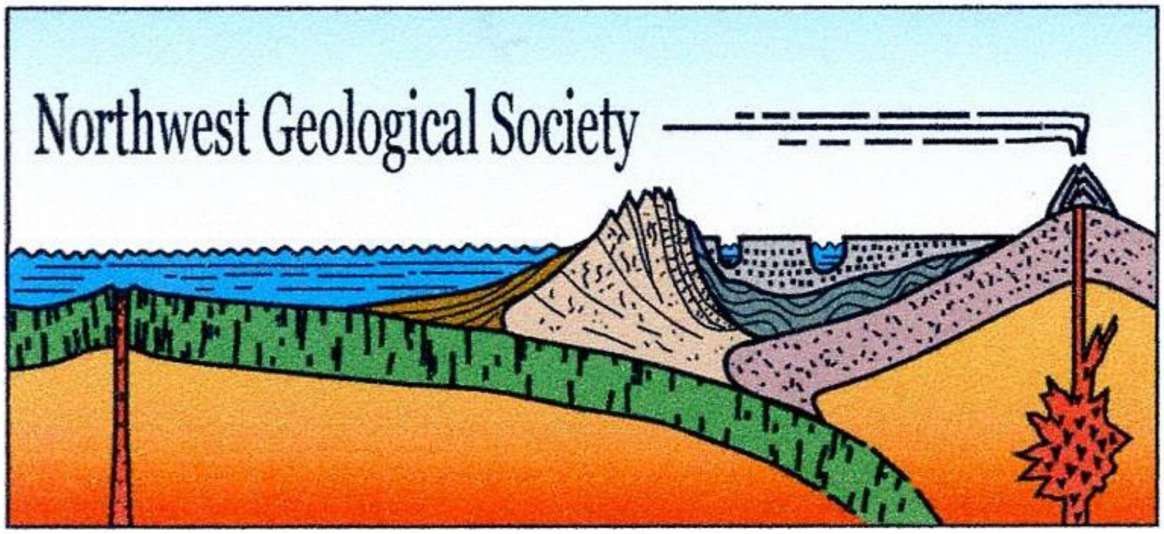

Society Publications in Pacific Northwest Geology

FIELD TRIP GUIDEBOOK #46

GEOLOGY OF THE CONTINENTAL MARGIN OF ANCESTRAL NORTH AMERICA: LAURENTIA IN NORTHEASTERN WASHINGTON

A joint field trip with the Columbia Basin Geological Society

October 4-5, 2014

Eric Cheney, University of Washington
Andy Buddington, Spokane Community College

NWGS FIELD TRIP GUIDEBOOK SERIES

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Field Trip Guidebook #45

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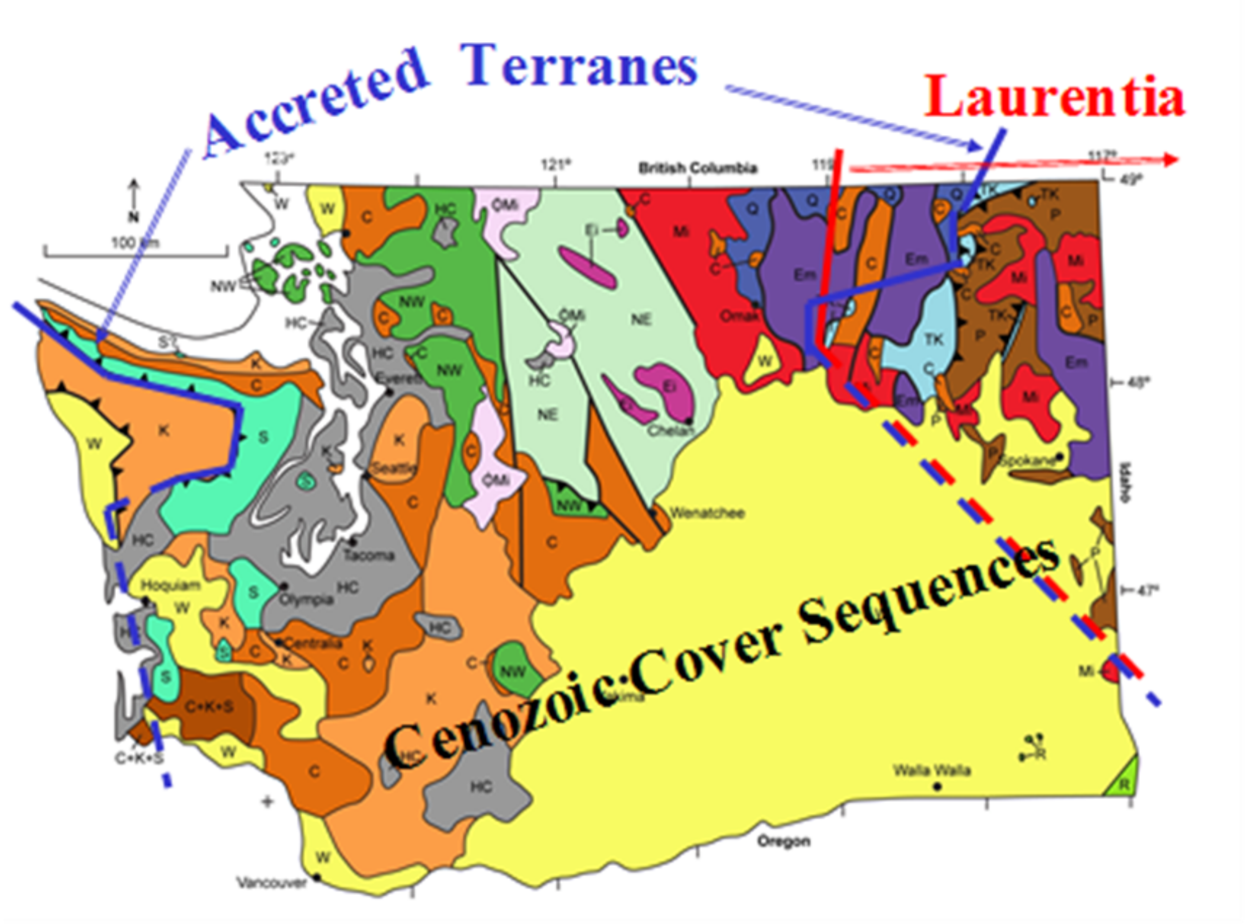

Cover photo: *Geology of Washington showing the extent of Laurentia, accreted terranes and Cenozoic cover sequences.*

TABLE OF CONTENTS

LIST OF FIGURES AND TABLE

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GEOLOGY OF THE CONTINENTAL MARGIN OF ANCESTRAL NORTH AMERICA: LAURENTIA IN NORTHEASTERN WASHINGTON

Eric Cheney, University of Washington
Andy Buddington, Spokane Community College

I. ABSTRACT

Northeastern Washington and adjacent Idaho and British Columbia are part of the western margin of Laurentia, the North American continent prior to the accretion of terranes beginning in the mid-Jurassic. Here, Laurentia is underlain by miogeoclinal and distal Mesoproterozoic to Mississippian strata that are involved in two thrust belts. The Mesoproterozoic to Mississippian formations commonly are over a kilometer thick. Unlike on the craton in Idaho and Montana, Neoproterozoic and lower Cambrian formations exist, but unconformity-bounded sequences in these and other successions are subtle.

The newly recognized Pend Oreille River fold and thrust belt (PORFT) bounds Laurentia on the west and extends from 49.2ºN to 48.1ºN, where it passes unconformably below Miocene basalts. Cheney and Zieg (2015) showed that PORFT consists of several regional, northwesterly verging thrust sheets (nappes). The northeastern part of PORFT is a virtual International Border fault zone; it accounts for the stratigraphic and structural dissimilarities of the Metaline district in WA and the adjacent Salmo district of BC. Northeasterly trending Eocene normal faults offset some of the thrusts across the International Border, which hampered their recognition. The lowest thrust, the Waneta, places Laurentian strata over the Quesnel terrane. Mid-Jurassic insertion of that terrane between the Laurentian cover sequences and their basement presumably caused PORFT.

Southeast of PORFT are well known southeasterly verging thrusts, which are here called the Colville River fold and thrust belt (CRFT). The Lane Mountain thrust is the most extensive thrust in CRFT. In northeastern WA, all Neoproterozoic and early Cambrian strata are in or west of CRFT; stratigraphy characteristic of the craton is east of it. CRFT is a series of back thrusts with respect PORFT. The former rifted margin of North America created space for deposition of the miogeoclinal sequences; later this margin probably was the backstop that caused PORFT and CRFT. The Laurentian rocks are preserved in the structural low between the Eocene Kettle and Priest River metamorphic core complexes.

II. INTRODUCTION

Ancestral North America before the accretion of terranes commencing in the mid-Jurassic is known as Laurentia. This field trip explores the part of the western margin of Laurentia that is in northeastern Washington. Important geologic elements include: (1) the pre-rift Middle Proterozoic Belt Supergroup and correlative Deer Trail Group (Miller and Whipple, 1989), (2) the Late Proterozoic “rift” sequence of the Windermere Supergroup (Miller, 1994), (3) lower to middle Paleozoic shallow water, miogeoclinal (passive margin) strata and deeper water more distal successions (Dutro and Gilmour, 1989), (4) Pennsylvanian to Jurassic marine sedimentary rocks and mafic volcanic rocks of the Quesnel terrane (Cheney et al., 1994), and (5) deformation related to the accretion of the Quesnel terrane to Laurentia (Watkinson and Ellis,1987; Cheney, 2010). Additionally, the Deer Trail Group hosts world-class (but currently uneconomic) magnesite deposits of controversial origin (Campbell and Loofbourow, 1962), and the Windermere Supergroup contains two diamictites that correlate with the global Sturtian (700 Ma) and Marinoan (635 Ma) glaciations of Snowball Earth (Hoffman, 1998; Lund and Cheney, 2015).

The trip emphasizes the importance of synthems. Synthems are unconformity-bounded sequences of inter-regional extent and of tectonic (not eustatic) origin. In northeastern Washington, most bounding unconformities are too subtle to see in outcrops; commonly they are only evident on regional maps. **Figure 1** illustrates the Laurentian synthems.

The field trip begins at Deer Lake and then travels west to the Huckleberry Mountains. From there we follow the Colville River valley north to Colville. We will spend the night in Colville. On the second day, the trip will travel from Colville northwestward to examine rocks along the valley of the Columbia River.

This field trip guide has a long history. The authors have conducted intermittent research in the area for decades, and independently they crafted field trips for their respective students. These resulted in Cheney (1998) and Cheney and Buddington (2012). Despite this long history, much is still not known about the detailed stratigraphy and regional structure. Regional geological mapping in the area at scales larger than 1:48,000 virtually ceased by 1990.

One individual is largely responsible for what we do know about Laurentia in northeastern Washington. He is F.K. Miller of the USGS. For four decades he conducted mapping in the area (Miller et al., 1999; Miller, 2000; other references cited herein).

III. OVERVIEW

We call northeastern Washington and adjacent Idaho and British Columbia the Tricorner. In the Tricorner, Laurentia consists of a crystalline basement of metamorphic and igneous rocks > 1.7 Ga and overlying Proterozoic to Paleozoic synthems. The crystalline basement is almost completely obscured by the overlying synthems.

Figure 2 shows the regional distribution of the synthems. Granitic intrusions and many faults, both of which are mostly Mesozoic and Tertiary, are omitted in **Figure 2** in order to better show the Laurentian rocks. In the Tricorner, Laurentia is bounded on the west by the Quesnel terrane, the easternmost accreted terrane in this part of the Cordillera (Fig. 2). This terrane (colloquially known as Quesnellia) accreted in the mid-Jurassic. In Washington and Idaho, the Laurentian rocks pass southward unconformably beneath the Cenozoic Tejas synthem, which here is predominantly the Miocene Columbia River Basalt Group (CRBG). Some Laurentian rocks protrude through the CRBG, but most such areas are too small to show in **Figure 2**.

The largest structure in **Figure 2**, which governs the distribution of the Laurentian rock units, is the early Cenozoic,

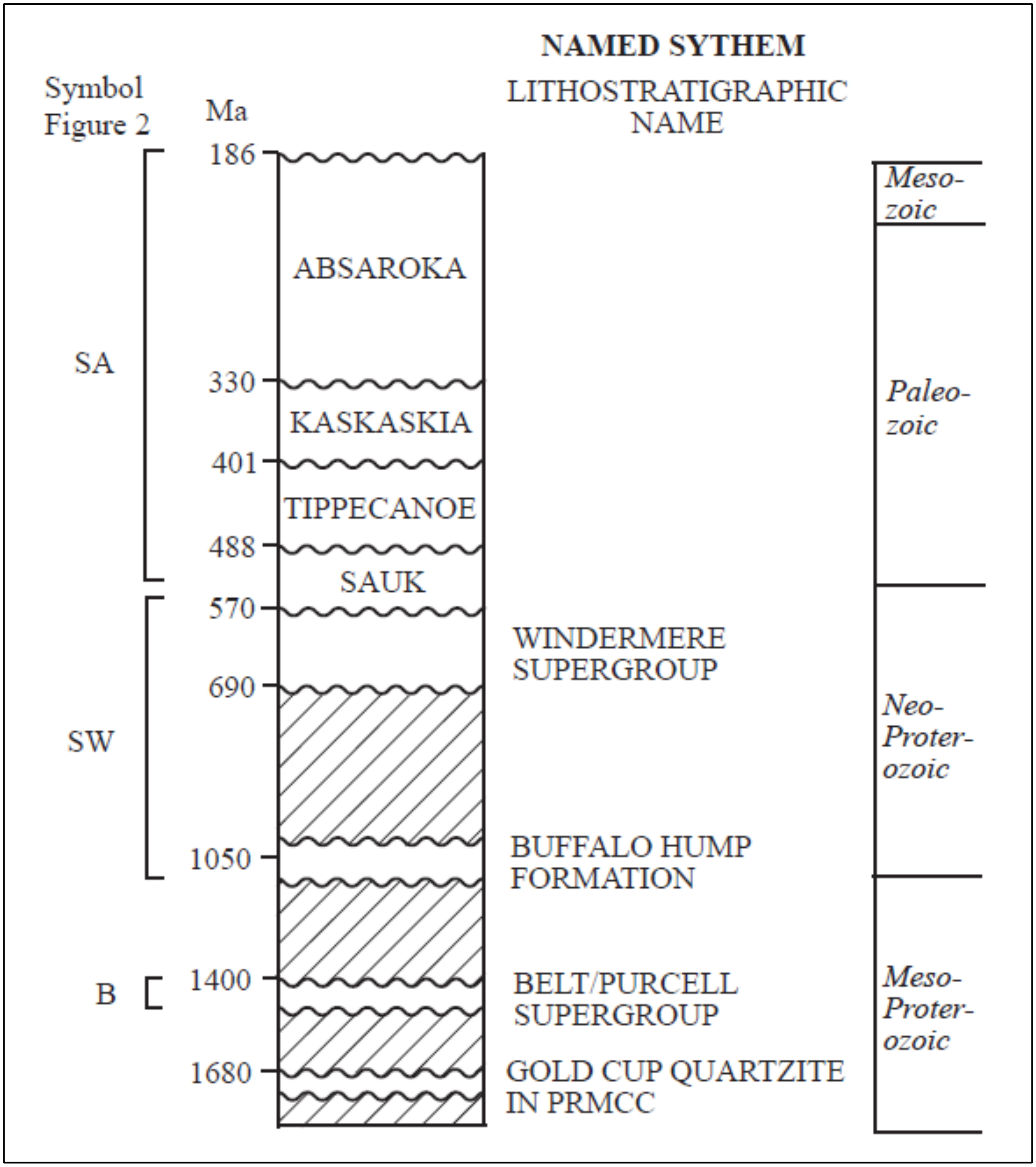


Figure 1. *LAURENTIAN SYNTHEMS. Note the temporal scale is logarithmic.*

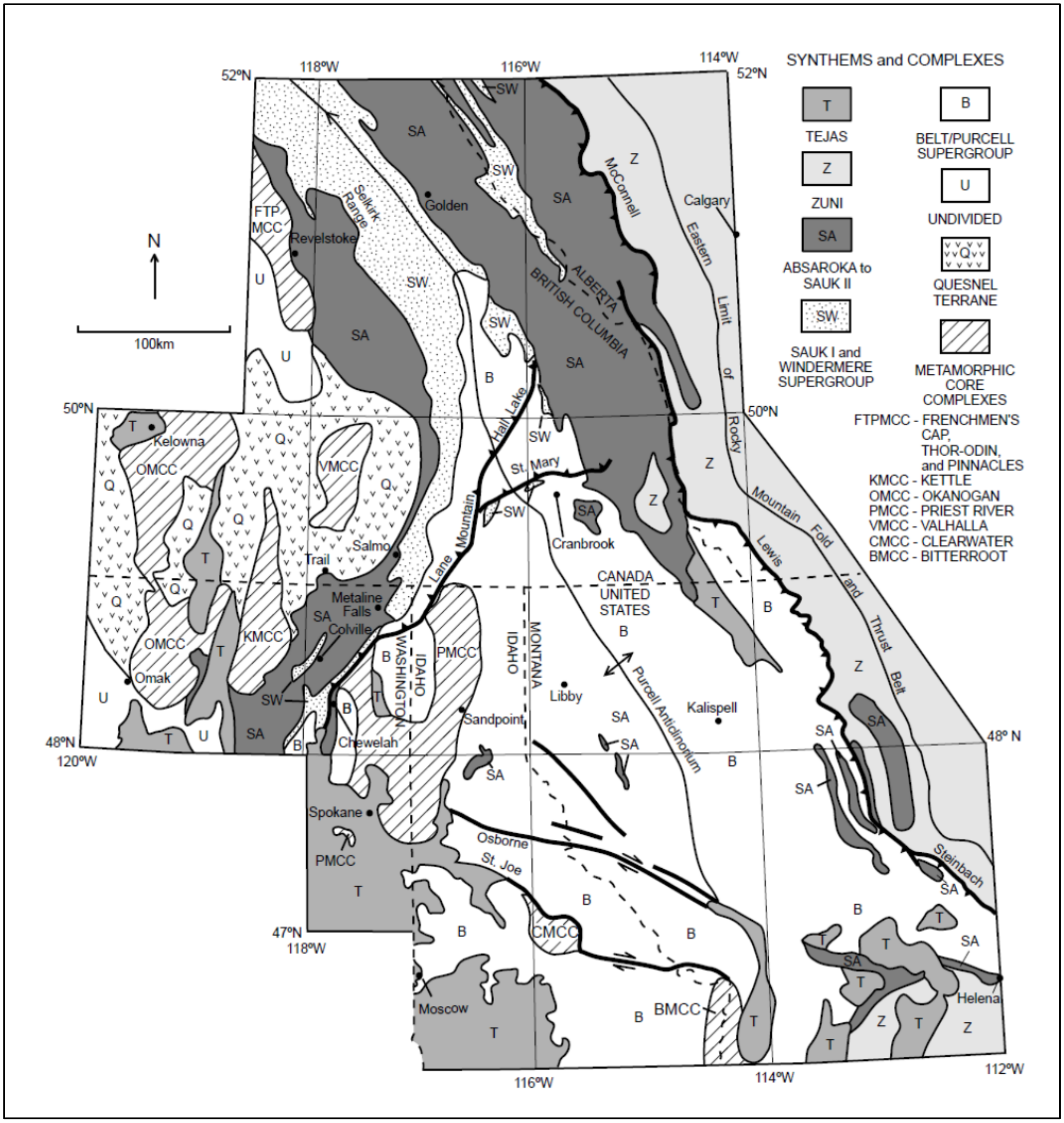


Figure 2. *GEOLOGY OF WESTERN LAURENTIA. For clarity, granitic intrusions and many faults are omitted. Sources of data are Wheeler and McFeeley (1991), Zientek et al. (2005), and Doughty and Chamberlain (1996).*

northwesterly trending Purcell anticlinorium. The oldest extensive synthem, the 1.5 to 1.4 Ga Belt/Purcell Supergroup, is in the core of the anticlinorium; younger synthems are on its limbs. The Paleozoic rocks on the arcuate western limb of the anticlinorium are called the Kootenay Arc; because this term was coined before the advent of plate tectonics, it has no implications for a former island arc.

The two major lithologic components of the Tricorner in **Figure 2** are metamorphic core complexes (MCCs) and the Proterozoic to Paleozoic synthems. Most of the granites, which intrude the MCCs and the Laurentian synthems, are mid-Jurassic or younger; thus, strictly speaking, they are not Laurentian rocks. The MCCs, which are fault-bounded antiforms, formed in the Eocene, but they contain some Laurentian rocks. Middle Eocene MCCs extend discontinuously from British Columbia to southern Idaho.

IV. LAURENTIAN STRATIGRAPHY

Introduction

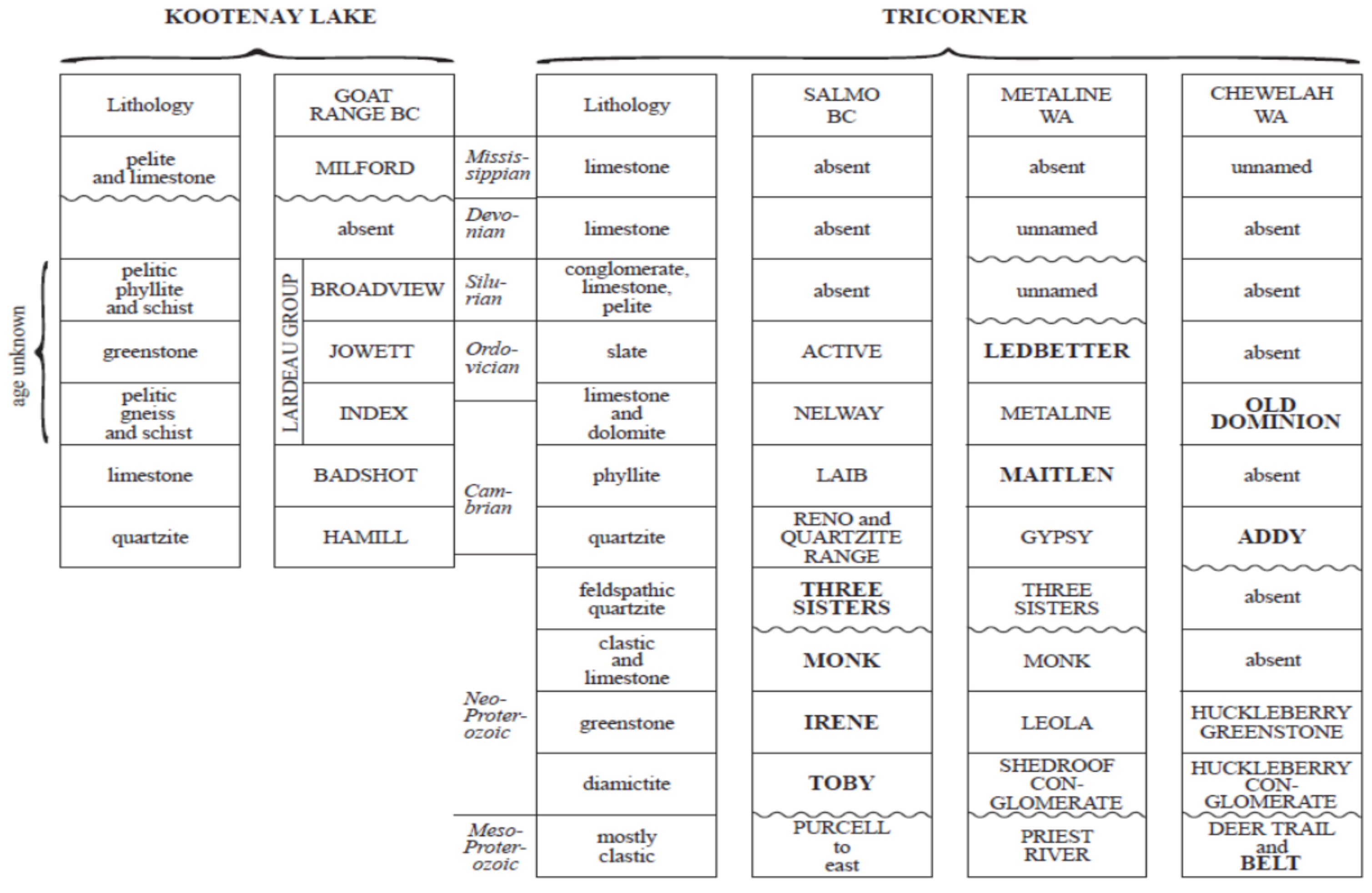
Multiple formational names, inherited from the original mapping in the Chewelah and Metaline areas of Washington and the Salmo area of southernmost British Columbia, obscure the regional continuity of the lithostratigraphy. This stratigraphy does track southeastward across major northeasterly trending thrust faults. Still other lithostratigraphic names prevail farther north in British Columbia (Höy and others, 1995; Reesor, 1996). For simplification, we use only the lithostratigraphic names with precedence, which are shown in bold font in **Figure 3**. Our sole exception to precedence is Metaline Formation, a name so widely used that Stoffel et al. (1991) condoned it. **Figures 4 and 5A** organize the lithostratigraphic units into unconformity-bounded sequences (UBS).

The two synthems in **Figure 2** younger than 186 Ma (Zuni and Tejas) were deposited during and after, respectively, terranes accreted to western margin of Laurentia. Because these two are post-Laurentian, they are not included in **Figure 1**.

Most of the formations of the Laurentian synthems on the western limb of the Purcell anticlinorium are a kilometer or more thick. Most formations are non-marine or are shallow marine quartzose sandstone, siltstone, and shale with minor limestone and dolomite. The cause of these thick accumulations was episodic rifting of the western margin of Laurentia; such rifting and the resultant attenuation of the crystalline basement provided space for the sediments to accumulate **Figure 5B**. Rifted portions of Laurentia now reside in either central Siberia or Australia.

Shaly and dark siliceous Devonian to Mississippian rocks with some basaltic volcanic rocks constitute the “black shale belt” along the Columbia River in Washington and British Columbia. Because units within the belt look alike are poorly fossiliferous, quite deformed, and poorly exposed, they are difficult to decipher. Accordingly, the black shale belt is less affectionately known as “the black crap”. These distal Laurentian rocks were deposited in deeper oceanic water outboard of the miogeoclinal rocks and were then overthrust by the miogeoclinal succession during the accretion of Quesnellia. The black shale belt is sufficiently enigmatic, that two decades ago it was thought to be exotic, the so-called Kootenay terrane.

The Purcell anticlinorium has greatly influenced stratigraphic studies in the



KOOTENAY LAKE				TRICORNER			
	Lithology	GOAT RANGE BC		Lithology	SALMO BC	METALINE WA	CHEWELAH WA
	pelite and limestone	MILFORD	*Mississippian*	limestone	absent	absent	unnamed
		absent	*Devonian*	limestone	absent	unnamed	absent
age unknown	pelitic phyllite and schist	LARDEAU GROUP: BROADVIEW	*Silurian*	conglomerate, limestone, pelite	absent	unnamed	absent
	greenstone	LARDEAU GROUP: JOWETT	*Ordovician*	slate	ACTIVE	**LEDBETTER**	absent
	pelitic gneiss and schist	LARDEAU GROUP: INDEX	*Cambrian*	limestone and dolomite	NELWAY	METALINE	**OLD DOMINION**
	limestone	BADSHOT		phyllite	LAIB	**MAITLEN**	absent
	quartzite	HAMILL		quartzite	RENO and QUARTZITE RANGE	GYPSY	**ADDY**
			Neoproterozoic	feldspathic quartzite	**THREE SISTERS**	THREE SISTERS	absent
				clastic and limestone	**MONK**	MONK	absent
				greenstone	**IRENE**	LEOLA	HUCKLEBERRY GREENSTONE
				diamictite	**TOBY**	SHEDROOF CONGLOMERATE	HUCKLEBERRY CONGLOMERATE
			Mesoproterozoic	mostly clastic	PURCELL to east	PRIEST RIVER	DEER TRAIL and **BELT**

Figure 3. *SYNONYMS FOR THE LITHOSTRATIGRAPHIC NAMES OF LAURENTIAN UNITS IN NORTHEASTERN WASHINGTON AND ADJACENT BRITISH COLUMBIA (from Cheney and Zieg, 2015). The names with precedence are in bold type. Yet another set of names for most units occurs farther north in British Columbia.*

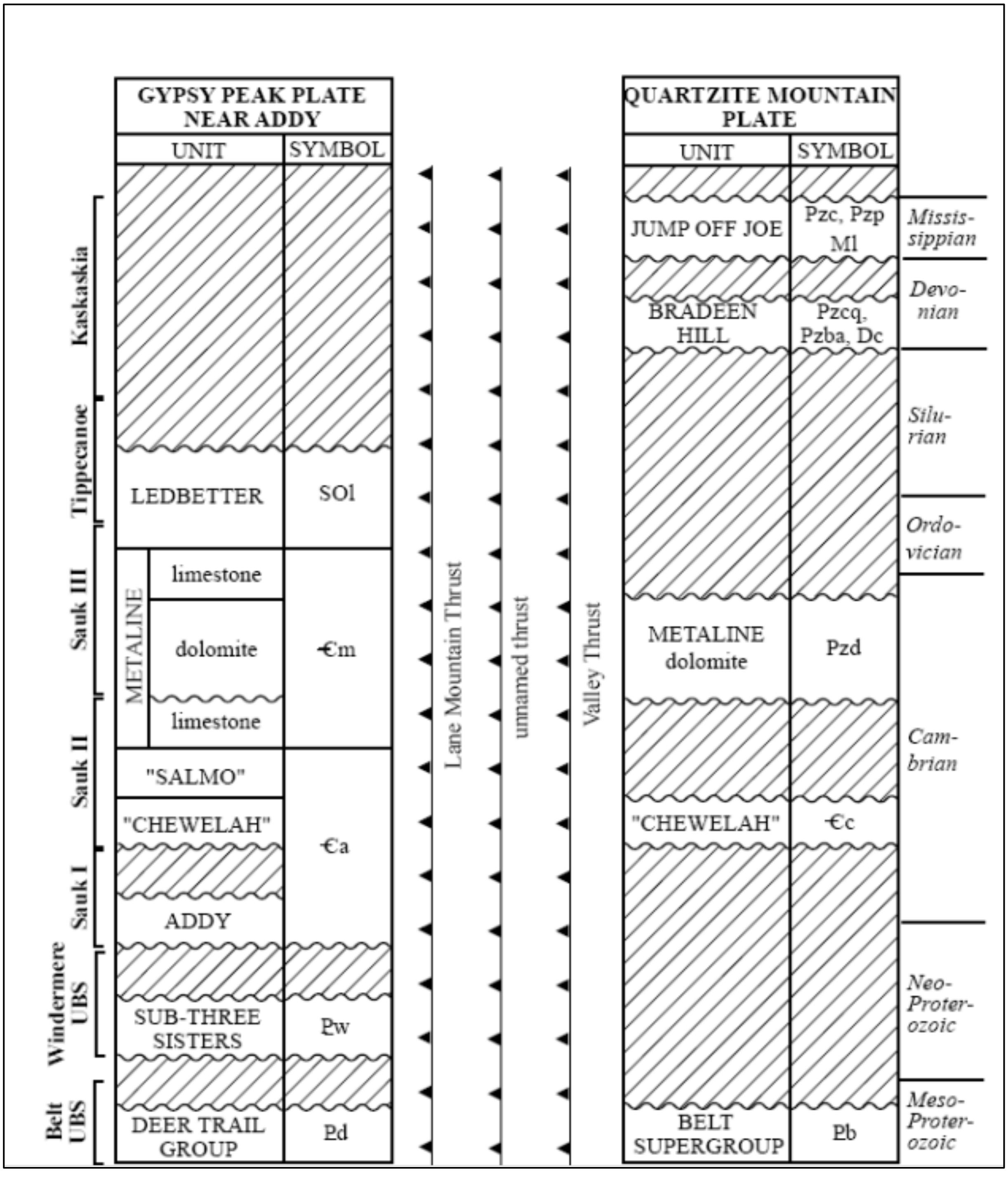


Figure 4. *COLUMNAR SECTIONS ACROSS THE COLVILLE RIVER FOLD AND THRUST BELT IN THE CHEWELAH AREA. The thrust faults strike northeasterly and dip northwesterly (Fig. 7). Except for the Metaline Formation, lithostratigraphic names are those with precedence. Names within quotation marks are informal ones used in this paper. This figure also is the explanation for Figure 7.*

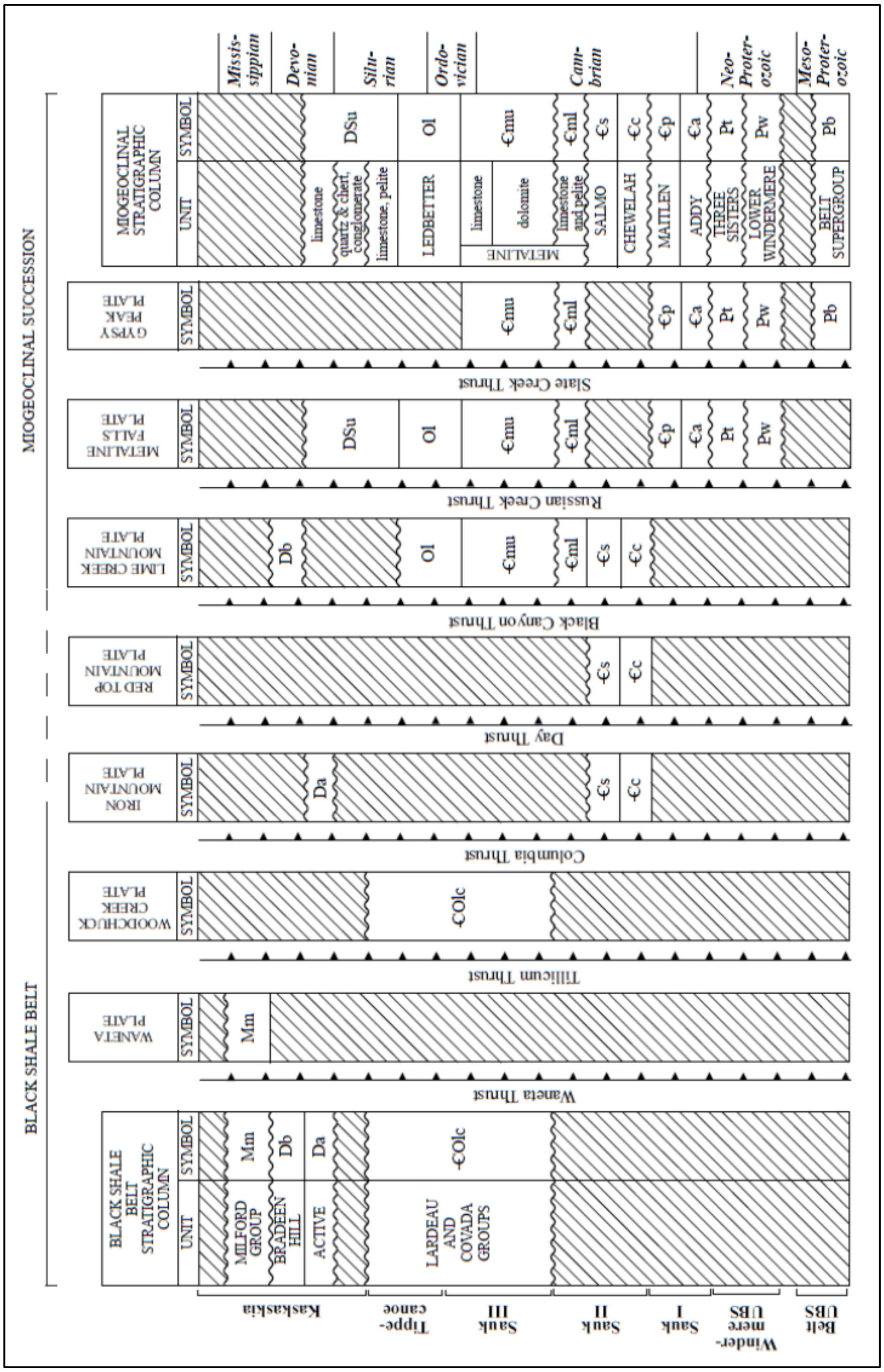


***Figure 5A**. PALEOZOIC UNCONFORMITY-BOUNDED SEQUENCES, CORRELATIONS, AND VARIATIONS IN STRATIGRAPHY ACROSS THRUST FAULTS IN PORFT. The thrust faults strike northeasterly. Except for the Metaline Formation, lithostratigraphic names are those with precedence. Names within quotation marks are informal ones used by Lund and Cheney (2012) and Cheney and Zieg (2012).*

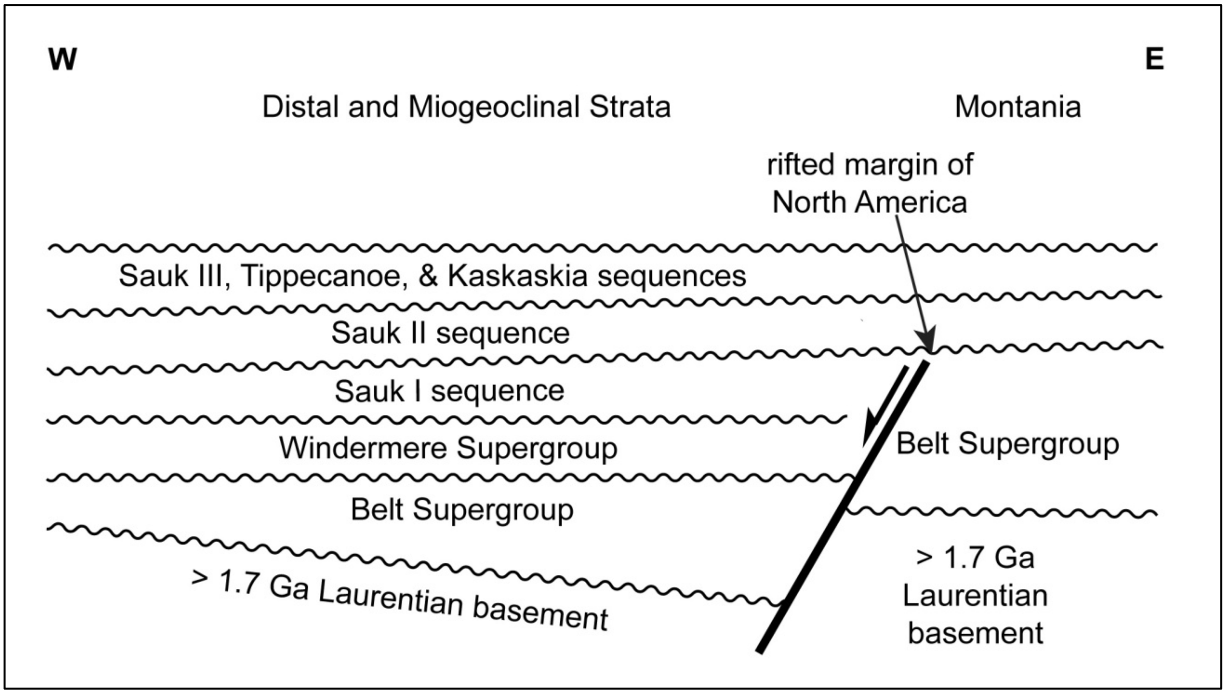


Figure 5B. *SCHEMATIC STRATIGRAPHIC DIAGRAM OF THE DEPOSITION OF SYNTHEMS ON THE WESTERN MARGION OF LAURENTIA.*

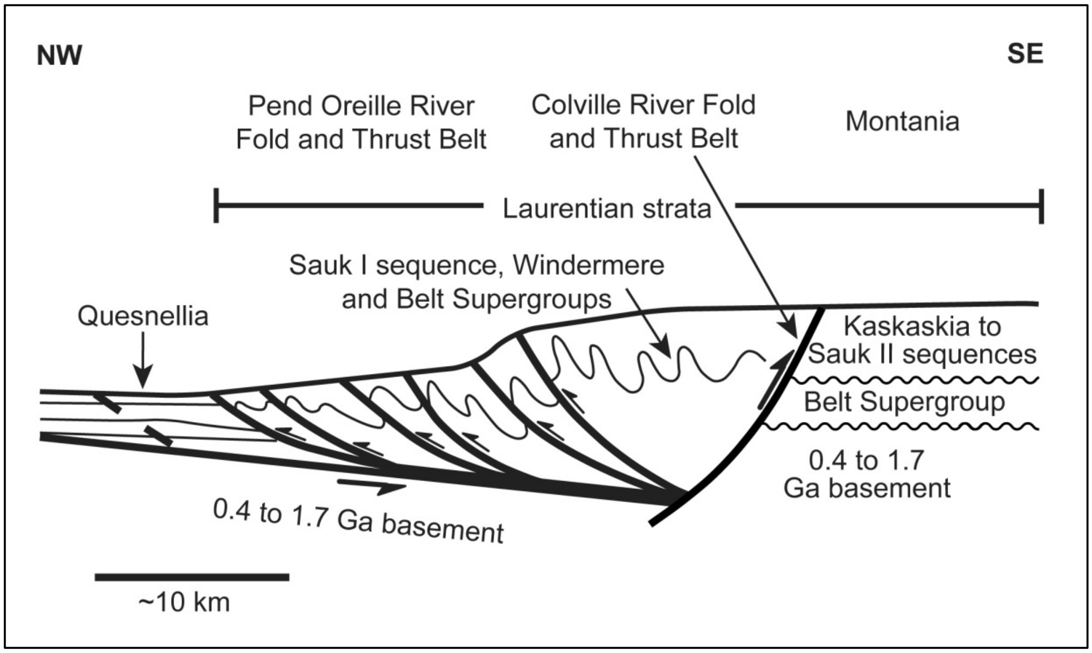


Figure 5C. *SCHEMATIC CROSS SECTION OF MID-JURASSIC THRUSTING IN NORTHEASTERN WASHINGTON. Cenozoic folding and faulting have modified this section but are not shown here.*

Tricorner. Synthems are well documented in the Phanerozoic strata on the eastern limb of the anticlinorium and farther east. However, the Phanerozoic strata of the Tricorner are thicker and more nearly conformable; they also are separated from their eastern correlatives by a swath of Belt/Purcell Supergroup that is up to a few hundred kilometers wide. Thus, the unconformity-bounded nature of these units in the Tricorner is under appreciated. **Figure 2** shows that these strata are not orphans: in Canada the Phanerozoic synthems occur on both limbs of the Purcell anticlinorium.

Another characteristic is that south of 50°N, the Windermere Supergroup and the basal UBS of the Sauk synthem, Sauk I, occur on the western limb but not on the eastern limb of the anticlinorium. The Windermere Supergroup and Sauk I either were never deposited south of 50°N, on what is now the eastern limb of the anticlinorium, or were subsequently removed by erosion on the sub-Sauk II and other unconformities. The Windermere Supergroup and Sauk I are thicker and seeming conformable successions compared to the younger synthems on the eastern limb of the anticlinorium. Thus, from a cratonic American viewpoint, the stratigraphy of the Tricorner seems strange.

Paleoproterozoic Quartzite

The oldest and least well-known Laurentian synthem consists of quartzitic strata that are slightly younger than 1.7 Ga. These rocks are discontinuously preserved from Wisconsin (Baraboo Quartzite) to South Dakota (Sioux Quartzite) and Montana (Neihart Quartzite) to the American southwest (Honda Quartzite) to Saskatchewan (Athabasca Group) to the Northwest Territories (Thelon Group). In the Priest River MCC the ≤ 1.7 Ga Gold Cup Quartzite overlies 2.68 Ga granitic gneiss. The quartzite of Monument Buttes in the eastern part of the Clearwater MCC might be about 1.7 Ga. A portion of the Kettle MCC in British Columbia also contains ≤ 1.7 Ga metasedimentary rocks.

Mesoproterozoic Belt Supergroup

The oldest extensive synthem, the 1.5 to 1.4 Ga Belt Supergroup, consists of quartzose and feldspathic sandstone, siltstone, and shale, with minor carbonate rock. In southeastern British Columbia it is called the Purcell Supergroup. The Supergroup is up to 16 km thick (Link, 1993). Because the Deer Trail Group west of Chewelah (Miller and Whipple, l989) and the Priest River Group east of Metaline Falls are unconformable below the Windermere Supergroup and are compositionally similar to parts of the Belt Supergroup, they probably are outliers of it. Despite its considerable extent and great thickness, no unconformity-bounded sequences are yet documented in the Belt/Purcell Supergroup.

The Buffalo Hump Formation (**Fig. 1**) near Chewelah, Washington is too young to be part of the Belt Supergroup and too old to be part of the Windermere Supergroup. Thus, it most probably is a remnant of a separate Proterozoic synthem. As rocks in the area of **Figure 2** become better mapped and dated, perhaps other Proterozoic synthems will be recognized.

Some world-class metallic ore deposits occur in the Belt/Purcell Supergroup. These include the sedex lead-zinc-silver deposit at Kimberly in southeastern British Columbia, mesothermal lead-zinc-silver veins east of Coeur d'Alene in northern Idaho, and strata-bound copper and silver sandstone-type (roll-type) deposits near Libby, Montana. Prior to the 1970s, the Deer Trail Group near Chewelah, Washington was a major commercial source of magnesium carbonate (magnesite), but it was rendered uneconomic by the electrolytic recovery of magnesium from seawater.

Neoproterozoic Windermere Supergroup

Unconformably overlying the Belt Supergroup is the 0.7 to 0.57 Ga Windermere Supergroup. The Supergroup is up to 8 km thick and extends discontinuously from southeastern California to Alaska (Link, 1993, Lund et al., 2002; Lund and Cheney, 2015). In the Tricorner contains unsorted boulders and cobbles (now recognized as marine glacial deposits), quartzose and feldspathic sandstone, basalt, shale, and minor limestone. Although formations in the Windermere Supergroup appear to be conformable, Lund and Cheney (2012) showed that they are not **(Fig. 6).** No significant ore deposits occur in the Windermere Supergroup.

Paleozoic Synthems

Miogeoclinal Neoproterozoic to Cambrian quartzite (Addy Quartzite), Cambrian pelite (Maitlen Phyllite), and Cambrian to Ordovician carbonate rocks (Metaline Formation) are widespread in the Tricorner (**Fig. 5A)**. Ordovician to Mississippian strata have more limited extents (Stoffel and others, 1991; Höy and Dunne, 2001).

An important aspect of **Figures 4 and 5A** is that the original differences in lithostratigraphic nomenclature of the miogeoclinal rocks varied from northeast to southwest (**Figure 3**). However, differences in the preservation of stratigraphic units vary from northwest to southeast across major thrust faults.

Cheney and Zieg (2015) made some significant stratigraphic revisions in the Chewelah area. The first is that in addition to the Addy Quartzite, a second (younger) Cambrian quartzite exists; this is the quartzite of Chewelah (hereafter abbreviated QOC). This quartzite extends as far west as the Columbia River (Cheney and Zieg, 2015). The QOC is inferred to be the previously unrecognized western equivalent of the middle Cambrian Flathead Quartzite of Montana. The Flathead Quartzite/QOC is at the base of Sauk II (Cheney and Zieg, 2015).

The second stratigraphic revision is that some rocks previously included in the Mesoproterozoic Deer Trail Group at Chewelah (Miller, 2000) most likely are Paleozoic (Weaver, 1920; Cheney and Zieg, 2015, table 2). This revision invalidates the Jumpoff Joe thrust of Miller (2000) and places a major thrust, the Valley thrust, 2 to 4 km farther west of the former Jumpoff Joe thrust/ (**Fig. 7**).

The pelitic and dark siliceous Paleozoic rocks of the black shale belt along the Columbia River (including the Covada Group in Washington and Lardeau Group in British Columbia) probably are distal North American strata (Smith and Gehrels, 1992; Colpron and Price, 1995). **Figure 5A** suggests that these may grade eastward into miogeoclinal rocks. Some rocks as far west as the southeastern portion of the Okanogan MCC also bear a strong resemblance to parts of the Covada Group (Smith and Gehrels, 1992).

The most distinctive rocks of the black shale belt are bedded barite deposits, which locally have Devonian fossils. (Moen, 1964; Mills et al. 1971). These deposits occur in the Bradeen Hill assemblage (Smith and Gehrels, 1992) of **Figure 5A**.

Cheney and Zieg recognized several unconformities in the Laurentian succession

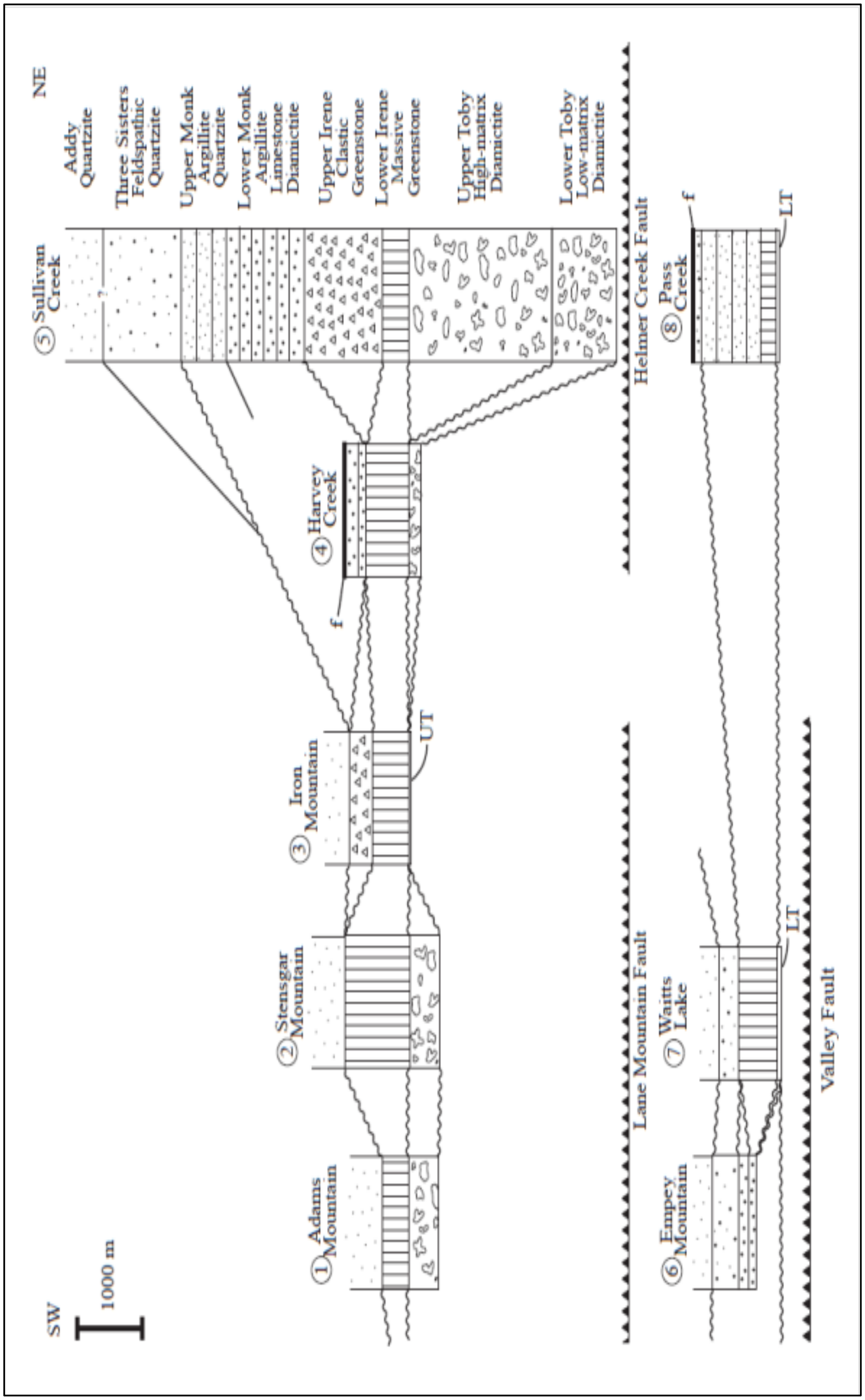


Figure 6. *UNCONFORMITY-BOUNDED SEQUENCES IN THE WINDERMERE SUPERGROUP OF THE TRICORNER (from Lund and Cheney, 2015).*

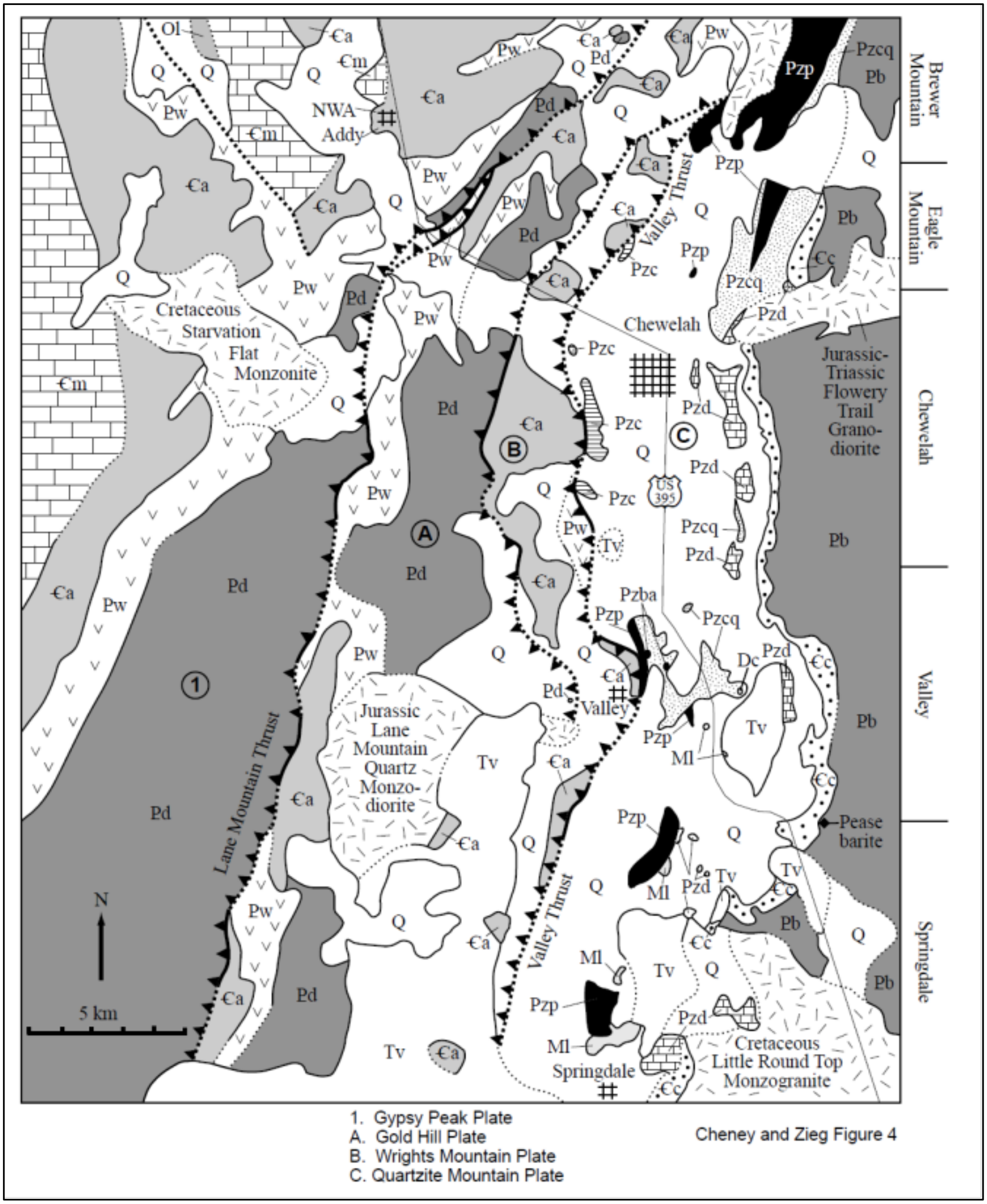


Figure 7. *TECTONIC MAP OF THE CHEWELAH AREA (from Cheney and Zieg, 2012). Figure 4 is the explanation for this figure.*

(**Figs. 4 and 5A).** The most impressive is the one at the base of Sauk I (the base of the Addy Quartzite). This unconformity progressively eliminates the Windermere Supergroup to the southwest (**Fig. 6).** The unconformity at the base of Sauk II (at the base of the OOC and the Metaline Formation) eliminates the Maitlen Phyllite south of Colville.

Ore Deposits

The most important ore deposits in the Phanerozoic synthems of the Tricorner are Mississippi Valley type (MVT) zinc-lead deposits in Cambrian carbonate rocks. MVT mines occur in the Salmo district, BC (Fyles and Hewlett, 1959; Addie, 1970), Metaline district, WA (McConnel and Anderson, 1967; St. Marie and Kesler, 2000), and the Deep Creek district, WA (Mills, 1977). MVT prospects also occur near Northport (Mills, 1977) and Addy. MVTs are unrelated to granitic intrusions and generally are low in silver. The MVT deposits in the Kootenay Arc range from undeformed to severely deformed, and some are contact metamorphosed.

The Addy Quartzite of Sauk I near Valley is mined for glass sand. At Addy, dolomite in the Metaline Formation was mined as the raw material for Mg alloys for aluminum. Locally, limestones in the Metaline Formation were quarried for the manufacture of cement. The bedded barite deposits and one known former sedex (lead-zinc-silver) deposit in the black shale belt are currently uneconomic.

V. STRUCTURE

Oldest Deformation

In British Columbia, lower Mississippian to lower Pennsylvanian rocks unconformably overlie, and contain clasts of, more intensely deformed rocks. Thus, some folding is Mississippian, and roughly equivalent to the Antler orogeny of the Basin and Range province to the south.

This oldest deformation is poorly documented in Washington. Refolded folds in the bedded barite deposits of the black shale belt (Mills et al., 1971) are probable evidence.

Mid-Jurassic Deformation

The middle Jurassic accretion of Quesnellia caused two northeasterly trending thrust belts in the Tricorner. The northwesterly dipping Colville River fold and thrust belt (CRFT) is on the east (**Figures 4 and 7**). The Pend Oreille River fold and thrust belt (PORFT) is on the west and dips southeastward (**Figs, 5C and 8).** In British Columbia and Washington, Cretaceous and a few middle Jurassic plutons intrude the fold and thrust belts (**Figs**. **7 and 11**)

Miller (1994, 2000) recognized the CRFT belt. Cheney and Zieg (2015) named it and modified it somewhat by identifying the Valley fault and eliminating Miller's (2000) Jumpoff Joe fault (**Fig. 7**).

Portions of the western belt, PORFT, were mapped by several authors, especially Yates (1964, 1971). Cheney and Zieg (2004, 2015) recognized that these portions are parts of seven regional thrusts. These thrusts cause the geology and zinc-lead deposits of the Salmo district in British Columbia to be significantly different than those in the adjacent Metaline district of Washington (**Fig. 11**). Figure 6 of Cheney and Zieg (2015) and the northeastern parts of **Figures 8 and 11** show that PORFT is virtually an International Boundary fault system separating the two districts. Cheney (2010) recognized an eighth thrust and named the belt PORFT for faults along the Pend Oreille

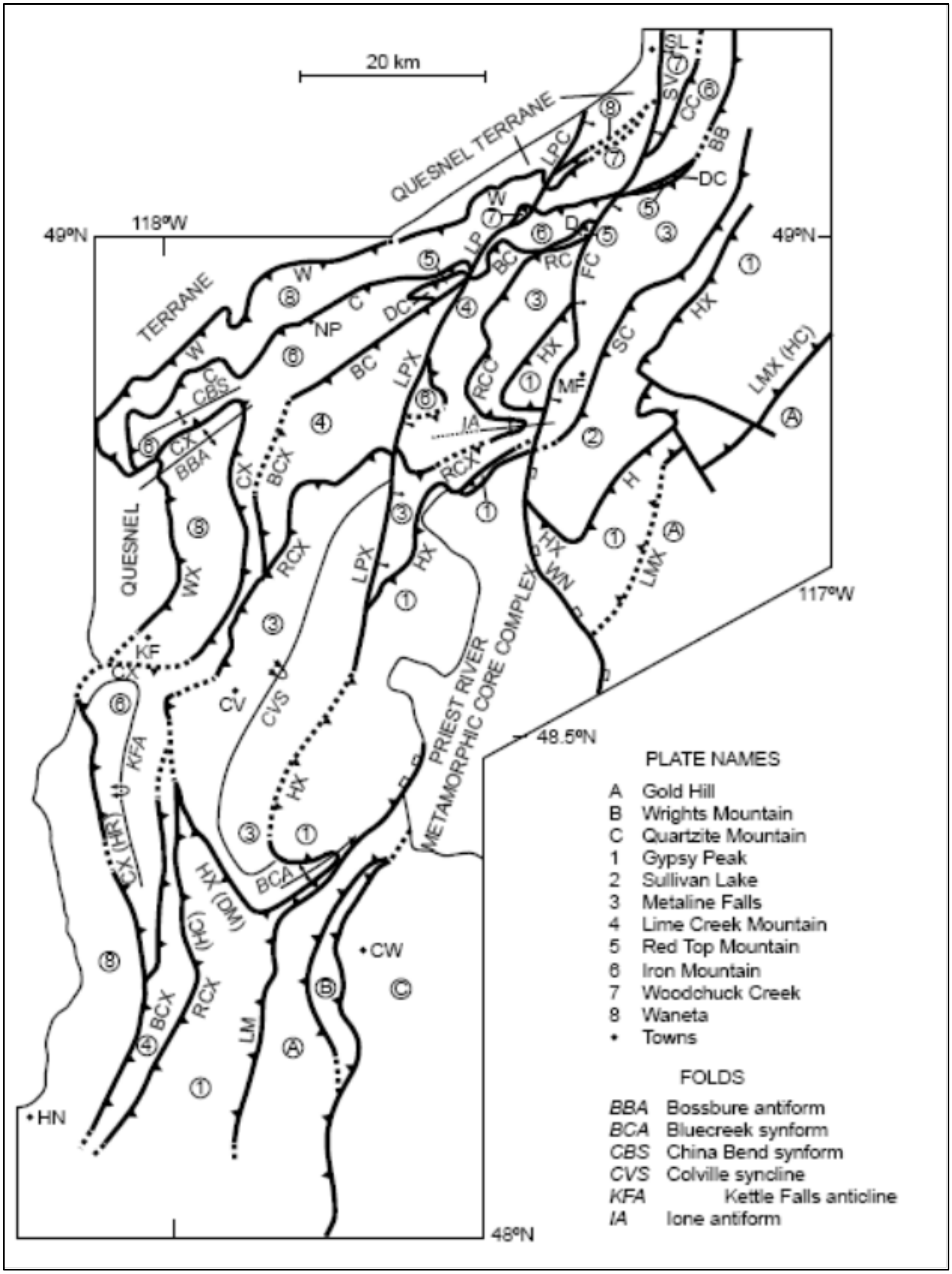

20 km
QUESNEL TERRANE
QUESNEL
TERRANE
49ºN
118ºW
117ºW
48.5ºN
48ºN
PRIEST RIVER METAMORPHIC CORE COMPLEX
SL
SV
CC
BB
DC
LPC
W
LP
BC
RC
FC
D
NP
C
DC
LPX
RCC
HX
SC
MF
IA
CBS
CX
BBA
BCX
RCX
WX
KF
CV
CVS
KFA
CX (HR)
BCA
HX (DM)
RCX (HC)
LM
CW
HN
H
LMX
LMX (HC)
WN
PLATE NAMES
A Gold Hill
B Wrights Mountain
C Quartzite Mountain
1 Gypsy Peak
2 Sullivan Lake
3 Metaline Falls
4 Lime Creek Mountain
5 Red Top Mountain
6 Iron Mountain
7 Woodchuck Creek
8 Waneta
• Towns
FOLDS
BBA Bossburg antiform
BCA Bluecreek synform
CBS China Bend synform
CVS Colville syncline
KFA Kettle Falls anticline
IA Ione antiform

Figure 8 (previous page). *THRUST SYSTEMS. The southeasterly dipping thrusts are the Pend Oreille River fold and thrust belt (PORFT). The northwesterly dipping thrusts in the southeast are the Colville River fold and thrust belt (CRFT). Figures 4 and 5 illustrate the stratigraphy in each sheet (plate). From the top to the bottom of PORFT the names of the thrusts with precedence (and synonyms) are: Harvey (Dunn Mountain) = H; Slate Creek = SC; Russian Creek (Black Bluff, Haller Creek) = RC; Black Canyon = BC; Day = D; Columbia (Huckleberry Range) = C; Tillicum = T, and Waneta = W. Eocene normal faults are Flume Creek (FC)/Western Newport (WN) and Leadpoint (LP). Portions of the faults with an X are extensions beyond the limits mapped by previous authors. CV is Colville; CW is Chewelah; HN is Hunters; KF is Kettle Falls; MF is Metaline Falls; NP is Northport; SL is Salmo. See Figure 11 for a map that shows the stratigraphic units in PORFT.*

River (which crosses the International Border).

Figures 5A, 8, and 11 illustrate that, in general, rocks become younger in lower thrust sheets of PORFT. Some stratigraphic units are restricted to one or a few plates. Deformation also increases downward. For example, above the Russian Creek thrust, deformation of the Metaline Formation (and its Mississippi Valley-type Zn-Pb deposits) is brittle; below this thrust deformation of the rocks and ore deposits are foliated (that is, deformation is ductile. In the Iron Mountain plate are coaxially refolded, recumbent isoclines, the axial planes of which generally dip to the southeast (Yates, 1964, 1970; Fyles, 1970; Mills 1977; Watkinson and Ellis, 1987). In the Salmo area, folds are nearly isoclinal and are upright or moderately overturned to the west (Fyles and Hewlett, 1959, Little, 1964; Fyles, 1970). Farther north in British Columbia, the isoclines dip more steeply to the east (Colpron and Price, 1995).

By using previously mapped segments and the stratigraphy of various thrust plates shown in **Fig**ure **5A,** Cheney (2010) extended PORFT southwestward to where it is unconformably overlain by the Miocene CRBG **(Figs. 8 and 11**). Our studies of this belt continue (Buddington et al., 2011).

The structural relationship of PORFT and Laurentia with respect to Quesnellia is quite clear. Fyles and Hewlett (1959) mapped the basal thrust of PORFT, the Waneta thrust, which dips 30 to 35 degrees southeastward, as placing Laurentian rocks over Quesnellia. That is, Quesnellia is wedged between the cover synthems of Laurentia and their basement (**Fig 5C).**

PORFT and CRFT constitute a two-sided thrust system. With respect to PORFT, CRFT is a series of back thrusts that places the miogeoclinal portion of Laurentia over its cratonic portion (**fig. 5C**).

Accordingly, the lower part of the miogeoclinal section of Laurentia in the Tricorner is strongly structurally controlled: the Windermere Supergroup and Sauk I only occur in and west of CRFT.

The two-sided nature of the mid-Jurassic thrust system and the restricted occurrence of the Windermere Supergroup and Sauk I provide clues to the origin of the thrust system. The rifted margin of Laurentia provided space for the sedimentation of the Windermere Supergroup and Sauk I (**Fig. 5B**). During accretion of Quesnellia, this rifted margin acted as a backstop to deformation and was reactivated (inverted) as a thrust system, the CRFT. The thrusts propagated upward to involve younger rocks than the original rift (compare **Figures 5B and 5C**).

Paleocene Deformation

In the third period of deformation, duplexing of the Belt/Purcell Supergroup by thrust faults in the earliest Cenozoic caused the Purcell anticlinorium (**Fig. 2**). Rocks originally in northeastern Washington were thrust *en masse* 200 km northeastward to form the anticlinorium (Price and Sears, 2000). The McConnel, Lewis, and Steinbach thrusts along the front of the Rocky Mountains, and numerous other faults not shown in **Figure 2**, are parts of this thrust system. East of the axial trace of the Purcell anticlinorium, rocks of the Phanerozoic synthems are mostly unmetamorphosed, but west of the axial trace, they are mostly in greenschist facies.

Eocene Extension

In the middle Eocene, the crust extended, causing formation of the MCCs in the crystalline basement; dextral strike-slip faults formed in strata above the basement (**Fig. 2**). The antiformal MCCs, which are discussed next, dominate the topography and geologic map pattern of the Tricorner. The Laurentian strata, PORFT, and CRFT are synformally preserved between the Priest River MCC on the east and the Kettle MCC on the west.

VI. METAMORPHIC CORE COMPLEXES

MCCs are antiforms of amphibolite-facies metasedimentary rocks, Mesozoic orthogneisses, and weakly foliated to unfoliated Eocene granitic intrusions. A distinguishing feature of MCCs is that they are almost entirely bounded by normal faults. These faults, which are not shown in **Figure 2**, generally have shallow dips and are called detachment faults. Typically, metamorphic rocks below the faults are in amphibolite facies; whereas, rocks above the faults and outside of the MCCs are in greenschist facies or are unmetamorphosed. Extension of the crust during the Eocene caused these faults and the rise of the MCCs.

The detachment faults have two zones of deformed rocks. Some of the amphibolite-facies rocks below the detachment faults are very well foliated and were so attenuated by ductile flow during extension that their grain size was considerably reduced, and the minerals were drawn out into streaks (lineations). Such rocks are called mylonites. The mylonites of the MCCs range from 0 to 4 km in thickness. Mylonites that are on the margins of the complexes usually are cut and capped by predominantly chloritic breccias (in greenschist facies). These breccias record brittle, not ductile, deformation. Mylonitic zones inside the metamorphic core complexes do not have associated chloritic breccias. Because the chloritic breccias are rarely more than 100 m thick in the Tricorner, they commonly are obscured by forests, lakes, and Quaternary sediments.

The age of formation of the MCCs is known from stratigraphic relations, radiometric cooling ages of mylonitic and other rocks, and conventional radiometric ages from dikes that cut the mylonites and the chloritic breccias. The best stratigraphic evidence is from the middle Eocene Klondike Mountain Formation adjacent to the Okanogan MCC in northern Washington (**Fig. 2**). There, the lower part of the formation is cut by detachment faults; but the middle part contains debris, including rock-avalanche deposits, from the MCC (Cheney, 2014).

Small portions of the original pre-1.7 Ga crystalline basement of western Laurentia are preserved in some MCCs. A small area in the Priest River MCC near Sandpoint, Idaho contains the oldest rocks in the area of **Figure 2**, a 2.68 Ga (Archean) granitic gneiss. A 1.79 Ga anorthosite occurs in the Clearwater MCC.

The metasedimentary rocks within the MCCs include metamorphosed Laurentian lithologies. For example, radiometric ages show that in the Priest River MCC, most of the metasedimentary rocks are metamorphosed Belt Supergroup. Thick quartzites in the Kettle metamorphic complex (**Table 1**) must be of Laurentian origin (rather than from oceanic terranes). Most of the thick quartzites of Laurentia are in the Windermere Supergroup and the Sauk synthem.

The MCCs behaved like crystalline basement during the middle Eocene crustal extension. The basement became decoupled along the detachment faults from the overlying greenschist to unmetamorphosed rocks. Another example of decoupling is the large Eocene strike-slip faults of the Lewis and Clark fault zone of northern Idaho and adjacent Montana, such as the Osborne fault (**Fig. 2**); these faults cut the rocks of the synthems but not those in the structurally underlying Priest River MCC. Thus, the strike-slip faults are the upper crustal response to the Eocene extension of the basement. They link extension in the Priest River MCC with the Clearwater and Bitterroot MCCs to the east and with metamorphic rocks in the Four Lakes area to the west of Spokane.

An interesting question is what actually is basement? During crustal extension in the Eocene, the MCCs acted mechanically like crystalline basement; however, the MCCs contain metamorphosed equivalents of synthems that were deposited upon the original pre-1.7 Ga crystalline basement of Laurentia. The answer is that the Mesozoic accretion of terranes caused amphibolite-facies metamorphism in some portions of the Laurentian synthems; thus, during middle Eocene extension these rocks behaved like (and with) the original pre-1.7 Ga basement.

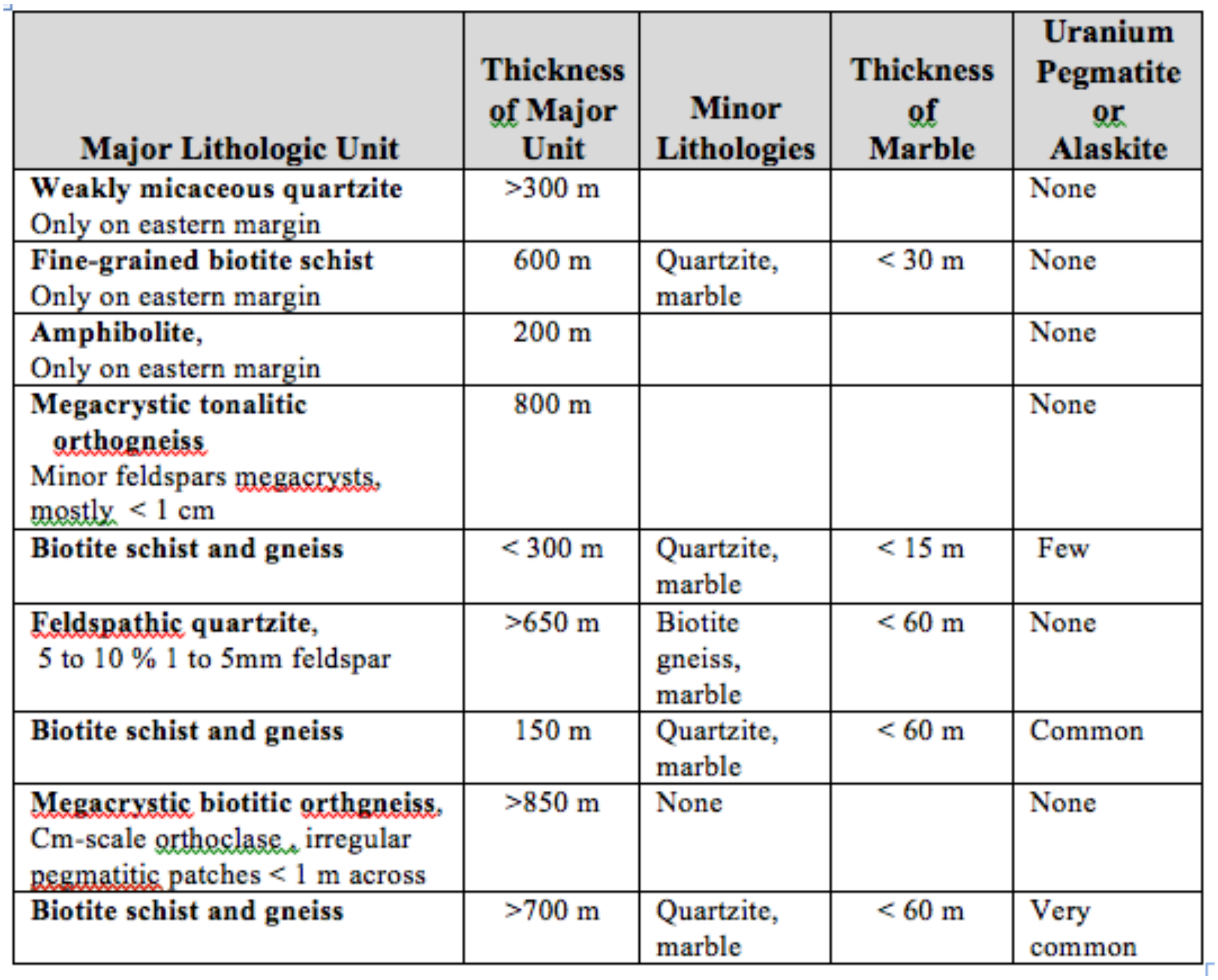
The MCCs in the Tricorner contain a few prospects but no significant ore deposits. Aplitic to pegmatitic bodies have been prospected episodically for Rössing-type uranium deposits in several MCCs, but no significant production has occurred.

VII. ROAD LOGS

DAY 1: SOUTH OF COLVILLE

On the first day of the field trip we will inspect the continental margin from Deer Lake to Addy. We will examine examples of the Middle Proterozoic rocks of the Deer Trail Group (**Fig. 9**) and Belt Supergroup (**Fig. 10**) along with a brief examination of Mississippian carbonates beneath the Valley thrust fault. We will also examine rocks of the Neoproterozoic Windermere Group and a magnesite deposit in the Magnesite Belt of Stevens County. We will finish with a look at Lower Paleozoic rocks. The best published map of the area is the 1:100,000 map of Miller (2000). Figure 7 is a revision of a portion of that map.

The field trip begins at the junction of North Deer Lake Road and US 395. This junction is about 35 miles north of Spokane on US



Major Lithologic Unit	Thickness of Major Unit	Minor Lithologies	Thickness of Marble	Uranium Pegmatite or Alaskite
Weakly micaceous quartzite Only on eastern margin	>300 m			None
Fine-grained biotite schist Only on eastern margin	600 m	Quartzite, marble	< 30 m	None
Amphibolite, Only on eastern margin	200 m			None
Megacrystic tonalitic orthogneiss Minor feldspars megacrysts, mostly < 1 cm	800 m			None
Biotite schist and gneiss	< 300 m	Quartzite, marble	< 15 m	Few
Feldspathic quartzite, 5 to 10 % 1 to 5mm feldspar	>650 m	Biotite gneiss, marble	< 60 m	None
Biotite schist and gneiss	150 m	Quartzite, marble	< 60 m	Common
Megacrystic biotitic orthgneiss, Cm-scale orthoclase , irregular pegmatitic patches < 1 m across	>850 m	None		None
Biotite schist and gneiss	>700 m	Quartzite, marble	< 60 m	Very common

Table 1. *TENAS MARY CREEK ASSEMBLAGE IN THE KETTLE METAMORPHIC CORE COMPLEX. (after Cheney, 2014, table 1).*

Notes: Progressively structurally higher major units are progressively higher in the table. All biotitic units are sillimanite-bearing. The last column refers to uranium-bearing biotitic pegmatites and to uranium-bearing bodies of biotitic alaskite to aplite.

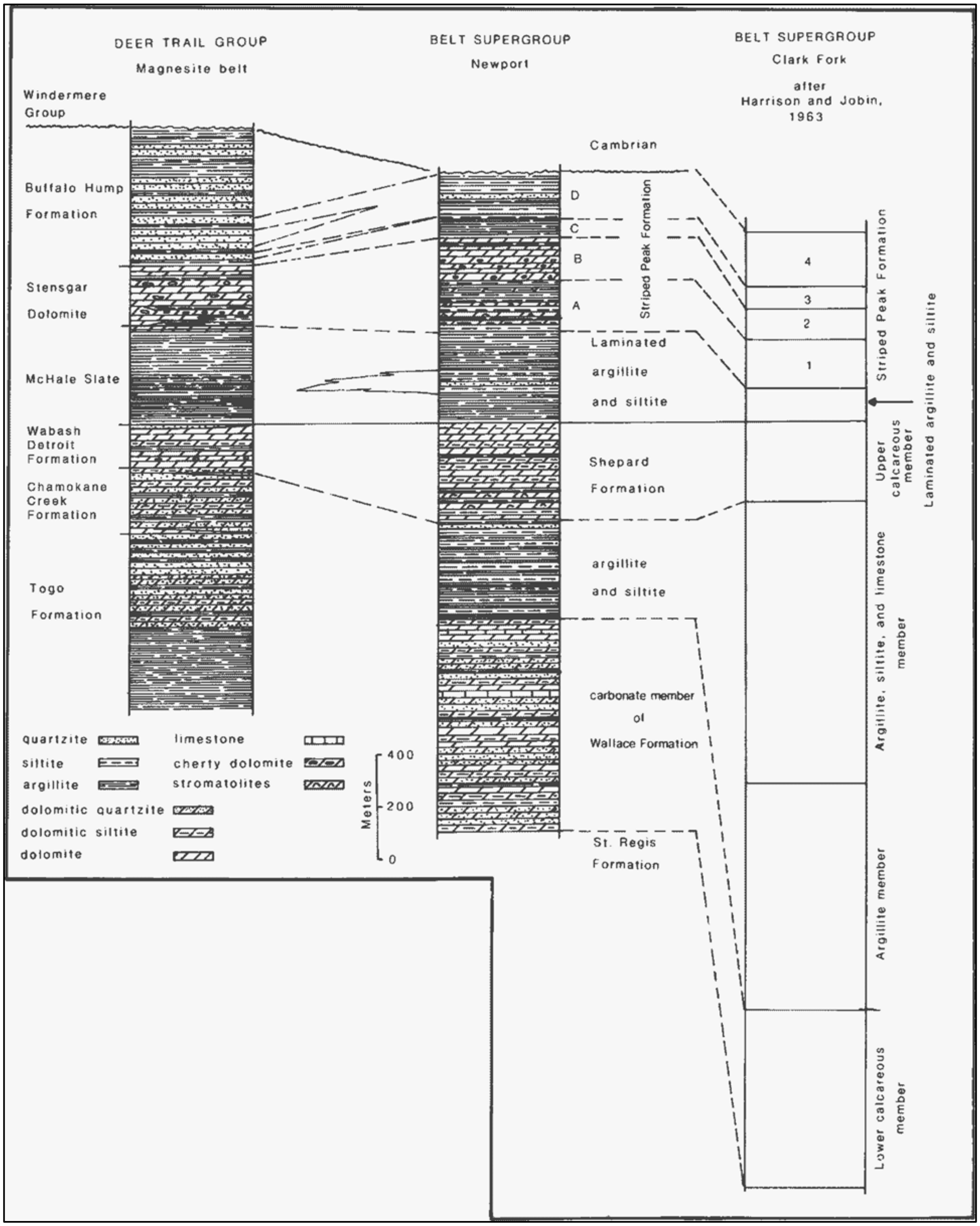


Figure 9. *STRATIGRAPHY OF THE DEER TRAIL GROUP (from Miller and Whipple, 1989).*

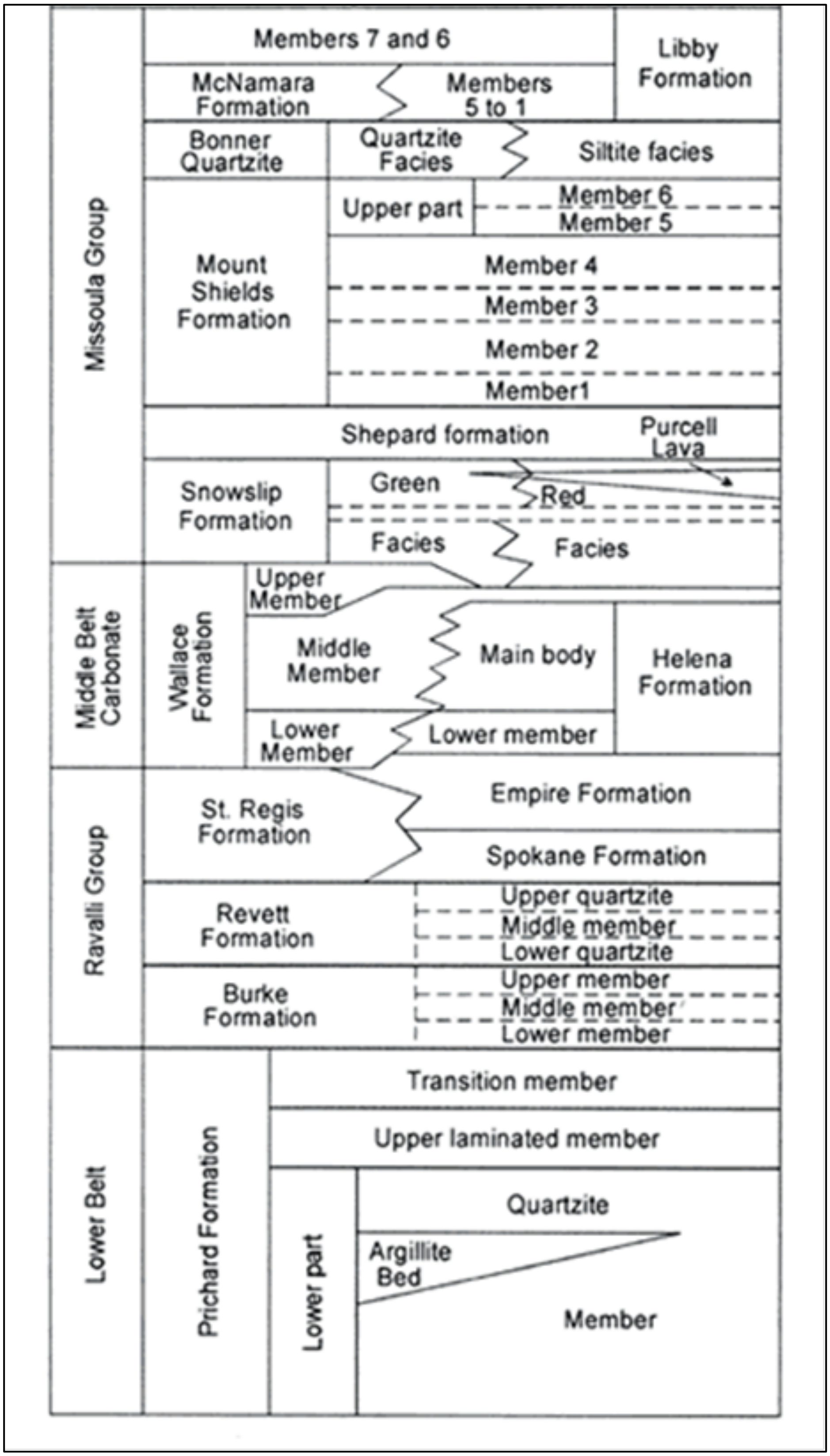


Figure 10. *STRATIGRAPHY OF THE BELT SUPERGROUP (from Harrison and Cressman, 1993).*

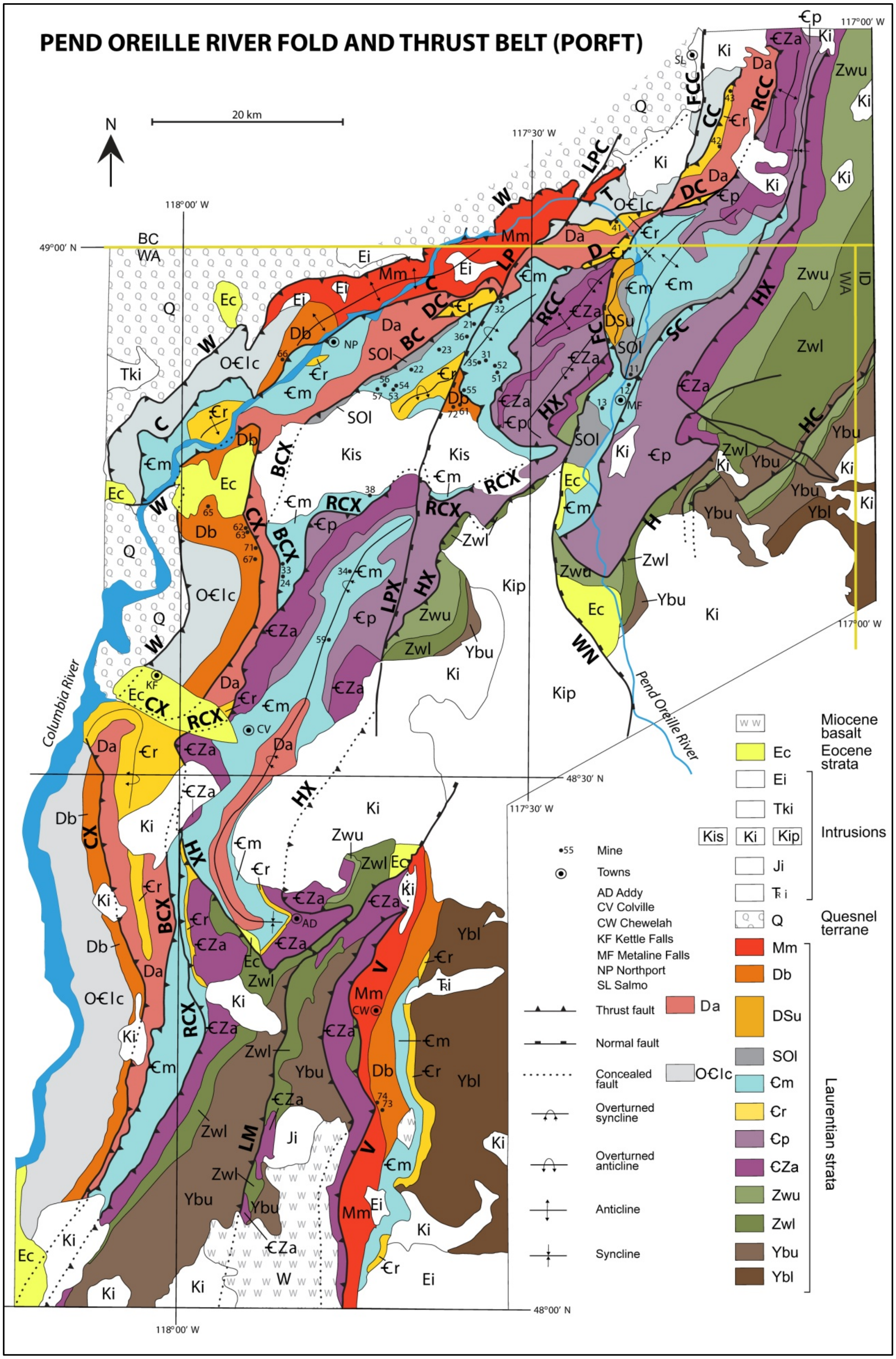

PEND OREILLE RIVER FOLD AND THRUST BELT (PORFT)
N
20 km
117°00' W
117°30' W
118°00' W
49°00' N
48°30' N
48°00' N
BC
WA
ID
Columbia River
Pend Oreille River
Miocene basalt
Ec
Eocene strata
Ei
Tki
Kis
Ki
Kip
Intrusions
Ji
TRi
Q
Quesnel terrane
Mm
Db
Da
DSu
SOl
O€lc
€m
€r
€p
€Za
Zwu
Zwl
Ybu
Ybl
Laurentian strata
Mine
Towns
AD Addy
CV Colville
CW Chewelah
KF Kettle Falls
MF Metaline Falls
NP Northport
SL Salmo
Thrust fault
Normal fault
Concealed fault
Overturned syncline
Overturned anticline
Anticline
Syncline
FCC
CC
RCC
LPC
T
DC
W
LP
C
D
BC
SC
HX
HC
BCX
RCX
CX
LPX
H
WN
LM
V

Figure 11 (previous page). *GEOLOGIC MAP SHOWING THE LITHOSTRATIGRAPHIC UNITS IN THE PEND OREILLE RIVER FOLED AND THRUST BELT (PORFT). Compare with Figure 8, which shows the individual thrust sheets in PORFT. For the names of the faults, see the explanation to Figure 8.*

395, 3.3 miles north of the junction of US 395 and SR 292 near the village of Loon Lake, 35 miles south of Colville on US 395, and 13.9 miles south of Chewelah on US 395.

We will start by examining a southwesterly dipping section of the Ravalli Group of the Belt Supergroup (**Fig. 10**) along the northwestern shore of Deer Lake.

We will not have access to toilet facilities while at Deer Lake.

0.0 Set the odometer at 0.0 miles and proceed eastward on North Deer Lake Road.

1.9 Stay left (north) at the fork in the road.

5.2 Park at the end of the pavement at the end of the northeastern arm of Deer Lake. We are a few km east of the southeastern part of **Figure 7.**

Two vehicles will turn around and proceed 0.5 miles back down the road to leave one vehicle to later transport drivers back to here. We will walk along the paved road 0.5 miles to the parked vehicle.

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

Figure 11 illustrates the stratigraphy of the Belt Supergroup. The Burke Formation underlies the first peninsula to the southwest of us. The parked car is in the Revett Formation. Belt geologists use the following field terms: quartzite if the rock is unscratchable by the steel blade of a knife, siltite if it is slightly scratchable, and argillite if it is easily scratchable. All three lithologies occur on this traverse. We will note differences in bedding thickness and other characteristics of the Burke and Revett formations as we walk up-section.

Miller and Clark (1975) stressed that the characteristics of the formations here are strikingly 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 1/4 m-scale beds, whereas the Revett has predominantly m-scale beds. Quartzites in both formations are rusty weathering, well-sorted, fine-grained, and gray, with mm- and cm-scale color laminations. Laminated argillite in the Burke has some ripple marks. Black spots in some argillites and quartzites may be biotite. Because of its greater abundance of argillite and siltite, the Burke has more visible muscovitic argillite (some with mudchips, interference and symmetrical ripples), small scale folding, and cleavage. The Revett has more cm- to m-scale quartz veins.

Note that significant portions of the Burke, and even the Revett, are covered (and likely underlain argillites and siltites).

6.9 Return 1.7 miles back down the road toward US 395.

STOP 1-2: ST. REGIS FORMATION

Again, Miller and Clark stressed that the St. Regis Formation here is similar to 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 deep purple. Mud chips are most noticeable in the purple rocks.

Consider what the purple color and laminated nature of this rock imply about its age.

10.5 Return to the junction with US 395 and reset the odometer to 0.0 miles. Turn right (north) on US 395 toward Chewelah. As we turn north on US 395, we are about 5 km north of the southern boundary of Figure 7.

0.0 The hillside to left (west) is underlain by the Middle Proterozoic Wallace Formation of the Belt Supergroup.

1.2 Columbia River Basalt Group (CRBG) on left. This is some of the most northerly exposed CRBG in NE Washington. Obviously, a major unconformity occurs below the CRBG.

1.0 Ravines are Pleistocene ice-margin meltwater channels (coulees).

2.2 QOC (middle Cambrian) is on the right (east).

3.0 If doing Optional Stop 1-A, turn right on Roitz Road. Note to the east the prominent ridge/hogback of QOC, which is unconformable on Belt Supergroup rocks.

3.6 Turn right on Solokar Road.

3.8 Start climbing up glacial morainal deposits.

4.1 Drive down and through an ice-margin stream canyon.

4.6 OPTIONAL STOP 1-A: PEASE BARITE DEPOSIT

Park on the left. Note that the deposit is labeled in the southeastern corner of **Figure 7**. Cross the road to the quarry.

Strata of the Belt Supergroup (**Fig. 10**) are exposed in the quarry and adjacent outcrops. Total production was 400 tons for drilling mud (Moen, 1964). Note that the quarry is elongate to bedding and follows a 3 foot wide zone of white to reddish black "bedded" barite (best exposures are at the south end and above). The host consists of thinly laminated, maroon argillite-siltite (some quartzite) with abundant mud cracks, salt casts, and ripples. Determine whether the barite is the same age as the enclosing strata (syngenetic or diagenetic) or is a (hydrothermal) addition to the strata (epigenetic). Belt aficionados will identify these strata as the Mt. Shields Formation within the Missoula Group.

Turn around and return to US 395.

6.0 Turn right (north) onto US 395.

7.8 Turn left (west) on Bulldog Creek Road toward Valley/Waitts Lake.

7.9 Kettle lake on left is within the lateral moraine of the Colville lobe of the Pleistocene Cordilleran ice sheet.

8.2 Turn left (south) on West Jump Off Road. Stay straight on W. Jump Off.

8.9 Ridge on right is of Mississippian limestones.

9.7 Outcrops on right and up the hill are Mississippian limestones.

10.7 STOP 1-3: MISSISSIPPIAN CARBONATES NEAR THE FOOTWALL OF THE VALLEY FAULT

Park in the quarry to the right. We are about 5km SSE of Valley in the unit labeled Ml in **Figure 7**.

This outcrop exposes Mississippian carbonates of North American affinity (a.k.a. Milford Group in British Columbia) in the footwall of the Valley thrust fault. The Milford Group is the youngest Laurentian unit in NE Washington (**Fig. 5**).

This outcrop consists of gray, thinly- to medium-bedded limestone, which is locally fossiliferous with small crinoids stem fragments and fossil hash. Cherty interbeds (1-3 cm) are displaced by multiple high-angle (calcite-filled) faults. Also abundant throughout the outcrop with increasing intensity toward the top (west) is brecciated carbonate with white sparry calcite matrix and calcite-filled veins. Climb to top for nice views of the Colville River Valley to the north. Cheney and Zieg (2015) placed the Valley thrust fault west of this deformed limestone (so that it is overthrust to the west by Addy Quartzite).

The previous interpretation of Miller and others (1975) and Miller (2000) was that the Jumpoff Joe thrust occurs more nearly in the center of the Colville valley. It reputedly juxtaposes westerly dipping strata of the Mesoproterozoic Deer Trail Group over westerly dipping quartzite (originally identified as Addy but here designated as QOC) and the Belt Supergroup. They assigned Pzcq, Pzp, and Pzc of **Figures 4 and 7** to the Deer Trail Group because in the Huckleberry Range 7 to 50 km southwest of Chewelah the Deer Trail Group contains cleaved pelitic rocks, greenstone, and carbonate rocks. Specifically, Miller and others (1975) regarded the greenstones in Pzcq as the intrusive equivalents of the Irene Volcanics of the Windermere Supergroup. Thus, the intruded rocks had to be older still, that is, they had to be representatives of the Deer Trail Group. Cheney and Zieg (2015) noted that these presumed Deer Trail rocks are lithologically similar to the Devonian Bradeen Hill assemblage. If the presumed Deer Trail rocks are Paleozoic, as Weaver (1920) suggested and Cheney and Zieg (2015) inferred from known Paleozoic fossil localities in some of the limestones, the Jumpoff Joe thrust does not exist. The Valley thrust is 2 to 4 km west of where Miller and others (1975) and Miller (2000) placed the Jumpoff Joe thrust.

The map pattern of the Paleozoic rocks east of the Valley fault suggests the presence of two major unconformities. In the Brewer Mountain area of **Figure 7**, Pzcq truncates the quartzite of Chewelah (QOC). Secondly, southward the eastern part of the limestone and pelite belt (Pzp, Pzc, and Ml truncates Pzcq at about the southern boundary of the Valley area. Because Pzcq includes the Devonian Bradeen Hill assemblage, the pelitic belt (with associated Pzp and Pzc) above it to the west must be younger than Devonian (if no faults exist). Significantly, the westernmost belt contains fossiliferous Mississippian limestones (like those at this stop) at its southern end at Springdale. Most likely, this upper belt is the pelite– and limestone-dominated assemblage of the Milford Group that is present in the Salmo district of British Columbia (**Fig. 5**).

The Lane Mountain thrust of Miller (2000) is the major fault of the Colville River fold and thrust belt (**Fig. 8).** The Valley thrust is truncated northward beneath the Lane Mountain thrust (**Fig.7**). In other words, the Valley thrust appears to be a footwall splay of the Lane Mountain fault.

Turn around and return to Bulldog Creek Road.

13.2 Turn left (west) on Bulldog Creek Road toward the town of Valley.

13.6 Stratified sand and gravel occur in the pit on the right. Downslope movement of material obscures the stratification. The road descends into the Colville River Valley, which was occupied by the Pleistocene Colville lobe of the Cordilleran ice sheet.

14.3 Turn right (north) on Highway 231 to Valley. Note the large sand and gravel quarry on the right in a Pleistocene kame deposit.

15.0 The mill and processing plant of Lane Mountain Silica is on the left. Quartzites of the Addy Formation on Lane Mountain to the west supply this mill. The mill eliminates clay and limonite to produce sand for high-quality (clear) glass. Clear glass sands must have a low iron content. Run-of-the quarry rock at Lane Mountain has 0.1 to 0.3% Fe. The iron content is reduced to 0.05 +/- 0.005% by differential froth flotation of the limonite (as in mills that process sulfide ores). Production (as of 2012) is about 400,000 tons per year. The capacity of any railroad cars on the siding is about 160 tons each.

The quartzite generally consists of rounded grains of quartz ≤ 2mm in diameter that are well cemented by interstitial quartz. As a result of this pervasive quartz cement, when crushed the rock breaks into angular grains, which makes it unsuitable for fracking shaly rocks for oil or natural gas.

15.4 Entering the metropolis of Valley, Washington. Note prominent cliffs of tan Addy Formation to the north (we are west of the Valley fault). We will stop at the municipal toilet facility.

15.7 Turn left (west) on the Waitts Lake Road at the main intersection in town.

15.8 Cross the railroad tracks.

15.9 Cross the Colville River. Note the small size of this stream relative to the broad valley. Also note that the Colville flows north toward the apparent highlands “up valley”. Both the Colville River and Pend Oreille River (to the east) have reversed drainage due to the lag time between glacial melting and isostatic rebound.

16.3 **OPTIONAL STOP 1-B: SPRINGDALE END MORAINE**

View to the south shows low-lying hills of the Springdale end moraine, the southernmost extent of the Colville lobe. At this location, the thickness of the ice was approximately 750 m (Carrara, et al., 1996). To the west, the prominent cliff face is the northernmost CRBG in the Colville valley.

17.3 Begin climbing a low hill, A quarry in Stensgar dolomite (Deer Trail Group) is on the right (north).

The Deer Trail Group (**Fig. 9**) is >2 km thick. In detail, the succession consists of argillite, siltite, quartzite, conglomerate, dolomite, and magnesite in lower greenschist facies that was strongly deformed during the Mesozoic (Evans, 1987; Watkinson and Ellis, 1987). In general, the Deer Trail Group is composed of two thinly bedded formations of dark grey to green slate with minor vitreous clean quartzite (Togo Formation and McHale Slate) that record relatively quiet water deposition. These formations are interbedded with two distinctive dolomite formations. The Edna Dolomite (now subdivided into the Wabash Detroit and Chamokane Creek formations (see below)), and the Stensgar Dolomite occur in the lower third and near the top of the Deer Trail Group, respectively. The carbonate units contain algal structures, oolites, salt casts, and layers of chert; they are interbedded with minor amounts of argillite and conglomerate (Campbell and Loofbourow, 1957, 1962; Campbell and Raup, 1964; Evans, 1987; Miller and Whipple, 1989). The Stensgar Dolomite contains deposits of magnesite (one of only two districts in the U.S.) that probably formed by evaporation of seawater (Frank and Fielding, 2003).

The Buffalo Hump Formation is younger than the Deer Trail Group (see below), and so technically it should be removed from **Figure 9**. The formation is composed principally of slate interbedded with lesser amounts of conglomerate and quartzite, some of which is festoon cross-bedded (Evans, 1987). It represents a major increase in the energy of deposition compared to the Deer Trail Group. The thickness of the Buffalo Hump and individual layers within it vary significantly along the strike (Campbell and Loofbourow, 1962; Evans, 1987).

Undated greenstone dikes and sills are common throughout the Deer Trail Group and may be feeders for the lavas in the overlying Irene Volcanics (Campbell and Loofbourow, 1957, 1962; Evans, 1987; Becraft and Weis, 1963). Some of the concordant igneous bodies, which occur at the upper contacts of both the Edna Dolomite and Stensgar Dolomite, may be volcanic in origin (Miller and Whipple, 1989), and a date on these could help determine the minimum age of the Deer Trail Group. An alternative is that some or all of greenstone dikes and sills are intrusions related to the Covada Group or Bradeen Hill assemblage; Smith and Gehrels (1991, 1992) reported that both units contain greenstones.

Prior to 1992, the entire Deer Trail Group was widely viewed as 1.5 Ga-1.4 Ga in age and correlative with the upper Belt-Purcell Supergroup (Wallace and Mt. Shields Formation) (Campbell and Loofbourow, 1962; Becraft and Weis, 1963; Evans, 1987; Miller and Clark, 1975; Miller and Whipple, 1989). This correlation was based only on lithological correlation between the two units, but substantial differences in lithology (i.e., there is no appreciable magnesite in the Belt-Purcell Supergroup) led to considerable uncertainty in how to correlate the two (Miller and Whipple, 1989). The presence of 1070 to1224 Ma detrital zircons in the lower part of the Buffalo Hump Formation (Ross et al., 1992) demonstrates that the Buffalo Hump Formation cannot be older than 1.1 Ga and cannot correlate with the Mesoproterozoic Belt/Purcell Supergroup. As a result, Winston and Link (1993) split the Buffalo Hump Formation from the Deer

Trail Group and retained the correlation of the remaining Deer Trail Group with the Belt/Purcell Supergroup. Evidently, he Buffalo Hump Formation is the remnant of a separate synthem.

18.5 Waitts Lake is on the left. We are now in the Gold Hill thrust sheet of **Figure 7**.

20.0 The view to the west is of Lane Mountain quarry. The ridge to the south is Jurassic quartz monzodiorite of Lane Mountain (Miller, 1996b).

21.4 Outcrops on the right are McHale Slate of the Deer Trail Group.

23.5 On left is the road to Lane Mountain Silica's quarries on Lane Mountain. On the right is an abandoned adit.

23.6 Carrs Corner: go left on Red Marble Road. We are crossing the Lane Mountain fault into the Gypsy Peak sheet of **Figure 7**. Considering the distance from Valley to here, the CRFT is about 8 miles wide here.

25.9 Wetlands on both sides of the road are in the slate-rich Togo Formation.

26.0 OPTIONAL STOP 1-C. CHAMOKANE CREEK FORMATION (FORMERLY EDNA DOLOMITE)

Miller (1996b) formerly defined this carbonate-bearing siltite, quartzite, argillite unit as the lower portion of the Edna Dolomite. Now it is the top of the highest thick, carbonate-bearing quartzite below the predominately dolomitic section of the Wabash Detroit Formation (Miller 1996b). Note the strong cleavage in phyllitic argillite in contact to the bedded dolomites and thick-bedded quartzites. Is there more than one deformational event apparent in this outcrop?

26.1 Red soils mark the Wabash Detroit Formation (formerly upper portion of the Edna Dolomite); see Optional Stop 1-E below.

26.6 Park on the right

OPTIONAL STOP 1-D: MCHALE SLATE, DEER TRAIL GROUP

This small quarry is in McHale Slate and consists of dark gray, well-laminated argillite and slate. Note the cleavage relative to bedding. Look closely for a second (or third?) deformational event recorded by crenulations of the cleavage.

The McHale Slate is named after exposures in McHale Canyon in the Addy quadrangle (Campbell and Loofbourow, 1962). In places argillite is interbedded with light-gray siltite, with some exhibiting graded bedding. Miller and Clark (1975) described some soft-sediment breccias. Dolomitic interbeds (<2 cm thick) occur toward the top of the formation. The total thickness of the McHale Slate is approximately 370 m (Miller, 1996b).

26.8 Outcrops are dark gray to black McHale slate.

27.0 OPTIONAL STOP 1-E. WABASH DETROIT FORMATION

Park wherever there is room.

Here the nose of a fold occurs in dolomites of Miller's (1996b) Wabash Detroit Formation, which he defined as the interval between the base of the lowest dark-gray argillite of the McHale Slate and top of highest thick carbonate-bearing quartzite of the Chamokane Creek Formation. The Wabash Detroit Formation contains abundant stromatolitic beds that are affected by cleavage. Greenstone flows or sills occur "persistently" within the Wabash Detroit unit up to the base of the McHale Slate (Miller, 1996b).

28.4 **OPTIONAL STOP 1-F. UPPER MCHALE SLATE**

Hard hairpin turns to the right; park on right above the turn; outcrop is on left.

Gray to dark gray phyllitic argillite and slate have a well-developed crenulation cleavage that cuts "ghost" bedding with carbonate interbeds. Tension fractures are filled with calcite. Again, is there evidence for more than one deformation in this outcrop?

28.8 Orange-red soils mark the Stensgar Dolomite

29.5 These are the lower benches of the Red Marble Quarry.

30.1 On the left is an access road to the Red Marble quarry

STOP 1-4: RED MARBLE QUARRY, STENSGAR DOLOMITE, DEER TRAIL GROUP

Park on the left. Walk 90 meters, on the left to exposures of steeply dipping McHale slate. Continue 250 meters along the upper bench road to Red Marble Quarry.

This quarry exposes the Stensgar Dolomite, which is a well-laminated dolomite that has been extensively mineralized with magnesite ($MgCO_3$). Small-scale crossbedding in the Stensgar Dolomite suggests deposition in shallow water. At this locality, the Stensgar is intruded by a diabase dike.

The Red Marble quarry is one of numerous magnesite deposits in the Magnesite Belt (Campbell and Loofbourow, 1962). All deposits appear to be within the same stratigraphic interval (middle Stensgar). The Stensgar Dolomite is up to 500 m thick at the Keystone mine (Evans, 1987) and thins to the southwest. The Stensgar Dolomite (where it is not magnesitic) consists of white to light gray laminated to thin-bedded dolomite, with minor silty to argillaceous interbeds.

The Red Marble quarry produced from 1949 to the early 1980's. It contains refractory-grade magnesite and is thought to have contained over 5 million tons of ore. The magnesite occurs as a lens up to 150 m thick and 1000 m long that is, overall, stratabound within the Stensgar Dolomite. In recent years the quarry has produced decorative rock.

The magnesite occurs in a variety of colors from gray to blackish-gray to red. Textural varieties include massive, coarse sparry, fine-grained, bedding parallel, "spotted" and "zebra-like". Spectacular solution breccias are in the southeastern bench faces at mid-level. In places the magnesite clearly crosscuts bedding within the dolomite.

The origin of the magnesite deposits is uncertain. The original purity of the Stensgar Dolomite may be a controlling factor, with the host horizon of the Stensgar having the least amount of pelitic or silicic impurities. Early workers suggested a hydrothermal replacement origin possibly associated with regional igneous activity. Arguments against igneous-related hydrothermal replacement are that no magnesite mineralization occurs within any other dolomitic units within the Deer Trail Group. An alternative interpretation is the recrystallization and remobilization of syndepositional magnesite as the result of an elevated geothermal gradient during tectonism (Frank and Fielding, 2003).

30.6 This is the contact with the Buffalo Hump Formation, which is stratigraphically above the Stensgar Dolomite. The Buffalo Hump Formation is composed mainly of slates (poorly exposed) and quartzites; it is at least 750 m thick (Campbell and Loofbourow, 1962). Black to brownish gray slates dominate the unit with Iinterbedded white to pale gray, light-brown, fine to coarse-grained quartzites. Interbeds of quartz pebble conglomerate occur within the unit, with clasts flattened parallel to cleavage. Evans (1987) reported 4:1 stretching ratios for clasts that plunge to the NNE.

The Buffalo Hump Formation is named after the characteristic assemblage exposed in the prominent knob (the Buffalo Hump) south of Huckleberry Creek, over which passed the aerial tram from the Finch quarry to the Keystone and Red Marble quarries. The tram was built by Northwest Magnesite Co.to transport the ore to the milling facility near Chewelah.

30.7 Stop at outcrop.

OPTIONAL STOP 1-G: QUARTZITE OF THE BUFFALO HUMP FORMATION

The rock is thick-bedded, coarse-grained, clean, white quartzite.

31.2 This is the trace of the Stensgar thrust of Evans (1987) and Miller and Yates (1976). This "thrust" places the younger Irene Volcanics over the older Buffalo Hump Formation, a relationship that is more compatible with an unconformity (Campbell and Loofbourow, 1962; Cheney and Zieg, 2015).

31.4 Outcrops are of diamictite in the Irene Volcanics (Windermere Supergroup).

31.6 The road crests at the Stensgar Mountain saddle. Park in the saddle. Weather-permitting, we will eat lunch here after doing Stop 1-5.

STOP 1-5: IRENE VOLCANICS AND TOBY FORMATION, (WINDERMERE SUPERGROUP

Beautiful views to the west are of the Huckleberry Mountains in the foreground with Lake Roosevelt (the Columbia River behind Grand Coulee dam), the southern portion of the Kettle MCC (to the northwest), and the Lincoln MCC to the southwest. Walk back down the road approximately 200 m. Cross the contact (not exposed) with greenstone (Irene Volcanics) above conglomerate of the Toby Formation (**Fig. 6**).

The Toby Formation) is up to 480 m thick and contains diamictite, conglomerate, siltite, argillite and lithic quartzite (Miller, 1996b). The diamictite and conglomerate are pale green to gray, matrix-supported, and dominate the unit. Clasts are of Deer Trail lithologies and consist of dolomite, argillite, siltite, and quartzite. Clasts are flattened. On BC Route 3 east of Salmo, some clasts are >10 m.

The Toby Formation is the lower of two diamictitic units within the Windermere Supergroup (Miller, 1996; Lund and Cheney, 2015). Lund and Cheney (2015) concluded that the diamictites of the Toby Formation are generally correlated with the globally recognized Sturtian glacial diamictites associated with Neoproterozoic Snowball Earth.

Drastic changes in the thickness of the Toby Formation along strike are caused by unconformities (**Fig. 6**). Note in **Figure 6** that the unconformity below the Addy Quartzite progressively eliminates the Windermere Supergroup to the southwest.

The view from here is instructive. Visible 8.4 km to the east is the silica quarry in Addy Quartzite on the top of Lane Mountain. The Red Marble quarry (Stop 1-4) is in the foreground to the left. All of the strata from Lane Mountain to here dip westward, which means that the Mesoproterozoic Stensgar Dolomite at the Red Marble quarry and the Neoproterozoic Toby Formation here are above the younger (Neoproterozoic to Cambrian) Addy Quartzite. This older-over-younger situation is caused by the Lane Mountain thrust, which passes along the western base of Lane Mountain (**Fig. 7**). Hills in the far distance are in the Priest River MCC

32.1 Continue up towards the summit of Stensgar Mountain. Outcrops of greenstone flows, tuffs, and volcaniclastic rocks are of the Irene Volcanics.

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32.2 Park above the outcrop near the switchback and walk back down.

OPTIONAL STOP 1-H: IRENE VOLCANICS

This stop is optional because Stop 1-8 is better. Note that the greenstones have chlorite-filled vesicles

32.6 Contact between Irene greenstones and the overlying Addy Quartzite.

32.7 Park at switchback; if in caravan of numerous vehicles, pull well into side road to north; this will be the turnaround point. Another option is to continue to the summit of Stensgar Mtn. for scenic views and to examine Irene greenstones on the north side of summit. A cell tower at the summit makes for good reception for those that need their hourly cellular phone fix. Walk up the road to prominent outcrops of Addy Quartzite.

STOP 1-6: ADDY QUARTZITE

The following description is from Miller (1996b). This is the Lower Member of the Addy Quartzite, which in this area is about 150 m thick. It is white, medium-grained, and vitreous, with a few cross beds. Beds are thick and massive (little internal stratification); minor interbedded argillite exists.

Cheney and Zieg (2015) pointed out that unlike the QOC, the Addy Quartzite does not have a basal conglomerate.

The unconformity between the Addy Formation and underlying Precambrian rocks is commonly referred to as a breakup unconformity, which records subsidence and sea level rise as the passive margin became fully developed and moved away from the rift. However, major unconformities occur at both the base of the Windermere Supergroup and the base of the Addy Quartzite (**Fig. 6**). This implies two rifting events, one in the late Neoproterozoic (about 0.7 Ga) and another in the latest Neoproterozoic (about 0.57 Ga).

Return to Carrs Corner.

42.4 Turn right at Carrs Corner back towards Waitts Lake.

42.5 OPTIONAL STOP 1-I: MONK FORMATION CONGLOMERATE AND LANE MOUNTAIN FAULT

Park on the left across from Lane Mountain Silica's quarry road. Because this is private property, seek permission from residents at the house at Carrs Corner. Proceed to outcrops (north) adjacent to abandoned adit.

Here the Lane Mountain fault thrusts the Togo Formation (Deer Trail Group) over the Monk Formation (upper Windermere Supergroup) conglomerate (Miller, 1996b). At the adit, Monk Formation dolomite (white to gray) with stretched pebble conglomerate occurs on the southeast. Miller (1994) informally subdivided the Monk into 3 members; Argillite member, Greenstone member, and Conglomerate member. In the latter he described a conglomerate with a khaki siltite/argillite matrix on the west side of Lane Mountain. He also described a matrix-supported diamictite in the conglomerate above the Greenstone member. The diamictite has a tan carbonate-bearing to dark green siltite/argillite matrix with a volcaniclastic component. Miller did not describe the lithologic variation of the clasts. Near Waitts Lake he described the Conglomerate member as a megabreccia with angular blocks of dolomite.

This Monk diamictite probably correlates with the Marinoan-aged Snowball Earth glaciation (635 Ma). One interesting point regarding Snowball Earth is the absence of a carbonate cap that typically followed the Snowball deep freeze event. Carbonate caps for the Sturtian-aged Snowball are "less well developed than the Marinoan ones" and that may be because the Sturtian oceans were "less oversaturated with $CaCO_3$ at the time of glacial termination" (P.F. Hoffman, personal communication). An alternative is that the Irene (and Monk) diamictites represent either very deep basinal environments (reverse solubility of $CaCO_3$) or subaerial deposition. A third interpretation may be that the white carbonates adjacent to the Monk conglomerate are, indeed, a carbonate cap.

Return to Valley via Waitts Lake Road.

0.0 At the intersection with Highway 231, reset odometer and turn left (north) toward Chewelah.

0.3 The prominent outcrops of Addy Quartzite on the right are in the hanging wall of the Valley thrust (**Fig. 7**). .

3.3 Junction with Highway 395. The Addy Quartzite is now behind us, We are now in the footwall of the Valley thrust Turn left (north) toward Chewelah.

5.2 Note (for your next rip) the Chewelah Casino on the right.

5.4 Enter the Texaco truck stop on the right and drive to the northeastern corner of the site.

STOP 1-7: QUARTZITE OF CHEWELAH (QOC)

To the northeast is Quartzite Mountain, a flatiron of QOC, the Quartzite of Chewelah (Cheney and Zieg, 2015).

This hogback may be photogenic but its tectonic significance is greater. We are in the footwall of the Valley thrust, which is the boundary between the craton to the east and the miogeocline to the west**!** .

On the craton, the Windermere Supergroup and Sauk I are absent, so that Sauk II is unconformable on either the Belt Supergroup or on pre-Belt crystalline rocks (Ballard and others, 1983). The base of the Sauk II in Montana is the Flathead Quartzite; its equivalent here is the QOC in the hogback. **Figure 7** shows that east of the Valley thrust, QOC is unconformable on the Belt Supergroup.

In contrast, the regional stratigraphy of the Tricorner northwest of the Valley fault is typical of westernmost pre-Jurassic North America. Correlatives of the Windermere, Sauk I, and Sauk II occur in southeastern California, east-central Nevada, west-central Utah, and north-central Utah, southeastern Idaho, and southeastern British Columbia (Link, 1993; Wheeler and McFeeley, 1991; Höy and et al., 1995; Reesor, 1996; Höy and Dunne, 2001; Lund and et al., 2003; Lund and Cheney (2015). Furthermore, two Cambrian quartzites exist in Nevada and southeastern California; the Zabriskie Quartzite is Middle Cambrian, whereas, the Prospect Mountain and Sterling quartzites are early Cambrian to Neoproterozoic (Hintze, 1985, Link and et al., 1993).

Return to US 395 and turn right (north) toward Chewelah

6.2 The tall chimney on left marks the remnants of the mill of the Northwest Magnesite Co. The magnesite was produced from the Red Marble (Stop 1-4) and other quarries

7.4 Entering Chewelah.

11.2 Addy Quartzite of Sauk I is on the right. Multiple belts of Addy Quartzite from here to Stop 1-8 are caused by repetition in the Colville River fold and thrust belt, which US 395 crosses almost perpendicularly (**Fig. 7**).

12.7 Quarry on right is in Stensgar Dolomite.

13.7 We are following the course of the Colville River northward; note how the valley narrows "downstream" toward highlands.

Drive just past a prominent and green roadside outcrop; park on the right across from the road to Blue Creek, WA. On **Figure 7**, we are at the conspicuous bend in the highway about 3.5 km south of Addy in the hanging wall of the Lane Mountain thrust.

13.9 STOP 1-8. GREENSTONES OF THE IRENE VOLCANICS

Units in the nearly vertical greenstone flows of the Irene Volcanics are difficult to distinguish. The greenstone is tholeiitic basalt and contains relict pyroxene and plagioclase phenocrysts (Miller and Clark, 1975). Epidote is common. Look midway up the road cut for stretched pillows. Also note the presence of chlorite filled vesicles. Near the south end of the road cut are styolitic quartz and calcite veins; elsewhere in the world such veins are typical of mesothermal gold-bearing veins in greenstones. A fault zone occurs on the north end of outcrop, with well-formed breccia.

Continue north on US 395 toward Addy and Colville

15.1 Irene greenstones are on the right.

15.2 Addy Quartzite makes rounded and polished (with striations) outcrops on the right. Note glacially sculpted knob of Addy to the west.

16.2 Turn left on Gifford Road. Ahead is the thriving metropolis of Addy, Washington. Follow Gifford Road south of town, across the Colville River, and below the prominent ridge on the right to a large roadcut on the right at the end of the ridge.

16.6 Park in the pull-off to the left. On **Figure 7** we are just southwest of Addy.

STOP 1-9. Addy Quartzite.

Recent road "straightening" created a nearly vertical roadcut. Miller (1996a) mapped these strata as the Upper member of the Addy Quartzite composed of "interbedded vitreous quartzite and argillite with minor siltite". The quartzite beds are white to gray with planar to wavy bedding with some cross beds. The quartzite is medium to fine-grained. Rubble adjacent to the parking area provides good samples and photographs of the various lithologies,

Here, the Upper Member has the lowest Cambrian trilobite *Nevadella addyensis* and is bioturbated (Miller, 1996a; Dutro and Gilmour, 1989). Additionally, the brachiopod *Kutorgina* has been reported from Addy Quartzite outcrops toward the north end of town (Glen Schofield, personal communication). These fossils in the top of the Addy Quartzite indicate that the bulk of the Addy Quartzite is latest Neoproterozoic (which is to say, that no significant unconformity occurs at the base of the Cambrian).

Continue west on Gifford Road

17.1 To the right is the road to the entrance to the inactive plant of Northwest Alloys, which refined magnesium alloys for Alcoa. On our return trip, time permitting, we will discuss the history of the plant, especially how it instigated nuclear power in Washington in the 1970s.

18.0 Follow Gifford road as it turns left (south).

19.0 Park at the corner of Kerner Road and Gifford Road. Walk back uphill on Gifford Road to a 200 m-long road cut.

STOP 1-10: FOLDS AND THRUSTS IN METALINE FORMATION

The rocks are dark gray limestone in Miller's (1996a) "thick- and thin-bedded member" of the Metaline Limestone. The outcrop has three domains, all of which exhibit a general dip to the northwest. In general, thrust faults dip to the southwest and movement on half folds show motion to the northeast. The southern domain is dominated by thickly bedded limestone. The middle domain consists of thinly bedded limestone with variable folding (tight and broad) cut by several faults; a 2 meter zone exhibits bedding- (and thrust-) parallel disturbance. The northern domain contains a broad synclinal fold composed of thinly bedded limestone and is cross cut by several thrust faults. Note the numerous nearly vertical gash veinlets. Field evidence, including numerous drag folds, indicates that movement along the thrusts was directed to the northeast. Note also smaller (and more subtle) southeast dipping isoclines within some of the limestone beds

A possible interpretation of this road cut is that it is in the hanging wall of the Lane Mountain thrust and that its major folds and thrusts indicate eastward movement on the fault. In contrast, the southeast dipping isoclines record somewhat earlier westward movement on PORFT.

Do collect a small sample of the limestone to compare with the Metaline Formation at Optional Stop 1-J, and, especially, at Stop 2-2.

Return to Highway 395, reset odometer, and turn left (north) toward Colville.

0.0 At the junction of Gifford Road and US 395 turn left of US 395 toward Colville.

Addy Quartzite is in the hillside and cliffs to the right (east). Sparse fossils are in the upper member of the Addy Quartzite on the south end of the hill west of town.

1.9 Addy quartzites are on right.

3.3 Glacial lake deposits and hummocky outwash terrain are underlain by Cretaceous granite.

5.9 Cretaceous granites with a ridge of Metaline Formation are to the north.

9.5 Old Arden Highway is on the right, with a ridge of Metaline and Ledbetter formations.

10.6 The high ridge to the right consists of limey argillite of the Ledbetter Slate (Ordovician).

11.4 Road cuts are Metaline Formation carbonates.

12.1 Park on the right shoulder.

OPTIONAL STOP 1-J: METALINE FORMATION LIMESTONES WITH CARBONACEOUS INTERBEDS

This outcrop is a fairly "typical" occurrence of well-bedded grey limestones of the Metaline Formation. Its proximity to the Ledbetter Formation suggests that this is the upper limestone member of the Metaline Formation in Sauk III (**Figs. 4 and 5**). Miller (1996a) mapped numerous informal members of the Metaline Formation, including (from older to younger) a limestone and carbonate-bearing quartzite, dolomite beds, thick- to thin-bedded limestone member, and upper shaly limestone member.

At this locality the Metaline exhibits thin to thick bedding of a gray to dark limestone with carbonaceous interbeds. Note the mild folding within the outcrop. Do collect a sample to compare with the unit at Stop 2-2 of Day 2.

12.8 Entering Colville. This is the end of Day 1. Benny's Colville Inn is on the right (eastern) side of Highway 395 just south of the traffic circle on the south side of town.

DAY 2: NORTHWEST OF COLVILLE

Day 2 will begin by examining lower Paleozoic rocks, including distal Laurentian ones. The trip will then examine Permo-Triassic rocks of Quesnellia, and it ends on the eastern margin of the Kettle MCC west of Kettle Falls.

0.0 At the intersection of US 395 and Williams Lake Road about 2 miles northwest of Colville set the odometer at 0.0 miles and proceed northwest on US 395

1.3 Opposite the intersection with Spanish Prairie Road is the reclaimed mill site (and reclaimed tailings) of the Bonanza mine of Stop 2-4.

2.5 Pull into quarry on the right.

STOP 2-1: CONGLOMERATE OF THE BRADEEN HILL ASSEMBLAGE

This is distal "black crap" (in the Waneta sheet west of the Columbia thrust). Note that the foliation dips southeastward.

Smith (1991) described similar chert conglomerate 25 km to the southwest as indicative of the Devonian Bradeen Hill Assemblage of **Figures 4 and 5**. There (Smith, 1991, p. 3) the "unit consists chiefly of thick, massively bedded, matrix-supported conglomerate. Pebbles are dominantly well-rounded to subangular, gray to black, and rarely white or greenish chert and siliceous argillite, with lesser amounts of sandstone, shale, and vein quartz clasts. Matrix sandstone is chert-quartz arenite, with quartz, chert, argillite, siltstone, sandstone, plagioclase and microcline clasts in descending order of abundance."

Turn around and return southbound to Williams Lake Road.

5.0 Turn left onto Williams Lake Road. Reset Odometer to 0.0.

0.0 Here the Colville Valley is underlain by a faulted inlier of regionally extensive Eocene volcanic and sedimentary rocks.

0.8 To the left (northwest) across the valley, is a quarry in rocks of the black shale belt. In contrast, the ridge on the right (east) is composed of carbonate rocks of the Metaline Formation. A major thrust fault (RCX in **Figure 8**) in the valley separates distal North American sedimentary rocks (black crap) on the west from miogeoclinal strata of the Cambro-Ordovician Metaline Formation.

5.7 Turn right on Clugston-Onion Creek Rd.

6.5 Stop at small outcrops.

OPTI0NAL STOP 2-A: ARGILLITES OF THE COVADA GROUP

These rocks are lumped with the Covada Group (**Fig. 5**); they are dominated by argillites with interbedded cherts, tuffs, and pillow basalts (Mills, 1983). They contain late Early Ordovician conodonts, trilobites, and brachiopods (Snook and others, 1981). Directly east of this locality, the package is dominated by argillite and greywacke with minor interbedded chert. Smith and Gehrels (1991) reported 1.76 to2.7 Ga detrital zircons from the Covada Group, which is consistent with derivation from the North American craton.

Continue northeast on Clugston Creek Road.

13.0 Park on the left near the far end of a long road cut at a bend in the road.

STOP 2-2: METALINE FORMATION AND LEDBETTER SLATE

This is the upper limestone member (here fine-grained marble) of the Metaline Formation (**Fig. 5**). Rather than climb the road cut, look for textures at the base of road cut and in the large blocks near its southern end. Compare the texture of the Metaline Formation here to the Metaline Formation south of Colville at Stop 1-10 and Optional Stop 1-J.

Dutro and Gilmour (1989) reported Early to Middle Ordovician conodonts from the upper 100 ft. of the Metaline Formation here. Here, the Metaline Formation is moderately recrystallized and foliated (look for mm- to cm-scale isoclines outlined by more dolomitic, lighter-colored folia). Veinlets filled with sparry calcite are perpendicular to the foliation (and the axial planes of the isoclines). Rocks (and MVT Zn-Pb ores) in Van Stone mine about 6 miles east of here are similarly well deformed (Mills, 1977).

Although the Spirit pluton crops out about 0.5 miles up the road from here, megascopic evidence of contact metamorphism is lacking here. The Metaline Formation here (and at the Van Stone mine) is deformed because structurally it is well below the Russian Creek thrust.

Two important points to note here are that we are still in the miogeoclinal rocks and those rocks become progressively more deformed below the Russian Creek thrust.

On the south end of the outcrop The Metaline Formation is in fault contact with the stratigraphically higher, graptolite-bearing Ledbetter Slate. Graptolites of the *Dicranograptus clingani* Zone are present throughout the Ledbetter (Dutro and Gilmour, 1989).

Note how downhill creep affects the dip of the Ledbetter Slate.

Turn around and return back toward the Williams Lake road.

15.1 Park in an abandoned quarry on the right.

STOP 2-3: BLACK CRAP

Although Dutro and Gilmour (1989) described this exposure as highly contorted Ledbetter Slate, note that it seems to lack graptolites and locally is too hard to be carbonate rock. The rock appears to be more deformed than the limestone at the last stop (but this may, in part, be a function of different lithologies: remember the presence of foliations and isoclines in the limestone). Although the shaly rock here is very well deformed "black crap" (possibly even including Ledbetter), it is not quite fubarite.

The discontinuous nature of the thinly bedded, dark gray to black slaty beds is due to faults and ruptured folds. Because the folds are difficult to access and are not really visible in three dimensions, their vergence is not obvious. However, the axial planes dip shallowly and the folds seem to verge westward. What could have caused such mayhem?

Continue south back to the Williams Lake road. Reset your odometer at the junction.

0.0 At the intersection of Williams Lake (Echo Valley Rd.) with Clugston Creek Road; turn right (north).

0.3 The mountain ahead on the right is composed of limestone and argillites with pillow lavas possibly of the Butcher Mountain Formation of the Covada Group (**Fig. 5**). The nearly horizontal top of the mountain is composed of limestone.

5.0 Turn left (west) on Evans Hill Cut Off Road.

7.0 Turn right (north) on Bonanza Hill Road and proceed uphill

7.8 Turn sharply right on a minor unmarked road that contours around the hill for about 0.2 miles to the reclaimed site (applause, please) of the Bonanza mine.

STOP 2-4: BONANZA MINE

No outcrops are nearby, and no photogenic buildings and few mining relics survive. However, some ore samples occur on the south side of the road. The following description of the deposit is from Mills (1985a).

Samples consist of stinger, to semi-massive, to massive banded steely galena (< 1mm in grain size) with some pyrite, pyrrhotite, barite, and bull quartz. Intermittent production from 1907 to 1952 produced 102,000 tons, grading 12% Pb, 0.1 % Zn, 0.01 % Cu, and 72 g/t Ag. The ore generally is 2 to 2.5 m thick and concordant with black graphitic phyllite in a northward plunging antiform. Due to minor folds in the antiform, dips of the sulfide zone vary from 25 to 55 degrees. The sulfide zone ranges from a few cm to 6 m thick, with the greatest thickness in the hinges of folds. Mills (1985a) identified the Bonanza as a sedimentary-exhalative (sedex) deposit. Such bedded deposits are major producers of Pb, Zn, and Ag. Some sedexes grade outward from a sphalerite-rich (ZnS-rich) core to more distal galena-rich zones. Paleozoic sedexes commonly grade laterally into, or are capped by, bedded barite.

Sedex and bedded barite deposits typically form around white smokers located on faults in thick, pelitic, trailing-edge environments. Possibly, the Bonanza is stratigraphically related to the belt of bedded barite deposits in the Bradeen Hill assemblage (black crap); the belt extends from the Clugston Creek Road to Northport (Moen, 1964; and Mills et al., 1971). So far, the Bonanza is the only known sedex in northeastern Washington. Contemplate the components of an exploration program. Also contemplate the political opposition that might arise from the mining of a significant discovery.

Return downhill to Evans Cut Off Road.

8.8 Evans Cut Off Road. Turn right (westbound). The Bonanza mine is almost the farthest west representative of Laurentia at this latitude. In the next mile westward along the Evans Cut Off Road, look for the Waneta thrust fault, which places Laurentian strata over Quesnellia.

11.0 At the junction with SR 25 turn left (southbound).

11.3 Welcome to the hamlet of Evans. We are in Quesnellia!

For the next mile, outcrops and quarries on both sides of the road (and in the bluffs to the east) are in Permian limestone. The limestone is fine-grained, gray, and has minor quartz pods and stringers. It also has some isoclines parallel and perpendicular to faint bedding.

According to Mills (1962), the quarries operated from 1912 to 1953. The $CaCO_3$ content of the rock varies from 71 to 98%. Material above 97% was suitable for the manufacture of cement (which is to say, selective mining was necessary to achieve > 97% $CaCO_3$. Production ceased because of the high silica content (1.5 to 3.5%.) and high phosphorus content (up to 0.05% P_2O_5) made the rock uneconomic at a time when producers were transitioning to larger and purer deposits closer to markets or cheaper transportation systems.

16.8 The village of Marcus is on the right (west).

Note that for the next 1.4 miles the rocks are white to slightly rusty weathering and make bold road cuts

18.2 Pull into Pingston Creek Road on the left and park. (MP 84.6 of SR 25)

STOP 2.5: LISTWANITE

This white weathering rock is fine-grained, pearly gray, and gneissic. It has minor quartz veinlets and ≤1% pyrite as disseminations and stingers. Minor light green stains are not malachite, but they do provide a clue to the identity of this enigmatic rock.

Geochemical analyses are a quick method of identifying the protolith of this rock. It has 1890 ppm Cr and 1690 ppm Ni; such high values are diagnostic of ultramafic rocks. This identification is support4d by 8.63 % Mg, 10.25% Ca and < 0.02 % K and Na. The rock is a listwanite, a carbonated ultramafic rock. Listwanite is primarily composed of magnesite, dolomite, and quartz. The green stain is the chrome mica, fuchsite. Ultramafic rocks are, of course, characteristic of accreted terranes.

The mapped extent of this listwanite is 1400 m along Lake Roosevelt and 400 m wide at Marcus. Its extent under the lake is unknown. Ultramafic rocks (including listwanites) in accreted terranes mark faults. The major fault in Quesnellia west of the Kettle MCC is the Chesaw thrust, which is marked by multiple bodies if listwanite (Cheney et. Al, 1994), all of which are considerably smaller than this body at Marcus. Perhaps this body and ultramafic rocks near Orient and Rossland, BC, mark the repetition of the Chesaw thrust on the eastern side of the antiformal Kettle MCC (Cheney, 2014).

Continues southbound on SR 25.

19.5 Park on right.

OPTIONAL STOP 2-B: TRIASSIC GREYWACKES AND SILTSTONES OF QUESNELLIA

Interbedded, rusty, medium-grained chert-bearing greywacke is interbedded with siltstone and black argillite. The beds are cut by strongly altered (and deformed), sulfide-bearing leucocratic dikes. The dike rocks have abundant fractures and the greywacke beds are folded into a broad synform.

20.8 Park on marrow shoulder adjacent to Lake Roosevelt (at MP 82.0 of SR 25)

STOP 2-6: SEDIMENTS OF GLACIAL LAKE COLUMBIA

Admire rhythmic sediments of Glacial Lake Columba. The lake was caused by an ice dam on the Columbia River downstream from the present site of Grand Coulee dam (about 180 km downstream from here). Overflow from the lake carved the Grand Coulee south of the dam. The level and extent of the lake varied as the ice north of it receded.

The altitude of SR 25 here is about 410 m. The normal level of Lake Roosevelt is 393 m.

The maximum level of Glacial Lake Columbia obviously was higher than these rhythmists. We have noted locally preserved portions of similar sediments as high as 500 m near Northport. For comparisons, the spillway of the glacial lake into Grand Coulee (present Banks Lake) is at an altitude of 479 m, rhythmists do occur at Banks Lake, and the rim of the Grand Coulee near Coulee Dam is 719 m, which is the maximum possible level of Glacial Lake Columbia. Colville and Chewelah in the valley of the Colville River are at altitudes of 491 and 509 m, respectively. East of Spokane, Kienke and Buddington (2007) described rhythmites at altitudes of 681 and 689 m.

Continues south on SR 25

21.7 At the junction with Highway 395 and Highway 25 turn right (west) on US 395.

The hills to the west are the Kettle MCC. Note the easterly dipping slopes of the mylonitic gneisses.

Before crossing the bridge, St. Paul's Mission is on the right; this Jesuit Mission church was established in the Hudson Bay Company's Columbia District in the 1830's, near HBC's Fort Colville.

24.1 While crossing the river, gaze to the right and imagine what was said to be the most important Native American salmon and steelhead fishing site along the Columbia River, Kettle Falls. Here, 1000 to 2000 Indian fishers came annually to line the banks adjacent the falls, fishing for salmon and steelhead. Explorer and fur trader David Thompson observed natives fishing at many sites along the Columbia and wrote that "Kettle Falls had by far the largest population of Indians all heavily dependent upon the salmon." Thompson named the falls Ilthkoyape Falls and the Indians who fished there the Ilthkoyape Indians. These are among the forebears of Indians who are today are organized as the Confederated Tribes of the Colville Reservation. Kettle Falls and the great upper Columbia fisheries were exterminated by the completion of Grand Coulee Dam by 1940, which flooded the area, impoverished the Indians, and created present-day Lake Roosevelt.

24.6 Barney's Junction is beyond the bridge (do not turn north on US 395). Park next to the restaurant.

STOP 2-7: MYLONITIC GNEISSES AND AMPHIBOLITES OF THE KETTLE RIVER DETACHMENT FAULT

Walk approximately 0.1 mile north to the roadcut and railroad cut. We will start on the west side of the highway.

This stop examines rocks of the eastern mylonitic margin of Kettle MCC. The MCC is composed of pre-Cenozoic metamorphic rocks and Tertiary foliated and unfoliated granitic intrusion, The metamorphic rocks of the Kettle MCC are collectively known as the rocks of Tenas Mary Creek (Orr and Cheney, 1977, Cheney 2014). The metamorphic rocks consist of two orthogneisses and two thick quartzites in biotitic gneiss and schist (Table 1). This stop is on the eastern margin of the Kettle MCC in the structurally higher orthogneiss and quartzite.

The following is the description from Fox and Wilson (1989) from their Stop 7:

> "West of the road, amphibolitic gneiss overlies mylonitic granitic gneiss and pegmatite. Layering and foliation are concordant, dipping 17^{o} east. All rocks are penetratively lineated, the lineation lying in the

> plane of foliation and trending 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. The amphibolite is mottled by lenses of coarse-grained amphibolite (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 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, are exposed in cross-section. A small white boudin above the prominent fold in the central part of the cut trends approximately N76°E."

This mylonite zone is the ductile portion of the Kettle River detachment fault (Rhodes and Cheney, 1981). Missing are the late stage chlorite breccias characteristic of many MCC's, but faint chloritic alteration appears to overprint the amphibolite facies rocks. Presumably, this chlorite is due to proximity to a chloritic breccia zone of the Kettle River fault, which, before erosion, may have been only a 100 m (or so) structurally above this locality.

Return to vehicles and proceed north on Highway 395.

25.1 Kifer Road is on the left (west). Turn around here and park.

STOP 2-8: FOLDED AND MYLONITIC EASTERN QUARTZITE OF THE KETTLE MCC

This is the (upper) eastern quartzite of Table 1. It has centimeter-scale banding, is very fine-grained (almost porcelainous), and slabby, which are characteristics of mylonitic quartzites. Gently dipping planes of foliation have a lineation that is N75°E (+/-10°). Look for isoclinal folds. The lineations are subparallel to the axial traces of the folds.

This and the previous stop are within the mylonitic zone of the Kettle River detachment fault. On the eastern limb of the Kettle MCC (Rhodes and Cheney, 1981), this mylonitic zone is up to 4m thick.

The presence of this quartzite and a thicker one in the center of this antiformal MCC show that the metasedimentary rocks are of Laurentian origin. Based on the ages of detrital zircons, the quartzites in the complex, most likely are Cambrian (Ross and Parish, 1991).

This is the end of field trip. Drive safely to Seattle or Spokane.

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