Northwest Geological Society

Society Field Trips In Pacific Northwest Geology

The Geology of North-Central Washington

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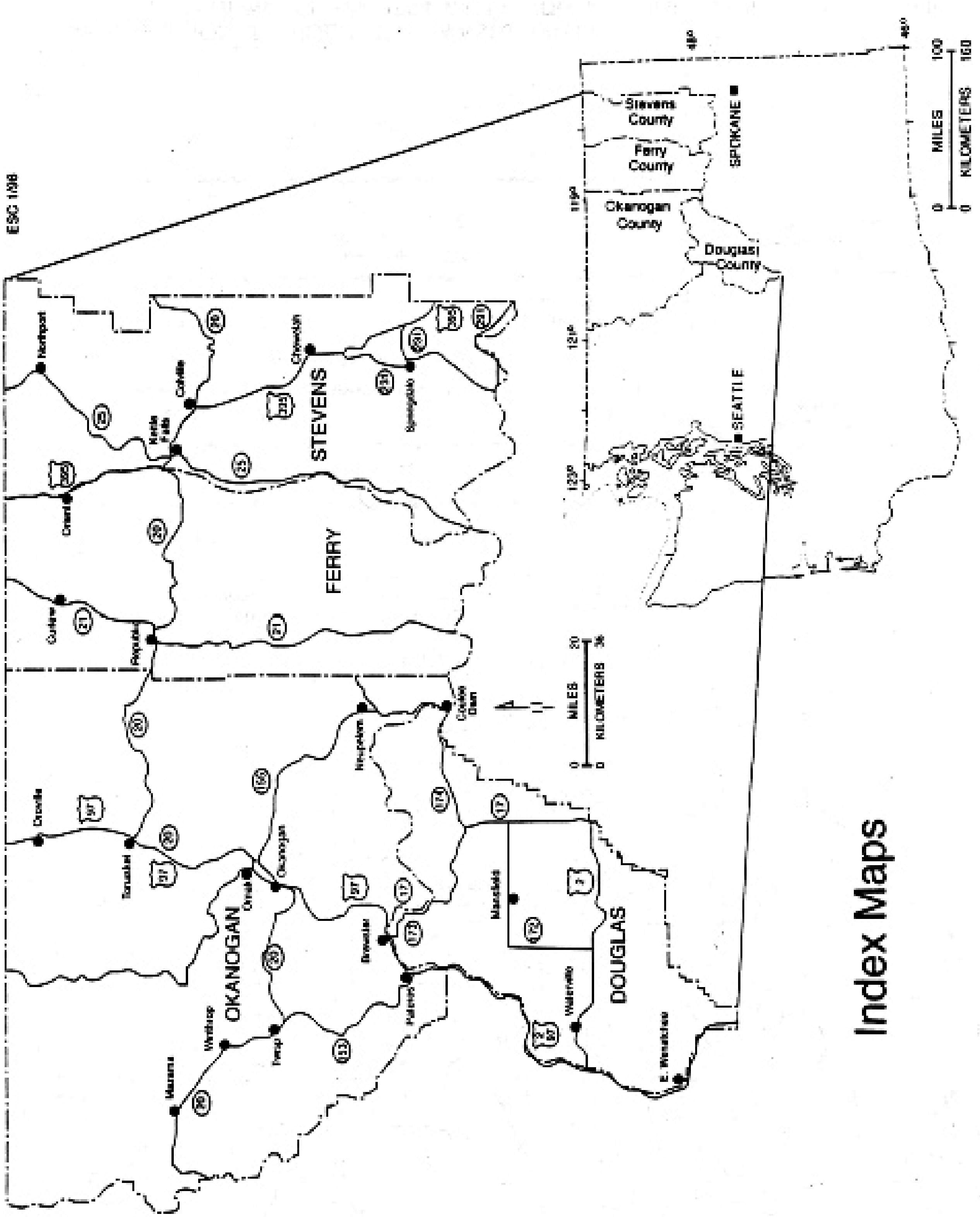


Figure 1 Index Maps

INTRODUCTION

The purposes of this field trip are to (1) inspect the regional units of north-central Washington, and (2) gain some insights on how they relate to each other. The trip will traverse the counties of northeastern Washington shown in Figure 1. Figure 2 shows the regional geological units of Washington: pre-Mesozoic North American unconformity-bounded stratigraphic sequences, metamorphic core complexes, accreted terranes, batholiths, and the Cenozoic unconformity bounded sequences that overlie the pre-Mesozoic North American sequences and the accreted terranes. This is not an exhaustive guide to the geology of northeastern Washington. McKee's lucidly written Cascadia (1972), published immediately before the plate tectonics washed over the continent, is an interesting historical benchmark. Monger and others (1982) outlined the terrane concept for the Pacific Northwest. The Washington Division of Geology and Earth Resources has issued a number of publications (Schuster, 1987; Joseph, 1989; Stoffel and others, 1991; Lasmanis and Cheney, 1994) that include regional overviews of the northeastern part of Washington. The annual meeting of the Geological Society of America and other geological societies in Swanson and Haugerud (1994) generated additional field guides and review articles. Other volumes that dealt at least partially with northeastern Washington are Riedel and Hooper (1989), Galster (1980), and Ross (1991). Derkey and others (1993) described the economic geology and current prospecting activities in more detail than this guide. Hodges's early compilation (1897) of the ore deposits of Washington and British Columbia should be a collector's item. The most important reference is the 1:250,000 map of northeastern Washington by Stoffel and others (1991).

This guidebook is substantially revised from a previous guidebook of the Northwest Geological Society (Cheney, 1993). Revisions include my own research and consulting, new contributions of other geoscientists; and the addition of a traverse of Cascade terranes along the Columbia River from Chelan to Wenatchee. The present guidebook is so immodest as to draw heavily on Cheney (1994, 1996, 1997), Cheney and others (1994), and Cheney and Rasmussen (1996).

ITINERARY

This is an ambitious four- or five-day field trip. Most participants will miss day two (pre-Mesozoic North America) and will do the last three days. Depending on the time available, some stops may have to be eliminated. Alternatively, optional stops can be made at some of the interesting road cuts described in the road logs.

The first day or night is consumed by driving from Seattle to northeastern Washington. East of Wenatchee most of this drive is on the Columbia River Basalt Group.

The second day is a transect across stratigraphic units that are indigenous to pre-Mesozoic North America, the Ordovician to Carboniferous eastern assemblage, and portions of the Kettle metamorphic core complex. The transect begins at Deer Lake south of Chewelah and proceeds through Colville to Republic. The second and third nights will be in Republic.

During the third day we will mostly examine Quesnellian rocks and the unconformably overlying Eocene Challis rocks in the Republic area. The trip heads westward to the Okanogan Valley on the fourth day to examine the Okanogan metamorphic core complex and more Quesnellian rocks. The fourth night will be in Omak. Both campgrounds and motels are available in Republic and Omak.

On the fifth day the trip heads southward across the northwestern corner of the Columbia Plateau to Chelan and Wenatchee for glimpses of the Columbia River Basalt, Pleistocene units, and amphibolite facies rocks that are typical of the accreted terranes of the northern Cascade Range. The trip ends in mid-afternoon at Wenatchee, from which Seattle is about three hours away.

This trip thus proceeds westward into generally younger rocks. A general discussion of these rocks follows in the section labeled Regional Geologic Units. Thus, portions of that section can be read on successive days.

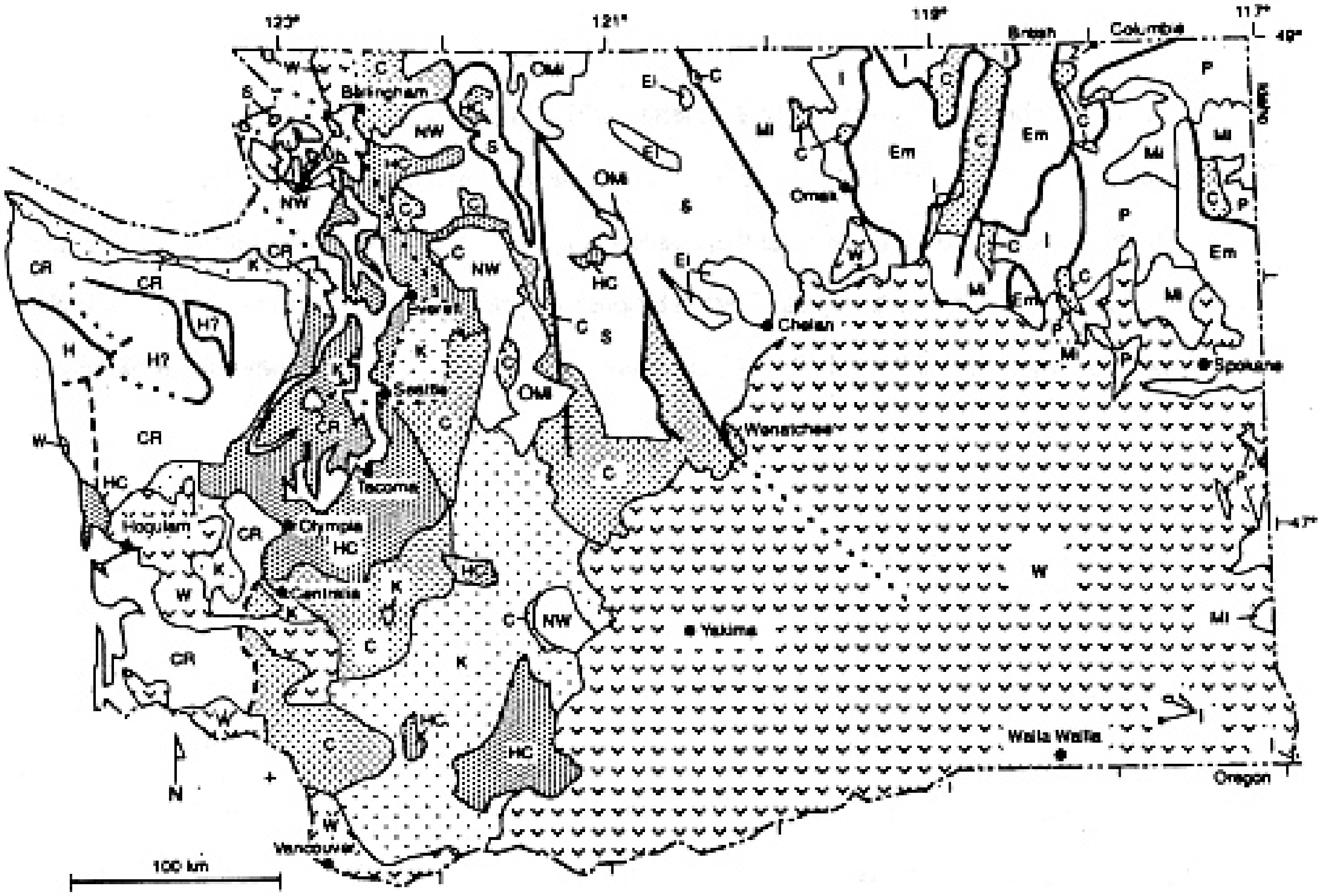
REGIONAL GEOLOGIC UNITS

INTRODUCTION

This guide accepts the importance of unconformity-bounded sequences (UBS) in sedimentary and volcanic rocks. Sequence stratigraphy commonly has not been utilized in Washington and other parts of the Pacific Northwest. A sequence may be defined as a reasonably conformable succession of lithostratigraphic units (formations or lithofacies) bounded above and below by unconformities or their identifiable correlative conformities. Readers unfamiliar with sequence stratigraphy will find a brief explanation in Cheney (1994). Those unfamiliar with the nomenclature, definition, and ages of North American sequences can review Sloss (1988); unfortunately, Sloss did not discuss Washington, nor did he discuss sequences older than the Sauk (>0.54 Ga). Sequences are natural stratigraphic units. Major sequences also are more useful than lithostratigraphic units on geologic maps ranging from 1:250,000 to 1:5,000,000. The boundaries of major sequences in the Pacific Northwest do not correspond to the paleontologically defined chronostratigraphic units (such as Precambrian, Cambrian, Miocene, etc.) that geologists have created as a basis for correlation.

PRE-MESOZOIC NORTH AMERICA

The rocks of pre-Mesozoic North America extend westward to at least the Columbia River (Figs. 2, and 3). They consist of Proterozoic and Paleozoic unconformity-bounded sequences and crystalline basement. The crystalline basement is exposed in metamorphic core complexes (MCC). As struc-



EXPLANATION

SYMBOLS	Age	Post-accretionary Units	Accreted Terranes (age of accretion)	North American Sequences
Faults (dotted where covered, dashed where inferred)	Oligocene to Pleistocene			HC - High Cascade
			H - Hoh	W - Walpapi
		OMi - batholiths		K - Kittitas
Contacts (dotted where covered, dashed where inferred)	Eocene	Em - metamorphic core complexs Ei - batholiths	CR - Coast Range	C - Challis
	Cretaceous		NW - Northwest Cascade S - Insular	Z - Zuni
	Jurassic	Mi - batholiths	I - Intermontane	
	Proterozoic and Paleozoic			P - Kaskaskia, Tippecanoe, Sauk, Proterozoic

tural entities, the MCC evolved in the Eocene; hence, they will be discussed later. The oldest known rocks in Washington are paragneisses > 1.7 Ga in the Priest River MCC east of Spokane and in the Kettle MCC near the International Border (Armstrong and others in Ross, 1991). Small remnants of Mississippian dolomitized limestone, the Jumpoff Joe Formation of Gheddida and others (1996), appear to be the youngest North American strata in Washington.

The western margin of North America rifted several times in the Proterozoic. Proterozoic and Paleozoic UBS were deposited off the trailing edge of the continent as miogeoclinal prisms, and they are considerably thicker in Washington than in the cratonic interior. Unfortunately, local lithostratigraphic names of Proterozoic and Paleozoic formations in Washington and adjacent British Columbia (Fig. 4) obscure the stratigraphic continuity of these rocks. Figure 5 organizes the lithostratigraphy into major UBS.

Three 0.54 to 1.5 Ga major miogeoclinal successions of western North America are informally referred to (Rainbird et al., 1996) as Succession "A" (> 1.08 Ga), Succession "B" (0.78 to 1.08 Ga) and Succession "C" (0.54 to 0.78 Ga). Figure 5 shows that the Belt Supergroup represents Succession "A". The Buffalo Hump Formation may be part of "B", and most of the Windermere Group is Succession "C".

Some problems may exist with this ABC designation. Firstly, now that the Belt Supergroup is known to be about 1.4 to 1.5 Ga (Aleinkoff and others, 1996) other sequences might exist between 1.4 and 1.08 Ga. Secondly, a still older sequence, labeled AQ in Figure 5, may exist. Quartzite-dominated intervals of this age are well known in the MCCs of British Columbia (Armstrong and others, in Ross, 1991); it is interesting to speculate that these and ~ 1.7 Ga quartzites in the cratonic interior, such as the Niehart (MT), Thelon (NWT), Athabaska (SK), Sioux (SD), Baraboo (WI), Umcompahgre (CO), Matzatal (AZ), and Honda/Ortega (NM) might be remnants of a craton-wide UBS. Lest this appear too amazing, it should be remembered that the Phanerozoic sequences are at least this widespread (Sloss, 1988).

Beltian rocks in Washington are not quite as correlative as Figure 4 implies. The rocks southeast of Chewelah are typical of the lower (pelitic) and middle (quartzite) Belt Supergroup of northern Idaho and adjacent Montana but different than those of the Deer Trail Group west of Chewelah (Miller and others, 1975). The Deer Trail Group most likely is the upper part of mixed lithologies of the Belt Supergroup (Miller and others, 1975; Miller and Whipple in Joseph, 1989). The Deer Trail Group also is known informally as the "Magnesite Belt" because of the former world-class production of magnesite from the Stensgar Dolomite west of Chewelah. Southeast of Chewelah, the Deer Trail is separated from the lower and middle Beltian rocks by thrust faults (Stoffel and others, 1991).

Figure 2. (Left) REGIONAL GEOLOGY OF WASHINGTON
Modified from Cheney (1994, fig. 11). The horizontal wavy lines in this and other figures represent unconformities.

Historically, the Windermere Group in northeasternmost Washington has included, from the base upward, the Shedroof Conglomerate, Leola Volcanics (greenstone), Monk Formation (argillite and dolomite), and the fluvial, quartzose Three Sisters Formation (Miller, 1994). Windermere rocks characteristically contain rounded grains of quartz. However, unlike the quartzites of the sequence A and the Gypsy/Addy quartzite in the Swauk sequence, Windermere quartzites are feldspathic. Because Edicarian fossils occur in parts of the Windermere in British Columbia (Hoffman and others, 1991), part of Windermere is Vendian. Locally, each Windermere formation is > 1 km thick.

A critical reading of Miller (1994) indicates that each formation in the Windermere Group in Washington is an unconformity-bounded unit. Thus the syndepositional faults inferred by Miller to explain abrupt changes in the stratigraphic thicknesses of these formations probably do not exist.

Conventionally, the Three Sisters Formation, which is feldspathic and pebbly, has been included in the Windermere Group of lithologically similar rocks (Stoffel and others, 1991). However, the Three Sisters is unconformable upon the Monk Formation and grades conformably upward into the Gypsy Quartzite (Lindsey and others, 1990). Hence, the Three Sisters and Gypsy (and correlatives) are part of the Sauk sequence (Fig. 5); whereas, the lower three Windermere formations are included in UBS "C" in Figures 4 and 5 and probably are Vendian. Whichever datum ultimately is chosen as the Cambrian-Vendian boundary, that boundary seems destined to be within the Sauk sequence.

The distinctive features of sub-Three Sisters portion of the Windermere, Succession C, are tillite (Shedroof Conglomerate) and metabasalt (Leola Valeanics). These lithologies are typical of UBS "C" and occur in British Columbia (Rainbird and others, 1996) and in the American part of the Cordillera as far south as southeasternmost California (Link and others, 1993). Late Proterozoic (Vendian and older) tillites occur worldwide.

Inspection of Stoffel and others (1991) indicates that the major stratigraphic pattern in northeastern Washington is that the units of "C" are progressively cut out to the southwest by the sub-Sauk unconformity. Metamorphically, the Sauk and older sequences are in greenschist facies; whereas, the graptolitic shales of the Ledbetter Formation of the Tippecanoe sequence do not appear to be. The major structural pattern is a series of northeasterly striking, northwesterly dipping thrusts that cause imbrication of the Proterozoic and Paleozoic sequences. Presumably these

Figure 3. (Following Page)
REGIONAL GEOLOGIC MAP OF THE SOUTHERN PART OF QUESNELLIA AND BOUNDING UNITS
Modified from Cheney and others (1994, fig. 2). The explanation to this figure also applies to Figures 8, 23, and 24.

MAP UNITS

Cover sequences

Tw	Miocene to Pliocene Walpapi Sequence, predominantly Columbia River Basalt Group		
	Tc	Eocene Challis Sequence	
	Tcsl	Scatter Creek hypabyssal rocks	
	Ts	Sanpoil Volcanics, rhyodacitic	
	To	O'Brien Creek Formation, arkosic	
Z	Cretaceous Zuni Sequence Sophie Mountain Formation, conglomerate		

Plutons

Ei	Eocene felsic plutons
Jl	Jurassic Shasket Creek alkalic plutons
Ml	Mesozoic felsic plutons
Mo	Mesozoic felsic orthogneisses

Quesnellia

Mu	Mesozoic rocks, undivided			
Jr	Jurassic Rossland Group			
	Jrh	Hall Formation, argillite		
	Jre	Elise Formation, mafic volcanic rocks		
	Jref	felsite		
Trb	Triassic Brooklyn Formation, argillite			
Pu	Carboniferous to Permian, western assemblage, Knob Hill and Attwood Groups			
	Pa	Attwood Group, undivided		
		Pap	pelitic phyllite	
		Paa	argillite	
		Paf	felsic volcanic rocks	
		Pac	carbonate rocks	
	Pk	Knob Hill Group, undivided		
		Pkg	Palmer Mountain greenstone	
um	ultramafic rocks and listwanite			

Southwestern Metamorphic Belt

Mom	Mesozoic(?) megacrystic orthogneiss
hmg	Mesozoic(?) pelitic gneiss
hmp	Mesozoic(?) pelitic phyllite
swm	Mesozoic(?) paragneiss and orthogneiss

Eastern Assemblage

OCo	Ordovician to Carboniferous, undivided, mostly pelitic rocks, including Ordovician Covada Group

Metamorphic Core Complexes

Ei	Eocene felsic plutons
Mi	Mesozoic felsic plutons
hmt	Mesozoic Tonasket orthogneiss
hm	metamorphic rocks, undivided
hmm	Tenas Mary Creek assemblage, Cretaceous orthogneiss and Proterozoic and Paleozoic paragneiss

Metamorphic rocks

hmu	rocks of unknown age and origin

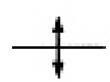
FAULTS

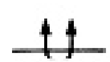
high-angle fault—dashed where approximate


detachment fault—blocks on upper plate


thrust fault—sawteeth on upper plate

FOLDS


upright antiform

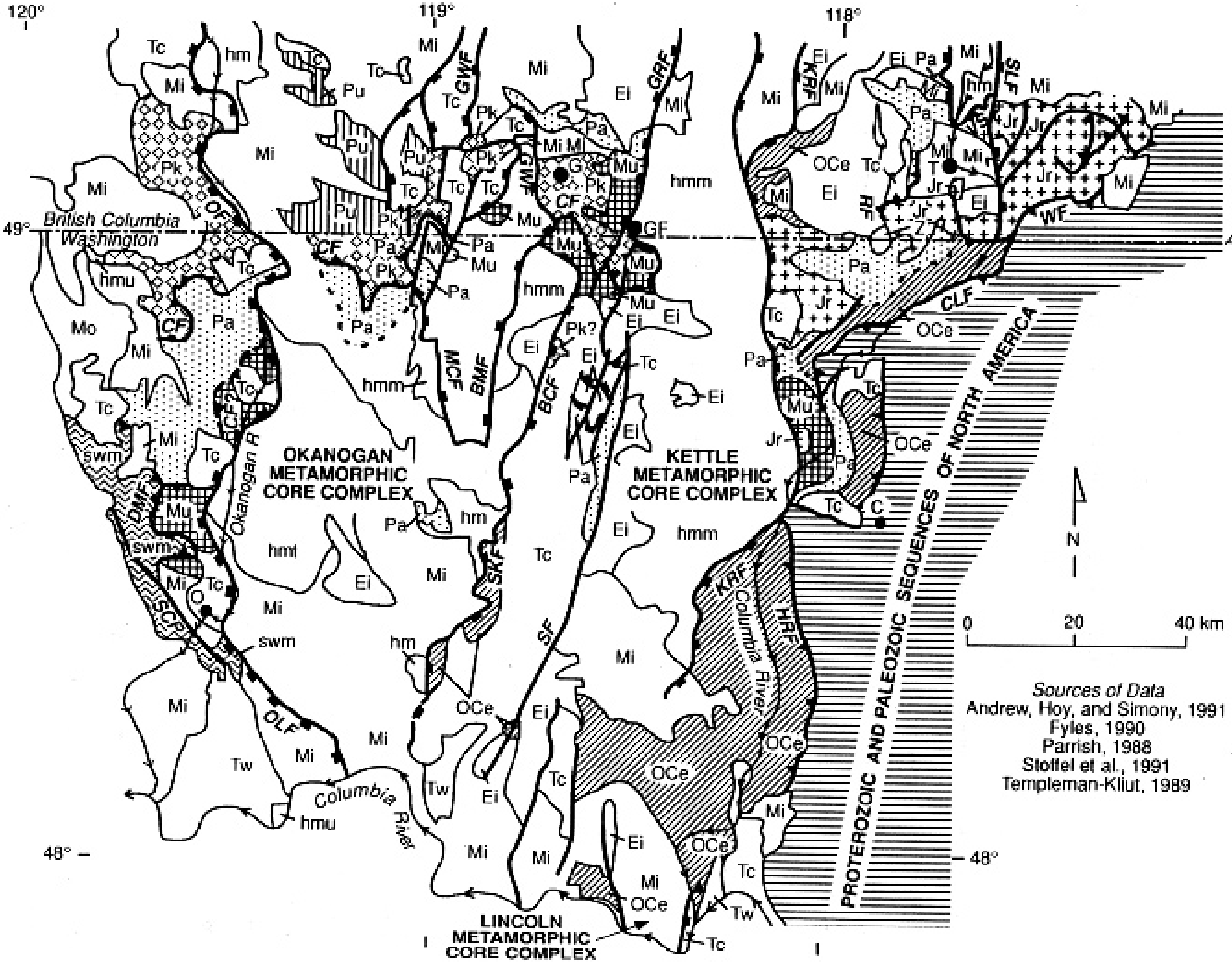

overturned antiform

TOWNS

C, Colville G, Greenwood GF, Grand Forks
O, Omak R, Republic T, Trail

ABBREVIATIONS OF FAULT NAMES

BCF	Bacon Creek fault
BMF	Bodie Mountain fault
CMF	Cayuse Mountain fault
CLF	Columbia fault
CF	Chesaw fault
DMF	Dunn Mountain fault
EMF	Eagle Mountain fault
GDF	Gold Drop fault
GRF	Granby River fault
GWF	Greenwood fault
HRF	Huckleberry Ridge fault
KRF	Kettle River fault
LCF	Lind Creek fault
LMF	Lambert Creek fault
MAF	Mount Attwood fault
MCF	Myers Creek fault
MWF	Mount Wright fault
No. 7F	Number 7 fault
OF	Okanogan fault
OLF	Omak Lake fault
RF	Rossland fault
SCF	Salmon Creek fault
SF	Sherman fault
SKF	Scatter Creek fault
SLF	Slocan Lake fault
SNF	Snowshoe fault
TMF	Thimble Mountains fault
VS	Valkyr shear zone
WF	Waneta fault
WMF	White Mountain fault



120°
119°
118°
49°
48°
British Columbia
Washington
OKANOGAN METAMORPHIC CORE COMPLEX
KETTLE METAMORPHIC CORE COMPLEX
LINCOLN METAMORPHIC CORE COMPLEX
PROTEROZOIC AND PALEOZOIC SEQUENCES OF NORTH AMERICA
Okanogan R
Columbia River
OLF
DMF
SCP
CF
GWF
MCF
BMF
BCF
SKF
SF
GF
GRF
KRF
HRF
RF
SLF
WF
CLF
N
0
20
40 km
Sources of Data
Andrew, Hoy, and Simony, 1991
Fyles, 1990
Parrish, 1988
Stoffel et al., 1991
Templeman-Kliut, 1989

SEQUENCE	LITHOLOGY	FORMATIONAL OR GROUP NAMES: SOUTH OF 48°30'	NORTH OF 48°30'	SOUTHERN B.C.
TIPPE-CANOE	ARGILLITE	LEDBETTER	LEDBETTER	ACTIVE
SAUK	CARBONATE	OLD DOMINION	METALLINE	NELWAY
	ARGILLITE	MAITLEN	MAITLEN	LIAB
	QUARTZITE	ADDY	GYPSY	RENO & QUARTZITE RANGES
	QUARTZITE & ARKOSIC CONGLOMERATE	NOT PRESENT	THREE SISTERS	THREE SISTERS
"C"	ARGILLITE	MONK	MONK	MONK
	GREENSTONE	HUCKLEBERRY	LEOLA	IRENE
	CONGLOMERATE (TILLITE)	HUCKLEBERRY CONGLOMERATE	SHEDROOF	TOBY
"A"	LARGELY CLASTIC	DEER TRAIL & BELT GROUPS	PRIEST RIVER & BELT GROUPS	PURCELL SUPERGROUP

Figure 4. SYNONYMOUS NAMES FOR THE LITHOSTRATIGRAPHIC UNITS OF NORTH AMERICAN SEQUENCES IN NORTHEASTERN WASHINGTON AND ADJACENT BRITISH COLUMBIA

Yet another set of names for most units occurs farther north in British Columbia.

thrusts were caused by the Mesozoic accretion of terranes to the west.

The North American Proterozoic sequences contain significant ore deposits. In the 1960s magnesite mining in the Deer Trail Group fell victim to the recovery of Mg by the electrolysis of seawater; this process is now being displaced by the importation of Chinese rock. Uranium was mined from the Togo Formation of the Deer Trail Group at the Midnite Mine about 50 km northwest of Spokane. Revett and St. Regis rocks have significant stratabound copper deposits in northwestern Montana and world-class Ag-Zn-Cu-Sb veins in the Coeur d'Alene district of northern Idaho; economic examples of these are still lacking in Washington.

The Sauk also is economically important. The uppermost carbonate unit has been the main producer in Washington (and adjacent BC) of lead and zinc (from deformed Mississippi Valley-type deposits) in the Metalline Falls, Salmo, and Northport-Colville districts; mineralization is, at least in part, related to karstification below the sub-Tippecanoe unconformity (Mills, 1977). At Northport this carbonate unit also is quarried for decorative white dolomite. At Addy, WA, it is quarried by Northwest Alloys as a source of MgCOs. At Valley, WA, the Addy quartzite is the source of glass sand, and this quartzite also was once used by Northwest Alloys to make ferrosilicon.

EASTERN ASSEMBLAGE

A belt dominated by Ordovician to Carboniferous pelitic rocks (but including some greenstone and chert) lies west of the Proterozoic to Paleozoic clastic and carbonate rocks indigenous to North America (Fig. 3). According to Smith (1991), this belt consists predominantly of three units. The Covada Group has an older Daisy succession (dominantly thick-bedded, medium- to coarse-grained, poorly sorted subarkosic wacke and arenite with finer-grained interbeds) and a younger Butcher Mountain succession of pillow basalt, tuff, massive basalt, and limestone. Sparse paleontological evidence indicates that the Covada Group is middle to late Early Ordovician. The Bradeen Hill succession differs from the Covada Group in that it contains quartz-rich and feldspar-poor sandstone and abundant fine-grained strata. It contains chert pebble conglomerate with gritty, quartzofeldspathic clasts that seem to be derived from the Covada Group. The Bradeen Hill succession includes fine-grained shale, chert, chert-quartz sandstone, chert-pebble conglomerate, quartz arenite and minor volcanic rocks.

Megascopically most of the pelitic rocks of this belt resemble the pelitic rocks of the Quesnel terrane to the west, but whereas the Quesnellian rocks are composed mostly of volcanic detritus, the Covada Group is subarkosic. The eastern assemblage also has several bedded barite deposits, one of

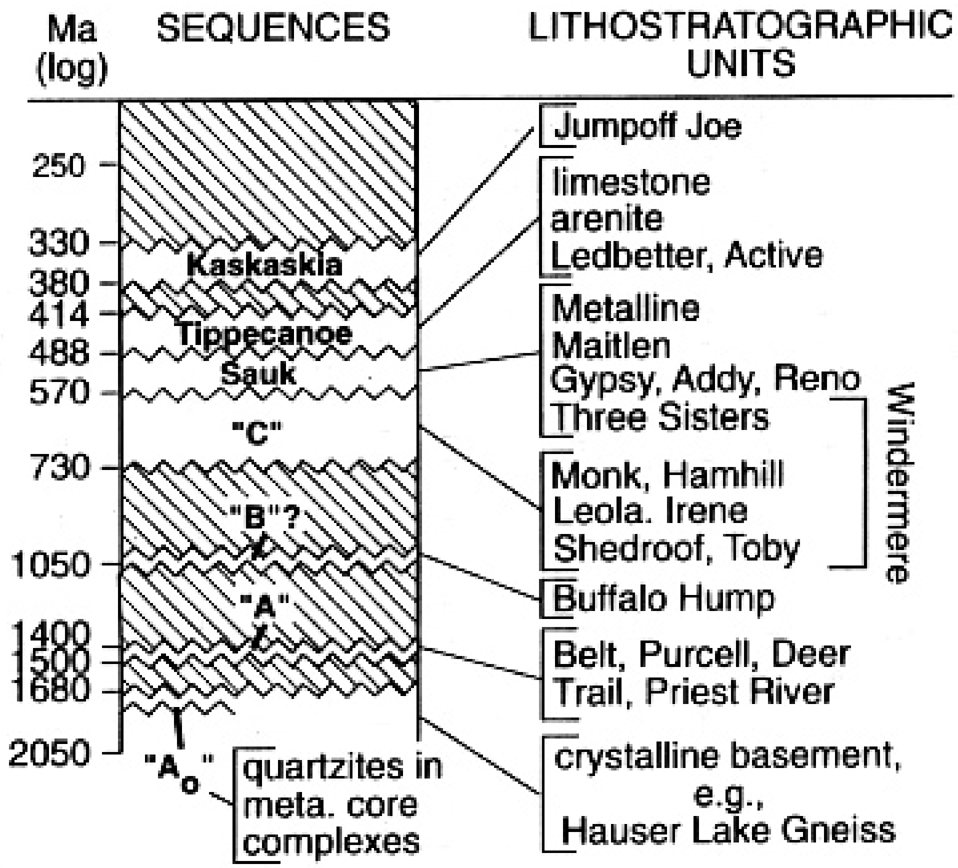


Figure 5 SEQUENCE STRATIGRAPHY OF THE NORTH AMERICAN ROCKS IN NORTHEASTERN WASHINGTON
Note that the time scale is logarithmic. See text for the lithostratigraphic position of the Deer Trail Group and the Three Sisters Formation. Formations in "C" are unconformity-bounded; no unconformities are yet known in "B".

which north of Colville is Devonian. The Covada Group extends at least as far west as the southern part of the Republic graben (Fig. 3).

Because the original relations of the Covada Group and associated rocks to the North American rocks to the east and to the Quesnel terrane to the west remain somewhat uncertain, this belt of rocks deserve a noncommittal name like "eastern assemblage." These rocks were originally included in the Intermontane superterrane of the Canadian Cordillera. However, terranes in this superterrane have island arc affinities, were amalgamated by the end of the Triassic, and accreted en masse to North America in mid-Jurassic (Monger and others, 1982). In contrast, the Covada Group is arkosic and its detrital zircons yield ages similar to ages from the cratonic interior. Thus, the Covada Group, at least, may have been the distal portion of the North American clastic and carbonate sequences to the east. In such a model, during the accretion of the Intermontane superterrane, distal North American pelitic rocks were thrust over the clastic and carbonate rocks of the continental margin. This boundary is the Huckleberry Ridge fault and the Columbia back thrust in Figure 3.

In Nevada, a counterpart of the eastern assemblage may be the Roberts Mountain allochthon and rocks of the Antler foredeep (Fig. 6). The Roberts Mountain allochthon consists predominantly of oceanic Ordovician to Lower Mississippian strata, including numerous Devonian bedded barite deposits. The allochthon was emplaced eastward against North America during the Mississippian Antler orogeny and was overthrust from the west by the Golconda allochthon.

QUESNELLIA

The Quesnel terrane (a.k.a. Quesnellia) is west of the eastern assemblage. If the eastern assemblage is a distal portion of North America, Quesnellia is the easternmost terrane of the Intermontane superterrane. The best description of the Quesnellian rocks in the area of Figure 3 is Fyles (1990).

The lithostratigraphic names that Fyles and his Canadian predecessors defined are shown in the middle column of Figure 7. Synonyms subsequently used in Washington (in the right-hand column) should be abandoned. Quesnellia includes a Carboniferous to Permian ophiolitic suite of ultramafic and mafic igneous rocks, mafic volcanic rocks, and chert (the Knob Hill Group) and a seemingly coeval succession (the Attwood Group), which consists of dark argillites with minor felsic volcanic to volcaniclastic rocks, and limestone. Both the Knob Hill and the Attwood are unconformably overlain by the Triassic Brooklyn Formation (meta-conglomerate, clastic limestone, and argillite). A younger unconformable succession of oceanic volcanic to volcaniclastic rocks and sedimentary rocks may be part of the Brooklyn Group (Fyles, 1990), part of the Jurassic Rossland Group (Cheney and others, 1994) as shown in Figure 2, or both. All of the Quesnellian rocks are in greenschist facies.

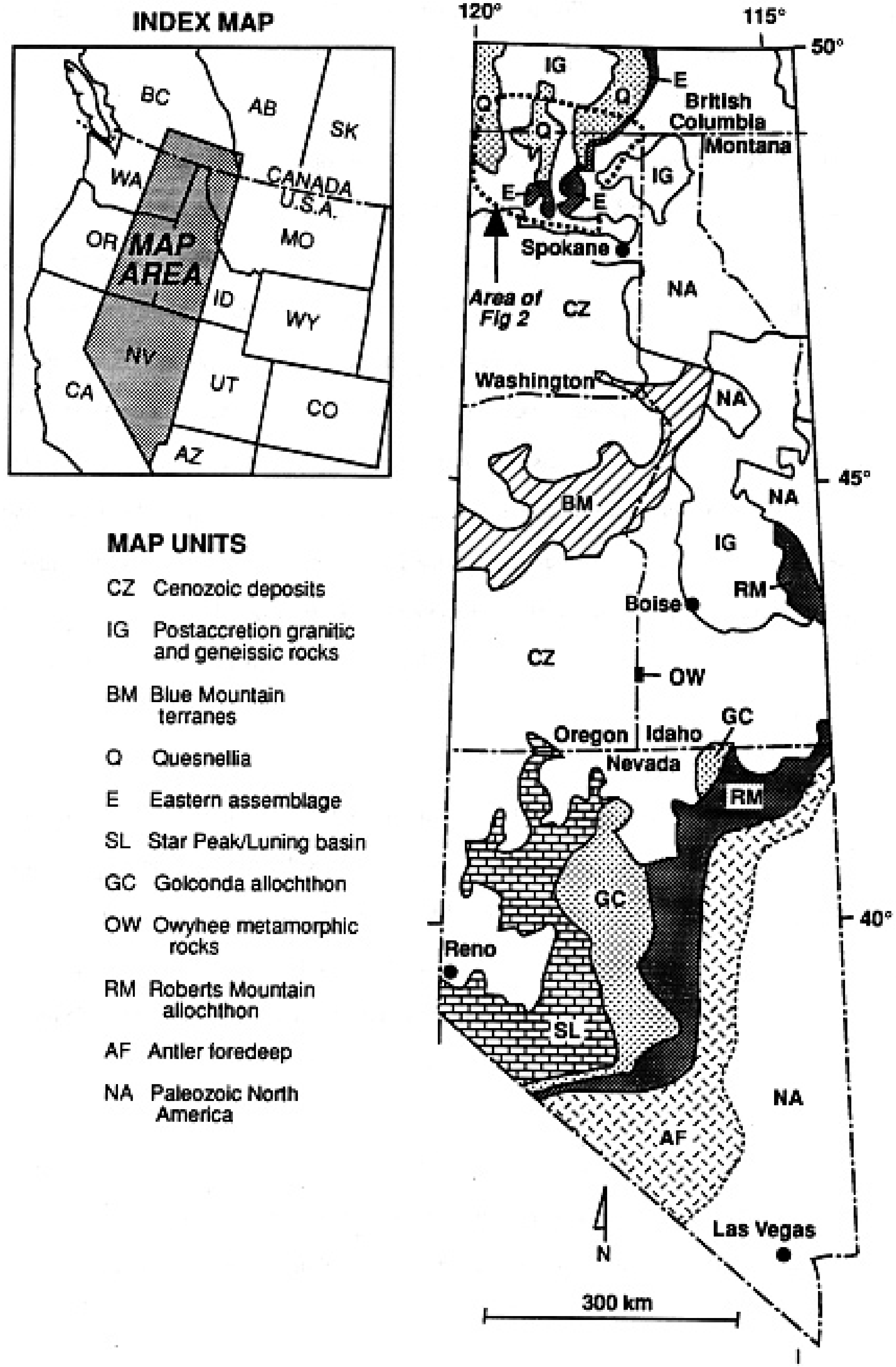


Figure 6. LITHOTECTONIC TERRANE MAP OF A PORTION OF THE NORTH AMERICAN CORDILLERA
Modified from Cheney and others (1994, fig. 1)

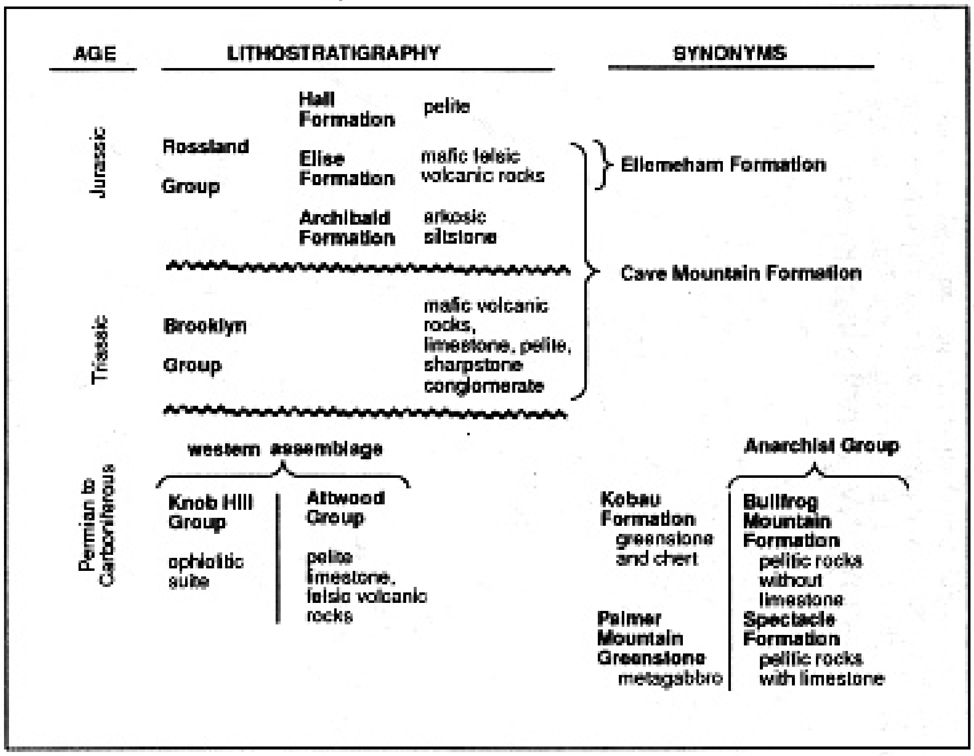


Figure 7. UNCONFORMITY-BOUNDED SEQUENCES OF QUESNELLIA
Cheney and others (1994, fig. 3). The vertical line illustrates that coeval units of the western assemblage are tectonically juxtaposed (by the Chesaw fault).

All of the Quesnellian rocks are cut by the Chesaw thrust. The thrust extends discontinuously from Omak (Figs. 3 and 8) to Grand Forks, BC and Republic (Fig. 9). This thrust cuts rocks as young as the Brooklyn Formation north of Curlew (Fig. 9) and correlative rocks in the Okanogan Valley north of Omak (Fig. 8). The thrust usually positions the ophiolitic Knob Hill Group over the Attwood Group, but in some places, Brooklyn or Rossland rocks are above or below the thrust. The trace of the thrust and its splays are marked by discontinuous bodies of serpentinite (hydrated ultramafic rock), listwanite (carbonated ultramafic rock), metagabbro, and amphibolite-facies rocks. Although portions of the thrust are extensive along the International Border (Fig. 9), it has not yet been extensively mapped south of Curlew. Thus, some Quesnellian rocks are shown as a single unit, PMu, in Figure 9.

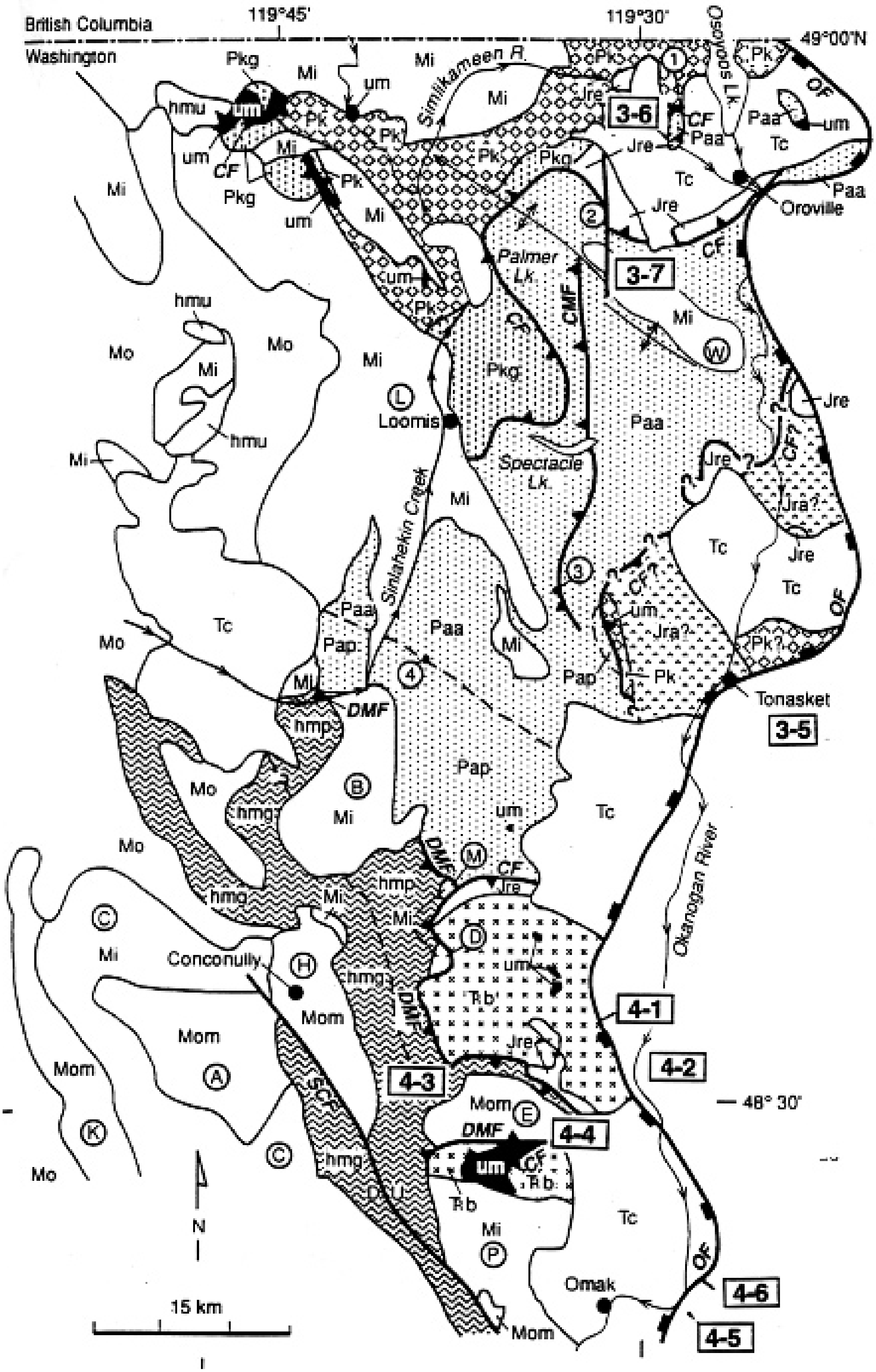
Fyles (1990) believed that the thrusts north of the International Border (marked by Knob Hill over Attwood) are individual faults rather than a single regional thrust (the Chesaw Thrust) of Cheney and others, 1994). More recent mapping recognized a klippe of Knob Hill north of Curlew (cross section C-C’, Fig. 9), which implies that at least some thrusts are repeated by folding (Cheney and Rasmussen, 1996).
‘

The age of the Chesaw thrust appears to be well constrained. The 199.4 ± 1.4 Ma Lexington quartz porphyry is deformed by the No. 7 fault along the International Border south of Greenwood (Fig. 9). West of the Okanogan Valley the Loomis pluton (Fig. 8), with a discordant K/Ar date on hornblende of 194 ± 6 Ma, appears to cut the Chesaw thrust. However, the age and intrusive relations of the Loomis pluton need to be confirmed. Although the 163 ± 0.4 Ma Shasket Creek alkalic complex appears to be restricted to the klippe of Knob Hill rocks north of Curlew, it does contact metamorphose Brooklyn limestone of the lower plate (Parker and Calkins, 1964).). According to Colpron and others (1996) accretion of Quesnellia to North America in southeastern BC occurred between 187 and 173 Ma and the southwest verging deformation (backfolds) occurred between 173 and 165 Ma. These dates imply that the Chesaw thrust may be slightly younger than the discordant date of 194 ± 6 Ma on the Loomis Pluton.

Figure 6 shows Quesnellia as equivalent (lithologically and temporally) to the Golconda allochthon of Nevada (Cheney and others, 1994). The Mesozoic rocks of Quesnellia most likely are correlative with the Mesozoic carbonate and volcanic rocks of the Star Peak/Luning basins of northwestern Nevada.

Three important mining districts occur in Quesnellian rocks. The Belcher district about 10 km northeast of Republic is described below. The Greenwood district in southern British Columbia is mostly between Greenwood, the Phoenix mine,

Figure 8. (Following Page)
GEOLOGIC MAP OF THE OKANOGAN VALLEY
Modified from Cheney and others (1994, fig. 6). The explanation for Fig. 3 is also the explanation for this figure. The dashed lines mark the gradation of argillite of the western assemblage (Paa) into phyllite (Pap) and of paragneiss of the southwestern metamorphic belt (hmg) into phyllite (hmp).
Plutons (circled) are: A, Mineral Hill phase of the Conconully pluton; B, Blue Goat; C, Conconully; D, Dunn Mountain; E, Evans Lake; H, Happy Hill; K, Leader Mountain; L, Loomis; M, Mud Lake; P, Pogue Mountain; W, Whiskey Mountain. Localities (circled) of felsic metavolcanic rocks in the Attwood Group are 1, Hot Lake; 2, Hicks Canyon; 3, Silver Mountain mine; 4, Lemansky.



British Columbia
Washington
119°45'
119°30'
49°00'N
48° 30'
Similkameen R.
Osoyoos Lk.
Oroville
Palmer Lk.
Spectacle Lk.
Loomis
Sinlahekin Creek
Tonasket
Okanogan River
Conconully
Omak
3-5
3-6
3-7
4-1
4-2
4-3
4-4
4-5
4-6
CF
CMF
DMF
OF
Mi
Mo
Mom
Tc
Pk
Pkg
Paa
Pap
Jre
Jra?
hmu
hmp
hmg
um
15 km
N

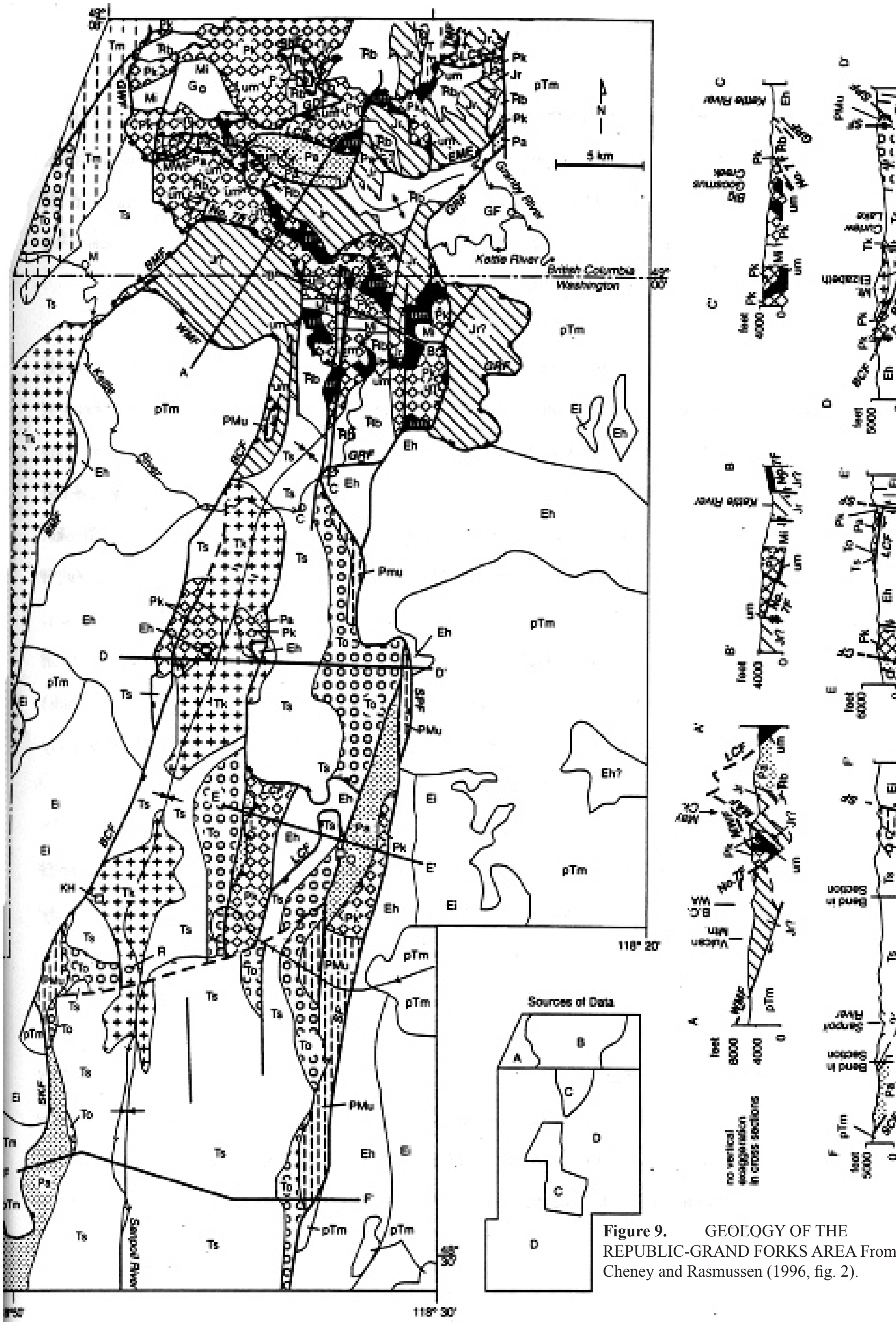


Figure 9. GEOLOGY OF THE REPUBLIC-GRAND FORKS AREA From Cheney and Rasmussen (1996, fig. 2).

and the International Border, but mineralization extends a few kilometers south of the border. The deposits are primarily (but not Historically, another important district was between Oroville and Loomis (Fig. 8). Numerous gold-quartz veins occur in Knob Hill rocks (usually adjacent to and extending into younger granitic plutons). A number of massive sulfide deposits also occur in the Knob Hill and Attwood rocks of the district. The gold discoveries near Oroville in the 1890s and the Yukon/Alaskan gold rush prompted the founding of the School of Mines at the University of Washington in 1901; mining engineering was the first engineering degree conferred by UW. By comparison, the Department of Geology and Mineralogy at UW was established in 1894.

BELCHER MINING DISTRICT

Because this trip will visit Quesnellian rocks of the Belcher mining district (Fig. 9 near Cross section E-E'), a brief description of the geology of the district (Fig. 10) is appropriate. The ores of the Lamefoot, Overlook, Key West, and possibly the Key East mines are similar and appear to be in the same stratigraphic interval of the Attwood Group. The best descriptions are of the Overlook deposit (Rasmussen, 1993; Rasmussen and others, 1998).

The following history of the district is from Rasmussen (1993). Several small underground mines existed in the early 1900's, from which massive magnetite and pyrite-pyrrhotite were railed to Granby, BC to use as flux in the smelter; these fluxes did earn minor credits in copper and gold. The Overlook deposit was discovered in 1987 and brought into production by Echo Bay Mines, Ltd., the present operator in the district. Underground mining at Overlook (1990 to 1992) was suspended due to the low grade of the ore and the mine was closed in 1998. In 1993 Key West and Key East were mined-out by small open pits. Reclamation of these pits and the attendant dumps is complete, but part of the Key West pit is still available for inspection. Lamefoot was discovered in 1990 and has been mined by underground methods since 1994. The ore from all four mines was trucked to a mill (2000 tons/day) south of Overlook.

Much of the ore in these mines consists of massive magnetite, massive pyrrhotite, or banded magnetite, jasper, and quartz/carbonate (a.k.a. "altered limestone"). These rocks occur stratigraphically (but not structurally) above felsic volcaniclastic rocks and below massive metalimestone (Figs. 10 and 11). The ore-bearing rocks are thought to be volcanogenic chemical sediments in the Attwood Group (Fig. 11, Rasmussen, 1993; Rasmussen and others, 1998), with local thickening of massive pyrrhotite in the noses of satellitic folds (Fig. 11). However, most of the ore in these rocks appears to be related to quartz veinlets. For example, significant amounts of ore at Overlook and Lamefoot are in 1 to 20 cm-wide veinlets of quartz ± pyrite ± chalcopyrite ± pyrrhotite ± aresnopyrite ± gold in the felsic volcaniclastic rocks adjacent to massive magnetite or massive pyrrhotite. Because the veinlets are mostly parallel to the massive magnetite and pyrrhotite, they cannot have been the feeder zone for the magnetite and pyrrhotite. D. E. Archibald (in Rasmussen and others, 1998) used ^Ar/^^Ar to date sericite in the envelopes around the veinlets as Jurassic (197± 3 Ma). Thus, the deposit may be considered a Jurassic Park (overprint) on Carboniferous to Permian Quesnellian rock, perhaps at or about the time the Chesaw thrust was active.

Facing directions of graded beds in the felsic volcaniclastic rocks indicate that the Quesnellian rocks of the Belcher district are significantly folded. The rocks at Overlook are subhorizontal but are overturned (Fig. 10). Facing directions and map patterns generated by detailed surface mapping by J. K. Glover and by drilling indicate that Lamefoot (Fig. 11) is in the overturned limb of an isoclinal antiformal syncline (Fig. 12). In the crest of this fold, a mined-out nearly horizontal lens of pelitic rock within massive sulfide did face downward (M. G. Rasmussen, 1998, personal communication). Despite the megascopic evidence for isoclinal folding, mesoscopically, the felsic volcaniclastic rocks and metalimestone are remarkably uncleaved and unfoliated. If the interpretation of an antiformal syncline is correct, small-scale (mesoscopic) folds should exist in Lamefoot rocks, especially in the banded magnetite, jasper, and quartz/carbonate, but none have been recognized to date. A few small-scale, steeply north plunging folds outlined by cm-thick chert do occur in the "Wardlaw" limestone (M. G. Rasmussen, 1998, personal communication). Small-scale folds in sulfidic rocks have been observed in drill core, but have been routinely dismissed as soft-sediment or slump folds.

The regional structure of the Belcher district may be extremely complex. Regionally the Knob Hill Group structurally overlies the Attwood Group along the Chesaw thrust. However, east of the Lamefoot mine, Knob Hill greenstones underlie the Attwood rocks (Fig. 12). Three observations suggest that this contact is the Chesaw thrust. Firstly, the only megascopically foliated Attwood rocks near Lamefoot occur in the limestone adjacent to the contact. Secondly, drilling indicates that the limestone pinches out at depth. Thirdly, on Wolf Camp Road north of Lamefoot Mine rocks along the contacts are scaley, lensoid, and the greenstone contains lenses of gray phyllite.

West of Lamefoot, the Eocene O'Brien Creek Formation dips vertically (Fig. 12). Thus, all of the steep dips in Quesnellian rocks at Lamefoot are post-O'Brien Creek. Because the O'Brien Creek beds face to the west, the pre-O'Brien Creek structure can be restored by rotating Figure 12 90° clockwise. After such rotation (Fig. 13), the Lamefoot rocks appear to be a westerly verging antiform, or backfold, in the Chesaw thrust. Similar backfolds occur in North American rocks immediately east of Quesnellia in Washington (Wilkinson and Ellis, 1987) and in Quesnellian rocks in southeastern BC (Colpron and others, 1996.

Figures 11, 12, and 13 omit the numerous Eocene (Scatter Creek) dikes and sills and small faults that cut the Lamefoot deposit. At Key West low-angle faults, presumably related to

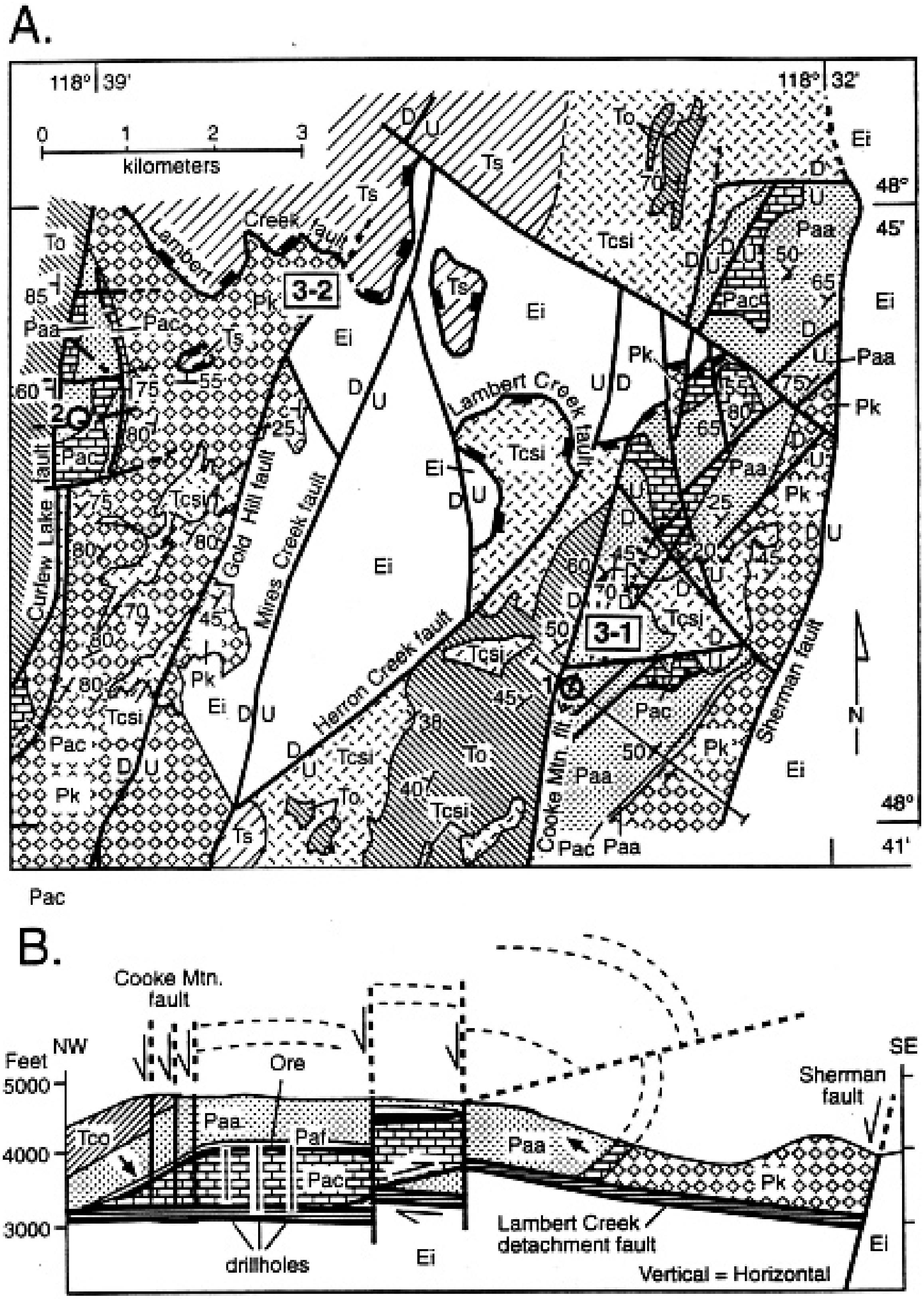


Figure 10. GEOLOGIC MAP OF THE LAMEFOOT-OVERLOOK-KEY AREA
Modified from Cheney and others (1994 fig. 5). In A, mineral deposits are 1, Overlook; 2, Lamefoot; and 3-1, Key. For comparison note that Overlook and Lamefoot are shown as OV and L near cross section E-E' of Figure 9. Note that the geologic cross section of the Overlook mine in B is a different scale than A. Bold inclined arrows in B illustrate the facing direction of graded beds.

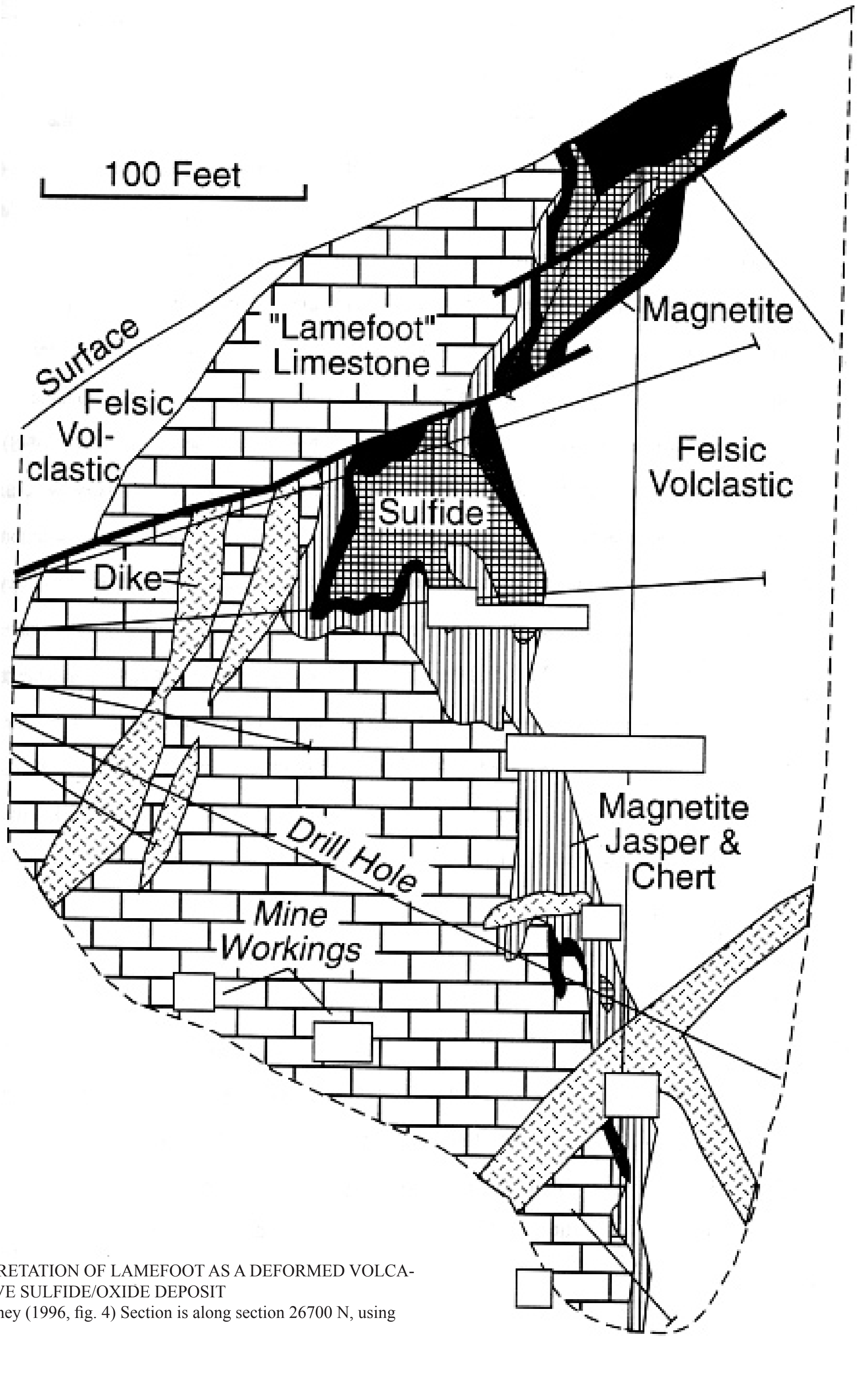


Figure 11. INTERPRETATION OF LAMEFOOT AS A DEFORMED VOLCANOGENIC MASSIVE SULFIDE/OXIDE DEPOSIT
Redrafted from Cheney (1996, fig. 4) Section is along section 26700 N, using data to 11/19/94.

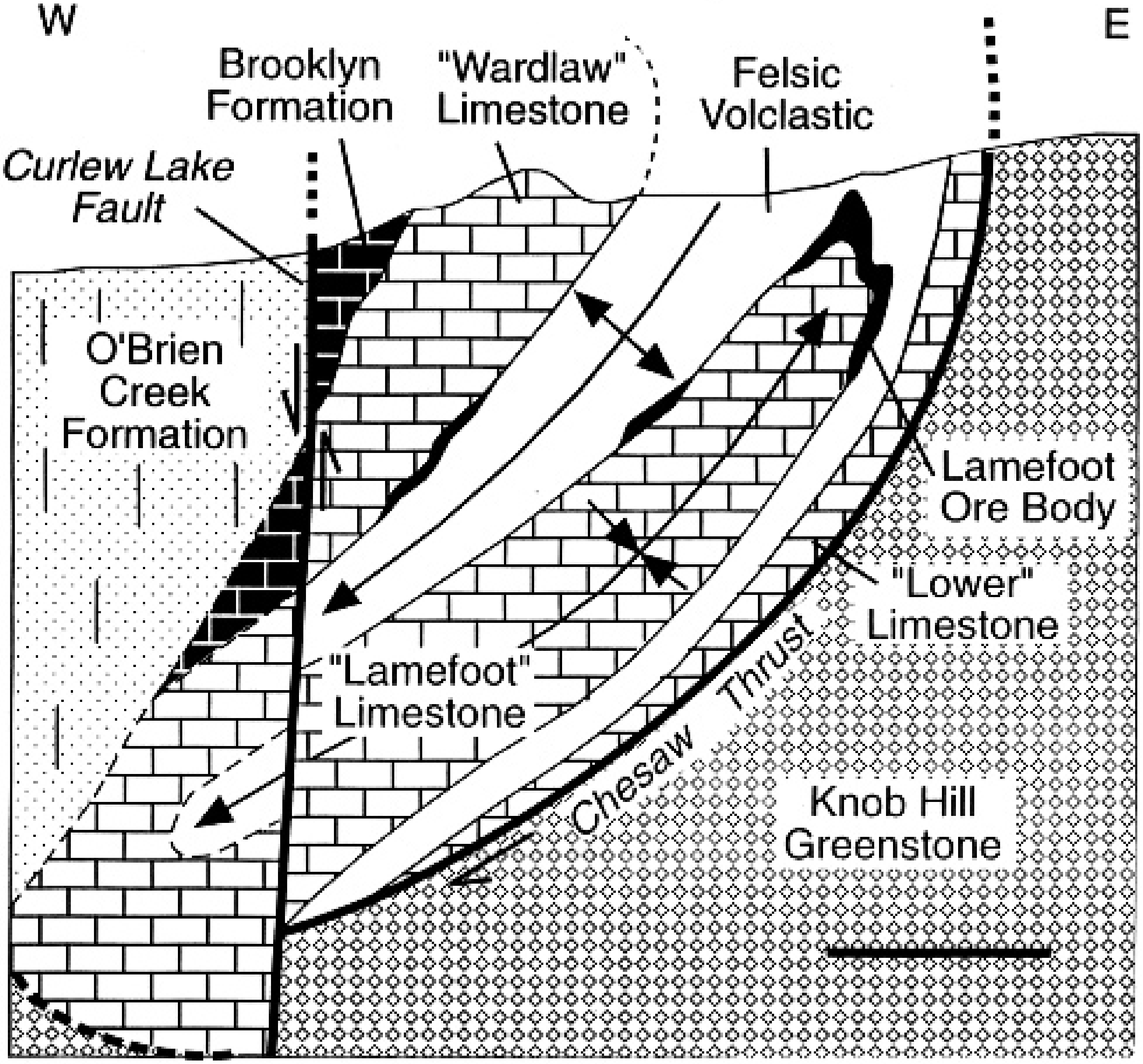


Figure 12. SCHEMATIC CROSS SECTION OF THE ISOCLINAL-FOLD MODEL FOR LAMEFOOT AT ABOUT 26700 N. Redrafted from Cheney (1996, fig. 2). Tertiary dikes and sills and the 500 series of faults are omitted. The easternmost surficial geology is projected from mapping at Stop 3-8.

the Kettle metamorphic core complex, cut all rocks including the Eocene dikes. A low angle fault floors the Overlook rocks (Fig. 10). Rotation on such a low-angle listric fault could be responsible for the vertical dips at the Lamefoot mine.

SOUTHWESTERN METAMORPHIC BELT

A belt of amphibolite-facies paragneiss and orthogneiss bounds the Quesnellian rocks on the southwest near Omak (Figs. 3 and 8). This southwestern metamorphic belt (SWMB) continues southeast of the Okanogan River (Atwater and others, 1984); the map of Stoffel and others (1991) implies that it could extend beneath the Columbia River Basalt Group to Grand Coulee. If so, it also truncates the Covada Group of the eastern assemblage. In the Okanogan Range to the west, the SWMB is intruded by a variety of Mesozoic (mostly Cretaceous) unfoliated to moderately foliated granitic plutons. On the southeastern margin of the Methow valley, the Cretaceous granitic plutons of the Okanogan Range intrude the amphibolite-facies Leecher metamorphic rocks, which might be correlative with the metamorphic rocks near Omak. The following description of the SWMB in the area of Figure 8 is summarized from Cheney and others (1994).

Fine-grained pelitic gneiss is the most common lithology in the SWMB, but the most distinctive rocks are orthogneisses and minor fuchsitic quartzite. The Reed Creek gneiss varies from fine-grained amphibolite to medium-grained hornblende metadiorite. The most characteristic unit of the SWMB is the hornblende- and biotite-bearing, feldspar megacrystic Leader Mountain Gneiss (Mom in Fig. 8). Mom has several percent potassium

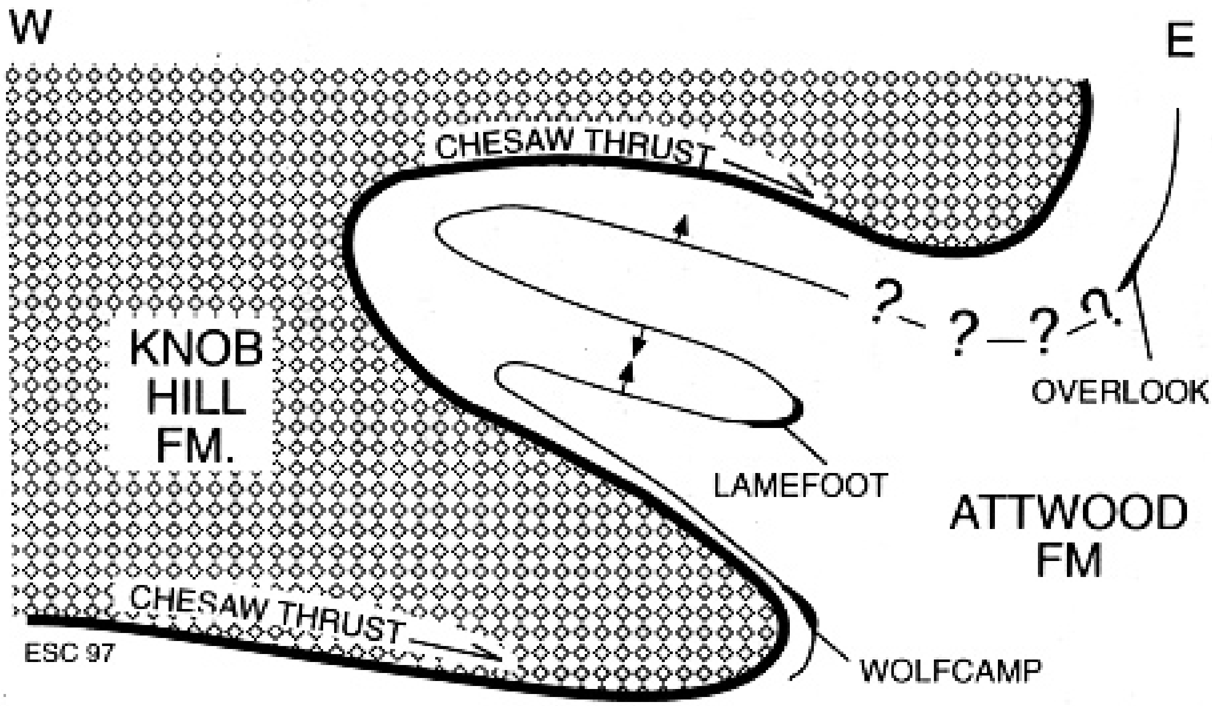


Figure 13 SCHEMATIC CROSS SECTION OF THE INFERRED PRE-O'BRffiN CREEK REGIONAL STRUCTURAL SETTING OF LAMEFOOT. Redrafted from Cheney (1996, fig. 5). For the present (post-O'Brien Creek) orientation, rotate this figure 90° counter-clockwise. The post-O'Brien Creek erosion surface is below the upper limb of the Chesaw thrust. Post-O'Brien Creek low-angle and high-angle faults that have disrupted the folds are not shown.

feldspar megacrysts up to 8 cm. The hornblende is ferrohastingsite (which is a distinctive blue green in thin section).

East of the Okanogan River the porphyritic granodiorite of Omak Lake of Atwater and others (1984) is megascopically similar to Mom. Significantly, Mom does not occur in Quesnellian rocks. Within pelitic rocks the boundary between the amphibolite-facies SWMB and greenschist facies rocks of Quesnellia is difficult to recognize. The argillites of the Quesnellia (the Attwood Group) become more phyllitic southwestward, and the pelitic gneisses of the SWMB become more phyllitic northeastward (Fig. 8). The metamorphic discontinuity between the two is the Dunn Mountain fault. At Dunn Mountain (underlain by pluton D of Figure 8), the SWMB is thrust over the Cave Mountain Formation (a probable composite of Brooklyn Formation (carbonates) and Rossland Group (greenstone) of Quesnellia). The thrust is most obvious to the south where Mom of the Evans Lake pluton (E in Figure 8) overlies the Cave Mountain Formation and serpentinite.
‘

The porphyritic phase of the Evans Lake pluton has concordant U/Pb and Pb/Pb dates from zircon of 177 ± 2 Ma (H. A. Hurlow, 1998, personal communication). Because this is the age of crystallization of the original pluton, metamorphism and the Dunn Mountain fault are younger. The SWMB, which contains the Leader Mountain orthogneiss is intruded by the trondhjemitic Okanogan Range batholith, which is 114 to 111 Ma (Hurlow and Nelson, 1993). In addition, discordant K-Ar dates from the Leader Mountain orthogneiss and surrounding plutons range from 99 to 62 Ma, and the Conconully pluton, which is intrusive into the orthogneiss, has concordant K-Ar dates of 81 Ma (Stoffel, 1990). These dates could be interpreted to mean that the Dunn Mountain fault is about the same age as the Chesaw thrust, is slightly older than 114 Ma, or, possibly, is as young as the discordant K-Ar dates. The least controversial conclusion is that the Dunn Mountain fault is between 177 and 114 Ma. Obviously, mapping and dating of the plutons and/or the phyllitic rocks along the Dunn Mountain fault could refine the age of the fault.

TERRANES OF THE NORTHEASTERN CASCADE RANGE

The rocks in the northern Cascade Range east of the Straight Creek fault (Fig. 14) are terranes that accreted to the Intermontane superterrane in the middle of the Cretaceous. These amphibolite facies metamorphic rocks and associated and younger plutons are shown as the Insular Superterrane in Figure 2. The terranes strike northwesterly; to the southeast they are covered by Tertiary unconformity-bounded sequences.

The Chelan Mountain terrane underlies most of the high peaks of the Northern Cascades. It is bounded on the northeast by the Ross Lake fault zone and on the southwest by the Entiat fault and the fault that bounds the Mad River terrane. Along the Columbia River, the Chelan Migmatite Complex (Hopson and Mattinson, 1994) consists of migmatite and gneissic to massive tonalite. The protolith of the complex appears to be Triassic plutons, but the metamorphism is Late Cretaceous. According to Hopson and Mattinson (1994) the migmatite diapirically rose through and shouldered aside other units of the Chelan Mountains terrane.

The Swakane terrane is southwest of the Chelan Mountains terrane, and separated from it by a septum of Mad River Terrane. According to Sawyko (1994) the Swakane Gneiss is homogeneous at all scales (map, outcrop, and thin section). Northeast of the Entiat fault it consists of plagioclase, quartz, biotite, garnet, staurolite ± sillimanite, a composition which formed at 10 to 12 kb and 580 to 625°C. The gneiss contains 1300-1600 Ma rounded zircons. Either the Swakane is a Proterozoic crustal fragment, or the zircons are detrital or xenocrystic.

POST-ACCRETIONARY NORTH AMERICAN SEQUENCES

Figure 2 indicates that five North American unconformity-bounded sequences post-date accretion of the Intermontane and Insular superterranes. However, only the Zuni, Challis, and Walpapi occur in northeastern Washington, where the Challis is the most extensive (Figs. 2 and 3).

The Zuni is restricted to a few tiny remnants of conglomerate of the Cretaceous (Cenomanian to Campanian) Sophie Mountain Formation. The conglomerate is unconformable upon Quesnellian rocks (Little, 1982) along the International Border between the Columbia and Kettle rivers (Fig. 3).

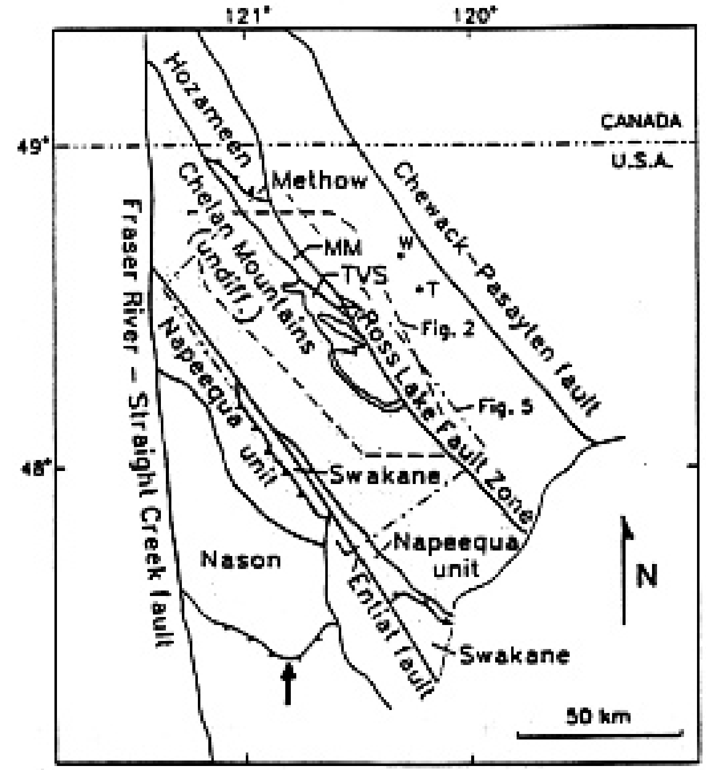


Figure 14. TERRANES OF THE NORTHEASTERN CASCADE RANGE From Miller and others (1994, fig. 1).

The Challis sequence consists of middle Eocene sedimentary, volcaniclastic, and volcanic rocks. These rocks are commonly regarded as having been deposited in a number of local grabens, such as the Republic graben, but Pearson and Obradovich (1977) showed that the same lithostratigraphic units occur in a number of the grabens (Fig. 15). Cheney (1994) subdivided the rocks into unconformity-bounded sequences (Fig. 16) and inferred that each sequence (as opposed to individual lithostratigraphic units) originally extended across Washington. The geographic continuity of these sequences was destroyed by intra-Challis and later unconformities and by later faulting and folding. Thus, remnants of the sequences are now preserved in numerous structural lows. Beyond Washington, the Challis sequence exists in southern British Columbia, western and north-central Oregon, Idaho, Nevada, southwestern Montana, and the Great Plains. It may even occur in the Gulf and Atlantic coastal states (Armentrout, 1996).

In the Republic area the Challis sequence has four unconformity-bounded formations. In the area of Figure 9 each is at least a kilometer thick, and each is poorly dated radiometrically. The oldest unit of predominantly tuffaceous and feldspathic sandstone and siltstone is the O'Brien Creek Formation south of the International Border and the Kettle River Formation north of it. The Marron formation of alkalic volcanic rocks lies unconformably upon the Kettle River Formation and barely extends south of the border. The Sanpoil Volcanics (biotitic rhyodacite and seemingly minor volcaniclastic rocks) are the most extensive Challis rocks within 15 km of Republic. The paucity of bedding within the Sanpoil makes its stratigraphy and structure difficult to assess.

The youngest Challis unconformity-bounded unit is the Klondike Mountain Formation (mostly volcaniclastic rocks and felsic flows). The three members of the formation defined by Muessig (1967) near Republic also are bounded by unconformities, but all are shown as a single unit in Figure 9. The fossiliferous basal Tom Thumb Tuff Member is well known for its leaf and insect fossils (see several articles in Washington Geology, v. 24, no. 2).

The major mine in the Challis sequence in northeastern Washington is the epithermal gold/silver Knob Hill mine at Republic; it operated from 1938 to 1995 and recovered more than 2.5 million ounces of gold and more silver. The epithermal gold/silver district in central Washington at Wenatchee also is in Challis rocks, and, like Republic, it is fairly unusual in that the major ore minerals are selenides. The Challis-aged molybdenum-copper deposit at Keller (near the Columbia River south of Republic) seems to be the most nearly economic of the porphyry Cu/Mo prospects. A sandstone-type uranium deposit was mined in Challis arkosic rocks at the Sherwood mine about 50 km northwest of Spokane.

The most voluminous lithostratigraphic unit of the Walpapi sequence in eastern Washington is the Columbia River Basalt Group (CRBG). Sources of most of the CRBG were northwesterly trending dikes in adjacent parts of Washington, Oregon, and Idaho. These dikes probably were related to

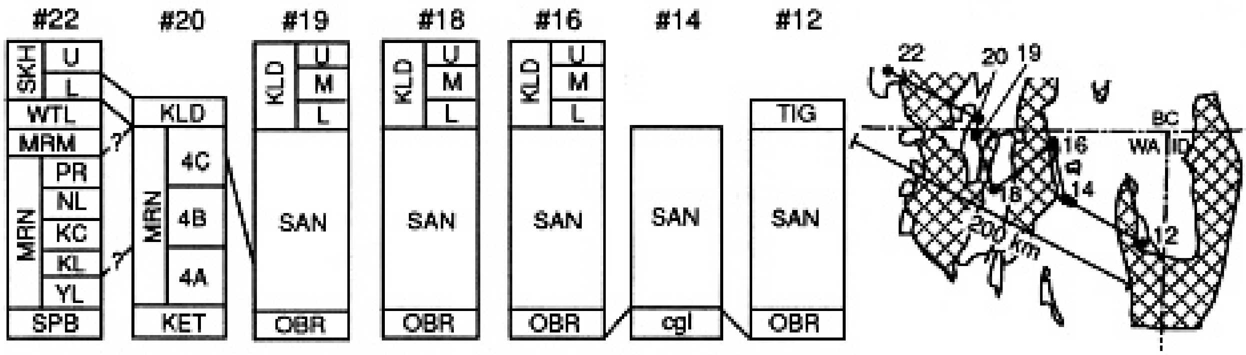


Figure 15. A PORTION OF THE CORRELATION DIAGRAM OF PEARSON AND OBRADOVICH (1977, FIG. 3) FOR EOCENE ROCKS IN NORTHEASTERN WASHINGTON AND ADJACENT BRITISH COLUMBIA
The location of each column is shown on the accompanying map. Abbreviations for formations are the same as those used in Fig. 16 with the following exceptions: cgl, conglomerate without volcanic clasts, probably in part correlative with the O'Brien Creek Formation; KET is Kettle River Formation; members of the Marron Formation are KC (Kearns Creek), KL (Kitley Lake), NL (Nimpit Lake), PR (Park Rill), WL (White Lake), and YL (Yellow Lake); 4A, 4B, and 4C are divisions of the Marron Formation; L, M, and U are the lower, middle, and upper members of the Klondike Mountain Formation.

rifting during development of the Basin and Range Province and may be the product of a plume in the mantle that migrated eastward as the Yellowstone hotspot.

The two basal units of the CRBG, the Imnaha and Grande Ronde Basalts, comprise the bulk of the CRBG and were extruded between 17.3 and 15.6 Ma. A number of unconformities occur within the CRBG; thus, episodic uplift and erosion or episodic changes in sea level occurred throughout CRBG time. The basalts also are arched over the Cascade Range (which is particularly obvious at Mission Ridge south of Wenatchee, Washington). Thus, the original volume and extent of the CRBG has been reduced (probably significantly), and the present topography of the Cascade Range is a post-CRBG feature (Cheney, 1997).

No significant metallic mineral production has been recorded from the Walpapi sequence in Washington. Felsic volcanic rocks younger than CRBG do host epithermal, precious metal and mercury deposits in Nevada, Idaho, and Oregon, but these rocks are not common in Washington.

METAMORPHIC CORE COMPLEXES

The metamorphic core complexes (MCC) of Washington and adjacent British Columbia and Idaho formed during Challis time. They are the most prominent structural and topographic features of northeastern Washington (Fig. 3).

The MCCs have two essential features: (1) they consist of amphibolite-facies metamorphic rocks and Eocene granitic plutons, and (2) their margins (except where truncated by later high-angle faults or overlain by the Walpapi sequence) are bounded by low-angle, normal faults (detachment faults). These faults consist 0 to 4 km of mylonitic rocks in amphibolite to greenschist fades capped by cataclastic rocks in greenschist or lower facies. Because the cataclastic rocks rarely are more than a hundred meters thick and are easily eroded, they rarely crop out in northeastern Washington. Rocks above the detachment fault can be of any kind, including unmetamorphosed Challis rocks.

The Kettle MCC and the northeasternmost arm of the Okanogan MCC have a distinctive succession of metamorphic rocks, known as the Tenas Mary Creek (TMC) assemblage (Orr and Cheney in Schuster, 1987; Stoffel and others, 1991). The TMC is shown as hmm in Figure 3.

The orthogneisses within the TMC are Cretaceous (Armstrong and others in Schuster, 1987; Armstrong and others in Ross, 1991). A feldspathic quartzite up to 650 m thick in the TMC defines the broadly domal pattern of the Kettle MCC in Washington, but north of the International Border a thinner and structurally lower quartzite and associated paragneiss occur. The thick upper quartzite has some 570 to 674 Ga zircons (Ross and Parrish in Ross, 1991), whereas, the structurally lower rocks have a variety of dates that suggest an age of 1.7 to 1.9 Ga; therefore, a major unconformity probably exists below the thick quartzite (Armstrong and others in Ross, 1991). Although Ross and Parrish favored correlation of the thick quartzite with the Gypsy of the Sauk sequence, the feldspathic nature of the quartzite suggests that it may be more akin to the Three Sisters Formation.

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The ages of zircons in the Gypsy, Three Sisters, and Windermere Group, a North American source for the 570 to 674 zircons, and any similarity of the TMC paragneisses to the Sauk or older North American sequences are still unknown. The structurally lower quartzite in the Kettle MCC is a cndidate for UBS A0. If the MCCs represent North American crystalline basement, the apparent maximum amount of obduction of Quesnellia and of the eastern assemblage is 125 km along the International Border; however, this distance must be reduced by at least 25 to 30% due to mid-Eocene extension on the detachment faults that bound the MCC.

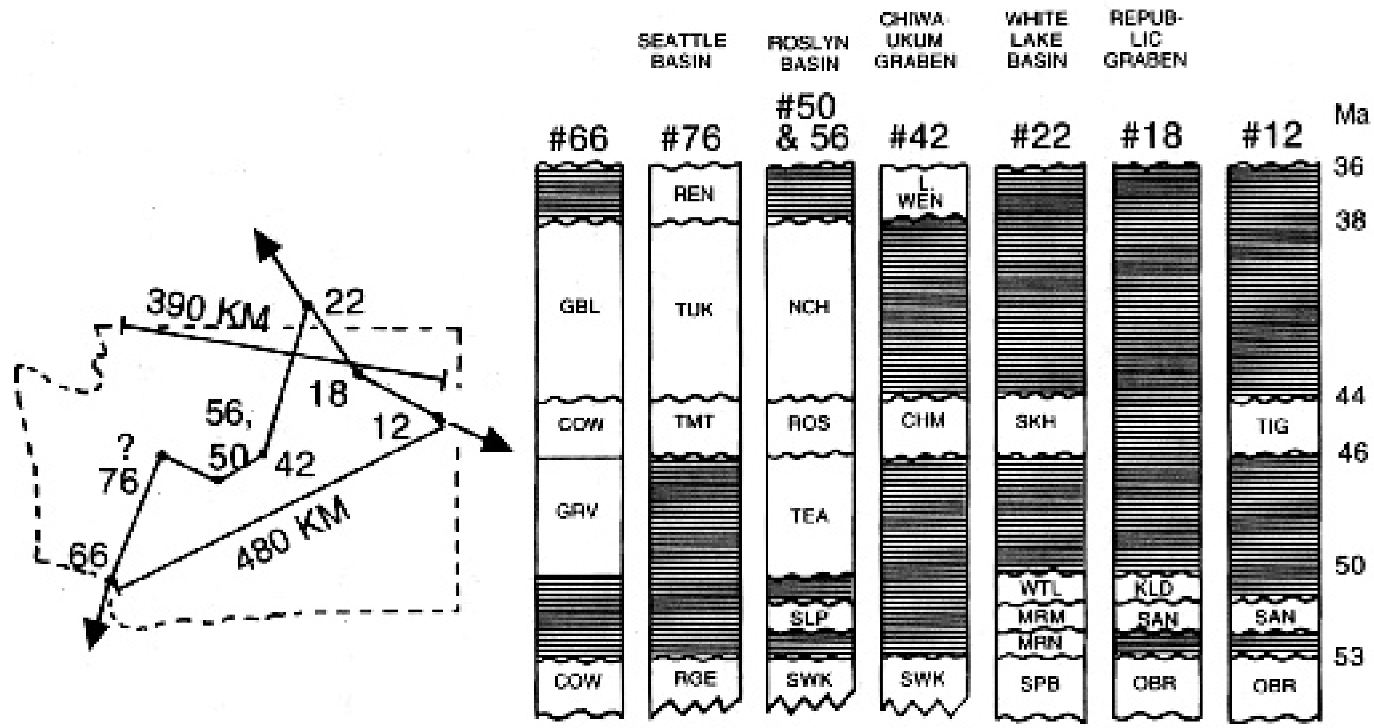

Figure 16 REGIONAL CORRELATION DIAGRAM FOR EOCENE ROCKS IN WASHINGTON AND SOUTHERN B.C.

Three suites of Paleocene to Eocene granitic intrusions occur in the Okanogan and Kettle MCC. Representatives of each have mylonitic foliations (Holder and Holder, 1988). The oldest, the Keller Butte suite of Holder and Holder (1988), includes the biotite-more-abundant-than hornblende, zoned, granitic intrusions (Storm King, Mount Bonaparte, Lyman Creek) in the Okanogan MCC. The equigranular homblende-biotite quartz dioritic Kettle Crest pluton of the Kettle MCC is a representative of the Devils Elbow suite. The youngest, or Herron Creek suite, consists of coarsely porphyritic and equigranular phases of quartz monzonitic to monzonitic rocks,such as the Long Alec Creek batholith in the Kettle MCC east of Curlew. Only the Herron Creek suite is shown separately on Figure 9.

The map of Stoffel and others (1991) shows that detachment faults cut all of the previously described regional units except the Zuni sequence (too areally restricted) and the Walpapi sequence (too young). Cooling ages within the crystalline rocks of the MCCs, ages of dikes within the detachment faults, and cross cutting relations of the detachment faults (Parrish and others, 1988) show that final development of the MCCs post-dates the Klondike Mountain and Tiger Formations, the two youngest Challis formations in northeastern Washington.

As shown by Figure 3, many of the bounding faults of the Tertiary grabens are detachment faults. The detachment faults record significant middle-Eocene extension of the crystalline basement beneath a cover consisting of the Proterozoic to Paleozoic and Eocene North American sequences, the eastern assemblage, Quesnellia, and the southwestern metamorphic belt. Cumulative extension is believed to be 25 to 30% (Parrish and others, 1988), and considerably more locally. Therefore, Challis successions now bounded by detachment faults may once have been considerably closer together, or even contiguous (Parrish and others, 1988). .

The unconformity that truncates the top of Tom Thumb Tuff Member of the Klondike Mountain formation may mark the rise of the MCCs. Large bodies of brecciated Herron Creek quartz monzonite occur in the middle member of the Klondike Mountain Formation west of the Bodie Mountain detachment fault; these are rock-avalanche deposits derived from rocks within the MCCs (Malte, 1995). Similar deposits occur along State Route 20 four miles west of the Okanogan/Ferry County border. Rock-avalanche deposits in southeastern California mark the uplift of MCCs in that area (Topping, 1993). Furthermore, the gold- and silver-selenide veins at Republic are associated with faults adjacent to the Bacon Creak detachment fault and are in Sanpoil and Tom Thumb rocks.

The metamorphic core complexes, or the detachment faults that bound parts of them, may have different ages. The unconformity at the top of the Tom Thumb Tuff Member could be contemporaneous with the Scatter Creek/Bacon Creek/White Mountain detachment fault on the eastern margin of the Okanogan MCC. However, on the western side of the NE arm of the Okanogan MCC, the Bodie Mountain detachment fault cuts the younger members of the Klondike Mountain Formation and the White Mountain fault (Fig. 9). Furthermore, the rock-avalanche deposits of Herron Creek quartz monzonite in the Klondike Mountain Formation may not be related to the Bodie Mountain fault: plots of SiC>2 vs. K2O and of Cr, Ba, and Th against TiC>2 from Malte's data (1995) show that the rock-avalanche deposits are less like the Empire Lakes pluton between the Bodie Mountain and Bacon Creek faults than the Long Alec Creek batholith east of the Granby River fault in the Kettle MCC near Curlew. If the rock-avalanche deposits are derived from the Long Alec batholith of the Kettle MCC, the intervening structural high (northeast

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arm of the Okanogan MCC) caused by the Bodie Mountain fault did not exist at the time of the avalanche.
Considerable vertical rotation may have occurred along some detachment faults, either because the faults are listric (decrease in dip downward) and(or) because of extension over ductile Eocene granitic plutons in a manner similar to that described by Brun and others (1994). Listric normal faults are common in the Miocene MCC of the American Southwest (Frost and Heidrick, 1996). These cause Tertiary cover sequences to dip backwards into the MCC in a series of domino-like fault blocks. In Washington, good examples of dips into the MCC occur along the Kettle River fault on the northeast side of Kettle MCC at First Thought Mountain (Rhodes and Cheney, 1981) and on the Bodie Mountain fault on the NE arm of the Okanogan MCC (see Pearson, 1967). The vertical dips of the O'Brien Creek Formation at the Overlook and Lamefoot mines (Figs. 10 and 12) may be examples of extreme rotation associated with the Lambert Creek detachment on the west side of the Kettle MCC.

The exception to backward dips is the largest swath of Challis rocks in northeastern Washington, the so-called Republic graben. Its synclinal structure, Sanpoil syncline of Figure 10, is stressed below.

Low-angle faults do occur in the upper plates of the detachment faults. Fyles (1990) mapped several in the Quesnellian and Challis rocks north of the International Border (Fig. 9). Similar features have been mapped in small open-pit mines in the Belcher Mining District. The paucity of low-angle faults south of the International Border may be due to less detailed mapping (fostered largely by the inability to recognize mappable units in the Sanpoil Volcanics). Alternatively, if the faults are listric, the higher structural level south of the International Border (abundant Challis instead of abundant Quesnellian rocks) could result in fewer low-angle faults.

Although some prospects are known, no significant metallic mineral production has been recorded from the crystalline rocks of the MCCs. A minor amount of uranium was recovered from the Priest River MCC north of Spokane in the 1950s, and sub-economic radioactive pegmatites in the Kettle and Okanogan MCC teased prospectors in the 1950s and 1970s. The mylonitic eastern quartzite of the Kettle MCC retails for $350/ton as patio rock in Seattle. A high-calcium marble in the Okanogan MCC north of Waconda was brought into production several years ago (Bleek and others, 1993).

SANPOIL SYNCLINE

The Quesnellian and Challis rocks in the Republic/Curlew/Danville valley, the so-called Republic graben, outline the regional Sanpoil syncline (Fig. 9). In this valley the Quesnellian and Challis rocks are mostly bounded by detachment faults. Younger high-angle NNE-trending faults, the largest of which is the Sherman fault, appear to cut some of the detachment faults, but the "graben" is primarily the synformal upper plate of one or more detachment faults.

Much of the geology in the valley is obscured by abundant Scatter Creek rhyocacite. This rhyodacite is a shallow intrusive suite similar in composition to the Sanpoil Volcanics and the Tom Thumb Tuff (Muessig, 1967; Tschauder, 1989). Not only is the Scatter Creek difficult to distinguish texturally from the Sanpoil Volcanics, it is also more resistant to weathering than the intruded rocks, so the intruded rocks are under-represented in outcrops. Although the intruded rocks appear scarce in much of the valley (see the maps of Parker and Calkins, 1964, and Muessig, 1967), their consistent strikes and dips imply that their structural pattern is not disrupted; if so, the Scatter Creek (rather than the intruded rocks) is discontinuous.

North of Curlew, bodies of Scatter Creek rock are fine-grained quartz monzonite (Parker and Calkins, 1964) and are particularly abundant along the trace of the No. 7 fault (Chesaw thrust). Thus, here the Scatter Creek may be a tabular body or swarm of tabular bodies along the fault. North of Curlew, the Scatter Creek is intricately jointed and locally even brecciated along the No. 7 fault and along the NNE high-angle faults that cut the thrust. Descriptions by Muessig (1967) suggest that the Scatter Creek also is well-jointed along other faults. Perhaps, minor rejuvenation of various faults happened during the waning stages of uplift of the MCCs.

To emphasize the pattern of the Sanpoil syncline mapped by Parker and Calkins (1964) and Muessig (1967), the Scatter Creek and the widespread Quaternary deposits are omitted from Figure 9. The syncline is outlined by the three Challis sequences and by considering all of the Quesnellian rocks to be a fourth basal unit. North of Curlew, the synformal structure is marked by the Knob Hill Group in the Curlew klippe of the No. 7 fault of the Chesaw thrust.Because the Sanpoil syncline has a length, northerly strike, and structural relief similar to the adjacent antiformal MCCs and is largely bounded by the same detachment faults, it is the synformal counterpart of the antiformal MCCs. Thus, the Challis regional sequences were not deposited in a local "graben" but, rather, are structurally preserved in the upper plates of detachment faults. Perhaps, the synclinal structure was produced because the MCCs behaved like giant crustal boudins and the supracrustal rocks structurally "puddled-up" along the intervening regional boudin line.

SUMMARY

This field trip traverses the Proterozoic to Paleozoic miogeoclinal trailing edge of North America, accreted terranes to the west, and post-accretionary cover sequences. The Proterozoic to Paleozoic North American rocks are much thicker than their counterparts in the cratonic interior to the east. The metasedimentary, amphibolite-facies rocks of the metamorphic core complexes may be the western edge of the pre-Beltian North American crystalline basement. The Intermontane superterrane accreted in mid-Jurassic. The Insular, Northwest Cascades, and Coast Range superterranes accreted outboard of the Intermontane superterrane. The Challis sequence is the most widespread of three regional Tertiary cover sequences in the Pacific Northwest. Mid-Eocene crustal extension formed the metamorphic core complexes and segmented the regional outcrop patterns of all older regional units. The Columbia River Basalt Group of the Walpapi sequence unconformably overlies all of the other regional units. Because the basalts dip away from the Cascade Range, they predate uplift of the range and were once more extensive.

ROAD LOG

INTRODUCTION

Beginning with Day Two, this road log lists cumulative mileage (and mileages between important features).

DAY ONE: SEATTLE TO DEER LAKE

- Take 1-90 from Seattle to Sprague, WA. At Sprague, take Exit 245 to SR 23 and 231.
- Take SR 231 north to US 2
- Turn east on US 2 and SR 231 to Reardan.
- At Reardan, turn left (north) on SR 231 toward Spring dale and Colville.
- At Springdale, turn right (east) on SR 292 toward US 395 and Spokane.
- Pass the town of Loon Lake and at US 395, turn left (north) toward Chewelah and Colville.
- 3.3 miles north of the junction of US 395 and SR 292, turn right (east) on Deer Lake North Road.

END OF DAY ONE

DAY TWO: DEER LAKE TO REPUBLIC

Day two inspects stratigraphic units indigenous to North America and finishes with a traverse of the Kettle metamorphic core complex. The 1:250,000 map of Stoffel et al. (1991) is a useful compendium of the regional geology. Permission must be obtained from Northwest Alloys (509-935-3300) to visit Stop 2-5.

This road log starts at the intersection of Deer Lake North Road and US 395. This junction is about mile 193.7 on US 395 and is approximately

a) 35 miles north of Spokane on US 395,

b) 3.3 miles north of the intersection of US 395 and SR 292,

c) 35 miles south of Colville on US 395, and

d) 13.9 miles south of Chewelah on US 395.

0.0 (0.0) Intersection of Deer Lake North Road and US 395.

1.9 (1.9) Stay left (north) at fork in road and drive along the northwest shore of Deer Lake.

2.2 (0.3) Pinelow Park (private campground). On former field trips Pinelow (509-233-2367) has provided various kinds of lodging (ranging from low to moderate prices) and a moderately-priced group breakfast. One option is to do stops 2-1 and 2-2 before breakfast.

2.7 (0.5) Camp Clifford, Salvation Army. This is another possible group lodging.

5.2 (2.5) End of pavement and end of northeast arm of Deer Lake. Vehicles can turn around here or at a junction another 1/2 mile northeast; they will return down the paved road and wait for us 0.5 miles southwest of here at the end of the traverse.

STOP 2-1: BURKE AND REVETT FORMATIONS OF THE BELT SUPERGROUP

Belt geologists use the following field terms: quartzite if the rock is unscratchable by a steel blade of a knife, siltite if slightly scratchable, and argillite of easily scratchable. All three “lithologies” occur on this traverse.

Figure 17 is a guide for Stops 2-1 and 2-2. Note that all of the Belt Group from the oldest (Pritchard Formation) to the middle carbonate unit (Wallace Formation) is present in Figure 17. Walk southwest along the road for 0.5 miles, proceeding up-section from the Burke Formation into the Revett Formation. Miller and Clark (1975) stress that the characteristics of these formations here are similar to those in northern Idaho.

The same lithologies occur in both the Burke and the Revett. The Burke is less quartzitic, more intricately folded (including kink folds) and better cleaved. The Burke has 1/3 m-scale bedding compared to predominantly m-scale layering in the Revett. Quartzites in both formations are rusty weathering, well sorted, fine grained, and gray with mm- and cm-scale colored planar laminations; the Burke has some ripple marks. Because of the greater abundance of siltites and argillite, the Burke has more visible muscovitic argillite (some with mud chips and interference and symmetrical ripples), small scale folding, and cleavage, but the Burke has fewer mm- to m-scale quartz veins. Note that significant portions of the Revett are covered (and likely to contain argillites and siltites).

Continue southwest toward US 395 6.9 (1.7) Pull out on right.

STOP 2-2: ST. REGIS FORMATION

Again, Miller and Clark (1975) stress that the St. Regis Formation is similar to its occurrences in northern Idaho. Here it consists of rusty weathering, laminated argillite and minor siltite in beds only a few cm thick. Although much of the rock is green or gray, some is pale to dark purple. Mud chips are most noticeable in the purple rocks.

Return to US 395.

10.5 (3.6) Junction of Deer Lake North Road and US 395, turn right (north) on 395 toward Colville and Chewelah.

24.4 (13.9) Traffic light in Chewelah on US 395.

30.0 (5.6) Junction of Blue Creek Road and US 395, turn left (west) on Blue Creek Road.

30.4 (0.4) Turn left (south) on Dry Creek Road.

30.9 (0.5) Intersection of Dry Creek road and Duncan Road. Vehicles can turn around here. Walk 0.1 miles south on Dry Creek Road to Stop 2-3.

STOP 2-3: HUCKLEBERRY "CONGLOMERATE"

Although this outcrop appears underwhelming, it represents an impoTant but discontinuous unit at the base of the Windermere Group. Here the rock is a phyllitic, poorly sorted, sandstone. Some of the flattened clasts are nearly 1 cm long. Note that the clasts are polymictic and some are quartz, which serves to separate this rock from the overlying Huckleberry greenstone, with which it has been lumped.

Elsewhere in Washington and southern BC, this unit is the Shedroof conglomerate and the Toby conglomerate, respectively (Fig. 4). These cobble conglomerates are unsorted, unstratified, and polymictic. Diamictites of this age are known on a few continents and, increasingly, are considered to be latest Proterozoic or Vendian tillites and possible worldwide chronostratigraphic (marker) units.

Note the kink bands superimposed on the phyllitic foliation. Notice the suspended mining operations in the Addy Quartzite in the hills to the northeast. These were for the ferrosilicon plant at Addy.

Return to the intersection of Blue Creek Road and US 395.

31.8 (0.9) Intersection of Blue Creek Road and US 395.

STOP 2-4: HUCKLEBERRY GREENSTONE

This fine-grained greenstone varies from nearly massive to slightly phyllitic. Epidote, calcite, and chlorite can be seen. Dark mottles on foliation surfaces and rare black phyllite and carbonate clasts > 1 cm imply that some of the greenstone was volcaniclastic. However, some lensoid features may be deformed pillows. Note that discontinuous quartz veinlets at the south end of the outcrop have various cataclastic features, a fairly common feature of quartz veins (especially auriferous ones) in greenstone. Because it dips steeply to the north, the Huckleberry Greenstone structurally overlies the younger Addy Quartzite.

Continue north on US 395 toward Addy and Colville.

34.3 (2.5) Turn left (west) off US 395 to Addy.

34.5 (0.2) Addy, turn left crossing railroad tracks and river and follow the road south around the ridge.

35.0 (0.5) Stop 2-5 is behind fence to the north; continue west. 35.5 (0.5) Marble Valley Road, turn right (north).

35.9 (0.4) Turn into main gate of Northwest Alloys.

36.1 (0.2) Main gate of Northwest Alloys. Mr. Ozzie Wilkenson (509-935-3300) is in charge of security: submit release forms and obtain hard hats and safety glasses.

36.3 (0.2) Turn right (south) at the outcrop at east end of plant. The drive through the Northwest Alloy plant provides an appreciation of the lithologic variation and of faults within the Addy.

36.7 (0.4) South gate of Northwest Alloys. Vehicles turn around.

STOP 2-5: ADDY QUARTZITE

This is the type locality for the Addy and is described by Dutro and Gilmour, Stop 15, in Joseph (1989) as follows:

"Addy Quartzite crops out on the ridge to the right, north of the road beyond the Allied Chemical fence. Examine this outcrop for Early Cambrian fossils (Nevadella and brachiopods). Use care, as we are examining this outcrop with company permission. NOTE: For persons making the trip by themselves, permission must be obtained from the company before entering the area beyond the fence."

The eastern part of the outcrop contains rare cm-scale molds of articulate brachiopods, rare cm-scale lumps that could be very poorly preserved rolled-up trilobites, and rare inch-scale

Figure 17 GEOLOGY OF THE DEER LAKE AREA
This figure is a portion from Miller and others, 1975
Plate 2

GEOLOGY OF THE DEER LAKE AREA.
This figure is a portion of Miller and others, 1975, Plate 2. Units arc:

Qag, undifferentiated Quaternary deposits
Tm, Tertiary mafic dikes
Kc and Km, granitic rocks
Ca, Addy Quartzite
pCwu, upper pan of the Wallace Formation
pCwl, lower part of the Wallace Formation
pCsr, St. Regis Formation
pCr, Revert Formation
pCb, Burke Formation
pCp, Pritchard Formation

trilobite cephalons. Quartzitic units in a small quarry next to the company's fence have cross beds and load casts.

On the north side of the plant site is a quarry in the Metalline Formation, from which Northwest Alloys obtains dolomite for its metallurgical products. With permission, it may be possible to visit the quarry.

. Return to US 395 via Addy.

38.4 (1.7) Junction of southern access road to Addy and US 395, turn left (north) toward Colville.

52.9 (14.5) Junction of US 395 and SR 20 at north end of Colville. Stay straight on US 395/SR20.

0.2 miles to the north, SR 20/US 395 turns abruptly west (left). A city block northeast of this turn, at the comer of 6th and Oak streets, an outcrop of the Reeves Limestone of the Maitlen Phyllite reportedly contains archaeocyathids.

55.1 (2.2) Turn right (north) on Williams Lake Road.

61.1 (6.0) Turn right (northeast) on Clugston Creek Road. Stay on paved road to Stop 2-6.

68.5 (7.4) Large road cut.

STOP 2-6: FAULTED CONTACT BETWEEN LEDBETTER SLATE AND METALINE LIMESTONE

This is Stop 8 of Dutro and Gilmour in Joseph (1989); their description follows:

"The contact is in the main roadcut and quarry on the right side of the road (east), and Ledbetter Slate crops out at the south end of the roadcut. Abundant graptolites in the Ledbetter; Early or early Middle Ordovician conodonts have been collected from the top of and 100 ft below the top of the Metaline Limestone here."

The well foliated and fractured nature of the Metaline is especially obvious in some of the larger blocks near road level. Some blocks contain dolomitic (?) isoclines (mm- to cm-scale); veinlets filled with sparry calcite are perpendicular to the foliation (and to the axial planes of folds). The rocks of the Mississippi Valley-type Pb-Zn deposits in the Metaline Formation (especially in the Van Stone Mine about 6 miles east of here) are similarly well deformed (Mills, 1977); mineralization occurs in rock with elongate clasts (deformed karstic breccia?).

Note that the Metalline and Ledbetter are in different North American sequences (Figs.4 and 5).

The Ledbetter appears to be less deformed than the Metalline (but see Stop 2-7). The Sauk is in greenschist facies, but is the Ledbetter? Note the unconformably overlying till at the northeast end of the roadcut.

Turn around and return south toward US 395/SR 20.

70.6 (2.1) Quarry and pull-out on right.

STOP 2-7: DEFORMED LEDBETTER SLATE

This is Stop 7 of Dutro and Gilmour in Joseph (1989). The Ledbetter is deformed by gently dipping, northeasterly verging folds. The Huckleberry Ridge-Columbia fault system is about a kilometer to the west; so, these folds represent thrusting of North American rocks back onto the craton during the collision of Quesnellia with North America.

Return to US 395/SR 20.

82.1 (11.5) At junction with US 395/SR 20 with Williams Lake Road, turn right (west).

84.6 (2.5) Pull into quarry on right (north) side of highway on the west side of the ridge.

STOP 2-8: EASTERN ASSEMBLAGE

The identity of these rocks is enigmatic (Stoffel and others, 1991), but lithologically they seem to most resemble the Bradeen Hill succession (Joseph, 1990). Note that the foliation dips gently to the southeast. The following description is from Stop 9 of Dutro and Gilmour in Joseph (1989):

"Devonian?/Carboniferous? chert-pebble conglomerate and graywacke on Rattlesnake Mountain. These clastic rocks are thrust eastward against the Metalline/Ledbetter of the Clugston Creek belt; the fault trends northward, contrast these lithologies with the Lower Paleozoic sequence seen [at Stops 2-6 and 2-7]."

Continue west on US 395/SR 20.

88.9 (4.3) Main intersection in Kettle Falls.

89.9 (1.0) Junction with SR 25, stay straight (west) on US 395/SR 20.

92.4 (2.5) Bridge over Columbia River (Franklin D. Roosevelt Lake behind Grand Coulee Dam). Rocks exposed during low water (May) are mylonitic quartzite (see Stop 2-10).

92.7 (0.3) Barney's Junction, turn right (north) on US 395 towards Laurier and Grand Forks and park in front of the motel; then walk 0.1 mile north to the roadcut and railroad cut

STOP 2-9: MYLONITIC EASTERN MARGIN OF THE KETTLE METAMORPHIC CORE COMPLEX

The metamorphic rocks of the Kettle MCC are collectively known as the rocks of Tenas Mary Creek (TMC). The type locality, Tenas Mary Creek, is in the northeastern arm of the Okanogan MCC. Because this stop (Fig. 18) is on the margin of the antiformal Kettle MCC (adjacent to the Kettle River detachment fault), it is structurally high in the TMC. The most abundant lithology along the west side of the highway is the granodioritic orthogneiss of the TMC. We will compare this unit with the other major orthogneiss (GPPG) at Stop 2-12. Although the cut here has several lithologies, they are lumped with the eastern orthogneiss (g) in Figure 18. This stop is well described by Fox and Wilson as their Stop 7 in Joseph (1989):

"West of the road, amphibolitic gneiss overlies mylonitic augen gneiss, which in turn overlies thinly interlayered amphibolitic gneiss and mylonitic granitic gneiss and pegmatite. Layering and foliation are concordant, dipping 17 degrees east. All rocks are penetratively lineated, the lineation lying in the plane of foliation and trending approximately N75°E. In the granitic gneiss, mylonite grades to or is thinly interlayered with ultramylonite. The mylonite is typically light-gray and medium to fine grained and has conspicuous foliation and lineation and abundant larger grains (porphyroclasts) of light gray feldspar, which are milled to spindle shapes. The ultramylonite is darker and much finer grained than the mylonite and has scattered sand-sized, light-gray feldspars and poorly developed lineation.

The railroad cut east of the road exposes the upper amphibolitic gneiss. This amphibolite is mottled by lenses of coarse-grained amphibole (and garnet), evidently recrystallized following cataclasis. Recumbent isoclinal (intrafolial) folds are abundant. Trends of fold axes in this area show considerable scatter..., but many trend approximately parallel to the lineation. At the north end of the cut, axes of sheath folds and refolded intrafolial folds trend obliquely to the lineation. Small boudins, some of amphibolite within mylonitic granitic gneiss, others of amphibolite, are exposed in cross-section. A small white boudin above the prominent fold in the central part of the cut trends approximately N76°E.

The mylonitic character of the rocks in this area was recognized by Campbell (1938). His carefully worded descriptions are well worth reading. Campbell considered these rocks to be part of the crushed border zone of the Colville batholith. He concluded (1938, p. 94) that the "...brecciated appearance of the rock, the slicing and displacement of the feldspars, the warping of quartz and feldspars as shown by strain shadows, and the lens-like grouping of fine particles about rounded and strained relic crystal..." were evidence of the pressure that had acted on the batholith."

Return to the vehicles and continue northward on US 395.

93.2 (0.5) Kifer Road on west. Excellent exposures of the eastern quartzite occur in quarries up this road. The quartzite is widely used as decorative stone (note the restaurant at Barney's Junction) and as paving blocks ($350/ton in Seattle).

93.7 (0.5) For the next mile, roadcuts are in the amphibolite structurally above the eastern orthogneiss and below the eastern quartzite.

94.9 (1.2) Nancy Creek Road on left (west).

95.6 (0.7) Stop. If necessary, vehicles can proceed 0.4 miles north to the Kamloops Island road to turn around.

STOP 2-10: FOLDED, MYLONITIC EASTERN QUARTZITE

Starting in amphibolite, walk 0.2 miles N050 to the knob west of the railroad track. The eastern quartzite (eq on Figure 18) has cm-scale banding and unusually well developed northeasterly plunging folds. The quartzite is aphanitic (almost porcelainous) and banded (slabby), which is typical of mylonitic quartzites. Gently dipping planes of foliation have a lineation that is N75° ± 10° (sub-parallel to the axial traces of the folds). Some of the smaller folds are truncated parallel to their axial planes (causing 1/2 folds). Close inspection reveals that much of the quartzite is intricately fractured, probably because it is within a kilometer of the Kettle River fault.

The metamorphic facies of this rock is in doubt. Of course, the rock has no chlorite. Sillimanite has yet to be reported with the muscovite.

Return to Barney's Junction.

98.6 (3.0) Barney's Junction, turn right (south) on SR 20 toward Republic and Tonasket.

102.1 (3.5) Excellent outcrop of mylonitic eastern orthogneiss on right.

102.9 (0.8) Junction with road to Inchelium, keep right (straight and westward) on SR 20.

105.7 (2.8) Road to Canyon Creek campground left (south).

106.5 (0.8) Parking here is terrible but the road is straight. If necessary, the vehicles will return to pick us up in 20 minutes.

STOP 2-11: MYLONITIC FELDSPATHIC QUARTZITE

Although on fresh surfaces this quartzite appears to be aphanitic (and porcelainous), it has several percent feldspar porphyroblasts 2-10 mm long (which are best seen on weathered surfaces). Contrast the grain size and composition with North American quartzites of previous stops. Note that the rock is lineated. This is the major (< 650 m thick) quartzite of the TMC rocks (q of Figure 11), which best defines the antiformal nature of the Kettle MCC south of BC; here the rocks dip gently eastward.

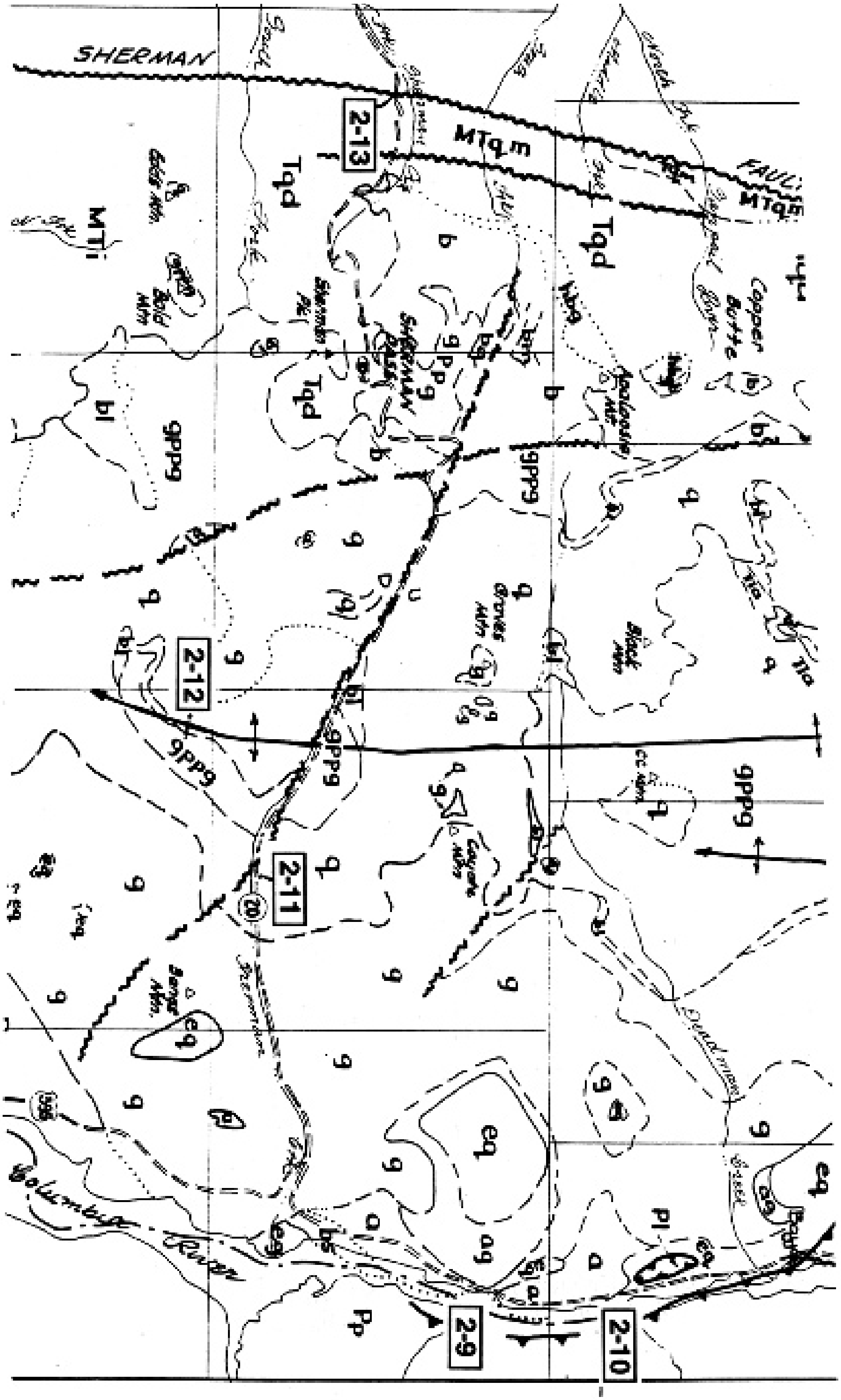

Figure 18 GEOLOGIC MAP OF THE KETTLE METAMORPHIC CORE COMPLEX IN THE VICINITY OF SR 20. Redrafted from Orr and Cheney (1987, fig. 2). Note that in this figure the detachment faults are shown by the sawtooth symbol usually used for thrust faults. Figure 19 is the explanation for this figure.

Stops are numbered.

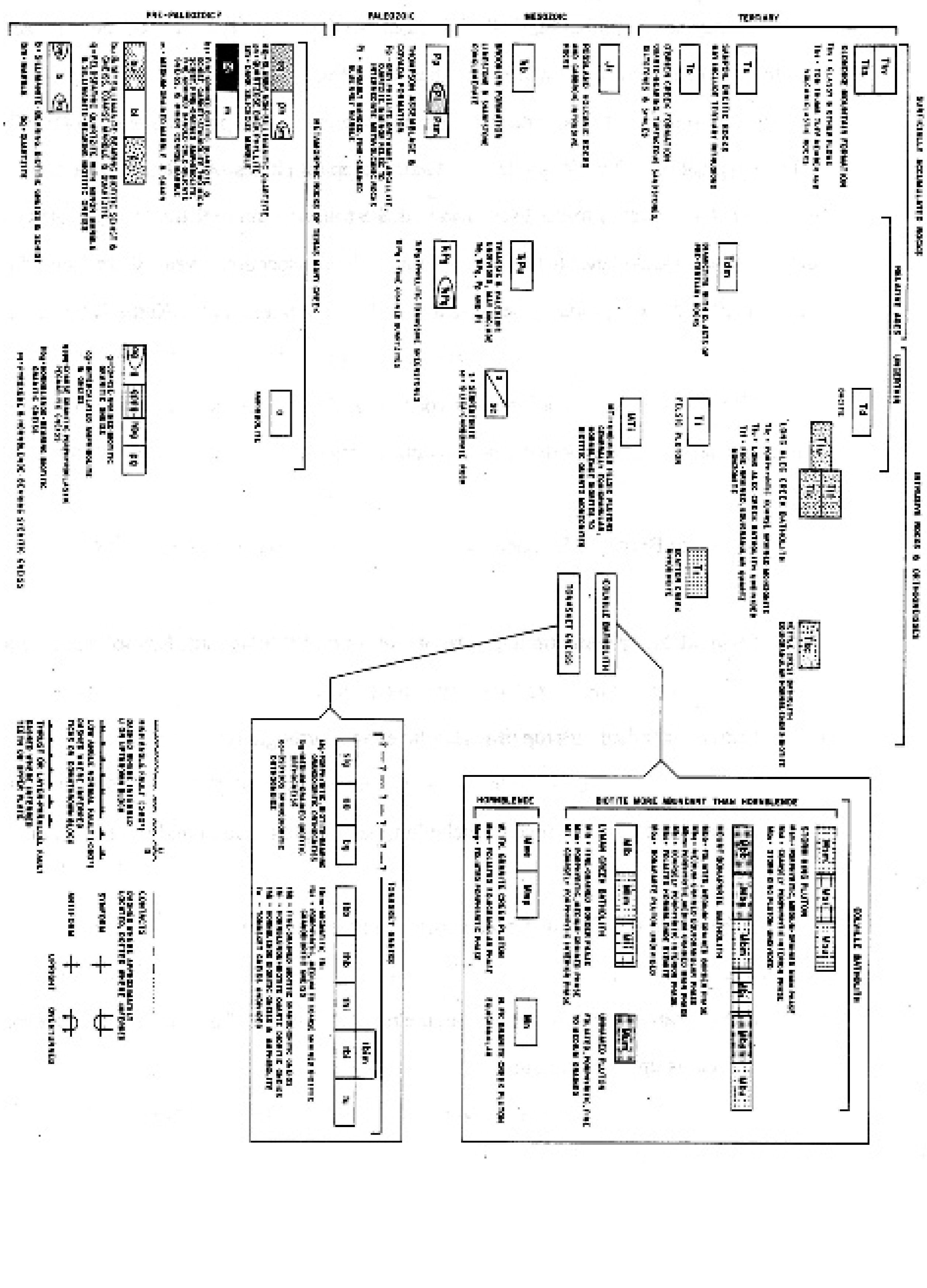

Figure 19. EXPLANATION FOR FIGURES 18 AND 21 Copied from Orr and Cheney (1987, fig. 2).

108.5 (2.0) South Sherman Road (#2020) turn left (south).

110.5 (2.1) Outcrop on right (north), vehicles can proceed another 0.5 miles to turn around.

STOP 2-12: LOWER TMC ORTHOGNEISS

This gray, porphyritic, pegmatitic gneiss is shown as gppg on Figure 18. Note the 1.5 to 6 cm K-feldspar megacrysts and the irregular pegmatitic patches. Note also the lack of ultramylonites and strong banding, but some feldspars do have a weak easterly lineation. The gently dipping foliation is due to being near the antiformal axis of the MCC.

Return to SR 20.

112.7 (2.1) Junction of South Sherman Road (Road #2020) and SR 20. Turn left (west) on SR 20 toward Republic.

124.4 (11.7) Excellent outcrop of GPPG in former streambed, but parking is terrible.

126.4 (2.2) South Sherman Road (#2020).

127.3 (0.9) Very large, biotite-poor pegmatite on right (north) side.

127.7 (0.4) Boudinaged pegmatites with broken feldspars occur in sillimanite-bearing biotitic schists. These biotitic rocks are believed to be structurally below GPPG (Orr and Cheney, 1987). Although the pegmatites are some of the most biotitic and radioactive in the Kettle MCC, the quartz is not dark gray to black (which normally is caused by radiation damage).

130.2 (2.5) Sherman Pass.
Sherman Pass (altitude 5575 feet) is the highest pass in Washington that is open to vehicular traffic in the winter.

On the south side of the road is the weakly foliated quartz dioritic border phase (with xenoliths and screens of metamorphic rocks) of the Eocene Kettle Crest batholith intrusive into the TMC metamorphic rocks.

The easternmost outcrops on the northern side of the pass are GPPG. Westward on the bench above the highway is the contact of GPPG with westerly dipping sillimanite-bearing gneiss and amphibolite. The relative structural positions of the GPPG and the sillimanitic pelitic rocks cannot be determined here, but to the north, the map pattern indicates that GPPG may be the structurally higher unit. The steep dips here are characteristic of the western margin of the Kettle MCC.

A 1/2 mile walk northward along the Kettle Crest trail starts in the quartz diorite and passes into sillimanitic pelitic rocks with weakly radioactive, boudinaged pegmatites. At the power lines is a good view westward across the Republic structural low a.k.a. “Republic graben,” or “Sanpoil syncline;” the jagged peaks in the farthest distance are in the Pasayten Wilderness.

133.6 (3.4) Toilets at a USFS “Point of Interest” about the 1988 White Mountain forest fire.

135.6 (2.0) Colville National Forest boundary.

136.6 (1.1) Park on right (north side of road).

STOP 2-13: SHERMAN AND CHESAW FAULTS

Muessig (1967) suggested that the serpentinite at this locality marks the Sherman fault, which is the eastern bounding fault of the Republic graben. The Sherman fault separates Challis and Quesnellian rocks on the west from Challis-aged granitic rocks of the western limb of the Kettle MCC (Muessig, 1967, plate 1). However, the Sherman fault is unusual here in that it is marked by vertically foliated serpentinite, felsic metavolcanic rocks, and float of coarse-grained muscovitic schist. Thus, this might be the southeastern continuation of the Chesaw fault (to be observed on Days 3 and 4). If so, the Sherman fault is either slightly farther to the east of here or is superimposed on the Chesaw fault.

137.1 (0.4) Outcrops for the next half mile are massive, white, volcaniclastic sandstones and interbedded dark siltstones and shales of the O’Brien Creek Formation. The O’Brien Creek is the basal unconformity-bounded formation of the Challis sequence (Fig. 16). The brownish and knobby weathering rocks for the next 9 miles to the junction of SR 20 and SR 21 are the Sanpoil Volcanics; these felsic rocks are the next unconformity-bounded formation above the O’Brien Creek.

144.8 (7.7) Junction of SR 20 with SR 21. Stay straight ahead (west) on SR 20 toward Republic.

147.5 (2.7) Junction of SR 20 with SR 21; turn right (north) toward Republic.

147.8 (0.5) Blinking traffic light, Republic. Walk back (downhill) 1/4 mile to see unaltered fine-grained tuff (with leaf and insect fossils) on the southern edge of Republic. This is the basal Tom Thumb Tuff of the Klondike Mountain Formation.

END OF DAY TWO

LOCAL DIRECTIONS IN REPUBLIC

TO BLACK’S BEACH RESORT

0.0 (0.0) Blinker in downtown Republic, proceed north (uphill).

0.15 (0.15) At T junction in front of the stone Episcopalian Church turn right.

7.5 (7.3) Turn right for Black’s Beach Resort.

8.0 (0.5) Road to right. Stay left for Black's Beach Resort.

8.2 (0.2) Entrance to Black's Beach Resort.

TO CURLEW STATE PARK

Using the road log for Day 1, return to the junction of SR 20 and 21 (3 miles) and continue north on SR 21 to the Lamefoot mine (about 6 miles). Turn left 0.2 miles past Lamefoot into Curlew State Park.

Reservations might be possible at the park by calling (509) 775-3592.

TO CAMPING AT THE FERRY COUNTY FAIRGROUNDS

Follow the directions for Day Three from 0.0 to about 2.8 miles; turn right into the Fairgrounds (before the junction of SR 20 and SR 21). Follow the road around to the right.

TO SWEAT CREEK CAMPGROUND

Follow the directions for Day Four from 0.0 to 8.5 miles.

DAY THREE: REPUBLIC

Day three will concentrate on Quesnellian rocks and structure in the Republic-Curlew-Danville valley (a.k.a. "Republic graben") and on the detachment faults that bound the valley (see Figure 9). Figures 10 and 20 indicate the stops that will be made. Stop 3-1 and 3-2 are eliminated in this edition of the guidebook, the first stop will be 3-3.

To visit the Key west open pit (Optional Stop 3A) permission must be obtained in advance from Echo Bay Minerals Co., (509) 775-3756.

0.0 (0.0) Reset odometer at the blinker in downtown Republic and proceed south (downhill) on SR 20.

0.6 (0.6) Turn left at junction of SR 20 and 21.

3.1 (2.5) Turn left on SR 21 toward Curlew and Grand Forks.

3.9 (0.8) Old Kettle Falls Road. Turn right only if proceeding to Optional Stop 3A; otherwise, resume road log at 0.0 miles after the description of Optional Stop 3A and continue north on SR 21 for Curlew and Stop 3-3.

The knob on the north side of this corner is Gold Hill, which had very limited past production despite its name. It is underlain by Quesnellian rocks (and Tertiary Scatter Creek dikes); so at this latitude, only the western half of the Republic graben is extensively underlain by Challis rocks.

6.3 (2.4) Turn left toward Echo Bay Minerals Co.

7.7 (1.4) Overlook mill site and security gate for Echo Bay Minerals Company's Kettle River Operations. Stop for clearance.

10.3 (2.6) Stay right (east) at fork in road.

12.5 (2.2) Open pit. Admire the reclamation.

OPTIONAL STOP 3A: KEY WEST OPEN PIT MINE

The ores of the Lamefoot, Overlook, Key East, and Key West are in the Attwood Group of Quesnellia (Optional Stop 3A is labeled 3-1 in Fig. 10). In addition to seeing the ore, this is a rare opportunity to examine the felsic volcaniclastic rocks associated with the ore. These rocks normally do not crop out well and, in any event, are under-reported in the Attwood Group. The peh'tic rocks that structurally overlie the felsic rocks also rarely crop out. Limestone is below the ore.

Two ore types were mined at Key West: (1) massive magnetite-pyrrhotite-chalcopyrite and (2) veinlets of quartz-pyrite-chalcopyrite above the massive ore. Key West produced 50,000 ounces of gold when it operated in 1993.
Note that Scatter Creek in the upper benches of the pit is associated with a zone of low angle deformation that also disrupts the massive ore, the felsic volcaniclastic rocks, and pelitic rocks.

Return to the Company's security gate and SR 21.

0.0 (0.0) The road log continues here at the corner of Old Kettle Falls Road and SR 21 whether or not Optional Stop 3A was omitted. Reset odometer.

1.0 (1.0) Large road cuts on the east side of the road at the base of Gold Hill are fine-grained, weakly foliated metabasaltic Knob Hill rocks.

5.0 (2.2) Lamefoot Mine is on right. Commercial underground mining began at Lamefoot in 1995. The Lamefoot area will be visited during Stop 3-8.

5.1 (0.1) Entrance to Curlew State Park on left (west)
.

16.6 (12.5) Bridge on SR 21 over Kettle River.

17.9 (0.3) Curlew across bridge to right (east).

25.8 (7.9) Turn right (east) on Lone Ranch Creek Road. Bridge crosses the Kettle River. Continue past the end of the pavement.

26.3 (0.5) Stop at outcrop on left (west) side of road.

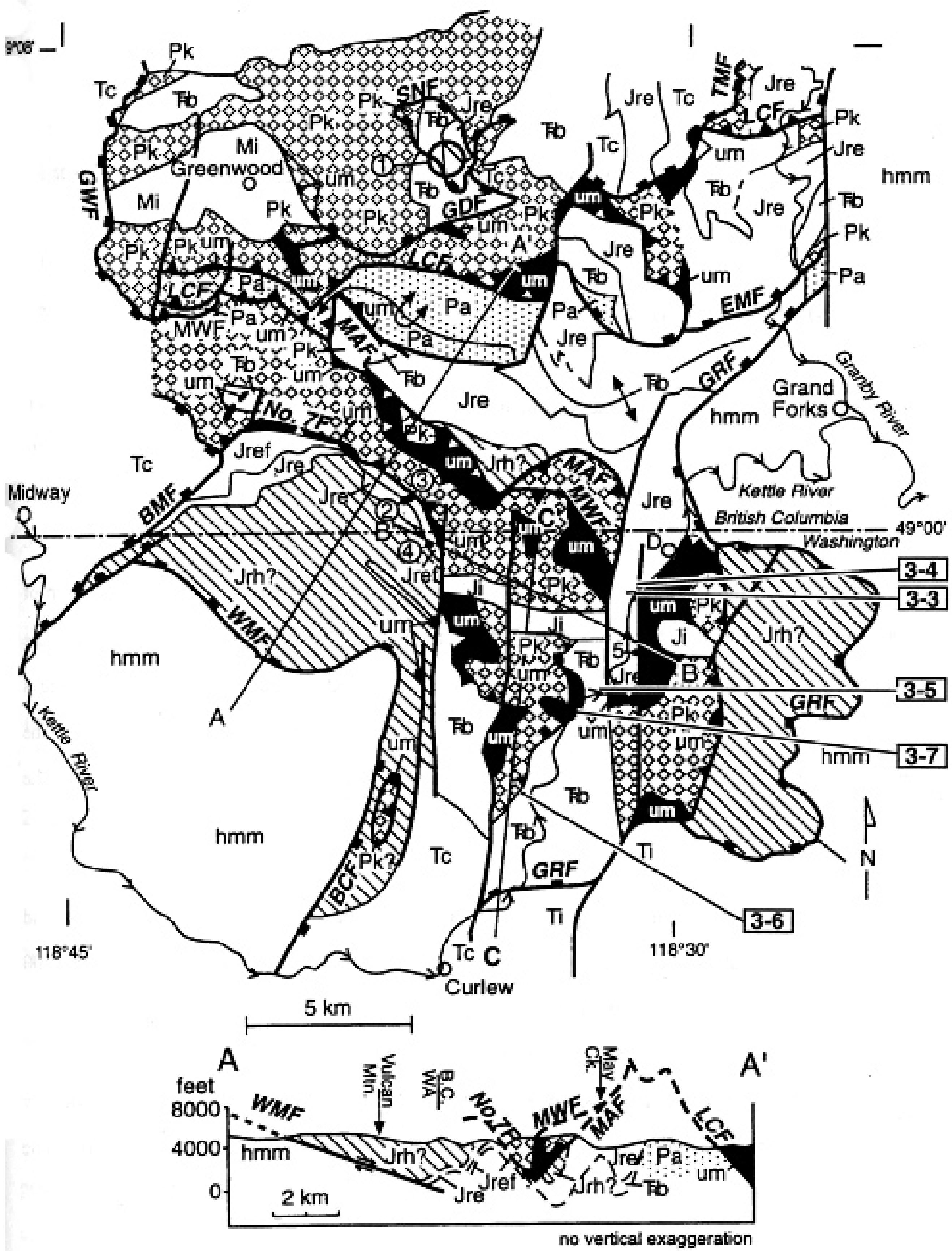

Figure 20. GEOLOGIC MAP OF THE CURLEW-GREENWOOD AREA
Note that this map shows somewhat more detail than Fig. 9. See Fig. 3 for explanation. Mineral deposits are: 1) Phoenix, 2) Lexington, 3) City of Paris, 4) Lone Star, and 5) Morning Star; the Golden Dike mine is in the central portion of Ji.

STOP 3-3: SERPENTINITE AND ROSSLAND (?) METAVOLCANICS

The location of Stop 3-3 is shown on Figure 20. Serpentinite with distinctive slick yellow-green surfaces marks the Chesaw thrust. Not all of the serpentinite along the thrust has this distinctive color, but even massive aphanitic black serpenite is magnetic. This outcrop appears to be part of small klippe or fault slice about 600 m long that is too small to show on Figures 9 and 20.

Walk southward down the road to examine phyllitic rocks that may be part of the Rossland Group and to determine their relationship to the serpentinite. In the area of Figure 20, these rocks are in the footwall of the Chesaw thrust.

Return to SR 21 26.8 (0.5) Turn right (north) on SR 21.

27.4 (0.6) Opposite a long road cut pull off on the shoulder of the road adjacent to the Kettle River.

STOP 3-4: ROSSLAND GROUP AND SCATTER CREEK

The location of Stop 3-4 is shown on Figure 20. Examine the volcaniclastic rocks at the southern end of the outcrop. The Elise Formation is the middle andesitic to basaltic formation of the Rossland Group. Although in most places the rocks are not foliated, they are in greenschist-facies. Fragmental textures are common. Volcanic rocks commonly are feldspar and augite or hornblende phyric.

In the middle part of the road cut, note the much lighter colored bodies of quartz and feldspar porphyry (QFP). These are similar to the Lexington QFP, which has been dated as 199.4 ±1.4 Ma. Try to determine the relationship of the QFP to the greenstones.

At the northern end of the road cut, Scatter Creek rocks are distinctly different from the greenstone. Although the Scatter Creek commonly is regarded as the hypabyssal equivalent of the Sanpoil rhyodacites, this rock could be termed a quartz monzonite. Locally such rocks are so common that they obscure the geology; thus they are omitted on Figures 9 and 20. Turn around and drive south toward Curlew.

28.7 (1.3) Upper Danville Road on right (west)

29.0 (0.3) Curve in road; pull out on east shoulder

STOP 3-5: BROOKLYN LIMESTONE

The location of Stop 3-5 is shown on Figure 20. Limestones of the Brooklyn Formation are typically clastic. Note that on weathered surfaces some sand- to granule-sized clasts weather "up", giving the rocks a sandpaper-like appearance; other, generally darker, clasts weather more nearly like the matrix. Brooklyn limestone is the most fossiliferous unit of this part of Quesnellia.

The dike containing phenocrysts of two feldspars is quartz latite porphyry, which Parker and Calkins (1964) associated with the Long Alec Creek batholith to the east.

Continue southward on SR 21.

31.2 (2.2) Park at the entrance to Little Goosmus Creek Road on the right (west) and walk 0.15 miles northward on SR 21.

STOP 3-6: BROOKLYN SILTSTONE AND SHARPSTONE CONGLOMERATE

The location of Stop 3-6 is shown on Figure 20. The road cut is dominated by green siltstone and sandstone and has minor interbeds of conglomerate. Clasts in the conglomerate are predominantly angular chert (up to 12 cm). Determine if the conglomerates are crudely graded, and if so, whether the beds are overturned. Remember that from Stop 3-4 SR 21 trends southwestward across a westerly dipping homocline. Thus 3-6 overlies 3-5, and 3-5 overlies 3-4.

Return to cars and return northward on SR 21

32.6 (1.4) Park in small turnout on right (east) side of road 100 feet north of milepost 162 and adjacent to a bend in the Kettle River. Walk 0.3 miles northward on SR 21
.

STOP 3-7: ROCKS OF THE CHESAW THRUST

The location of Stop 3-7 is shown on Figure 20. Note the abundance of serpentinite cobbles along the northwest side of the road. This is the trace of the Chesaw thrust. The serpentinite crops out over a vertical interval at 200 m on the hillside to the northwest. It is bounded by Scatter Creek on the north, west, and south. The base of the hill on the skyline to the . northeast (which is south of Stop 3-3) also is serpentinite; whereas, the topographically low intervening rocks are Brooklyn, Rossland, and Scatter Creek.

Return southward along the SR 21 to the next road cut and determine the lithology, metamorphic facies, and probable mode of emplacement of this Rosetta Stone. Unfortunately, the next outcrop to the south of the Rosetta Stone is Scatter Creek.

Walk eastward from the Rosetta Stone across SR 21 to the outcrop on the north side of the bend of the Kettle River. Speculate why the latite porphyry is so finely jointed (especially high-angle, northerly trending zones).

Turn around and drive south on SR 21 toward Curlew. North of Curlew, SR 21 crosses the detachment fault (Granby River fault?) that separates the Long Alec Creek batholith of the Kettle metamorphic core complex on the east from Quesnellian and Challis rocks of the Sanpoil syncline at the west.

Similar fault rocks will be seen at Stop 3-9.

38.0 (5.4) SR 21 crosses Kettle River at Curlew. Store and restaurant ahead on right. Continue south on SR 21.

55.6 (17.6) Entrance to Curlew State Park on right (west).

55.7 (0.1) Turn left (east) on Wolfcamp Road adjacent to Lamefoot Mine.

Reset odometer.

The retaining walls of concrete blocks 0.2 to 0.6 miles up the road were used in 1990 to 1991 to collar drill holes used to develop Lamefoot. Some of these holes are shown on Figure 11.

0.9 (0.9) Stop as the road curves eastward and upward along a roadcut on the right (east).

STOP 3-8 KNOB HILL GREENSTONE AND CHESAW THRUST

Knob Hill greenstone here is typically non-descript. Walk southward back down the road, noting that the greenstone is progressively more scaley (including minor interleaved pelitic phyllite). South of the greenstone is metalimestone and magnetite-bearing rocks similar to Lamefoot ore. Compare this traverse with the eastern portion of Figure 12.

If permission has been granted by Echo Bay Minerals Co., an additional stop can be made 0.4 miles to the south. Walk up the dirt road on the east side of valley to see (1) felsic volcaniclastic rocks, (2) the sulfide-bearing (oxidized to limonite) and magnetite-bearing ore zone (discovery site) of Lamefoot, and (3) metalimestone. Search for bedding or foliation in the metalimestone. This stop is similar to the geology shown at the surface in Figure 11.

If doing Optional Stop 3B, continue northeastward on Wolf Camp Road; otherwise return toSR21.

6.9 (0.9) Stop.

OPTIONAL STOP 3B: LAMBERT CREEK DETACHMENT FAULT

This stop is labeled 3-2 on Figure 10. This fault was originally mapped as a thrust by Muessig (1967). It is now believed to be a top-to-the-east detachment fault on the west side of the Kettle MCC (Fig. 10). It is cut by the high angle Sherman fault, which bounds the Republic graben on the east at this latitude.

The extensive but weak limonite is from weathering of sulfides (predominantly pyrite). Imagine what this rock would look like if all of the limonitic fractures were chloritic instead.

Note that clasts in the breccia consist of laminated siliceous rocks (chert) of the Attwood Formation and volcanic rocks of the Sanpoil Volcanics. A porphyritic rock, locally veined but rarely brecciated, cuts the breccia. Conceivably, this is not actually the Lambert Creek fault zone but a zone of brecciated rock in the hangingwall (caused by adjustment of the hangingwall block to a non-planar fault.

Return to the junction of SR 21 with Wolfcamp Road and reset odometer. 0.0

(0.0) Turn left (south) on SR 21.

2.1 (2.1) Turn right (west) on W. Herron Creek Road to cross valley.

3.1 (1.0) T-junction, turn left (south) toward Republic.

7.1 (4.0) Nearly horizontal strata of the Tom Thumb Tuff (basal Klondike Mountain Formation) are on right.

7.7 (0.6) Intersection with Clark Avenue (main street of Republic) on left (south). Episcopalian Church on right. Go straight onto Knob Hill Road.

7.8 (0.1) Stonerose fossil quarry is on the right in Tom Thumb Tuff. To dig and collect, purchase a ticket at the museum opposite the city park. Otherwise, peruse *Washington Geology*, v. 24, no. 2 (1996).

8.4 (0.6) Road enters Eureka Gulch, historically, the main gold producing area of the Republic area.

9.2 (0.8) Knob Hill Gold Mine (inactive) on right. The dormant Knob Hill mine was the largest epithermal gold mine in Washington. Lasmanis (1996) provided a review of the history and geology of the district. The district was staked in February 1896 as soon as the Colville Indians were evicted from the northern half of their reservation. Mining began at Knob Hill in 1910 and was continuous from 1937 to 1995. About 2.5 million ounces of gold and three times as much silver were produced from selenide minerals. Evaluation continues of the nearby Golden Eagle deposit, from which the gold is difficult to extract. Tschauder (1989) and Fifarek and others (1996) described the geology of the mine.

11.0 (2.0) Turn right on Swamp Creek Road.

12.0 (1.0) Junction of Swamp Creek and Baraett Creek Road

STOP 3-9: BACON CREEK FAULT

Stop 3-9 is on the North Fork of Granite Creek northwest of 3-3 on Figure 21. The Bacon Creek fault bounds the southeastern side of the northeastern arm of the Okanogan MCC. It separates the Klondike Mountain Formation (lowest or Tom Thumb Tuff Member) on the southeast side of the Barrett Creek Road from the granitic rocks of the MCC on the northwestern side of Swamp Creek Road.

Look at the limonitically weathered rocks on the northwest side of Swamp Creek Road. The limonite reveals the former presence of pyrite. The lack of mafic minerals and former presence of pyrite indicate that the rock was hydrothermally altered, presumably by fluids that followed the fault.

Scramble uphill to the base of the first big slab of bedrock. Note that chlorite fills anastomosing fractures and the rock has a pronounced set of closely spaced joints. Locally, this rock deserves to be called chlorite breccia. Identify the former mafic mineral(s).

Continue uphill along the left (south) side of the slabby bedrock. Traverse onto the slabs as curiosity and safety demand. At the crest of the hill, continue northwestward until in unaltered (non-chloritic) rock. Note that the unaltered and chloritic rocks are not mylonitic. This is common on the steeper limbs of MCCs in this region.

Return to the crest of the ridge to the scenic viewpoint about 20 m northeast of the uphill traverse. Look below to the Klondike Mountain Formation on the southeastern side of the Barrett Creek Road and estimate the minimum and maximum possible dips of the Bacon Creek fault.

Using the minimum possible dip, estimate the minimum possible thickness of the chloritic breccia (perpendicular to the dip of the fault).

Remembering the evidence for hydrothermal pyrite at the base hill, note that the Knob Hill gold mine is 3 km to the south (in the swale). Note that the mine occurs in the hanging wall of the Bacon Creek fault.

The second largest epithermal gold mine in the Sanpoil syncline, K2 west of Curlew, occurs in a similar structural position. The deposit is in a fault system that cuts Sanpoil Volcanics about 1/2 km east of the Bacon Creek fault. K2 was discovered in 1993 by Echo Bay by drilling after finding anomalous gold in a stream sediment; mining began in 1995. K2 currently produces about 8000 tons of ore per week at about 0.15 ounces per ton (opt) with a cut-off grade of 0.12 opt. The ore is trucked to the Overlook mill.

Look eastward across the valley (mostly below 1100 m) to the Kettle Crest (locally higher than 2100 m) in the distance. The Kettle Crest is in the Kettle MCC. The high-angle Sherman fault west of the crest is the eastern bounding fault of the Republic "graben," but segments of the Lambert Creek detachment fault of Optional Stop 3B occur west of the Sherman fault; so, the "graben" is floored by one or more detachment faults (Figs. 9, 10, and 20).

Return to the cars and prepare to go. *Reset odometer.*

0.0 (0.0) Intersection of Barrel Creek and Swamp Creek roads; go south on Swamp Creek Road.

1.2 (1.2) Fork in road. Keep right on Swamp Creek Road and continue down the main valley (the trace of the Bacon Creek fault)

3.7 (2.5) Turn right (west) off Swamp Creek Road towards golf course.

3.9 (0.2) Old road and caved adit on right (northeast). Walk up road to portal of mine. The mine is west of 3-3 on Figure 21.

STOP 3-10: MATT ORMSBY'S GOLD MINE

Matt, an octogenerian, was working this mine in the 1980s. Presumably this "sooty" phyllitic rock with quartz stringers and phacoids of marble and chert (?) is Quesnellian. The shallow dipping fabric implies that the Bacon Creek fault (slightly below these rocks) dips about 20° easterly.

.

Return to cars and to Swamp Creek Road.

4.1 (0.2) At junction with Swamp Creek Road turn right (south) toward SR 20.

4.8 (0.7) At junction with SR 20 turn left (east) toward Republic.

6.7 (1.9) This long road cut is Stop 4-1

.

7.0 (0.3) Blinking traffic light in downtown Republic.

END OF DAY THREE

DAY FOUR REPUBLIC TO OMAK

In addition to aspects of Challis stratigraphy, Day Four inspects rocks associated with (1) the bounding faults of the Okanogan MCC, (2) the Chesaw fault in the Oroville area, and possibly (3) the Dunn Mountain fault (southwestern metamorphic belt). Again, the 1:250,000 map of Stoffel et al. (1991) is a useful compendium of the regional geology. Permission and a key must be obtained from Mr. "Buck" Heaberle (509) 826-1137 to visit Stop 4-10.

This is an ambitious itinerary, requiring an early start. The following omissions might be contemplated:

(1) Omit 4-5 in favor of 3-4; proceed directly from 4-4 to 4-6,

(2) Limiting 4-6 to the metadiorite on the isthmus,

(3) Omit 4-9 in favor of 3-9; proceed from 4-11 to 4-13 or Omak (end of Day Four), and

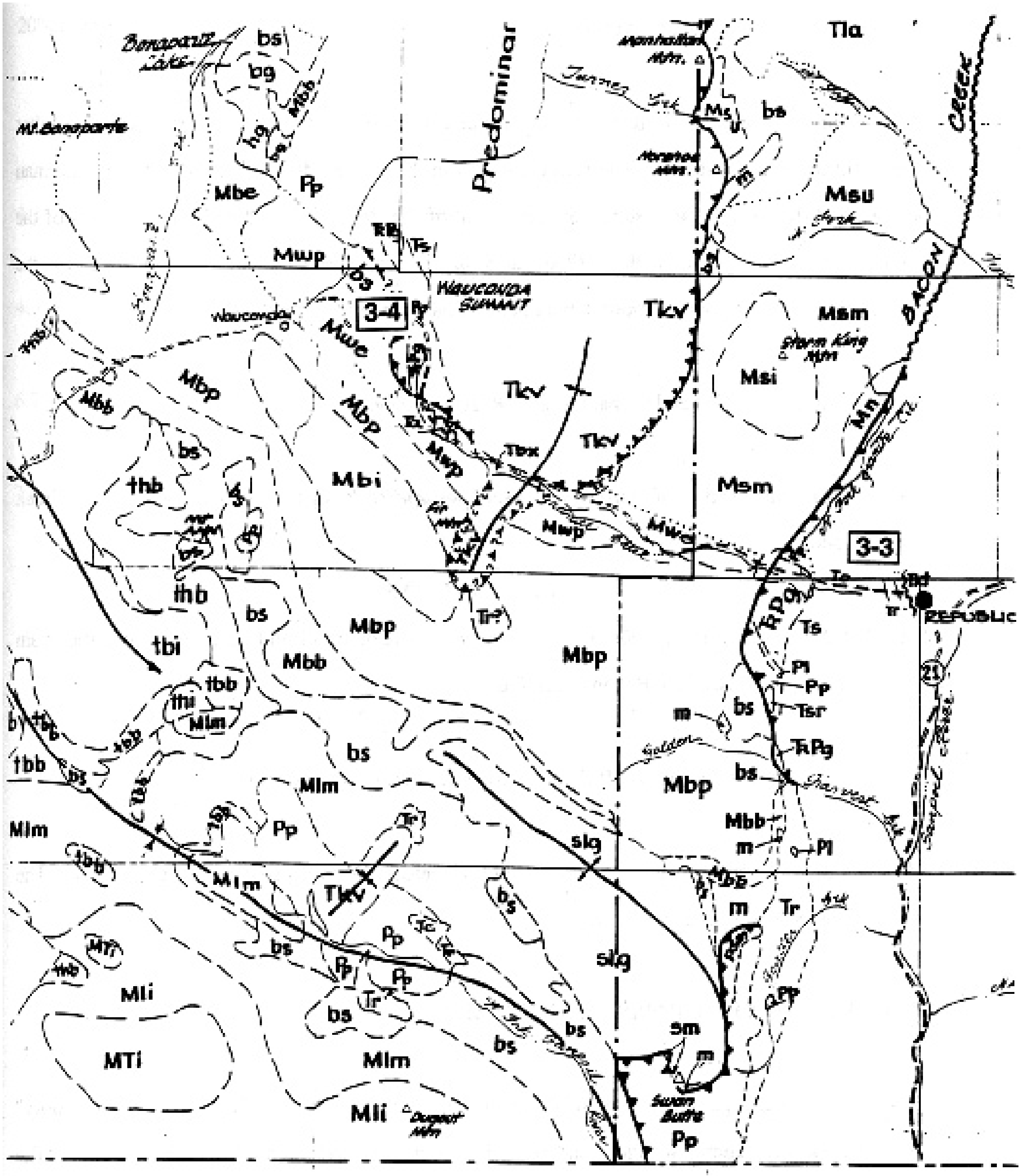

Figure 21. GEOLOGIC MAP OF THE OKANOGAN METAMORPHIC CORE COMPLEX IN THE VICINITY OF SR 20
Redrafted from Orr and Cheney (1987, fig. 2). Note that in this figure detachment faults are shown by the sawtoothed symbol usually used for thrust faults. Figure 19 is the explanation for this figure. Stop 3-3 on the map is Stop 4-1 of the text, and 3-4 on the map is 4-2 of the text.

(4) Omit 4-11 in favor of 4-9 and 4-10 (but then the tectonic relationships of 4-10 are missed). Proceed directly from 4-8 to 4-9.

0.0 (0.0) Reset odometer at the blinking light in Republic. In the municipal park one block to the northwest is a meter-scale “golden” cube commemorating the cummulative production of 2,000,000 ounces of gold from the Knob Hill mine from 1938 to 1989. The mine closed in 1994 after producing about 2.5 million ounces. On the west side of the park is the Stonerose Museum, which, among other things, displays fossils from the Tom Thumb Tuff Member of the Klondike Mountain Formation.

0.3 (0.3) Long road cut at Eureka Gulch.

STOP 4-1: KLONDIKE MOUNTAIN FORMATION, O’BRIEN CREEK FORMATION, AND SCATTER CREEK RHYODACITE

This is stop 3-3 on Fig. 21. Walk westward along SR 20 for about half a mile to the other side of the valley. Vehicles will pick us up on the far side. The basal part of the Tom Thumb Tuff Member of the Klondike Mountain Formation crop out east of the creek; note that it contains large angular blocks. The argillitic alteration of the Klondike Mountain and O’Brien Creek formations is due to weathering of the disseminated pyrite.

At the west end of the traverse, the O’Brien Creek Formation, which has characteristic black phyllite chips, is intruded by dikes of Scatter Creek rhyodacite. Pervasive diagenetic laumontite makes the volcaniclastic rocks of the O’Brien Creek (and correlative rocks) typically white. The dikes have feldspar and hornblende phenocrysts (greater than 1 cm), which are characteristic of the Scatter Creek. Both the O’Brien Creek and the Scatter Creek are faulted, pyritic, and somewhat altered. (Note the evidence of a former mine.)
.
The juxtaposition of the Klondike Mountain Formation against the O’Brien Creek Formation without any interbedded Sanpoil Volcanics implies that the creek is the trace of a fault. This fault was named the Republic fault by Muessig (1967), who described additional evidence for it.

Continue west on SR 20.

2.5 (2.2) The Swamp Creek Valley to the north marks the trace of the Bacon Creek fault, the eastern bounding fault on the northeastern arm of the Okanogan MCC (Figs. 21 and Stop 3-9). The outcrops for the next 5 miles are in hornblende-bearing granitic rocks, which are minor rock types within the slightly foliated, biotitic, quartz dioritic to quartz monzonitic plutons of the “Colville batholith.”

8.5 (6.0) Sweat Creek Campground: Possible rest stop. On the hill northeast of the campground are columnarly jointed, glassy, black flow rocks typical of the upper portion of the Klondike Mountain Formation (minimum age 41 Ma).

9.0 (0.5) On the south side of SR 20 is an unsorted, unstratified rock (diamictite), the clasts are predominantly hornblende-bearing granitic rock, but westward the number of non-granitic clasts, especially amphibolite, increase. One block of amphibolite is about 2 m long. On the north side of the valley 0.6 miles to the west, the diamictite contains a sandy lens 7 m long and 0.3 m thick with 5 to 8 cm layering. There, the diamictite is overlain by the glassy flow rocks of the Klondike Mountain Formation.

. 9.7 (0.7) Medium-grained hornblende-bearing granitic rock is cut by breccia dikelets and hair-line fractures. At the west end of the southern side of the road cut, an unbrecciated porphyritic dike cuts the brecciated granitic rocks.
.
Conceivably, brecciated but unaltered rocks such as these could occur where a detachment fault intersected the paleosurface (i.e. “daylighted”). However, an alternative interpretation is that rocks are part of a rock-avalanche deposit similar to those described by Malte (1995) in the middle Klondike Mountain Formation about 30 km on strike to the north. The fact that these outcrops appear to be entirely surrounded on the valley walls by Tertiary rocks supports the second hypothesis.

10.7 (1.0) A small porphyritic intrusion (or lava dome) of unknown age with spectacular flow banding is in a quarry on the left (south). Non-flow banded portions with columnar jointing parallel the flow banding.

11.0 (0.3) The road traverses amphibolite facies rock of the Okanogan MCC for the next mile.

13.4 (2.4) Wauconda Pass. The road traverses greenstones for the next 1/2 mile and then passes through gray phyllites. These rocks are outside of (or above) the MCC (Fig. 21).

13.7 (0.3) Stop on wide shoulder of the road.

STOP 4-2: MYERS CREEK DETACHMENT FAULT

This is stop 3-4 on Figure 21. Examine the presumed Attwood phyllite and fine-grained quartzite near the driveway and then walk westward down SR 20. Do not cross the fence. .

North of the fence approximately 100 m west of the quartzite, is fine-grained limestone typical of Attwood rocks. About 130 m west of the limestone, weakly lineated and variably retrograded amphibolite occurs at the fence line; another 20 m to the west are outcrops of garnet-staurolite, two-mica schist. Speculate on the nature and orientation of the contact between the rocks of different metamorphic grades.

Continue westward on State Route 20.

17.0 (3.3) Wauconda P. O., store, and restaurant. The highest mountain to the north is Mount Bonaparte (7257 feet). It is part of the Challis-aged Mount Bonaparte pluton of the Keller Butte suite of Holder and Holder (1988). This batholith is tabular, easterly dipping and concentrically zoned. Constituent plutons on the eastern margin of the Okanogan MCC (Figs. 3, 19 and 21) are Storm King, Mount Bonaparte, and Lyman Creek.

23.5 (6.5) The road curves through a narrow gully at about mile 279.4. The rocks are the migmatitic and pegmatitic basal zone of the Mount Bonaparte batholith. Rocks west of here are westerly dipping Tonasket gneiss. Although layered, the Tonasket gneiss was a concentrically zoned pluton; it has amphibolitic borders, gneissic dioritic margins, and a gneissic quartz dioritic interior (Figs. 19 and 21). Within this former pluton, hornblende, biotite, and the color index decrease inward.

28.1 (4.6) Aeneas Valley road is on the left (south). From here westward to Tonasket, the Tonasket gneiss has a regional westerly dip. However, reversals in the dip of the foliation, such as the obvious one 3 miles to the west, outline northwesterly striking folds that are parallel to the northwesterly lineations in the gneiss. Presumably, movement of the Okanogan detachment fault (ODF), which bounds the MCC on the west, was parallel to these structures (imagine two corrugated sheets moving along each other), rather than westward down the dip of the fault (across the corrugations).

41.3 (13.2) Upon entering Tonasket, turn left (south) on Tonasket Avenue (one block east of the junction of SR 20 with US 97). Proceed south one block to Seventh Street, turn left (east) and continue to the end of Mill Drive.

41.8 (0.5) At the end of Mill Drive, ask permission to walk 0.15 mile eastward to the stream

STOP 4-3: ULTRAMYLONITIC TONASKET GNEISS
This is stop 3-5 of Figure 8.
Note the "cherry interlayers" (spectacular ultra-mylonites) within the Tonasket gneiss. They and the gneiss are cut by chloride fractures. This is the mylonitic part of the Okanogan detachment fault on the west side of the Okanogan MCC (OF on Fig. 3). Presumably, chloride breccia occurs to the west under cover. Note that lineations and ultramylonitic zones strike approximately N 290° and remember the corrugated sheet model for movement on the ODF.

Return to US 97 via 7th Street.

42.3 (0.5) US 97 turn right (north) to Oroville. Note Whitestone Mountain west of the highway north of town. The white stone of the lower 3/4 of the mountain is identical to the O'Brien Creek formation of the Republic area. The brown upper part is identical to the Sanpoil Volcanics.

60.5 (17.8) In Oroville at the B-P station turn left (west) on Central Avenue (marked by signs for Nighthawk and Golf Course).

62.9 (2.4) Entrance to Oroville Golf Course. Vehicles will turn around 1/4 mile to the northwest and wait for us.

STOP 4-4: QUESNELLIAN LITHOLOGIES AND STRUCTURE

This is stop 3-6 on Figure 8.

Using Figure 22, walk 0.6 miles northwest along the road and then along the ridge northeast of it. Observe various Quesnellian lithologies (phyllitic greenstone, slatey argillite, phyllitic felsic rocks, folded marble, unweathered gray listanite (carbonated ultramafic rock) in road cuts, and weathered (orange) and well folded listwanite on the ridge.

By comparison with the Quesnellian rocks seen on Day Two, the pelitic phyllite, felsic phyllite, and limestone are parts of the Attwood Group in the footwall of the Chesaw thrust. The felsic phyllite represents the under-appreciated (and poorly mapped) felsic volcanic (volcanic, volcaniclastic, or tuffaceous) rocks in the Attwood; look for quartz eyes.

The listwanites have a number of interesting features. Note the distinctive green fuchsite, (unweathered rock might otherwise be difficult to identify). Locally coarse-grained listwanite that is cut by fractures weathers into distinctive "elephant hide." The intricate folding of the listwanites is accentuated in weathered (orange) outcrops. Note that orange lichens prefer to grow on this orange rock. Look for down dip lineations in the orange listwanite between the road and the ridge. In adits along the crest of the ridge note that fibers in some quartz veinlets are perpendicular to foliation. If the sun is sufficiently hot, speculate why the former prospectors were excited.

On the southeast side of the ridge, phyllitic felsic rocks and cm-scale intercalated limestones are as intricately folded as listwanite. Judging from an adit on the southeast side of the ridge, former prospectors mistook well folded felsic rocks for listwanite (note the absence of both orange weathering and fuchsite).

Fox and Rinehart (1968) mapped this area before the discovery of the Chesaw thrust. The trace of the antiformally folded thrust can be approximated by "connecting-up the dots" of listwanite on their map (Figure 22).

Return to Oroville.

65.5 (2.6) Intersection of Nighthawk road (Central Avenue) and US 97, turn right (south).

65.8 (0.3) Turn right (west) to Lake Wannacut.

66.1 (0.3) Bridge over Similkameen River.

66.8 (0.7) Turn right at Golden Road to Wannacut

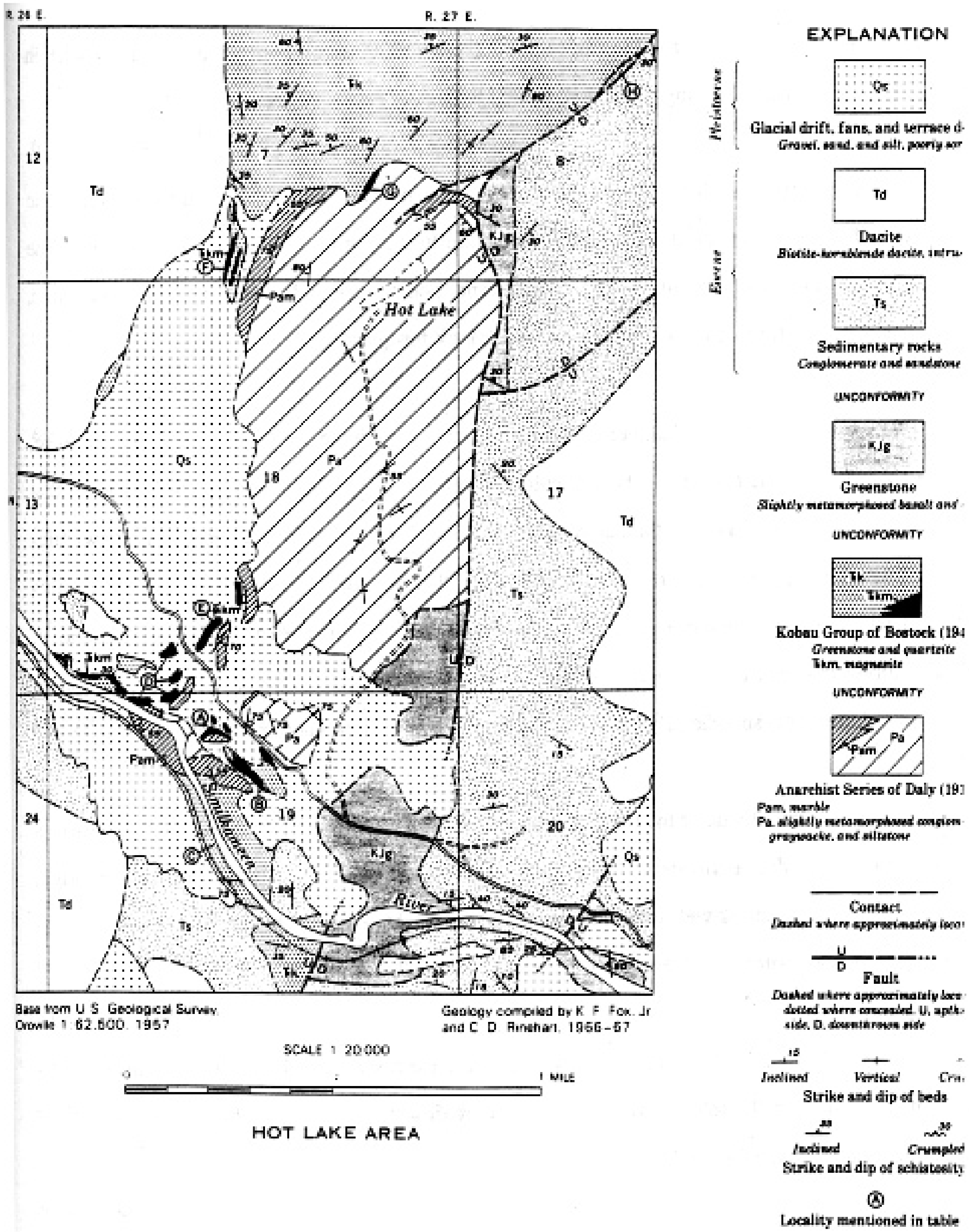

Figure 22. GEOLOGIC MAP OF THE OROVILLE GOLF COURSE AREA

Copied from part of Fox and Rinehart (1968, plate 1). Neither this map nor Fox's slightly revised version (1970) of it depicts the Chesaw fault. Units are: Qs, undifferentiated Quaternary; Td, Tertiary dacite; Ts, Tertiary sedimentary rocks; KJm, Ellemeham greenstone; Trk, Kobau greenstone; Trm, magnesite; Pa, Anarchist conglomerate, graywacke, and siltstone; Pam, Anarchist marble.

Lake.

66.9 (0.1) Stay left at fork in road.

68.6 (1.7) Turn right on Blue Lake Road to Wannacut Lake.

71.2 (2.6) Road to Blue Lake boat launch.

STOP 4-5: SHEARED ELLEMEHAM FORMATION (ROSSLAND GROUP)

This is part of stop 3-7 of Figure 8.
This is the hangingwall of the Chesaw fault (Fig. 23). Walk eastward from the road to the Blue Lake boat launch. Excellent examples of coarse volcaniclastic Ellemeham Formation occur along the southwest shore of Blue Lake.

72.0 (0.8) Isthmus on northeast end of Wannacut Lake on left (south).

STOP 4-6: CHESAW THRUST

This is part of stop 3-7 of Figure 8.
Make a 1.0 mile (round trip) traverse along the northeast end of Wannacut Lake to see the lithologies of Figure 16. Alternatively, if time is short, the most instructive aspect of this traverse is to see that metadiorite in the thrust zone becomes green phyllitic slate (mmp of Figure 23). This is well shown on the knob in the isthmus.

Note the unusual thrust relationship shown in Figure 23: from Blue Lake to Wannacut Lake, younger rocks of the Rossland Group (Jurassic) appear to be thrust over older Attwood Group. This unusual circumstance is explained by the EUemeham or Rossland lying unconformably upon the Knob Hill Group in the upper plate of the Chesaw thrust in the northwest corner of Figure 23. Thus, regionally, Knob Hill rocks, which happen to be unconformably overlain by Rossland, are thrust over Attwood.

From Stop 4-6 continue westward.

72.8 (0.8) Turn left (south) on Wannacut Lake Road and drive along the west side of the lake. The southeast side of the lake is underlain by the light weathering Whiskey Mountain pluton (Fig. 23).

75.6 (2.8) Road to left (east) is to Sun Cove Resort. Continue south and proceed downhill

78.6 (3.1) At a gravel pit on the right is a scenic view. The valley to the south (which contains Spectacle Lake on the west and Whitestone Lake on the east) was the pre-glacial course of the Smilkameen River. Because this valley was blocked by outwash, the river cut the gorge west of Oroville (in the vicinity of Stop 4-4).
On Whitestone Mountain to the southeast, brown Sanpoil-like volcanic rocks overlie white O'Brien Creek-like rocks. Note how structurally low these rocks are compared to the Okanogan MCC on the east (and compare with the Sanpoil syncline). The quarry on Cayuse Mountain to the southwest produces Attwood limestone for agricultural purposes.

79.6 (0.9) At the junction of the Wannacut Lake road with the paved Loomis-Oroville Road turn left (east) toward Tonasket. Ultimately, this road crosses the Okanogan River at Tonasket

90.1 (10.5) Tonasket. Reset odometer at junction with UW 97.

0.0 (0.0) In Tonasket, turn south on US 97 (toward Omak).

2.0 (2.0) Tonasket gneiss with faulted "cherry" ultramylonite and chloritic fractures.

(2.3) Bridge over the Okanogan River at Janis. The stockpile of white rock east of US 97 is high-calcium marble from the Okanogan MCC north of Wauconda. The major use of this rock is for coatings on high quality (very white) paper (Bleeck and others, 1993). In contrast, Quesnellian marbles have too much MgO to be used in paper or cement.

US 97 crosses the Okanogan River and follows Wagon Road Coulee (along the trace of the Okanogan detachment fault). However, the Okanogan River forsakes the fault and swings southeastward into the Okanogan MCC. The river emerges from the MCC at Riverside (Stop 4-8). As we proceed southward down Wagon Road Coulee to Stop 4-7, note the large kettles. South of 4-7 are large outwash terraces.

8.8 (4.5) Deep kettle on right (west) is the site of Crumbacher Lake.

12.1 (3.3) Power line crosses US 97.

13.1 (1.1) Pull out on west side of US 97.

STOP 4-7: RECUMBENT FOLD IN CAVE MOUNTAIN FORMATION

This is stop 4-1 of Figure 8.
A recumbent fold occurs in the cliff on the west side of the coulee. The strata are mostly carbonates of the Triassic Cave Mountain Formation and most likely correlate with the Brooklyn Formation. At Optional Stop 4B serpentinite underlies the Cave Mountain Formation and marks the Chesaw Fault (Fig. 24). At Stop 4-7, US 97 follows the trace of the Okanogan detachment fault, which must floor the Cave Mountain Formation and, hence, the Chesaw fault. Presumably, the recumbent fold in the carbonate rocks of the Cave Mountain Formation predates the Okanogan MCC.

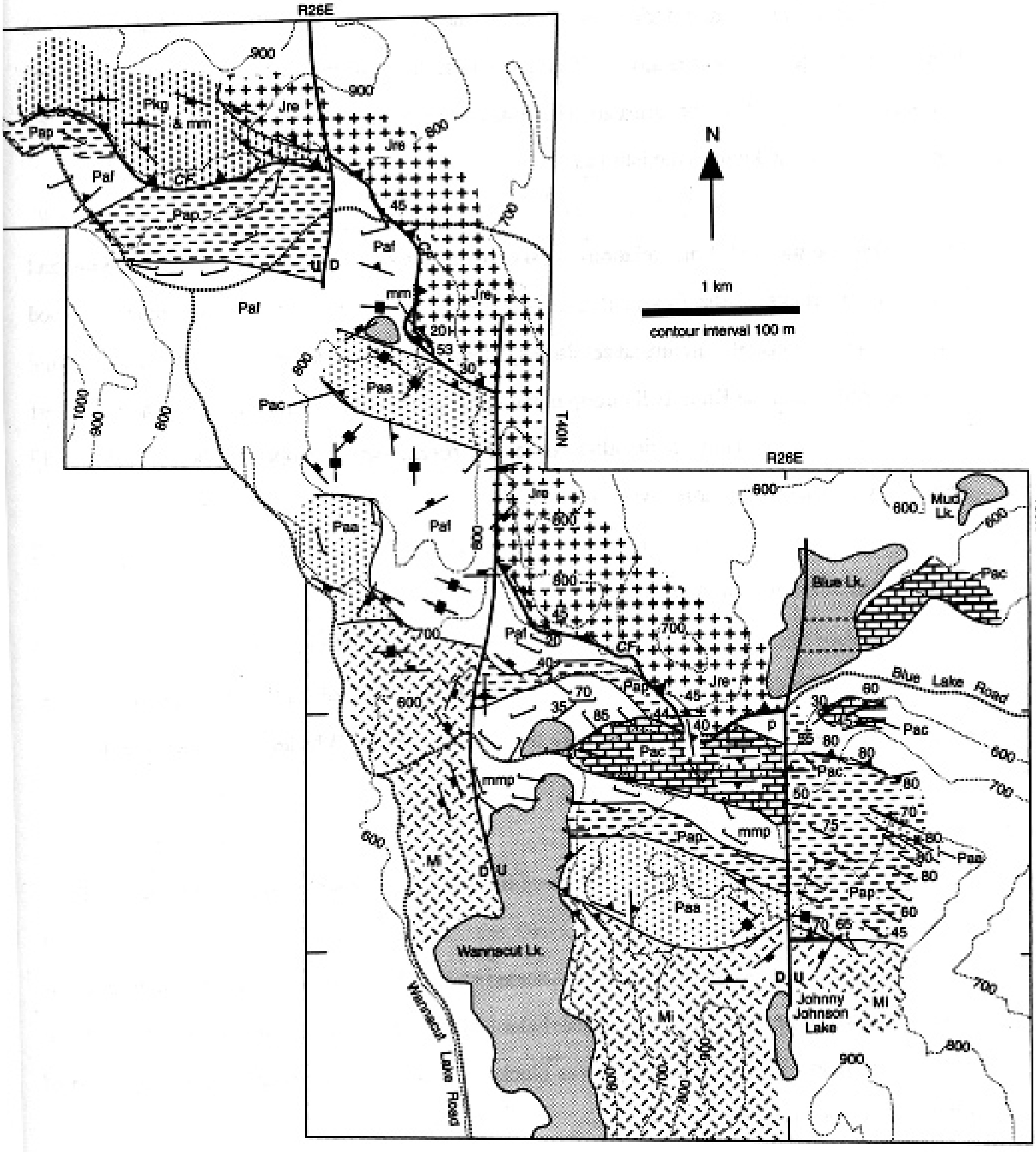

Figure 23. GEOLOGIC MAP OF THE CHESAW FAULT AT WANNACUT LAKE

Geology by E. S. Cheney, 1992, 1993. Units which do not appear in the Explanation to Figure 3 are: Mm, mafic pluton; Mmp, phyllitic mafic pluton; Pag, greywacke of the Attwood Formation; and p, pegmatite and aplite.

16.2 (3.0) On the south side of Riverside, pull off on right (west) toward Conconully at junction of Johnson road.

STOP 4-8: MYLONITIC HOGBACKS OF OKANOGAN MCC

This is stop 4.2 of Figure 8.

The mylonitic hogbacks of the western limb of the Okanogan MCC are especially well developed (photogenic) where the Okanogan River emerges from the MCC.

For Optional Stop 4A and 4B, reset odometer and continue west on Johnson Road toward Conconully. If stops 4A and 4B have been eliminated, this road log continues on p. 76.

3.3 (3.3) Turn right (west) toward Conconully

5.6 (2.3) At the junction with Limebelt Road turn right (north).

STOP 4A: PORPHYRITIC PHASE OF EVANS LAKE PLUTON

This is stop 4-3 of Figure 8.

This is the Leader Mountain gneiss, one of the most distinctive rocks of the southwestern metamorphic belt (Mom of Fig. 8). Previous mappers considered it to be the porphyritic phase of the Evans Lake pluton (pluton E on Figure 8), but several bodies of this lithology occur in the southwestern metamorphic belt. Note the characteristic hornblende and the K-spar megacrysts. Hornblende is less abundant than biotite. The hornblende is ferrohastingsite, which has a distinctive green pleochroism that most petrographers find noteworthy. Compare the foliation here with that at Optional Stop 4B and/or Stop 4-11.

Turn around and head southeast toward Riverside and Omak.

7.5 (1.9) Stop at Haeberle Ranch house on right to submit release forms for Stop 4B.

The ultramafic rocks of the Haeberle ranch have been prospected for nickel sulfides, talc and chromite. In 1993, Mr. Haeberle still reminisced about Prof. Peter Misch of UW who taught the UW field camp here four decades before. The UW field camp was also held here in the early 1980s.

7.8 (0.3) Turn left (northeast) on dirt road to Optional Stop 4B. Sign on gate: "NSA Camp." Walk or drive. The traverse is rough (but not tough). If driving, do not record mileage. Beware of rattlesnakes on the traverse.

STOP 4B: CHESAW AND DUNN MOUNTAIN FAULTS

Figures 8 and 24 show the Cave Mountain limestone in contact with serpentinite (Chesaw thrust). Additionally, the Dunn Mountain fault is marked by the amphibolite facies Leader Mountain gneiss (a.k.a. the porphyritic phase of the Evans Lake pluton) overlying non-contact metamorphosed Cave Mountain limestone and serpentinite.

At this stop, climb through the serpentinite to the adit in limestone in NE Section 5 then traverse to the section corner and then walk northwestward along the Dunn Mountain fault in section 32.

Although the limestone/serpentinite contact is inferred to be the Chesaw thrust, Figure 8 shows that the younger Cave Mountain (Jre and Trb) is thrust over older Attwood Group (Pap). Possible explanations are (1) Pap is not Attwood but Rossland, or (2) regionally the Cave Mountain rests unconformably on Knob Hill (see Figure 23 of Wannacut Lake).

Mineral exploration of the Haeberde Ranch (Prescott, 1996) confirmed the relations shown in Figure 24. In 1973 Exxon drilled 2 holes in the serpentinite west of Johnson Creek to total depths of 400 feet in SW/4 NE/4 Sec. 6 and 1194 feet near the center of SW/4 Sec. 5. The best results of these holes were 0.17 to 0.18% sulfide nickel (total nickel 0.24 to 0.20%) with 120 ppm Co and 20 ppm Cu. Presumably sulfidization of the serpentinite was caused by the Pouge Mountain quartz monzonite. In 1996 Echo Bay Exploration, Inc. drilled a gold anomally in the SW/4 of Sec. 31 west of Johnson Creek. Significantly, a vertical 300 foot hole collared in the Evans Lake pluton entered serpentine at a depth of 200' and bottomed in carbonate rocks. Other drill holes indicated that the serpentinite dipped northwesterly and that a northwesterly dipping serpentinite also occurred with the carbonate rocks.

Return to paved road and continue southeast (left) for Omak.

8.0 (0.2) Fork in road, stay right (straight) for Omak.

12.3 (4.3) Turn left for Omak.

13.3 (1.0) Turn right for Omak.

14.0 (0.7) Turn left for Omak.

White outcrops on north side of road are Tertiary volcaniclastic rocks equivalent to the O'Brien Creek Formation.

14.9 (0.9) Turn right for downtown Omak.

15.3 (0.4) At traffic light in downtown Omak (Central Avenue) turn right.

15.5 (0.2) Proceed one block to the municipal park for rest stop.

Return to traffic light.

15.7 (0.2) Traffic light, stay straight on Central Avenue, which is SR 155.

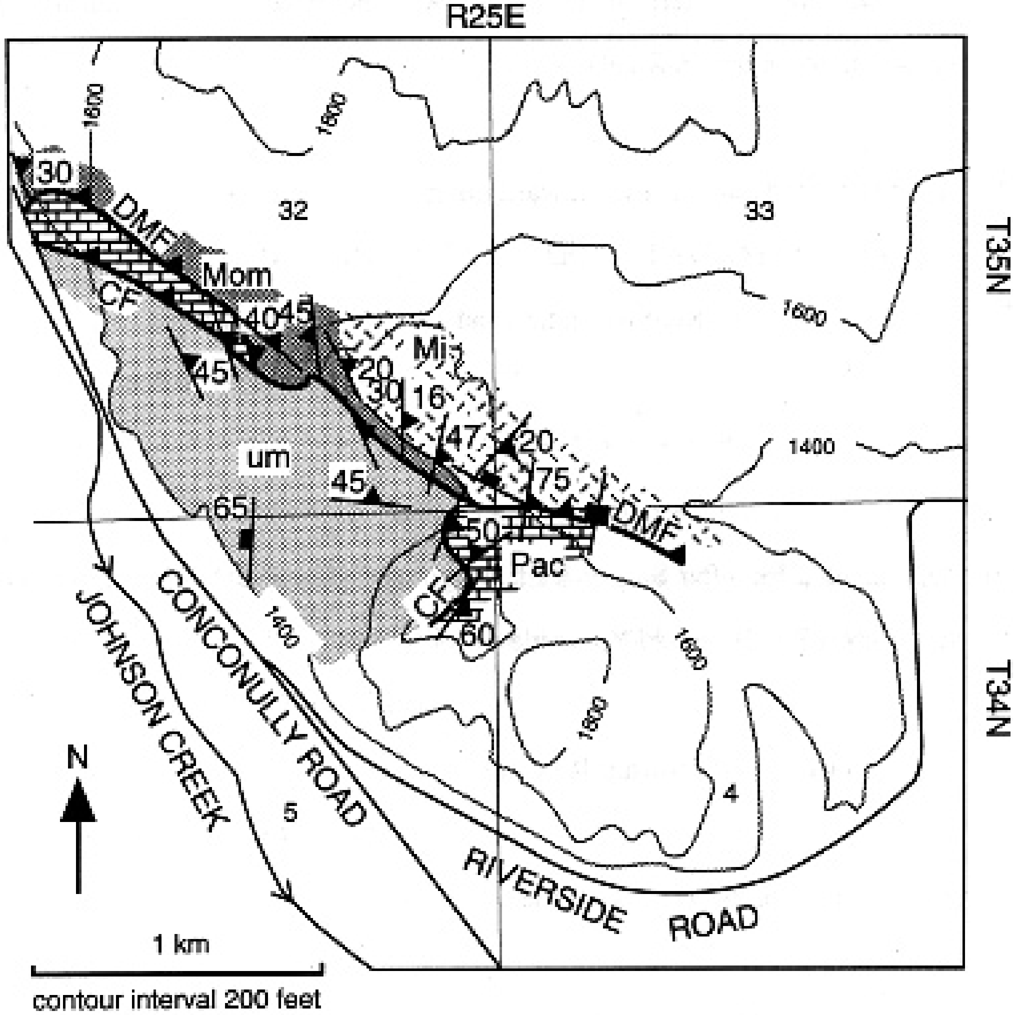

Figure 24. RECONNAISSANCE GEOLOGIC MAP OF THE SOUTHERN SIDE OF THE EVANS LAKE PLUTON Mapping by E. S. Cheney, 1991, 1993. See Explanation to Figure 3.

18.6 (2.9) After driving up the terrace east of the Okanogan River, turn left (north) off SR 155 on dirt road (Omak Mountain Road).

18.9 (0.3) Turn left (west) on dirt road toward quarry.

19. 1 (0.2) Quarry. Stop 4-9. Rejoin regular road log at mile 30.3 (Stop 4-10).

To resume the regular road log after Stop 4-8 (if not going Optional Stops 4A and 4B) turn left (opposite Johnson Road) toward Riverside

16.3 (0.1) Turn left (down hill) toward Riverside.

16.4 (0.4) Turn right to downtown Riverside.
Until the coming of the railroad in 1914, Riverside was the head of navigation for steamships up the Okanogan River from the Columbia River. It was a "jumping-off point" for the Cariboo gold rush in 1859 and 1860.

16.6 (0.2) Downtown Riverside. Turn left on Tunk Valley road toward Keystone.

16.7 (0.1) Bridge over Okanogan River.

16.9 (0.2) At T junction turn right (south) toward Omak.

24.3 (7.4) Turn right on driveway south of greenhouse.

24.6 (0.3) End of driveway. First ask permission, and then walk southwest 200 m along fence line.

STOP 4-9: BRECCIA OF THE OKANOGAN DETACHMENT FAULT

This is stop 4-6 of Figure 8.

Chloritic granitic breccia (aka "junk-rock breccia") marks the outer margin of the Okanogan detachment fault. Such rocks rarely crop out in northeastern Washington. The protolith of 4-9 is 4-10, that is, the breccia is a later cataclastic (and presumably shallow) deformation superimposed on the ductilely deformed (mylonitic) rocks.

Turn around and return to highway.

24.9 (0.3) Turn left (south) on highway.

28.1 (3.2) At T junction with SR 155 turn left (east) toward Nespelem.

29.8 (1.7) After driving up the terrace, turn left (north) off SR 155 on Omak Mtn. Road (dirt road).
‘
30.1 (0.3) Turn left (west) on dirt road to quarry.

30.3 (0.2) Quarry.

STOP 4-10: MYLONITE OF THE OKANOGAN DETACHMENT FAULT

This is stop 4-5 of Figure 8.

The mylonitic carapace of the Okanogan MCC here is 1.0 to 1.5 km thick (Goodge and Hansen, 1994). We will examine the feldspar megacrystic granite for classic mylonitic textures; porphyroclasts (with pull-apart quartz veinlets that do not cut the matrix of the rock), lineations, finer-grained zones, and two foliations (S-C fabrics). S-C fabrics indicate that the sense of displacement on the Okanogan detachment fault is top-to-west. Compare the mineralogy of their porphyritic biotite granodiorite with samples of the Leader Mountain gneiss (Optional Stop 4A and 4-11).

* Return to SR 155.

30.8 (0.5) SR 155, turn right (west) toward Omak.

32.5 (1.7) Turn left (south) just each the lumber mill on Omak Lake Road. Proceed southward over Antoine Pass. The road follows the trace of the Okanogan detachment fault. Good outcrops of chlorite breccia are reported on the southwest side of the valley southeast of Antoine Pass (Goodge and Hansen, 1994). Just past the end of the pavement is a turnoff to the left leading down to the well-used swimming beach at the head of Omak Lake. Continue about a mile past this turnoff.

40.5 (8.0) Last road cut below crest of hill.

STOP 4-11 LEADER MOUNTAIN GNEISS (A.K.A. OMAK LAKE GRANODIORITE OF GOODE AND HANSEN (1994)

Disregard the pink pegmatites and other cross cutting felsic rocks. The host rock is a distinctive lithology of the southwestern metamorphic belt (Mom of Figure 8). Search for the foliation. Compare with samples from stops 4A, 4B and 4-10.

Rocks in the next major road cut 0.1 miles to the southeast are hornblende orthogneisses similar to the Reed Creek orthogneiss of the southwestern metamorphic belt.

Because Omak Lake overlies the ODF (or OLF on Figure 3) the southwestern metamorphic belt is in the hangingwall of the fault.

Tribal police do not permit camping at Omak Lake. Return to Omak for dinner, camping (at Omak Stampede Grounds) or motels.

END OF DAY FOUR

DAY FIVE OMAK TO SEATTLE

The first part of the trip traverses the Columbia River basalts of the Waterville Plateau. A possible goal is to be at Optional Stop 5A in the early or mid-morning sun. Depending on the schedule, the trip can end at Optional Stop 5B (with Seattle about three hours away).

0.0 (0.0) Reset odometer at entrance ramp of SR 155 to US 97 and proceed southward toward Wenatchee.

27.2 (27.2) Turn left (east) on SR 17.

32.8 (5.6) Road on right is to Colville Confederated Tribe Trout Hatchery.

33.0 (0.2) Wide pullout on right along a curve in highway

STOP 5-1: NORTHERN MARGIN OF THE COLUMBIA RIVER PLATEAU

Two significant unconformities occur beneath the CRBG. Apparently a recessive unit occurs between CRBG and the crystalline basement that forms the broad bench below the CRBG. The quarry in buff rock (deeply weathered granitic basement) is below the bench and the recessive unit. The top of the bench is discordant to the overlying CRBG. This recessive unit is arkosic sandstone in the Foster Creek drainage to the south. Although this unit is generally regarded as Miocene (Stoffel et al., 1991), and related to the CRBG, its arkosic nature and discordance to the CRBG suggest that it is one of the Challis arkosic sequences. However, east of Foster Creek along SR 17, the strata beneath the CRBG are much finer grained and tuffaceous-looking; they might be Kittitas.

The Chief Joseph dam (which comes into view in 1.3 miles) is, of course, anchored in the granitic basement.

Continue southward across the Columbia River.

37.5 (4.5) Turn right to Mansfield on Bridgeport Hill Road. From here to US 2 at Farmer and to US 97 at Chelan Fallsis a Winnebago-free zone. Preserve it as such.

39.4 (1.9) Arkosic rocks exposed in West Foster Creek. These routinely are considered part of the Walpapi sequence (Stoffel and others, 1991), but might they be Challis?

41.0 (1.6) For the next mile, note the fine-grained white tuffaceous rock in the valley of West Foster Creek. Such rocks are especially obvious to the east where SR 17 traverses the valley of East Foster Creek. Routinely these strata are considered to be Miocene and associated with the CRBG (Stoffel and others, 1991). An alternative explanation is that they are distal portions of the Oligo-Miocene Kittitas sequence; distal portions of this sequence are widespread but mostly covered by CRBG in eastern Washington and eastern Oregon (Cheney, 1997).

42.9 (1.9) Road ascends into Grande Ronde basalt of the CRBG.

45.4 (2.5) Road "tops out" on the Waterville Plateau. The surface of the Waterville Plateau is dotted by black "haystack rocks," erratics of CRBG deposited by the Okanogan lobe of continental ice. A haystack shape is formed by the apron of talus around the base of the erratics. Some erratics are house-sized.

49.7 (12.2) Junction of B NE with 14 NE (SR 172) turn right (west) on 172 toward Waterville.

54.7 Junction of SR 172 and McNiel Canyon Road to Chelan. Stay left on SR 172.

58.7 (9.0) 10 NE Street (Mile Post 10).

59.7 (1.0) Just over the crest of the hill (at Mile Post 9) is a small pullout on the right at 9 NE Street.

STOP 5-2: 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 between here and Stop 5A. 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. To the west is the Cascade Range dominated by Mount Stuart (9415 feet).

Continue south after Optional Stops 5A and 5B, continuing with this road log. If Optional Stops 5A and 5B are eliminated, reset odometer, turn around and return to McNiel Canyon Road. The road log resumes after Stop 5B.

68.7 (9.0) Turn right (west) on US 2 toward Wenatchee.

78.4 (9.7) Douglas. For a cultural stop, check out the 1915 church north of downtown.

80.2 (1.8) Foreset (deltaic) pillow-palagonite unit in CRBG. Are these rocks overturned?

82.8 (2.6) In downtown Waterville is a right angle turn in US 2 at the intersection of Locust and Chelan; leave US 2 by continuing straight (south) on Chelan, which is signed for the Badger Mountain ski area. The municipal park one block southwest of this intersection has toilets.

85.3 (2.5) Take right fork for E. Wenatchee (Badger Mountain Road).

'

101.4 (16.1) Begin steep descent to East Wenatchee.

105.3 (0.9) Pull off on left adjacent to a grassy knoll.

STOP 5A: OVERVIEW OF THE WENATCHEE AREA

The panorama is dominated by Mission Ridge, Wenatchee, and the Columbia River to the southwest and by Mount Stuart to the west. To the west, the ridge descending to US 2 has a clump of trees, which is Ohme Gardens State Park. Beyond this ridge is the southwesterly striking Entiat fault that intersects the northern tip of Wenatchee Heights (note variable dips in Chumstick strata on Wenatchee Heights). South of Wenatchee Heights is a huge landslide. The main canyon southwest of Wenatchee and northwest of Wenatchee Heights is Squilchuck Canyon. The next canyon to the northwest is the site of the former Cannon gold mine and its tailings dam.

The full width of the Chiwaukum graben is visible between Ohme Gardens (6 miles away) and the base of the Mount Stuart Range (21 miles distant). The graben preserves the following Challis sequences: Swauk Formation at the Cannon mine, Chumstick Formation between Ohme Gardens and Mount Stuart (and unconformably overlain by the CRBG at Mission Ridge), and the Wenatchee Formation southwest of the Cannon mine.

Below the viewpoint the disected plateau is capped by Pleistocene sediments on the Chumstick and Wenatchee formations. The ramp extending from Ohme Gardens northwest up Burch Mountain is the sub- Wenatchee Formation erosion surface.

The most obvious feature at this stop is the eastward dip of the CRBG on Mission Ridge (Fig. 25). The CRBG clearly dips off the Cascade Range. The topography of the range clearly is post-CRBG. This has obvious implications for (1) the former extent of the CRBG (and Walpapi sequence), (2) the concept of an "ancestral" Columbia River (and other rivers), (3) how the CRBG extended as far west as the present Pacific Ocean in Oregon and Washington, (4) the beginning of the current period of subduction along the Cascadia subduction zone, and (5) the apple industry of greater Wenatchee.

110.3 (5.0) Turn left into Fancher Heights development and stay on main road.

110.8 (0.5) Stop at the Pangborn-Herdon Memorial on the left.

STOP 5B: OVERVIEW OF THE WENATCHEE AREA

Details not discernible at 5A can be seen.
Use the street map of East Wenatchee (Fig. 26) to navigate to US 2 (northwest of Optional Stop 5B) and the bridge over the Columbia River. From the bridge, Seattle is about a three-hour

drive.

At Stop 5-2 turn around, reset odometer, and return to McNiel Canyon Road.

5.0 (5.0) Turn left (west) on McNiel Canyon Road.

8.7 (3.7) Take right fork to Chelan.

9.7 (1.1) Begin descent down McNiel Canyon. Note that sedimentary strata overlie basalts.

10.0 (0.2) At hairpin turn note that no sedimentary rocks occur between CRBG and metamorphic rocks and that the CRBG can only be a few tens of meters thick.

11.4 (1.4) Look for pullout for photogenic overview of Lake Chelan and the Columbia Gorge.

17.1 (5.5) T junction with US 97. Turn right toward Chelan Falls.

17.7 (0.6) Junction with SR 150, continue north on US 97

18.7 (1.1) Park on wide shoulder on the right (east) next to large roadcut.

STOP 5-3

This is Stop 1 of Hopson and Mattinson (1994). Figure 27 is a schematic diagram and table from Hopson and Mattinson 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 5-3 and 5-4 are represented by parts of the left-hand (migmatitic) portion of schematic diagram. Hopson and Mattinson 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 27 seem convincing, isotopic and other geochemical supporting evidence has not yet been published.

Hopson and Martinson report that 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. These relations are thought to be consistent with a huge, amphibolite-facies, mushy, ductilely rising (protodiapiric) mass emplaced into mid-crustal rocks.

According to Hopson and Martinson, the relative ages of the rocks on both sides of highway at Stop 5-3 are:

1. metatonalite derived from Triassic Marblemount/ Dumbbell plutons,

2. xenoliths of metagabbro and biotitic hornblendite (remnant cumulates) = 3M (see fig. 27),

3. synplutonic dioritic dikes into anatectic tonalite = 3M or 4M,

3 a. synplutonic mottled mafic dike of comingled dioritic and trondhjemitic melts = 3M or4M,

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. lamphrophyre dikes (5M) associated with the nearby 50- to 45-Ma Cooper Mountain and Duncan Hill plutons

Turn around and return south on US 97 to the junction with SR 150.

19.3 (0.5) Turn right (west) on SR 150.

19.9 (0.6) Hairpin turn.

20.1 (0.2) Stop on right shoulder opposite a very high road cut.

STOP 5-4

This is the classic layered migmatite locality of Chelan Falls and Stop 3 of Hopson and Mattinson (1994). Refer again to Figure 27 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

22.3 (2.2) At junction with SR 150 and US Alt 97 turn left (west) for Chelan.

Reset odometer.

(0.9) (0.9) In downtown Chelan stay on US Alt 97 and turn left for Wenatchee.

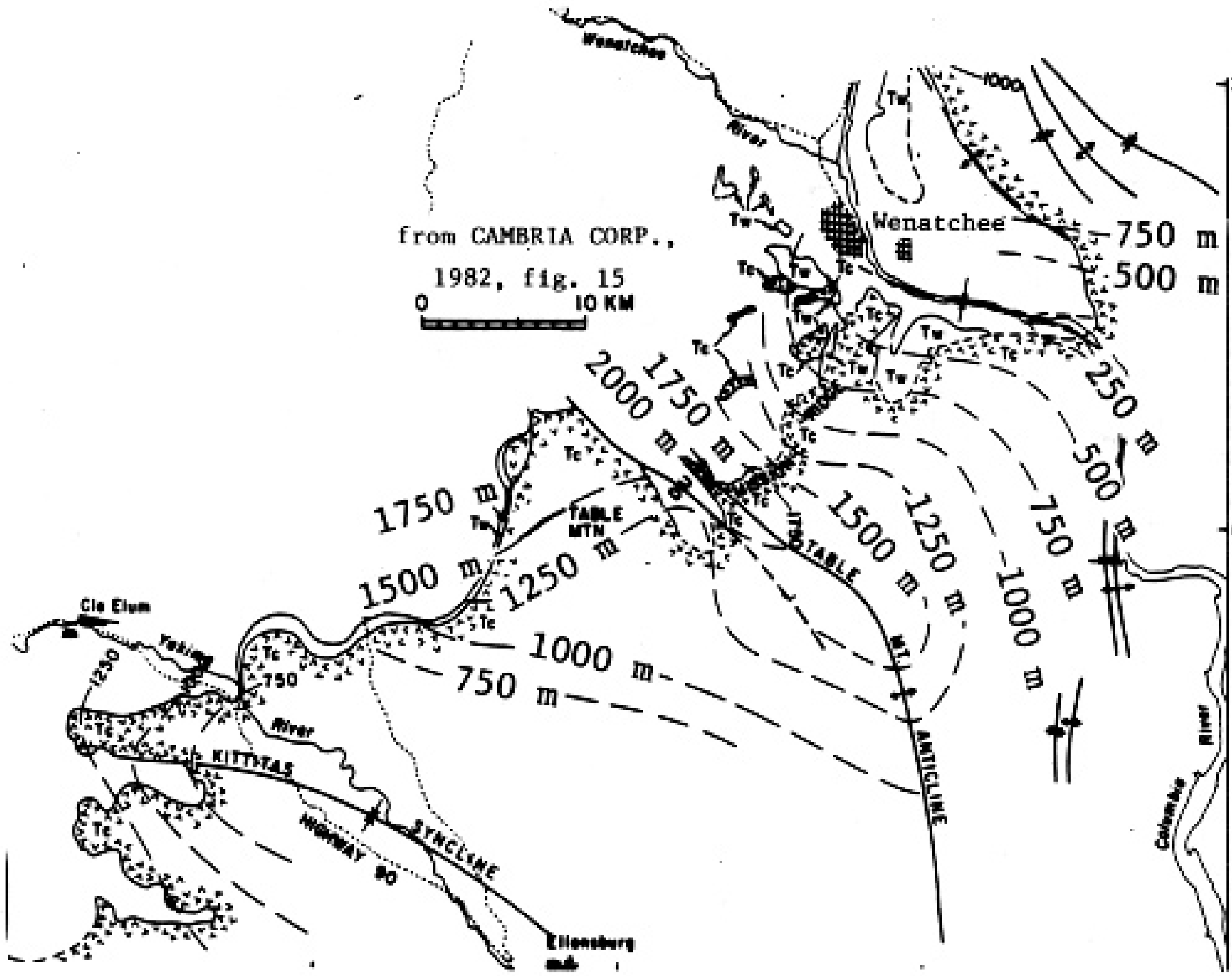

Figure 25. STRUCTURE CONTOURS ON THE BASE OF THE GRANDE RONDE BASALT IN THE WENATCHEE / ELLENSBURG AREA Note the major folds and the regional southeasterly dip.

7.0 (6.1) Begin descent of Knapp Coulee to the Columbia River.

12.1 (5.1) SR 971 (Navarre Coulee Road) on right (west).

16.0 (4.9) At Mile Post 218.5 at Earthquake Point below Ribbon Cliffs park on the right (west) next to the interpretive sign.

STOP 5-5

The sign is remarkably informative.

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

The tonalitic Entiat orthogneiss here is part of the Chelan Mountains terrane and is 85 to 76 Ma. Elsewhere this orthogneiss is intrusive into the Chelan Migmatite Complex (Hopson and Mattinson, 1994).

The origin of the basaltic dikes (the ribbons of Ribbon Cliffs) is unknown. Perhaps they are equivalent to 5M of Hopson and Mattinson (1994). Teanaway basalt occurs south of Swauk Pass in the area around Cle Elum. If the dikes are Teanaway, the original extent of that basalt was much greater than now.

The 1872 earthquake has an interesting 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 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”

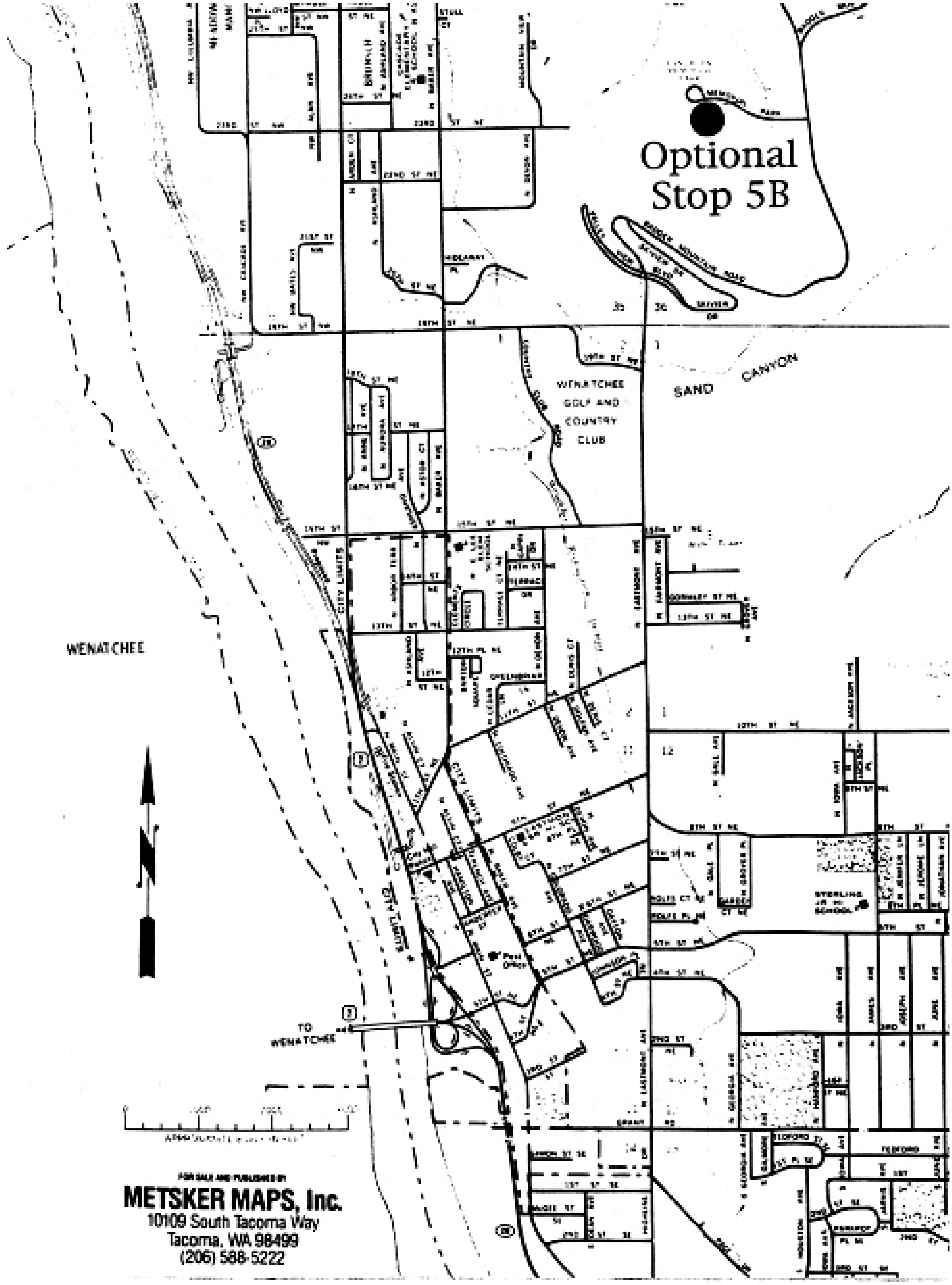

Figure 26. (Above) STREET MAP OF EAST WENATCHEE

Figure 27.(Right) SCHEMATIC REPRESENTATION OF AGE RELATIONS IN THE CHELAN MIGMATITE COMPLEX. From Hopson and Mattinson (1994, figure 5 and table 1).

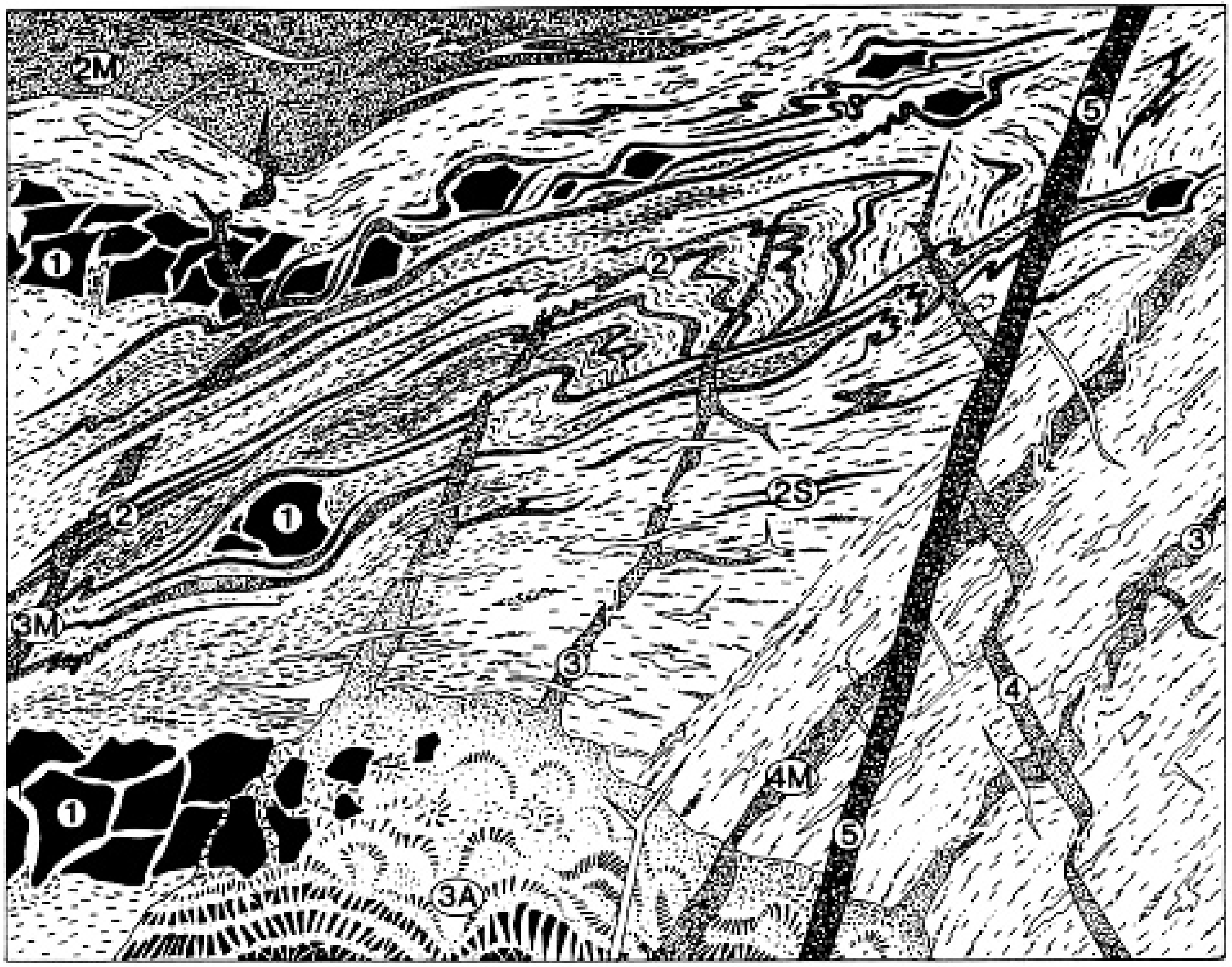

FIGURE 5. Schematic drawing depicting age relationships and structural styles of dark-colored rocks of the Chelan Migmatite Complex. Encircled numbers denote the five main classes and variants of metabasite and basite listed in Table 1. Small white bodies are leucosomes. Left-hand two-thirds of the diagram shows features that typify the migmatite facies of CMC, and the right-hand one-third depicts typical metatonalite facies. The drawing is stylistic and not to scale: i.e., the scale is internally variable with large-scale and small-scale features normalized to similar size.

TABLE 1. Mafic Magma Stages and Corresponding Rocks

STAGE 1	**Agmatite Blocks.** Metaperidotite, metapyroxenite, hornblendite, metagabbro.
STAGE 2	**Layered Migmatite and Concordant Mafic Bodies.** Amphibolite (metagabbro, metadiorite, metatonalite) layers, schlieren.
2M	**Migmatitic Metabasite with intermingled Silicic Rock.** Metagabbro, metadiorite + trondhjemite blebs, marbling, etc.
2S	**Mafic Layers and Schlieren in Metatonalite.** Amphibolite (metagabbro, metadiorite).
STAGE 3	**Early Synplutonic Dikes (disrupted, cut by leucosomes).** Microamphibolite (metagabbro, metadiorite, 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.

that placed the epicenter between Earthquake Point and Hope—east of the crest but sufficiently distant from Hanford. Malone (1977) recognized that the seismic velocities of the crusts of central and western Washington are different; he 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 show that the causative fault had dextral movement. The earthquake was shallow, and ground rupture did occur.

Thus, 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 and 1965),

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

Continue south on US Alt 97.

20.3 (4.3) Bridge over Entiat River.

21.3 (1.0) Park on right (west shoulder.

STOP 5-6

The Entiat orothogneiss here has both minor fault zones that dip northerly and numerous chloride fractures. This locality is less than a kilometer from the boundary between the Chelan Mountains terrane and the Mad River and Swakane terranes to the southwest.

Continue south of US Alt 97.

23.0 (1.7) Biotitic Swakane Gneiss with foliation dipping northerly.

27.3 (4.3) Note that foliation in the Swakane Gneiss is nearly horizontal.

28.5 (1.5) Swakane Gneiss dips southerly.

28.8 (0.3) Turn left (east across highway) to viewpoint above Rocky Reach dam.

STOP 5-7

Examine the Swakane biotite gneiss and boudinaged pegmatite. Continue south on US Alt 97.

34.0 (5.2) Turn right (west) on Ohme Gardens road.

34.7 (0.7) Continue past intersection.

34.9 (0.2) Park on wide shoulder on the left (east).

STOP 5-8

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 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 marks 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 sequence-bounding unconformities. Along the lower one, Wenatchee Formation is nonconformable upon Swakane Gneiss. The Wenatchee Formation apparently consists of two different units. South of Wenatchee it has quartz pebble conglomerates and lignitic shales that have an Eocene flora (Tabor and others, 1982). in contrast, at Blue Grade across the Columbia River, the formation is tuffaceous, has numerous paleosols, and yielded fission-track ages from zircon of 34.5 ± 1.2 and 39.8 ± 9.0 Ma. The younger Blue Grade succession is interpreted (Cheney, 1997) to be the distal portion of Oligocene-middle Miocene volcanic rocks (Kittitas sequence), proximal portions of which are exposed in the southern Cascade Range.

Along the upper unconformity near the skyline flow of MSU unit R2 of the Grande Ronde Basalt of the CRBG of the Walpapi sequence unconformably overlie the Blue Grade portion of the Wenatchee Formation.

The high ridge to the south above the city of Wenatchee is Mission Ridge. It is underlain MSU N2 of the Grande Ronde. Figure 25 shows that this unit rises from 250 m at the Columbia River to over 2000 m 20 km to the west. This eastward dip away from the Cascade Range clearly shows that uplift of the range post-dates the CRBG.
‘

Continue south.

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35.0 (0.1) Turn left.

35.1 (0.1) At the traffic light on US 2 and US 97 are two choices:

1. End the trip here by turning right onto the ramp that leads to US 2. Seattle is about three hours away (depending on the traffic).

2. Extend the trip by proceeding to Optional Stop 5B for a rather spectacular overview of the geology of the Wenatchee area. Option Stop 5B is at Francher Heights, the bluff northeast of the Columbia River. To get there, proceed straight at this traffic light, cross the bridge that conveys US 2 and US 97 over the Columbia River, at the T junction beyond the bridge turn right (south) on SR 28, and use Figure 25, the street map of East Wenatchee, to navigate to and from Fancher Heights.

END OF DAY FIVE

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