

**Ellensburg Chapter
Ice Age Floods Institute**

Lower Grand Coulee

Field Trip Leader:

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8 November 2015

Preliminaries

Field Trip Overview

The Lower Grand Coulee extends from Dry Falls to Soap Lake. It is perhaps the most striking of the coulees of the Missoula Flood-created Channeled Scablands. We will explore saline lakes, ice age lakes, hanging valleys, flood bars, giant current ripples, folded Columbia River Basalts, butte and basin topography, potholes, caves, rhino casts, and human activity related to the ice age floods in the Lower Grand Coulee. Stops will include the Ephrata Expansion Bar south of Soap, Soap Lake (a closed basin lake at the downstream end of the Lower Grand Coulee), a flood bar covered with giant current ripples at the mouth of East Lenore Coulee, Lake Lenore caves (notable as models of human occupation sites in the area), and Dry Falls at the head of the coulee.

Tentative Schedule

9:00 am	Depart CWU
10:30	Stop 1—Ephrata Expansion Bar
11:15	Depart
11:30	Stop 2—Soap Lake (inc. restroom)
12:15 pm	Depart
12:30	Stop 3—East Lenore Coulee Bar
1:30	Depart
1:45	Stop 4—Lake Lenore Caves (inc. pit toilet)
3:15	Depart
3:30	Stop 5—Dry Falls (inc. restroom)
4:15	Depart
6:00	Arrive at CWU

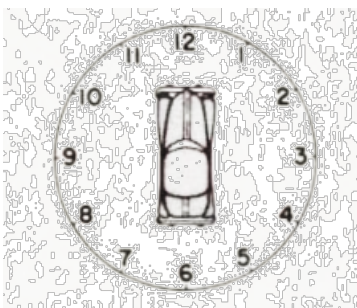


Figure 1. Relative bearings using a clock. Assume that your automobile is always pointed to 12 o'clock. Source: Campbell (1975, p. 1).

Our Route & Stops

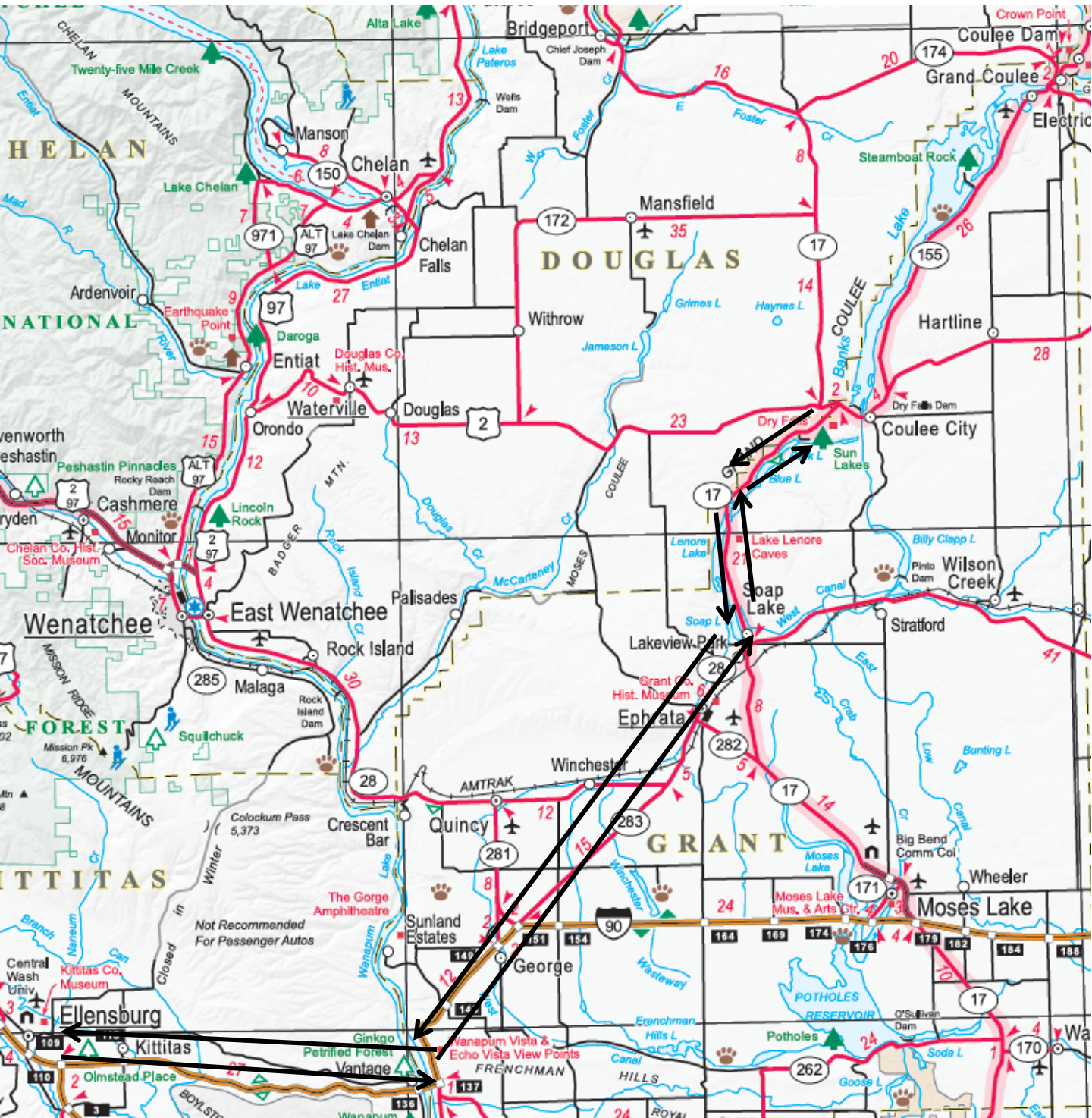


Figure 2. Our route shown with arrows and stops noted with numbers. Source: Washington State Department of Transportation http://www.wsdot.wa.gov/NR/rdonlyres/14A6187A-B266-4340-A351-D668F89AC231/0/TouristMapFront_withHillshade.pdf

Ellensburg to Quincy Basin

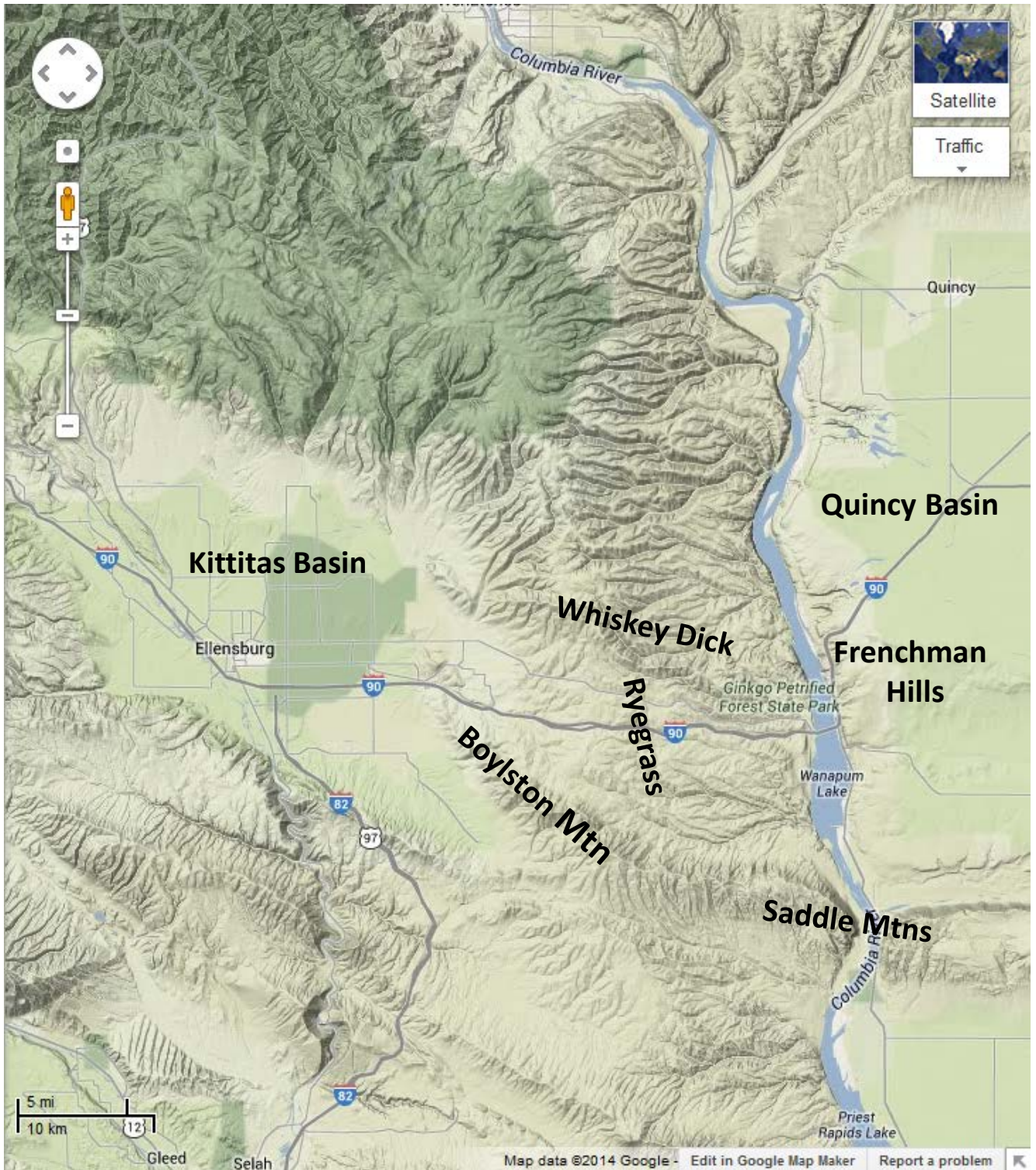


Figure 3. Topography of Ellensburg to Quincy Basin part of our route. Source of image: Google Maps.

Ellensburg to Quincy Basin

Route: Part of our route to Stop 1 takes us from Ellensburg to the Quincy Basin via I-90 (Figures 2 & 3).

Lithology & Structure: Ellensburg lies near the western margins of the Columbia River Basalts. Our drive from Ellensburg begins on the floor of the Kittitas Basin *syncline* with downfolded Columbia River Basalts ~4000 feet below us (Figures 4, 5, 6 & 7). Mantling the Columbia River Basalts are volcanic sediments of the Ellensburg Formation, *alluvial fan* sediments from the surrounding mountains, Yakima River *alluvium*, and *loess*. East of Kittitas we ascend the Ryegrass *anticline*.

Climate in the Kittitas Basin: The wind towers of the Wildhorse and Vantage Wind Farm remind us of the regularity and strength of winds on the eastern margins of the basin. The thick deposits of *loess* that blanket the Badger Pocket area in the southeastern part of the Kittitas Basin are a reminder of the importance of wind over time as well.

Missoula Floods: Descending the Ryegrass anticline, we reach the upper limit of Missoula Flood *slackwater* at ~1260 feet (Figure 8) between mileposts 133-134. Look for changes in the shrub steppe vegetation as well as thick gravel deposits to indicate that we have crossed into the area once inundated by floodwaters. Also, keep your eyes peeled for light-colored, out-of-place rocks atop the basalts in this area—these are iceberg-rafted *dropstones* (also called *erratics*) deposited by the floods. As we descend to Vantage at ~600 feet elevation on the Columbia River, recognize that floodwaters lay ~600 feet over our heads at their deepest extents. The Columbia River “Gorge” here is a result of pre-Missoula Flood, Missoula Flood, and post-Missoula Flood erosion. East of the Columbia River, the ~horizontal bench we follow until nearly entering the Quincy Basin and the Columbia Basin Irrigation Project is a *stripped structural surface* created by selective erosion of Columbia River Basalts to the level of the Vantage sandstone. Several landslides are visible atop the Vantage sandstone in the slopes to the right (east) of our vehicles. From here, we also have fine views of *Channeled Scablands* (to your west) that are so indicative of Missoula Flood-ravaged surfaces.

Climate in the Vantage Area: In Vantage, we are in a very different climate from that of Ellensburg. Because we are ~900 feet lower than Ellensburg, temperatures are likely 4-5°F higher. With distance from the Cascade Range, it is also slightly drier here than in Ellensburg. In fact, this is probably the warmest and driest place of our entire field day. *Parabolic* and *barchan* dunes here indicate that winds are more southwesterly than the northwesterlies of Ellensburg, likely being shaped by local topography.

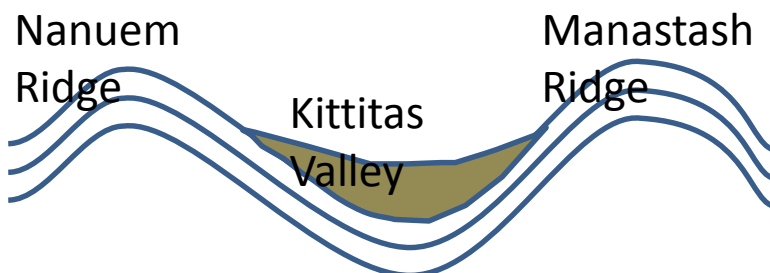


Figure 4. Location of Kittitas Basin syncline between Nanuam Ridge and Manastash Ridge anticlines. Source: Jack Powell.

Ellensburg to Quincy Basin

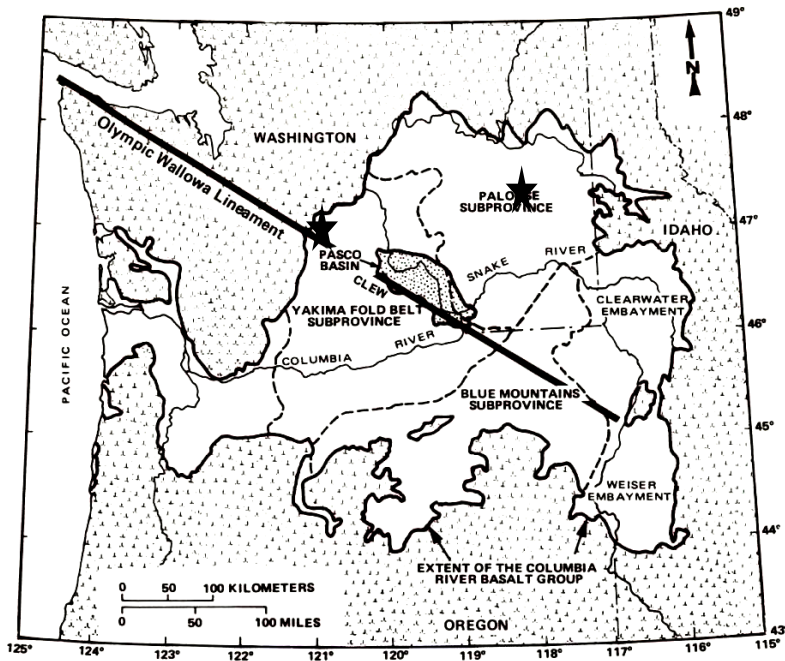


Figure 5. The Columbia Plateau and the areal extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Stars indicate locations of Ellensburg and Coulee City. Source: Reidel & Campbell (1989, p. 281).

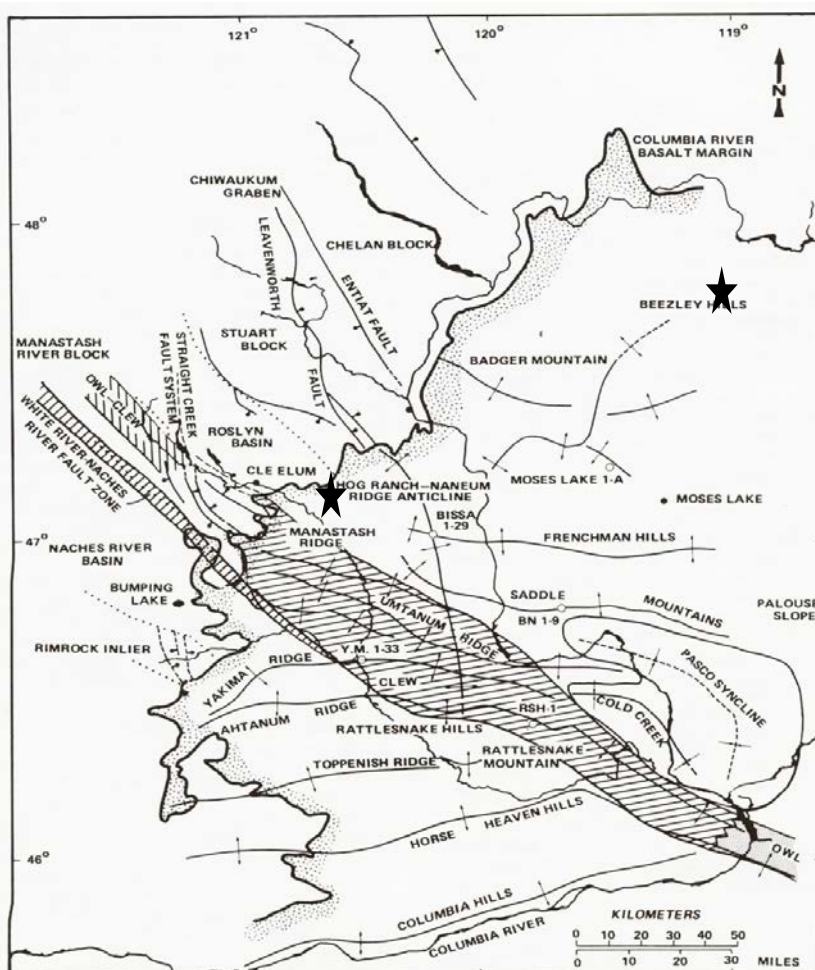


Figure 6. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Stars indicate approximate locations of Ellensburg and Coulee City. Source: Reidel & Campbell (1989, p. 281).

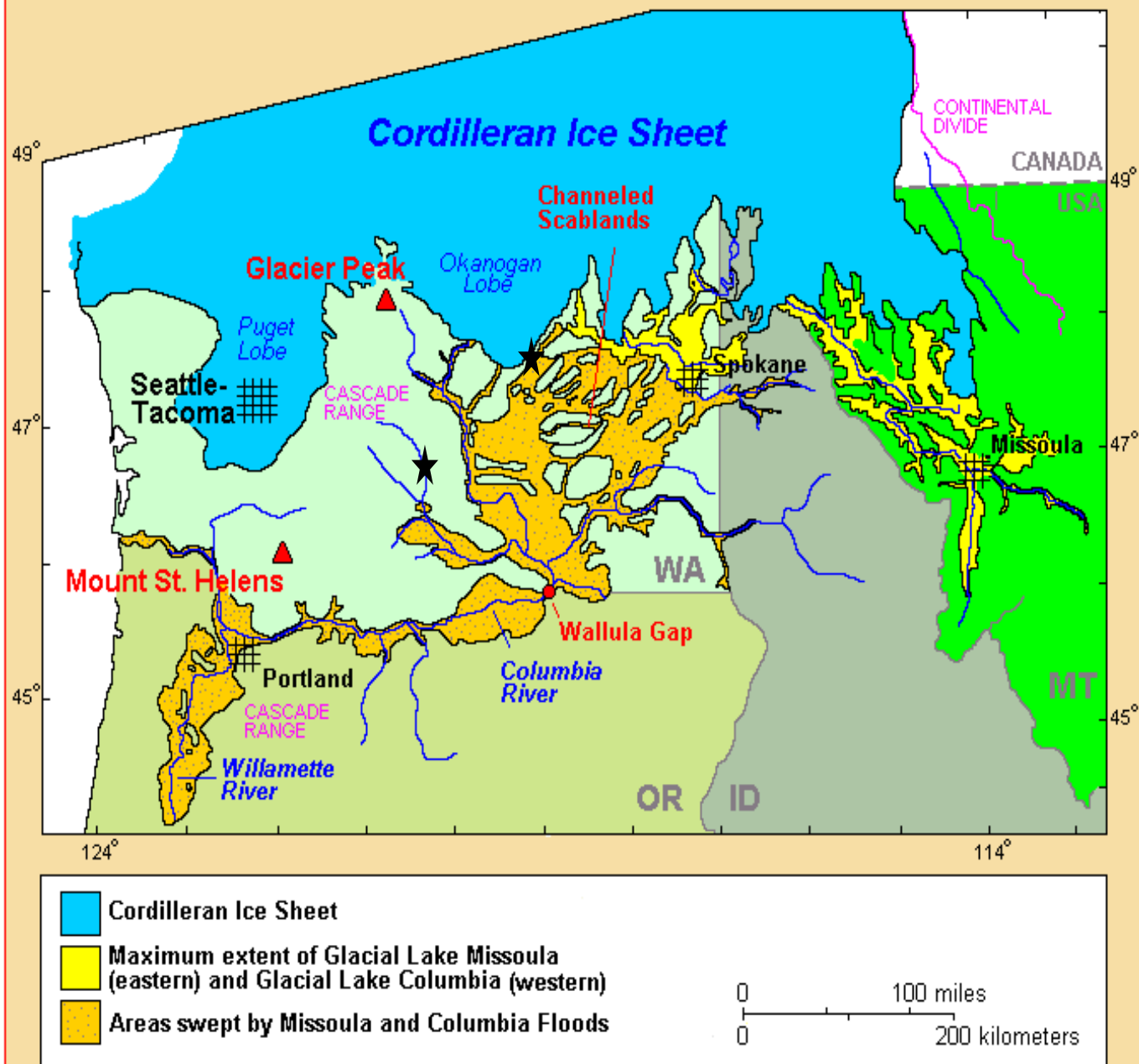
Ellensburg to Quincy Basin

Series	Group	Formation	Member	Isotopic Age (ml. y.)	Magnetic Polarity	
Miocene	Upper	Saddle Mountains Basalt	Lower Monumental Member	6	N	
			Ice Harbor Member	8.5		
			Basalt of Goose Island		N	
			Basalt of Martindale		R	
			Basalt of Basin City		N	
			Buford Member		R	
			Elephant Mountain Member	10.5	R,T	
			Pomona Member	12	R	
			Esquatzel Member		N	
			Weissnefels Ridge Member			
			Basalt of Slippery Rock		N	
			Basalt of Tenmile Creek		N	
			Basalt of Lewiston Orchards		N	
			Basalt of Cloverland		N	
			Asotin Member	13		
			Basalt of Huntzinger		N	
			Wilber Creek Member			
			Basalt of Lapwai		N	
	Basalt of Wahluke		N			
	Umatilla Member	13.5				
	Basalt of Silhusi		N			
	Basalt of Umatilla Member		N			
	Middle	Columbia River Basalt Group	Wanapum Basalt	Priest Rapids Member	14.5	
				Basalt of Lolo		R
				Basalt of Rosalia		R
				Roza Member		TR
				Shumaker Creek Member		N
				Frenchman Springs Member		
				Basalt of Lyons Ferry		N
				Basalt of Sentinel Gap		N
				Basalt of Sand Hollow	15.3	N
				Basalt of Silver Falls		NE
				Basalt of Ginkgo		E
				Basalt of Palouse Falls		E
				Eckler Mountain Member		
				Basalt of Dodge		N
				Basalt of Robunette Mountain		N
	Vantage Horizon					
	Lower	Columbia River Basalt Group	Grande Ronde Basalt	Member of Sentinel Bluffs	15.6	N ₁
				Member of Slack Canyon		
				Member of Field Springs		
				Member of Winter Water		
				Member of Umtanum		
				Member of Ortlely		
				Member of Armstrong Canyon		
Member of Meyer Ridge						
Member of Grouse Creek				R ₁		
Member of Wapshilla Ridge						
Member of Mt. Horrible						
Member of China Creek				N ₁		
Member of Downey Gulch						
Member of Center Creek	R ₁					
Member of Rogersburg						
Member of Teepee Butte						
Member of Buckhorn Springs		16.5				
Imnaha Basalt	Columbia River Basalt Group			17.5	R ₁	
					T	
					N ₁	
					R ₁	

Figure 7. Stratigraphy of the Columbia River Basalt Group. Source: Reidel and others (2002).

Ellensburg to Quincy Basin

Pacific Northwest and the "Missoula Floods"



Topinka, USGS/CVO, 2002; Modified from: Waitt, 1985

Figure 8. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Stars indicate approximate locations of Ellensburg and Coulee City.

Source: Cascade Volcano Observatory website.

Quincy Basin to Ephrata Expansion Bar

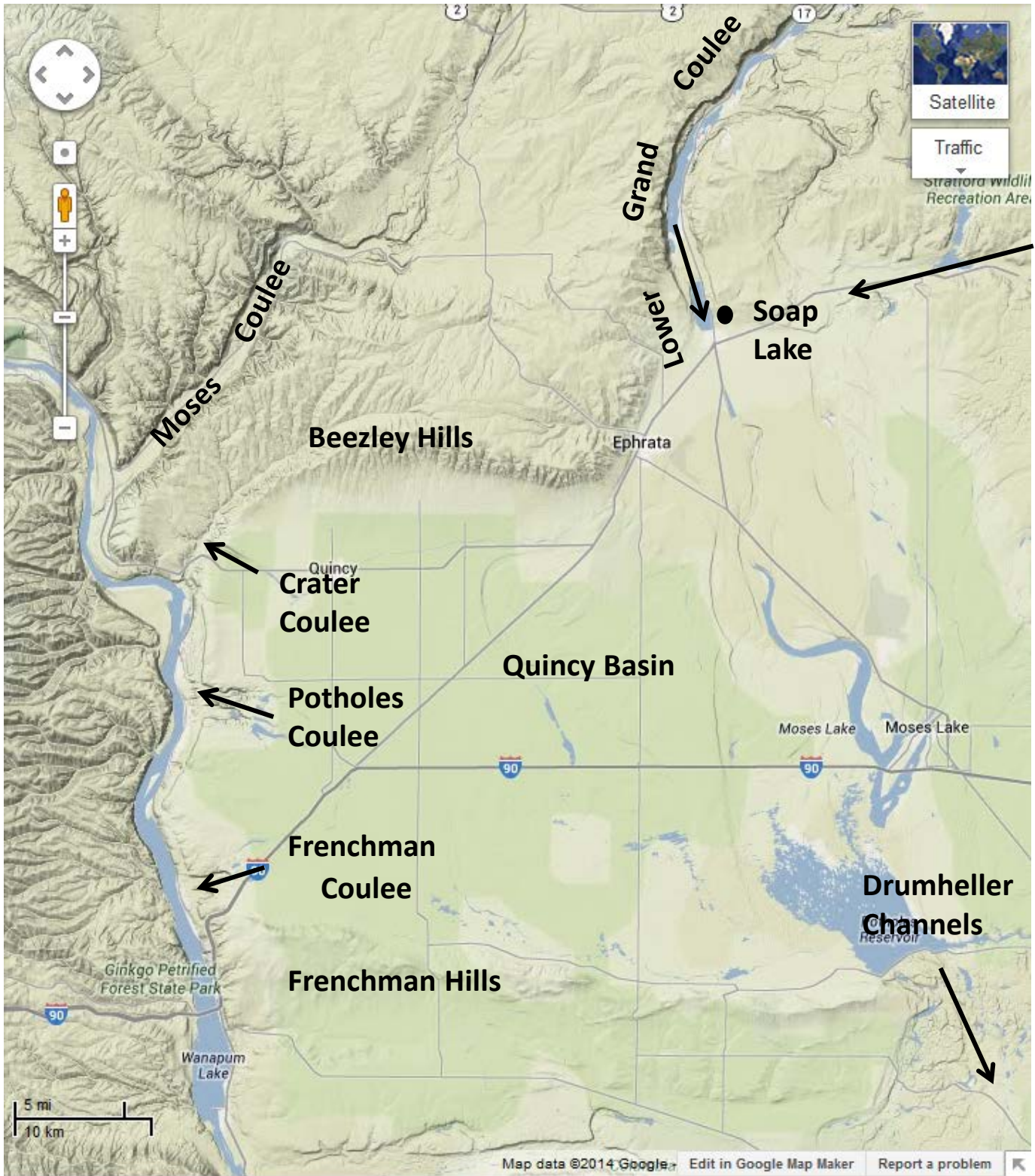


Figure 9. Topography of the Quincy Basin to Lower Grand Coulee part of our route. Arrows show direction of flood flows into, and out of, the Quincy Basin. Source of image: Google Maps. 9

Quincy Basin to Ephrata Expansion Bar

Route: This leg of the route takes us across the Quincy Basin to south of the mouth of the Lower Grand Coulee (Figures 2 & 9). We enter the Quincy Basin essentially where I-90 reaches its high point before descending to the Silica Road exit. We will follow I-90 to just east of George, then take WA 283 to Ephrata. In the southern part of Ephrata (just south of Safeway) we will turn right (east) onto WA 282 toward Moses Lake. Follow WA 282 for approximately 5 miles until its junction with WA 17. Turn left (north) onto WA 17 and follow it for approximately 3.5 miles north to its junction with the gravel road leading east to Rocky Ford. Take this road approximately 1 mile to the very large basalt boulder on the north side of the road. This is Stop 1.

Substrate: The Quincy Basin is underlain by *Miocene* Grande Ronde and Wanapum basalts of the Columbia River Basalt group (Figures 5 and 6). The individual flows are interbedded with sedimentary units including *diatomaceous earth*, which is mined in the basin. The Ringold Formation, a mix of *Tertiary* and *Quaternary alluvial* and *lacustrine* sediments, is found in scattered exposures in the basin. Gravels, sands, and silts associated with late Quaternary Missoula Floods cover much of the basin. Loess mantles much of the slopes of the basin. The tan soils of the basin are low in organic matter and indicate aridity.

Structure and Flooding: The Frenchman Hills and Beezley Hills (Figure 9) are anticlines on the northwestern part of the Yakima Fold and Thrust Belt (Figure 7). These anticlines guided floodwaters entering the basin from the northeast and east. Flood outlets from the basin were (clockwise from the northwest) at Crater Coulee, Potholes Coulee, Frenchman Coulee, and Drumheller Channels (Figure 9).

Columbia Basin Irrigation Project: The Quincy Basin is a vastly different place now than in 1952 when Columbia River water was first delivered to the area via the Columbia Basin Irrigation Project. Prior to that time, it was a dry, sand-covered basin characterized by ranching and meager attempts at dryland farming. Now it boasts over 60 different crops. Water for these crops reach the Quincy Basin from Lake Roosevelt via Banks Lake Reservoir and a series of canals and siphons.

Cover Sand: Windblown sand originating from the Columbia River and from wind reworking distal Missoula Flood deposits covers much of this bar. Unlike the deposits near Moses Lake, these deposits take on the flatter form of cover sand rather than dunes, perhaps reflecting the lower amount of sand available. These sands are a main parent material for the basin's soils.

Patterned Ground: Patterned ground appears as pimple-like features on the gravelly to bouldery Missoula Flood deposits as we near Ephrata. If you look closely, you can also see patterned ground on the Beezley Hills. Given the position of these features, they must have formed following the floods in the latest *Pleistocene* or *Holocene*. Are they cold climate phenomena, the result of water or wind erosion, seismic activity, burrowing rodents, or something else?

Stop 1—Ephrata Expansion Bar

Location: We are located at the very large basalt boulder along the Rocky Ford Road, south of Soap Lake and the mouth of the Lower Grand Coulee.

Flood Bars: We are standing atop a boulder strewn, giant *bar*. Bars differ from alluvial fans in that the load is transported at the base of a stream or river. Most researchers (e.g., Baker, 1973) refer to this an *expansion bar* which forms where flowing waters leave the confines of a canyon. In doing so, they lose velocity and the ability to carry their *load*. Some (e.g., Rice and Edgett, 1997) refer to it as multiple bars emplaced on an outwash plain. I follow convention here. This giant expansion bar formed at the junction of the mouth of the Lower Grand Coulee and the Crab Creek Valley as the floodwaters from the Grand Coulee and Crab Creek-Telford scabland tracts waters left their confines and merged (Figures 10 & 11). These floodwaters also left *distributary channels* throughout the basin as flows diverged from the Lower Grand Coulee. Ephrata lies in once such channel, aptly named the Ephrata Channel. Rocky Ford (Figures 11 & 12) is the easternmost distributary channel.

Bedload & Berg-Rafted Boulders: As far as you can see on this surface, there are boulders...and lots of them! They come in many shapes and sizes. Take a close look at these boulders—i.e., they are not all basalt. Many are granitic rocks that were plucked from bedrock and travelled at least 50 miles from the vicinity of Steamboat Rock in the Upper Grand Coulee to reach this site. These boulders likely represent *bed load* as well as berg-rafted sediments. Bed load is sediment transported at the base of stream. It moves by bouncing, rolling, and creeping along the stream bottom. It is typically the largest load transported by normal streams, and requires the greatest velocities. Students on a recent field trip to the site measured intermediate boulder diameters of 5 to 9 feet. When applied to Figure 13, it shows mean flood flow velocities of 30 to 40 feet/second (20 to 27 miles/hour). If flood velocities were approaching 30 miles/hour here, what were they like in the confines of the Lower Grand Coulee? Note the subangular to subrounded nature of the boulders. One would think that 50 miles of bedload transport would have rounded these boulders more than it did. The larger boulders were likely berg-rafted to the site and deposited when the icebergs grounded. The largest of these boulders is basalt which must have been emplaced on glacial ice of the Cordilleran Icesheet near the head of the Upper Grand Coulee approximately 60 miles north of here.

Post-Flood Modifications: Look closely at the surfaces of the granitic rocks. Many are shedding a thin surface layer through a process known as *exfoliation*. This is a form of weathering. Exfoliation occurs because of the removal of overlying rock which allows the remaining rock to expand. This expansion leads to *sheeting joints* that parallel the rock surface. Many of the granitic rocks also have ~circular depressions on their surfaces that are the result of chemical weathering processes known as *dissolution* and *hydrolysis*. As a result of these weathering processes, the rock becomes softer and *weathering pits* form. The large basalt boulder is surrounded by post-flood *talus* which represents rockfall that was generated by *frost action* weathering.

Stop 1—Ephrata Expansion Bar

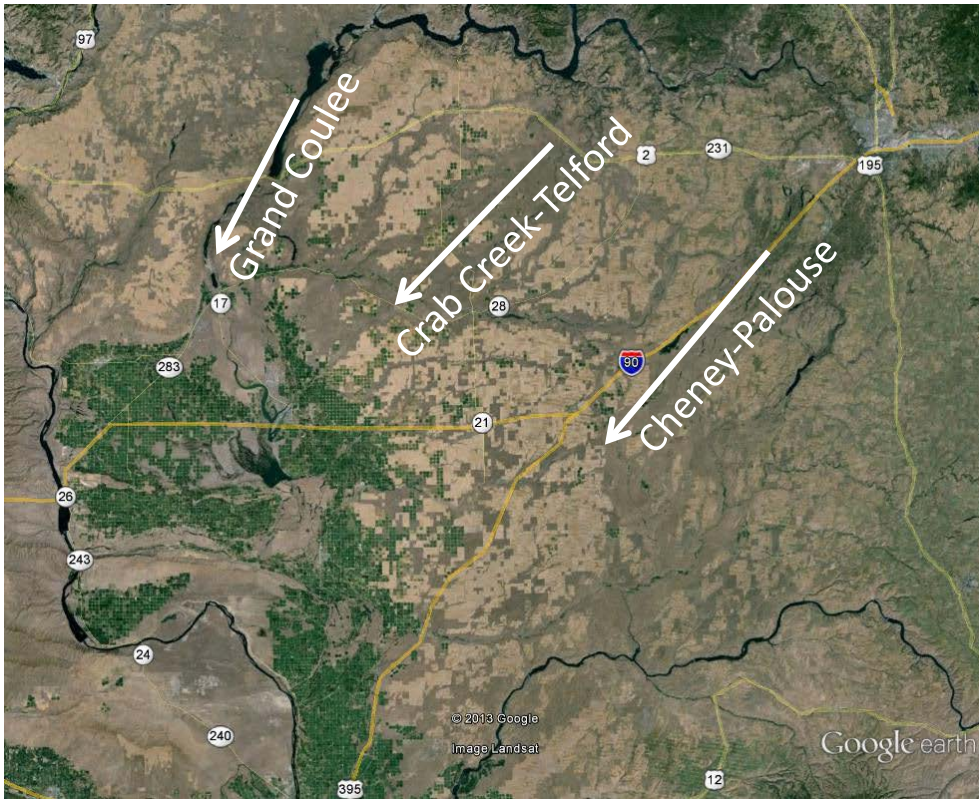


Figure 10. Channeled scabland tracts of central Washington state. Scablands are the darker areas. Number indicates field trip stop. Source: Google Earth.

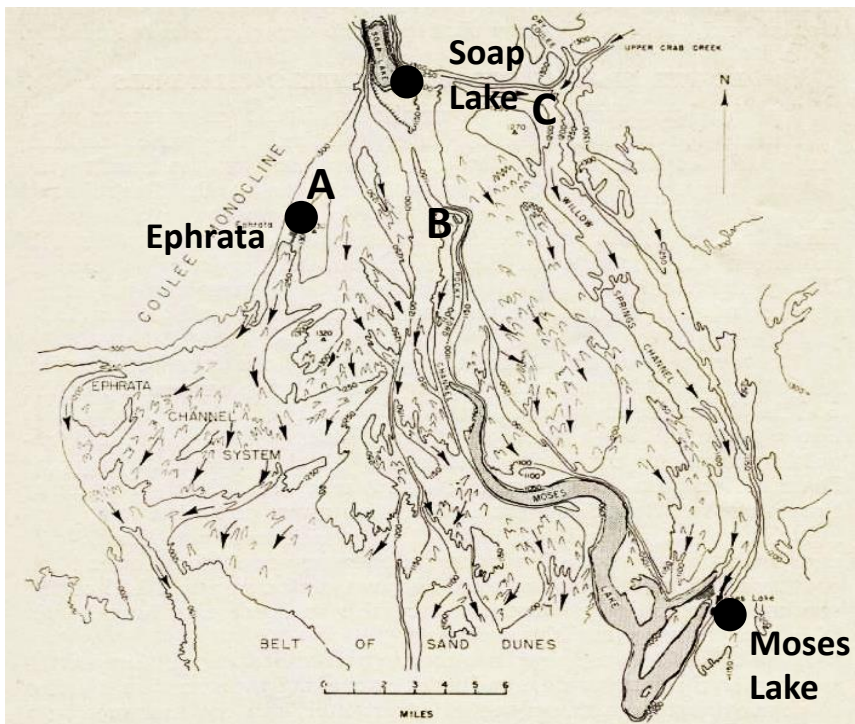


Figure 11. Quincy Basin distributary channels. Note three main distributaries from west to east—Ephrata (A), Rocky Ford (B), and Willow Springs (C). Note origins of distributaries at apex of Ephrata Fan (i.e., expansion bar). Source: Bretz (1959, p. 33).

Stop 1—Ephrata Expansion Bar



Figure 12. Ephrata Expansion Bar. Note the lack of irrigated agriculture over the coarsest parts of this bar. Number indicates Stop 1. Source: Google Earth.

Stop 1—Ephrata Expansion Bar

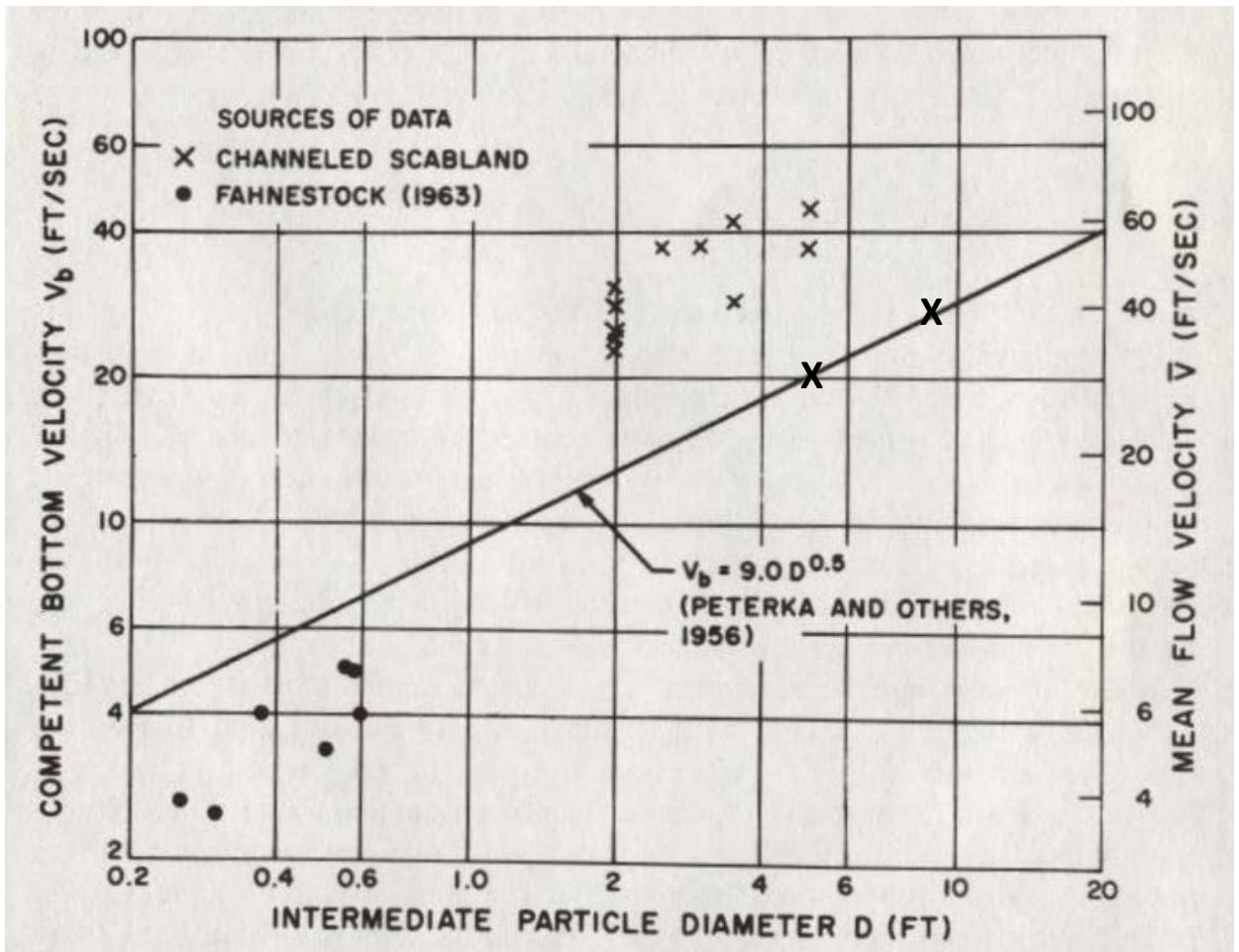


Figure 13. Relationship of particle size to velocity. Note X's representing recent measurements at the site. Source: Baker (1973).

Ephrata Expansion Bar to Soap Lake

Route: Return to WA 17 and turn right (north). Follow WA 17 to the City Park along WA 17 at the north end of the City of Soap Lake.

Stop 1--Soap Lake

The Lower Grand Coulee: Soap Lake is located at the distal end of the Lower Grand Coulee (Figures 14 & 15). The Lower Grand Coulee formed from recession of a cataract in Columbia River Basalts as water spilled along the inclined limb of the Coulee Monocline. This cataract receded ~17 miles to its present location at Dry Falls. Its difficult to imagine erosion of this magnitude in hard basalt. The high velocity of floodwaters through the Lower Grand Coulee (30 m/sec or 67 mph—Baker, 1978) led to erosion 214 feet below the present lake surface (Bretz and others, 1956). Grand Coulee operated early and often as a major path for Missoula Floods (Figure 14). In fact, it was the geomorphic evidence found in the Quincy Basin that led Bretz and others (1956) to identify the relations between the Grand Coulee and other coulees and ultimately the evidence for multiple floods through the area (Bretz, 1969). During the late Pleistocene, these floods likely occurred between about 15,500 to 13,000 years before present (Waitt and others, 2009). As floodwaters exited the Lower Grand Coulee, they rapidly lost velocity depositing their load. This deposition from the Lower Grand Coulee resulted in the formation of the huge Ephrata expansion bar. This bar impounds Soap Lake. Approximately 110 feet of flood gravels overlie the flood scoured basalt floor of Soap Lake (Bretz and others, 1956).

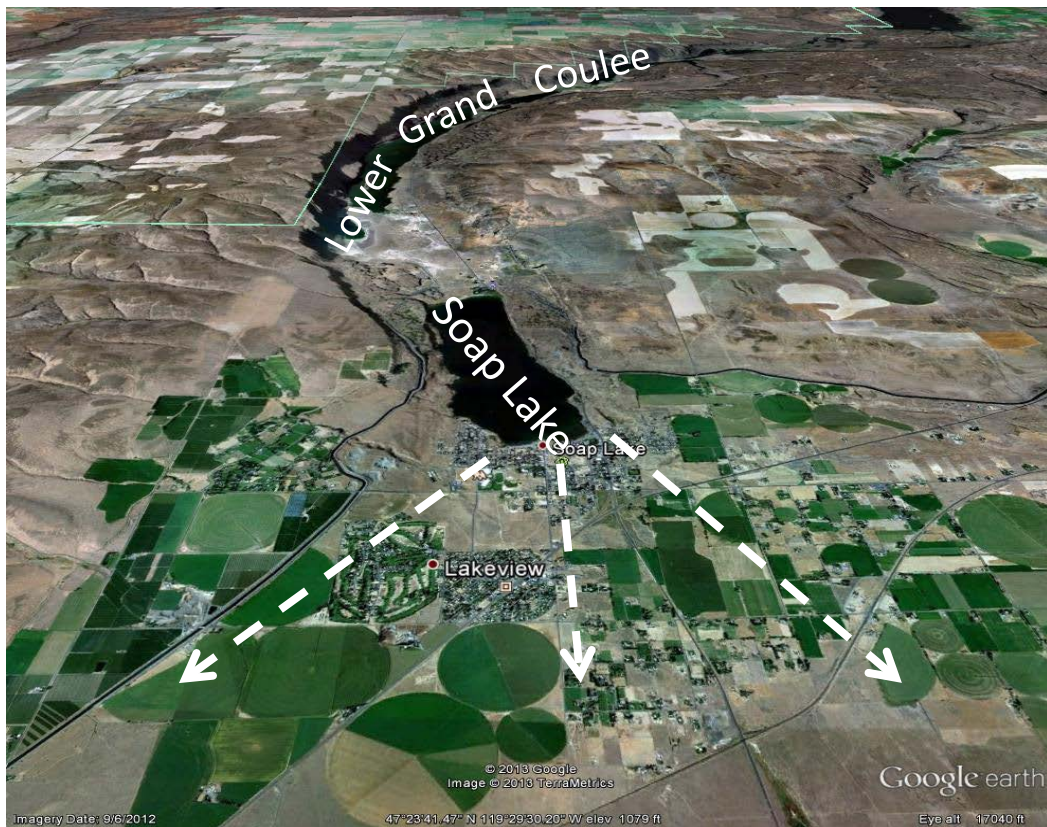


Figure 14. Oblique view of Soap Lake at the terminus of the Lower Grand Coulee. Solid arrow shows flood flows. Dashed arrows show development of expansion bar. Source: Google Earth.

Stop 1—Soap Lake



Figure 15. Topography of the Lower Grand Coulee and vicinity. Blue Lake rhinoceros site shown with star. Source of image: Google Maps.

Stop 1—Soap Lake (continued)

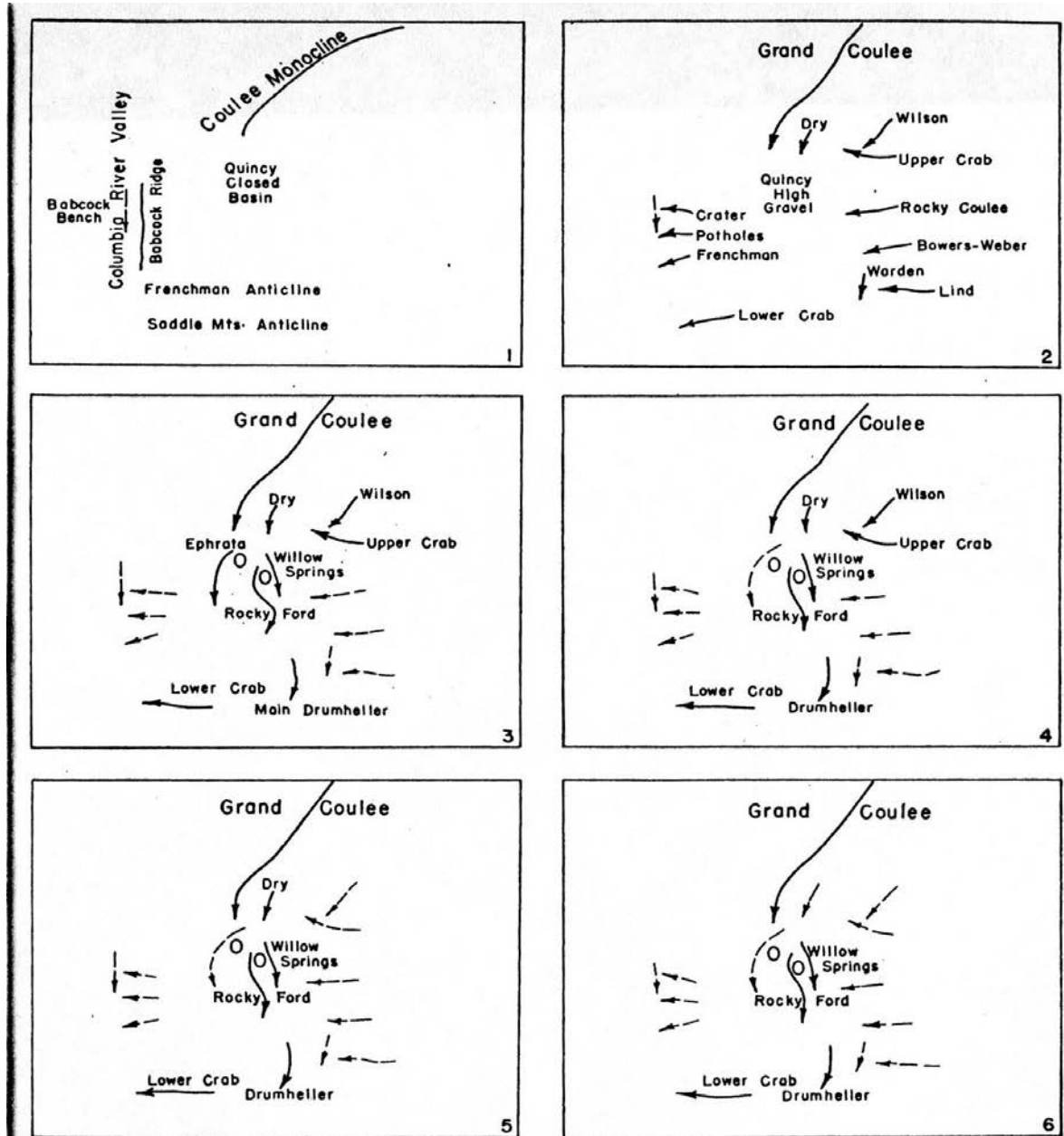


Figure 16. Sequence of floods into the Quincy Basin according to Bretz and others (1956). Note that portions of west-flowing floods from the Crab Creek-Telford Scabland Tract emptied into the Quincy Basin at Soap Lake.

Stop 1—Soap Lake

Glacial Lake Bretz: Flood gravel-capping lake silts south and north of present-day Soap Lake suggest that a once-deeper lake existed here to an elevation of ~1150 feet impounded behind the expansion bar (Waite, 1994). WSU Anthropologist Roald Fryxell's student Jerry Landye (1973) named this Lake Bretz, and suggested it was a Late Pleistocene lake formed following the passage of the last Missoula Floods through the coulee. The high point of this lake was about 5 feet below the lowest point on the expansion bar (~1155 feet) impounding the lake south of the present day intersection of WA 28 and 17. Glacial Lake Bretz extended upcoulee nearly to Dry Falls Lake. Watch for the white outcrops of Glacial Lake Bretz sediments along WA 17 between Soap Lake and Dry Falls. I have found molluscs in several of these outcrops. To my knowledge, no one has dated these molluscs to determine the timing of the lake.

Soap Lake as a Closed Basin Lake: Soap Lake's current high water surface (~1075 feet) is about 80 feet below the lowest point on the expansion bar (~1155 feet) south of the intersection of WA 28 and 17. Soap Lake gets its name from its soapy appearance, especially when the wind whips up the surface of the lake. This soapy appearance comes about because it is a *closed-basin lake*. Soap Lake is the terminal lake of a chain of Lower Grand Coulee lakes and has no surface outlet. In arid to semi-arid settings, water loss from such closed basin lakes occurs primarily because of evaporation which concentrates minerals in the remaining water. Closed basin lakes therefore tend to be saline and/or alkaline, and because of its terminal position, Soap Lake is the most saline and alkaline of the Lower Grand Coulee lakes (Bennett, 1962). As such, Soap Lake is the 3rd largest saline lake in Washington (behind Omak Lake and Lake Lenore (Bennett, 1962)). The main salt is Sal Soda (Na_2CO_3). Because of evaporation, Soap Lake is also an alkaline lake with a pH of 9. In the 1940's, the lake had total dissolved solids of about 37 g/L and was 20% more saline than seawater (Bennett, 1962; Edmondson, 1992).

Human Activity at Soap Lake: Humans have long exploited the mineral waters of Soap Lake beginning with Native Americans and continuing with Euroamericans. The lake was called Sanitarium Lake because of purported therapeutic value of lake waters at around turn of century. The small settlement that began in 1904 was incorporated as Soap Lake in 1919. People came from all over to soak in and ingest the Soap Lake waters for their healing effects. The town of Soap Lake was built (physically and economically) around these mineral waters (Fiege, n.d.).

Columbia Basin Irrigation Project and Soap Lake: Inflow of Columbia Basin Irrigation Project water in the early 1950's diluted lake waters causing concern for City of Soap Lake residents and business owners. To solve this problem, the Bureau of Reclamation installed pumps in wells adjacent to the lake to intercept the incoming fresh Columbia River water. Since 1959, the salinity of the lake has generally been stable at about 15 g/L total dissolved solids. However, this concentration is well less than when the lake was first measured in the 1940's (Edmondson, 1992).

Soap Lake to East Lenore Coulee Bar

Route: From the Soap Lake City Park, we will drive approximately 6 miles north on WA 17. Just before basalt bedrock outcrops on the east side of the road, turn east (right) onto a dirt road. Continue east on this for about 0.2 miles where we will park near a gravel pit.

Stop 2--East Lenore Coulee Bar

Location: We are parked on a side road near the mouth of East Lenore Coulee (Figure 16). From our parking spots, we will hike upslope to the top of the East Lenore Coulee Bar.

East Lenore Coulee: East Lenore Coulee parallels the lower Grand Coulee. Its head lies just south of Dry Coulee. It apparently formed prior to the excavation of Dry Coulee (Figure 17) as evidenced by its position elevationally above Dry Coulee. It terminated in the Lower Grand Coulee at our field trip stop site.

Substrate: Much of the substrate that we see in the Lower Grand Coulee is Grande Ronde and Wanapum basalt of the Columbia River Basalt Group (Figures 5, 6 & 18). Missoula Flood gravels and Glacial Lake Bretz sands, silts, and clays also outcrop on the coulee floor (see below). Quaternary, post-flood talus mantles slopes below cliffs throughout the coulee.

East Lenore Coulee Flood Bar: The floodwaters that raged across the basalts and eroded East Lenore Coulee deposited their sediment load upon leaving the confines of the coulee. This deposit is a bar that formed sub-fluvially (i.e., at the base of the flood flow) as velocity decreased. Bars typically have blunt upvalley “heads” and long, tapering downvalley “tails”. Their surfaces slope downvalley. Some have described their forms as “whalebacks”, a shape very different from a dissected terrace, a form *uniformitarianists* would have preferred finding in these areas. They are composed of well to poorly sorted and bedded gravels and sands. The situation in which velocity decreases determines the type of bar (Figure 19): 1) *crescent bars* — form on the inside bend of channels; 2) *longitudinal bars* — form in mid-channel or along a channel wall; 3) *expansion bars* — form where channels widens abruptly; 4) *pendant bars* — form downcurrent of mid-valley obstacle or valley-wall spur on bend; 5) *eddy bars* — form in a valley at the mouth of a tributary; and 6) *delta bars* — form where floodwater on a high surface adjacent and parallel to a main channel encounters a transverse tributary valley where it deposits. Here, we are on a pendant bar, the most common type of bar found in the channeled scablands (Baker, 1973). Giant flood bars such as this are one of the pieces of evidence J Harlen Bretz used to argue for a catastrophic flood origin for the channeled scablands. This bar is nearly 1.3 miles long! Bretz and others (1956) referred to the linear moat-like depression between the top of the bar and the basalt bedrock coulee walls as a “fosse”. Note the fosse on Figure 20 and on the ground. Fosse form on longitudinal and pendant bars as a result of turbulence and velocity changes as floodwaters encounter coulee walls.

Giant Current Ripples: Notice on Figure 20 that there appear to be “ripples” atop the bar surface. These are giant current ripples formed at the base of the raging floodwaters. These are just one of over 100 sets of these features in Missoula Flood channels (Baker, 1978). Using Google Earth, we can see at least six giant current ripples at the mouth of East Lenore Coulee. Giant current ripples form transverse to flow and are asymmetrical in cross section with gentle upcurrent (*stoss*) slopes and steeper downcurrent (*lee*) slopes. Sediment is transported up the stoss slopes and deposited as foreset beds on the lee slopes. In average-sized streams and rivers, current ripples range from inches to perhaps a few feet in wavelength and height. Measurements on Google Earth reveal that these current ripples range from 65 to 140 feet in wavelength! Bretz used giant current ripples as another key piece of his evidence of huge floods, rather than uniform flow, shaping the landscape. Figures 21-24 show the relationships between ripple chord (i.e., wavelength), ripple height, water depth, water velocity, and stream power. Note on these figures that as depth and velocity increases, current ripple wavelength and height increases.

Stop 2—East Lenore Coulee Bar

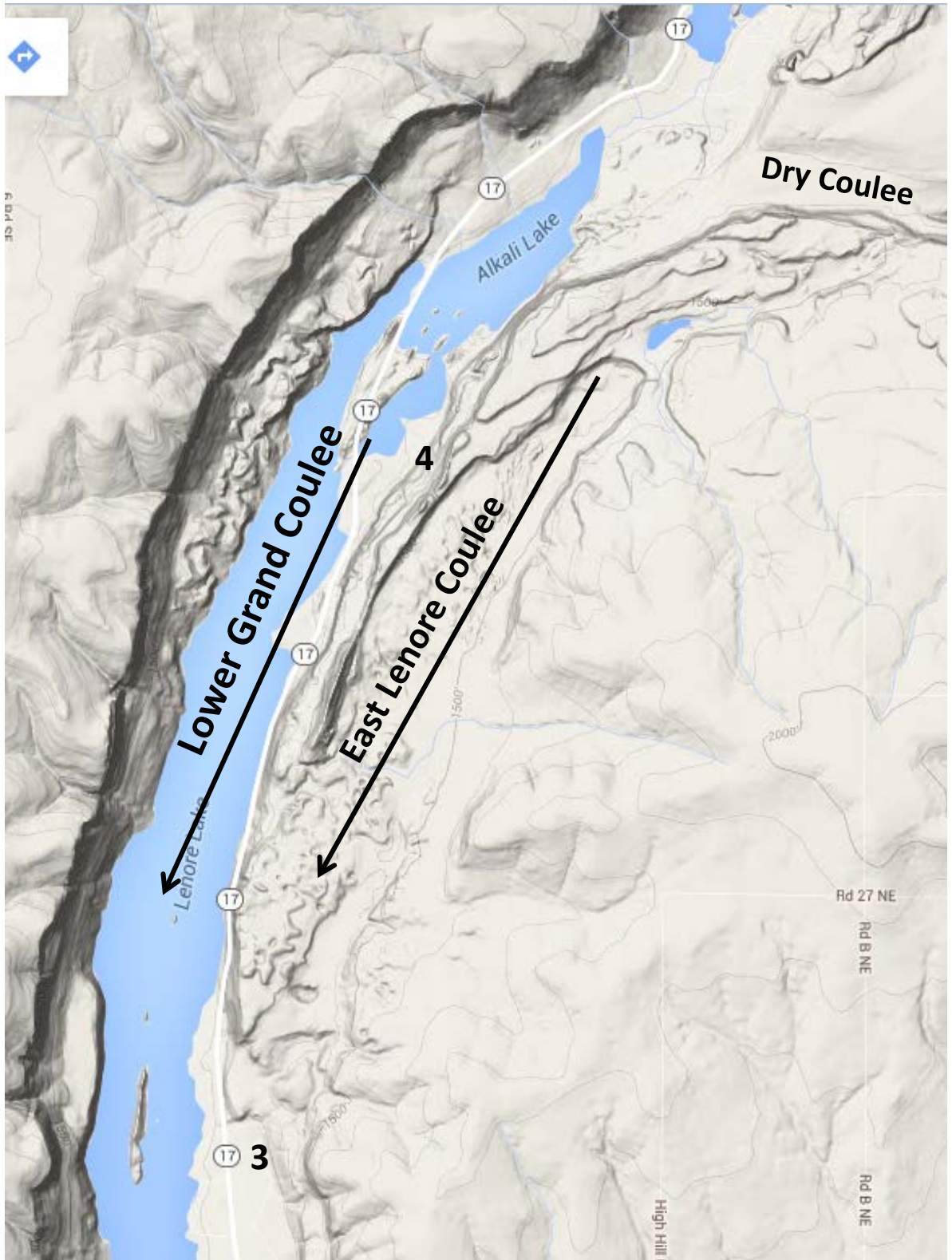


Figure 17. East Lenore Coulee and surroundings. Numbers indicates location of field trip stops. Source: Google Maps.

Stop 2—East Lenore Coulee Bar

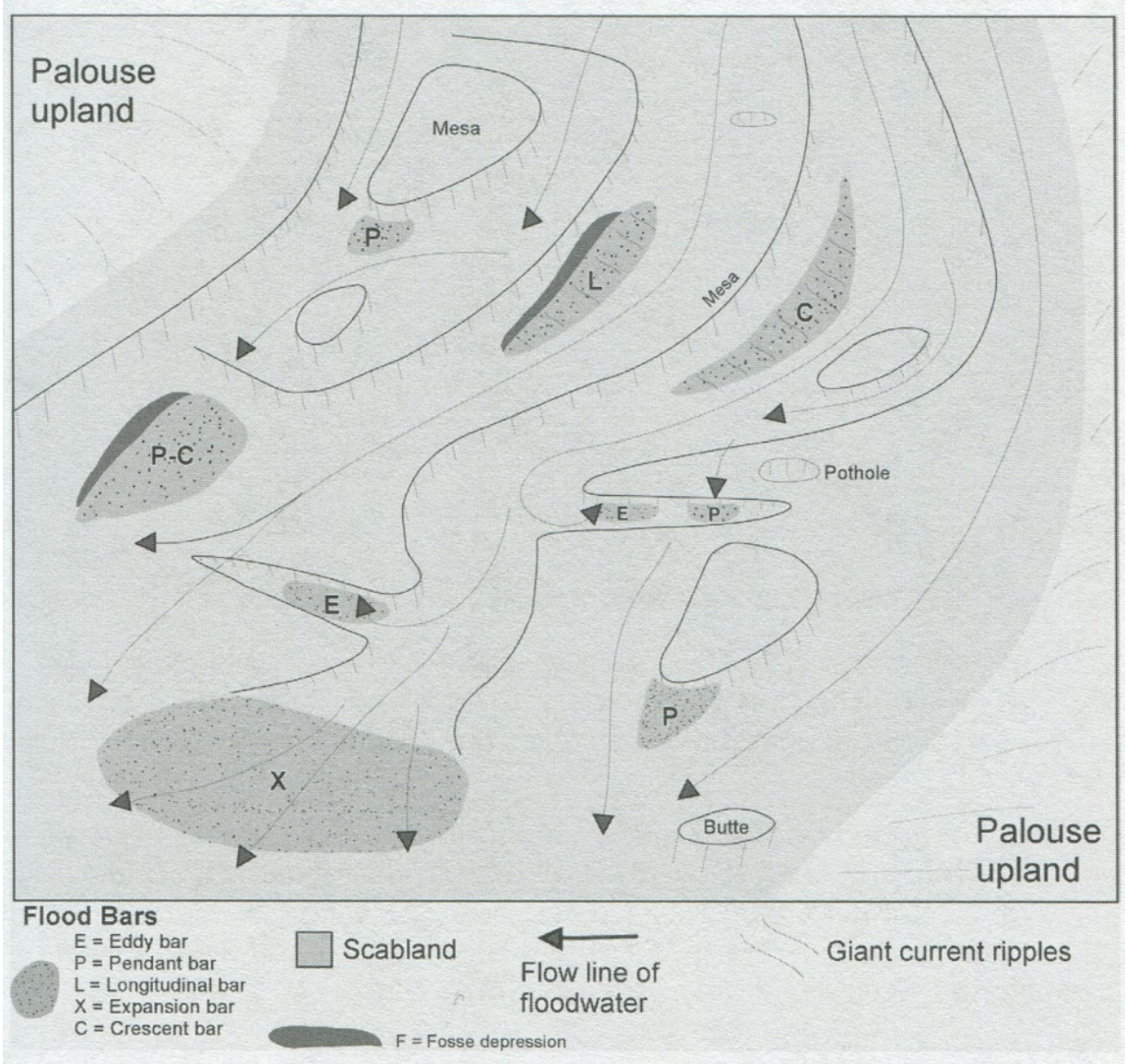


Figure 19. Types of flood bars. From Bjornstad and Kiver (2012, p. 51).

Stop 2—East Lenore Coulee Bar



Figure 20. The pendant bar at the mouth of East Lenore Coulee. Red line is approximate outline of the bar. Arrows indicate direction of flood flow in East Lenore Coulee and the Lower Grand Coulee. Note giant current ripples. Number indicates parking location. Source: Google Earth.

Stop 2—East Lenore Coulee Bar

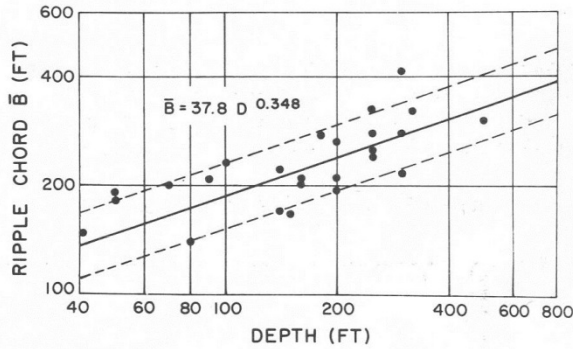


Figure 21. Logarithmic regression of ripple chord as a function of depth. The dashed line represent one standard error. From Baker (1978b, p. 113).

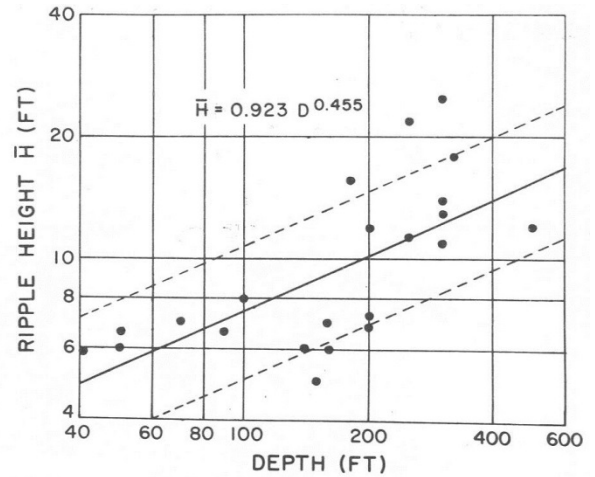


Figure 22. Logarithmic regression of ripple height as a function of depth. The dashed lines represent one standard error. From Baker (1978b, p. 113).

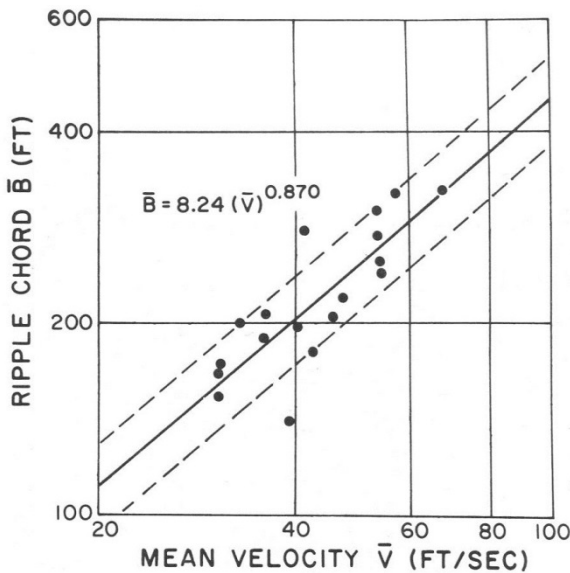


Figure 23. Ripple chord as a function of mean flow velocity (discharge velocity) as calculated by the slope-area methods. The dashed lines represent one standard error. From Baker (1978b, p. 113).

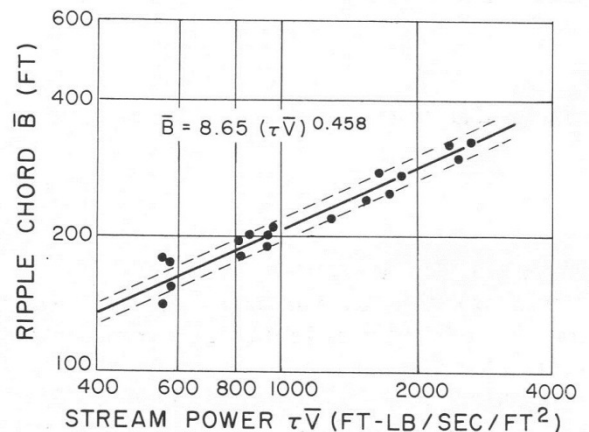


Figure 24. Mean ripple chord as a function of stream power. The dashed lines represent one standard error. From Baker (1978b, p. 115)

Importance of a birds-eye perspective: How does a geologist or physical geographer really see the giant current ripples? From the air! In fact, Bretz didn't really see these features until he examined airphotos (Bretz and others, 1956). Shadows, low light angles, and a light dusting of snow may also help this overhead perspective. Sometimes vegetation differences from the wave crest to the wave trough may further enhance them. The important thing is the overhead view. And this is a perspective that we now have readily at our fingertips with Google Earth.

East Lenore Coulee Bar to Lake Lenore Caves

Route: To get from East Lenore Coulee Bar to the Lake Lenore Caves, we return to WA highway 17, turn right (north), and follow this highway approximately 3.5 miles to a turnoff onto a gravel road. This ~0.5 mile long road leads to the Lake Lenore Caves parking lot. You will need a Discover Pass to park here.

Stop 3—Lake Lenore Caves

Location: We are located near the Lake Lenore Caves in the Lower Grand Coulee. To reach the caves from the parking lot, we will ascend concrete steps up the basalt cliff, then follow a trail south for approximately 0.25 miles.

Geologic Structure & Missoula Floods: Geologic structure dictated the paths of Glacial Lake Columbia water and Glacial Lake Missoula floodwaters in the Lower Grand Coulee. The Lower Grand Coulee follows the Coulee Monocline for much of its path. *Monoclines*, like their name implies, are single incline folds associated with compression. The Coulee Monocline extends from Ephrata at least as far east as Hartline (Figure 15). You can see evidence of it in the tilted basalts of the numerous *hogback islands* present in the lakes on the floor of the coulee (Figure 25). Flood flows coming over the Coulee Monocline in the Upper Grand Coulee in the vicinity of Coulee City migrated to the southwest to follow the topographic low created by the Coulee Monocline and the flanks of the High Hill anticline. Floodwaters followed the base of the monocline, exploiting the folded and crushed rocks here to erode the Lower Grand Coulee. In the vicinity of Lake Lenore, floodwaters also excavated the synclinal valley of East Lenore Coulee. (Figure 26). In each case, floodwaters exploited the less resistant of the uptilted beds leaving behind *homoclinal ridges* and valleys that are further eroded to become *hogbacks* and *cuestas*. The result of the flooding and associated erosion of the monocline was that the cataract receded headwardly (i.e., upvalley) from near present-day Soap Lake 17 miles to near Dry Falls (Figure 15).

Coulees: The term “coulee” is defined in different ways depending on the region in which the term is used. Wherever it is used, it typically means some form of valley or drainage. Here, “coulee” means a steep walled, relatively flat bottomed canyon. The Lower Grand Coulee is one of the best examples of a Channeled Scablands coulee, and our viewpoint from near Lake Lenore Caves is one of the best places to see this coulee.

Lake Lenore Caves



Figure 25. Hogback islands (see arrows) as erosional remnants of the Coulee Monocline. Source: Author photo (November 2007).

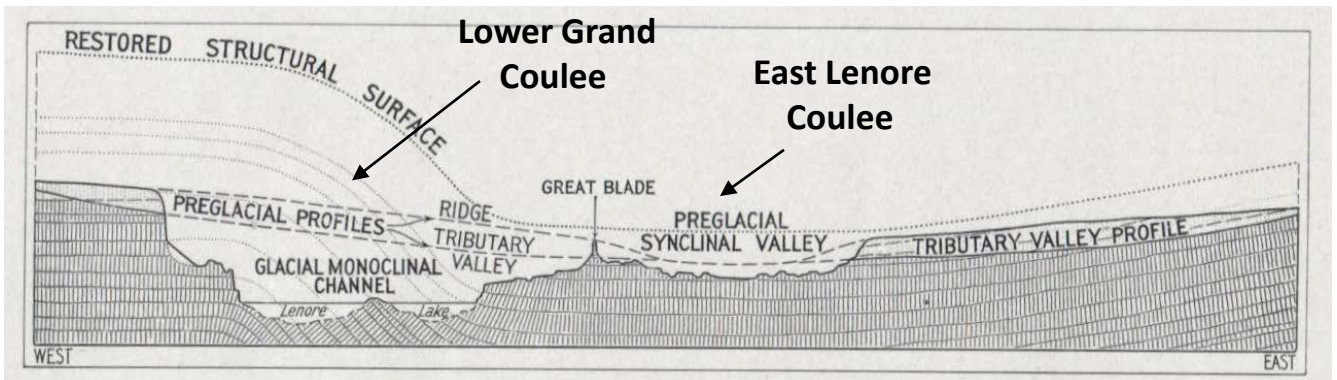


Figure 26. Cross section of Lower Grand Coulee showing relationships between geologic structures, pre-flood valleys, and flood channels. View north. Source: Bretz (1932, p. 66).

Stop 3—Lake Lenore Caves

Regarding coulees, Bretz, in 1932 (p. 1), stated:

Grand Coulee is a canyon fifty miles long, nearly a thousand feet deep and about a mile in minimum width. It is now streamless. Trending north-south, it crosses the highest portion of the Columbia Plateau in Washington, an interfluvial area fifteen hundred feet above the Columbia River which is itself entrenched at the coulee head along the plateau's northern margin. Its grim black walls of basalt frown across a broken chain of linear lakes, some of them as wide as the coulee floor. This floor is diversified with extraordinary stream-channel features. Here are potholes a hundred feet deep in rock, dry cataracts one hundred to four hundred feet high, and river bars one hundred to two hundred feet thick. Yet many of the lakes are ephemeral or alkaline, the cataracts are merely dry cliffs, and the river bars are hills on the abandoned great stream bed. Permanent streams have almost completely disappeared from the region. Glacial ice caused the drainage detour across the divide and the making of this great trench. On the reopening of the old drainage ways temporarily occupied by ice the coulee became dry, and under the present semiarid climate it lies naked of forest mantle, every detail of its form clearly displayed.

Stripped Structural Surfaces: The basalt bench that we follow from the top of the concrete steps is a stripped structural surface formed in Grand Ronde Basalt. It is “stripped” in that the lava flows above this were eroded by ice age floods. It is “structural” in that it represents the top of a Grand Ronde flow. We know it's the top based on the gas bubble holes (i.e., *vesicles*) and upper *colonnade* present (Figure 27). Specific forms of erosion included *abrasion* (where the water carries debris that abrades the surface), *hydraulic action* (where vortices in the water pluck the bedrock—see below), and *cavitation* (implosion of gas bubbles under tremendous pressure).

Potholes: Large circular depressions are common on Channeled Scablands surfaces. These resulted from large, rapidly rotating “vortices” (i.e., *kolk*s) created in fast moving, deep floodwaters (Figures 28 & 29). These vortices “plucked” basalt chunks from the exposed basalt flows creating deep, steep sided potholes.

Buttes, Mesas, and Blades. Incomplete stripping of basalt flows resulted in *buttes*, *mesas*, and *blades* in the basalts (Figure 30). The prominent ridge upslope of us is a blade that remained following the erosion that created the Lower Grand Coulee and East Lenore Coulee. It is the accumulations of these types of features that leads to the common “butte and basin topography” of the Channeled Scablands.

Hanging Valleys: Evidence for the rapid, flood erosion of the Lower Grand Coulee can be seen in the *hanging valleys*, especially evident on the west side of the coulee (Figure 31). These valleys represent pre-ice age flood valleys that were truncated by the flood flows. Uniform river processes result in valleys that join at essentially the same level. This is the *Law of Accordant Junctions* (or Playfair's Law).

Rockshelters: The Lake Lenore Caves are actually *rockshelters* formed in potholes or on the coulee walls by vortices erosion. Because of the flow of the water, the vortices were often tilted downstream (Figure 29) leading to undercutting of the downstream lips of the potholes. The most readily plucked basalts were the *colonnades* of the flows. On the ground, notice how the rockshelters often form at the *colonnade/entablature* boundary.

Stop 3—Lake Lenore Caves

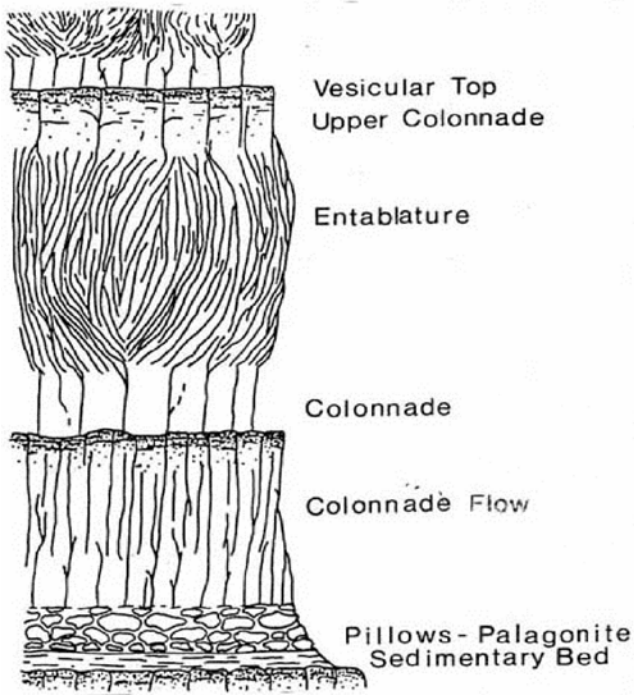


Figure 27. Typical Columbia River Basalt flow cross-section. Source: Jack Powell.

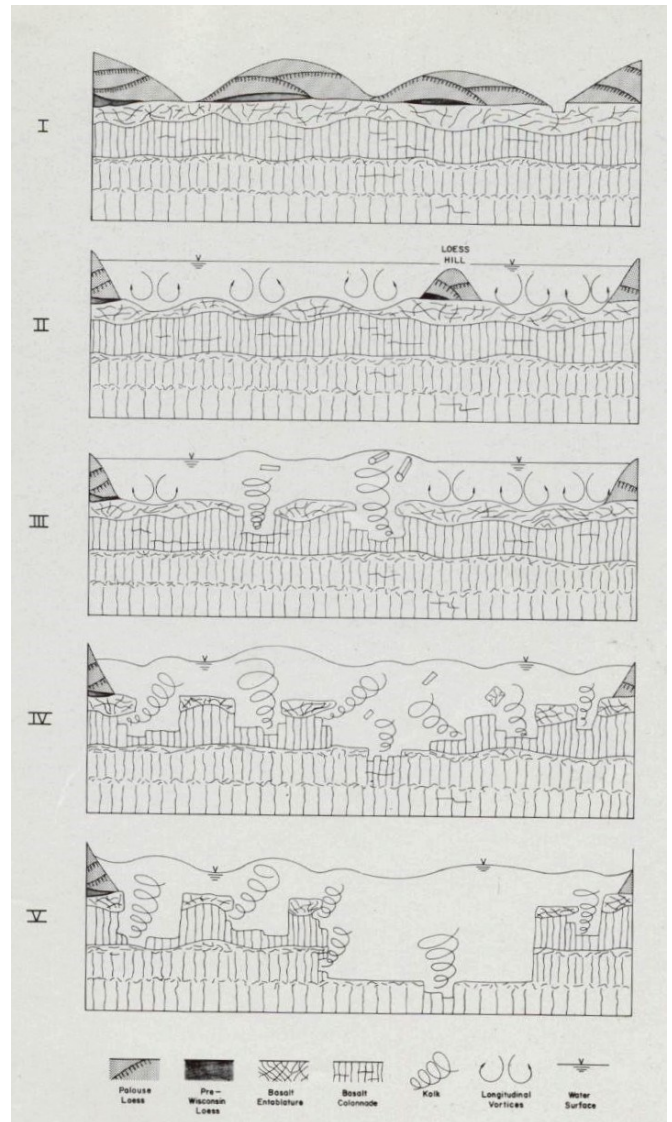


Figure 28. Illustration of kolk-based erosion in columnar jointed basalts. From Baker (1978b, p. 105).

Stop 3—Lake Lenore Caves

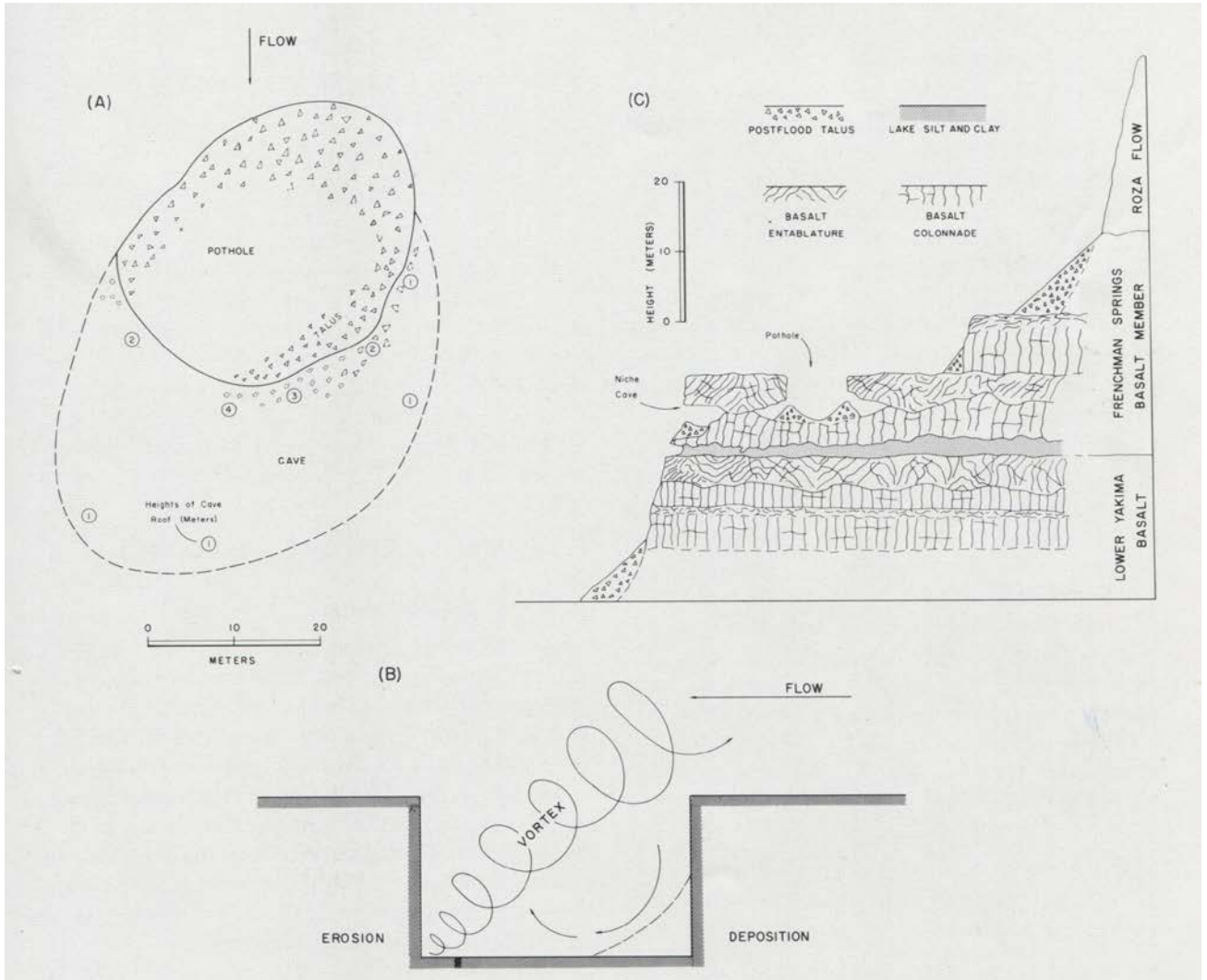


Figure 29. Pothole erosion at Lake Lenore Caves. A. Undercutting of the pothole rim on the downstream side. B. Experimental observations of this same phenomenon. C. Relationship of pothole to basalt stratigraphy. Source: Baker (1978a, p. 75).

Stop 3—Lake Lenore Caves



Figure 30. Lake Lenore caves site. Note stripped structural surfaces, mesas, and blade separating the Lower Grand Coulee and East Lenore Coulee. Arrows indicated water flow direction. Number indicates parking spot. Source: Google Maps.

Stop 3—Lake Lenore Caves



Figure 31. Hanging valleys (indicated with arrows) in the west wall of the Lower Grand Coulee. Source: Author photo (November 1996)

Lower Grand Coulee Archaeology: Native Americans have long used the Lower Grand Coulee for its varied resources. Various plant and animal resources were exploited here over the past 4000 years on a year round as well as seasonal basis. As one would expect in a semi-arid environment, much of the archaeological evidence is located near freshwater sources and associated riparian vegetation zones (Norman, 1996). Ethnographic evidence suggests that, in more recent times, a *rotary transhumance* system existed where the Lower Grand Coulee was a major stop on a hunting and gathering circuit that ranged from the Columbia Basin to the Cascades. Native Americans came from large villages on the Columbia River in search of roots such as lomatium and bitterroot in the spring. The best lomatium grounds extended along the Beezley Hills near Quincy east and north along the Coulee Monocline to near Coulee City (Washington, 1956). While I have yet to find an archaeological report on the Lake Lenore Caves, it seems likely that these rockshelters served as seasonal or perhaps permanent dwelling sites for Native Americans.

Lake Lenore Caves to Dry Falls

Blue Lake Rhino: The eight foot long, one ton, Blue Lake rhinoceros died 14.5 million years ago. Its bloated body was lying among some fallen trees in a shallow water body (Figure 32). The pillow complex of the advancing Priest Rapids basalt flow lifted up and encased the trees and the rhino carcass. It was found in 1935 along the west wall of Jasper Canyon at Blue Lake (Figure 15) when hikers entered a small cavern which turned out to be the rhino's body cast containing a few silicified bone fragments. The presence of the rhino plus pollen samples suggests that approximately 14.5 million years before present the climate of what is now central Washington was similar to that of the southeastern United States—i.e., warm and moist (Kaler, 1988).



Figure 32. Artists rendition of the burial of the Blue Lake rhinoceros.
Source: www.justgetout.net



Figure 33. Leg holes (arrowed) of Blue Lake Rhino. Teenage Erik Lillquist for scale. Source: Author, 2009.

Stop 4—Dry Falls

Location: We are at Dry Falls at the head of the Lower Grand Coulee (Figures 15 & 34) .

Glacial Lake Missoula and its Floods: The floods that shaped this landscape came from Glacial Lake Missoula in western Montana (Figure 8). Glacial Lake Missoula originated when the Purcell Trench Lobe of the Cordilleran Icesheet blocked the mouth of the Clark Fork River near Lake Pend Oreille and Sandpoint creating Glacial Lake Missoula. At its maximum, it held 530 mi³ of water which is about one-half the volume of modern day Lake Michigan. It was 2000 feet deep at its ice dam. Periodically, the ice dam failed releasing lake waters as glacial outburst floods or *jokulhlaups* that swept across northern Idaho and into northeastern Washington creating the Channeled Scablands. Floodwater velocities reached nearly 70 mph in places (Baker, 1987). The Upper Grand Coulee formed when the Okanogan Lobe of the Cordilleran Icesheet blocked the Columbia River Valley near Grand Coulee thus creating Glacial Lake Columbia (Figure 8). This lake spilled to the south as did Missoula Floods that entered the lake. Floods reaching the south end of the Upper Grand Coulee could follow multiple paths to arrive in the Quincy Basin (Figure 32) because of the shear volume of water exiting the Upper Grand Coulee and the lack of the topographic confinement there. Given evidence in the San Poil River Valley to the north (Atwater, 1987), perhaps as many as 90 floods of varying magnitudes passed through the Upper Grand Coulee during the late Pleistocene. Stratigraphic evidence suggests the Upper Grand Coulee formed prior to the last glaciation (Atwater, 1986). Given the relationship between the Upper and Lower Grand Coulee, it seems likely that they formed during similar times. So...in addition to the ~90 floods that likely passed through the Grand Coulee in the Late Pleistocene, many more may have come through during earlier glacial periods.

Dry Falls Origins: Dry Falls is the upvalley position of the cataract that receded approximately 17 miles from Soap Lake. It is in this location only because the floodwaters that created it were shut off by the retreat of the Okanogan Lobe thus opening the Columbia River Valley to Columbia River as well as Missoula Flood flow. Dry Falls is over four miles wide and nearly 400 feet high (Figure 35). It stretches from here to Castle Lake (Figure 35). It is so large, it is referred to as a *cataract*. Deep (~500 feet deep), fast flows have great erosive power, setting up vertical vortices that exploited the columnar joints of the basalts, especially in the zone of the weakened rock at the base of the Coulee Monocline. These vortices combined with abrasion and cavitation to erode the Lower Grand Coulee. It is difficult to imagine approximately 17 miles of erosion in hard basalt bedrock; however, with many floods in the late Pleistocene and perhaps many more earlier floods, the amount of recession per flood could have been a mere ~0.25 miles for each flood (Waitt and others, 2009).

Dry Falls Landforms: Dry Falls is characterized by a variety of distinctive landforms. Dry Falls Lake, Red Alkali Lake, Green Lake, and Castle Lake (Figure 35) all occupy *plunge pools* in the Dry Falls cataract. Umatilla Rock is a blade --i.e., a remnant between the flood flows that created Dry Falls Lake and Red Alkali Lake/Green Lake. Large bars are present on the floor of the Dry Falls cataract including one that impounds Perch Lake. Large boulders on the floor of the Dry Falls cataract may be *bedload* of the floods or post-flood rockfall. Longitudinal grooves like those above Dry Falls are present where the flood flow moved kolks downstream.

Stop 4—Dry Falls

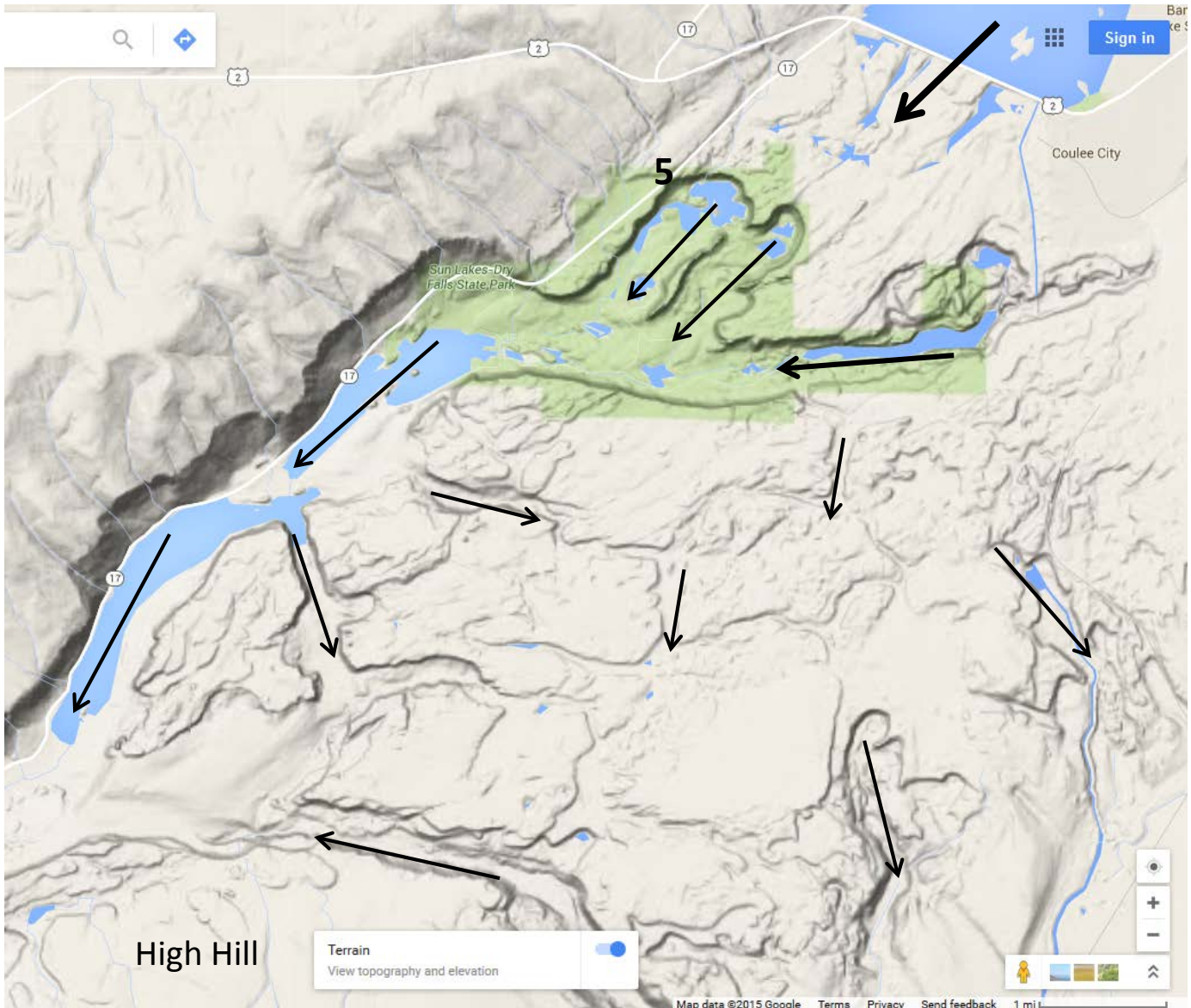


Figure 34. Map of topography in vicinity of Dry Falls and Coulee City. Heavy arrow indicates flood flow down Upper Grand Coulee. Lighter arrows are chaotic flood paths below Coulee City. Note the anastomosing channels south of Dry Falls. Number indicates field trip stop. Source: Google Maps.

Stop 4—Dry Falls

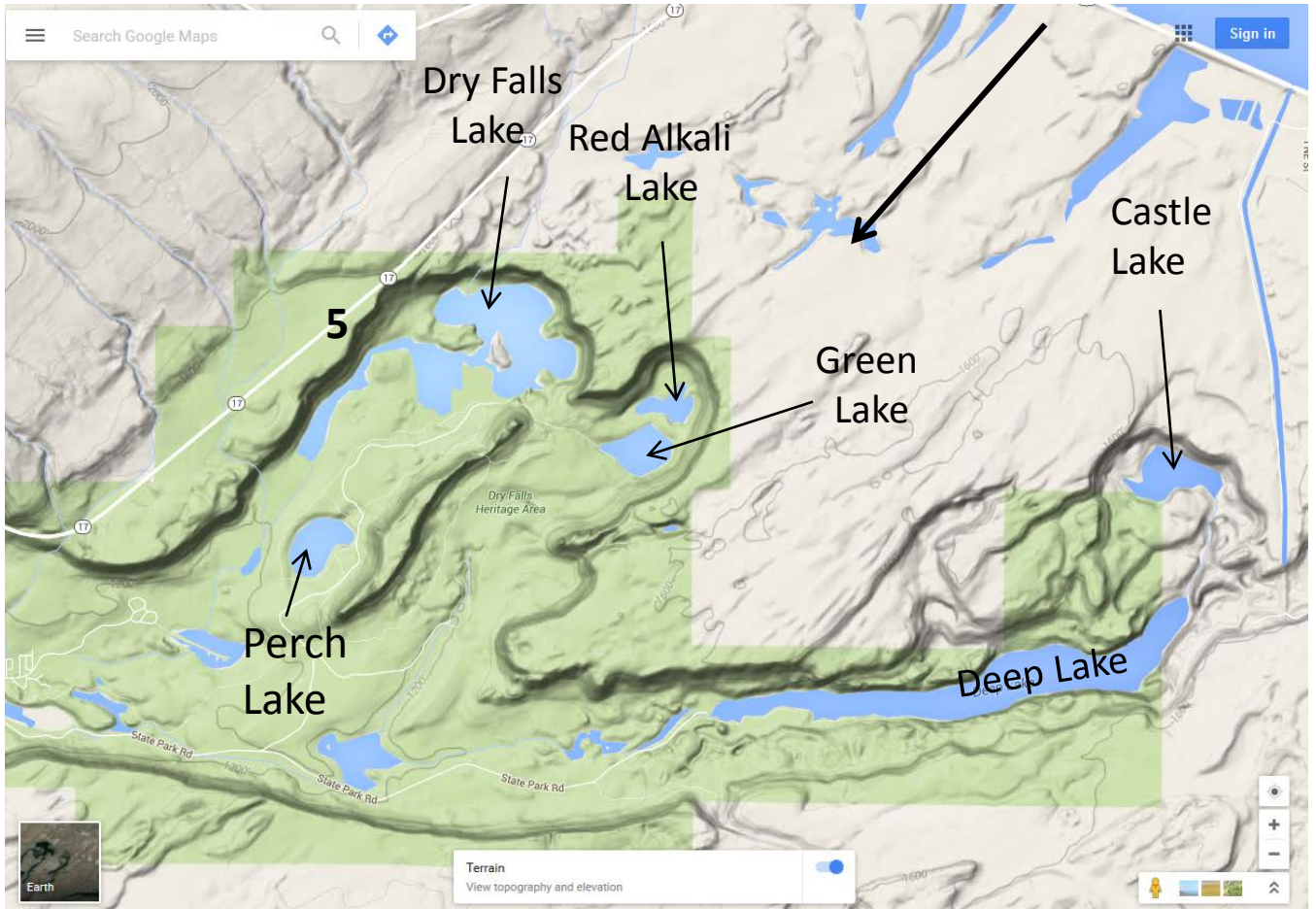


Figure 35. Map view of the Dry Falls cataract. Bold arrow indicates primary flood flow direction. Number indicates field trip stop. Source: Google Maps.

Pulling it all Together...

J Harlan Bretz (Figure 36), beginning in 1923, argued that the Channeled Scablands were the result of catastrophic flooding rather than uniform stream processes over a long period of time. He built his argument on careful, detailed field work over time. For more than 40 years, Bretz was ostracized by the mainstream geological community for such thinking. In time, and with more research in the area, he was vindicated.

The key pieces of evidence that led Bretz to this catastrophic flood origin conclusion were:

- giant bars
- giant current ripples
- hanging valleys on coulee walls
- anastomosing channels
- basin and butte topography
- giant potholes
- giant, dry cataracts
- backwater deposits (inc. upvalley foresets of silt, sand & gravel)
- loess scarps

Our field trip today explored seven of these pieces of evidence!



Figure 36. J Harlan Bretz. Source: Special Collections Research Center, University of Chicago Library

Selected References

- Anglin**, R. 1995. *Forgotten Trails: Historical Sources of the Columbia's Big Bend Country*. WSU Press. Pullman.
- Atwater**, B.F. 1986. Pleistocene glacial-lake deposits of the Sanpoil River Valley, Northeastern Washington. *U.S. Geological Survey Bulletin* 1661.
- Atwater**, B.F. 1987. Status of Glacial Lake Columbia during the last floods from Glacial Lake Missoula. *Quaternary Research* 27: 182-201.
- Baker**, V.R. 1973. Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington. *Geological Society of America Special Paper* 144. 79 p.
- Baker**, V.R. 1978a. Paleohydraulics and hydrodynamics of scabland floods. Pp 59-79 in V.R. Baker and D. Nummedal, eds., *The Channeled Scabland: A Guide to the Geomorphology of the Columbia Basin, Washington*. NASA, Washington, D.C.
- Baker**, V.R. 1978b. Large-scale erosional and depositional features of the Channeled Scablands. Pp 81-116 in V.R. Baker and D. Nummedal, eds., *The Channeled Scabland: A Guide to the Geomorphology of the Columbia Basin, Washington*. NASA, Washington, D.C.
- Baker**, V.R. 1987. Dry Falls of the Channeled Scabland, Washington. Pp. 369-372 in M.L. Hill, ed., *Centennial Field Guide Volume 1, Cordilleran Section of the Geological Society of America*.
- Bennett**, W.A.G. 1962. Saline lake deposits in Washington. *Washington Division of Mines and Geology Bulletin* 49.
- Bjornstad**, B. and E. Kiver. 2012. *On the Trail of the Ice Age Floods: The Northern Reaches: A Geological Field Guide to Northern Idaho and the Channeled Scabland*. Keokee Books. Sandpoint, ID.
- Bretz**, J H. 1928. The Channeled Scabland of Eastern Washington. *Geographical Review* 18: 446-477.
- Bretz**, J H. 1932. *The Grand Coulee*. American Geographical Society Special Publication 15.
- Bretz**, J H. 1959. Washington's Channeled Scabland. *Washington Division of Mines and Geology Bulletin* 45.
- Bretz**, J H. 1969. The Lake Missoula Floods and the Channeled Scabland. *Journal of Geology* 77: 505-543.
- Bretz**, J H., H.T.U. Smith, and G.E. Neff. 1956. Channeled Scabland of Washington: New Data and interpretations. *Bulletin of the Geological Society of America* 67: 957-1049.
- Campbell**, N.P. 1975. A geologic road log over Chinook, White Pass, and Ellensburg to Yakima highways. *Washington Division of Geology and Earth Resources Information Circular* 54.
- Edmondson**, W.T. 1992. Saline lakes in the lower Grand Coulee, Washington, USA. *International Journal of Salt Lake Research* 1 (2): 9-20.
- Fiege**, B. n.d. *The Story of Soap Lake*. Soap Lake Chamber of Commerce. Soap Lake, WA.
- Gulick**, C.W. 1990. Geologic map of the Moses Lake 1:100,000 quadrangle, Washington. *Washington Division of Geology and Earth Resources Open File Report* 90-1.
- Gulick**, C.W. and M.A. Korosec. 1990. Geologic map of the Banks Lake 1:100,000 quadrangle, Washington. *Washington Division of Geology and Earth Resources Open File Report* 90-6.

Selected References (continued)

- Kaler**, K.L. 1988. The Blue Lake rhinoceros. *Washington Geologic Newsletter* 16 (4): 3-8.
- Landye**, J.J. 1973. Environmental significance of Late Quaternary nonmarine mollusks from former Lake Bretz, Lower Grand Coulee, Washington. M.A. Thesis, Washington State University.
- Norman**, L.K. 1996. Prehistoric occupation of the Grand Coulee, an Inland, Lacustrine Environment. M.S. Thesis, Western Washington University.
- Reidel**, S.P. and N.P. Campbell . 1989. Structure of the Yakima Fold Belt, central Washington. Pp. 275-306 in N.L. Joseph, ed., *Geologic Handbook for Washington and Adjacent Areas. Washington Division of Geology and Earth Resources Information Circular 86.*
- Reidel**, S.P., V.G. Johnson, and F.A. Spane. 2002, Natural gas storage in basalt aquifers of the Columbia Basin, Pacific Northwest USA--A guide to site characterization: Richland, Washington, Pacific Northwest National Laboratory.
- Rice**, J.W. Jr. and K.S. Edgett. 1997. Catastrophic flood sediments in Chryse Basin, Mars, and Quincy Basin, Washington: Application of sandar facies model. *Journal of Geophysical Research* 102: 4185–200.
- Waite**, R.B., R.P. Denlinger and J.E. O’Conner. 2009. Many monstrous Missoula Floods down Channeled Scablan and Columbia Valley. Pp. 775-844 in J.E. O’Conner, R.J. Dorsey, and I.P. Madin, eds., *Volcanoes to Vineyards: Geologic Field Trips Through the Dynamic Landscape of the Pacific Northwest*, Geological Society of America Field Guide 15
- Washington**, N. 1956. The nomadic life of the Tsin-Cayuse as related by Billy Curley (Kul Kuloo) in the Fall of 1956 to Nat Washington, Jr. Unpublished typewritten manuscript. Ephrata, WA.