Northwest Geological Society

Society Field Trips in Pacific Northwest Geology

FIELD TRIP GUIDEBOOK # 24

Floods, Flows, Faults, Glaciers, Gold and Gneisses, From Quincy to Chelan to Wenatchee

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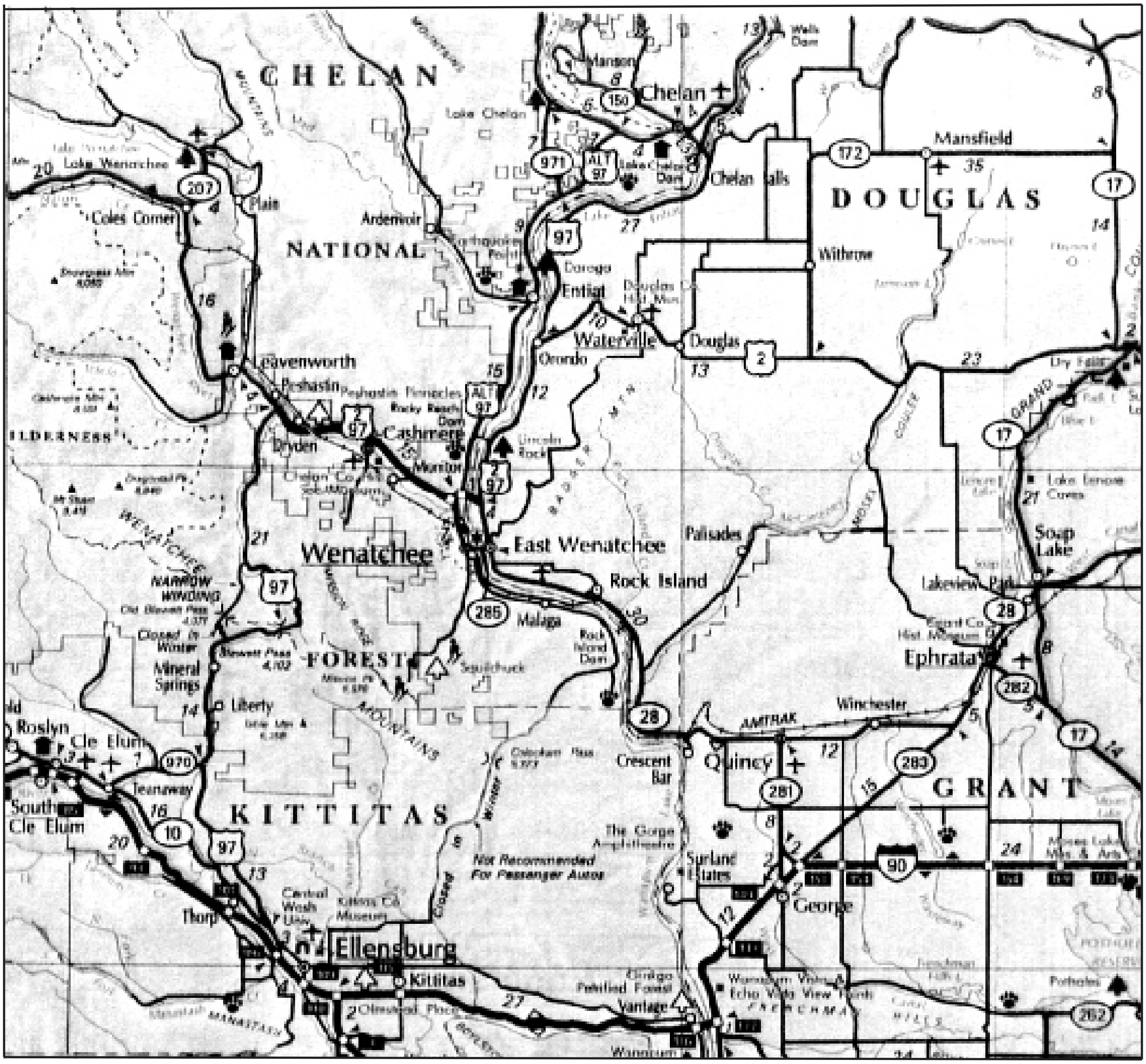
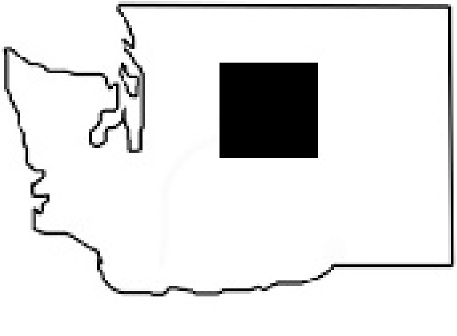


Figure 1 (Above) Highway map of the Field Trip area. *Image to the right shows map location. Adapted from the Official Washington State Highway Map 2008-2009 (1:842,000), Washington State Department of Transportation.*



Floods, Flows, Faults, Glaciers, Gold and Gneisses, From Quincy to Chelan to Wenatchee

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 McNeil 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 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). Two scenic overviews are Wenatchee Heights (along the Eagle Creek fold and thrust belt) and from atop Pangborn bar (of Missoula flood vintage) of the entire Wenatchee district. 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 Formation, Miocene CRBG, and deformed Pliocene Thorp Formation).

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

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, 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 exposes pre-Cenozoic crystalline rocks which dominate the northern part of the range, whereas Cenozoic sedimentary and volcanic rocks are generally younger and more extensive more extensively preserved to the south. The Wenatchee area is in the transition zone into the Cenozoic rocks (Fig. 2). Pleistocene volcanoes, such as Mt. Rainier, discontinuously cap the Cascade Range.

The crystalline rocks of the northern Cascades are terranes that amalgamated by Late Cretaceous time. The three amphibolite-facies terranes along the Columbia River from Chelan to Wenatchee (Fig. 4) include the Chelan Mountains, Mad River, and the Swakane Terranes (Stops 1-7, 1-8, 1-10 and 1-11) The Swakane Biotite Gneiss (Stop 1-11) comprises 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 are part of the regional Challis sequence of dominantly clastic and volcaniclastic lithologies (Table l; Fig. 2). The key formation in the Wenatchee area is the arkosic Chumstick Formation. This formation was originally interpreted to fill the Chiwaukum "graben" (Willis, 1953; Gresens et al., 1981,

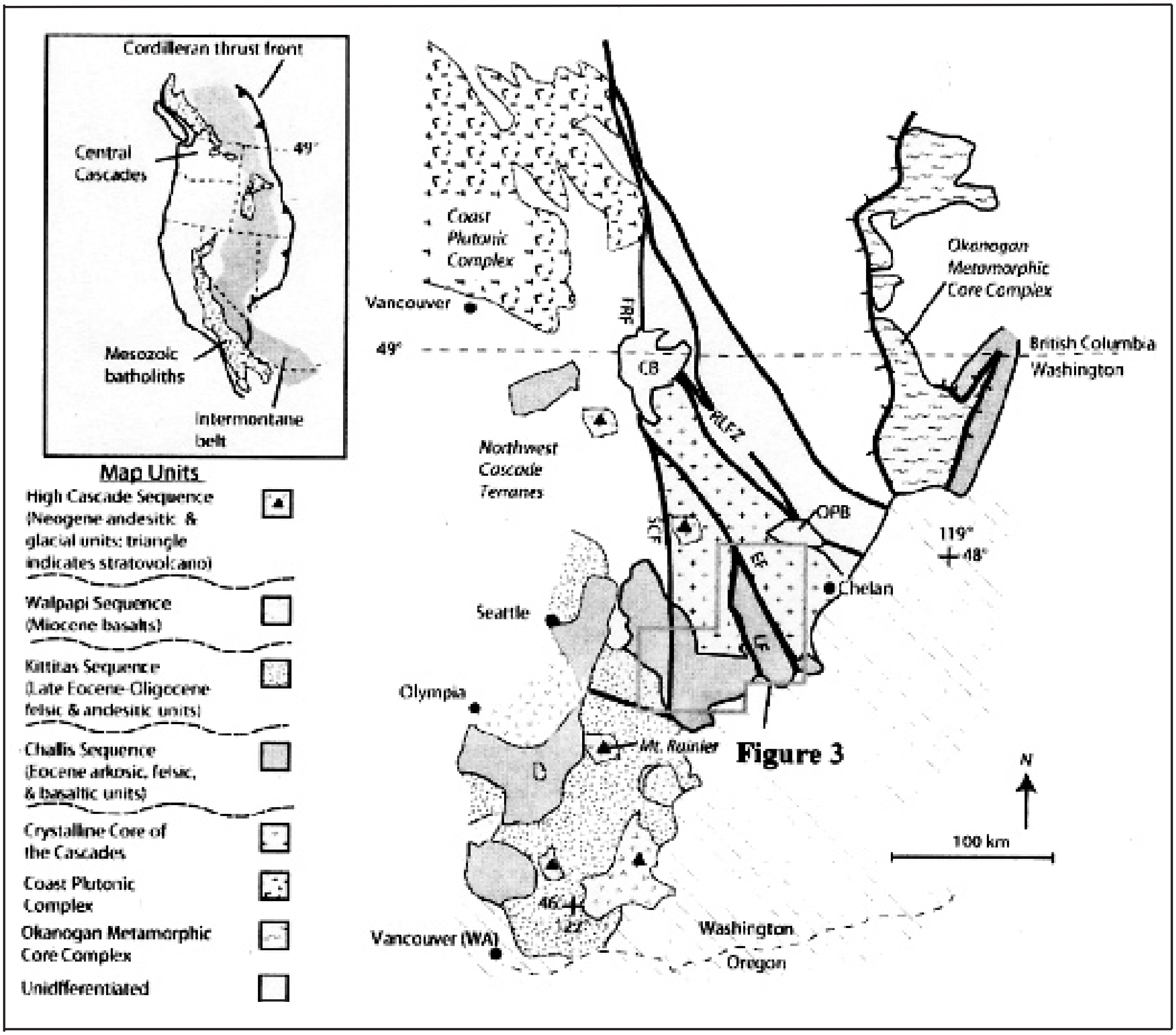


Figure 2: Geologic map of central Washington State*, showing the extent of the four major Cenozoic unconformity-bound sequences mentioned in the text (Cheney and Hayman, 2009, fig. 1. Wavy lines in the explanation are regional unconformities. This field trip is on both sides of the eastern margin of 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 Mount Rainier is the highest.*

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 rationale for this reasoning was that major faults in the northern part of the range (Fig.2) dextrally offset pre-Cenozoic units by tens to perhaps hundreds of kilometers (Umhoefer, 1987; Umhoefer and Miller, 1996). Some of these faults, and the Ross Lake fault in particular (Fig. 2), 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. Cheney (1997) interpreted this as the Farallon magmatic arc, as distinct from the modern Cascade arc. 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.

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)

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 Mountain	basalt of Frost	basalt with some felsite, felsic volcaniclastic rocks, and minor arkose	46 to 48
Taneum	Silver Pass, Peoh Point, Mount Catherine	felsite and felsic volcaniclastic rocks	50 to 52
Swauk	Manastash, Guye	predominantly arkosic	53 to 57

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.

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, this unit occupies a large regional syncline known as the Pasco Basin. The basalts issued from fissures in the common corner of Oregon, Washington, and Idaho. The major unconformity below the basalts, and several within them (Stop 1-1), show that the 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 syn-tectonically in local basins. In contrast, Cheney and Hayman (2009) stressed that these formations are preserved in fault-bounded, regional synclines, not in separate depositional basins. Thus, Cheney and Hayman (2009) renamed the Chiwaukum graben as 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 to the southwest. Additionally, parts the Chumstick Formation probably are parts of the

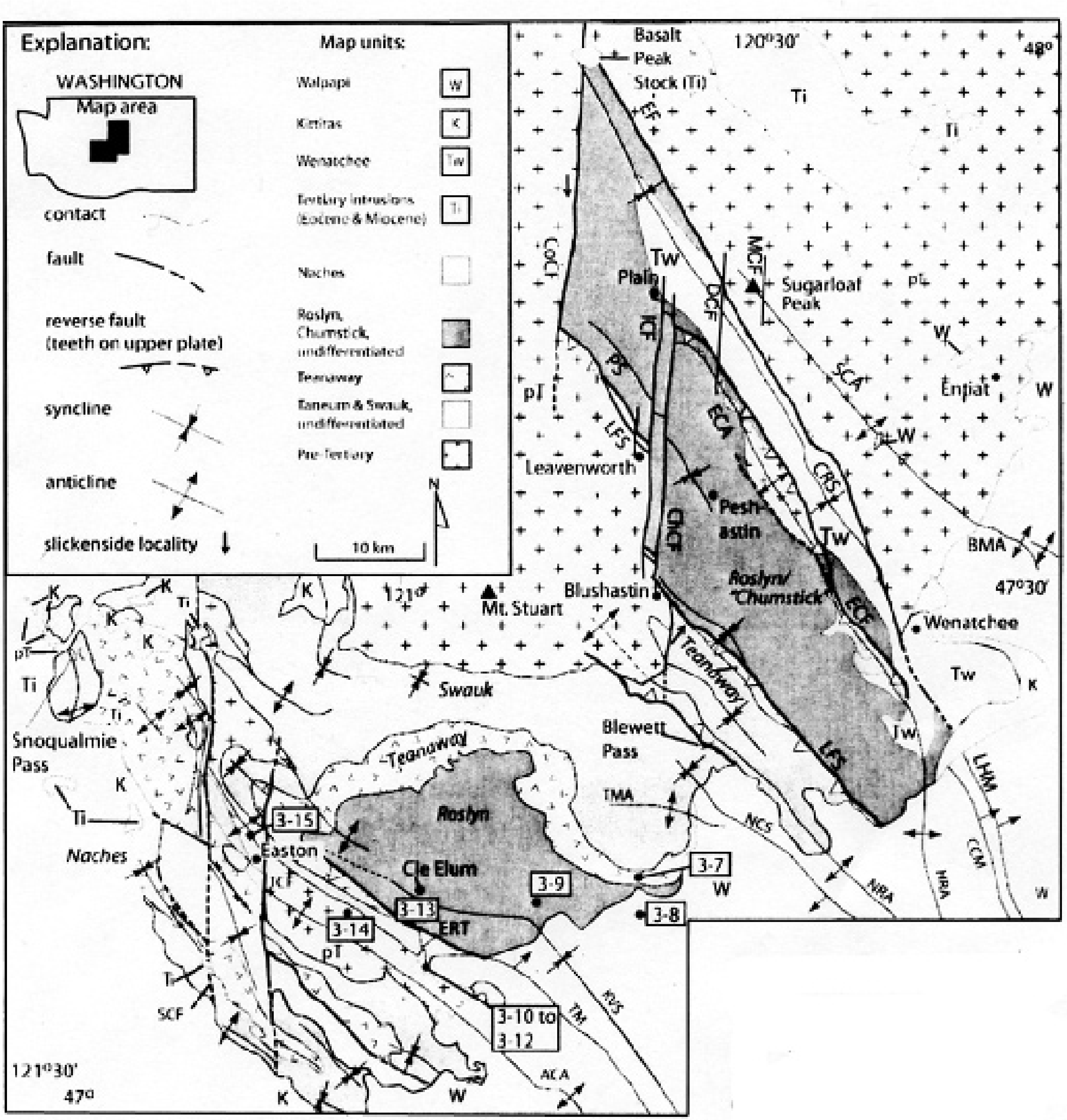


Figure 3. Regional Geology *(after Cheney and Hayman, 2009, fig. 2) For sources of data see Cheney and Hayman (2009). Abbreviations are: ACA, Ainsley Canyon anticline; BMA Badger Mountain anticline; ChCF Chumstick Creek fault; CCM, Colockum Creek monocline; CoCF Coulter Creek fault; CRS, Chiwawa River 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, Kitittas 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; NTCF, Tucker Creek fault, TM, Taneum monocline, and TMA, Table Mountain anticline*

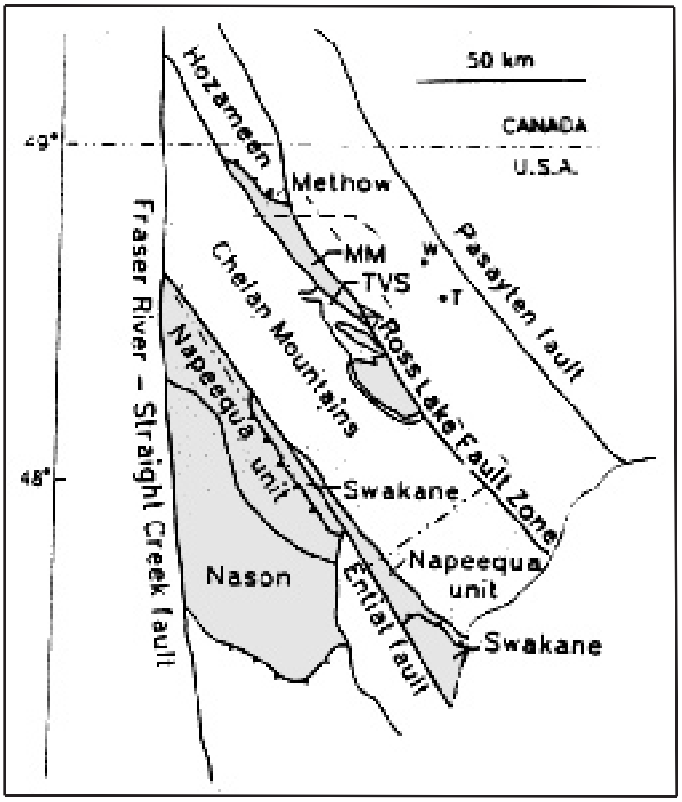


Figure 4. Terranes of the northeastern Cascade Range *(after Miller et al. 1994) The Napeequa Unit is also known as the Mad River terrane.*

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 was previously 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 are probably components of the regional Straight Creek fault, which is Eocene to Oligocene in age. These faults partially bound the structural low. Repetition of the stratigraphy by the north-south faults within the structural low probably contributes to the apparent very great thickness (>6 km) of the Chumstick Formation.

The Eocene folds and faults were reactivated by the deformation affecting 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.

REGIONAL EOCENE STRATIGRAPHY

Formations 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 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 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.

Chumstick Formation

Primarily based upon the presence and ages of felsic tuffs in the Chumstick Formation (Table 3), Gresens et al. (1981) distinguished it from the Swauk Formation. This new name was predicated on the notion that the Chumstick Formation was deposited in the Chiwaukum graben. However, Table 2 shows that the characteristics of the Chumstick Formation are remarkably similar to those of the Roslyn Formation, which is 25 kilometers southwest

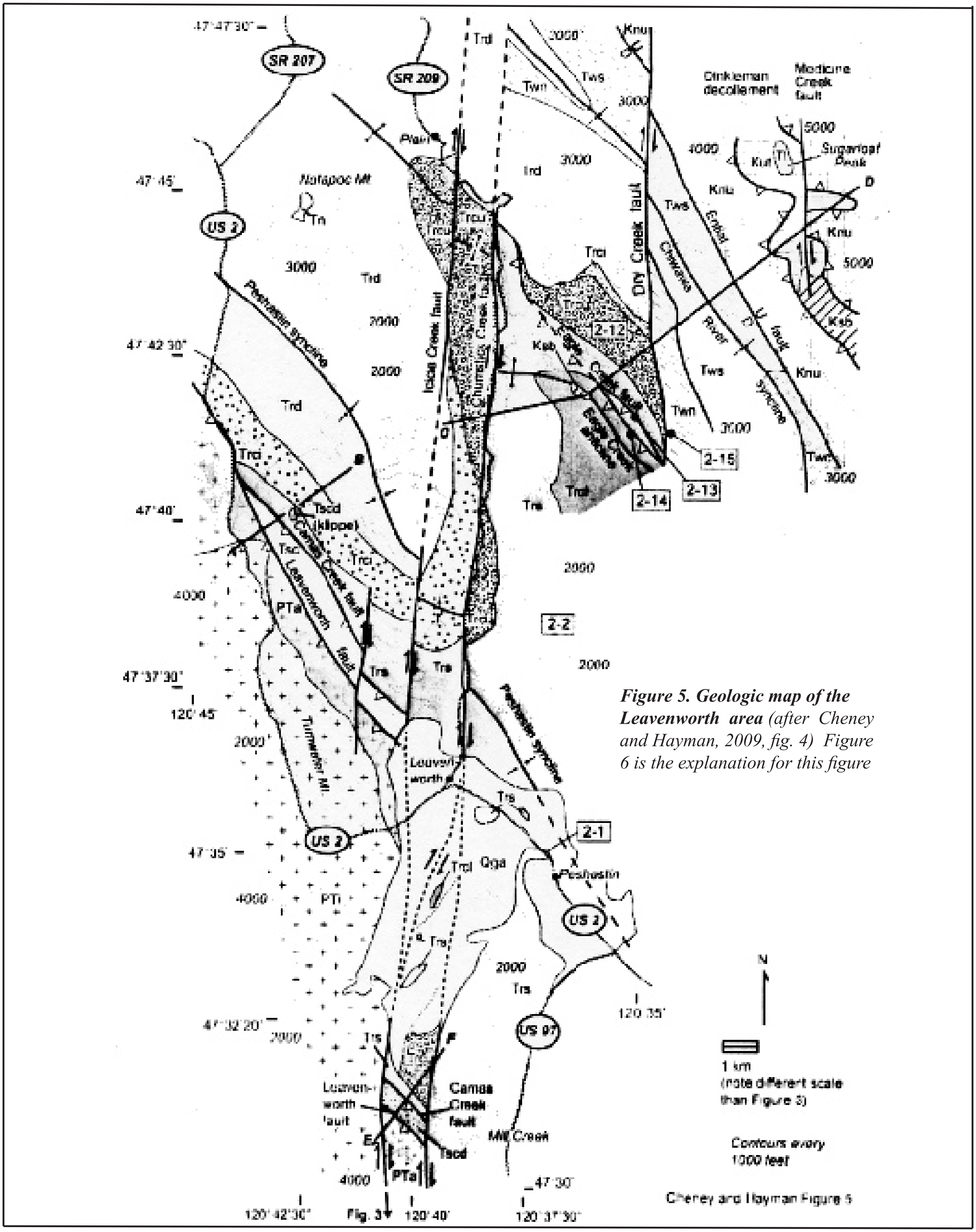


Figure 5. Geologic map of the Leavenworth area *(after Cheney and Hayman, 2009, fig. 4) Figure 6 is the explanation for this figure*

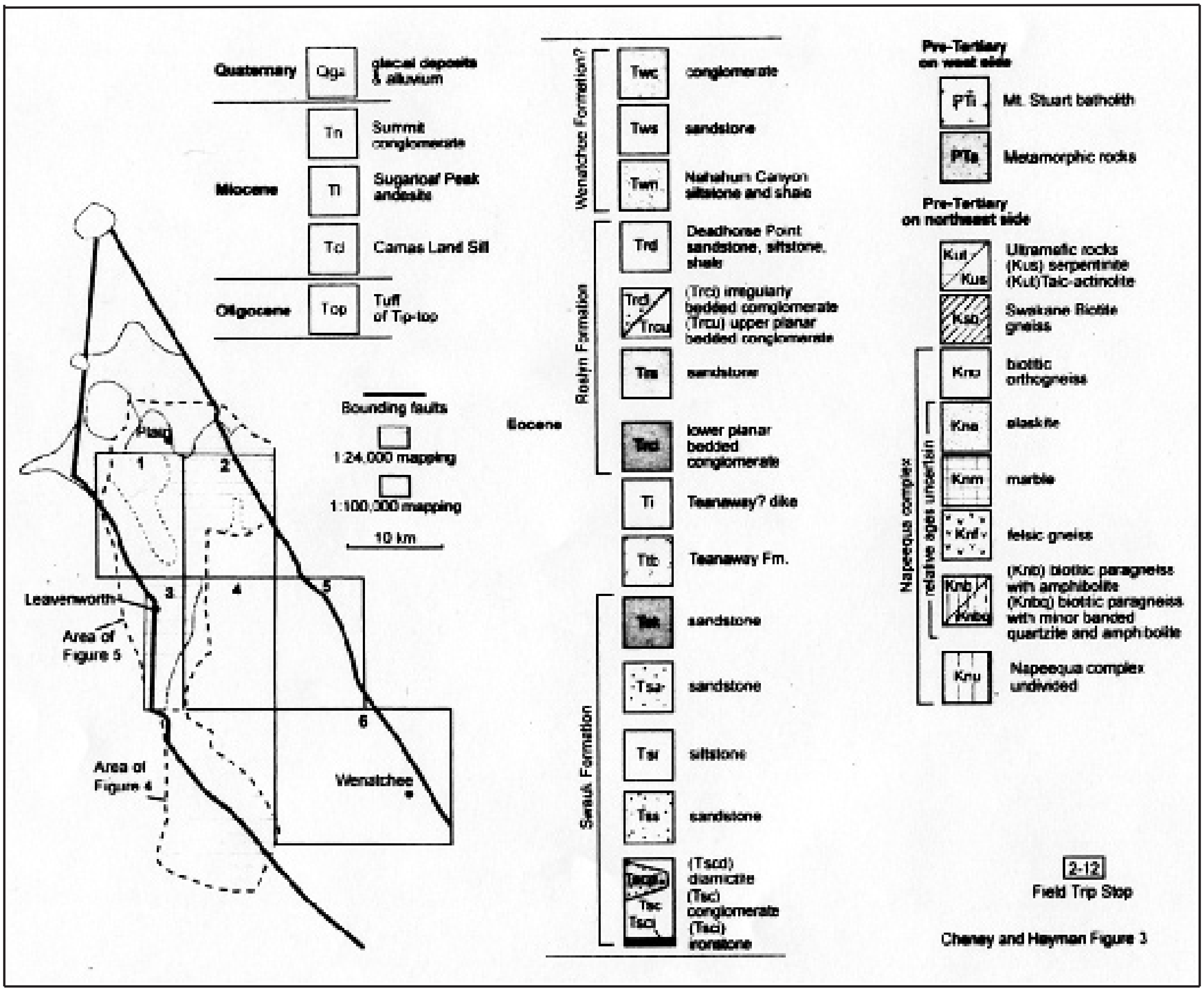


Figure 6. Index to 1:24,000 geologic mapping and lithologic units in and adjacent to the Chiwaukum Structural Low*. This figure is also the explanation for Figure 5. Areas of previous geologic mapping are 1) Whetten (1980a), 2) Whetten and Laravie (1976), 3) Whetten (1980b), 4) Whetten (1980c) , 5) Whetten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

of the Leavenworth fault (Fig. 3). Furthermore, the Chumstick and Roslyn formations are in the same stratigraphic position on opposite limbs of the regional Naneum Ridge anticline (Fig. 3); thus, they are the same stratigraphic unit. Because the name "Roslyn Formation" has precedence (see references in Tabor et al., 1982), the name "Chumstick Formation" should be abandoned. Nonetheless, to avoid confusion, the name Chumstick Formation is useful to refer to that portion of the Roslyn Formation in the Chiwaukum Structural Low.

The uppermost portion of the Chumstick Formation, as defined by Gresens et al. (1981) and Gresens (1983) and as mapped by Tabor et al. (1987), is the Nahahum Canyon Member. It is mostly dark lacustrine shale and siltstone (Stop 2-7). However, Evans (1988, 1994) included the overlying sandstone and conglomerate in the Chiwawa River syncline in the Nahahum Canyon Member. Evans (1994, fig. 9) showed the following thicknesses for each of the three units in the Chiwawa River syncline: the shaley Nahahum Canyon Member ≈ 780 m; the middle sandstone ≈ 850 m, and the upper

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)

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 under-lying 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 Tse 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 that interbedded conglomerate (this study)		Much less common than interbedded conglomerate (this study)
Volcaniclastic units	Multiple felsic tuffs 1 to 12 m thick; FT ~45 ± 3Ma (Gresens et al., 1981)	Basal 500 m has rhyolitite 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 conglom-erate 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)	Tsd of Figs. 3 and 8A has mostly tonalitic clatsts

Notes: FT is fission track age from zircon in cited reference. NA is not applica conglomerate ≈ 300 m. The cross sections of Whetten and Laravie (1976) and of Whetten and Waitt (1978) show comparable thicknesses.

Tuffs in Chumstick Formation below the Nahahum Canyon Member on the southwestern limb of the Eagle Creek anticline are potential marker units. Unfortunately, the tuffs are only 0.5 to 12 m thick; thus, most are difficult to map. Furthermore, individual tuffs have not been distinguished and correlated geochemically (McClincy, (1986). When they are, the abrupt termination of some of them (Tabor et al., 1987) may prove to mark faults and/or folds that repeat the section. In contrast, Cheney and Hayman (2009) used a conglomerate-bearing sandstone (units Tcri and Tcru of Figure 5) ≈ 0.6 to 1.0 km thick as marker unit in the Chumstick Formation.

The uniformity of the radiometric dates in the Chumstick Formation (Table 3) may indicate that units, including intrusions, are not essentially coeval, but that the dates have been reset. This should be tested by modern dating techniques, especially U/Pb for the zircons and Ar40/Ar39 for potassic samples.

Wenatchee Formation

Gresens et al. (1981) and Gresens (1983) showed that the 250-m thick, arkosic Wenatchee Formation is unconformable upon the Chumstick Formation in the Wenatchee area (Stops 2-3 and 2-4). However, the Wenatchee Formation may be equivalent to the Nahahum Canyon Member of the Chumstick Formation for the following reasons. In the Wenatchee area, the Nahahum Canyon Member is on the northeastern limb of the Eagle Creek anticline, whereas, the Wenatchee formation is on the southwestern limb (Gresens, 1983). Both formations are predominantly black siltstone and shale (Gresens, 1983), and even some sandstones in each are similar (Gresens, 1983) At Wenatchee, a distinctive 60 m-thick conglomerate (Stop 2-6) with clasts of felsic volcanic rock and vein quartz up to 0.3 m in diameter strikes northwestward along the southwestern margin of the northeast dipping Nahahum Canyon Member. Gresens (1983) and Cameron (1996) believed that the conglomerate is a tectonic sliver, but the northeastern-most strand of the Eagle Creek fault is southwest of the conglomerate (Patton and Cheney, 1971; Margolis 1987), not northeast of it. Thus, this may simply be the basal conglomerate of the Nahahum Canyon Member. Significantly, the Wenatchee Formation and the Nahahum Canyon Member on opposite limbs of the Eagle Creek anticline also are unconformable on the same unit, which Gresens (1983) believed to be the Swauk Formation tuffs and flow domes in the 60-m conglomerate date the base of the Nahahum Canyon Member. A K-Ar date on biotite from the Compton tuff is 46.2 + 1.8 Ma (Margolis, 1988). K-Ar dates on biotite from Wentachee Dome are 43.2 + 0.4 and 42.5 + 1.6 Ma (Table 3). In opposition to this proposed correlation of the Wenatchee Formation and the Nahahum Canyon Member is a fission track date of 33.4 + 1.4 Ma from a tuff in the Wenatchee Formation (Tabor et al., 1982).

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

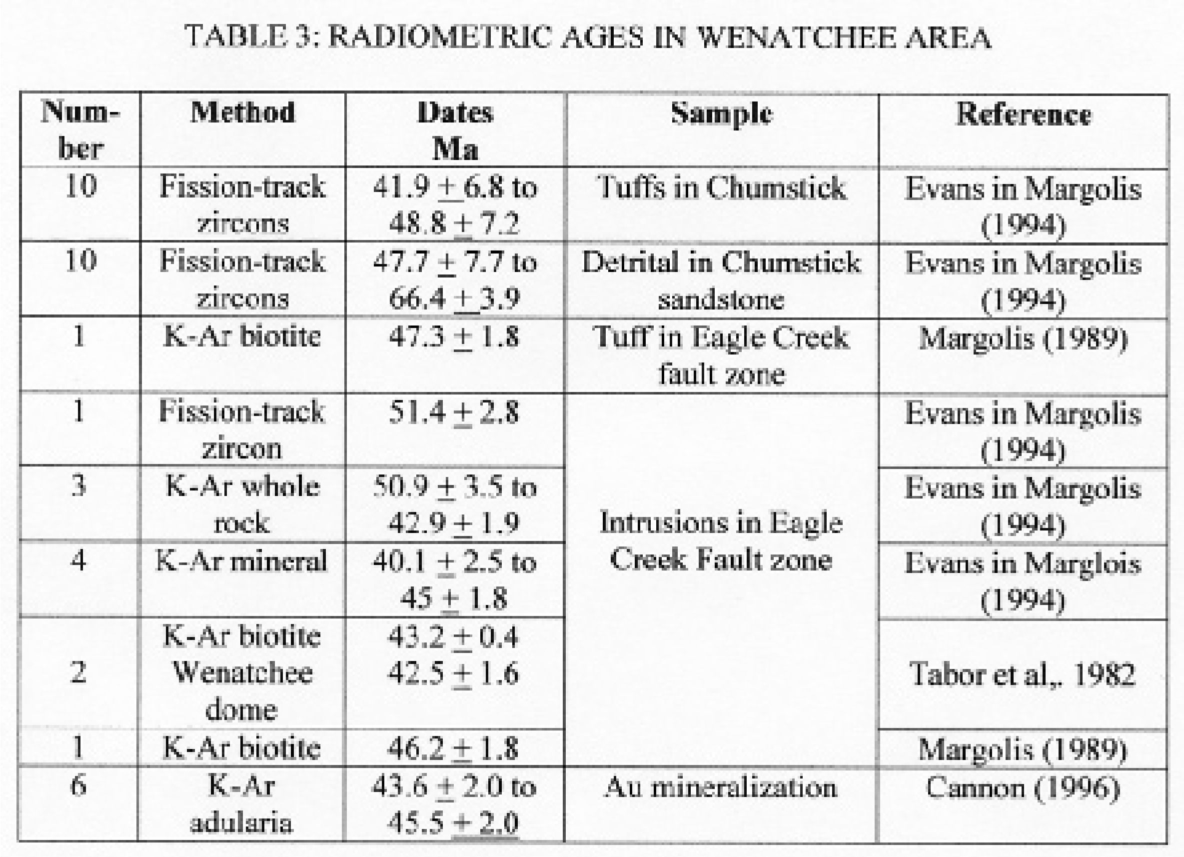


TABLE 3: RADIOMETRIC AGES IN WENATCHEE AREA

Number	Method	Dates Ma	Sample	Reference
10	Fission-track zircons	41.9 ± 6.8 to 48.8 ± 7.2	Tuffs in Chumstick	Evans in Margolis (1994)
10	Fission-track zircons	47.7 ± 7.7 to 66.4 ± 3.9	Detrital in Chumstick sandstone	Evans in Margolis (1994)
1	K-Ar biotite	47.3 ± 1.8	Tuff in Eagle Creek fault zone	Margolis (1989)
1	Fission-track zircon	51.4 ± 2.8	Intrusions in Eagle Creek Fault zone	Evans in Margolis (1994)
3	K-Ar whole rock	50.9 ± 3.5 to 42.9 ± 1.9		Evans in Margolis (1994)
4	K-Ar mineral	40.1 ± 2.5 to 45 ± 1.8		Evans in Marglois (1994)
2	K-Ar biotite Wenatchee dome	43.2 ± 0.4 42.5 ± 1.6		Tabor et al,. 1982
1	K-Ar biotite	46.2 ± 1.8		Margolis (1989)
6	K-Ar adularia	43.6 ± 2.0 to 45.5 ± 2.0	Au mineralization	Cannon (1996)

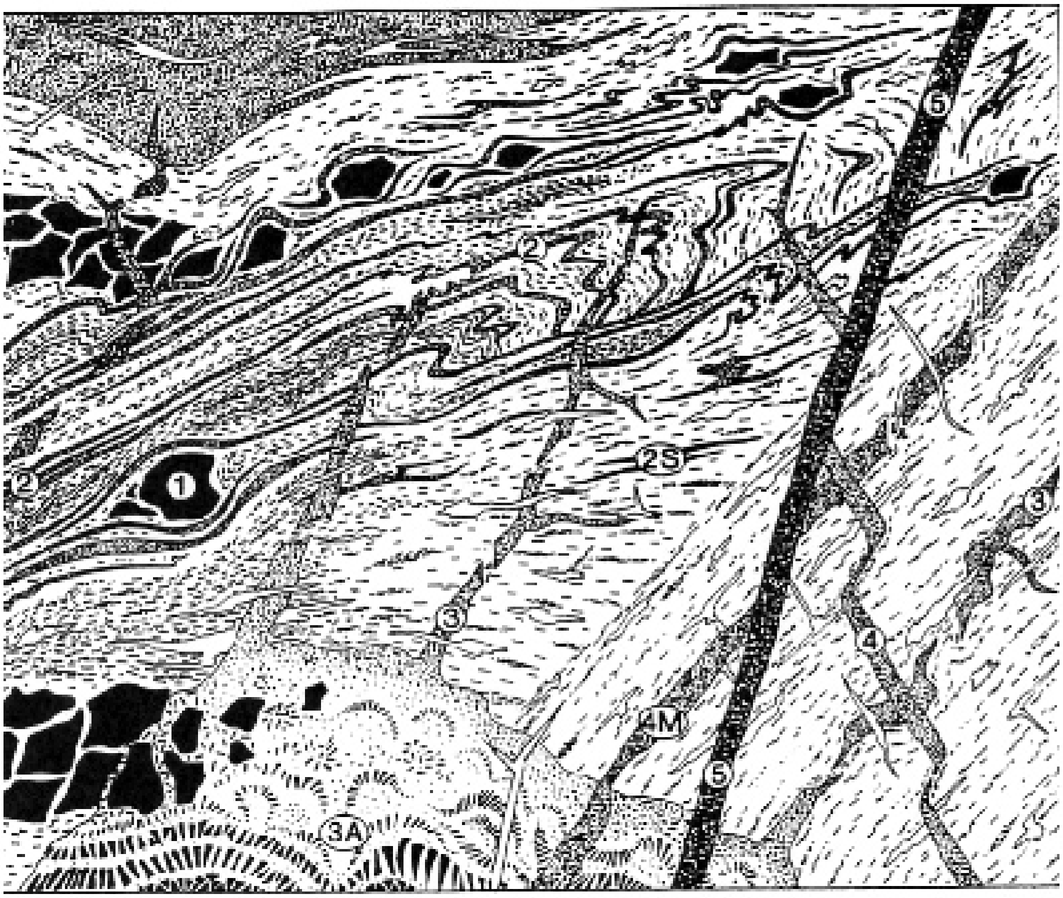
Basalt Group (Fig. 3). Cheney and Hayman documented two major episodes of folding. The Eocene rocks were folded along northwesterly axes about 40 Ma and are offset by north-south strike slip faults (Table 4, Fig. 3). The (Pliocene and younger) folding of the Columbia River Basalt Group occurred along 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).

ECONOMIC GEOLOGY

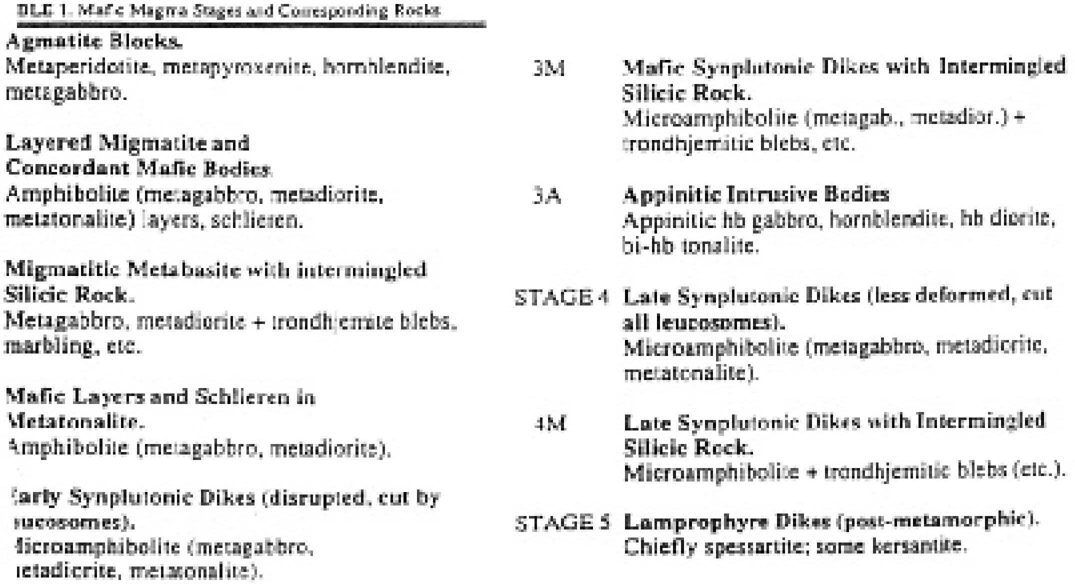
Mineralization in the Wenatchee gold belt is in silicified and pyritized arkosic sandstones in the Eagle Creek fault zone. The L-D mine (1949 to 1967) in the central part of the belt (Fig. 8) produced 1.0 million tons of ore averaging 0.396 ounces of gold and 0.607 ounces of silver per ton (Patton and 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 space 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 siltsone/mudstone units vary significantly in thickness.



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 basite listed in Table 1. Small white bodies are leucosomes. Left-hand two-thirds of 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.



BLE 1. Mafic Magma Stages and Corresponding Rocks

	Agmatite Blocks. Metaperidotite, metapyroxenite, hornblendite, metagabbro.
	Layered Migmatite and Concordant Mafic Bodies. Amphibolite (metagabbro, metadiorite, metatonalite) layers, schlieren.
	Migmatitic Metabasite with intermingled Silicic Rock. Metagabbro, metadiorite + trondhjemite blebs, marbling, etc.
	Mafic Layers and Schlieren in Metatonalite. Amphibolite (metagabbro, metadiorite).
	arly Synplutonic Dikes (disrupted, cut by ucosomes). licroamphibolite (metagabbro, etadiorite, metatonalite).
3M	**Mafic Synplutonic Dikes with Intermingled Silicic Rock.** Microamphibolite (metagab., metadior.) + trondhjemitic blebs, etc.
3A	**Appinitic Intrusive Bodies** Appinitic hb gabbro, hornblendite, hb diorite, bi-hb tonalite.
STAGE 4	**Late Synplutonic Dikes (less deformed, cut all leucosomes).** Microamphibolite (metagabbro, metadiorite, metatonalite).
4M	**Late Synplutonic Dikes with Intermingled Silicic Rock.** Microamphibolite + trondhjemitic blebs (etc.).
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).*

TABLE 4. MAJOR NORTHWESTERLY STRIKING FOLDS ON THE EASTERN FLANK OF THE CASCADE RANGE.

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**
Swakane Creek anticline	Pre-Tertiary crystalline	Unnamed fault (Gulick,1990)		1450 m	Badger Mountain anticline, Moses Stool anticline (Gulick, 1990)
Chiwawa River syncline	"Chum-stick" Formation		Coulter Creek fault (this study)	CRBG absent	
Eagle Creek anticline	Pre-Tertiary crystalline	Eagle Creek fault, but low angle to south (Patton and Cheney, 1971	Chumstick Creek & Icicle Creek faults (this study); Wenatchee area (Patton and Cheney, 1971)	CRBG absent	Laurel Hill monocline, Colockum Creek monocline
Peshastin syncline	"Chum stick" Formation		Chumstick Creek & Icicle Creek faults (this study)	CRBG absent	
Naneum Ridge anticline	Pre-Tertiary crystalline	Camas Creek & Leaveworth faults (Cheney, 2003)	Chumstick Creek fault (this study)	2000	Naneum Ridge anticline
Naneum Creek syncline	Swauk Formation			1700	Naneum Creek syncline
Table Moun-tain anticline	Swauk Formation		Table Mountain anticline	1750	
Kitittas Valley syncline	Roslyn Formation			750	KitittasValley syncline
Ainsley Canyon anticline	Pre-Tertiary crystalline (Cheney, 1999)	Easton Ridge fault (Walker, 1980)		1450	Ainsley Canyon anticline

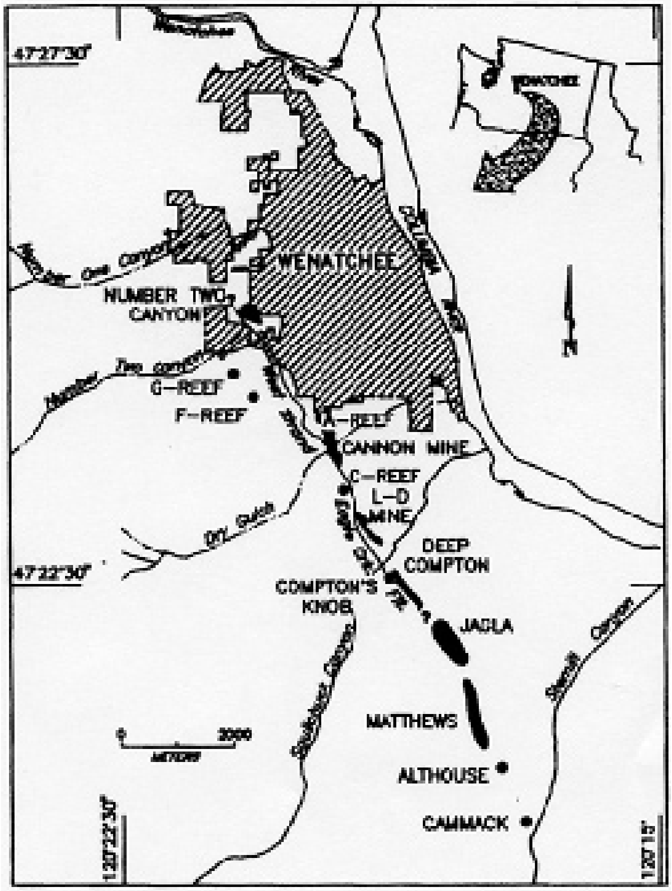


Figure 8. Important Deposits of the Wenatchee Gold Belt
(Cameron, 1996, Fig. 1)

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 (l996) 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 aquatards 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) post-dates mineralization (Cameron, 1996) and is cut by the north-south faults (Patton and Cheney, 1971; Cameron, 1996). The rhyodacite is about 43 Ma (Table 3).

MISSOULA FLOODS

Most of the Missoula floods were jökulhlaups resulting from the failure of glacial ice dams impounding glacial Lake Missoula on the Clark Fork River. Evidence now exists for hundreds of such floods (Waitt, 1994). The floods crossed the Columbia Plateau (mostly underlain by the Miocene Columbia River Basalt Group) of eastern Washington and adjacent Idaho and Oregon, hydraulically ponded at the Wallula Gap on the Columbia River (at the Washington/Oregon border), and surged up valleys tributary to the Columbia River. Current research in the Walla Walla valley suggests that similar floods may have occurred during earlier Pleistocene ice ages (P. K. Spencer, May 2009, personal communuication).

Where the floods crossed eastern Washington they eroded the “channeled scablands”. Examples of channeled scabland occur between Spokane and the Grand Coulee. The channels are coulees cut in the bedrock of Columbia River Basalt. The intervening scablands are erosional remnants of loess on the basalt. The loess supports grasslands (both natural and wheat). The deepest channels are the spectacular Grand Coulee and Moses Coulee (Stop 1-3).

According to Waitt (2009) the earliest flood, about 15,500 yr BP, flowed down the Columbia River and 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 the Moses Coulee and back-flooded through Wenatchee. As the Okanogan Lobe advanced to block the Moses Coulee, floods carved the 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.

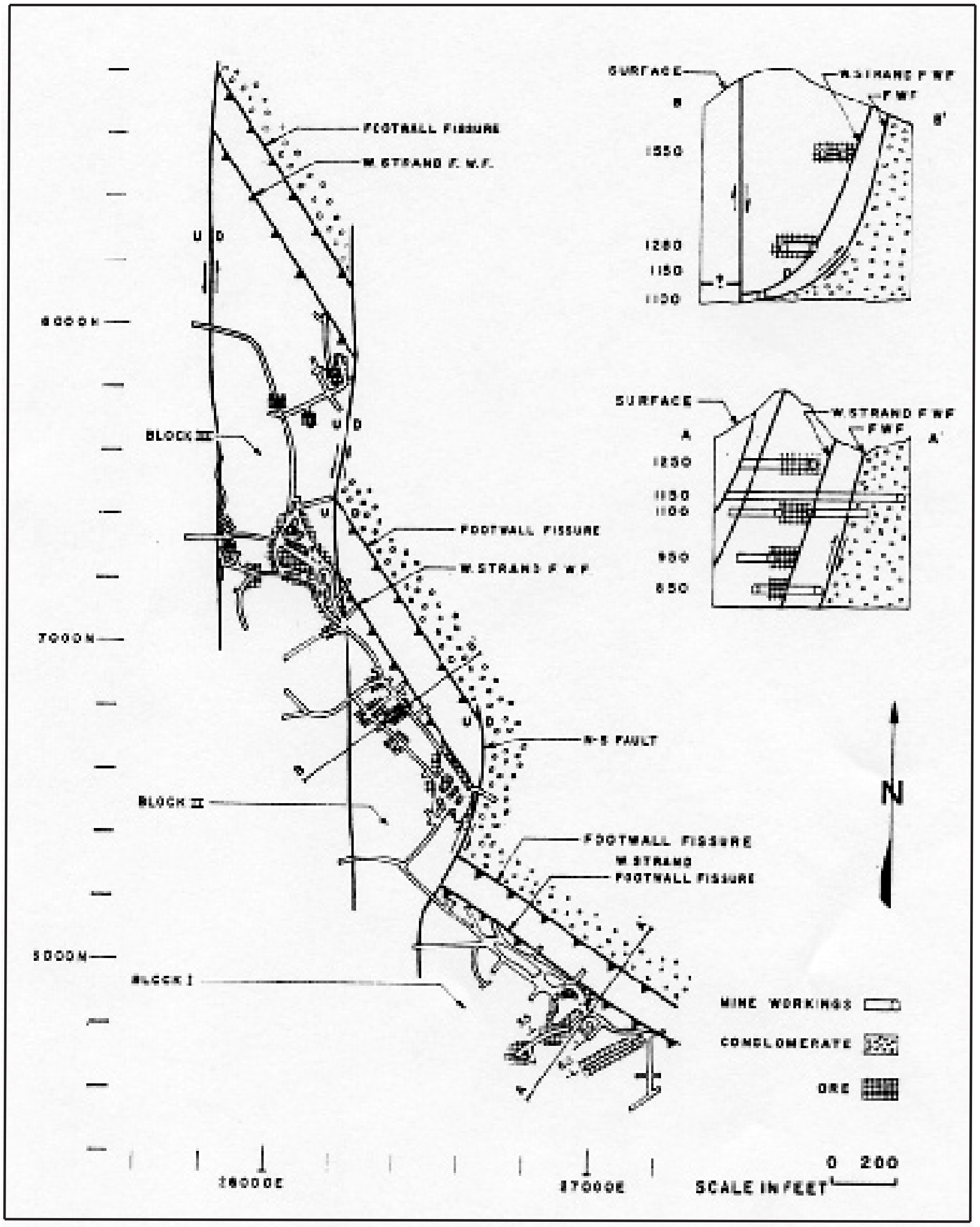


Figure 9. Generalized geology of the 1250 level of the L-D mine *(Patton and Cheney, 1971, Fig. 4). Ores in Blocks I and II are northwesterly dipping veins.*

FIELD TRIP LOG

ROAD LOG FOR 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 down hill.

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 the 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 (Waitt, 1994) when floods exiting the Quincy basin and backflowed upstream toward Wenatchee (Waitt, 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 the West Bar indicate down-valley flow. This bar and the lower, more riverward bar, which is studded with bounders, seem to be equivalent to bars at Malaga (downstream from Wenatchee) and at Chelan Falls (upstream from Wenatchee) (Waitt, 1994).

Continue westbound (but now northward) on SR 28.

At MP 18, the mouth of the Moses Coulee and the bar across it are visible ahead. The gravel in this bar is almost entirely basalt, indicating derivation from the Moses Coulee, not from up the Columbia (Waitt, 1994). Portions of the Trinidad bar overtop the Moses Coulee Bar (R.B. Waitt, 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 the west wall of the coulee is a maximum of 24 m deep.

.

Turn left (west) an 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 unconsoldiated 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 McNeil 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 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. Invasive sills are common elsewhere near the bottom contact of the CRBG..

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 bridge 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 that hornblende. Lamoprophyres are fine-grained, dark-colored rocks with mafic pheocrysts but no feldspar phenocrysts. Lamprophyre is an alkalic, not a mafic, rock.

Figure 7 (p 12) 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, ductilely 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. leucotrondhjemitic and granitic viens, 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 tonalititic 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. lamphrophyre 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 Orhogneiss at Earthquake Point

The sign is remarkably 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 Enitat 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, 200l).

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 Swkane 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 to12 kbar and maximum temperatures of 640 to 750ºC. Although the Swakane Biotite Gneiss is the youngest terrane in the niortheastern Casacde 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).

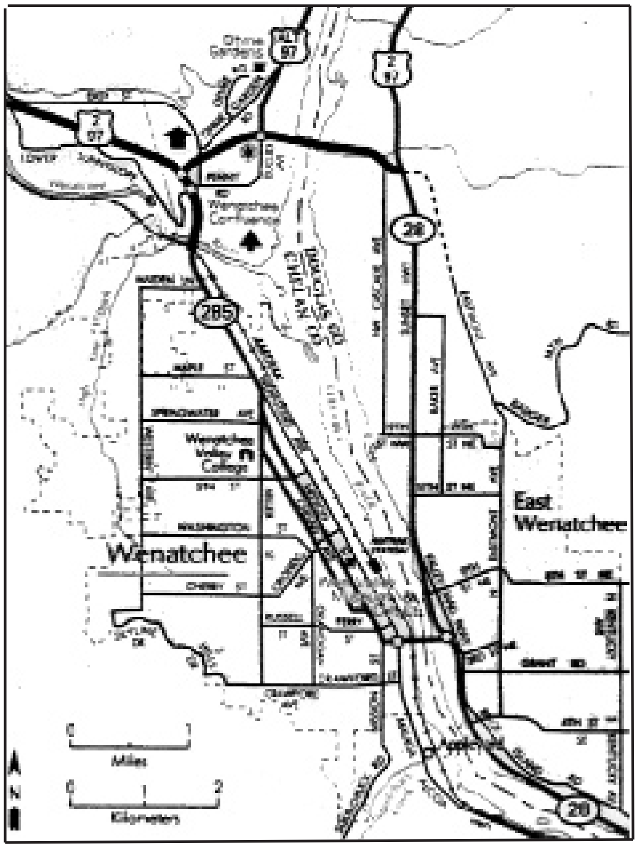


Figure 10 Road map of Wenatchee and East Wenatchee. *Washington State Department of Transportation Highway Map 2008-2009*

ROAD LOG FOR DAY 2

Use Figure 10 (above) 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 Grand Avenue. Continue 0.2 miles to the Pangborn-Herndon Memorial.

Stop 2-1. Overview from the Pangborn-Heardon Monument on Pangborn Bar

First, revere Pangborn and Herndon

Then revere 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 Wenetchee/EastWentachee, 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 Wentachee 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, manoeuver 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 11a). We are 1180 feet above Squilchuck Creek to the jnorthwest. The NORCO well and exploration drilling of the past three decades encountered mineralization beneath Wenatchee Heights (compare Figs. 8 and 11-A).

The cross section of Figure 11A 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 11A). In contrast to what is shown in Figure 11A, which shows a fault between the mine rocks and the Wenetchee Formation (because the Wenatchee Formation and Nahahum 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. 11A).

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 Creeek 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 shaft and the decline for vehicles were 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 tail-

Figure 11 Geology of the Eagle Creek Fault Zone

Figure 11a (Right) *is figure 2 of Patton and Cheney, 1971. The Cannon mine is on the NW side of the 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).*

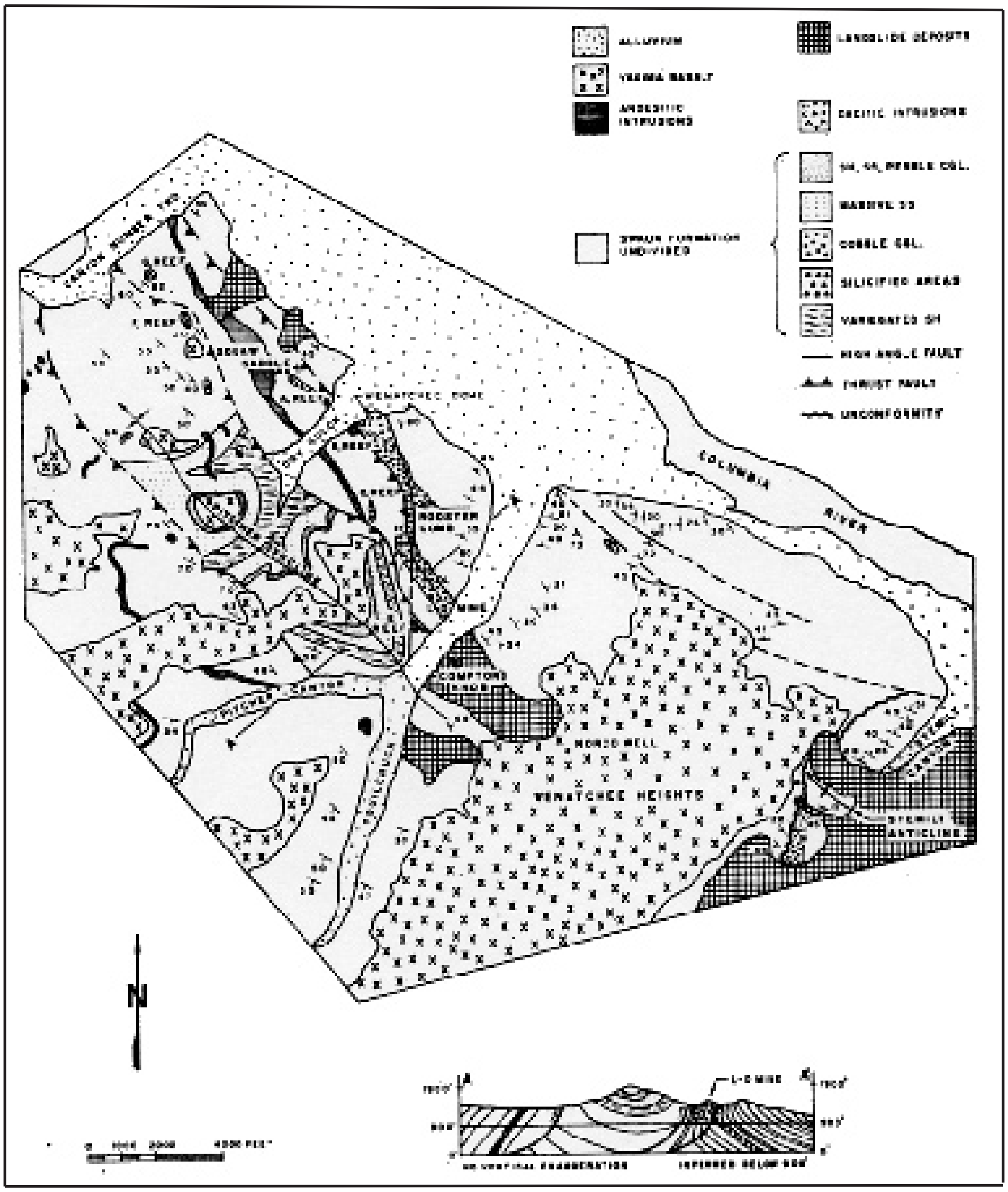
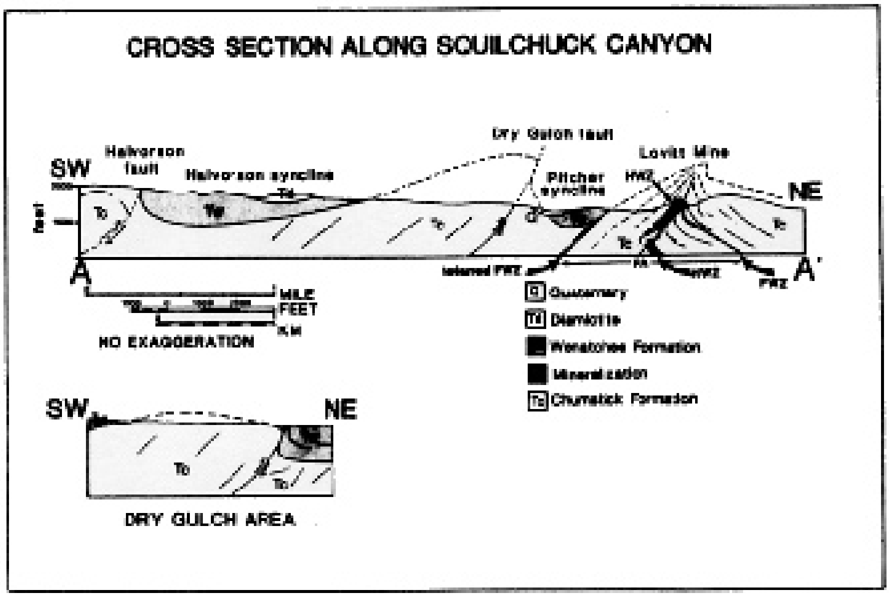


Figure 11B (Right) *is Figure 3 of Margolis (1989). Abbreviations are HWZ = hanging wall zone of mineralization; FWZ = footwall zone of mineralization, and PA = prophylitic alteration.*



ings 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 12 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 aquatards for the hydothermal 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 Slpet 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) Touchet 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 SW. Note that deformation preferentially occurs in black shale, with resultant dismemberment of thin beds of sand-

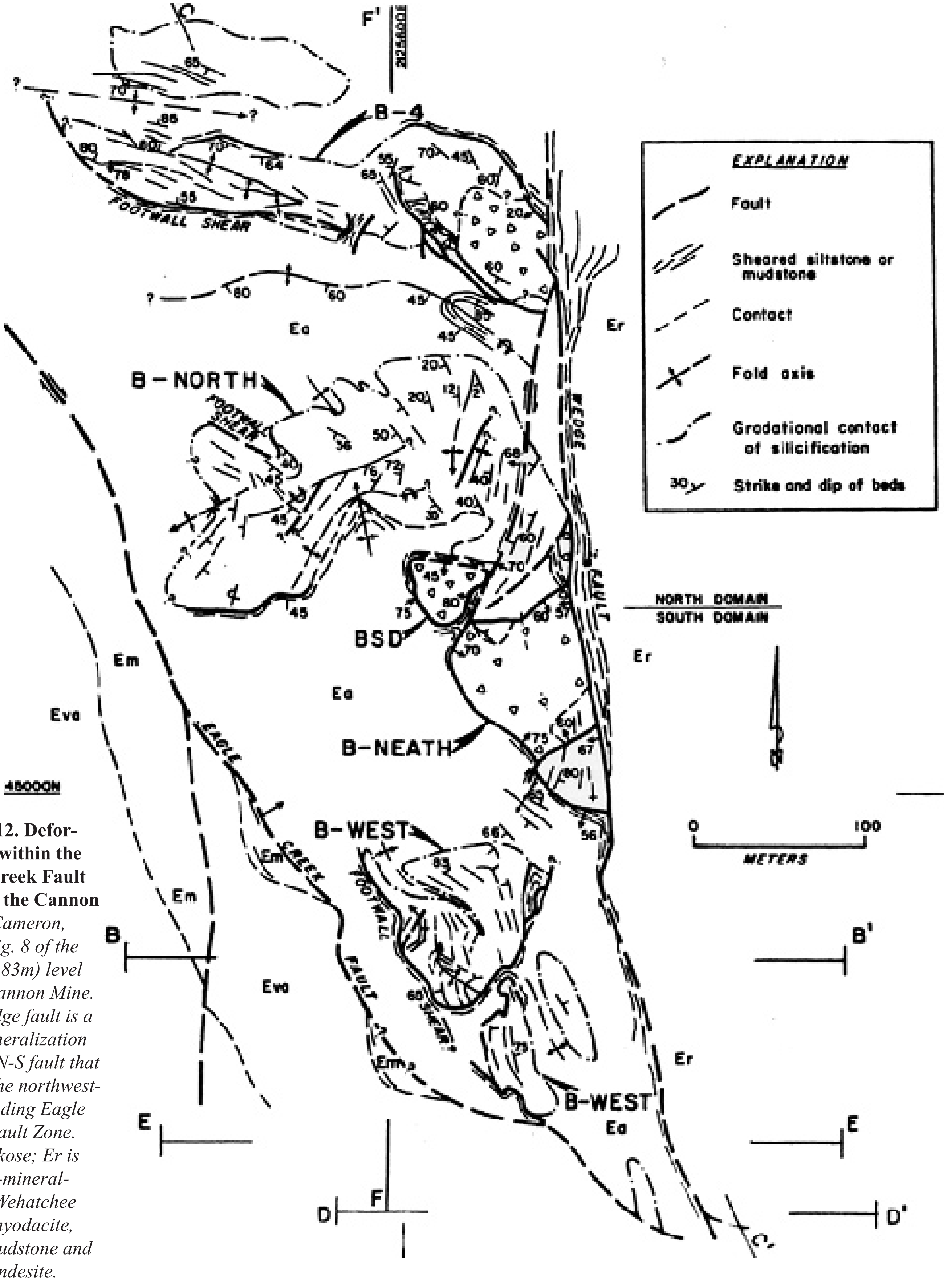


Figure 12. Deformation within the Eagle Creek Fault Zone at the Cannon Mine *(Cameron, 1996, Fig. 8 of the 600 ft (183m) level of the Cannon Mine. The Wedge fault is a post-mineralization dextral N-S fault that offsets the northwesterly trending Eagle Creek Fault Zone. Ea is arkose; Er is the post-mineralization Wehatchee Dome rhyodacite, Em is mudstone and Eva is andesite.*

stone. 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% to5% (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.l, 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 columnarly 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 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 >50º 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 volcaniclastic unit in the Swauk Pass Member

An intermediate volcaniclastic rock with felsic clasts occurs in the Swauk Pass Member (Tss of Fig. 6). The map of Tabor et al. (1982) shows that volcaniclastic 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 volcaniclastic 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.l 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) onSR-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.

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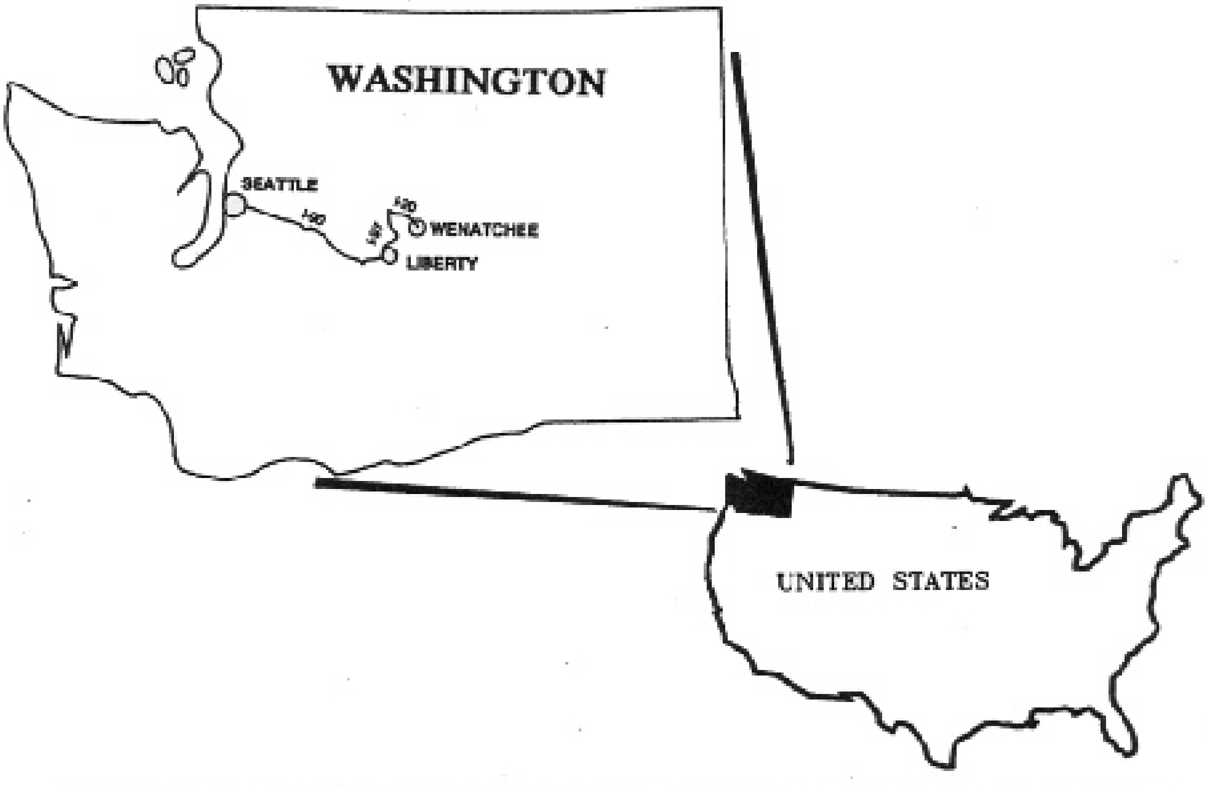
Appendix 1

GUIDEBOOK SERIES
Volume 20

EPITHERMAL GOLD MINERALIZATION, WENATCHEE AND LIBERTY DISTRICTS, CENTRAL WASHINGTON

Edited By Jacob Margolis



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Day Two Refer to Figures 1 and 2 (pages 16 and 17 at end of road log).

- Arrive at Cannon Mine for start of surface tour of Wenatchee district. Park at the south end of Miller Street at the mine administration building on Circle Street. The large knob 50 feet south of the end of Miller Street is Wenatchee Dome.

- STOP 1 - Wenatchee Dome. Walk to the base of the dome at the east end of the administration building. Wenatchee Dome is a flow-banded phyric rhyolite, apparently intrusive, containing phenocrysts of plagioclase, quartz, and minor biotite. A perlitic border is present along the western margins of the intrusion, and the flow banding is generally parallel to the exposed margins of the dome. The dome is part of a larger body of rhyolite which extends in a northwesterly direction. It is unaltered and unmineralized; a published K-AT date on biotite (43.2±.4 Ma; Gresens, 1983) indicates that it is about 1 Ma younger than mineralization. Itislikely that the rhyolitic magma was present at deeper levels during mineralization and later rose to its presentlevel, solidifying aftergoldmineralization. Ottetal. (1986) report silica contents of 77-80 weight percent for the devitrified portions of the rhyolite. Similar rhyolite is exposed about 0.5 miles southeast of here at Rooster Comb, crags visible from the mine area. The Rooster Comb rhyolite has not been dated and is similar in appearance to Wenatchee Dome. However, Margolis (1987) traced aconformable, rhyolitic ash-flow tuff (46.2±1.8 Ma) with its associated, underlying, red-brown mudstone (commonly magnetic) and felsic cobble conglomerate north from the area of Wenatchee Heights through the east side of the Lovitt mine to the south edge of Rooster Comb. This tuff appears to be a district-scale impermeable cap to hydrothennal alteration, which occurs only west (beneath) the trace of the tuff. It remains unclear whether Rooster Comb is part of this tuff, part of the Wenatchee Dome intrusion, or a separate intrusion. Mineralization in the Cannon mine occurs west of the rhyolite.

- STOP 2 - B-reef. B-reef is the prominent northwesterly-trending rib exposed on the southwest side of the administration building several hundred feet west of Wenatchee Dome. Underground mining here at the Cannon mine has reached to levels about 150 feet below the outcrop. Note the preserved bedding on the west side where pervasive silicification is strong; bedding is about 310/40SW. Minor brecciation accompanies the silicification in some areas, but note the rarity of quartz veins, more common in the mined portions of the deposit. The east side of the outcrop is only weakly altered and bedding is well-preserved; note the local bedding-parallel shear fabrics.

Grab samples from B-reef show gold grades lower than typical of mined areas. Oxidation here has resulted in trace amounts of native silver and copper. Refer to Cameron (this volume) for more details. Visible from this point are: the trace of A-reef to the northwest, which is on strike with B-reef; the gently-dipping post-mineralization Wenatchee Formation (Oligocene, unconformable on Chumstick) at high levels on either side of Dry Gulch to the southwest; and a rib of outcrops of conformable basalt within the Chumstick Formation to the south on the north-facing hillside.

The use of the term reef in the district reflects the fact that the exposed silicified zones are tabular and stratiform within arkosic sandstone.

- Walk west along Circle Street to a dirt road which continues uphill to the northwest to the prominent outcrops of A-reef under the powerline. Examine the A-reef outcrop area.

- STOP 3 - A-reef. A-reef is on strike, with regards to the strike of the Chumstick Formation, of B-reef and consists of pervasively silicified arkosic sandstone (bedding well-preserved locally, about 320/50NE) surrounded by a poorly-exposed argillic zone which can be seen under the powerline on a bulldozed pad.

The same package of mineralized beds has been traced from B-reef to A-reef, indicating a stratiform alteration. Compared to B-reef, A-reef contains more quartz veins and discontinuous, patchy zones of texture-destructive silicification. The mined portion of A-reef is downdip of here to the east along the same stratiform silicification exposed. A steep, east-dipping, northwest-striking fault (see Cameron, this volume, Fig. 4) on the west side of the exposed A-reef separates it from an anticline to the west which contains apparently conformable andesite and basalt flows or sills. The andesite has been dated at 50.9 ±3.5 Ma (whole-rock, K-AT; Ott, 1988). The fault, termed the "west strand of the Eagle Creek fault" by Cameron et al. (1992; see paper in this volume), is considered to have west-side-up motion. Mineralization in the Cannon mine area occurs only east of this structure.

- Walk back to vehicles, travel north on Miller Street, and turn left on Crawford Street heading west.
At its end, turn right onto South Hills Drive. At this point, about 500 feet ahead up the hill, minor mineralization has been intersected in drilling. Follow the road to its end and turn left onto Red Apple Road, starting to clock mileage from 0.0; keep left and follow Skyline Drive. At 0.6 miles is a brown water tank on the right side of the road. Stop about 200 feet before the water tank on the right shoulder where there is a good view of Wenatchee.

- STOP 4 - Look north along Western Avenue. In distance is ridge of Swakane Biotite Gneiss on the northeast side of the Entiat fault outside of the Chiwaukum graben. Drilling about 1000 feet north of here under the orchards intersected minor mineralization (unpublished data). This point is directly on strike with the stratiform zones of mineralization examined at the last two stops.

- Continue on Skyline Drive passing outcrops of brown andesite or basalt on left side of road. These andesites are the northwestward extension of those immediately west of A-reef noted at stop 3.
- Turn left onto Canyon #2 Road heading west. Begin clocking new mileage at this turn. Note the drill roads on the south side (to the left) of the canyon here (area 5 of Gill, this volume). The altered zone above the drill roads is G-reef. Stop at 0.65 miles at outcrops on right side of the road; park to left at driveway.

- STOP 5 - These outcrops consist of relatively indurated conglomeratic arkose dipping steeply to the northeast. Note the cobbles consist largely of granitoid and biotite gneiss, presumably the Swakane Gneiss exposed immediately northeast of the Entiat fault hi this region. Gresens (1983) noted that rocks hi the area of alteration and mineralization are distinctly more indurated than typical Chumstick Formation, and concluded that they represent the older Swauk Formation; this outcrop is one of his type examples of Swauk. Margolis (1987) recognized, however, that the induration and other differences are due to a propylitic alteration, and these rocks should be considered a district-scale propylitic facies and not a different formation. Similar propylitic alteration of arkose, flanking silicic and sericitic alteration, occurs in the area of the Lovitt mine and Wenatchee Heights several miles to the south. Propylitic features of the rock at this outcrop are observable in thin-section and consist chiefly of epidote replacing plagioclase and pyrite cubes (now limonite) replacing biotite, which is largely chloritized.

- Continue up Number 2 Canyon for 1.2 miles to the prominent rib of outcrops on the right side of the road; park ahead to the left on the widened shoulder.

- STOP 6'- Gresens (1983) mapped this northwest-trending rib of alteration, which crosses the road here, as an altered mafic sill that dips west, the unaltered continuation of which is exposed about 1 mile northwest of here. A whole-rock, K-Ar date of 48.3 ±2.8 Ma was obtained by Gresens (1983) on this less altered portion of the dike to the north. The dike continues to the southeast, but is not well exposed, and is not everywhere altered as it is here. Alteration here is weak, as is mineralization. Note the calcite veins and only rare silica, present as slickensided veins trending northwest (some show subhorizontal motion of uncertain direction). The less altered andesite at the base of the outcrop at the road may be part of the younger Oligocene (±30 Ma) Horse Lake Mountain intrusive complex (Gresens, 1983) which is exposed throughout the area west and northwest of here and which also intrudes the Wenatchee Formation (±34 Ma). Some of these younger dikes are exposed northeast of the trace of the gabbro sill. Note the poorly-indurated and unaltered Chumstick Formation arkose exposed east of the altered zone. Does this weak alteration here and its dying-out to the northwest reflect the distal portions of the gold-bearing hydro thermal system exposed southeast of here at the Cannon and Lovitt mine areas, or is it a separate, weak hydrothermal system triggered by the emplacement of the sill?

- Head back down Number 2 Canyon Road to its termination at Western Avenue; turn left, and then right on Cherry Street heading east. At traffic light, turn right onto Miller Street heading south. Turn left onto Crawford Street and continue east for about 3/4 mile. Turn right at park onto Methow Street and start new mileage. Unaltered, northeast-dipping arkosic sandstone of the Chumstick Formation exposed intermittently from 1.3 to 1.7 miles. At 1.7 miles is the Lovitt mine; park to the left at the mine office. Permission to examine the Lovitt mine area beyond the outcrops at the road must be obtained from Lovitt Mining Company /P.O. Box 2896, Wenatchee, Washington, phone 509-662-1251 or 604-655-1817].

- STOP 7 - Lovitt mine on north side of Squilchuck Canyon. Refer to Patton and Cheney (1971), Margolis (1987,1989), Roberts (1990) for background information on the Lovitt mine geology and mineralization. Mineralization was discovered here in 1885, but significant underground mining took place from 1949 to 1967, with about 0.91 million tons of ore grading 0.4 and 0.6 ounces per short ton Au and Ag, respectively, being mined. The stratiform, silicified ridge extending from the road uphill is referred to as D-reef and contains mineralization within silicified arkose and in quartz veins within it. The metallic assemblage is dominated by pyrite, arsenopyrite, chalcopyrite, native gold, acanthite, naumannite, and tetrahedrite within quartz-calcite-adularia gangue (Patton, 1967; Roberts, 1990). Silicified arkose of D-reef dips steeply southwest and is bound on its northeast side by a southwest-dipping thrust fault coincident with a deformed mudstone horizon referred to as the “footwall fissure”. Most material mined here was from D-reef in the hanging wall of the footwall fissure. However, steepened and overturned beds in the footwall of the fault exposed along the northeast side of D-reef are also altered and mineralized beneath a felsic tuff, termed the Compton tuff by Margolis (1987).

The overall structure here has been interpreted by Margolis (1987, 1989) as resulting from post-mineralization, northeast-directed, Oligocene thrusting following deposition of theWenatchee Formation, with D-reef in a fault-propagation fold (anticline) cored by the footwall fissure. To the southeast, the large, topographically low area southeast of Squilchuck Canyon is the continuation of the alteration and mineralization under a landslide area; note the drill roads. This north-facing slope is the area of a cross-section in Margolis (1989, Figure 4); the final field stop is at the top of Wenatchee Heights. (No, you don’t have to walk to the top.) A similar stratiform alteration system is traceable for several kilometers from the top of Wenatchee Heights through the Lovitt mine. Two continuously altered horizons are discernable: one in the hanging wall of the footwall fissure (D-reef), and a stratigraphically higher one, which is locally exposed in the footwall (northeast side) of the footwall fissure, where it is overturned due to drag folding by the thrust deformation (footwall syncline). This second, or footwall zone, immediately underlies the Compton tuff and its underlying, locally magnetic mudstone, and is largely confined to a cobble conglomerate comprised of felsic volcanic clasts. West of here, the white rocks north of Methow Street are the post-mineralization Oligocene Wenatchee Formation, which unconformably overlies the Chumstick on the eastern limb of the Pitcher syncline (see Figure 3 in Margolis, 1989).

- STOP 7a - Examine the silicified arkose of D-reef exposed at Methow Street. Note the pervasive silicification, the strongjoint pattern, apparently following bedding, that dips steeply southwest, and rare quartz veins.

- Walk up the gravel mine road which leaves Methow Street under the bridge about 150 feet east of the silicified outcrops. The light-colored, massive rock used as road metal on the mine road is the rhyolite of Wenatchee Dome. At the first bench walk to the left (southwest) under the rail trellis to behind the building.

- STOP 7b - Note the unindurated, unaltered Chumstick arkose dipping steeply northeast and overturned steeply northwest as D-reef is approached, the result of drag folding under the southwest-dipping footwall fissure reverse fault. These arkosic beds are apparently stratigraphically above the Compton tuff and the footwall alteration zone beneath it.

- Return to main mine road continuing northeast and uphill. Turn left at next bench and walk southwest toward D-reef.

- STOP 7c - Again, walking toward D-reef on this bench (1150-foot level), note the unaltered arkose dipping northeast and becoming steeper as D-reef is approached. Slumping on this level obscures the dips farther southwest, however.

- Return to main mine road and continue uphill; follow hairpin turn to left and continue along the main mine road. Note the unaltered arkose with well-developed cross-bedding. At the next intersection, proceed straight at the same level which ends at the 1250 level portal on the northeast wall of D-reef. Stop at the outcrops on the right about 100 feet before the portal.

- STOP 7d - This outcrop exposes argillized and silicified conglomerate (note limonite staining) of the footwall zone beneath the footwall fissure which follows the northeast wall of D-reef. Note the black shale on the northeast side of the conglomerate and then the unaltered arkose farther northeast. This black shale, locally magnetic, is traceable stratigraphically above this conglomerate for at least 2 kilometers along strike. The Compton tuff, which lies above the mudstone, is not exposed at this bench, possibly due to bedding-parallel deformation (common along mudstones), but is traceable farther above across other benches along a narrow topographic rib as can be seen at the next stop. Throughout the Lovitt mine area, mudstone horizons, which served as aquitards during hydrothermal activity, separate alteration types and have preferrentially accomodated post-mineralization shearing. The felsic porphyry cobbles in the conglomerate are in contrast to more abundant gneiss and granitoid typical of other Chumstick conglomerates. It would be interesting to date these cobbles (perhaps using a zircon fraction); it is likely that their source was the 47 Ma felsic volcanism present under Wenatchee Heights to the south (Norco volcanic complex of Margolis, 1987), which may have been the source of the Compton tuff overlying the conglomerate. Examine the silicified and argillized arkose at the 1250 portal.

- Return to main mine road and proceed to the left uphill to next intersection (about 1315 feet elevation). Note the large quartz veins dipping north and south exposed on the wall of D-reef. These veins were the focus of the early mine efforts. Follow main road to the right uphill and stop after about 50 feet to examine subcrop in road cut on the north side of the road.

- STOP 7e - Note the dark red-brown mudstone subcrop here which lies west of subcrop of platy rhyolite, apparently the Compton tuff. As seen before, no alteration occurs in arkose east of this rhyolite. The conglomerate is not well-exposed here; it would be west of the mudstone, but is traceable uphill along the west side of the mudstone and the felsic tuff.

- From this road intersection, walk northwest at this level to a clump of trees at the base of the talus slope of silicified blocks on the edge of D-reef.

- STOP 7f - Walk carefully up the boulders toward the cliff of D-reef examining the vein textures and silicification, and examine the large caved stope along the east wall of D-reef. The cavern exposes the steeply west-dipping deformed mudstone of the footwall fissure; but the north face of this cavern should not be approached. Use extreme caution here, as the walls of D-reef overhang the cave.

- End of Lovit mine tour. Follow main mine road back to Methow Street. For a self-guided tour, follow the mine road to higher levels of D-reef and walk to the top of Rooster Comb northeast of the mine area to examine the felsite and a good view of the Wenatchee area. D-reef may be crossed at higher levels, and you may continue back to Methow Street following the southwest wall of the reef. Propylitized arkose is locally exposed on the northwest side of the reef.

- From the Lovitt mine office drive southwest on Methow Street for about 0.4 miles and turn right on Squilchuck Road. Begin Clocking Mileage from 0.0.

- 0.1 miles - Blue and red mudstones, including paleosols, of the Wenatchee Formation exposed to the right on the southwest limb of the Pitcher syncline, a thrust-related fold. Pitcher Canyon Road leaves to the right; continue on Squilchuck Road. The geology along Squilchuck Canyon is shown in Figures 2 and 3 of Margolis (1989).

- 0.6 miles - Chumstick Formation dipping about 45° SW exposed to the right.

- 0.9 miles - Gently-dipping Wenatchee Formation at 2:00 on southeast limb of the northwest-striking Halvorson syncline, which is in the hanging wall of the Halvorson thrust of Margolis (1987). -1.45 miles

- Chumstick Formation on left side of road dipping 60°SW. -1.50 miles - Leaving Chumstick Formation, crossing contact between Chumstick and overlying, more gently west-dipping Wenatchee Formation exposed to the southwest and dipping about 35°SW in the northeastern limb of the Halvorson syncline.

- 2.3 miles - Turn right onto Halvorson Road and start new mileage.

- 0.3 miles - STOP 8 - Park on shoulder of road. The Halvorson thrust (not exposed), crosses the road here and follows a conspicuous gulley north of the road. Note the steeply upturned Wenatchee formation east of the gulley and the northeast-dipping Chumstick arkose in the inferred hanging wall of the thrust exposed hi the road cut about 20 feet west of the cable sign.

- Return to Squilchuck Road and start new mileage.

-0.25 miles - The Halvorson thrust crosses the road here at the yellow fire hydrant on right side of road.

- 0.50 miles - Turn left onto Wenatchee Heights Road.

-1.50 miles - At 12:00 is cover of basaltic diamictite of probable Pliocene age derived from Columbia River Basalt exposed west of here at higher elevations. The poorly-sorted basalt cobble conglomerates inverted topography and are locally 600 feet thick along the crest of Wenatchee Heights and other hills in the area.

- 2.60 miles - Turn left onto Edgemont Road.

- 2.80 miles - Turn left onto Jagla Road. Follow Jagla and its right-angle turns.

- 4.30 miles - Park along rusty metal guard rail.

- STOP 9 - Looking to the northwest, the Wenatchee Formation outlines the Pitcher syncline, interpreted by Gresens (1983) and Margolis (1987,1989) as afootwall syncline to the southwest-dipping Dry Gulch thrust fault on the west side of the syncline. The thrust is well-exposed hi Dry Gulch Canyon northwest of Squilchuck Canyon which is now the site of the Cannon mine tailings dam. The silicified zone at the Lovitt mine can be seen east of the syncline. Underneath this area at Wenatchee Heights and beneath the diamictite cover, is the Norco volcanic complex (NVC), named for the Norco well, a wildcat natural gas well drilled here in the 1930's. The NVC consists of at least 200 meters of rhyodacitic flows overlain by more silicic, welded tuffs which are intercalated with bedded rhyolite breccias containing a carbonaceous matrix which may have resulted from phreatic explosions through a lake (Margolis, 1987). Hydrothermal alteration, including silicification, argillization, and propylitization, and weak gold mineralization are present in both the volcanic units and overlying arkose. A K-Ar date of 47.3 ± 1.8 Ma on biotite from a basal felsic flow unit indicates that the volcanism is contemporaneous with the Teanaway Basalt exposed west of the Wenatchee region. Although the NVC is pre-mineralization, the error on its age overlaps with the 44.2 ± 1.9 Ma age of adularia from the Cannon mine; the alteration of the NVC may have immediately followed or accompanied the volcanism and predated mineralization at Cannon. Mineralization has been intersected hi drilling southeast of this location as well (see Gill, this volume).

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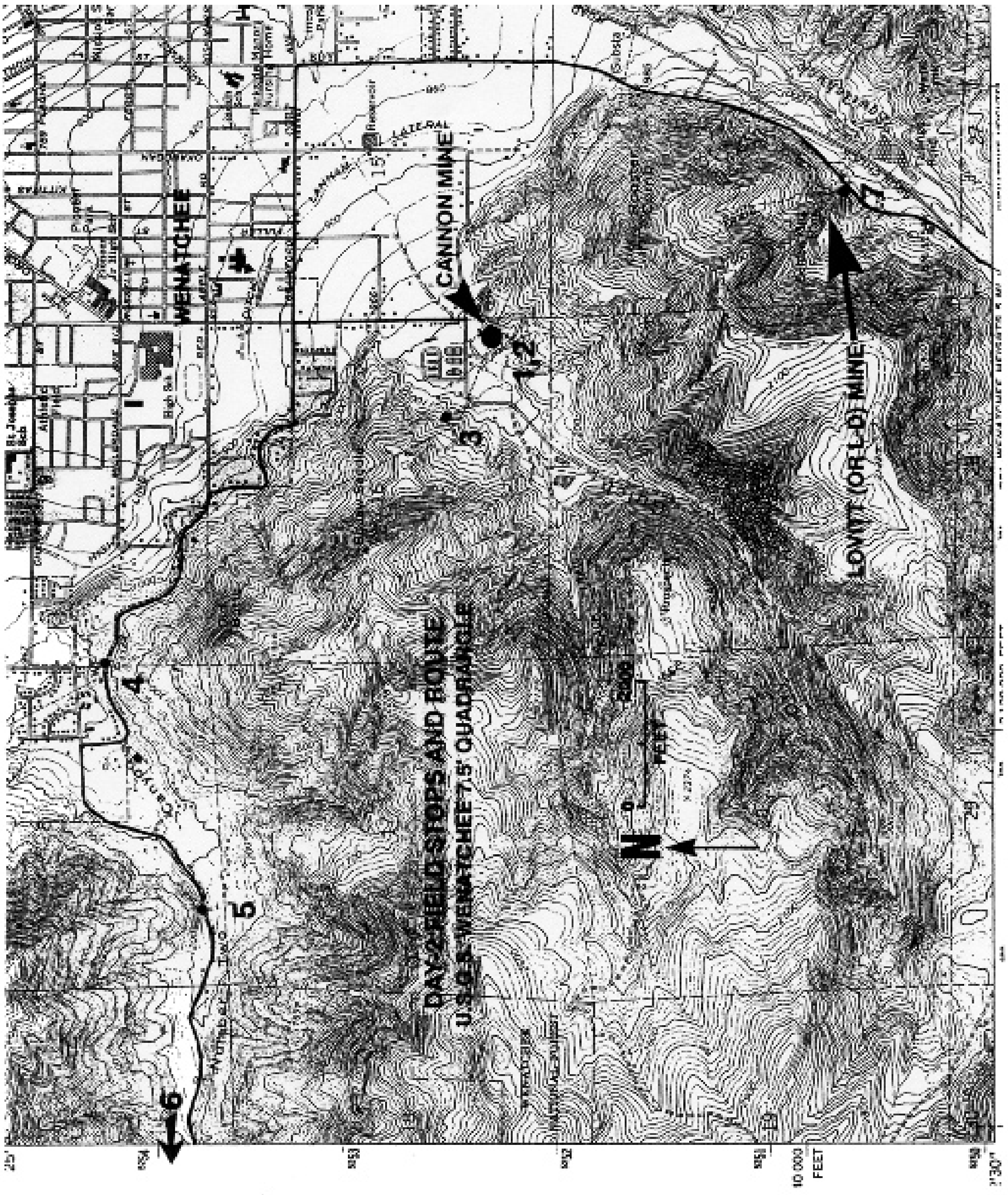

Figure 1. Topographic map showing day-2 stops 1 through 6.

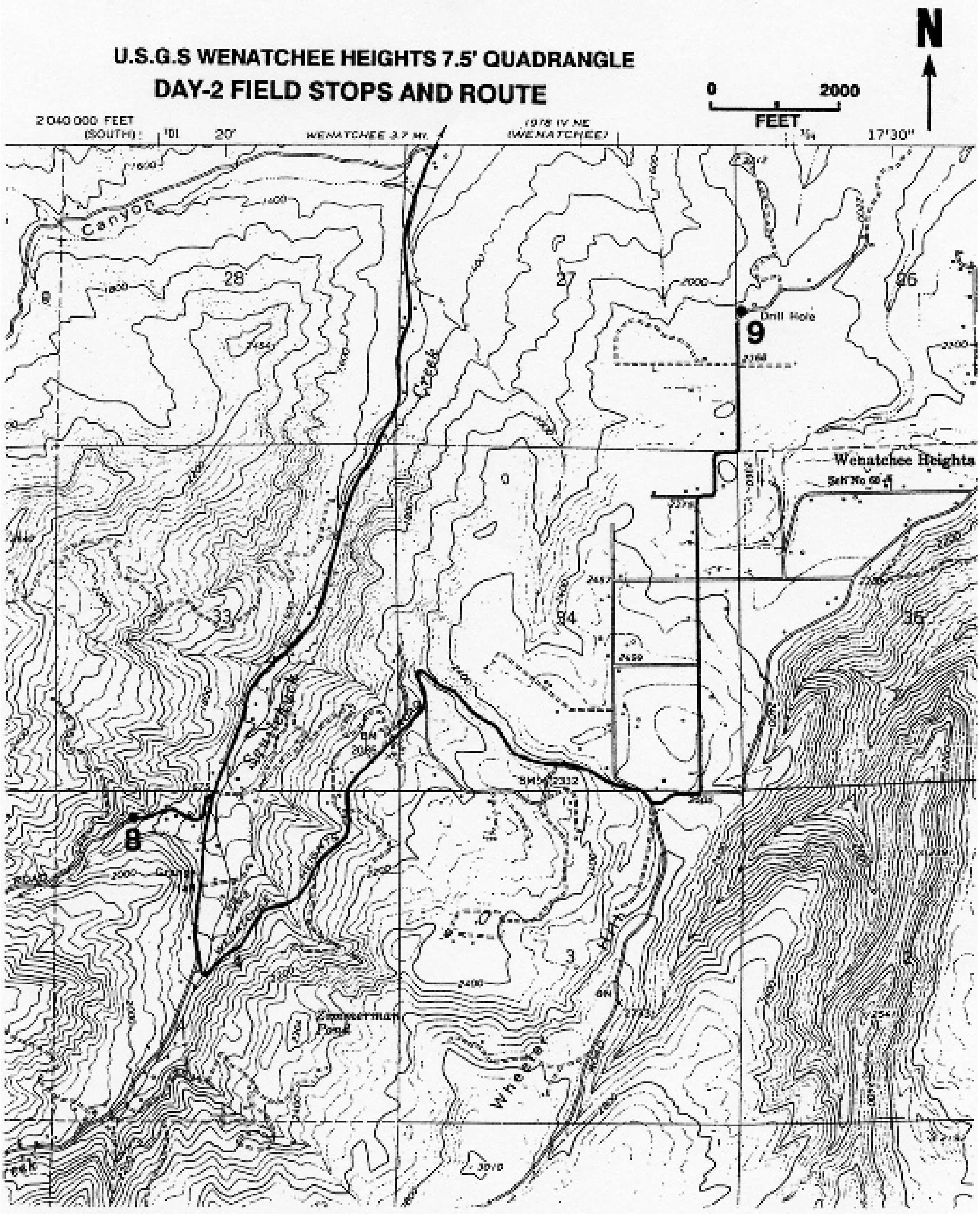

Figure 2. Topographic map showing day-2 stops 8 and 9; this map adjoins Figure 1 to the south.