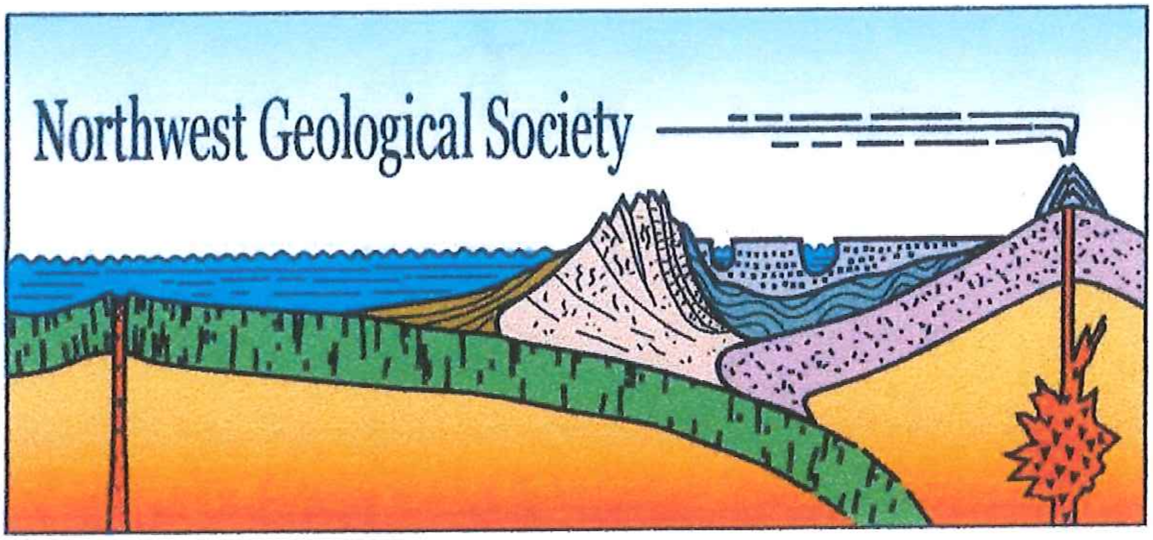


Society Publications in Pacific Northwest Geology

FIELD TRIP GUIDEBOOK #036

STRATIGRAPHY AND STRUCTURE OF GRANDE RONDE BASALT IN THE UPPER NACHES RIVER BASIN, SOUTH-CENTRAL WASHINGTON

June 12 – 13, 2010

Paul Hammond
Portland State University Department of Geology

NWGS FIELD TRIP GUIDEBOOK SERIES

This field trip guide has been reformatted from the original document provided by the authors. All the original text and illustrations are reproduced here, and nothing has been added to the document in the process.

Of particular note, some stops on these trips may be located on private property. ***Publication of this guide does not imply that public access has been granted to private property.*** If there is a possibility that the site might be on private property, you should assume that this is the case. ***Always ask permission before entering private property.***

NORTHWEST GEOLOGICAL SOCIETY FIELD GUIDEBOOK SERIES
Field Trip Guidebook #036

Published by the Northwest Geological Society, Seattle, WA.
Publication Date: © 2010

STRATIGRAPHY AND STRUCTURE OF GRANDE RONDE BASALT IN THE UPPER NACHES RIVER BASIN, SOUTH-CENTRAL WASHINGTON

Paul Hammond, Portland State University Department of Geology

I. ABSTRACT

Seven lava flows compose the upper section (R_2-N_2) of Grande Ronde Basalt, of the Columbia River Basalt Group, in the upper Naches River basin in Kittitas and Yakima Counties, Washington. Here these flows lap out on older volcanic rocks of the eastern flank of the Cascade Range and are locally covered by volcaniclastic deposits of the Ellensburg formation. The lava flows are folded in two directions, axes striking ENE and NNW, and broken and displaced by N- to NW-striking, steeply dipping normal and revers faults, and ENE-striking, shallowly S-dipping thrust faults. The structures define three domains: to the west the Cascade Range of NW-striking folds and faults; a middle, northward-narrowing domain of ENW-striking Yakima folds and thrust faults; and to the east the Olympic-Wallowa lineament (OWL) of NNW-striking folds and reverse and thrust faults. During this NWGS field trip into the area, we will examine and analyze these structures, visit several other sites of particular geologic interest, and strive to understand the origin of the structures affecting the basalt lava flows.

On the first day, starting from Ellensburg, we are exposed to the stratigraphy and structures of the lava flows in the Yakima River Canyon. From Yakima the trip heads northwest into the upper Naches River basin, viewing first structures in Cleman Mountain, an anticline with about the tallest amplitude in the Columbia Plateau, the huge, approximate 2 Ma Sanford Pasture landslide in itself a tectonic structure, and Bethel Ridge, another impressive anticline striking perpendicular, oddly enough, into Ceman Mountain. We will overview the October 11, 2009 Nile landslide, one of the largest landslides in Washington in historic time, which blocked highway WA 410 and diverted the Naches River. On the return trip to Yakima, site of our overnight accommodations, we'll traverse Bethel Ridge. On day tow the trip will include a view point to the west from Cleman Mountain, examine several more structures, including the pop-up structures north of Cliffdell, and the complex Indian Flat fault zone overlooking the Bumping River, after which the trip returns tin the afternoon via Chinook Pass to Puget Sound.

TABLE OF CONTENTS

NOTE: This Table of Contents is not the usual kind; the subjects are listed on pages out of numeric order. The purpose has been to place the figures and tables in the guidebook where they can be more easily referenced. They are arranged in three groups: the first consists of Figures 1-5 and Tables 1-2, starting at page 1 behind this Table of Contents. The second group consists of Figures 6-30 and Table 1, after the text (or lengthy discussion) and before the trip logs in pages 19-30. The last group consists of Figures 36-45 and comes at the end. Also note that Day 2 Log is composed of pages 35A-35B.

Tables

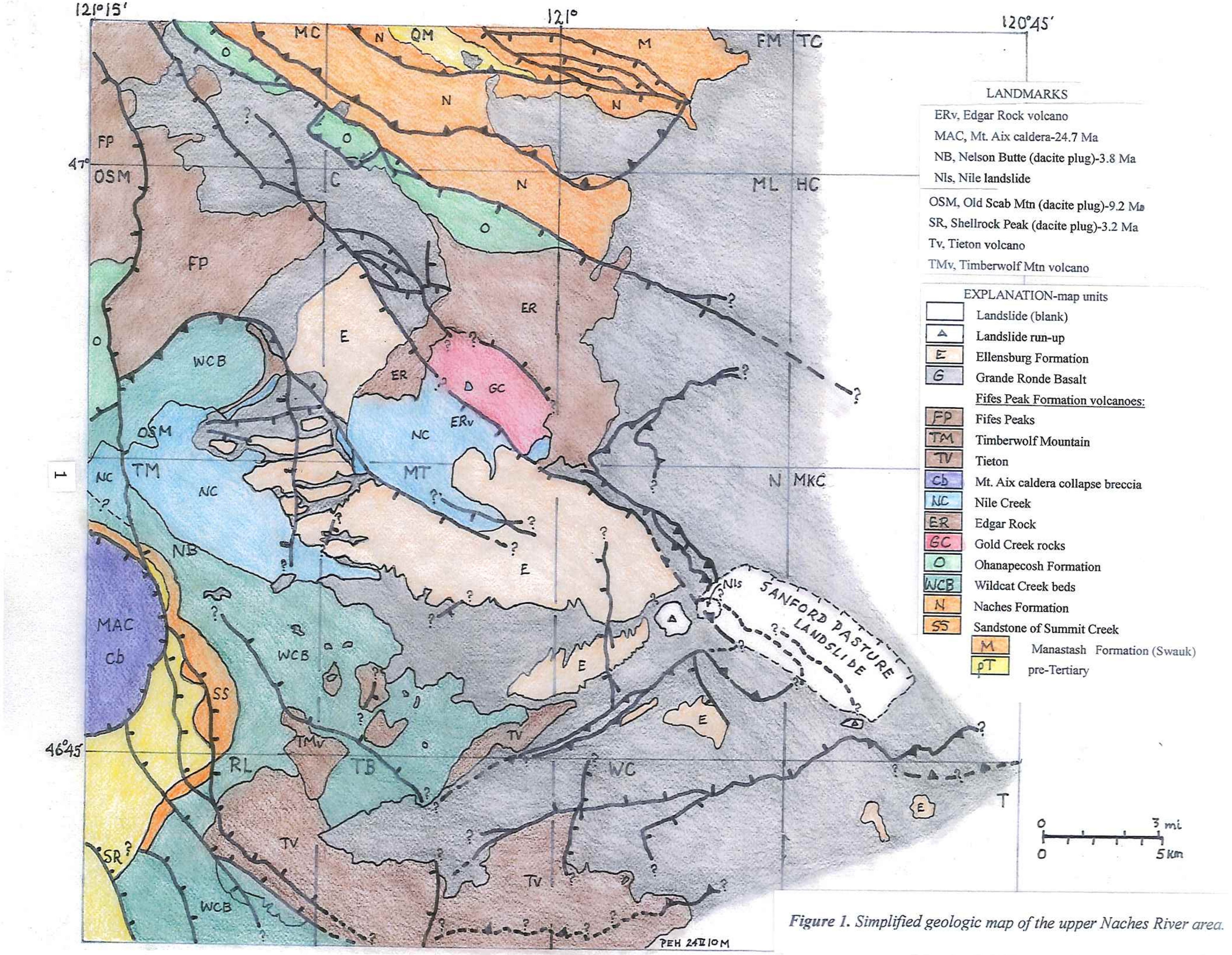
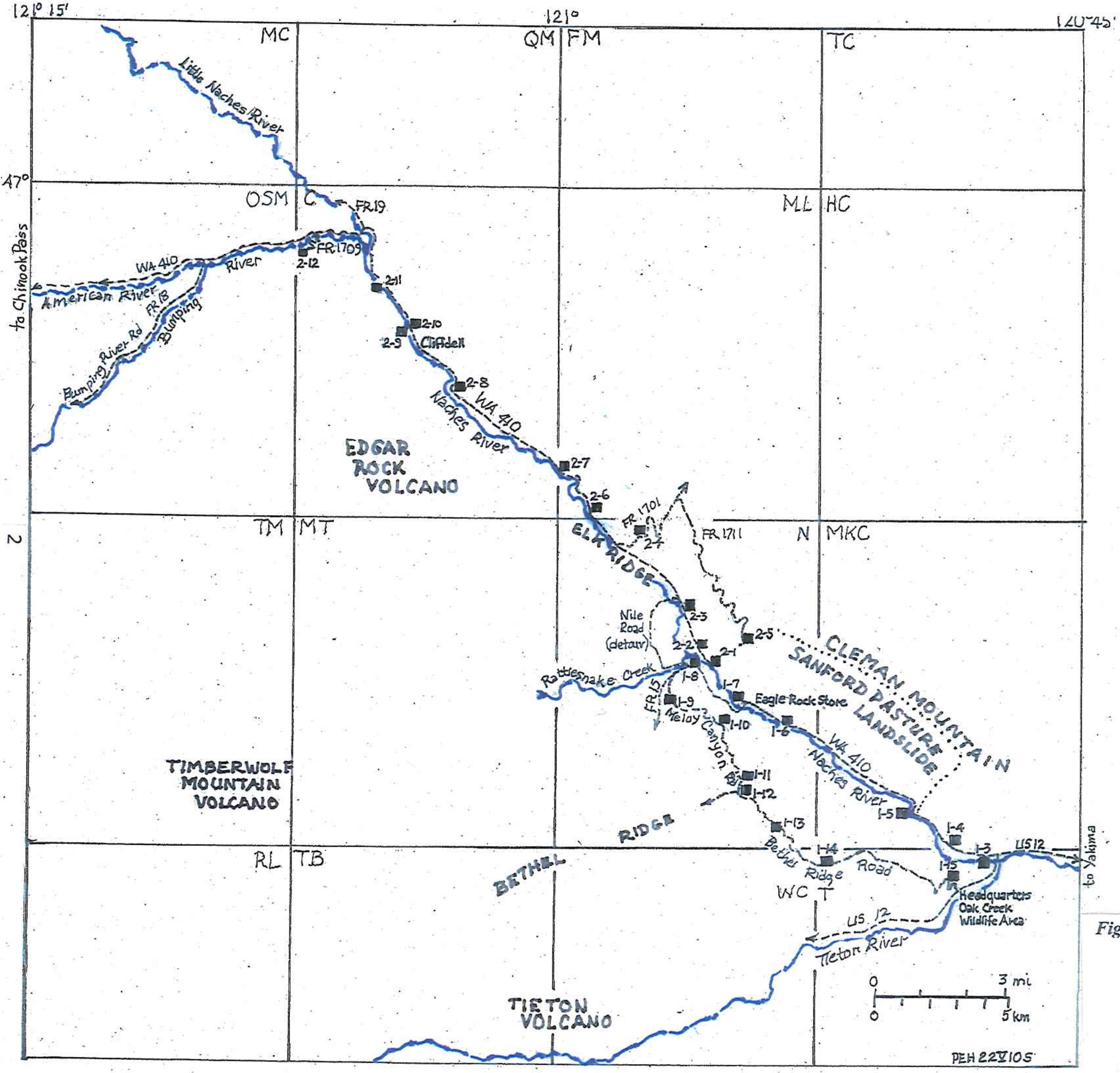


Figure 1. Simplified geologic map of the upper Naches River area.

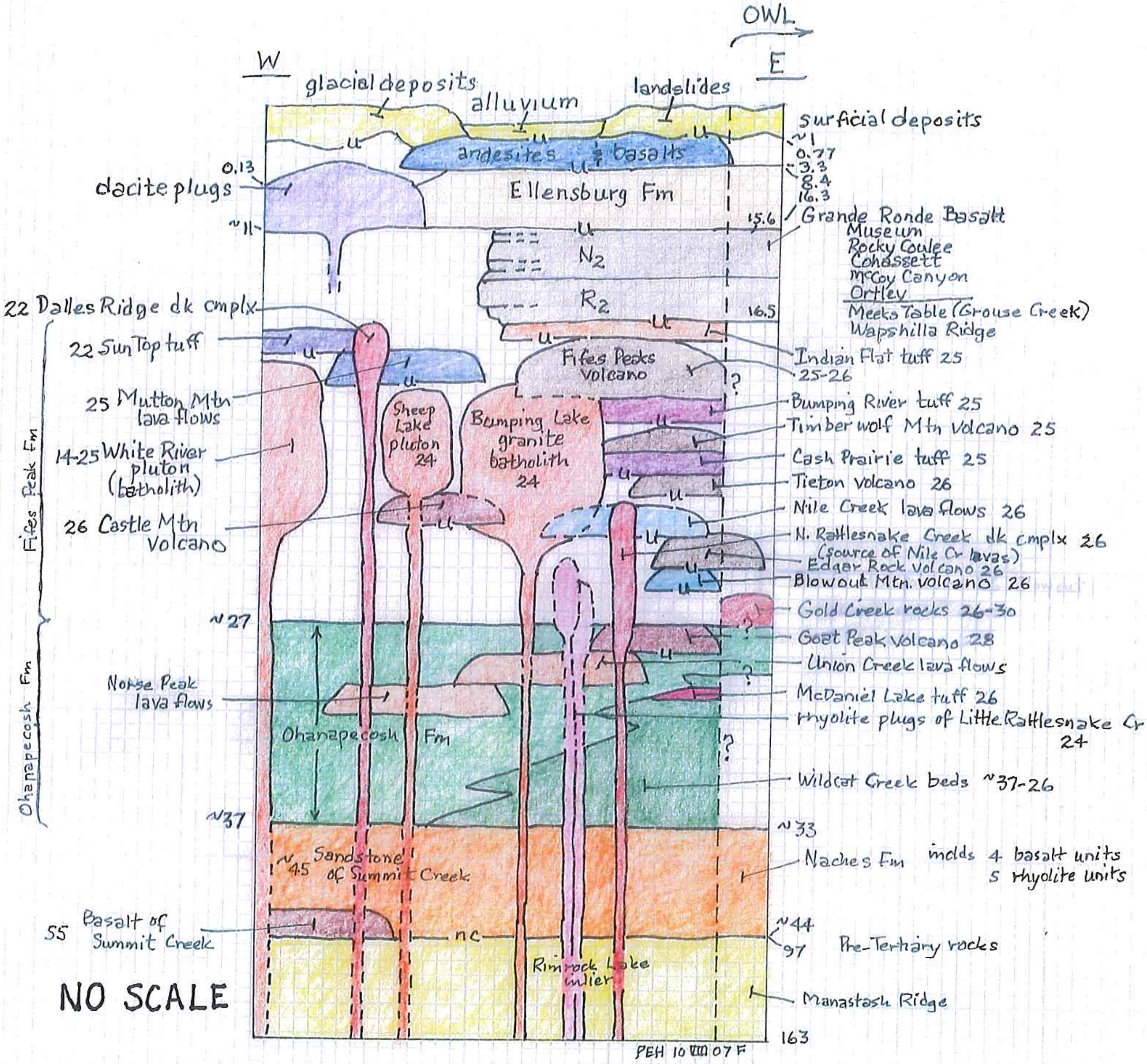


QUADRANGLES

C, Cliffdell
FM, Frost Mountain
HC, Hudson Canyon
MC, Mt. Clifty
MKC, Milk Canyon
ML, Manastash Lake
MT, Meeks Table
N, Nile
OSM, Old Scab Mountain
QM, Quartz Mountain
RL, Rimrock Lake
T, Tieton
TB, Tieton Basin
TC, Taneum Canyon
TM, Timberwolf Mountain
WC, Weddle Canyon

Figure 2. Map of routes and stops

FR Forest Road
route
stop ■ 1-10



Schematic columnar section of principal rock units in upper Naches River basin. No scale in time, thickness, or size implied. u, unconformity; nc, nonconformity; OWL, rock units in Olympic-Wallowa lineament (zone). Numbers in Ma (million years ago).

) unit cut by intrusion

} unit not cut by intrusion

Figure 3. Schematic diagram showing stratigraphy, geographic relations, and ages of map units in upper Naches River basin

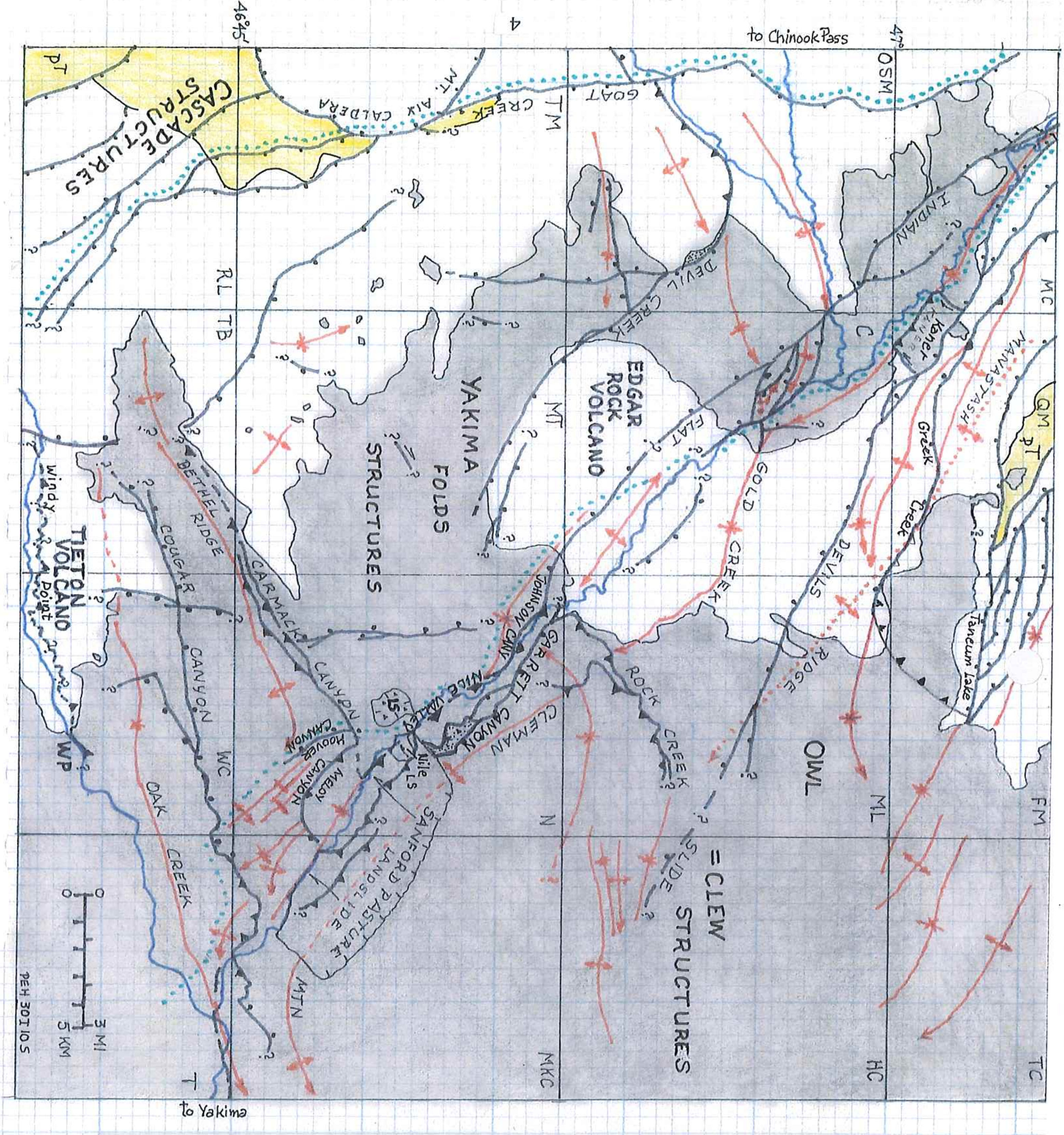


Figure 4 Grande Ronde Basalt and structures in upper Naches River basin. Shows present distribution of lava flows with all younger deposits--Ellensburg, landslides, alluvium--stripped off.

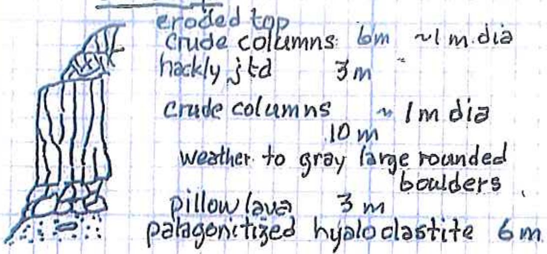
fault with ticks on down block
thrust fault with barbs on HW
anticline showing plunge
syncline showing plunge
boundary of domain

LFU/Symbol — Color code (colorerase) — Thickness, m — Outcrop

MUSEUM (Mu, Tgmu)
NRMP

🟦 light blue 20068

0–50
locally ≤ 100
avg 30

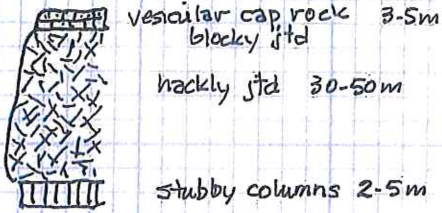


ROCKY COULEE (RC, Tgrc)
NRMP

🟦 indigo blue 1291

0–55
avg 30

single emplacement and cooling unit



interbed of brown claystone or white tuff

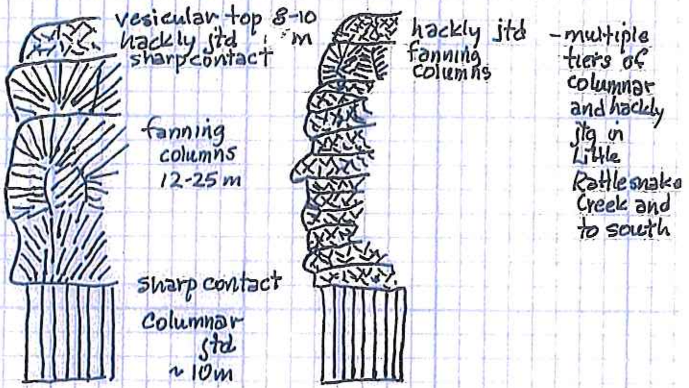
COHASSETT (C, Tgc)
NRMP

🟪 purple 1282

0–90
avg 70
locally 200

invasive lava flow
multiple (~7) emplacement and cooling units

locally most of flow is palagonitized hyaloclastite breccia and tongues of pillow lava – in upper Wenas Creek



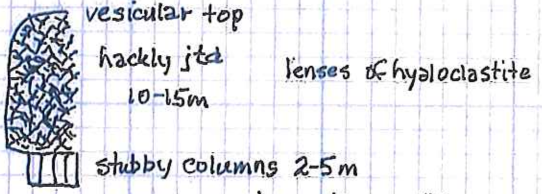
interbed of palagonitic hyaloclastite with pillow fragments

McCOY CANYON (MC, Tgmc)
NRMP

🟩 grass green 20061

0–20
avg 15

probably multiple emplacement and cooling units



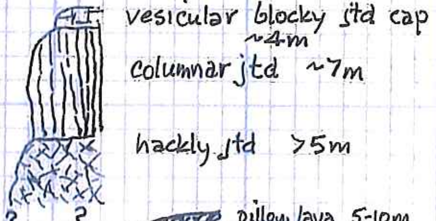
interbed of white tuff and pale yellow-brown fine sandstone 0–15

ORTLEY (O, Tgo)
NRMP

🟥 tuscan red 1275

0–50
avg 25

single emplacement and cooling unit



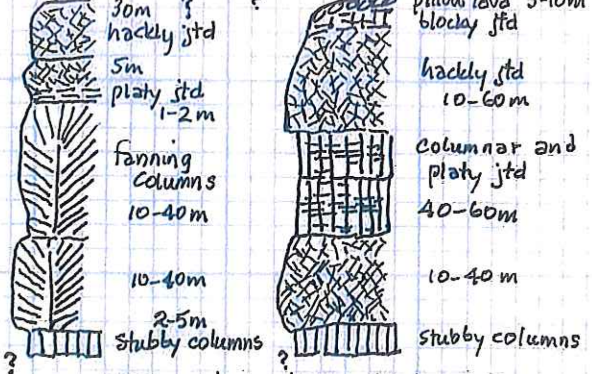
? interbed of white tuff and pale yellow-brown fine sandstone 0-15

MEEKS TABLE (MT, Tggc)
(GROUSE CREEK)
RRMP

🟪 violet 1289

0–150
avg 80
locally 300

invasive lava flow
multiple emplacement and cooling units



? interbed – coarse sandstone, conglomerate

WAPSHILLA RIDGE (WR, Tgwr)
RRMP

⬛ black 1280

0–50
avg 30
locally 100

single emplacement and cooling unit

overlies a white to yellow-white fine tuff and sandstone, 0–6 m

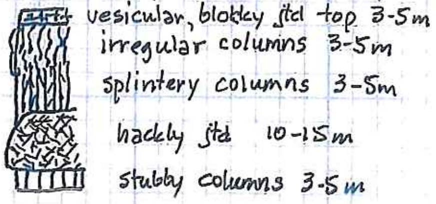


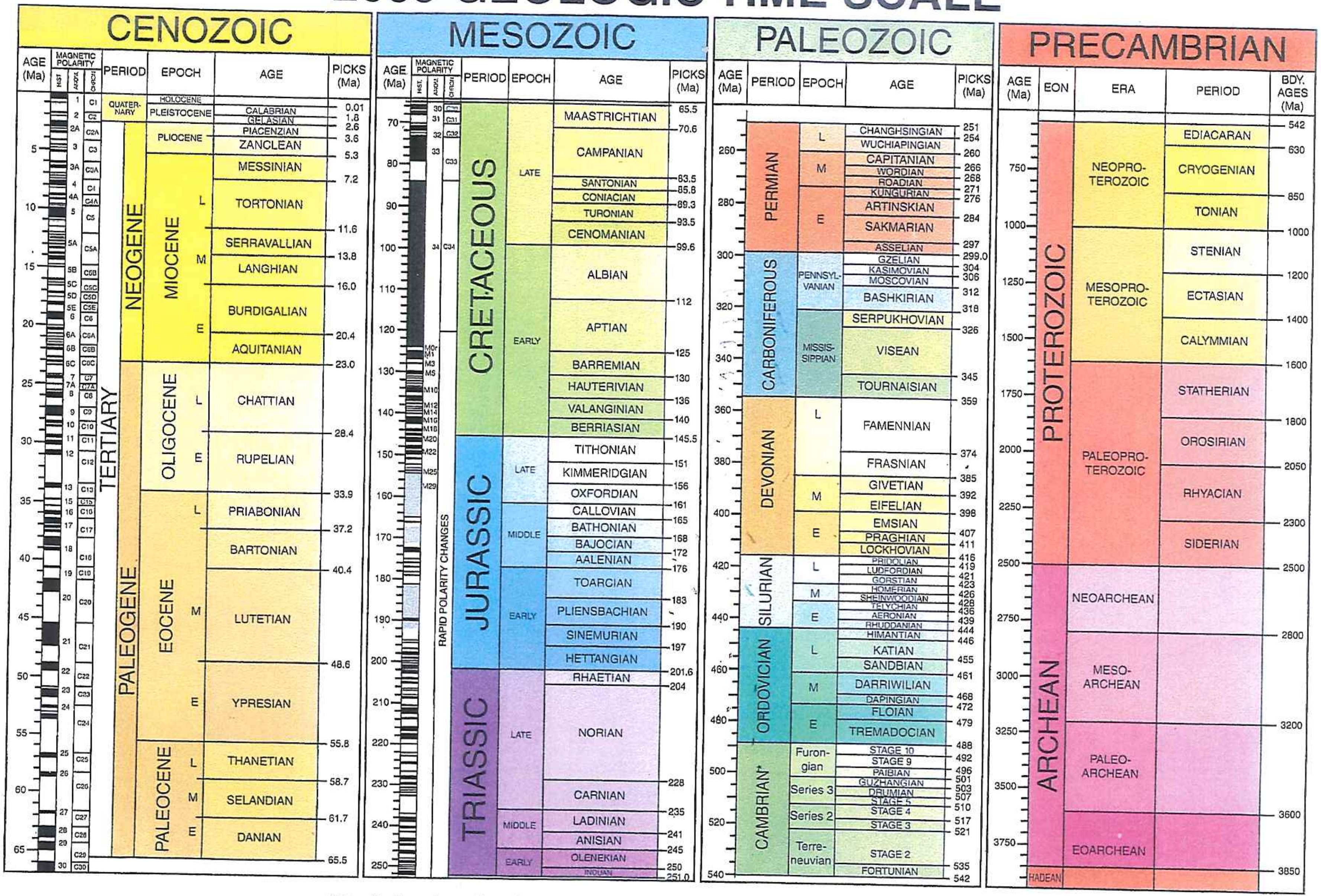
Figure 5. Grande Ronde Basalt lava-flow units in upper Naches River basin.

SERIES		GROUP	FORMATION	MEMBER	ISOTOPIC AGE (m.y.)	MAGNETIC POLARITY	
MIOCENE	UPPER	COLUMBIA RIVER BASALT GROUP	SADDLE MOUNTAINS BASALT	LOWER MONUMENTAL MEMBER	6	N	
				Erosional Unconformity			
				ICE HARBOR MEMBER	8.5		
				Basalt of Goose Island		N	
				Basalt of Martindale		R	
				Basalt of Basin City		N	
				Erosional Unconformity			
				BUFORD MEMBER		R	
	MIDDLE			ELEPHANT MOUNTAIN MEMBER	10.5	R,T	
				Erosional Unconformity			
				POMONA MEMBER	12	R	
				Erosional Unconformity			
				ESQUATZEL MEMBER		N	
				Erosional Unconformity			
				WEISSENFELS RIDGE MEMBER			
				Basalt of Slippery Creek		N	
				Basalt of Tenmile Creek		N	
				Basalt of Lewiston Orchards		N	
				Basalt of Cloverland		N	
				ASOTIN MEMBER	13		
				Basalt of Huntzinger		N	
				Local Erosional Unconformity			
				WILBUR CREEK MEMBER			
				Basalt of Lapwai		N	
				Basalt of Wahluke		N	
				Local Erosional Unconformity			
				UMATILLA MEMBER			
				Basalt of Sillusi		N	
				Basalt of Umatilla		N	
				Local Erosional Unconformity			
			WANAPUM BASALT	PRIEST RAPIDS MEMBER	14.5		
				Basalt of Lolo		R	
				Basalt of Rosalia		R	
				Local Erosional Unconformity			
				ROZA MEMBER		T,R	
				FRENCHMAN SPRINGS MEMBER			
				Basalt of Lyons Ferry		N	
				Basalt of Sentinel Gap		N	
				Basalt of Sand Hollow	15.3	N	
				Basalt of Silver Falls		N,E	
				Basalt of Ginkgo		E	
				Basalt of Palouse Falls		E	
				ECKLER MOUNTAIN MEMBER			
				Basalt of Shumaker Creek		N	
				Basalt of Dodge		N	
				Basalt of Robinette Mountain		N	
				Local Erosional Unconformity			
			GRANDE RONDE BASALT	SENTINEL BLUFFS UNIT	15.6	N_2	0.4 ± 0.20 My
				SLACK CANYON UNIT			
				FIELD SPRINGS UNIT			
				WINTER WATER UNIT			
	LOWER		PRINEVILLE BASALT	UMTANUM UNIT			
				ORTLEY UNIT			
				ARMSTRONG CANYON UNIT			
				MEYER RIDGE UNIT		R_2	
				GROUSE CREEK UNIT			
				WAPSHILLA RIDGE UNIT			
				MT. HORRIBLE UNIT			
			PICTURE GORGE BASALT	CHINA CREEK UNIT		N_1	
				DOWNEY GULCH UNIT			
				CENTER CREEK UNIT		R_1	
				ROGERSBURG UNIT			
				TEEPEE BUTTE UNIT			
				BUCKHORN SPRINGS UNIT	16.5		
			IMNAHA BASALT	See Hooper and others (1984) for Imnaha Units		R_1	
						T	
						N_0	
					17.5	R_0	
				STEENS BASALT			

***Table 1.** Stratigraphy of Columbia River Basalt Group (from Reidel et al., 1989), with Steens Basalt added (Camp et al., 2003)*

**new age range of Grande Ronde Basalt (Barry et al., 2009)*

2009 GEOLOGIC TIME SCALE



CENOZOIC

PERIOD	EPOCH	AGE	PICKS (Ma)
QUATERNARY	HOLOCENE		0.01
	PLEISTOCENE	CALABRIAN	1.8
		GELASIAN	2.6
TERTIARY NEOGENE	PLIOCENE	PIACENZIAN	3.6
		ZANCLEAN	5.3
	MIOCENE L	MESSINIAN	7.2
		TORTONIAN	11.6
	M	SERRAVALLIAN	13.8
		LANGHIAN	16.0
	E	BURDIGALIAN	20.4
		AQUITANIAN	23.0
PALEOGENE	OLIGOCENE L	CHATTIAN	28.4
	E	RUPELIAN	33.9
	EOCENE L	PRIABONIAN	37.2
		BARTONIAN	40.4
	M	LUTETIAN	48.6
	E	YPRESIAN	55.8
	PALEOCENE L	THANETIAN	58.7
	M	SELANDIAN	61.7
	E	DANIAN	65.5

MESOZOIC

PERIOD	EPOCH	AGE	PICKS (Ma)
			65.5
CRETACEOUS	LATE	MAASTRICHTIAN	70.6
		CAMPANIAN	83.5
		SANTONIAN	85.8
		CONIACIAN	89.3
		TURONIAN	93.5
		CENOMANIAN	99.6
	EARLY	ALBIAN	112
		APTIAN	125
		BARREMIAN	130
		HAUTERIVIAN	136
		VALANGINIAN	140
		BERRIASIAN	145.5
JURASSIC	LATE	TITHONIAN	151
		KIMMERIDGIAN	156
		OXFORDIAN	161
	MIDDLE	CALLOVIAN	165
		BATHONIAN	168
		BAJOCIAN	172
		AALENIAN	176
	EARLY	TOARCIAN	183
		PLIENSBACHIAN	190
		SINEMURIAN	197
		HETTANGIAN	201.6
TRIASSIC	LATE	RHAETIAN	204
		NORIAN	228
		CARNIAN	235
	MIDDLE	LADINIAN	241
		ANISIAN	245
	EARLY	OLENEKIAN	250
		INDUAN	251.0

PALEOZOIC

PERIOD	EPOCH	AGE	PICKS (Ma)
			251
PERMIAN	L	CHANGHSINGIAN	254
		WUCHIAPINGIAN	260
	M	CAPITANIAN	266
		WORDIAN	268
		ROADIAN	271
	E	KUNGURIAN	276
		ARTINSKIAN	284
		SAKMARIAN	297
		ASSELIAN	299.0
CARBONIFEROUS	PENNSYLVANIAN	GZELIAN	304
		KASIMOVIAN	306
		MOSCOVIAN	312
		BASHKIRIAN	318
	MISSISSIPPIAN	SERPUKHOVIAN	326
		VISEAN	345
		TOURNAISIAN	359
DEVONIAN	L	FAMENNIAN	374
		FRASNIAN	385
	M	GIVETIAN	392
		EIFELIAN	398
	E	EMSIAN	407
		PRAGHIAN	411
		LOCKHOVIAN	416
SILURIAN	L	PRIDOLIAN	419
		LUDFORDIAN	421
		GORSTIAN	423
	M	HOMERIAN	426
		SHEINWOODIAN	428
	E	TELYCHIAN	436
		AERONIAN	439
		RHUDDANIAN	444
ORDOVICIAN	L	HIMANTIAN	446
		KATIAN	455
		SANDBIAN	461
	M	DARRIWILIAN	468
		DAPINGIAN	472
	E	FLOIAN	479
		TREMADOCIAN	488
CAMBRIAN*	Furongian	STAGE 10	492
		STAGE 9	496
		PAIBIAN	501
	Series 3	GUZHANGIAN	503
		DRUMIAN	507
		STAGE 5	510
	Series 2	STAGE 4	517
		STAGE 3	521
	Terreneuvian	STAGE 2	535
		FORTUNIAN	542

PRECAMBRIAN

EON	ERA	PERIOD	BDY. AGES (Ma)
			542
PROTEROZOIC	NEOPROTEROZOIC	EDIACARAN	630
		CRYOGENIAN	850
		TONIAN	1000
	MESOPROTEROZOIC	STENIAN	1200
		ECTASIAN	1400
		CALYMMIAN	1600
	PALEOPROTEROZOIC	STATHERIAN	1800
		OROSIRIAN	2050
		RHYACIAN	2300
		SIDERIAN	2500
ARCHEAN	NEOARCHEAN		2800
	MESOARCHEAN		3200
	PALEOARCHEAN		3600
	EOARCHEAN		3850
HADEAN			

*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.

Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C.

Sources for nomenclature and ages are primarily from Gradstein, F., Ogg, J., Smith, A., et al., 2004, A Geologic Time Scale 2004: Cambridge University Press, 589 p. Modifications to the Triassic after: Furin, S., Preto, N., Rigo, M., Roghi, G., Gianolla, P., Crowley, J.L., and Bowring, S.A., 2006, High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs: Geology, v. 34, p. 1009–1012, doi: 10.1130/G22967A.1; and Kent, D.V., and Olsen, P.E., 2008, Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): Testing for polarity bias and abrupt polar wander in association with the central Atlantic magmatic province: Journal of Geophysical Research, v. 113, B06105, doi: 10.1029/2007JB005407.

THE GEOLOGICAL SOCIETY OF AMERICA®

Table 2.

INTRODUCTION

Purpose

The purpose of this field trip is to familiarize one with the local geology and especially the stratigraphy of the Grande Ronde Basalt and structures affecting lava flows in the upper Naches River area, their possible origin, and relation to the Yakima folds and the Olympic-Wallowa Lineament (OWL, or Cle Elum-Wallula lineament, CLEW).

Geologic Setting

Pre-Tertiary rocks. The upper Naches River basin, located in the southeast-central flank of the Cascade Range of Washington, exposes a nearly complete section of Cenozoic volcanic and sedimentary rocks composing the range (Figs. 1 and 3). In addition, the strata are underlain by a basement of pre-Tertiary metamorphic and plutonic rocks, in the Rimrock inlier (Miller, 1989) and the Manastash Ridge inlier (Goetsch, 1978; Macdonald, 2006), located west and north respectively of the field trip area, representing the core of the range.

Sandstone of Summit Creek. Nonconformably overlie the basement rocks is a suite of stratified rocks composing the bedrock. The lowermost Cenozoic unit of the bedrock west of the Naches River is the sandstone of Summit Creek (Vance et al., 1987). It consists of light-colored micaceous (muscovite>biotite), feldspathic quartz sandstone, a few thin siltstone-mudstone, conglomerate, and coal beds, deposited chiefly by southward to westward-flowing streams, 50 to 600 ft thick; middle to upper Eocene in age. It was deposited on a deeply eroded, undulating surface underlain by the pre-Tertiary metamorphic and plutonic rocks.

Naches Formation. Similar sandstones east of the Naches River are assigned to the Naches Formation (Hammond, 2010). In addition to the sandstone beds the Naches contains 100-500 ft thick interstratified sequences of basalt and rhyolite lava flows and tuff. The formation is 3000 to 6400 ft thick and 44 to 42 Ma, middle Eocene in age (Walker and Geissman, 2009).

Ohanapecosh Formation and tuffaceous rocks of Wildcat Creek. Proceeding upward in the stratigraphic section, the sandstone grades into and is overlain conformably by the tuffacous rocks of Wildcat Creek (Swanson, 1964, 1978), which form a lower member of the Ohanapecosh Formation (Fiske and others, 1963), originally described in Mount Rainier National Park west of the area. This unit consists of well-stratified varicolored fine- to coarse-grained volcaniclastic beds and tuff of chiefly andesitic composition, deposited in streams and lakes, 300 to 3,500 ft thick, lower Oligocene in age (Fig. 3). These deposits are believed to be the airborne distal products of volcanoes to the west. North of the latitude of Edgar Rock volcano (Fig. 2) equivalent strata are the coarser facies—tuff breccia, conglomerate, and a few andesitic lava flows, as well as tuff, some up to 100 ft thick, and volcaniclastic beds—of the Ohanapecosh Formation. The Ohanapecosh Formation is 5,000 to 7,200 ft thick and about 28 to 32 Ma, lower Oligocene in age (Walker and Geissman, 2009). These formations will not be visited in the field trip.

At the conclusion of Ohanapecosh deposition, the region suffered a period, between 29 and 28 Ma, of mild deformation and erosion, when development of the OWL began (Table 3).

Fifes Peak Formation. Unconformably overlying the strata of Wildcat Creek and the Ohanapecosh Formation are the andesitic volcanic strata--lava flows and breccia, laharic breccia, and tuff--of the volcanoes of the Fifes Peak Formation (Fiske and others, 1963, also named in Mount Rainier National Park. The two volcanoes in the area of the field trip are Tieton volcano (Swanson, 1964, 1966, 1978) in the southern part and Edgar Rock volcano (Carkin, 1988) in the north. The prominent remains of Timberwolf Mountain volcano further west can be seen from Cleman Mountain (Stop 2-5). Cores of these three volcanoes stood above the surrounding fields of Grande Ronde Basalt as steptoes. All volcanoes of the formation are composed of andesite, chiefly basaltic andesite, a little basalt and some dacite. Associated tuffs vary in composition from dacite to rhyolite, and in volume. Edgar Rock contains the most rubbly lava flows of the formation, as well as laharic breccias, but little tuff. Some flows of lava and laharic breccia of andesite of Nile Creek, derived from the North Rattlesnake Creek eruptive center well to the west (Hammond, 2005), occur along the western margin of the field trip area (Fig. 3; Stop 2-7). These lavas are recognized by their light gray color and a sprinkling of black, coarse-grained crystals of hypersthene. The combined thickness of Fifes Peak Formation strata ranges from 500 to 5,900 ft. Their ages are 24 to 27 Ma, upper Oligocene in age (Walker and Geissman, 2009).

Following the volcanism of the Fifes Peak Formation, all strata were deformed and deeply eroded, locally cutting down to the pre-Tertiary rock, marking the second and much stronger period, between 22 and 16 Ma, of deformation and erosion than the first (Table 3).

Grande Ronde Basalt. During middle Miocene, about 16 to 15.6 Ma (Table 1), the area was invaded and largely buried by as much as 1500 ft (equal to the combined thicknesses of the flows), by a succession of seven flood lava flows of Grande Ronde Basalt of the Columbia River Basalt Group. They formed a vast grayish plain that extended 190 mile to the present eastern border of Washington, and a line of higher peaks and isolated steptoes of earlier volcanoes 5 miles or more to the west. Although the flows were erupted in what is now eastern Washington and Oregon, they advanced northward and westward on a descending surface, entering into the Naches River area from the southeast, as determined by the orientation of local pillow lavas, like foreset bedding in stream deposits (Swanson, 1964, 1967, 1978). Recognizing these individual lava flows, how they can be traced, and how they were subsequently deformed is the subject of this field trip. The rock is dark gray to black, very fine grained, aphanitic; parts of some flows show microphenocrysts of plagioclase. Under a petrographic microscope, crystals of clinopyroxene in a matrix of ilmenite-magnetite and glass, in addition to the plagioclase, can be seen. All Grande Ronde Basalt flows in the upper Naches River basin have very similar mineralogy and texture; they cannot be identified confidentially with only a hand specimen observation. The youngest of these flows to enter this area is the Museum flow (Fig. 5), age about 15.6 Ma (Table 1). Termination of younger lava flows, of Wanapum Basalt (Table 1), lie east of the upper Naches River basin, between the junction of highways US 12 and WA 410 and Yakima, and will be passed during the trip. More on the basalt lava flows in a section below.

Near cessation of outpouring of Columbia River Basalt, the region, possibly all of the Pacific Northwest, entered a period of its greatest Cenozoic deformation, between about 10 and 3 Ma, culminating between 5 and 3 Ma. The effect was deformation—folding and faulting of the basalt lava flows and all older strata and uplift of mountain ranges including the Cascade Range—and accompanying deep erosion still in progress today at a slower rate. Keep these deformations (Table 3) in mind if the process of deformation is to be understood.

Ellensburg Formation. A sequence of light-colored, generally well-defined beds, commonly forming rims, composed of conglomerate, laharic breccia, and a lesser number of tuff form the Ellensburg Formation. This formation in this area are well described by Luker (1985), Smith (1988), and Humphrey (1996). The beds of coarser clasts, generally whitish, to pale brown, to reddish rounded stones of hornblende-biotite-plagioclase andesite-dacite, its signature or type lithology, dark-colored pyroxene-plagioclase andesite (compositionally basaltic andesite to andesite), and dark-gray to black aphanitic rarely containing tiny white plagioclase microphenocrysts of Grande Ronde basalt. All clasts are generally in a soft, friable white ash matrix. I call this lithology the volcanic facies of the Ellensburg Formation, because the coarser sedimentary deposits of the formation east of the Yakima River and bordering the Columbia River contain abundant clasts of metamorphic and plutonic rocks, including pinkish quartzite, derived from terrains (provences) bordering the Columbia Plateau. These deposits define the ancestral course of the Columbia River. In the upper Naches River basin the formation has a maximum thickness of 1,500 feet and ranges in age from 14.32±0.90 to 9.06±0.74 Ma ^{40}Ar/^{39}Ar (Hammond, 2005, 2009, 2010, and in preparation), middle to upper Miocene in age (Walker and Geissman, 2009). The formation rests with slight, about 5°, angular unconformity upon Grande Ronde Basalt, best seen along the north side of Rattlesnake Creek. From a vantage point looking west one can visualize a broad flat plain of Ellensburg deposits radiating from several andesite-dacite domal volcanoes, located within 2-3 miles of the present crest of the Cascade Range. Peaks such as, from south to north, Shellrock, Rattlesnake, Pear Butte, Nelson Butte, Old Scab Mountain, and Gold Hill are but a few of the remnant eruptive sources of the formation.

Post-Ellensburg deposits consist of a scattering of several small basalt and andesite cones and lava flows, including the TietonAndesite (Stop 1-15), atop ridges and within valleys near the Cascade crest. They range in age from 3.34±0.04 Ma to 188.4±16.5 ka ^{40}Ar/^{39}Ar, middle Pliocene to Pleistocene age (Walker and Geissman, 2009).

Surficial deposits, as the name applies, are stream, glacial and landslide deposits, generally not older than Pleistocene age, in valleys and on some slopes. The field trip passes and has opportunities to observe the Sanford Pasture landslide, one of possibly the largest landslides in the United States, on the southwest flank of Cleman Mountain (Figs. 1 and 20). With a length of about 5.5 mi, a scarp 1000 ft high, and a width of 2.1

mi between the scarp and the Naches River (presumably the landslide transported all its debris into the valley), the landslide moved as much as 2.3 mi^3 (9 km^3), a huge amount of Grande Ronde Basalt. No other rock has been identified in its landslide debris. Reactivation of a small part of the landslide in the Nile landslide, October 11, 2009, (Figs. 20 and 21; Stops 1-7 and 2-1), has renewed interest in the Sanford Pasture landslide. Mapping in the area has found no evidence of a large lake impounded by the slide. Runup deposits on the opposite side of the valley occur only at Horseshoe Bend (Stop 1-5), and atop the mesa at Eagle Rock (Stop 1-8). These findings suggest that the landslide occurred incrementally and never did totally block the Naches River valley. Over the long time since the river has cleared the valley of landslide debris. A large gravel deposit, the Cowiche Gravels, in which the Tieton Andesite lava flow filled a valley, is located south of Naches. If the gravel can be traced to the landslide, then the 1.69 Ma age of the lava flow indicates that the landslide is at least about 2 Ma old.

GRANDE RONDE BASALT

Volume and extent

Stratigraphically, the Grande Ronde Basalt forms more than 50% of the huge total volume, about 240,000 km^3, of lava flows in the Columbia River Basalt Group (Camp et al., 2003; Table 1). And the flows cover more than about 175,000 km^2. Flood lava flows, such as these of the Columbia River Basalt, are some of the largest rock units in the Earth's crust. Even more impressive is that this volume of flows erupted in only 2-3 m.yrs! (Note in Table 1 that the total volume of Grande Ronde Basalt erupted in only 0.4 m.yr. [Barry et al., 2009].) Add to this knowledge that some flows advanced 250 miles across the plateau; a few flows---the Pomona, Gingko, Ortley, Grouse Creek, and Wapshila Ridge, among others---have traveled an additional 150 miles to the Pacific Ocean along the course of the ancestral Columbia River to form many capes and sea stacks along the northern Oregon coast.

Types of lava flows, tiering, and jointing

Two types of flows are recognized---sheet flows and lobate flows (Fig. 6). Sheet flows are produced by a continuous eruption of magma, which spreads more or less continuously filling low-lying area adjacent to the vent or fissure until the eruption ceases. Then the ponded lava cools uniformly, as a single cooling unit, from the top downward generally more rapidly than from the relatively cool underlying ground upward, the two processes forming one to two tiers, of contraction jointing, until solid rock has formed within the one flow of lava. The cooling rate of a flood lava flow depends on the original temperature of the lava, the thickness of the flow, and whether it is a sheet or lobate flow; the rate may be 10s to 100s of years. The upper tier, called the entablature, consists of irregular jointing--blocky or commonly hackly jointing. Hackly jointing consists of irregular-shaped interlocking blocks, resembling a 3-dimenional jigsaw puzzle, which is very resistant to erosion. The lower tier is the colonnade and is generally columnarly jointed. Generally, the thicker the flow the thicker the colonnade, and the thinner the flow the thicker the entablature. The entablature meets the colonnade at a plane commonly parallel to the surface of the flow. Also, the columnar jointing forms perpendicular to isothermal surfaces that are planes of equal temperature within the flow as it cools. Secondary platy jointing perpendicular to the vertical joints is also common in columnar jointing. Interruptions of the cooling rate, such as earthquakes or injections of new lava, cause irregularities in the isotherms and jointing. The sheet flow also has commonly vesicular to scoriaceous zones, of gas bubbles generally of steam, trapped during cooling, of variable thickness at the bottom and top of the flow, mostly commonly thicker at the top. If the erupted lava is quite fluid, a ropy or pahoehoe surface forms at the top.

A lobate flow is one composed of different lobes, or subflow-units of different tiering, produced by a sporadic or very slow rate of lava outpouring, forming lobes of lava which overlie one another or side by side, or are injected into or beneath lobes as invasive lava. These flows become compound flows and cool as compound cooling units. Within lobate flows columnar jointing is rare unless the lobe is quite large and cools as a separate unit. Blocky jointing is the common jointing in the lobes. Also, the contacts between lobes may lack vesicles, especially where the lobes are in contact with lobes of the same flow. Another means of recognizing a lobate or invasive lava flow is finding lenses of sedimentary or other foreign rock within a flow. Often a flow where it has advanced into a lake burrows into the bottom sediments, displacing the sediments from their stratigraphic position (Stop 1-6; shown in lower right of Fig. 6). This relationship is often observed on the Columbia Plateau. All these processes produce tiering in the flows. Generally, a flood basalt sheet flow consists of two or more tiers; a lobate flow can consist of multiple, discontinuous tiers. Observe the variations in the lava flows of the area sketched in Fig. 5.

Manner of eruption

The eruption of flood lava can be from single vent, generally along a fissure, or crack, most often from a fissure as a fissure eruption. Fissures, generally striking northwest, have been traced over 60 miles in the plateau of eastern Washington; many are 10 to 30 ft in width (Reidel et al., 1989). At night the eruption can be spectacular, even from a distance, which is essential if one is to survive the eruption. Red hot lava can be ejected to heights of 2,000 feet, accompanied by clouds of brown to black chilled lava particles and steam. Generally a blanket of scoria and ash is deposited adjacent to the fissure depending on the wind direction, but as more or more lava is ejected and eventually as vigorous lava flows from the fissure, the earlier scoria and ash is swept away by the lava. Lack of scoria and ash adjacent to dikes often precludes recognition of a former active fissure.

Mapping the lava flows

Early mapping of the lava flows consisted of tracing a flow or sequences of flows until they were covered by vegetation, landslide, talus, or soil, cut out by faulting, or pinched out. Abundant phenocrysts of plagioclase, especially in the Frenchman Springs Member (Table 1), or a flow with distinctive jointing, served as marker lavas in the field. In the post-World War II era, because many flows have an aphanitic texture and variable jointing, stratigraphic mapping in the field was found to be unreliable. In the 1970s and 1980s paleomagnetic orientations of single or groups of lava flows became a valuable tool in mapping (Reidel et al., 1989). As the lava flow cools tiny crystals of magnetite or ilmenite-magnetite, common in the basalt lava flows, are oriented parallel to the lines of magnetism in the Earth existing at the time of their cooling. Those orientations in which the magnetically positive end of the rock or drill core points toward the Earth's north pole are positive; in the reverse direction the rock or core has a negative orientation. With a light-weight, easy to carry flux-gate magnetometer, field determinations could be made on oriented hand specimens. Thus the Grande Ronde Basalt was found to consist of four magnetic polarity intervals (Table 1). However, it was necessary in mapping Columbia River Basalt lava flows one needed a means of recognizing a lava flow in the established basalt stratigraphy, either a previously recognized lava flow in the area or a marker sedimentary or tuff interbed. It was also recognized that magnetic orientation should be determined on samples taken at the base of the columnar jointing or in the glassy contact zone at the base of the flow, that part of the flow often unfortunately concealed by talus, vegetation, or soil. In some flows, especially the thicker granular flows, determination of magnetic orientation is commonly unobtainable. In these flows the magnetic crystals have lost their magnetic orientation because of the frequent changes in the Earth's magnetic directions since the lava flow cooled. Readings varied from positive to negative among the samples tested, giving the lava flow an indefinite magnetic orientation. In the 1990s and 2000s measurements of cores obtained by drilling have contributed to precise identification of individual flows (Fig. 7). Here the precision in drilling (as many as a dozen drill cores in one field site) and computer determinations of magnetic directions have successfully shown that each flow has a definitive magnetic direction, serving to identify the flow, as shown in the 3-dimensional stereographic plots (Fig. 7). (The stereograph is a means of projecting 3-dimensional data, here directions, to a two-dimensional plot. Compass directions are shown along the perimeter. Dipping or plunging, directions are measured from the perimeter, 0°, to 90° vertical at the center of the plot.)

Chemical signature

Identification of single lava flows and mapping in the upper Naches River basin has been accomplished by extensive sampling and whole-rock chemical analyses by X-ray fluorescence (XRF) determination in the GeoAnalytical Laboratory at Washington State University, Pullman. Samples have been collected from isolated outcrops, roadcuts, and accessible stratigraphic sections. Plotting MgO% versus TiO_2% (Landon and Long, 1989) has enabled identification and location of contacts of the seven Grande Ronde Basalt lava flows, most importantly the location of faults displacing the flows in the area. In addition to these two oxides, Reidel et al., (1989) has found P_2O_5, Zr, and Ba useful in distinguishing Grande Ronde Basalt flows. And Russ Evarts (Wells et al., 2009) is successfully using TiO_2 versus Cr/P_2O_5 to separate flows in his mapping in the Columbia River Gorge. Landon and Long (1989) initially plot the MgO content on the x-axis and TiO_2 on the y-axis. The same is shown for Reidel et al. (1989) and the U.S. Geological Survey (Wells et al., 2009). However, with TiO_2% being the least variable of the two oxides, it is generally easy to identify a flow by comparing that oxide in the chemical analyses of the seven flows in the upper Naches River basin. For an example, Figure 8A shows a plot of the analyses of basalt samples in the Cliffdell and Manastash quadrangles. No Museum flows occur in these quadrangles. Figure 8B is a table of the average chemical analyses of the six flows in the same quadrangles.

Structures

Structure in the upper Naches River basin is complicated, especially along the Naches River valley and at Manastash Ridge in the north (Fig. 4). There are variations in folds and faults, and in their orientation. Two of the major folds, Bethel Ridge and Cleman Mountain strike into one another. Overall, the number of folds and faults is about equal. How to make sense of this complication? First, look at the folds.

Among folds anticlines are the most important (Fig. 9). They represent narrow parts of the crust that have been elevated by deformation, either by uplift from below or horizontal compressive push. Whereas synclines are those parts of a system of folds where the level of the crust has not changed during the deformation. The difference in height between the trough of a syncline and the top of its adjacent anticline is a measure of the amount of uplift, possibly a measure of the total force involved. Stratigraphically, the oldest rocks are in the core of the anticline, the youngest in the trough of the syncline. All folds can be described in a series of terms: width, length, height or depth (the amplitude between the trough of the syncline and height of the axial crest of the adjacent anticline), dip of the flanks, interlimb angle (in an anticline, the angle between the dip of the flanks), and the strike and dip of the axial plane. All folds die out at their ends or are cut off by faults. The width and length of a series of folds indicates the area in which a force has been applied.

On the other hand, faults are breaks in the Earth's crustal surface where displacement between sides of the fault has occurred (Fig. 10). (A fracture is a break but without measurable movement between sides.) Faults are described similarly in a series of terms: strike, length (the distance the fault can be traced), dip of the fault plane, and in the amount of displacement or movement, normal displacement or dip-slip, lateral or horizontal displacement or strike-slip, oblique displacement or oblique-slip. Rarely do faults show rotational displacement. Often detailed examination of the fault plane shows lineations or slickensides or gash (due to tensional stress) and shear (due to compressional stress) fractures that can be either measured or show direction of displacement. Another factor in describing faults can be the width and nature of the rock within the fault zone, whether the rock is mylonitic to cataclastically, and the position of the shear or slip plane within the zone. Faults generally die out at their ends; in some locations they merge with folds. Ground or blocks of rock adjacent to the fault plane are commonly described as HW, hanging wall, and FW, footwall, determined by their relation to the dip of the fault. Keep in mind that a miner working underground bumps his head on the HW as he walks on the FW.

A domain is a geographic area containing similar structures that differ from adjacent areas or domains. Domains can be separated by major fault zones, narrow transition zones where the structures change trends, or even by geographic landforms. Figure 4 shows three domains in the upper Naches River basin. West of the Goat Creek fault), along the west margin of the map (and west of the map), is the large domain of the southern Washington Cascade Range with NW-striking folds and faults of chiefly normal displacement. The central part of the map, between the Goat Creek fault and the Naches River, is a domain of ENE-striking folds and chiefly thrust faults. This domain narrows in width to the north and pinches out at the map edge. It represents a small part of the Yakima fold belt, and is the major area of observation in this field trip. The area east of the Naches River is the domain of OWL, consisting of NW-striking folds and thrusts.

Olympic-Wallowa Lineament (OWL)
The lineament was recognized by Raisz (1945) as a series of elongated landforms, running diagonally from NW to SE across Washington into NE Oregon, from the northern Olympic Mountains (the Straits of Juan de Fuca), through the Wallula Gap, to the northeastern side of the Wallowa Mountains in Oregon. In reality it is a zone varying 20 miles or less in width. It origin has been debated since Raisz's (1945) paper. Cle Elum-Wallula Lineament (CLEW) is that part of the lineament between Cle Elum and Wallula, Washington (Kienle et al., 1977). The Straight Creek fault in the North Cascades (Range) of Washington, a major N-S Paleogene fault, of right-lateral displacement, with an offset of 54 mi (90 km), joins OWL in the northern vicinity of CLEW. The Taneum Lake fault, shown in the north central part of the map (Fig. 4), mapped by Goetsch (1978), is the probable southeast continuation of the Straight Creek fault. It disappears beneath the Columbia River Basalt in the CLEW but may extend beneath the basalt at depth, through the Pasco basin, and be involved in the faulting in the vicinity of Wallula. Analysis of the structures in the upper Naches River basin indicates that in this area OWL is a compressional zone of folding and faulting, including several thrusts.

Structural analysis
Once the structures have been mapped and the details of each noted, as listed above, and shown in Figs. 9 and 10, the next step is to determine, in a structural analysis, the directions of applied forces or stresses, which caused the structures. The easiest and simplest method is to relate the structural orientations of the folds and faults to three mutually perpendicular axes

(Fig. 11; Park, 1989, p. 34; Boulter, 1989, p.95-96). The horizontal or maximum principal stress axis is set as σ_1, the intermediate axis as σ_2, and the minimum axis as σ_3, shown each as 1, 2, and 3, respectively, in Figure 11. Normally, the maximum and intermediate axes are horizontat, parallel to the Earth's surface. And the minimum axis is vertical, perpendicular to the Earth's surface. Now set the axes parallel to or perpendicular to the strikes of the structures as shown and listed in Fig. 11. In Figure 4 the maximum principal stress of the folds and thrusts in the Yakima folds domain, and including the Rock Creek thrust in the OWL domain, are oriented NW. But the normal faults in the Yakima folds domain are not parallel to this maximum stress direction. And the thrusts in the north part of the OWL domain are not perpendicular to the maximum stress direction. Often, geological structural relations do not work out simply. So what's going on here? Here the maximum stress directions are not opposed to one another; they are offset, creating a clockwise rotation or shear. The western side of the map, west of the Naches River, is moving northward at a slightly greater rate than the eastern side. This relationship is the same as in the San Andreas fault system in California. Movement of this fault has been extensively studied by many geologists, and summarized and illustrated by Silvester (1988, p. 1674). The diagram is shown in the lower right of Figure 11 as it pertains to the map area. In Figure 12 the stress directions are drawn in the map as envisioned today. The N-S maximum (compressive or shortening) stress, σ_1, is offset in a clockwise rotational shear, and the major normal faults are parallel to this N-S stress. The intermediate (extension or lengthening) direction is parallel to the horizontal stress, σ_2, or E-W. The least stress, σ_3, is normal to the map and the Earth's surface. It is the direction in which the anticlines are folded upwards. Whereas the two greater stresses, σ_1 especially and σ_2, oppose the resistance between rock masses within the crust. The shear faults and major folds strike about 45° to the maximum stress. And the shear folds, of which there are many, especially in the northern part of the map, are oriented about 20° to the strike of the shear faults. The black arrows in the opposite corners of the map give the sense of rotation in the area. Lastly, as mentioned earlier, the southern part of the map area has been moving northward at a slightly greater rate than the area to the northeast, to the extent that the southwestern area appears to be underthrusting Cleman Mountain. The southwestern area of the map is pushing in a northerly direction against the area east of the Naches River. The narrow transitional zone of folds and faults between Cleman Mountain and the northeastern end of Bethel Ridge is a compressional zone with some possible northward movement. A similar zone of small faults and folds (pop-up structures) exists in the north (north of Cliffdell, Fig. 2) where the Bumping River joins the Naches River. Thus, the Naches River area lies within a broad rotational shear zone. In the upper Naches River basin small amounts of movement are taken up by many right-lateral faults and shear folds. As a result, since the early Cenozoic, the geographic shape of the upper Naches River basin has been gradually changing, lengthening E-W and shortening N-S.

Now, what are the direction and force causing these structures in the upper Naches River basin and possibly in the Pacific Northwest? In the above steps the indication is a N-S compression, a shortening stress, or force. An important clue, or understanding here, is that most all deformation of the crust is the result of movement in the underlying mantle. The force, or stress, then, is the movement of the mantle. The mantle can move upwards in the uplift of mountain ranges, such as the Cascade Range, Rocky Mountains, and Colorado Plateau. (Some geophysicists say this upward movement is a swelling of the mantle.) In most occurrences, however, the crust becomes thicker in low density rock through magmatic processes and therefore rises isostatically. And in some regions part of one mantle slides beneath adjacent mantle in a subduction zones, possibly causing uplifting of the overlying mantle. Or parts of the mantle move horizontally; one part moves alongside another part, or toward or away from each other, in the latter forming troughs that fill with sedimentary or volcanic rock. In any of these movements the overlying crust is affected. In the upper Naches River basin the underlying mantle cannot be moving toward a central area or the area would be bulging upward. Therefore, the mantle must be moving to the north or south. The indication again in the structural analysis is that the mantle is moving north. This direction of movement is also supported by the vergence (movement) direction of most Yakima folds; the folds are asymmetrical with the steeper flank facing north, the axial planes dipping south, most forethrusts occur in the north flanks dipping south.

Yakima folds and Yakima Fold Belt

The Yakima folds are series of anticlines and synclines, striking generally east-west, in the western part of the Columbia Plateau, in south-central Washington and a smaller part of north-central Oregon (Fig. 14; Reidel and Campbell, 1989). The folds are actually slightly bowed or convex to the north. They strike WSW in the western part of their area and ESE in the east (Fig. 15). Most folds change strike from more or less E-W to SE where they intercept the Olympic-Wallowa Lineament. As in the upper Naches River basin, the area southwest of OWL is moving northward slightly faster than the area to the east, thereby probably causing the change in strike of the fold axes. The anticlines range in height from about 1000 to 3000 feet, with flatish tops, forming broad ridges, varying in length from about 10 to 50 miles and in width from about 10 to 25 miles, and are spaced up to about 22 miles apart (Watters, 1989). Flanks of the Yakima folds are generally mildly to gently dipping, less than 15°; dips as much as 50° occur locally. As stated above, the northern flank is commonly steeper, indicating a direction of vergence. Thrust and steeply dipping reverse faults also occur commonly in the north flanks of the anticline, although many anticlines have faults in both flanks, a forethrust and a back thrust (Stop 1-2; Fig. 17). Some folds especially along the Columbia Hills, along the northern side of the Columbia River to the south, are steeper and faulted in their south flanks (Anderson, 1987). Also in the Columbia Hills steeply dipping faults, with a small amount of right-lateral displacement, traverse the folds obliquely. The Columbia Plateau is likely the only region in the United States where anticlines form ridges, the folds being geologically young and the rocks resistant to erosion. Elsewhere in the United States the folds are eroded to hogbacks. In the upper Naches River area Bethel Ridge and Cleman Mountain anticlines are examples of Yakima folds (Fig. 16*)*, although Cleman Mountain is part of the Olympic-Wallowa Lineament. Note also in Figure 16 that the Carmack Canyon thrust lies much higher in Bethel Ridge anticline than the Nile Valley thrust in Cleman Mountain. The reason for this difference is presently not understood. Then note in Figure 15 that a few folds can be traced in some locations into older strata beyond the margin of the Columbia River Basalt. Similarly, in the upper Naches River basin some faults extend into the pre-Grande Ronde Basalt rocks in locations outside the field trip area.

Origin of Yakima folds

Two processes are necessary to understand the deformation process---how the Yakima folds formed and why they formed in only the western part of the Columbia Plateau (Fig. 14) First, the gradual northward movement of the mantle is driving the process. And two, there is a blockage to the northward movement of the crust that develops the folds? Regionally, northern Washington and western Canada have a thicker crust composed of crystalline metamorphic and plutonic rocks than the region to the south, and this northern part of the crust acts as a buttress, resisting the northward movement of the crust (Fig. 13). Thus, the slow, gradual northward movement of the underlying mantle is the probable cause of the crustal structures in the Yakima fold belt as well as in the upper Naches River basin. In addition, the clockwise rotational shear in the Naches River area could be caused by movement of the crust to the west and north around the deeply seated Snoqualmie batholith-Mount Stuart massif, north of the belt, which projects farther south than most deep-seated crystalline rock of northern Washington shown in the Geologic Map of Washington State (Schuster, 2005). In Figure 13 the upper cross section is, therefore, the preferred interpretation. With the mantle and overlying crust slowing moving northward, and the crust compressing, a series of thrust faults arose from décollements (a subhorizontal to shallowly dipping detachment zone) at different depths (Anderson, 1987; Watters, 1989), in the basalt section, in the Cenozoic strata section, or possibly from the top of the pre-Tertiary basement. The anticlines are buckle folds (folds which change shape in cross section) generally in the HW of the forethrusts (Laubscher, 1981; Davis, 1981; Price, 1982); that is, where the HW has overridden the FW, and the FW consists of the same basalt flows that compose the HW. Back thrusts develop in more tightly compressed anticlines, for example Umtanum anticline (Stop 1-2; Fig.18). Here it should be noted that the thrusts in the Manastash Ridge area do penetrate the basement rocks, indicating that they arise from a yet deeper source.

The structure map of the Yakima fold belt (of which Fig. 15 is a small part) shows a narrowing spacing between folds to the north in the fold belt, not in the diagonally drawn domains across the fold belt in Watters (1989). Yet no studies have so far shown that there is a greater shortening, or compression, within the folds to the north. The first indication that a forethrust dips 30° beneath an anticline was obtained through chemical stratigraphy of the drill core in borehole BN No. 1-9 (Fig. 15; Campbell, 1989) on the south flank of the Saddle Mountains anticline (Tincher & Reidel, 2009). Hopefully, detailed stratigraphic studies in the plateau, particulary in the area of deep bore holes, will confirm the shallow dip of thrust faults, possibly showing a steeper dip at greater depths.

The lower cross section in Figure 13 was an earlier attempt by Hammond to show that the Yakima folds were caused by compressional squeezing of the crust by the mantle, producing a series of uplifted E-W elongated wedges. Because the majority of the faults in the Naches River basin are steeply dipping, an upward force was in initially considered in the model.

However, in this model it is difficult to explain shallowly dipping thrust faults in the flanks of the folds and faults which dip 30° beneath a fold Tincher & Reidel, 2009). Three common types of Yakima folds—drap fold, fold with flank faults, and fold with compressed core (Fig. 18)--are shown in cartoons along the margin of Figure 13.

CONCLUSIONS

1) Seven lava flows of Columbia River Basalt in the upper Naches River basin in the western margin of the Columbia Plateau consist of the upper part of Grande Ronde Basalt, R_2 and N_2. Each lava flow is identified by its MgO versus TiO_2 chemical signature. The lava flows in descending stratigraphic order are: Museum, Rocky Coulee, Cohassett, McCoy Canyon, Ortley, Meeks Table, and Wapshilla Ridge. The four top flows compose the Sentinel Bluffs unit and are high-MgO in composition. These flows and the Ortley are N_2. The lower two flows are low-MgO and R_2.
2) Each lava flow varies in internal structure---tiering, jointing, content of hyaloclastite and pillow lava, and whether it's a sheet flow or composed of lava lobes. Flows 100 m or more in thickness are commonly invasive flows of lava lobes; thinner flows are sheet flows.
3) Structural domains in the upper Naches River basin consist of (1) Cascade Range of NW-striking faults and shear folds, (2) E-W-striking Yakima folds with E-W thrust or reverse faults and N- to NW-striking normal faults, and (3) N-NW-striking thrust and reverse faults and shear folds defining the Olympic-Wallowa Lineament (OWL), a compressional zone.
4) Yakima folds are caused by the northward underflow of the mantle toward a resisting buttress of deeply seated crustal rocks in northern Washington. The movement is subjecting the area to a right lateral rotational (clockwise) shear. Folds are caused by shallow to steeply dipping generally southward faults arising from probable décollements within the basalt section, more likely in the thick underlying Cenozoic section, and possibly the contact between the Cenozoic section and pre-Tertiary basement rocks.

ACKNOWLEDGMENTS

Many thanks to Steve Jensvold for aid in compiling the road log and providing information. Similarly, many thanks to Jack Powell for his geologic contributions, including several diagrams and images. Thanks too to Tom Badger for the photograph of the Nile landslide from Eagle Rock. Over many years Robert Bentley provided much information in discussion and supplying maps and reports (Bentley, 1977; Bentley et al., 1988), enriching my geologic knowledge of the area. And thanks to the Northwest Geological Society, especially Greg Ferris and John Figge, for organizing the field trip and providing guidance in making this field trip guide. Paul E. Hammond accepts full responsibility for all errors, omissions, and misstatements in the guide.

REFERENCES CITED

Anderson, J.L., 1987, Structural Geology and ages of deformation of a portion of the southwest Columbia Plateau, Washington and Oregon: Ph.D. thesis, University of Southern California, Los Angeles, 283 p.

Barry, T., et al., 2009, New age dates from Grande Ronde Basalt lavas, Columbia River Basalt: Implications for periodicity of flood basalt eruptions and duration of major pulses: Geological Society of America, Abstracts with Programs, v. 41, no. 7, p. 298.

Bentley, R.D., 1977, Stratigraphy of the Yakima Basalts and structural evolution of the Yakima ridges in the western Columbia Plateau, *in* Brown, E.H., and Ellis, R.C., eds., Geologic excursions in the Pacific Northwest: Bellingham, Western Washington University Press, p. 339-389.

Bentley, R.D., Powell, Jack, Jensvold, Steven, and Campbell, N.P., 1988, Structural geology and stratigraphy of the Cleman Mountain area, "Cleman Mountain Report": Report submitted to Meridian Oil Company, Denver, Colorado, December 15, 1988, 103 pages, 5 plates, 2 tables.

Boulter, C.A., 1989, Four Dimensional Analysis of Geological Maps: Techniques of Interpretation: John Wiley & Sons, New York, NY, 296 p.

Campbell, N.P., 1989, Structural and stratigraphic interpretation of rocks under the Yakima fold belt, Columbia Basin , based on recent surface mapping and well data, p. 209-222, *in* Reidel, S.R., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colorado, Geological Society of America, Special Paper 239, 386 p.

Camp, V.F., Ross, M.E., and Hanson, W.F., 2003, Genesis of flood basalts and Basin and Range volcanic rocks from Steens Mountain to the Malheur River Gorge, Oregon: Geological Society of America Bulletin, v. 115, no.1, p. 105-128.

Carkin, B. A., Geology and petrology of the Fifes Peak Formation in the Cliffdell area, central Cascades, Washington: M.S. thesis, Western Washington University, Bellingham, 1988.

Davis, G.A., 1981, Late Cenozoic tectonics of the Pacific Northwest with special reference to the Columbia Plateau: Richland, WA, Washington Public Power Supply Final Safety Analysis Report for WPN-2, Appendix 2.5N.44 p.

Fiske, R.S., Hopson, C.A., and Waters, A.C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geological Survey Professional Paper 444, 93 p.

Goetsch, S.A., 1978, The metamorphic and structural history of the Quartz Mountain—Lookout Mountain area, Kittitas County, central Cascades, Washington, scale 1:24,000: M.S. thesis, University of Washington, Seattle, Washington, 86 p.

Hammond, P.E., 2005, Geologic Map of the Timberwolf Mountain 7.5-minute Quadrangle,Yakima County, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-60, 1 sheet, scale 1:24,000.

Hammond, P.E., 2009, Geologic Map of the Meeks Table and western two-thirds Nile 7.5-minute Quadrangles, Yakima County, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-74, 1 sheet, scale 1:24,000.

Hammond, P. E., 2010 (soon to be released), Geologic map of the Cliffdell and western two-thirds of the Manastash Lake 7.5-minute Quadrangles, Yakima and Kittitas Counties, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-76, 1 sheet, scale 1:24,000.

Hammond, P. E., in preparation, Geologic Map of northern parts of Rimrock Lake, Tieton Basin, and western two-thirds of the Weddle Canyon 7.5-minute Quadrangles, Yakima County, Washington: Washington Division of Geology and Earth Resources, Geologic Map.

Humphrey, C.C., 1996, Correlation of the upper Ellensburg Formation with the Old Scab Mountain eruptive center, east-central Cascade Range, Washington; Portland, OR, Portland Stare University, Master of Science thesis, 201p.

Kienle, C.J., Jr., Bentley, R.D., and Anderson, J.L., 1977, Geologic reconnaissance of the Cle Elum-Wallula lineament and related structures, *in* Washington Public Power Supply System PSAR for WPPSS Nuclear Projects 1 and 4, Shannon and Wilson, Inc., Amendment 23, 33 p.

Landon, R.D., and Long, P.E., 1989, Detailed stratigraphy of the N_2 Grande Ronde Basalt, Columbia River Basalt Group, in the central Columbia Plateau, p. 55-66, *in* Reidel, S.P., and Hooper, P.R, eds., Volcanism and tectonism in the Columbia Rver flood-basalt province: Boulder, Colorado, Geological Society of America, Special Paper 239, 386 p.

Luker, J.A., Jr., 1985, Sedimentology of the Ellensburg Formation northwest of Yakima, Washington: Cheney, WA, Eastern Washington University, Master of Science thesis, 184 p.

Laubscher, H.P., 1981, Models of development of the Yakima deformation: Washington Public Power Supply System, Inc., Final Safety Analysis Nuclear Project no, 2 Report, Amendment 18, Appendix 2.5-0, 64 p.

Miller, R.B., 1989, The Mesozoic Rimrock Lake inlier, southern Washington Cascades: Implications for the basement to the Columbia Embayment: Geological Society of America Bulletin, v. 101, p. 1289-1305.

MacDonald, J.H., Jr., 2006, Petrology, Petrogenesis, and Tectonic Setting of Jurassic rocks of the Central Cascades, Washington, and Western Klamath Mountains, California-Oregon: Ph.D. dissertation, Albany, N.Y., University of Albany, 415 p.

Park, R.G., 1989, Foundations of Structural Geology: Chapman and Hall, a division of Routledge, Chapman, and Hall, Inc., 29 West 35th Street, New York, NY 10001, 148 p.

Price, E.H., and Watkinson, A.J., 1989, Structural geometry and strain distribution within eastern Umtanum fold ridge, south-central Washington, p. 265-281, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, CO, Geological Society of America, Special Paper 239, 386 p.

Raisz, E., 1945, The Olympic-Wallowa Lineament: American Journal of Science, v. 243-A, no. 5, p. 479-485.

Reidel, S.R., and others, 1989, The Grande Ronde Basalt, Columbia River Basalt Group; Stratigraphic descriptions and correlations in Washington, Oregon, and Idaho, p. 21-53, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and Tectonism in the Columbia River flood-basalt province: Boulder, Colorado, Geological Society of America, Special Paper 239, 386 p.

Reidel, S.R., and Campbell, N.P., 1989, Structure of the Yakima Fold Belt, central Washington, p. 275-303, *in* Joseph, N.L., ed., Geologic guidebook for Washington and adjacent areas: Washington Division of Geology and Earth Resources Information Circular 86.

Schuster, J.D., 2005, Geologic Map of Washington State: Washington Division of Geology and Earth Resources Geologic Map GM-53.

Silvester, A.G., 1988, Strike-slip faults: Geological Society of America Bulletin, v. 100, no. 11, p.1666-1703.

Smith, G.A., 1988, Sedimentology of proximal to distal volcaniclastics dispersed across and active foldbelt—Ellensburg Formation (late Miocene), central Washington: Sedimentology , v. 35, no.6, p. 953-977.

Swanson, D.A., 1964, The middle and late Cenozoic volcanic rocks of the Tieton River area, south-central Washington, scale 1:48,000: Ph.D. thesis, The John Hopkins University, Baltimore, Maryland, 330 p.

Swanson, D.A., 1966, Tieton volcano, a Miocene eruptive center in the southern Cascade Mountains, Washington: Geological Society of America Bulletin, v.77, p. 1293-1314.

Swanson, D.A., 1967, Yakima Basalt of the Tieton River area, south-central Washington: Geological Society of America Bulletin, v. 78, p. 1077-1100.

Swanson, D.A., 1978, Geologic map of the Tieton River area, Yakima County, south-central Washington: U.S. Geological Survey Miscellaneous Field Studies, Map MF-968, 1 sheet, scale 1:48,000.

Swanson, D.A., Cameron, K.A., Evarts, R.C., Pringle, P.T., and Vance, J.A., 1989a, Cenozoic volcanism in the Cascade Range and Columbia Plateau, southern Washington and northernmost Oregon, *in* Field excursions to volcanic terranes [terrains] in the western United States, Volume II: Cascades and Intermountain West, Chapin, C.E., and Zidek, Jiri, eds.: New Mexico Bureau of Mines and Mineral Resources, Memoir 47, p. 1-50

Swanson, D.A., 1989b, Cenozoic volcanism in the Cascade Range and Columbia Plateau, southern Washington and northernmost Oregon: 28th International Geological Congress, Field Tip Guidebook T 106, 60 p.

Tincher, C.R., and Reidel, S.R., 2009, New evidence for the nature of the Saddle Mountains fault zone, p. 226: Geological Society of America, Abstracts with Programs, v. 41, no. 7, 744 p.

Tolan, T.L., and Reidel, S.P., 1989, Structure map of a portion of the Columbia River flood-basalt Province, in Reidel, S.P., and Hooper, P.R., eds., Volcanism and Tectonism in the Columbia River flood-basalt province: Boulder, Colorado, Geological Society of America, Special Paper 239, 386 p.

Vance, J.A., Clayton, G.A., Mattinson, J.M., and Naeser, C.W., 1987, Early and middle Cenozoic stratigraphy of the Mount Rainier- Tieton River area, southern Washington Cascades, *in* Schuster, J.E., ed., Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 269-290.

Walker, J.D., and Geissman, J.W., 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C.

Watters, T.R., 1989, Periodically spaced anticlines of the Columbia Plateau, p. 283-292: *in* Reidel, S.R., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colorado, Geological Society of America, Special Paper 239, 386 p.

Wells, R.E., et al., 2009, The Columbia River Basalt Group---From the gorge to the sea. *in* O'Connor, J.E., Dorsey, R.J., and Madin, I.P., eds., Volcanoes to Vineyards: Geologic Field Trips through the Dynamic Landscape of the Pacific Northwest: Geological Society of American Field Guide 15, p. 737-774, doi: 10.1130/2009.fld015(32).

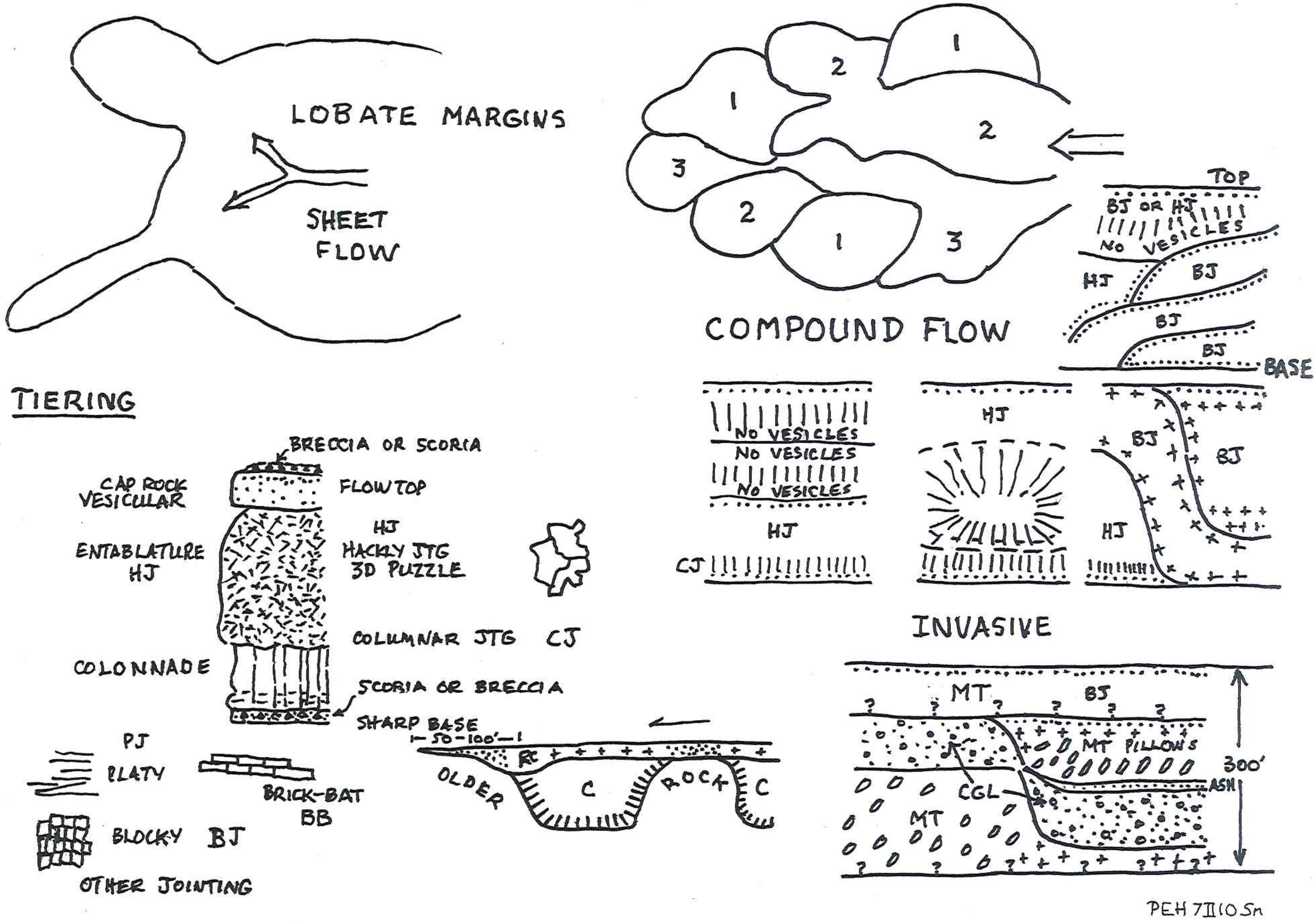


Figure 6. Columbia River Basalt lava flow types, showing tiering, jointing, and invasive lava.

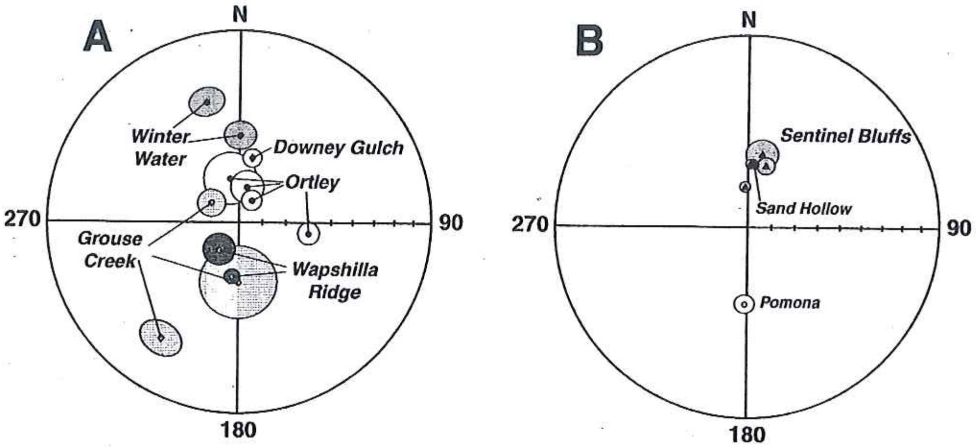


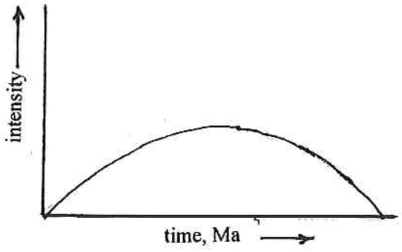
Figure 7. *Paleomagnetic directions for Columbia River Basalt flows in Columbia River Gorge. (A) Low-MgO Grande Ronde Basalt flows. (B) Sentinel Bluffs Member of high-MgO Grande Ronde Basalt, basalt of Sand Hollow (Frenchman Springs Member of Saddle Mountains Basalt), and Pomona of Saddle Mountains Basalt. Normal: lower hemisphere directions represented by solid symbols; reversed, upper hemisphere directions by open symbols; all shown with 95% confidence ovals (from Wells et al., 2009).*

10 to 5/3 Ma, upper Miocene into Pliocene, after deposition of Columbia River Basalt and Ellensburg Fm; possibly began gradually as early as 15.5 Ma with deposition of Wanapum Basalt
--intense at culmination
--folding and faulting of Columbia River Basalt, e.g., the Yakima folds
--uplift of Cascade Range

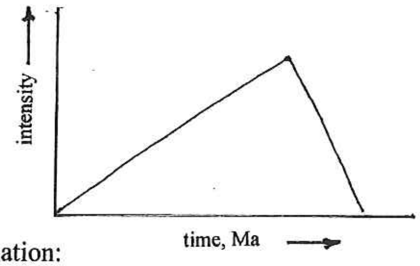
22 to 17/16 Ma, lower Miocene, between deposition of Fifes Peak Fm and Columbia River Basalt
--moderately intense
--folding and faulting of all pre-Columbia River Basalt rock units
-- deep erosion, locally eroding Cenozoic strata down to preTertiary rock

29 to 28 Ma, at close of lower Oligocene, between deposition of Ohanapecosh Fm and Fifes Peak Fm
--mild deformation, some folding and faulting
--some erosion
--possible beginning of deformation in OWL

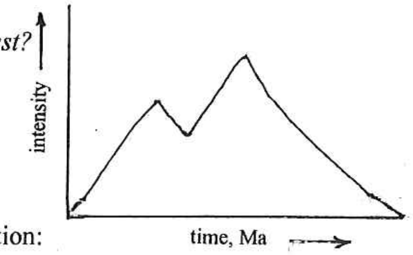
Table 3. *Deformation intervals in the upper Naches River Basin and the Pacific Northwest? Three cartoons showing possible character of deformation intervals.*



Gradual culmination:
Gradual increase to culmination then ceasation



Sharp culmination:
Constant increase to culmination then rapid ceasation



Double culmination:
Constant increase to a primary culmination, short time later strong culmination, then gradual decrease

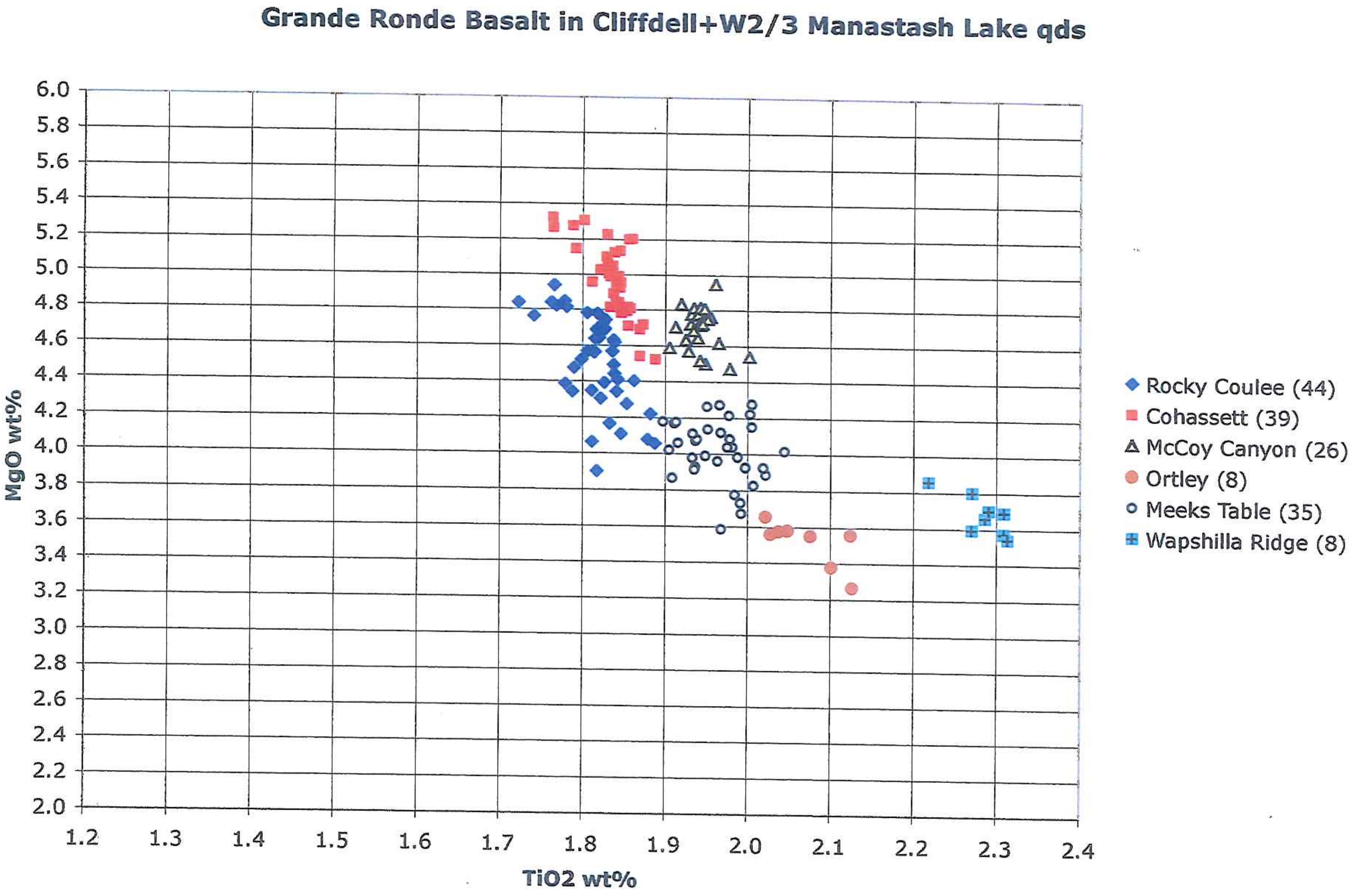


Figure 8A. *MgO vs TiO_2 plot showing distinction between Grande Ronde Basalt flows.*

GRANDE RONDE BASALT LAVA FLOWS IN CLIFFDELL-W2/3 MANASTASH LAKE 7.5' QUADRANGLES, WASHINGTON

	ROCKY COULEE		COHASSETT		McCOY CANYON		ORTLEY		GROUSE CREEK (MEEKS TABLE)		WAPSHILLA RIDGE	
	n=44		n=39		n=26		n=8		n=35		n=8	
	averages	std dev	averages	std dev	average	std dev	average	std dev	average	std dev	average	std dev
analysis total	98.56	0.85	98.71	0.69	98.75	0.61	98.79	0.70	98.34	1.13	98.46	0.70
SiO2	54.78	0.34	54.07	0.26	54.17	0.36	56.45	1.06	55.43	0.44	55.04	0.21
Al2O3	14.35	0.16	14.23	0.13	14.14	0.24	14.50	0.38	14.11	0.28	13.79	0.08
TiO2	1.815	0.035	1.836	0.026	1.943	0.020	2.070	0.043	1.964	0.038	2.283	0.031
FeO*	11.06	0.36	11.30	0.32	11.62	0.67	10.18	1.45	11.37	0.76	12.24	0.23
MnO	0.198	0.009	0.207	0.007	0.213	0.007	0.194	0.059	0.192	0.013	0.206	0.006
CaO	8.58	0.42	8.91	0.16	8.72	0.14	7.75	0.15	7.91	0.36	7.43	0.11
MgO	4.53	0.26	4.97	0.20	4.70	0.12	3.52	0.13	4.02	0.17	3.68	0.11
K2O	1.34	0.11	1.21	0.07	1.26	0.08	1.69	0.12	1.57	0.16	1.84	0.12
Na2O	3.01	0.15	2.95	0.08	2.94	0.05	3.30	0.18	3.12	0.12	3.08	0.05
P2O5	0.331	0.022	0.325	0.019	0.299	0.013	0.356	0.013	0.323	0.015	0.404	0.007
Ni	13	5	16	6	14	5	16	4	14	5	17	3
Cr	39	12	48	4	26	6	16	8	20	8	12	4
Sc	37	4	37	3	38	2	37	4	34	4	34	1
V	307	14	308	8	339	8	364	6	343	8	392	9
Ba	562	53	486	27	477	23	731	80	630	29	687	16
Rb	33	4	28	2	28	1	44	4	40	4	47	3
Sr	315	7	306	6	315	8	333	19	316	10	327	9
Zr	158	5	153	4	154	4	173	7	162	5	180	6
Y	34	2	34	1	33	1	37	3	34	2	37	1
Nb	11.8	1.1	11.2	0.9	11.1	1.0	12.2	1.0	11.4	0.9	12.8	1.1
Ga	20	1	20	1	21	1	22	1	21	1	21	1
Cu	25	5	32	4	24	4	31	6	27	5	31	2
Zn	114	5	114	3	115	3	126	8	117	3	126	3
Pb	6	2	5	2	6	1	9	1	7	2	8	1
La	21	11	19	4	19	3	26	7	21	3	25	3
Ce	40	15	42	6	41	4	47	5	46	6	54	4
Th	4	1	3	1	3	1	5	0	5	1	5	1

***Figure 8B.** A table showing average compositions of flows in Fig. 8A.*

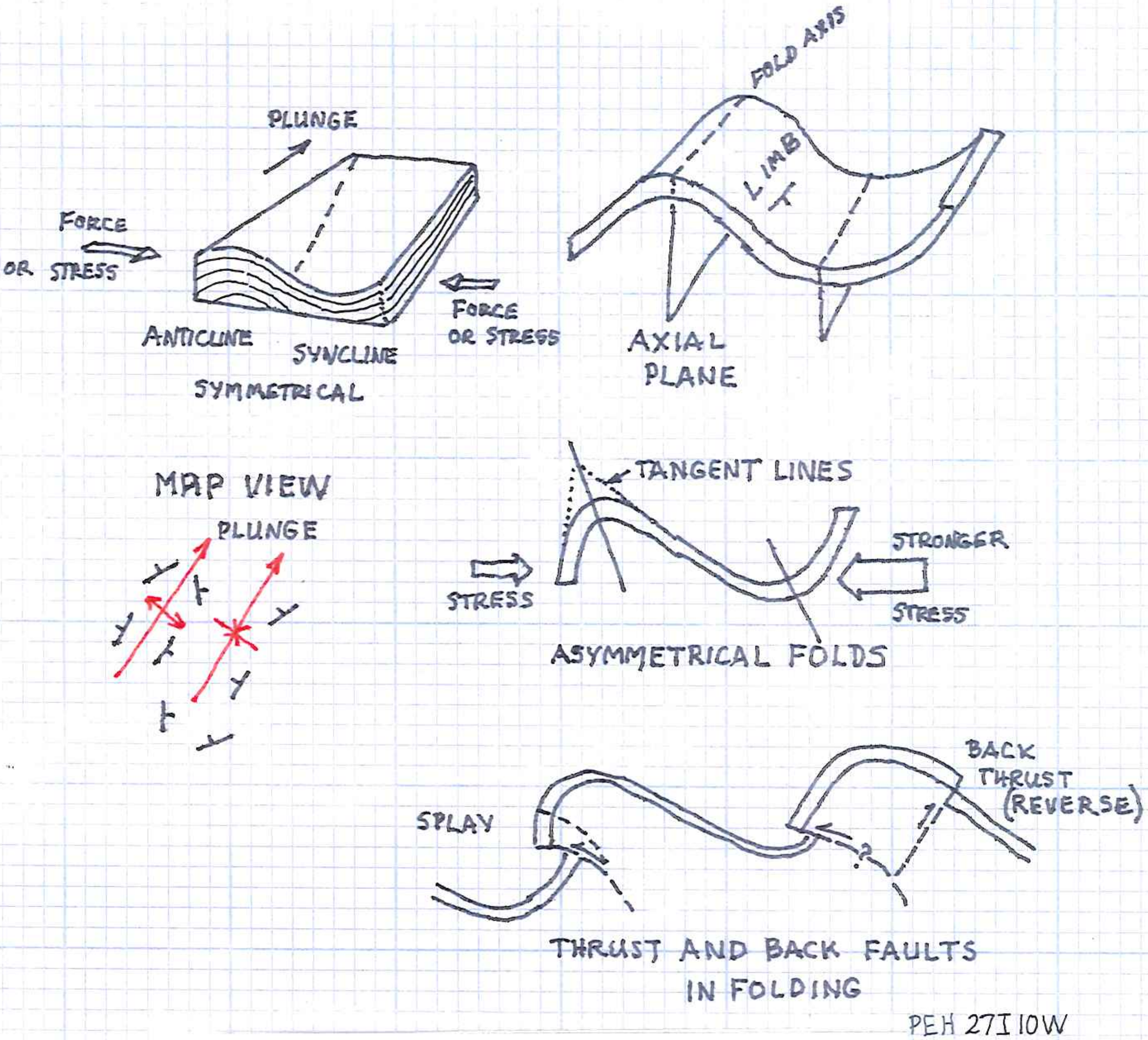


Figure 9. *Features of folds basic to describing and understanding them.*

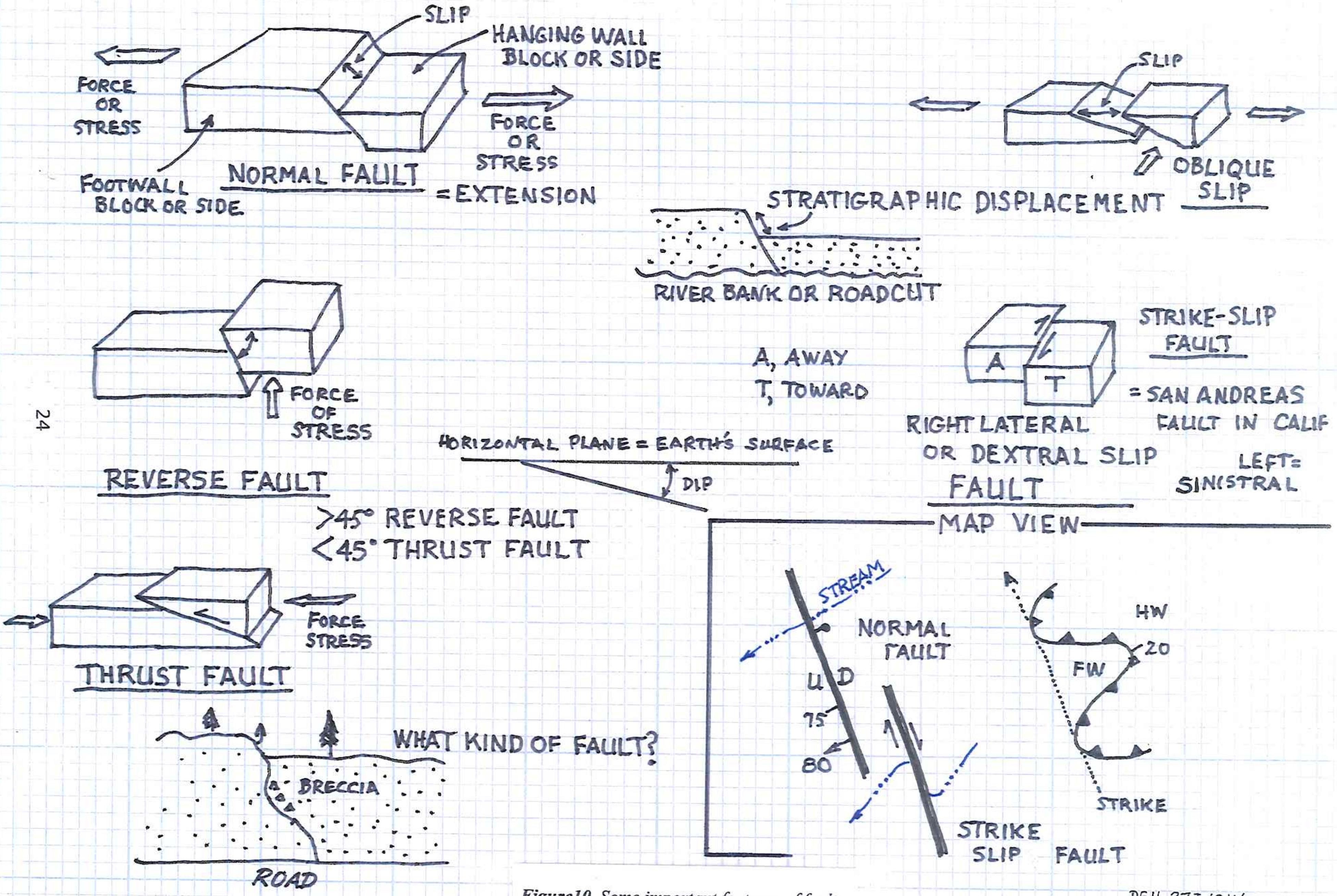
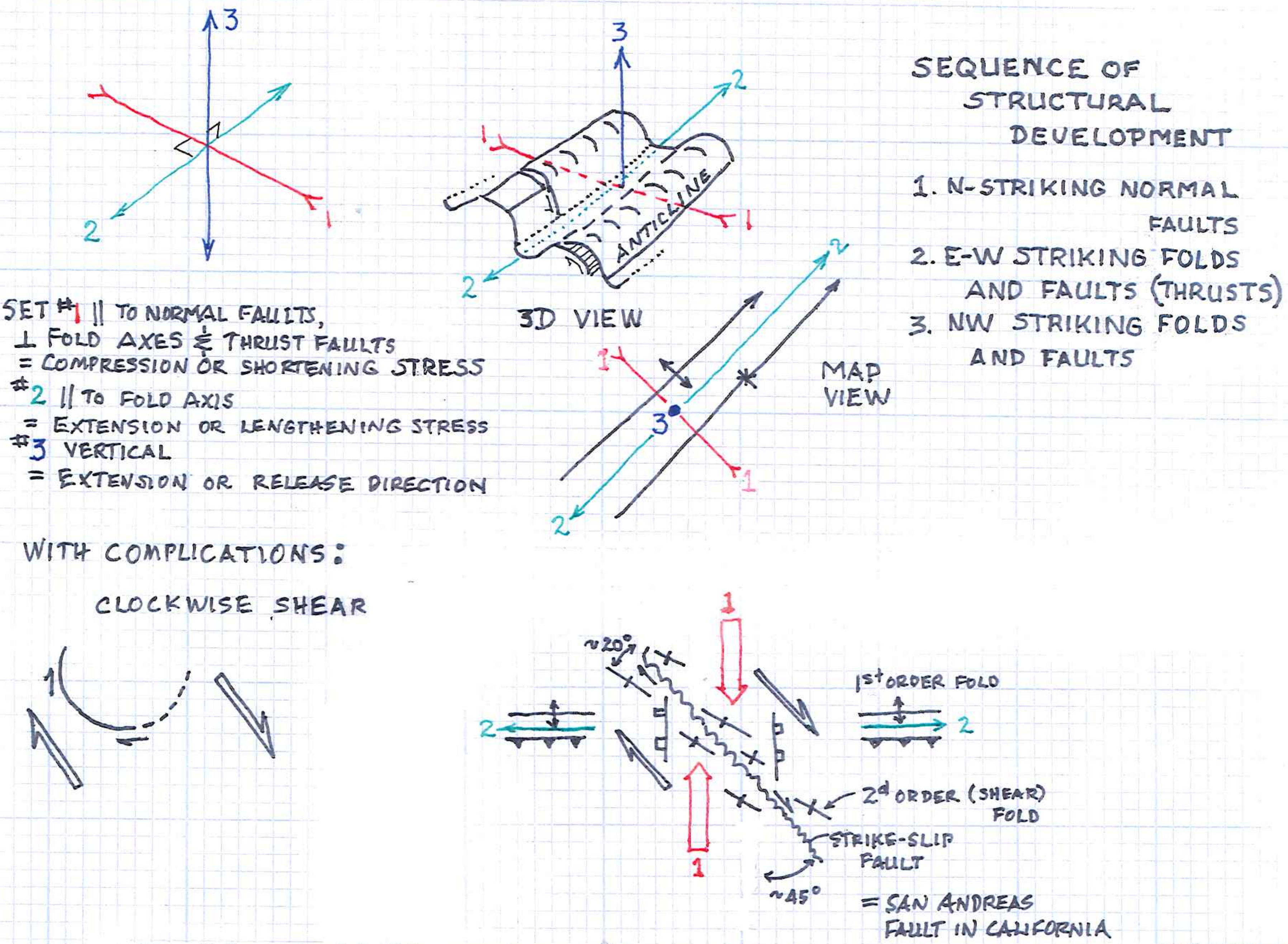


Figure10. *Some important features of faults.*

PEH 271 IOW



SEQUENCE OF STRUCTURAL DEVELOPMENT

1. N-STRIKING NORMAL FAULTS
2. E-W STRIKING FOLDS AND FAULTS (THRUSTS)
3. NW STRIKING FOLDS AND FAULTS

SET #1 || TO NORMAL FAULTS,
⊥ FOLD AXES & THRUST FAULTS
= COMPRESSION OR SHORTENING STRESS
#2 || TO FOLD AXIS
= EXTENSION OR LENGTHENING STRESS
#3 VERTICAL
= EXTENSION OR RELEASE DIRECTION

WITH COMPLICATIONS:

CLOCKWISE SHEAR

= SAN ANDREAS FAULT IN CALIFORNIA

Figure 11. *Structural analysis. Giving steps setting structural directions with respect to given three directional axes. Showing complications in a right-lateral clockwise shear, presently affecting the Pacific Northwest, adding directions of shearing.*

PEH 6II105

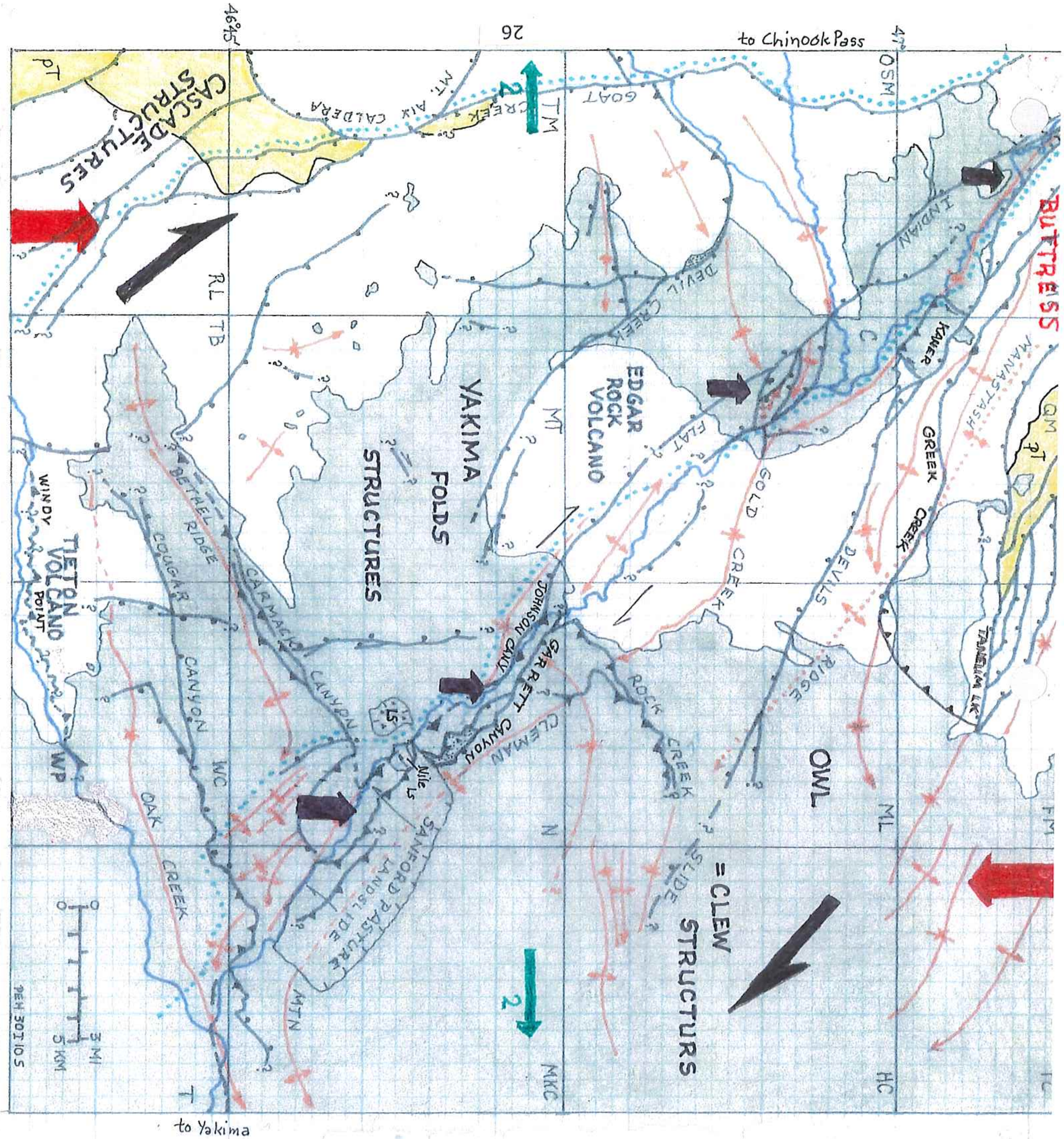


Figure 12. *Stress (force) directions in the upper Naches River basin. Red arrows mark principal shortening stress. Note buttress to north. Green arrows give lengthening direction. Small black arrows give northward movement of area southwest of Naches River, underthrusting area to northeast. Diagonal long black arrows give sense of rotation. Structural symbols as in figure 4.*

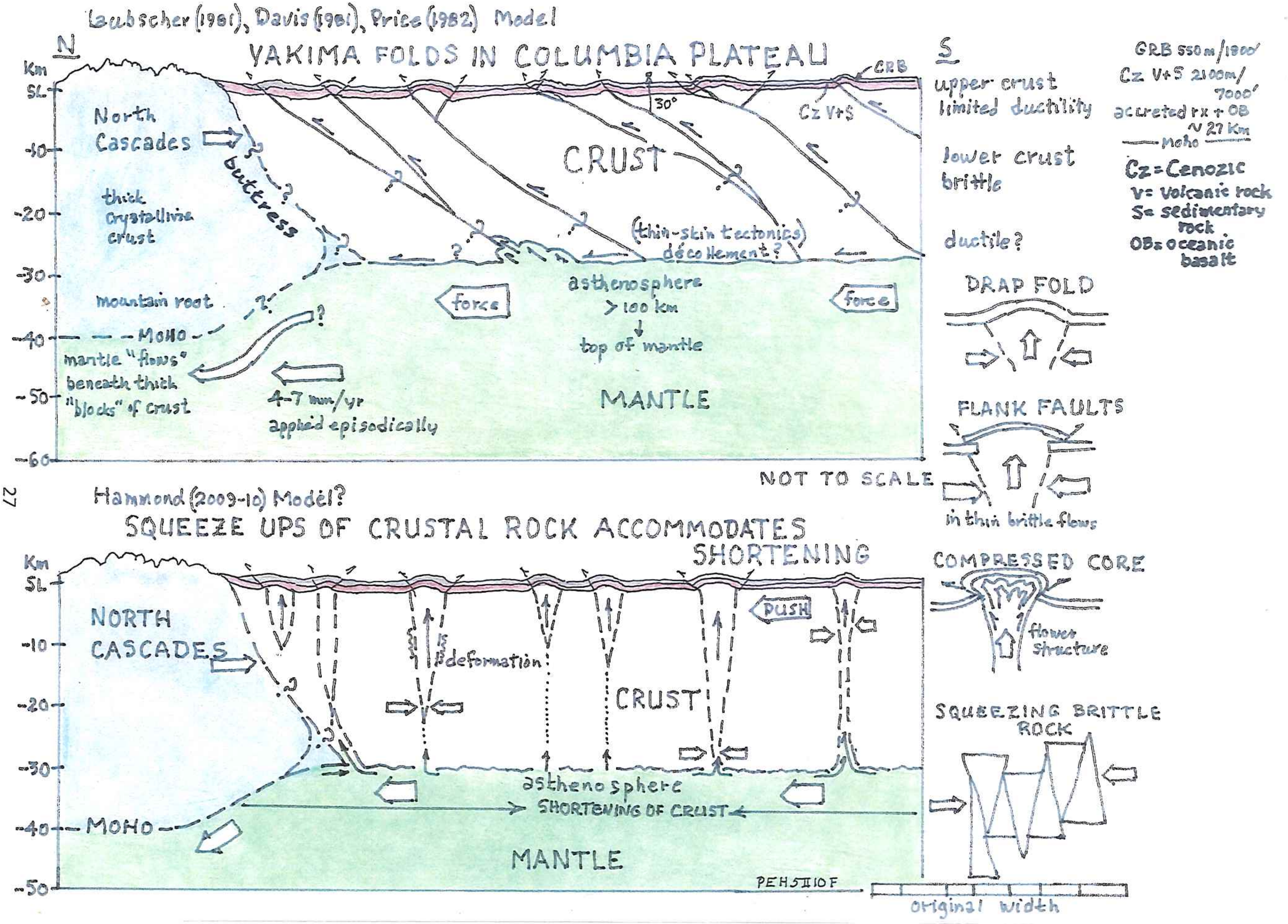
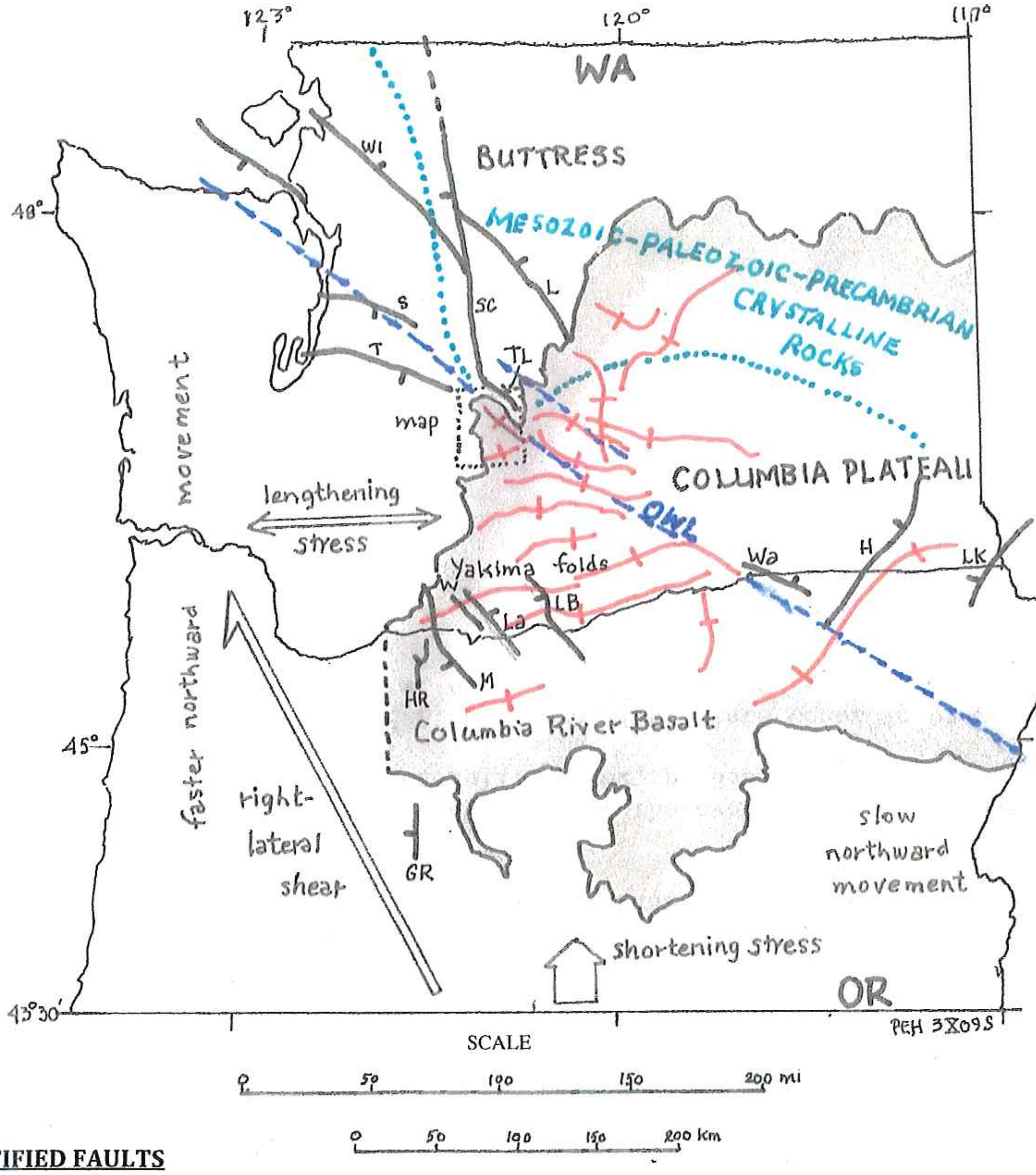


Figure 13. *Cross sections through crust showing possible origins of Yakima folds. The upper section is now favored. A recent borehole south of Saddle Mountains penetrated thrust fault, giving dip of fault at 30°* (Tincher & Reidel, 2009).

YAKIMA FOLDS AND ASSOCIATED STRUCTURES IN PAC NW



IDENTIFIED FAULTS

GR, GREEN RIDGE
H, HITE
HR, HOOD RIVER
L, LEAVENWORTH
LA, LAUREL
LB, LUNA BUTTE
LK, LIMEKILN
M, MAUPIN
S, SEATTLE
SC, STRAIGHT CREEK
T, TACOMA
TL. TANEUM LAKE
W, WARWICK
WA, WALLULA
WI, WHIDBEY ISLAND FAULT

Figure 14. Map showing setting of Yakima folds in Columbia Plateau and vicinity, major structures associated with the folds, and regional stress directions.

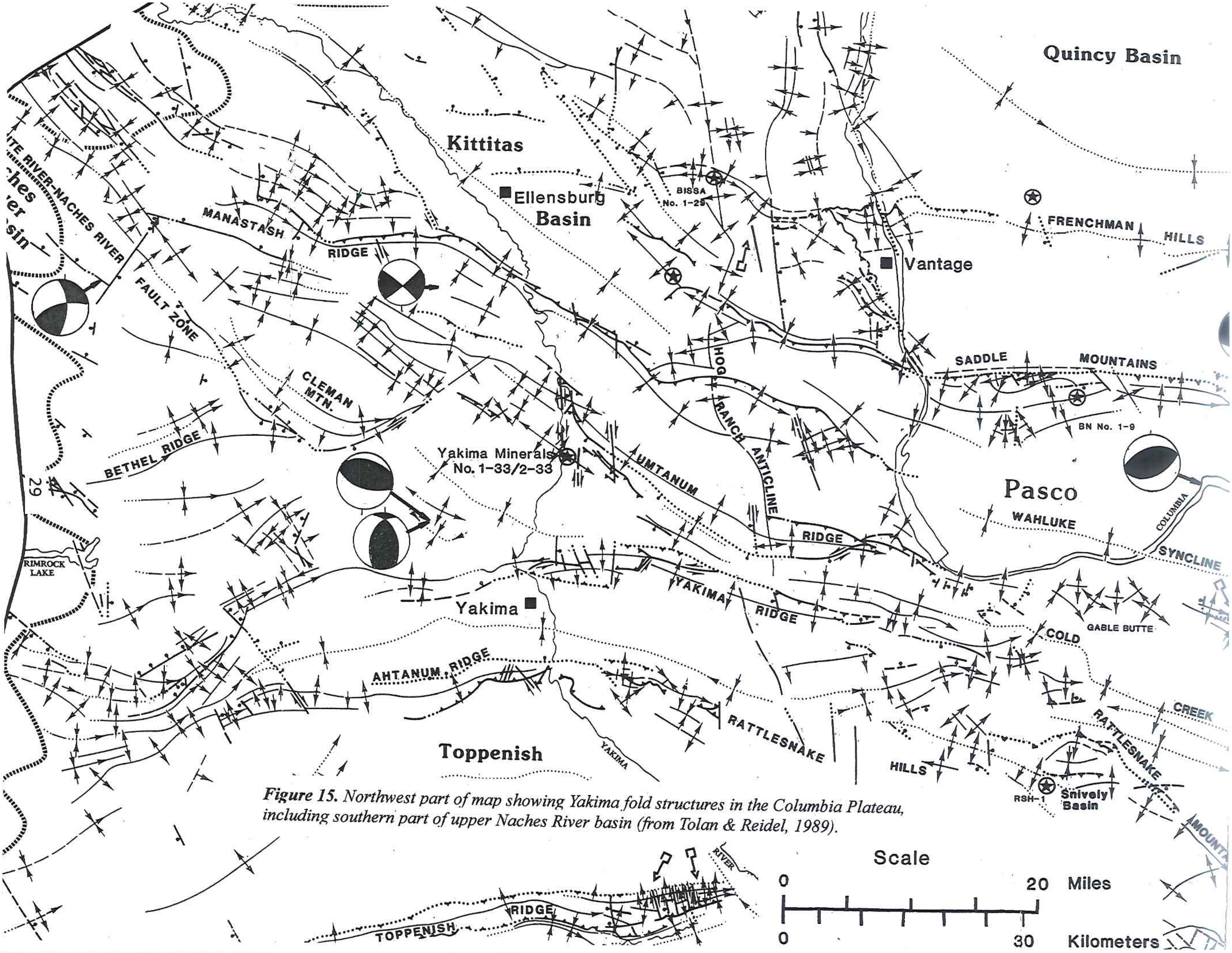


Figure 15. Northwest part of map showing Yakima fold structures in the Columbia Plateau, including southern part of upper Naches River basin (from Tolan & Reidel, 1989).

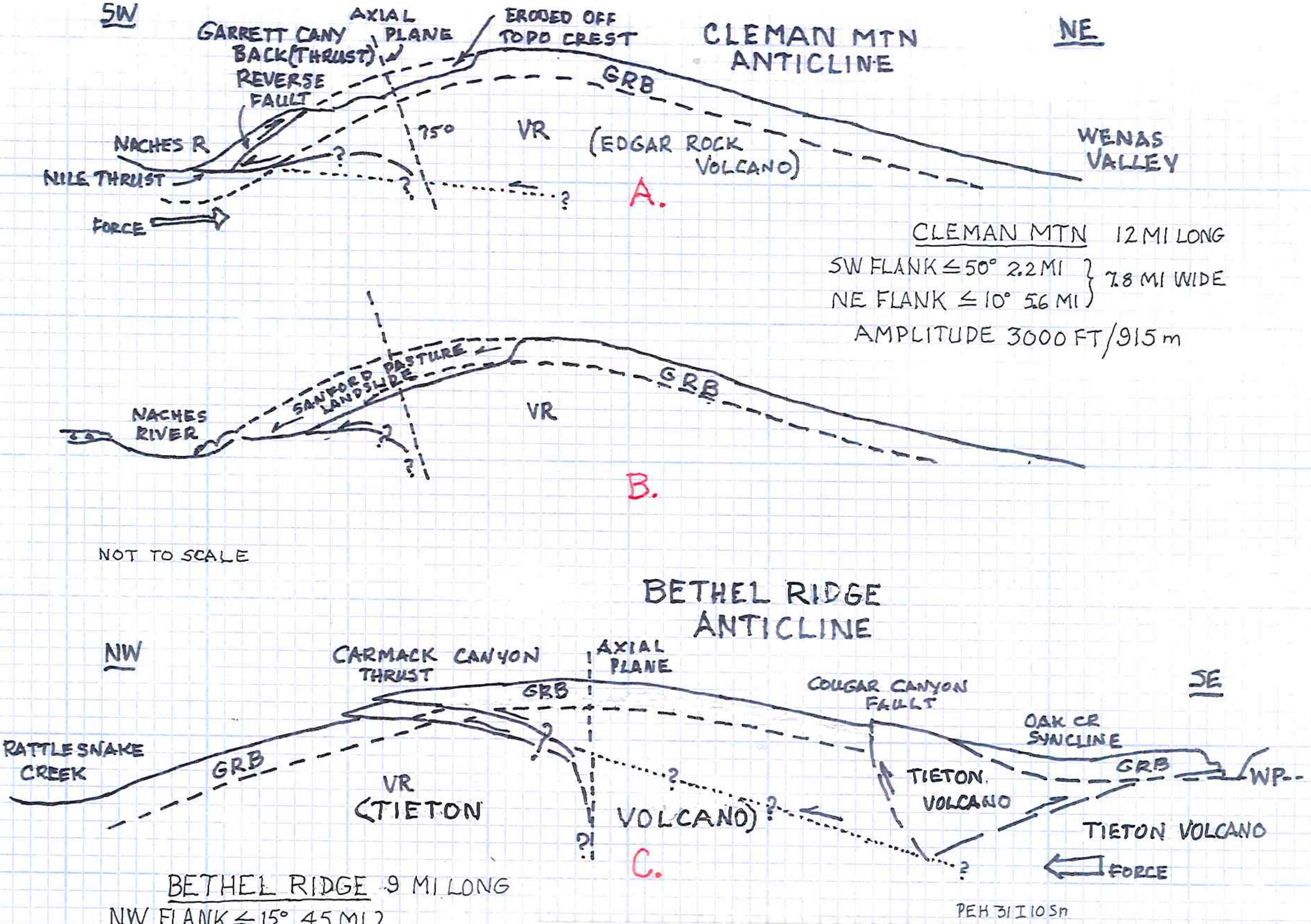


Figure 16. *Simplified cross sections through Cleman Mountain and Bethel Ridge anticlines. (A) Cleman Mountain north of Sanford Pasture landslide. Northeast flank of Cleman Mountain not mapped. (B) Cleman Mountain at Sanford Pasture landslide. (C) Bethel Ridge anticline. Note higher position of thrust faults in Bethel Ridge anticline; also, Windy Point (WP) thrust on southeast side of Bethel Ridge could be forethrust. Then Cougar Canyon and Carmack Canyon could be back thrust.*

ROAD LOGS

The descriptions at the stops are brief or only specific features are mentioned. Much information can be gathered by studying the figures. Most information is concentrated in the first part of this field trip guide.

ROAD LOG DAY 1

Ellensburg-Yakima River Canyon-Yakima-lower Naches River-Nile landslide-Bethel Ridge

Head south 4.5 miles to Stop 1-1 from McDonald's meeting place on Canyon Road. South of Ellensburg Canyon Road becomes highway WA 821. Continue into Yakima River Canyon eroded into folded and faulted Columbia River Basalt.

STOP 1-1. N46°54'50"W120°30'19.5", Ellensburg South 7.5'. Stratigraphy and structure in north flank of Manastash Ridge anticline (Fig. 17).

Pull onto wide shoulder on right (west) side overlooking Yakima River. Complicated stratigraphy and structure in Columbia River Basalt in north flank of Manastash Ridge. Study fig. 17; compare it to the features in the highway cut. WATCH FOR TRAFFIC!

Continue 11.1 miles south to stop 1-2 on highway WA 821. Pass through broad synclinal valley enroute to Umtanum Ridge.

STOP 1-2. N46°48'53.5"W120°26'56", Wymer 7.5'. Stratigraphy and structure in Umtanum anticline (Fig. 18).

Stop at Beck Memorial, a basalt boulder atop a concrete pedestal, on right side of highway. Read the Memorial plaques. Then view east,using field glasses, at faulted Umtanum (Baldy) anticline, one of the best exposures of a Yakima fold in the Columbia Plateau. Estimate the degrees of dip of the flanks of the anticline. What is the approximate dip of the axial plane? Trace the faults, referring to fig. 18. Which fault occurred first, becoming possibly the forethrust?

Continue 35 miles to stop 1-3; 20 miles to NW Yakima; another 15 miles to stop 1-3. Continue south on highway WA 821 to junction with I-82. Follow I-82 to north edge of Yakima. Turn off west—watch signs carefully—to US 12. Continue west on US 12 to NW40th exit. Head south through stop signal. Park in Fred Meyer or McDonalds. From here return north to left lane at stop light at Fruitvale Blvd. Turn left (west) and head west on US 12 through Naches to stop 3.
Route south from stop 1-2 passes through wide synclinal Burbank Valley. As Selah Butte anticline is approached, route passes above a broad valley with the Roza dispersion dam on the Yakima River. This is the type area of the Roza lava flow (Table 1). The small structure in the middle of the clear area is the site of Shell's exploratory drill hole Yakima Minerals No. 1-33/2-33 (Campbell, 1989). Exit south entrance to Yakima River Canyon, pass rim and type area of Pomona basalt lava flow. Bypass exit to Selah but do exit to right before crossing freeway to I-82. Continue south and southwest on I-82 into Selah Gap (exposed lava flows of Frenchman Springs and Priest Rapids, Table 1 in Yakima Ridge anticline), taking care to follow signs to highway US 12 and Naches. Possible rest stop in NW Yakima. On US 12 head west and northwest in lowermost Naches River valley. Northwest of Yakima lies Yakima Ridge anticline. Swanson (1989a, p. 25-26; 1989b, p. 30-32) gives good descriptions of geologic features in this part of the Naches Valley. Bluff on left (south side) is 280-ft thick termination of Tieton Andesite lava flow, 40Ar/39Ar-dated at 1.64±0.07 Ma (Hammond, in preparation). About midway to Naches, highway passes, on right (north) side, western terminations of Pomona Basalt and Frenchman Springs lava flows (Table 1). As Naches is approached, prominent ridge ahead is Cleman Mountain. Enter Naches, stop light in town center. Stop 1-3 is 5.0 miles ahead. At junction with highway WA 410 TURN Left. Go another 0.2 mile to large parking area on left. WATCH OUT FOR ONCOMING TRAFFIC.

STOP 1-3. N46°44'40"W120°47'16", Tieton and Milk Canyon 7.5', Structures in south Cleman Mountain anticline, (Fig. 19).

Cross highway US12 to west and climb a few steps atop alluvial terrace for a wider view of the mountain. Use field glasses. The southern part of Cleman Mountain has not been mapped geologically, so the geology is not well understood. And looking from the valley here does not give one a good picture. Refer to fig. 19. In cross section A, the axial plane dips about 65° north, passing through the middle slopes of the ridges to the north. The Waterworks fault, supposedly a back thrust, strikes E behind ridge 3582' (point 3100' in the cross section), dipping steeply south, and gradually descends across the south flank of the next ridge to the east, and disappears beneath the alleviated floor of the Naches River valley. Lava flows of both R2 and N2 dip 55° to 20° S, less steeply at lower elevations. In the area of cross section B, E of the Waterworks fault, the lava flows dip more steeply south, and locally are overturned. All slopes here consist of R2 lava flows; the higher ridges to the north are composed of N2 lavas. East of cross section, B, the anticline plunges about 10° E. The sharp break in the slope to the east, forming the contact with the Ellensburg Fm, is the trace of the NE-striking Oak Creek syncline, not a fault contact. Return to vehicles.

Stop 1-4 lies 1.8 miles ahead to west. Return to junction highways US 12 and WA 410. Turn left (west) onto highway 410. Naches River is to left; steep slopes of Cleman Mountain to right.

STOP 1-4. N46°45'14.2"W120°49'04.9", Milk Canyon 7.5' Waterworks fault---not well exposed in roadcut.

Turn right into short parking space (enough for four vans). Here Waterworks fault crosses river and strikes east, ascending slopes of Cleman Mountain. Fajult is very poorly exposed at highway level. 120-ft high roadcuts of Ortley lava flow lie on both sides of fault, making determination of fault displacement difficult. The displacement here is probably minor. A possible amount of oblique slip may be important.

Proceed west 0.8 miles to stop 1-5 on a dangerous bend. IN APPROACHING THIS STOP DRIVER MUST WATCH FOR ONCOMING TRAFFIC BEFORE MAKING TURN TO LEFT (west) in large parking area.

STOP 1-5. N46°45'40"W120°49'46.8", Milk Canyon 7.5'. Horseshoe Bend (Figs. 4 and 20).

From this spot one can view a little stratigraphy. Using field glasses, possibly trace Waterworks fault west into Cougar Canyon, note debris of Sanford Pasture landslide in hill to west, forming an eye-catching hoodoo, and south margin of the landslide to the north. Note the beautiful gravel terrace to the north, which appears to consist of two deposits, a lower well-sorted, boulder oriented deposit, and an upper unsorted deposit. Walk N a short distance, carefully cross highway to guard rail to view rock quarry. Source rock is conglomerate and Meeks Table lava forming wall of quarry. Note, in field glasses, lenses of sand in invasive lava in back wall. Above highway to east are fresh exposures of boulder gravels and tuff interbeds, suggesting pauses in deposition of the gravels, possibly during evacuation of Sanford Pasture landslide deposits up valley.

Highway was cut in upper part of Ortley lava. Underlying Meeks Table lava is exposed in river bedrock and quarry. House to north sits on ledge cut into SW-dipping sand interbed separating Ortley and Meeks Table lava flows. This stop sits in trough of NW-striking Naches River valley syncline, which is not named in Fig. 4.

Stop 1-6 lies 5.1 miles ahead. Continue north and northwest on highway WA 410. The highway follows approximately the west margin of the Sanford Pasture landslide deposits. On right lies thick stream-cut, unsorted, abundant angular rock deposits and a few low hills of deformed lava flows, whereas to left (west) lie steep, nearly smooth slopes, with scattered outcrops of horizontal to steeply dipping lava-flow rims. Stop 6 is at a blind bend. To avoid potentially busy traffic in vehicle crossing highway to a parking area, vans continue north past stop 1-6 0.7 miles to junction of South Nile Road and highway 410, turn around, and return south to roadcut in bluff on eastside. Vehicles pull onto west side shoulder. FIELD TRIPPERS MUST WATCH FOR TRAFFIC IN BOTH LANES.

STOP 1-6. N46°48'06.0"W120°54'21.8", Nile 7.5'. Meeks Table flow pancakes tuff and conglomerate bed.

Two lobes of the Meeks Table lava flow, composed largely of pillow lava, pancake a conglomerate and tuff interbed in a hill at the base of the Sanford Pasture landslide. See sketch in lower right of Figure 6. Probably the best exposure of pillow lavas in the field trip is in Meeks Table in the high roadcut to the north. These pillows die out to the south or change into blocky jointed compact lava underlying the gravel bed. The contact between the lava and the conglomerate is erosional, probably by the stream that deposited the conglomerate. The conglomerate contains about 1% clasts of pinkish to whitish 24 Ma biotitic Bumping Lake granite, the only true (95% granite, margins of 5% quartz diorite-granodiorite) of Cenozoic age in the Cascade Range. This occurrence indicates that in 10 m.yrs. erosion had deroofed the batholith. The tuff bed atop the conglomerate (it should be dated!) was subsequently overlain by a pillowed lobe of Meeks Table lava. These depositional units indicate that some time expired during these events, more than 10 years, possibly 100 years.

To continue north, vehicles, one by one, head south to turn around at a driveway, and return north 0.7 miles to junction of South Nile Road with highway 410 (at Woodshed Restaurant and Eagle Rock Store). Wait there for all vehicles. A possible break or lunch stop. Then all vehicles drive north 0.1 mile on highway 410 to barricade. Park alongside highway. Field trippers walk north short distance along highway to observe margin of Nile landslide.

STOP 1-7. N46°48'43"W120°55'13.5", Nile 7.5'. South margin of toe of Nile landslide. (Figs. 20, 21, 22, and 23A)

Walk north to rock rubble of Nile landslide blocking highway. Note damaged homes (if still present since early May 2010), now vacated, and uplifted terrain (low pressure ridges) marking southwest margin of north lobe of landslide. Some discussion of events leading up to the early morning landslide October 11, 2009, a Sunday, and following. Return to vehicle(s).

Stop 1-8 lies 1.5 miles along South Nile Road from highway junction. Good view of landslide across field. At junction of FR 1500 and South Nile road, turn left onto FR 1500 before crossing bridge over Rattlesnake Creek. Stop alongside road opposite small quarry on left.

STOP 1-8. N46°49'07.3"W120°56'03.4", Nile 7.5'. Four views: Ellensburg Fm to W; Cleman Mtn to NE; Sanford Pasture landslide to E; and landslide breccia of Eagle Rock to S. (Figs. 20, 21, 22, and 23A)

Four-way views: west to terraced slopes of Ellensburg Formation, northeast to steeply dipping slope of Cleman Mountain, east to north end of Sanford Pasture landslide above Nile landslide, and south to low rim of Rocky Coulee lava flow on left, underlying light-colored sandy friable deposits of Ellensburg Formation in steep-walled quarry, and capping rubbly landslide deposit of Meeks Table basalt, weathering to hoodoos. Some discussion.

Stop 1-9 is 0.7 miles ahead. Continue west on FR 1500 0.5 miles. Take left fork unpaved, ascending Meloy Canyon road; proceed 0.2 miles atop Rocky Coulee lava flow to stop 1-9. Stop on right side of road to allow descending traffic to pass.

STOP 1-9. N46°48'47"W120°56'41", Nile 7.5'. View of Ellensburg Fm. (Fig. 1)

Good field-glasses view of Ellensburg Formation, volcanic facies, to north across Rattlesnake Creek. Stratigraphic sections here have been described by Luker (1985), Smith (1988), and Humphrey (1996). Probably more than 75% of these deposits came from Old Scab Mountain domal volcano, now a peak at only 5702 ft elevation, 13 mi (21 km) WNW from this exposure (Humphrey, 1996). Elevation at this stop is 2200 ft. Thickness of the section is 1100 ft (335 m) with the top at 3200 ft elevation. Why are the rims composed of the coarser deposits?

1.9 miles to stop 1-10 via steep, rough road ahead. Now the fun begins! If vehicles cannot make it loaded, field trippers can walk ~200 yards to flat stretch above, lightening the load per vehicle. From there vehicles should be able to climb road to top of Bethel Ridge. Continue up steep, and locally bumpy, road to stop 1-10, mostly through unconsolidated conglomerate of Ellensburg Formation.

STOP 1-10. N46°47'35.3"W120°55'51.5", Nile 7.5'. Contact between McCoy Canyon lava flow and Ellensburg Fm. (Figs. 20, 22, and 23B)

Elusive vertical contact between McCoy Canyon lava flow to north and conglomerate of Ellensburg Formation at the Carmack Canyon thrust. Up the road a bit the hackly jointed McCoy Canyon resembles the Rocky Coulee flow. Where is the contact? Good view to east to Naches valley and Sanford Pasture landslide.

Continue 7.9 miles south to stop 1-11 on winding, locally steep and rocky Meloy Canyon road atop Bethel Ridge. Multiple vehicles must stay within sight of one another because route passes many unmarked side roads. Road continues atop McCoy Canyon and Ortley lava flows before climbing through Cohassett lava flow to summit of Bethel Ridge.

STOP 1-11. N46°46'46.0"W120°55'00.8", Nile 7.5'. View E of Sanford Pasture landslide. (Fig. 20)

View to east of entire length of Sanford Pasture landslide and Cleman Mountain. Note different landforms within the landslide. What are their origins? Stop is in upper part of Cohassett lava flow. Thin remnant flows of Rocky Coulee cap ridge.

Continue south 0.9 miles to stop 1-12 at junction of Meloy Canyon and Bethel Ridge roads.

STOP 1-12. N46°46'13.9"W120°54'42.1", Nile 7.5'. Hoover Canyon fault. (Figs. 1 and 4)

Cohassett lava flow, to left (east), poorly exposed except atop low ridge, and whitish conglomeratic volcanic sandstone of Ellensburg Formation, volcanic facies, to west, marks location of NW-striking Hoover Canyon normal fault, east side up. Note broad axial crest of Bethel Ridge anticline, a Yakima fold. Hoover Canyon fault is important for at least two reasons: 1) The fault separates uniformly sloping south flank of Bethel Ridge anticline from uplifted series, to east, of NNW parallel-striking folds and faults, pop-up structures, which is a compressional zone, 2-3 miles wide, separating ENE-striking Bethel Ridge anticline and NNW-striking Cleman Mountain anticline. And 2) Bethel Ridge and these intervening folds and faults are believed to have moved northward with respect to Cleman Mountain but no evidence of strike displacement on the poorly exposed faults (recognized only by stratigraphic offset) has been found.

From here Bethel Ridge road descends south flank of Bethel Ridge anticline through Oak Creek State Wildlife Area to highway US 12. Road lies atop bare lava flows, is very rough, requiring slow travel. Locally boulders must be rolled off to enable passage. If there is a strong need to follow this road, with a high-clearance vehicle, then travel may be attempted; otherwise travel is not recommended.

Distance to next stop 1-13 is 0.9 miles. Bethel Ridge road descends slope chiefly atop Rocky Coulee and Museum lava flows. Contacts between these lava flows are difficult to discern.

STOP 1-13. N46°45'53.1"W120°53.0'49.0", Nile 7.5'. View south and west from S flank of Bethel Ridge anticline. (Figs. 1 and 4)

Museum lava flow caps ridge on both sides of road. Views south of many east-dipping ridges of Columbia River Basalt; southwest to Mt. Adams, Goat Rocks, south-dipping slope of Bethel Ridge; and west to sharp-pointed Shellrock Peak, ^{40}Ar/^{39}Ar 3.20±2.00 Ma (Hammond, in preparation), a possible source of

late deposited Ellensburg Formation, and Mt. Rainier.
Continue downslope 2.3 miles to stop 1-14. Views of Sanford Pasture landslide to northeast and steeply dipping south flank of Cleman Mountain anticline to east. Road turns gradually to east.

STOP 1-14. N46°44'46.6"W120°51'47.9" Tieton 7.5', Cross Waterworks/Cougar Canyon fault. (Figs. 1 and 4)

Stop before hill 3578 to east. Not well exposed but here Waterworks/Cougar Canyon fault, seen earlier at stop 1-5, crosses Bethel Ridge. Its course can be roughly traced through ridges to south.
Continue another 3.6 miles east down ridge crest to stop 1-15. Good views to east of south part of Sanford Pasture landslide and south slopes of Cleman Mountain. At makeshift corral, road turns south. At this location a spur road heads northwest, curving to northeast, and in a short distance one can find Cohassett lava flow overlying light-colored Ellensburg Formation, separated by Waterworks/Cougar Canyon fault. From here west fault is called Cougar Canyon fault. Bethel Ridge road continues southeast down ridge, crossing poorly exposed thin deposits of Ellensburg Formation, eventually taking a series of sharp turns with views ahead of Tieton River valley and cliffs of spectacular columnar-jointed older Tieton Andesite before coming to stop 1-15.

STOP 1-15. N46°43'44.5"W120°48'53.9" Tieton 7.5'. Tieton Andesite lava flow.

Rubbly to blocky jointed dark-colored Tieton Andesite lava flow, the younger flow of Tieton Andesite $^{40}Ar/^{39}Ar$ dated at 1.39±0.10 Ma (Hammond, in preparation). Being small in area, the lava flow is not shown in the map, Fig. 1. Light-colored, finely bedded silt (volcaniclastic?) deposits, possibly of Ellensburg Fm, or younger if banked against ridge, underlie lava.

Continue down road, through yard of Oak Creek State Wildlife Area, to junction with highway US 12, 0.4 miles. Turn left heading northeast, pass Stop 1-4, to junction US 12 with WA 410, 2.1 miles. Turn right (east) and head for Yakima, 20 miles. End of Day 1 field trip.

ROAD LOG DAY 2

Yakima-Naches River valley-SW slope Cleman Mountain-Rock Creek thrust-Megabreccia-Pop-up structures-Indian Flat fault

From Yakima head west and northwest on highways US 12 and WA 410 along Naches River, passing stops 1-3 through 1-7 of yesterday. Turn left (west) onto South Nile Road. Continue on this road, pass yesterdays' stop 1-7, cross Rattlesnake Creek, and continue north on Nile Road to north junction with highway WA 410. At junction turn right (south) and continue 3.2 miles to barricade blocking north approach to Nile landslide, Stop 2-1. (Total distance from NW Yakima: about 33 miles).

STOP 2-1. N46°48'54.5"W120°55'19.5", Nile 7.5'. North side of toe of Nile landslide. (Figs. 20 and 22)

Ahead to south lies 40-ft high rock rubble, forming north margin of Nile landslide. Here one can see forced-up surface of highway and broken and deformed guard rail, and new course of Naches River to west. McCoy Canyon lava flow lies along east margin of road. About one-third the distance from the barricade, at N46°49'03.5"W120°55'29", an isolated roadcut exposes a breccia zone atop undeformed basalt. This breccia could be the base of the Sanford Pasture landslide. Turn around and head north on highway WA 410.

Head 2.4 miles north to stop 2-2 along WA 410. Pull into space along left (west) side of highway.

STOP 2-2. N46°50'43.9"W120°56'57.1". Nile 7.5'. Top of GRB statigraphic section. (Fig. 5)

This locality marks top of stratigraphic section containing most lava flows forming Grande Ronde Basalt in the Naches River Basin. It is a good reference section, although the Meeks Table flow, down the highway to the north, is fractured and broken up, obscuring lava flow units within it. Note the lenses of tuff or hyaloclastite incorporated in the Rocky Coulee flow. The upper part of the section can be walked or slowly driven through to the interbed deposits, chiefly tuffs, between the Meeks Table and McCoy Canyon flows. Look for tiering, different forms of jointing, and possible lava lobes.

Continue 0.8 miles north to stop 2-3 at junction with North Nile Road, base of stratigraphic section.

STOP 2-3. N46°51'22.7"W120°57'11.0", Nile 7.5'. Base of GRB stratigraphic section. (Figs. 4 and 5)

Contact between Meeks Table flow and underlying Wapshilla Ridge flow lies just south of road junction. Five hundred feet north of junction Wapshilla Ridge flow is cut off by Garrett Canyon fault in a poorly exposed zone along east side of highway. Garrett Canyon fault, a major fault (a back thrust) along southwest flank of Cleman Mountain, has brought Wapshilla Ridge and overlying lava flows, atop Meeks Table flow.

Stop 2-4 lies 2.3 miles to north. Travel highway 410 1.4 miles to FR 1701 and make a sharp right turn to the east and ascend 0.9 miles on gravel road to stop 2-4.

STOP 2-4. N45°52'15.3"W120°57'31.1", Nile 7.5'. View to west of Elk Ridge and GRB stratigraphy. (Figs. 4, 24A,B and 25A,B)

View to west across Naches River valley to Elk Ridge (local name). It contains the same series of lava flows in the same attitude as the southwest flank of Cleman Mountain. To the south (not well shown) is the Ellensburg Formation in the asymmetrical Nile Creek syncline. The Nile valley thrust fault, underlying the southwest flank of Cleman Mountain, is interpreted to change attitude to vertical, and continue NNW through Johnson Canyon on the back, west side of Elk Ridge, and connect with the Indian Flat fault (Stop 2-12) to the north. In the same process the Garrett Canyon fault was rotated to a horizontal attitude, and it is believed to continue to the east as the Rock Creek thrust, shown in Fig. 24B. At Elk Ridge there could be as much as 1000 ft of vertical displacement on the fault in Johnson Canyon. Only about 300 ft of displacement is shown in cross section in Fig. 25A.

Stop 2-5 lies 6.3 miles to the southeast on southwest flank of Cleman Mountain. Continue up FR 1701 through switchbacks 0.8 mile to FR 1711 to the right. Follow this road up and south 5.5 miles. If skies are clear and visibility good, stop 2-5 is worth visiting. Otherwise, head to stop 2-6.

STOP 2-5. N46°49'59.1"W120°54'17.8", Nile 7.5'. View west from Cleman Mounain.

Tremendous view to west of Bethel Ridge, Nile valley, Rattlesnake Creek, Ellensburg Formation in Nile Creek syncline. Distant peaks, from south to north, are Mt. Adams, Goat Rocks, Shellrock Peak, Bethel Ridge, Timberwolf Mtn., Bismark Peak and Mt. Aix in the Mt. Aix caldera, Nelson Butte, Old Scab Mtn, Goat Peak of the Ohanapecosh Fm, and Fifes Peaks, including Mt. Rainier. Also view south into Sanford Pasture landslide. From here visualize a flattish Ellensburg-covered terrain before uplift of Cascade Range, then stream incision of terrain as the Cascade Range rose.

Stop 2-6 lies 7.7 miles to northwest along highway WA 410. Return north along FR 1711 to FR 1700, then west to the highway. From junction with highway to stop 2-6 is 0.8 mile. WATCH FOR TRAFFIC IN BOTH DIRECTIONS. Pull ahead of bend to west side of highway near fire station, leaving space between vehicles. For safety, field trippers remain on west side of highway behind guard rail.

STOP 2-6. N 46°52'41.5"120°58'48.0", Manastash Lake 7.5'. Rock Creek fault zone. (Fig. 26A)

Rock Creek thrust zone is one of the better exposed fault zones in the area and readily accessible. Here hanging and foot walls are of Wapshilla Ridge. To the east, fault has brought Meeks Table upon all lava flows, generally rising stratigraphically. Also here, a lens of hyaloclastite, probably separating two lobes of the lava flow, occurs in the fault zone. Study zone with the aid of Fig. 26A. Return to vehicles.

1.5 miles to stop 2-7 to north along highway WA 410. To north of Rock Creek highway passes from Grande Ronde Basalt into underlying lava flows and breccia of Edgar Rock volcano (Fig. 3). Park to right against high rockcut opposite bridge. May have to remove some boulders. Drivers be sure left tires are off high surface.

STOP 207. N46°53'29.4"W120°59'55.6", Manastash Laek 7.5'. Landslide of Nile Creek andesite at Eagles Nest.

Here an irregular sequence of andesitic lava flows, boulder conglomerate, and tuff fill a low topographic location. The rock is part of the andesite of Nile Creek (Fig. 3). Look at pieces of andesite for large black crystals of hypersthene. Could conglomerate be a debris flow or hyperconcentrated stream flow? Look for prismatic jointing in clasts in conglomerate. Lava flow at north end of cut has same chemistry as flow near top of ridge to west. This 3000 ft long x 900 ft high x 1000 ft thick block apparently slide from ridge to west to bottom of Naches River valley without significantly disrupting its internal stratigraphy. This event probably occurred more than 2 Ma, after deposition of Grande Ronde Basalt.

Continue 3.5 miles north to stop 2-8 along highway. After about 1 mile highway passes into Gold Creek rocks (Fig. 3) in core of Edgar Rock volcano. In coming to stop 2-8, after bend in highway and no oncoming traffic, pull across to north side of highway to large parking area.

STOP 2-8. N46°55"24.5"W121°02"50.3", Cliffdell 7.5'. Megabreccia in Gold Creek rocks.

At crushed (shocked) rock megabreccia in top of Gold Creek rocks. Unweathered gray rock consists of tightly packed angular fragments of diverse sizes and lithologies, chiefly basalt and andesite. One fragment of hornblende andesite gave ^{40}Ar/^{39}Ar age of 26.34±0.4 Ma (Hammond, 2010). Megabreccia is part of debris flow deposit, possibly derived from collapse of Gold creek volcano prior to eruption of Edgar Rock volcano.

Continue 2.5 miles north to stop 209 at west end of bridge north of Cliffdell. Since last stop highway passes through narrow valley of Naches River, eroded in chiefly breccia beds and many dikes of Edgar Rock volcano. Note that bedding is slightly steeper than 32° angle of repose, indicating that volcano has been squeezed along a north-south axis. Bridge lies 0.8 mil north of Cliffdell.

STOP 2-9. N46°56'58.9"w121°04'20.7", Cliffdell 7.5'. GRB stratigraphic offset in Naches River valley.

From here north in the pop-up structures (Fig. 4). Short stop to demonstrate difference in elevation of two north-dipping lava flows. Rocky Coulee and Cohassett (Fig. 5), on different sides of Naches River. Flows are cut by NNW-striking Sawmill Flat fault (not named in Fig. 4), west side up.

Continue 0.2 miles across bridge and north along highway 410 to stop 2-10. Pull off to west (left) side of highway. Watch for oncoming traffic in crossing highway to roadcut.

STOP 2-10. N46°57'06.7"W121°04'17.5" Cliffdel 7.5'. Slickensided fault plane.

Short stop to show slickensides (dip-slip) on shear plane of Sawmill Flat fault (not named in Fig. 4) causing displacement observed at stop 2-9. Be cautions in crossing highway; look both ways.

Continue 1.1 miles up highway to next stop 2-11 on west side of highway overlooking Naches River. Watch for oncoming traffic.

STOP 2-11. N46°57'49.1"W121°05'07.9", Cliffdell 7.5'. Offset in Rocky Coulee lava flow between sides of Naches River.

Similar to stop 2-9, showing difference in elevation of Rocky Coulee lava flow on opposites sides of Naches River, caused by movement on same fault. Lava flows here dip east. Axis of Little Naches River syncline lies east of highway. East of synclinal axis flows turn up sharply to form large anticline extending east to Manastash Ridge (Fig. 4).

Continue 4.4 miles to last field trip stop of day, stop 2-12. Continue north following highway 410. Highway swings to west in a big bend, crosses bridge over Little Naches River, and continues west. At 2.9 miles turn left onto FR 1709. Take middle road of three after crossing narrow wood bridge over Bumping River. FR 1709 turns to right and up. Continue past large quarry 0.7 miles to curve where spur 400 takes off to west. Spur is gated. Follow winding, ascending spur to flat area at 0.8 miles. Park. This location at N46°58'45.4"W121°07'18.0". Walk about 300 yards west along road to stop 2-12.

STOP 2-12. N46°58'41.5'W121°07'29.5", Cliffdell and Old Scab Mountain 7.5'. Indian Flat fault zone overlooking Bumping River.

At NW corner of pop-up structures zone. (Fig.26B)
Spur is cut into a cliff of Meeks Table lava flow, overlooking Bumping River. WATCH YOUR STEP! Rocks generally clutter road because of little traffic. Here NNW-striking Indian Flat fault is exposed in a 50-foot long zone of breccia and shear planes (Fig. 26B). To west of fault zone a block of Rocky Coulee lava is probable landslide. What is the sense of displacement on the fault? What are the clues?

Return to vehicles. Retrace route to highway WA 410. End of field trip. Chinook Pass is west (to left) from junction with highway WA 410.

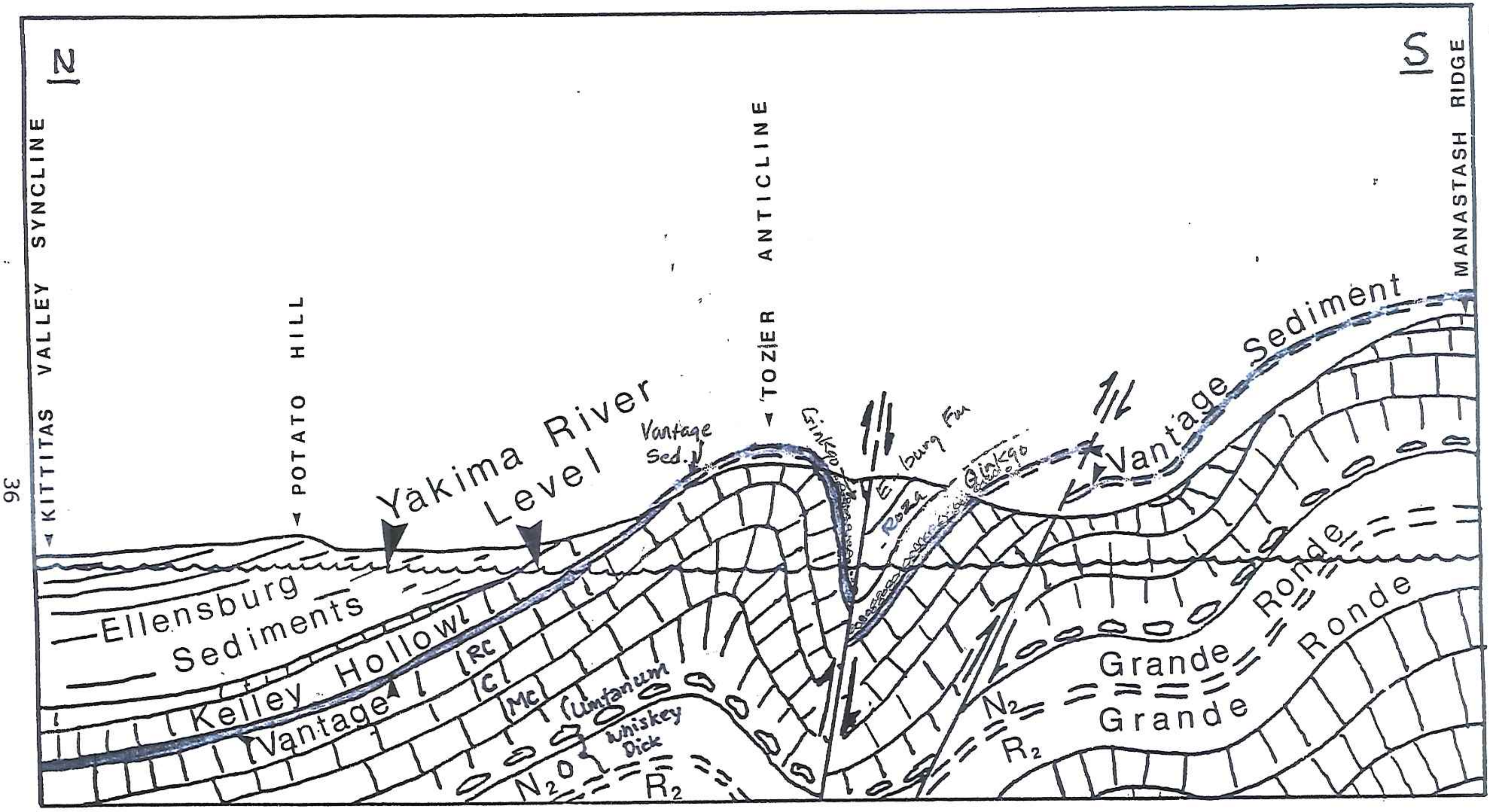
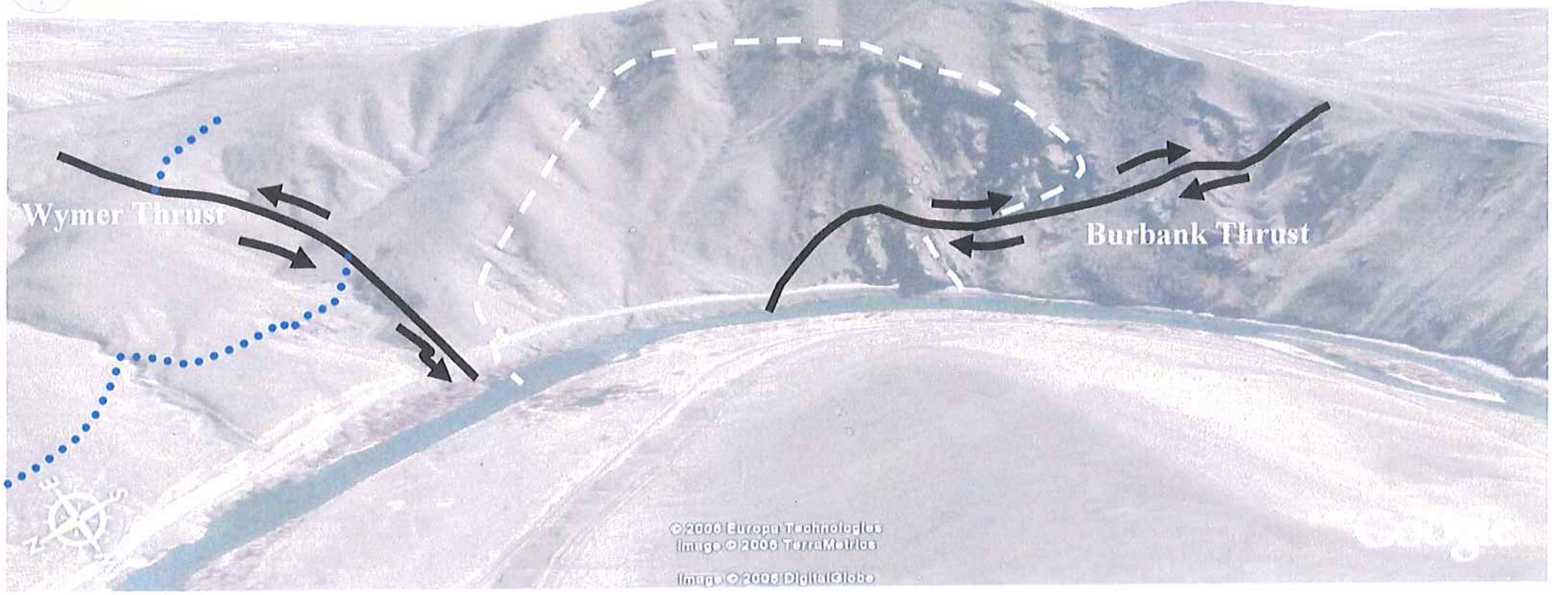


Figure 17. (Stop 1-1) *Schematic cross section of long roadcut east side of hwy WA 821 south of mouth of Yakima River canyon. Complicated structures in Columbia River Basalt lava flows, in upper part of Grande Ronde Basalt and lower part of Wanapum Basalt (Table 1). Tozier anticlinal ridge is but a foothill compared to the much larger Manastash Ridge. Kelley Hollow is the old name for the Gingko lava flow at the base of the Wanapum Basalt. Vantage sandstone is a widespread marker bed separating the Wanapum from Grande Ronde. Here the Vantage consists chiefly of tuff. Lava flows in the top of the Grande Ronde are: RC, Rocky Coulee; C, Cohassett; MC, McCoy Canyon; Umtanum and Whiskey Dick are names given to the two flows in the Ortley unit. Refer to Figure 5. (Sketch by Jack Powell, 1987).*

Umtanum Anticline
. at Baldy



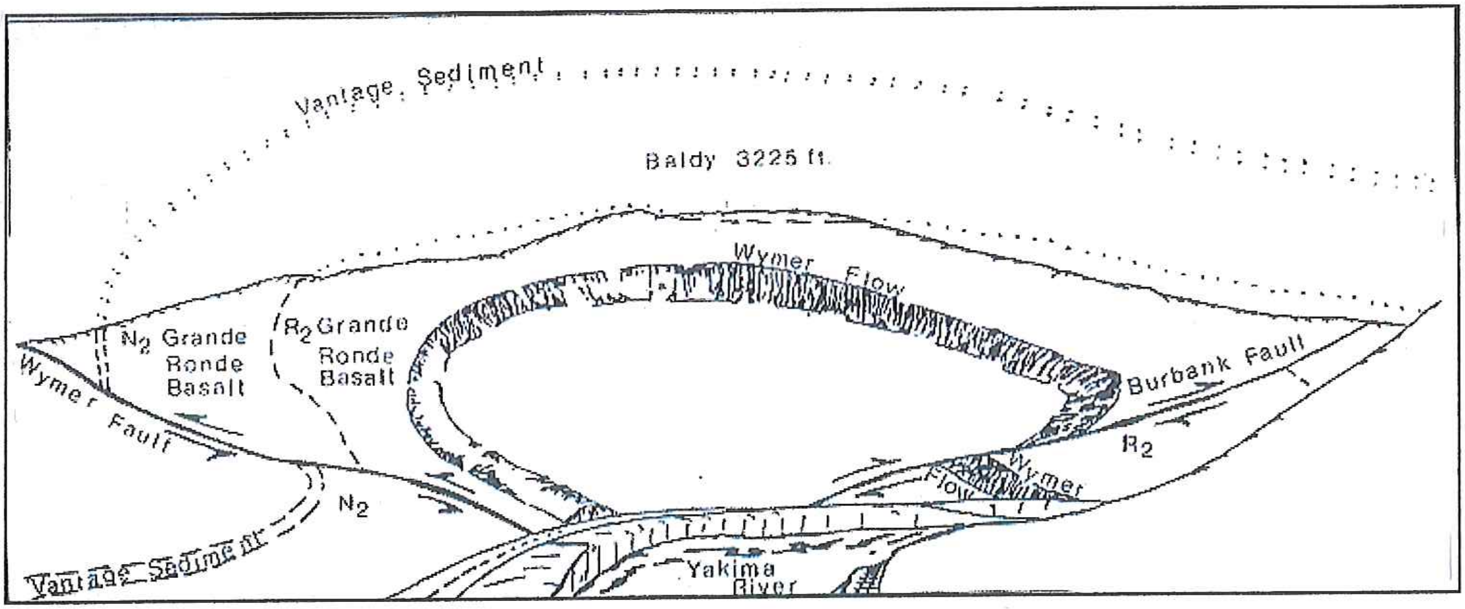
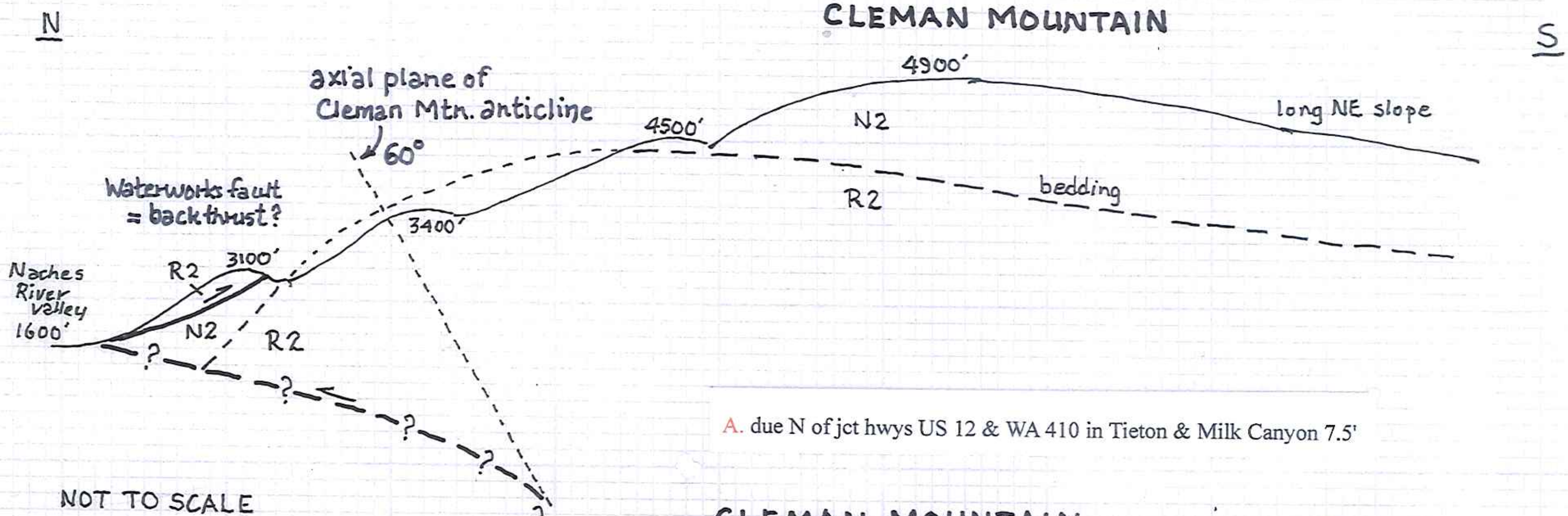
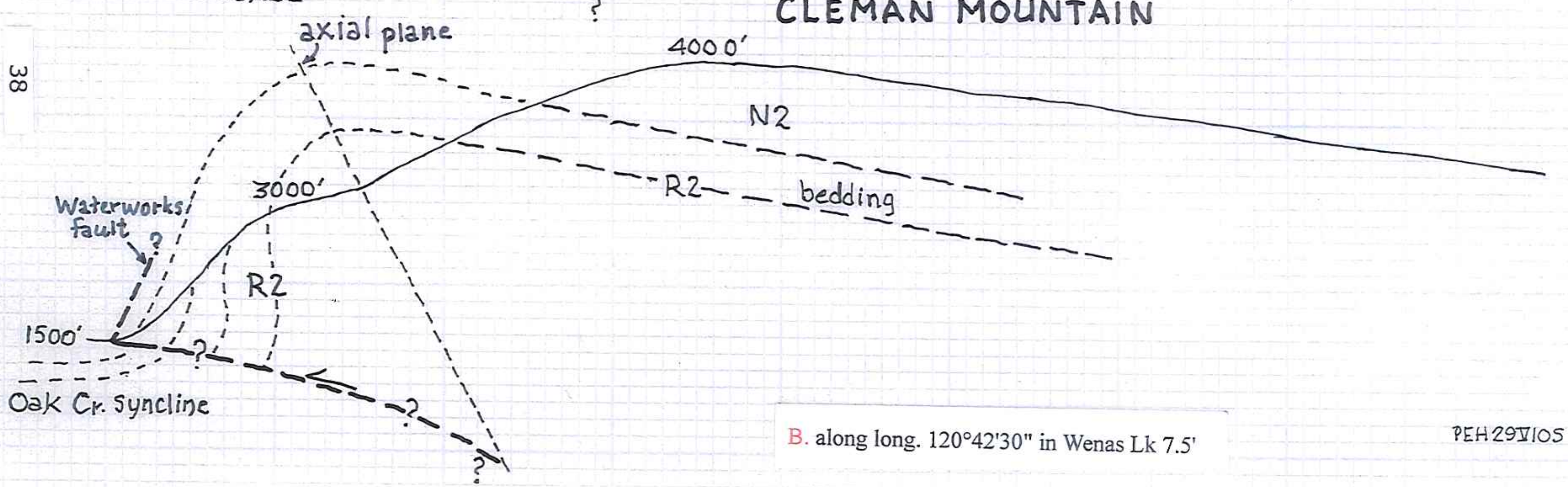


Figure 18. (Stop 1-2) *Mt. Baldy and the Umtanum anticline looking east from the Beck Memorial along hwy WA 821 in the Yakima River canyon. One of the best cross sectional views of a Yakima fold ridge on the Columbia Plateau. Note the steeply dipping to overturned flows in the flanks and the truncation of the bedding by the thrust faults. What developed first-- the fold or the faults? Which of the faults was the first to move? Here the Wymer flow is the next flow below the Wapshilla Ridge flow (Figure 5). (Lower diagram drawn by Jack Powell, 1989)*



A. due N of jct hwys US 12 & WA 410 in Tieton & Milk Canyon 7.5'



B. along long. 120°42'30" in Wenas Lk 7.5'

PEH29VI05

Figure 19. (Stop 1-3) *Schematic N-S cross sections through the south part of Cleman Mountain anticline, showing the main structural features that can be observed from along hwy WA 410 looking to the north. (A) located north of the intersection of hwys US 12 and WA 410. (B) located about 3.5 mi E of (A).*

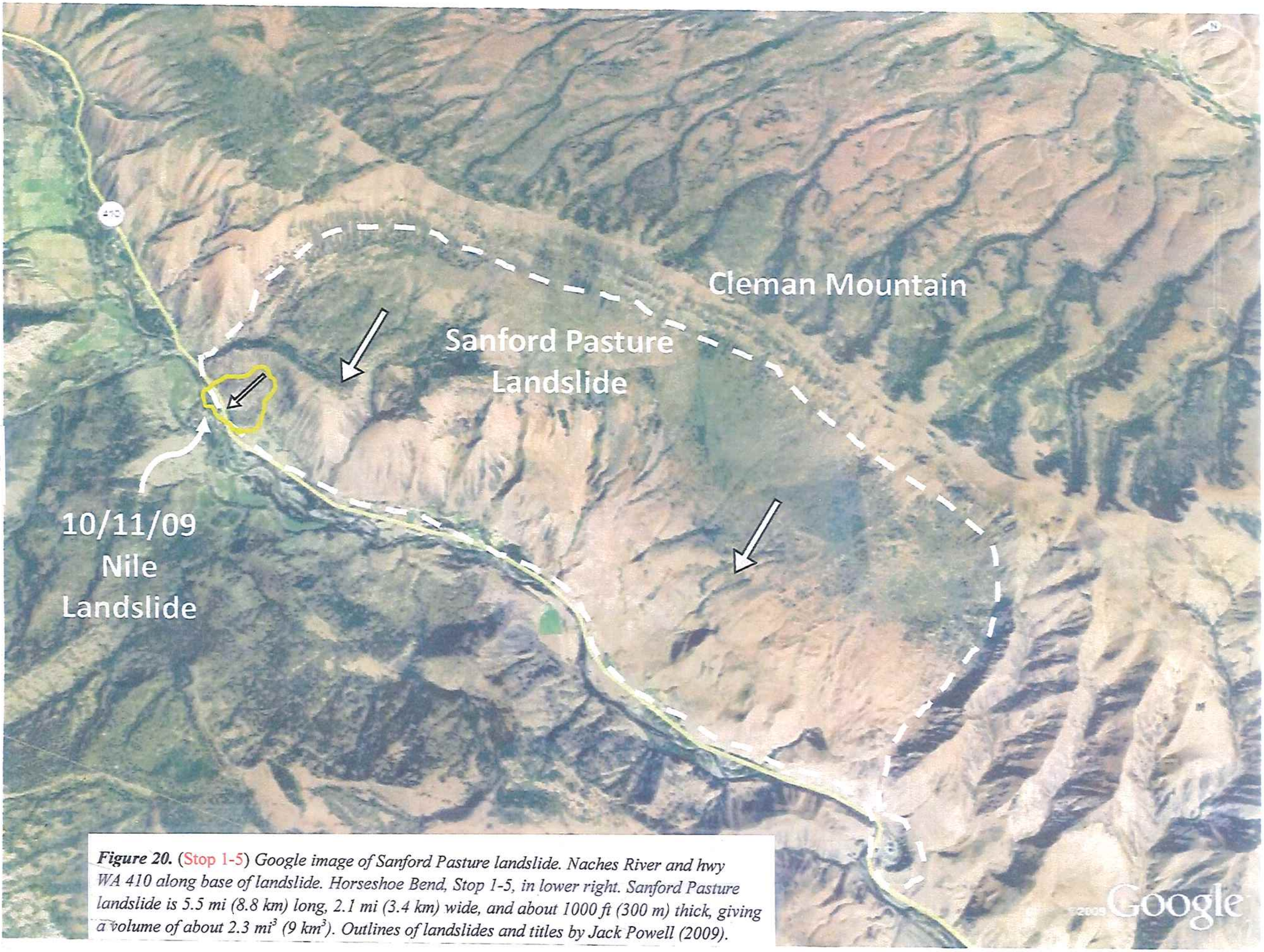


Figure 20. (Stop 1-5) *Google image of Sanford Pasture landslide. Naches River and hwy WA 410 along base of landslide. Horseshoe Bend, Stop 1-5, in lower right. Sanford Pasture landslide is 5.5 mi (8.8 km) long, 2.1 mi (3.4 km) wide, and about 1000 ft (300 m) thick, giving a volume of about 2.3 mi^3 (9 km^3). Outlines of landslides and titles by Jack Powell (2009).*

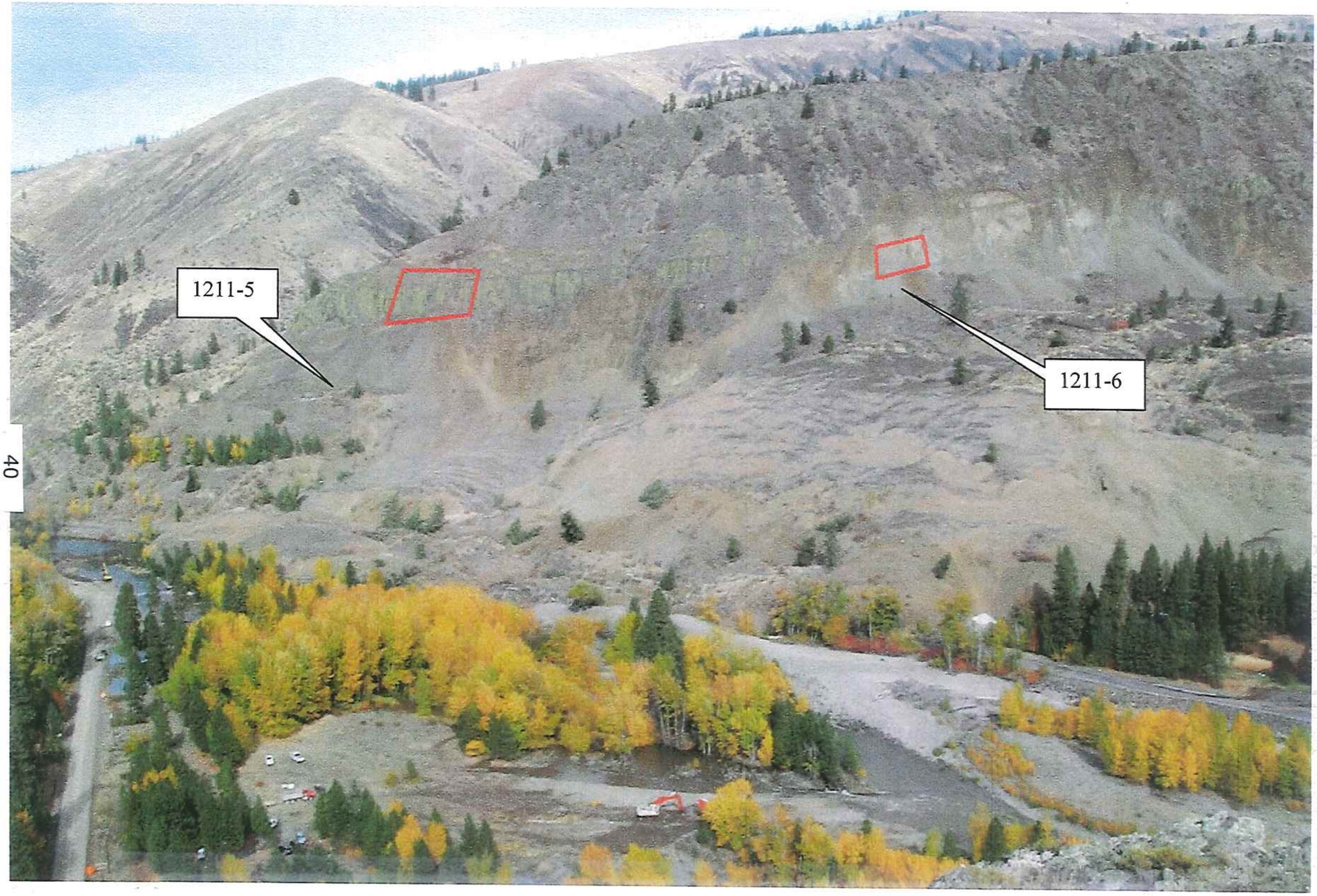


Figure 21. (Stop 1-7) *View of Nile landslide taken from atop ridge to west. White building in lower right marks entrance to quarry buried by landslide. Ridge at head of landslide is slump block in map. Ridge at skyline is southwest slope of Cleman Mountain north of Sanford Pasture landslide. Stop 2-5 is at very top of picture. Numbers mark rock sample sites. Photograph provided by Tom Badger, geologist, WA DOT.*

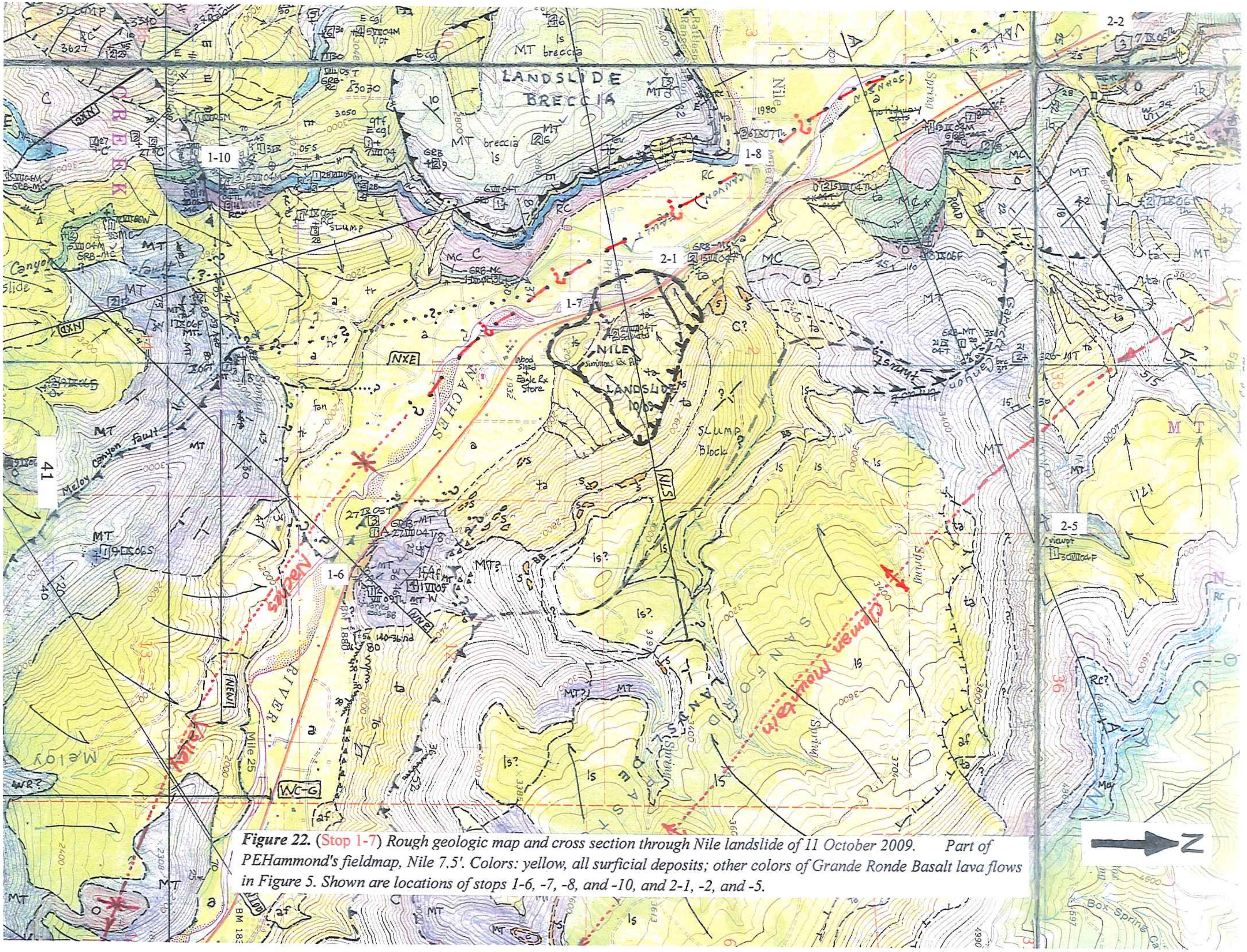


Figure 22. (Stop 1-7) *Rough geologic map and cross section through Nile landslide of 11 October 2009. Part of PEHammond's fieldmap, Nile 7.5'. Colors: yellow, all surficial deposits; other colors of Grande Ronde Basalt lava flows in Figure 5. Shown are locations of stops 1-6, -7, -8, and -10, and 2-1, -2, and -5.*

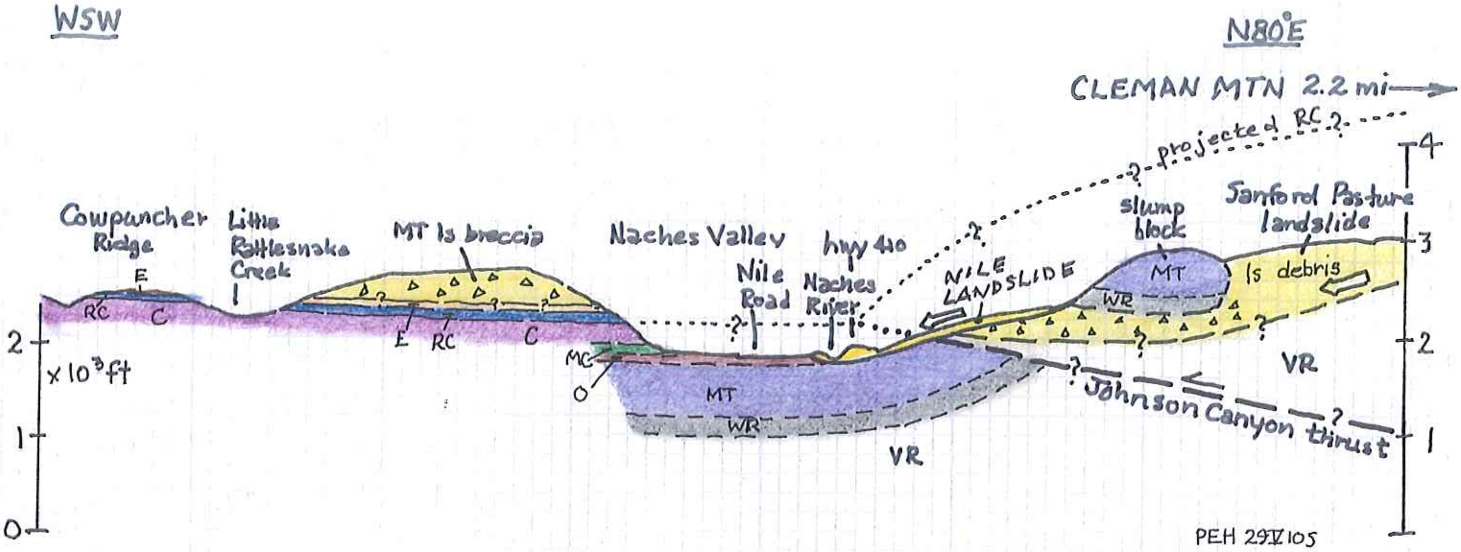


Figure 23A. (Stop 1-7) *Cross section through Nile landslide (identified by NLS in map), showing possible relation to Sanford Pasture landslide, a tentative interpretation. Units identified as: C, Cohassett; E, Ellensburg; MC, McCoy Canyon; MT, Meeks Table; RC, Rocky Coulee; VR, unidentified volcanic rock; WR, Wapshilla Ridge.*

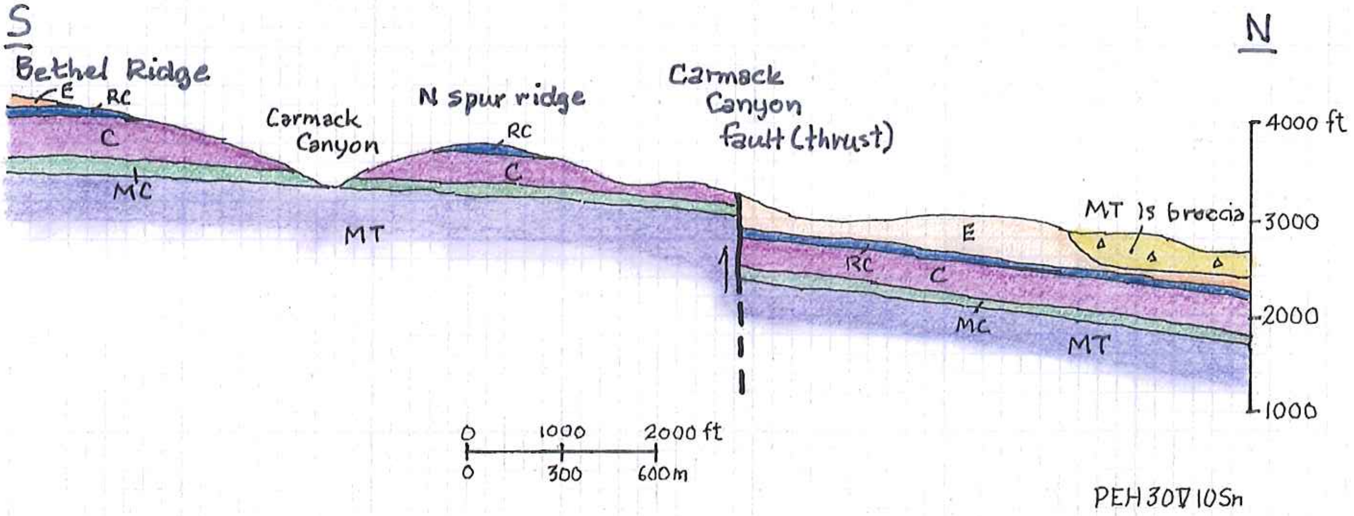


Figure 23B. (Stop 1-10) *N-S cross section through Carmack Canyon fault in north spur ridge of Bethel Ridge. Shows stratigraphic relations as ridge is ascended.Stratigraphic offset on the fault is between 120 and 160 ft (35-50 m). Units identified as: C, Cohassett; E, Ellensburg; MC, McCoy Canyon; MT, Meeks Table; RC, Rocky Coulee; WR, Wapshilla Ridge.*

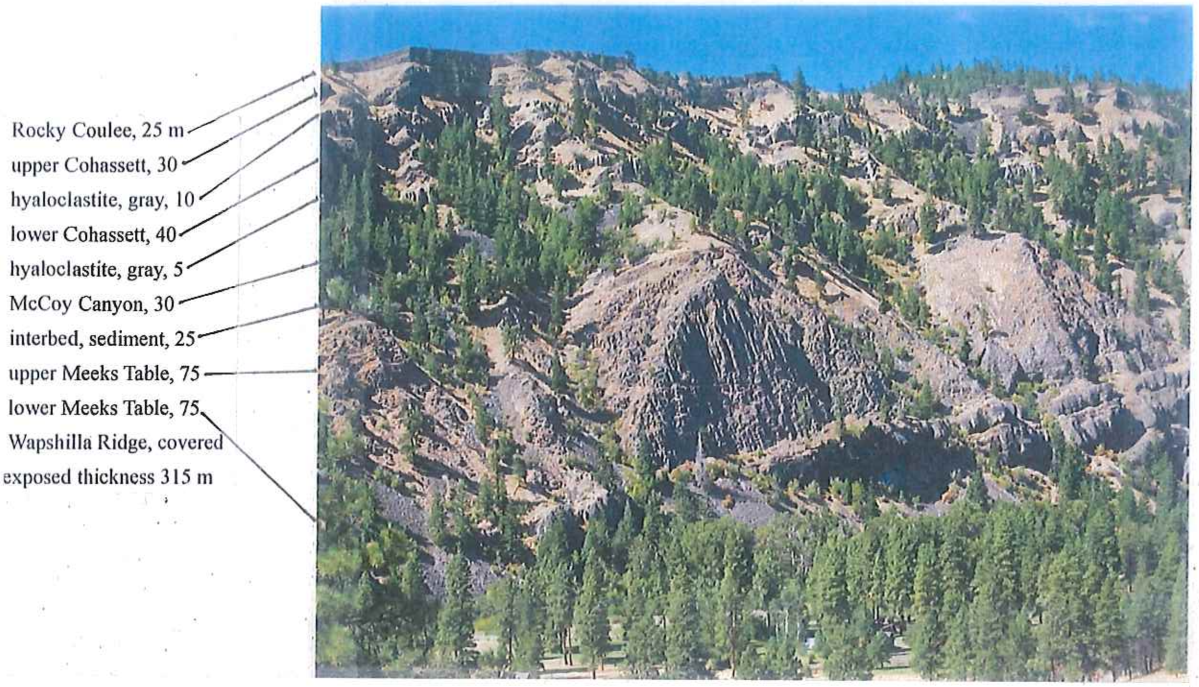


Figure 24A. (Stop 2-4) *View west from FR 1701 of Grande Ronde Basalt stratigraphic section in Elk Ridge. One of better sections but difficult to access. Estimated thicknesses are approximate. The thick, columnar-jointed, upper part of the Meeks Table flow I call "the organ pipes."*

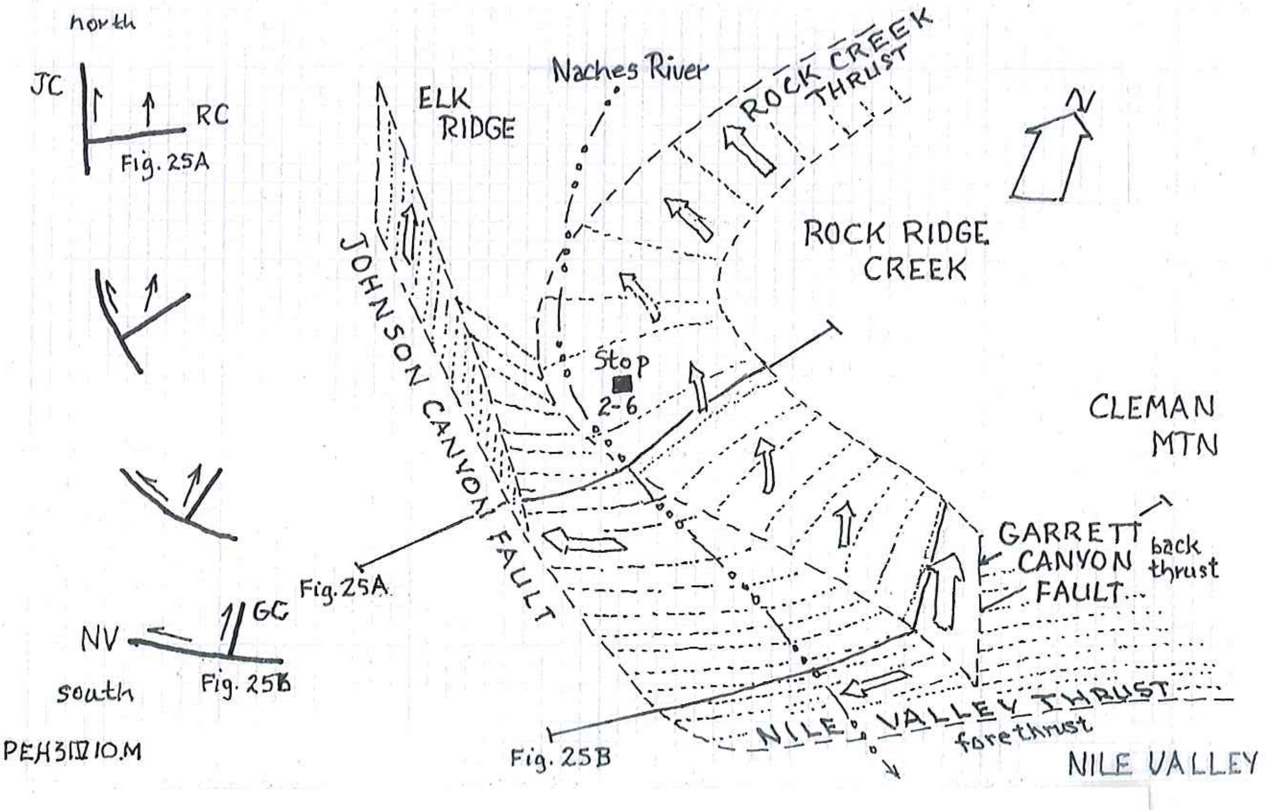
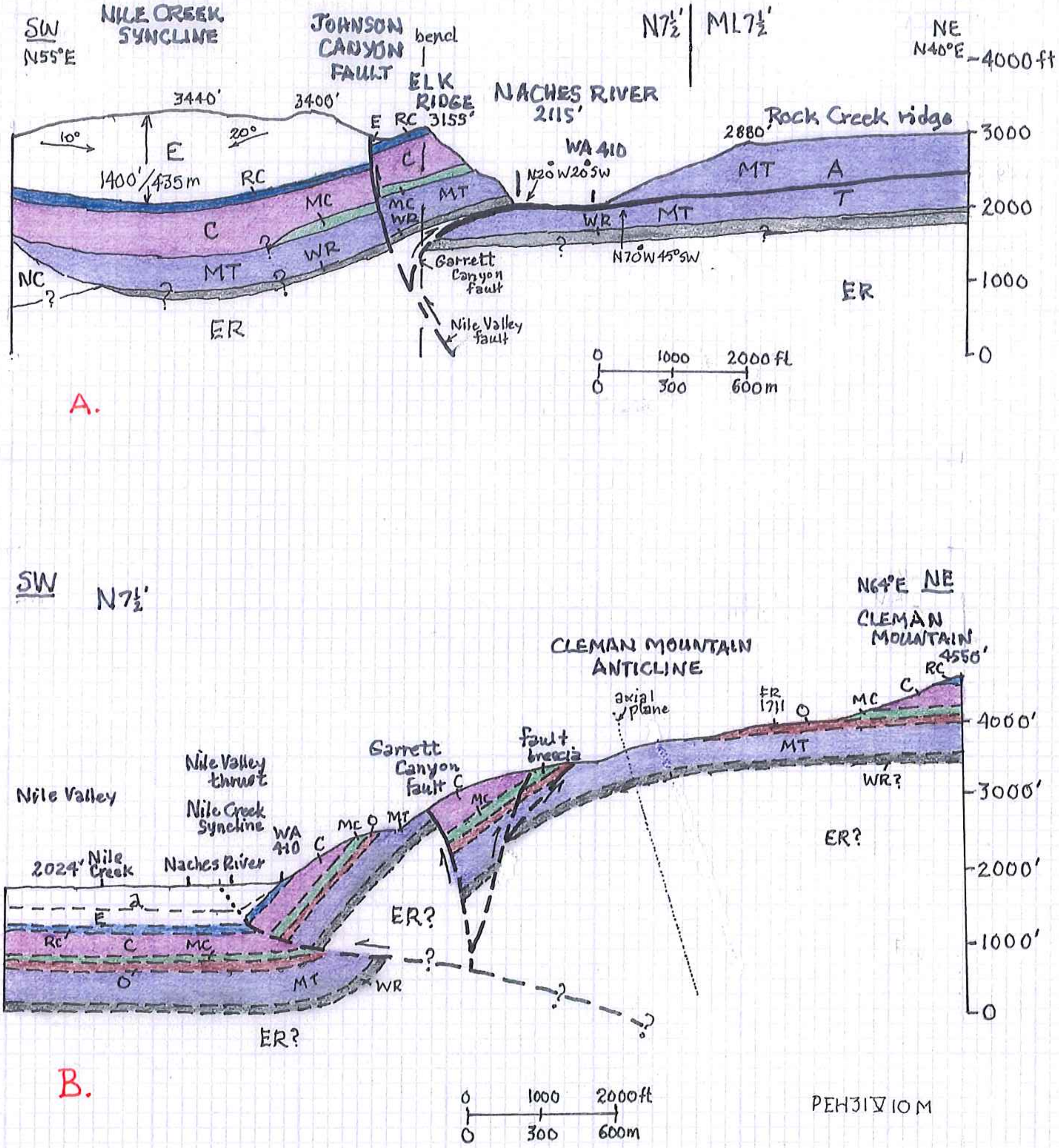


Figure 24B. (Stops 2-4 and -6) *A 3-D diagram showing the interpreted relationship between faults Nile Valley, Garrett Canyon, Johnson Canyon, and Rock Creek. As Nile Valley and Garrett Canyon faults are traced northward, they rotate clockwise, thus changing their attitudes but not necessarily their sense of displacement. To the north the Nile Valley fault becomes the Johnson Canyon fault, and the Garrett Canyon fault becomes the Rock Creek thrust, although the Nile Valley and Rock Creek thrusts may join as a single fault plane beneath the northern part of Cleman Mountain. The "stick figures" along the margin show the rotation. Refer to figures 25A and B.*



Figures 25 A and B. (Stops 2-4 and -6) *Structural cross sections oriented SW to NE across (A) from Elk Ridge to Rock Creek ridge, and (B) from Nile Valley to Cleman Mountain, north of the Sanford Pasture landslide (Fig. 4), showing stratigraphic and structural relations in the area. Most map units are identified in Figure 5. Others are: ER, Edgar Rock volcano; NC, Nile Creek lava flows; and WR, Wapshilla Ridge basalt flow.*

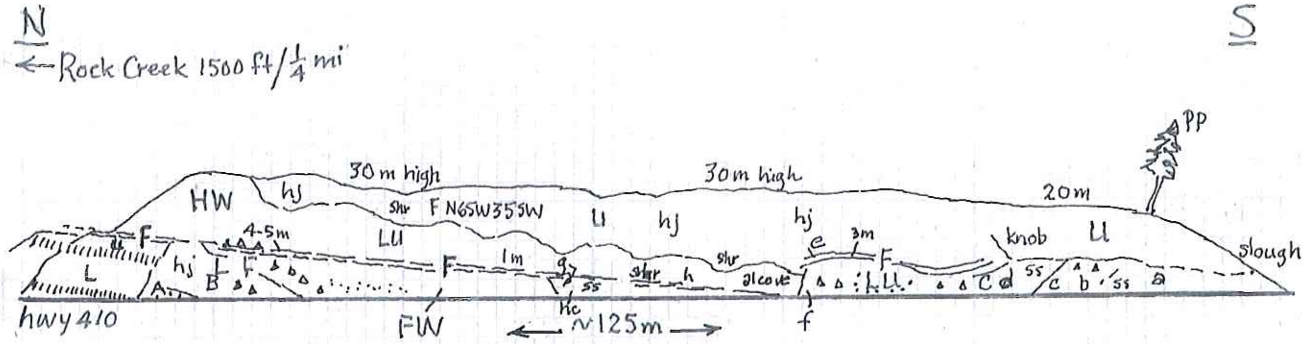


Figure 26A. (Stop 2-6) *Sketch of Rock Creek thrust fault exposed in cut on east side of hwy WA 410 on a blind curve. EXTREME CAUTION ADVISED. STAY BEHIND GUARD RAIL ON WEST SIDE OF HWY. Fault is major linear zone rising to north from middle of cut. It strikes E-W dipping 8°S, but attitude varies in this exposure. Fault cuts two flows of Wapshilla Ridge lava flow, which are separated by 2 m of sandy hyaloclastite. Thin zone of pillow lava occurs at base of lower flow exposed to north of cut. Total thickness of fault zone exposed here is about 30 m. Fractures and minor faults with slickensides are listed below. Other features are also identified.*

△ breccia
∴ vesicles
//// cj, columnar jtg
hj, hackly jtg
ss, slickensides
F, fault

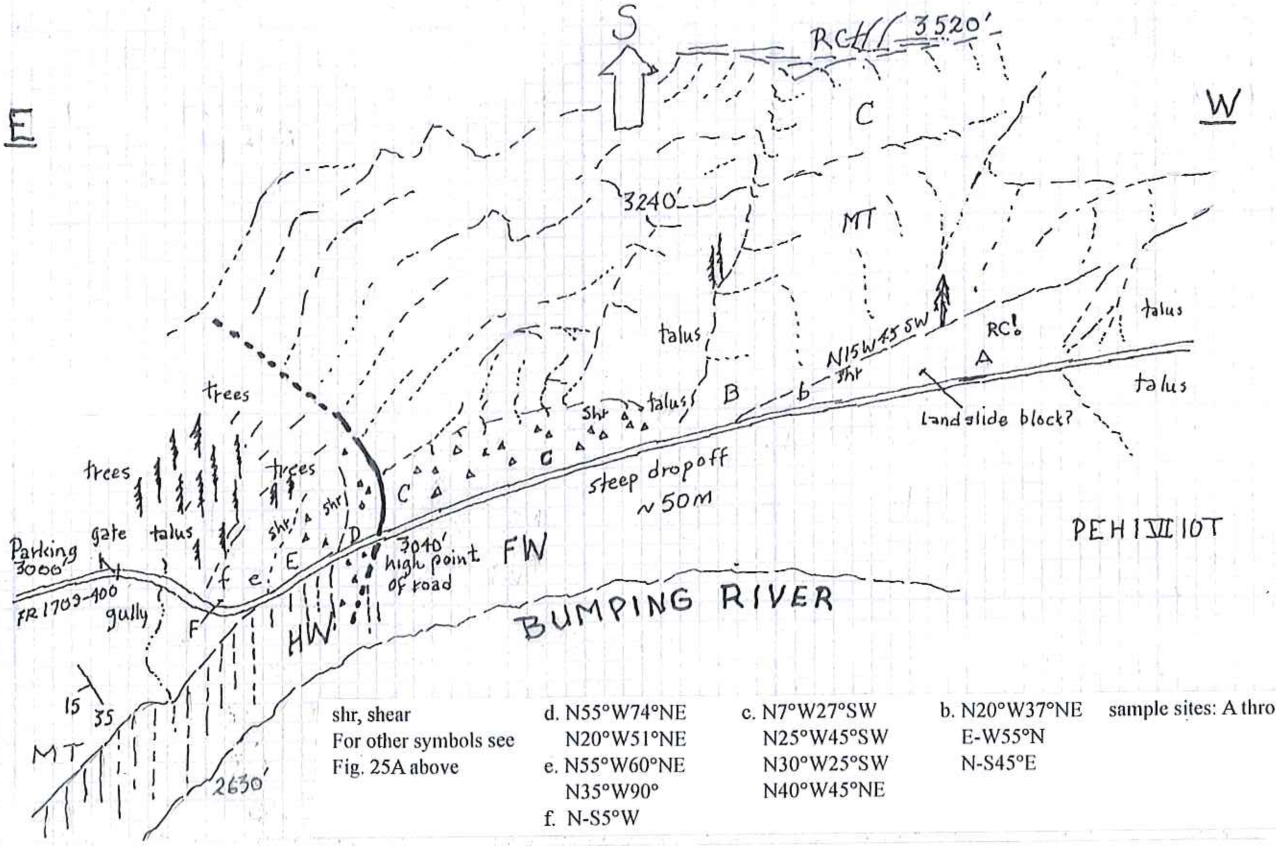
U, upper lava flow
UL, includes upper & lower lava flows
L, lower lava flow

g. N53°W49°SW
N65°W3°5SW
h. N30°W25°NE

d. N50°E30°NW
e. E-W10°S
f. N15°W40°NE

a. N20°E20°SE
b. N30°W25°NE
c. N70°E52°NW
N50°E40°NW

sample sites: A, B, C



shr, shear
For other symbols see Fig. 25A above

d. N55°W74°NE
N20°W51°NE
e. N55°W60°NE
N35°W90°
f. N-S5°W

c. N7°W27°SW
N25°W45°SW
N30°W25°SW
N40°W45°NE

b. N20°W37°NE
E-W55°N
N-S45°E

sample sites: A through F

Figure 26B. (Stop 2-12) *Panoramic sketch of Indian Flat fault zone along preciptious FR 1709-400 above Bumping River. WATCH YOUR STEP. Major fault occurs at high point of road. It strikes N55°W dipping 74°NE. Details in fault zone are given above. From your observations of the surrounding geology and the sketch can you deduce the sense of displacement on this fault? One hint: south of here on the east side of the fault the Rocky Coulee flow sits at a higher elevation than it does on the west side. Your conclusion may indicate the importance of this fault.*