP 2-2: Former L-D Gold Mine

This is stop 7 of Margolis (1994). Rather than take the hikes in Margolis (1994) we will confine our attention to the lack of reclamation and to roadside outcrops and blocks.

Note the L-D mine of Figure 8. Figure 9 shows the geology of the mine. The thrust faults are the northeastern portion of the Eagle Creek fault zone. Note that a

conglomerate (a representative of which we will see at Stop 2-6) is in the footwall of the thrust system.

The mine rocks consist of silicified arkose, which was, appropriately, called “bastard granite” by miners. The outcrops and blocks (from uphill) display two styles on mineralization (veinlets in silicified arkose and breccia composed of fragments of veinlets). These styles produced most of the tonnage at the L-D mine (Patton and Cheney, 1971) and are common at the Cannon mine (Cameron in Margolis, 1994). However, unlike the Cannon, at the L-D mine individual northward dipping veins were large enough to mine separately (Patton and Cheney, 1971).

Residences and retaining walls south of the mine are faced with gossanous, silicified sandstone quarried from the mine. E. H. Lovitt marketed this decorative rock as “Autumn Leaf”.

Use the road log of Margolis (1994) to proceed directly to his Stop 9 on Wenatchee Heights. *En route*, also note his descriptions of the Chumstick and Wenatchee formations and of the Pliocene basaltic diamictite.

STOP 2-3: Overview of Eagle Creek fault from Wenatchee Heights #

This is Stop 9 of Margolis (1994) and the NORCO well site on Wenatchee Heights (see Figure 10a). We are 1180 feet above Squilchuck Creek to the northwest. The NORCO well and exploration drilling of the past three decades encountered mineralization beneath Wenatchee Heights (compare Figs. 8 and 10-).

The cross section of Figure 10A illustrates the view from looking to the northwest. Note the different appearances of (1) the tan

Nahahum Canyon Member of the Chumstick Formation northeast of the thrust (in the footwall), (2) the rusty, silicified, and apparently vertically dipping rocks of the L-D mine (Swauk or Chumstick formation), and (3) the Wenatchee Formation (with gray and pink slopes in the Pitcher syncline southwest of the mine rocks). The different appearances of the Nahahum Canyon Member and the Wenatchee Formation led Patton and Cheney (1971), Gresens (1983) and Margolis (1989) to believe that they are different units, even though they are compositionally similar and occur in the same stratigraphic and structural position. Also note that northerly trending faults dextrally offset the mine rocks (see Figures 9 and 10A). In contrast to what is shown in Figure 10A, which shows a fault between the mine rocks and the Wenatchee Formation (because the Wenatchee Formation and Nahum Canyon Member were believed to be different units), the Wenatchee Formation is unconformable on the mine rock (Gresens, 1983, Margolis, 1989).

The former Cannon mine (Stop 2-5) is on the other side of the ridge a mile northwest of the L-D and is in the same fault zone (Fig. 10A).

Rooster Comb north of the mine rocks on the ridge above the L-D mine is a dacitic intrusion. It is the offset portion of Wenatchee dome (Stop 2-5) at the Cannon mine (Patton and Cheney, 1971, fig. 2; Cameron, 1996, fig. 3)

Looking to the NNW, the high-angle Entiat fault bounds the sedimentary rocks of the Chiwaukum Structural Low. The fault passes southwest of Burch Mountain, the highest hill north of Wenatchee and west of the Columbia River. Under downtown Wenatchee, the fault probably is marked by the main northwesterly streets of the city.

Return towards the L-D mine. About ½ mile downhill from the hairpin switchback in SW/4 section 34 in Figure 2 of Margolis (1994, p. 17), pull out on the northwest shoulder.

STOP 2-4: Overview of Halvorsen thrust

This stop substitutes for Stop 8 of Margolis (1994). Note the distinguishing characteristics of the Wenatchee and Chumstick formations. Then, identify the features on the southwestern end of the cross section along Squilchuck Creek in Figure 10B, the Eagle Creek fold and thrust belt.

Proceed back down Squilchuck Road past the L-D mine. At the intersection of Mission Street and Crawford Street (Fig. 1) turn left on Crawford Street. Where it intersects Miller Street, turn left (south) on Miller Street, proceed 0.5 miles to the end of the street, and park at the Wenatchee School District building at the end of Miller Street. This is the site of the former Cannon mine.

STOP 2-5: Wenatchee Dome, former Cannon Mine, and A-Reef

The office building of the Wenatchee Public School system formerly was the office building of the Cannon mine. The mine closed in 1994. Permission to visit the mine site must be obtained from Wenatchee Public Schools (509 663-0555). “A reef” (Stop 3 of Margolis, 1994) is accessible without permission because it is on WA DNR land.

In addition to hiking to Stops 1 (Wenatchee Dome), 2 (B Reef), and 3 (A Reef) of Margolis (1994, p. 6-8), note the reclamation and compare it to the L-D mine. We may be able to drive to the foot of A-Reef.

As part of the reclamation, the headframe and mill of the mine were removed, and the

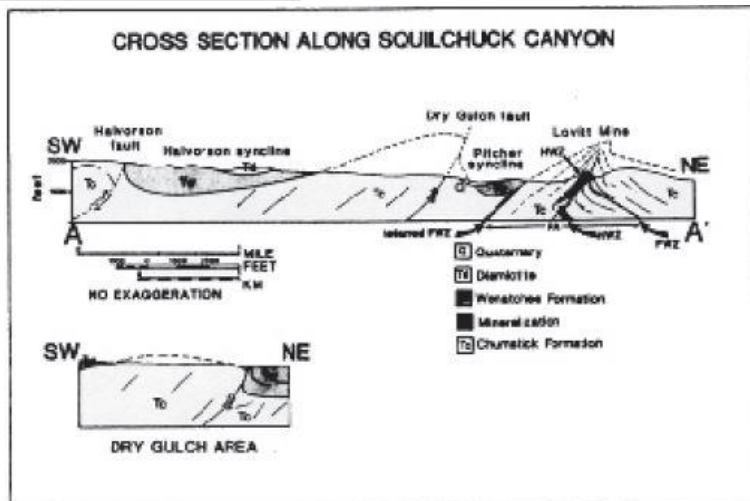
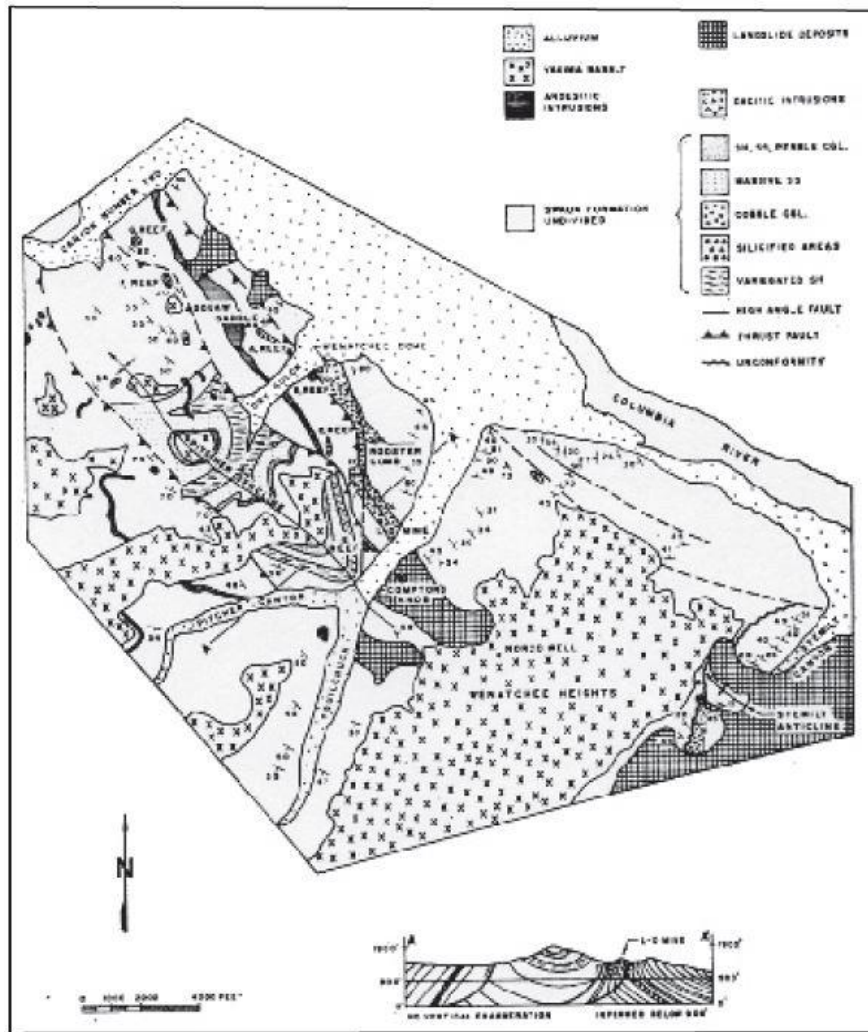


Figure 10. Geology of the Eagle Creek fault zone. Top is Figure 2 of Patton and Cheney, 1971). The Cannon mine is on NW side of Wenatchee Dome. Two revisions of this map are that the rocks in the Pitcher Syncline and above the unconformity in Stemilt Canyon are the Wenatchee Formation of Gresens (1983), and the Yakima Basalt is the Pliocene diamictite of Tabor et al. (1982), Gresens (1983) and Margolis (1989). **Bottom** is Figure 3 of Margolis (1989). Abbreviations are HWZ = hangingwall zone of mineralization; FWZ = footwall zone of mineralization, and PA = propylitic alteration.

plugged. However, during development of the mine, the decline and shaft were sunk in Wenatchee dome for better stability. Sand was quarried from the Wenatchee Formation in Dry Gulch for backfill in the mine. Previously, E.H. Lovitt quarried the sand and sold it (and his ore) as flux to the (now defunct) ASARCO copper smelter in Tacoma. The tailings impoundment and the quarry in Dry Gulch are almost visible from the upper adit of A Reef (Margolis, 1994, Stop 3).

The view of the Wenatchee area from the top of Wenatchee Dome (Stop 1 of Margolis, 1994) is excellent. Across the Columbia River is the gigantic Pangborn bar (Stop 2-1).

Figure 11 illustrates the complexity of deformation in the Eagle Creek fault zone in the mine. Another example of deformation is the dismembered siltstone at the lower adit of A Reef. During deformation, changes in volume in the Chumstick Formation and in the mine rocks (here and at the L-D mine) were concentrated in siltstone; whereas, sandstone was more competent (and brittle). The siltstones were aquitards for the hydrothermal solutions that caused the mineralization (Patton and Cheney, 1971; Margolis, 1989, 1994; Cameron, 1996).

The upper adit of A Reef has a 5-cm wide, banded (epithermal) veinlet similar to those bulk-mined underground at Cannon.

The post-ore, dextral Wedge fault cuts Wenatchee Dome (Er in the Fig. 11). Much of the mining occurred, not near the shaft in Wenatchee dome, but beneath the stables of the Applelatchee Riders (across the street). This area is on the west side of the N-S Wedge fault. Another N-S fault probably is required to offset the conglomerate in the footwall of the Eagle Creek fault from Applelatchee Riders to Stop 2-6.

After returning from A Reef, drive 0.5 miles north on Miller Street. Turn left (west) on Crawford Street. Turn left (south) on Oak Street. Turn right (west) to 1123 Splet Street.

STOP 2-6: Basal conglomerate of the Nahahum Canyon Member

The footwall conglomerate of the L-D mine (Fig. 9) is a distinctive unit. Unfortunately, few good outcrops of this conglomerate exist within easy walking distance. Although no outcrop remains at 1123 Splet, large fragments from the excavation for the site are in the roadside retaining wall. Note the size and rounded nature of the clasts. Clasts of vein quartz are more numerous than clasts of felsic volcanic rock. Although the conglomerate crops out poorly in the area, previous geologists easily mapped it by its distinctive “float” of quartz pebbles.

Return to Miller Street and follow it northward to SR-285 (the main avenue of Wenatchee). Turn left (northwest) and proceed about 1.3 miles to Horselake Road.

Horselake Road is on the northwest side of SR-285 about 0.3 miles southwest of the bridge over the Wenatchee River. Follow Horselake Road for about 1 mile (west 0.2 miles, north, 0.5 miles, then west 0.3 miles) to prominent outcrops on the south side of the road. J.T. Figge kindly supplied the directions to, and information for the description of, this stop.

STOP 2-7 (optional): Touche Beds

These are Touchet Beds, slack-water sediments that accumulated in glacial Lake Lewis behind Wallula Gap during the Missoula Flood events. Deposits of this type also occur near Touchet in the Walla Walla valley and in the Yakima valley (Waitt, 1994,

fig. 44). Here, the beds are well-stratified, range from ~5 – 30 cm in thickness, and are typically buff to gray in color. Many display graded bedding, some of the beds exhibit current-flow indicators. In many places, the relationship between individual beds appears unconformable. In other places, relationships are not so clear. About 30 distinct beds occur here. The prevailing interpretation from the type section is that each bed represents a different flood event (Waitt, 1980, 1994).

Return to S-R 285 and turn left (northwest). Then, 0.2 miles from the middle of bridge over the Wenatchee River, bear right on Easy Street. At 2.5 miles Easy Street curves northward. Continue another 0.4 miles, take a sharp left, and park on the shoulder headed south. Walk back up Easy Street to view a reference section of the Nahahum Canyon Member (Gresens et al., 1981).

STOP 2-8: Nahahum Canyon Member of the Chumstick Formation #

The outcrops consist of buff sandstone and black siltstone and black shale in planar beds 0.1 to 2 meters thick. The sandstone to siltstone and shale ratio is about 2:3. The sandstones have ripple marks and flute casts (Gresens, 1983). The beds dip to the NE. Note that deformation preferentially occurs in black shale, with resultant dismemberment of thin beds of sandstone. This type of deformation also is common along the Eagle Creek fault in the Wenatchee area (Stop 2-5).

The total organic content of the black rocks is as high as 4% to 5% (Evans, 1988, table 3.2). An interesting speculation is whether these rocks, rather than discrete beds of coal in the Roslyn Formation, might be the source rocks for natural gas beneath the Columbia River Basalts in the Yakima area.

Drive 0.3 miles south downhill to join US 2 at MP 117.3. Turn right toward Leavenworth. At MP 104.7 turn southbound on US-97 for Cle Elum and Seattle.

At MP 178.1, US-97 crosses the covered, northwesterly trace of the main strand Leavenworth fault (Fig.3). One mile to the south the highway enters the gorge of Peshastin Creek in pelitic rocks of the Ingalls Tectonic Complex. Note that columnar jointed Teanaway dikes intrude the Ingalls Tectonic Complex.

At MP 174.0 is Blewett! The Historical Marker relives the glory days of gold mining between 1877 and 1910 in Culver Gulch west of the highway (Margolis, 1994; Woodhouse et al., 2002). Continue southbound on US 97 through the Ingalls Tectonic Complex. At MP 172.1, park in the large area on the southwestern (left) side of the road.

STOP 2-9 (optional): Conglomerate of Tronsen Creek and the Magnet Creek Fault Zone

Walk about 200 m south on US-97. On the eastern side of the highway is a photogenic exposure: a small normal fault in the conglomerate of Tronsen Creek Member of the Swauk Formation (Tsc in Fig. 6) is occupied by a Teanaway dikelet. The polymictic conglomerate contains clasts of greenschist-facies rocks of the Ingalls Tectonic Complex and of tonalite similar to the Mount Stuart batholith.

Walk back to the parking area. The northeasterly striking Magnet Creek fault passes just north of the parking area. It juxtaposes the pre-Tertiary Ingalls Tectonic Complex on the northwest against the Swauk Formation to the southeast. The fault bounds part of the nose of the basement rocks in the

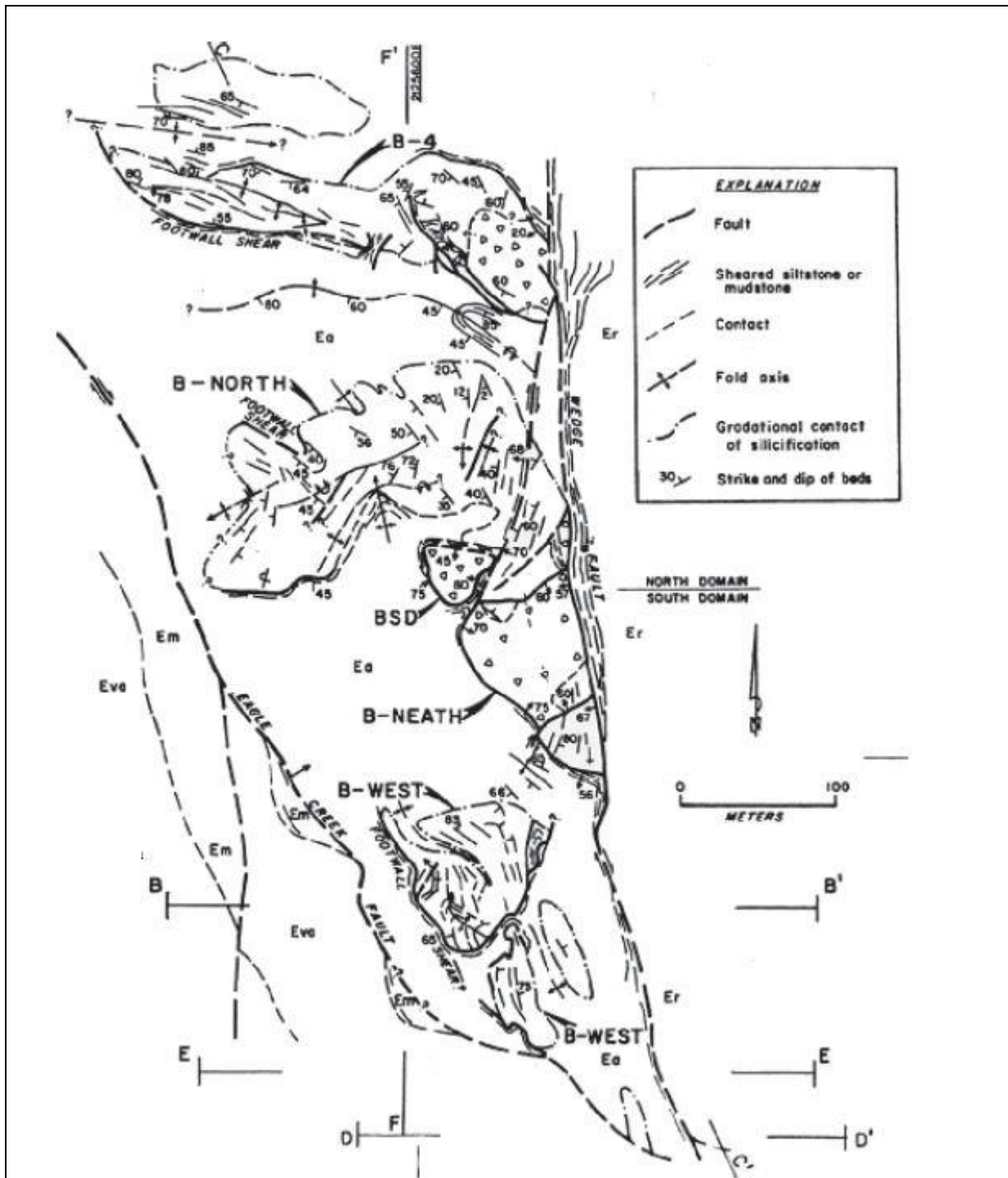


Figure 11. Deformation within the Eagle Creek fault zone at the Cannon Mine (Cameron, 1996, fig. 8 of the 600 (183 m level of the Cannon mine). The Wedge fault is a post-mineralization, dextral, N-S fault that offsets the northwesterly trending Eagle Creek fault zone. Ea is arkose; Er is the post-mineralization Wenatchee Dome rhyodacite; Em is mudstone and Eva is andesite.

Naneum Ridge anticline (Fig. 3). Sheep Mountain above and northeast of the

highway is mostly greenstone of the Ingalls Tectonic Complex. Across the highway,

black serpentinite is against strata of the Swauk Formation, which are intruded by variably fractured and altered Teanaway dikes.

Continue southward on US-97 to Blewett Pass (formerly Swauk Pass) at MP 163.9. Turn east (left) and proceed 0.4 miles (past the end of the pavement) to the USFS toilet on the right side of the road.

STOP 2-10: Scenic View of Tronsen Ridge

100 m back down the road from the toilet is a view (through trees) of much of the Swauk Formation. To the southeast (far right) are well forested, flat-topped ridges capped by nearly flat lying Columbia River Basalt Group. The inter-regional unconformity below the basalt can be visualized by extrapolating the basalt northward over strata of the Swauk Formation, which dip about 40° to the northeast. The thick-bedded strata on the southern part of the ridge are the basal conglomeratic Tronsen Creek Member of the Swauk Formation (Tsc in Fig. 6). Farther north, the middle portion of the ridge is underlain by the sandstones of Swauk Pass Member of the Swauk Formation (Tss in Fig. 6); the sandstone also has thick beds in it (which makes it indistinguishable from the Tronsen Creek Member at this distance). On the barren slopes to the north are the thinner and planar-bedded siltstone and sandstone of the Tronsen Ridge Member of the Swauk Formation (Tsr in Fig. 6). The Tronsen Ridge Member dips $\geq 50^\circ$ northeastward and is unconformable on the Swauk Pass and Tronsen Creek members. Nearly vertical Teanaway dikes are conspicuous as ribs in the Tronsen Ridge Member and are present (but less conspicuous) in the other two members.

Return downhill to Blewett Pass on US-97 and turn left (southbound but here westward) on US-97. Proceed to MP 163 and park on

the very wide left (south) shoulder of the highway.

STOP 2-11 (optional): Sandstone of the Swauk Pass Member of the Swauk Formation #

The sandstone and black siltstone are typical of the Swauk Pass Member of the Swauk Formation (Evans and Johnson, 1989, fig. 4). This (Tss in Fig. 6) is the areally most extensive member of the Swauk Formation (Tabor et al., 1982). Here, the three thick beds of massive sandstone in generally upward thinning successions may be crevasse splays on a flood plain represented by the black siltstones. Fossil palm fronds have been collected here.

Continue southbound on US 97. At MP 161.2, park on the very narrow shoulder and climb to the quarry.

STOP 2-12 (optional): Teanaway Dike cutting a volcanoclastic unit in the Swauk Pass Member

An intermediate volcanoclastic rock with felsic clasts occurs in the Swauk Pass Member (Tss of Fig. 6). The map of Tabor et al. (1982) shows that volcanoclastic rocks such as this are minor interbeds in the Swauk Pass Member. This one has a strike length of 8 km (Taylor et al., 1988). Remnants of a Teanaway dike occur on the wall of the quarry. The back-fill in the quarry includes serpentinite of the Ingalls Tectonic Complex.

At the eastern end of the quarry, beds of sandstone are nearly vertical and somewhat boudinaged. Given these dips and intensity of deformation, the original geometry and extent of the “Swauk basin” obviously are not preserved.

Continue southbound on US-97. Note that most of the strata dip southerly, and some are intruded by rusty weathering Teanaway dikes.

On the left at MP 152.5 is the road to Liberty. Placer gold was discovered along Swauk Creek in 1873. Production from the Liberty district was from placers, “hard-rock mining”, and dredging (Jordan, 1967; Woodhouse et al, 2002). “Boom time” was 1891 to 1901. Sporadic production continues today. The source of the gold is quartz veinlets in the Swauk and Taneum formations and along the contacts of Teanaway dikes. The sandstone of Swauk Pass is hydrothermally altered and weakly mineralized for >9 km along a WNW trending anticline (Margolis, 1994).

At MP 151.9 notice the “windrows” of gravel from dredging for gold in 1926 or 1940 (Jordan, 1967). “Volunteer” vegetation makes these windrows barely noticeable today. At MP 151.2, park on the right (western) side of the highway at the Liberty Café.

STOP 2-13 (optional): Teanaway Formation

This stop (3-7 in Fig.2) illustrates that the Teanaway Formation is not solely composed of basalt. The basalt commonly is rusty weathering, black, and vesicular or amygdaloidal. Here sparsely amygdaloidal basalt occurs below bedded, felsic volcanoclastic rock. Note that the regional dip is still southward.

Continue southbound on US-97. At MP 149.7 at the junction of US-97 with SR 970, turn left on US 97 toward Ellensburg. At the

pass at MP 147.1 of US 97, park on the wide shoulder on the right.

STOP 2-14: Moderately dipping Thorp Gravel

This is Stop 3-8 of Figure 2. Conglomerate (mostly clasts of basalt) of the Thorp Gravel overlies Grande Ronde Basalt, the basal formation of the Columbia River Basalt Group (Tabor et al, 1982). The Thorp Gravel is about 4 Ma. Significantly, here both formations have a sufficient dip to project northwestward over the red weathering ridges of the Teanaway Formation, which are the foothills of the Cascade Range. Near Ellensburg, Thorp Gravel overlies the Ellensburg Formation, which is stratigraphically above the Grande Ronde Basalt but which is missing here. Therefore, the sub-Thorp contact is an unconformity. It is the basal unconformity of the High Cascade sequence, and it records the topographic birth of the modern Cascade Range (Cheney, 1994, Cheney and Hayman, 2007).

Return down hill to the junction of US-97 and SR-970 and turn left (westbound) on SR-970 toward Cle Elum. At MP 6.9 of SR-97, turn right (north) on Teanaway Road. Proceed about 0.4 miles and turn left on Old Bridge Road. Continue to the Teanaway River and stop at the western end of the bridge.

STOP 2-15: Roslyn Formation

This white arkosic sandstone dips southwesterly toward the axis of the Kittitas Valley syncline. The sandstone is like those of the Chumstick Formation. Figure 3 shows that the Roslyn and the Chumstick formations occur above Teanaway Formation on opposite limbs of the Naneum Ridge

anticline, which indicates that the Roslyn and Chumstick formations are equivalent.

Return to SR-970 and follow it toward Cle Elum until it joins I-90 at Exit 85. Take I-90 westbound toward Seattle.

REFERENCES CITED

- Booth, D.B., Troost, K.G., and Hagstrum, J.T. 2004, Deformation of Quaternary strata and its relation to crustal folds and faults, south-central Puget Lowland, Washington State: *Geology*, v. 32, p. 505-508.
- Bressler, C.T, 1951, The petrology of the Roslyn arkose, central Washington: unpublished Ph.D. dissertation, Pennsylvania State College, University Park, 147 p.
- Buza, J.W., 1979, Dispersal patterns and paleogeographic implications of lower to middle Tertiary fluvial sandstones in the Chiwaukum graben, east-central Cascades, Washington, *in* Armentrout, J.M., Cole, M.R., and Terbest, H. Jr., eds., *Cenozoic Paleogeography of the Western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section*, p. 63-74.
- Cameron, D.E., 1996, Structural setting and features of Au-Ag orebodies in the Cannon Mine, Wenatchee, Washington: *in* Coyner, A.R. and Fahey, P.L., eds., *Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995*, p. 1089-1110.
- Cashman S.M., and Whetten, J.T., 1976, Low temperature serpentinization of peridotite fanglomerate on the west margin of the Chiwaukum graben, Washington, *Geological Society of America Bulletin*, v. 87, p. 1773-1776.
- Cheney, E.S., 1994, Cenozoic unconformity-bounded sequences of central and eastern Washington: *Washington Division of Geology and Earth Resources Bulletin* 80, p. 115-139.
- Cheney, E. S., 1997, What is the age and extent of the Cascade magmatic arc? *Washington Geology*, v. 25, No. 2, p. 28-32.
- Cheney, E.S., 2003, Regional Tertiary sequence stratigraphy and regional structure on the eastern flank of the central Cascade Range, Washington, *in* Swanson, T.W., ed., *Western Cordillera and adjacent areas, Geological Society of America Field Guide* 4, p. 177-199.
- Cheney, E.S., 1999, Geologic map of the Easton area, Kittitas County, Washington: *Washington Division of Geology and Earth Resources Open File Report* 99-4, scale 1:31,680, with 11 p. text.
- Cheney, E.S., and Hayman, N.W., 2007, Regional Tertiary sequence stratigraphy and structure on the eastern flank of the central Cascade Range, Washington, *in* Stelling, P., and Tucker, D., eds., *Flood, Faults, and Fire: Geological Field Trips in Washington State and Southwest British Columbia: Geological Society of America Field Guide* 9, p. 170-209, doi: 10.1130/2007.fld 009(09).

- Cheney, E.S., and Hayman, N.W., 2009, The Chiwaukum Structural Low: Cenozoic shortening of the central Cascade Range, Washington State, USA: Geological Society of America Bulletin, *in press*.
- Cheney, E.S., and Sherrod, B.L., 1999, The egg-crate of the Pacific Northwest: Geological Society of America Abstracts with Programs, v. 31, No. 5, p. A44.
- Doran, B., Miller, R.B., Michels, Z., 2007, Structure and implications of Eocene dike swarms in the Washington Cascades: Geological Society of America Abstracts with Programs, v.39, no.2, p. 10.
- Doughty, P.T., and Price, R.A., 1999, Tectonic evolution of the Priest River Complex, northern Idaho and Washington: a reappraisal of the Newport fault with new insights on metamorphic core complex formation: Tectonics, v. 18, p. 375-393.
- Evans, J.E., 1988, Depositional environments, basin evolution, and tectonic significance of the Eocene Chumstick Formation, Cascade Range, Washington: unpublished Ph.D. dissertation, University of Washington, Seattle, 325 p.
- Evans, J.E., 1994, Depositional history of the Eocene Chumstick Formation – Implications of tectonic partitioning for the history of the Leavenworth and Entiat-Eagle Creek fault system, Washington: Tectonics, v. 13, p. 1425-1444.
- Evans, J.E., and Johnson, S.Y., 1989, Paleogene strike-slip basins of central Washington: Swauk Formation and Chumstick Formation: Washington Division of Geology and Earth Resources Information Circular 86, p. 215-237.
- Gresens, R.L., 1982, Early Cenozoic geology of central Washington State: II. Implications for plate tectonics and alternatives for the origin of the Chiwaukum graben: Northwest Science, v. 56, p. 259-264.
- Gresens, R. L., 1983, Geology of the Wenatchee and Monitor Quadrangles, Chelan and Douglas Counties, Washington: Washington Division of Geology and Earth Resources Bulletin 75, 75 p.
- Gresens, R.L., Whetten, J.T., Tabor, R.W., and Frizzell, V.A., 1977, Tertiary stratigraphy of the central Cascades Mountains, Washington State: Part I. Summary of the stratigraphy, structure, and geologic history of early to middle Tertiary continental deposits, *in* Brown, E.H., and Ellis R.C., eds., Geological Excursions in the Pacific Northwest, Western Washington University Press, Bellingham, WA, p. 84-88.
- Gresens R.L., Naeser, C.W, and Whetten, J.W., 1981, Stratigraphy and age of the Chumstick and Wenatchee formations: Tertiary fluvial and lacustrine rocks, Chiwaukum Graben, Washington: Geological Society of America Bulletin, Part II, v. 92, p. 841-876.
- Haugerud R.A., van der Heyden, P., Tabor, R.W., Stacey, J.S., and Zartman, R.E., 1991, Late Cretaceous and early Tertiary plutonism and deformation in the Skagit Gneiss Complex, North Cascade Range, Washington and British Columbia:

- Geological Society of America Bulletin, v. 103, p. 1297-1307.
- Hopson, C.A., and Mattinson, J.M., 1994, Chelan Migmatite Complex, Washington: field evidence for mafic magmatism, crustal anatexis, and protodiapiric emplacement, *in* Swanson, D.A., and Haugerud, R.A., editors, Geologic Field Trips in the Pacific Northwest: 1994 Geological Society of America Annual Meeting, Seattle, University of Washington, Department of Geological Sciences, v. 2, p. 2K-1 - 2K-21.
- Hunting, M.T., 1943, Inventory of mineral properties in Chelan County, Washington: Washington Division of Geology Report of Investigations 9, 63 p.
- Johnson, S.Y., 1985, Eocene strike-slip faulting and nonmarine basin formation in Washington, *in* Biddle, K.T. and Christie-Blick, N., eds, Strike Slip Deformation, Basin Formation, and Sedimentology, Society of Economic Paleontologists and Mineralogists Special Publication 37, p. 283-302.
- Jordan, J., 1967, You're at Liberty Here, Mines and Miners of the Swauk: Franklin Press, Yakima, Washington, 103 p.
- Laravie, J.A., 1976, Geologic Field Studies along the Eastern Border of the Chiwaukum Graben, Central Washington: unpublished M.S. thesis, University of Washington, Seattle, 55 p.
- Mackin, J.H., and Cary A.S., 1965, Origin of Cascade Landscapes: Washington Division of Mines and Geology Information Circular 41, 35 p.
- Margolis, J., 1989, Arkose-hosted, aquifer-controlled, epithermal Au-Ag mineralization, Wenatchee, Washington: Economic Geology, v.84, p. 1891-1902.
- Margolis, J., 1994, Epithermal Gold Mineralization, Wenatchee and Liberty Districts, Washington: Society of Economic Geologists Guidebook Series, v. 20, p. 31-34.
- Matzel, J.E.P., Bowring, S.A., and Miller, R.B., 2006, Times scales of pluton construction at differing crustal levels: Examples from the Mount Stuart and Tenpeak intrusions, North Cascades: Geological Society of America Bulletin, v. 118, p. 1412-1430.
- MacDonald, J.H., Harper, G.D., Miller, R.B., Miller, J.S., Mlinarevic, A.N., and Miller, B.V., 2008, Geochemistry and geology of the Iron Mountain unit, Ingalls ophiolite complex, Washington: Evidence for the polygenetic nature of the Ingalls complex: Geological Society of America Special Paper 438, p. 161-174.
- McClincy, M.J., 1986, Tephrostratigraphy of the middle Eocene Chumstick Formation, Cascade Range, Douglas County, Washington, unpublished M.S. thesis, Portland State University, Portland, OR, 125 p.
- McLean, N.M., Bowring, S.A., Miller, R.B., Whitney, D.L., Gordon, S., 2006, North Cascades, WA: The collapse of a continental magmatic arc: EOS Trans. AGU, 87(52), Fall Meeting. Supplemental Abstract T31C-0469.
- Mendoza, M.K., 2008, Tectonic implications of Eocene Teanaway dike swarm in the

- Eastern Swauk basin, Central Washington: Geological Society of America Abstracts with Programs, v. 40, no, 2, p.10.
- Miller, R.B., and Bowring, S.A., 1990, Structure and chronology of the Oval Peak batholith and adjacent rocks: Implications for the Ross Lake fault zone, North Cascades, Washington: Geological Society of America Bulletin, v. 102, p. 1361-1377.
- Mitchell, S.G., and Montgomery, D.R., 2006, Polygenic topography of the Cascade Range, Washington State, USA: American Journal of Science, v. 306, p. 736-768, doi 10.2475/09.206.03.
- Montgomery, S.L., 2008, New exploration concepts highlight Columbia River basin's potential: Oil and Gas Journal, v. 106, No. 2, p. 35-42.
- Newman, K.R., 1981, Palynologic biostratigraphy of some early Tertiary nonmarine formations in central and western Washington: Geological Society of America Special Paper 184, p. 49-65.
- Nimick, D.A., 1977, Glacial Geology of Lake Wenatchee and Vicinity, Washington: Unpublished MS thesis, University of Washington, Seattle, WA, 52 p.
- Page, B.M., 1939, Geology of the Chiwaukum Quadrangle, Washington: unpublished Ph.D. dissertation, Stanford University, 203 p.
- Paterson, S.R., Miller, R.B., Alsleben, H., Whitney, D.L., Valley, P.M., and Hurlow, H., 2004, Driving mechanism for > 40 km of exhumation during contraction and extension in a continental arc, Cascade core, Washington: Tectonics, v. 23, TC3005, doi:10.1029/2002TC001440.
- Patton, T.C., and Cheney, E.S., 1971, L-D Gold Mine, Wenatchee, Wash: New structural interpretation and its utilization in future exploration: Transactions of the Society of Mining Engineers, v. 250, p. 6-11.
- Porter, S.C, and Swanson, T.W., 2008, ³⁶Cl dating of the classic Pleistocene glacial record in the northeastern Cascade Range, Washington, America Journal of Science, v. 308, p. 130-166, doi 10.2475/02.2008.02.
- Pratt, T.L., 2008, Is downtown Seattle on the hanging wall of the Seattle fault: EOS Transactions, American Geophysical Union, v. 89 (53), Fall Meeting Supplement, Abstracts, T21B-1950.
- Reidel, S.P., Campbell, N.P., Fecht, K.R., and Lindsey, K.A., 1994, Late Cenozoic structure and stratigraphy of south-central Washington: Washington Division of Geology and Earth Resources Bulletin 80, p. 159-180.
- Reidel, S.P., Martin, B.S., and Petcovic, H.L., 2003, The Columbia River flood basalts and the Yakima fold belt: Geological Society of America Field Guide 4, p. 87-105.
- Reiners, P.W., Ehlers, T.A., Garver, J.I., Mitchell, S.G., Montgomery, D.R., Vance, J.A., Nicolescu, S., 2002, Late Miocene exhumation and uplift of the Washington Cascade Range, Geology, v. 30, p. 767-770.

- Sherrod, B.L., Brocher, T.M., Weaver, C.S., Buckham, R.C., Blakely, R.J., Kelsey, H.M., Nelson, A.R., Haugerud, R., 2004, Holocene fault scarps near Tacoma, Washington, USA: *Geology*, v. 32, p. 9-12.
- Silling, R.M., 1979, A gravity study of the Chiwaukum graben, Washington: unpublished M.S. thesis, University of Washington, Seattle, WA, 100 p.
- Tabor, R.W., Waitt, R. B., Jr., Frizzell, V.A., Jr., Swanson, D.A., Byerly, G.R., and Bentley, R.D., 1982, Geologic Map of the Wenatchee 1:100,000 Quadrangle, Central Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1311, 26 p, 1 pl., scale 1:100,000.
- Tabor, R.W., Frizzell, V.A., Jr., Vance, J.A., and Naeser, C.W., 1984, Ages and stratigraphy of lower and middle Tertiary sedimentary and volcanic rocks of the central Cascades, Washington -- Application to the tectonic history of the Straight Creek fault: *Geological Society of America Bulletin*, v. 95, p. 26-44.
- Tabor, R.W., Frizzell, V.A., Jr., Whetten, J.T., Waitt, R.B., Swanson, D.A., Byerly, G.R., Booth, D.B., Hetherington, M.J., and Zartman, R.E., 1987, Geologic Map of the Chelan 30-Minute by 60-Minute Quadrangle, Washington: U. S. Geological Survey Miscellaneous Investigations Series Map I-1661. 1 sheet, scale 1:100,000, with 29 p. text.
- Tabor, R.W., Haugerud, R.A., Hildreth, W., and Brown, E.H., 2003, Geologic Map of the Mount Baker 30- by 60-Minute Quadrangle, Washington: U. S. Geological Survey Geological Investigations Series I-2660, 2 sheets, scale 1:100,000, with 73 p. text.
- Taylor, S.B. Johnson, S.Y., Fraser, G.T., and Roberts, J.W., 1988, Sedimentation and tectonics of the lower and middle Eocene Swauk Formation in eastern Swauk Basin, central Cascades, central Washington: *Canadian Journal of Earth Sciences*, v. 25, p. 1020-1036.
- Tolan, T.L., and Reidel, S.P., 1989, Structure map of a portion of the Columbia River flood-basalt province, *in* Reidel, S.P., and Hooper, P.R., eds., *Volcanism and Tectonism in the Columbia River Flood-Basalt Province: Geological Society of America Special Paper 239*, 1 sheet, scale approximately 1:560,000.
- Umhoefer, P., 1987, Northward translation of "Baja British Columbia" along the late Cretaceous to Paleocene margin of western North America: *Tectonics*, v. 6, p. 377-394.
- Valley, P.M., Whitney, D.L., Paterson, S.R., Miller, R.B., Alsleben, H., 2003, Metamorphism of the deepest exposed arc rocks in the Cretaceous to Paleogene Cascade belt, Washington: evidence for large-scale vertical motion in a continental arc: *Journal of Metamorphic Geology*, 21, 203-220.
- Waitt, R.B., 1980, About 40 last-glacial Lake Missoula jökulhlaups through southern Washington: *Journal of Geology* v. 88, p. 653-679.
- Waitt, R.B., 1994, Scores of gigantic, successively smaller Lake Missoula floods through channeled scabland and Columbia valley, *in* Swanson, D.A., and

- Haugerud, R.A, editors. Geologic Field Trips in the Pacific Northwest: 1994 Geological Society of America Annual Meeting, published by the Department of Geological Sciences, University of Washington (Seattle), v.1, p 1K1-1K88.
- Waitt, R.B., 2009. Routes to Wenatchee of the Columbia valley megafloods from glacial lake Missoula and other sources: Geological Society of America Abstracts with Programs, v. 41, on. 5, p. 33.
- Walker, C.W., 1980, Geology and energy resources of the Roslyn-Cle Elum area, Kittitas County, Washington: Washington Division of Geology and Earth Resources Open File Report 80-1, scale 1:24,000, with 59 p text.
- Wernicke, B., and Getty, S.R., 1997, Intracrustal subduction and gravity currents in the deep crust: Sm-Nd, Ar-Ar, and thermobarometric constraints from the Skagit Gneiss Complex, Washington: Geological Society of America Bulletin, v. 109, 1149-1166.
- Whetten, J.T., 1980a, Preliminary bedrock geologic map of the Chiwaukum 4 NW quadrangle, Chiwaukum graben, Washington: U.S. Geological Survey Open-File Report 80-456, scale 1:24,000, 5p.
- Whetten, J.T., 1980b, Preliminary bedrock geologic map of the east half of the Chiwaukum 4 SW quadrangle, Chiwaukum graben, Washington: U.S. Geological Survey Open-File Report 80-616, scale 1:24,000, 5 p.
- Whetten, J.T., 1980c, Preliminary bedrock geologic map. Chiwaukum SE quadrangle, Chiwaukum graben, Washington: U.S. Geological Survey Open-File Report 80-723, scale 1:24,000.
- Whetten, J.T., and Laravie, J.A., 1976, Preliminary geologic map of the Chiwaukum 4 NE quadrangle, Chiwaukum graben, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF 794, scale 1:24,000.
- Whetten, J.T., and Waitt, R.B., Jr., 1978, Preliminary geologic map of the Cashmere quadrangle, Chiwaukum lowland, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF 908, scale 1:24,000.
- Willis, C.L.1953, The Chiwaukum graben, a major structure of central Washington: American Journal of Science, v. 251, p. 789-797.
- Woodhouse, P., Jacoboson, D., Cady, G., and Pisoni, V., 2002, Discovering Washington's Historic Mines, Volume 2, The East Central Cascade Mountains and the Wenatchee Mountains: Arlington, Washington, Oso Publishing Co., 336 p.

ADDENDA TO TEXT

Addendum to ROAD LOG FR DAY 1

In 2018 we will overnight in Ephrata and join the log of the 2009 field trip at Quincy, headed for Babcock Bench and Stop 1-1.

Addendum to Stop 1-1

The main aquifers in the CRBC are the combined upper and lower contact zones of underlying and overlying flows. Such aquifers could also spread contamination of radioactive and other wastes, and they have been proposed as sites of carbon sequestrations (by reaction of CO₂with the basaltic rock).

Addendum to Stop 1-7

See Dessimoz et al. 2012 in addenda to references.

Addendum to Stop 1-10

Sherrod et al. (2015) found and trenched an active fault scarp in Spencer Canyon south of Entiat and across the river from Orondo. The fault dips NW. A low-level seismic swarm still occurs in the area. Sherrod et al (2015) concluded that this fault is the site of the 1872 earthquake.

Contrary to what the sign states, B.L Sherrod (personal communication, October 2018) maintains that damming of the river by the 1872 earthquake was due to slumping of the talus at the base of the cliff.

Addendum to Stop 2-1

The structural relief on the CRBG represented by Mission Ridge is impressive. At Mission Peak the base of MSU N2 is approximately 2050 m, which is its maximum altitude in the State. N2 descends eastward in 23 km to about 350 m near the Columbia River. From viewpoints, such as this one across the Columbia River from Wenatchee, N2 on Mission Peak projects over Mount Stuart 41.5 km to the northwest. Mount Stuart at 2850 m is the highest peak in the crystalline core of the central Cascade Range. In the opposite direction 75 km to the southeast of Mission Peak near Mattawa, the cross sections of Staisch et al. (2018, fig. 13) and the relevant topographic maps place the base of N2 at about sea level. So, the demonstrable structural relief on N2 is 2 km, and if N2 extended above Mount Stuart, the relief would have been approximately 3 km. Because another kilometer of CRBG occurs below N2 at Mattawa, the total structural relief on all of the CRBG is correspondingly greater.

Addendum to Stop 2-3

The identity of the nearly vertical silicified and mineralized strata remains controversial. If the K/Ar date of 50.9 Ma for mafic intrusions in the fault zone is valid (Table 3), the host strata are Swauk Formation (thrust over Nahahum Canyon/Wenatchee rocks).

Because they dextrally offset mineralization and strands of Eagle Creek fault zone, the north-south faults were important in the development of the L-D mine. At the time Figure 9 was published, the only other recognized north-south fault in the Cascade Range was the major Straight Creek Fault. Figure 3 (published in 2009) and Cheney (2014, fig.3) show that several dextral north-south faults exist in the range; more might be undiscovered.

Note in Figure 3 that at least 3 such faults dextrally offset the Leavenworth fault system (LFS). Detailed mapping by Cheney and Hayman (2009) characterized the LFS as a high-angle reverse fault. In contrast, several previous authors and Eddy (2017) concluded that the LFS is a dextral strike slip fault that bounds a pull-apart basin in which the Chumstick Formation was deposited. The apparent dextral displacement along the LFS is due to the later (post-depositional) north-south faults.

Addendum to stop 2-8.5 (optional)

About 2 miles northwest of Cashmere on US 2 turn right on North Dryden Road for Peshastin Pinnacles State Park. This is the last scheduled potty stop of the trip.

The pinnacles are west dipping strata of the Chumstick Formation. They are coarse grained sandstone with pebble lags (Eddy, 2017). They are a favorite rock-climbing site. Climbing them has been likened to scrambling up rotten orange peels.

The geologic significance here is that the strata dip westerly; whereas at the stops in Wenatchee, the strata dip NE. This reversal of dip is due to the Eagle Creek anticline, which north of US 2 is cored by Swakane Biotite Gneiss (Fig. 3). The axis of this anticline crosses US 2 at Cashmere 3.5 km to the southeast. This anticline and other folds show that the Chiwaukum is not (or is no longer) a simple pull-apart basin or syndepositional graben, as commonly supposed; instead, it is a structural low that preserves a fold and thrust belt (Cheney and Hayman, 2009).

Addendum to stop -2-`12 (optional)

The U/Pb age of the volcanoclastic rock, 51.5 Ma (Eddy et al., 2016, 2017), provides an age for the Swauk Pass Member. Eddy (et al., 2016, 2017) inferred that this dates the lithologic ally similar Silver Pass volcanic rocks of the Taneum Formation. However, the Silver Pass rocks unconformably overlie the Swauk Formation (Cheney, 2016a).

Addendum to Table 3.

Recent U/Pb ages have revised the ages in this table. Tuffs in the Chumstick Formation are 48.0 to 49.1 Ma (Eddy et al. 2016) The rhyodacite of Wenatchee dome, which intrudes the Eagle Creek fault, is 44.4 Ma (Gilmour, 2012).

ADDENDA TO REFERENCES CITED

Cheney, E.S., and Hayman, N.W., 2009, The Chiwaukum structural low: Cenozoic shortening of the central Cascade Range, Washington State, USA: Geological Society of America Bulletin, v. 121, p. 1135-1153, doi 10.1130/B2666446,1;8.
This expresses the minority viewpoint that stratigraphic units are regional and that basins are not small and extensional.

Cheney, E.S., 2014, Tertiary Stratigraphy and structure of the eastern flank of the Cascade Range, Washington, in Dashtgard, S., and Ward, B. editors, Trials and Tribulations of Life on an Active Subduction Zone: Geological Society of America Field Guide 38, p. 193-226 doi:10.1130/2014.0038(09).
Cheney's most recent field guide for the bedrock geology of region. The guide updates some of the discussions, figures, and tables in the 2009 field guide. A specific suggestion is that the Nahahum Canyon Member of the Chumstick Formation is the Wenatchee Formation in the footwall of the Eagle Creek thrust.

Cheney E.S., 2016a, Overview of the Cenozoic unconformity-bounded sequences of Washington, in Cheney, E.S., editor, The Geology of Washington and Beyond, from Laurentia to Cascadia: University of Washington Press, Seattle, WA, p. 193-190.
This is particularly useful in correlating the Challis formations

Cheney, E.S., 2016b, The Neogene eggcrate of the Pacific Northwest, in Cheney, E.S., editor, The Geology of Washington and Beyond, from Laurentia to Cascadia: University of Washington Press, Seattle, WA, p. 206-219.
Describes Neogene folding in PNW

Cheney, E.S., 2017, Evidence for a 5 Ma erosion surface and the subsequent rise of the anticlinal Cascade Range, Washington: Geological Society of America Abstracts with Programs. v. 49, no. 6, doi: 10.1130/abs/7AM-300312.
The Cascade Range is a SSW plunging anticlinorium that rose < 4 Ma.

- Dessimoz, M., Müntemer, O., and Ulmer, P., 2012, A case for hornblende dominated fractionation of arc magmas: the Chelan Complex (Washington Cascades). *Contributions to Mineralogy and Petrology*, v.163, p. 567-589, doi 10.1007/s00210-011-0685-5.
The Chelan complex underwent protracted cooling a 700^o at > 30 km depth. Major and trace elements demonstrate that tonalite can be derived from basaltic magma by crystal fractionation of amphibole at high pressure without crustal contamination. In contrast, Hopson and Mattinson (1994) believed that the migmatite is remobilized crust.
- Eddy, M.P., Bowring, S.A., Umhoefer, P. J., Miller, R/B., McLean, N.M., and Donaghy, E.E., 2016, High-resolution Temporal and stratigraphic record of Siletzia's accretion and triple junction migration from nonmarine sedimentary basins in central and western Washington: *Geological Society of America Bulletin*, v, 128, no. 3/4B, p. 425-441., doi:10.1130/B1335.1.
Reports new U/Pb ages for many Challis units. Reverts to the concept that the Chiwaukum is a pull-apart basin (syndepositional graben).
- Eddy, M.F., Umhoefer, P.J., Miller, R.B., Donaghy, E.E., Gundersen, M., and Semes. F.I., 2017, Sedimentary, volcanic, and structural processes during triple-junction migration: Insights from the Paleogene record in central Washington, in Haugerud, R.A., and Kelsey, H. M., eds., *From the Puget Lowland to East of the Cascade Range: Geologic Excursions in the Pacific Northwest: Geological Society of America Field Guide 49*, p. 143-173, doi:10.1130/2017.0049(07).
- This field trip is based on Eddy et al., 2016)*
- Gilmour, L.A., 2012, U/Pb ages of Eocene and younger rocks on the eastern flank of the central Cascade Range, Washington USA: unpublished MS thesis, University of Washington, Seattle, WA, 50 p.
The unfaulted Wenatchee rhyodacitic dome in the Eagle Creek fault zone is 44.4 Ma. The andesite at Natapoc Mountain at 3.98 Ma may be the oldest example of Cascade volcanism.
- Methner, K., Flebig, J., Wacker, U., Umhoefer, P. I., Chamberlain, C. P., and Mulch, A. ,2017, Eo-Oligocene Cascade topography revealed by the clumped ($\Delta 47$) and oxygen isotope ($\delta 18O$) record of the Chumstick basin (WA, USA): *Geological Society of America Abstracts with Programs*, v. 49, No.6; doi: 10.1130/abs/2017AM-300515.
18O of calcite-cemented concretions shows no rain shadow during diagenesis of the Chumstick Formation
- Miller, R.B., Gordon, S.M., Bowring, S., Doran, B., McLean, N., Michels, Z., Shea, E., and Whitney, D.L., 2016, Linking deep and shallow crustal processes during regional transtension in an exhumed continental arc, North Cascades, northwestern Cordillera (USA): *Geosphere*, v. 12, no. 3, p. 900–924, doi:10.1130/GES01262.1.
Latest update on geology of NE Cascade Range. Metamorphic deformation (foliation) over by 43 Ma (which coincides with the pre-Kittitas unconformity).
- Mustoe, G.F., and Leopold, E. B., 2014, Paleobotanical evidence for the post-Miocene uplift of the Cascade Range: *Canadian Journal of Earth Science* v, 51,

p. 809 – 824, doi: org/101137(cjes-2013-0203).

Paleoflora show no rain shadow (no uplift of the Cascade Range during deposition of the Ellensburg Formation (less than 10 Ma).

Sherrod, B.L., Blakeley, R.J., and Weaver, C. S., 2015, Lidar helps identify evidence of the 1872 earthquake near Chelan, Washington: American Geophysical Union, abstract

The active Spencer Canyon fault near Entiat was the probable source of the 1872 earthquake.

Staisch, L., Kelsey, H., Sherrod, B., Möller, A., Paces, J., Blakely, R., and Styron, R., 2018, Miocene-Pleistocene deformation of the Saddle Mountains: Implications for seismic hazard in central Washington, USA: Geological Society of America Bulletin v. 130, no. 3/4, p. 311-437; <https://doi.org/10.1130/B31783.1>.

A thrust in the Saddle Mountains anticline of the Yakima fold belt displaces the 9.5 to 3.5 Ma Ringold Formation.