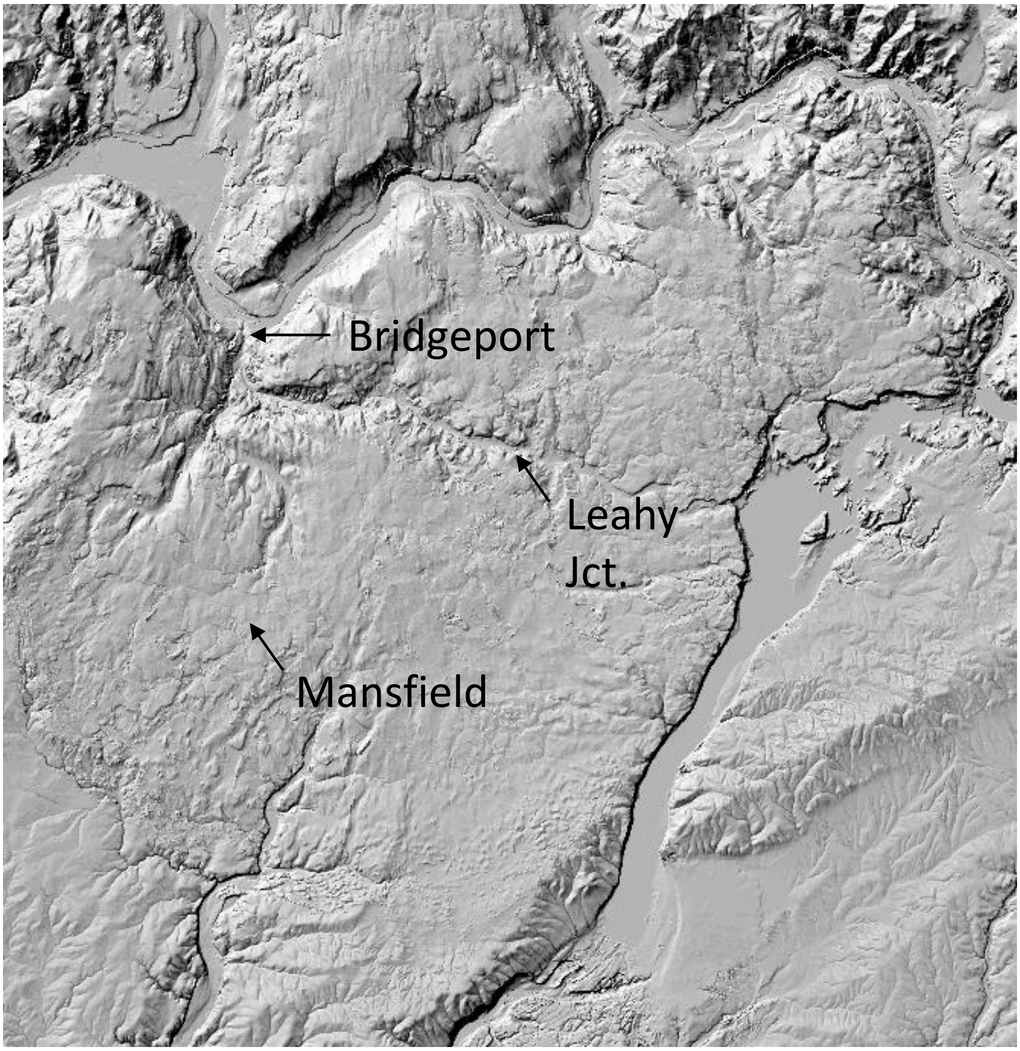
Ellensburg Chapter—Ice Age Floods Institute
Field Trips

Glacial Lake Foster on the Waterville Plateau



Field Trip Leader:

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12 June 2022

Introduction

The Cordilleran Icesheet shaped Central Washington’s Waterville Plateau through direct glacial action, glacial outwash, drainage rearrangement, and formation of ice marginal lakes. Our September 2019 IAFI field trip focused on direct glacial and glacial outwash evidence on the plateau. This field trip will focus on a large ice marginal lake, Glacial Lake Foster, that occupied much of the northern part of the Waterville Plateau. Our trip will begin near Leahy on the northeastern portion of the Waterville Plateau where we will examine Foster Coulee and a coarse-textured, large fan delta that formed where a meltwater stream flowed into Glacial Lake Foster. In the north central portion of the plateau, we will explore fine-textured, deep water deposits in the Chalk Hills. Further west, we will look at recent changes in channel incision, and at the effects of beaver dams on sediment deposition. Our trip will end at a gully that was recently eroded into basin floor sediments in Smith Draw. Sediment layers exposed here include glacial outwash or till, Glacier Peak tephra, Glacial Lake Foster sediments, Mt. Mazama tephra, shallow lake/wetland sediments, and loess. A variety of dates indicate that ~15,000 years of geologic history is exposed there. Work by a CWU graduate student plus conversations with landowners indicates that gully incision occurred here prior to the mid-century, likely as a result of weather events and land use changes.

Tentative Schedule

10:30 am	Arrive Stop 1—Foster Coulee (South of Leahy)
11:15	Depart
11:30	Arrive Stop 2—WADOT Gravel Pit (East of Leahy)
12:30 pm	Depart
1:00	Arrive Stop 3—Chalk Hills
2:00	Depart
2:30	Arrive Stop 4—West Foster Creek
3:15	Depart
3:30	Arrive Stop 5—Upper Smith Draw
4:30	Depart

Our Field Stops

Figure 1. The approximate locations of field trip 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

Preliminaries

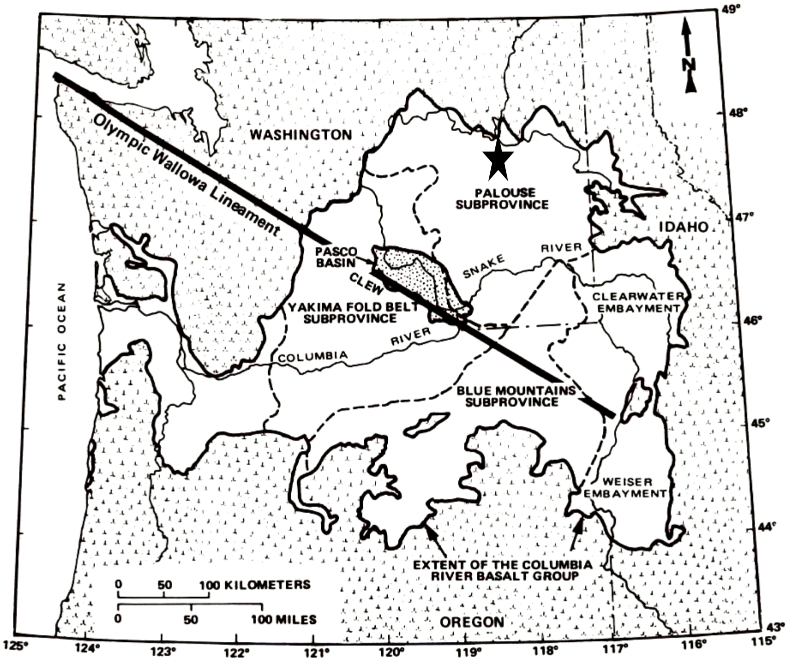
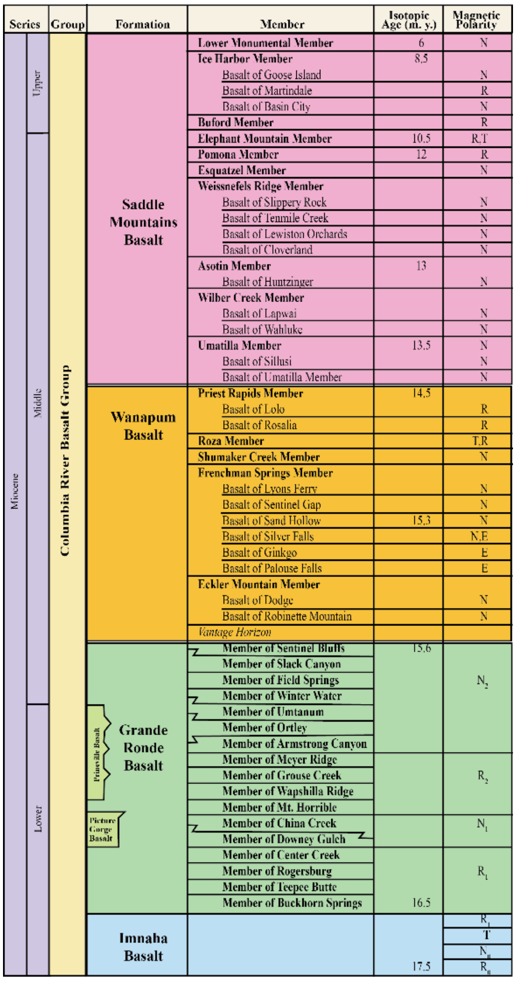


Figure 2. The Columbia Plateau and the areal extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Star indicates approximate location of the Foster Creek Watershed. Source: (Reidel & Campbell, 1989, p. 281).



Series		Group	Formation	Member	Isotopic Age (m. y.)	Magnetic Polarity
Miocene	Upper	Columbia River Basalt Group	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
	Middle			**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	N
				Basalt of Sillusi		N
				Basalt of Umatilla Member		N
			Wanapum Basalt	**Priest Rapids Member**	14.5	
				Basalt of Lolo		R
				Basalt of Rosalia		R
				Roza Member		T,R
				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		N,E
				Basalt of Ginkgo		E
				Basalt of Palouse Falls		E
				Eckler Mountain Member		
				Basalt of Dodge		N
				Basalt of Robinette Mountain		N
				Vantage Horizon		
			Grande Ronde Basalt	**Member of Sentinel Bluffs**	15.6	N_2
				Member of Slack Canyon		
				Member of Field Springs		
				Member of Winter Water		
	Lower		Prineville Basalt	**Member of Umtanum**		
				Member of Ortley		
				Member of Armstrong Canyon		
				Member of Meyer Ridge		R_2
				Member of Grouse Creek		
				Member of Wapshilla Ridge		
				Member of Mt. Horrible		
			Picture Gorge Basalt	**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			R_1
						T
						N_0
					17.5	R_0

Nomenclature of the Columbia River Basalt Group (from Reidel and others, 2002)

Figure 3. Stratigraphy of the Columbia River Basalt Group. Recent research indicates that the Vantage horizon formed at 16.1-16.0 mya, and that an ash bed in the Priest Rapids Member formed at about 15.9 mya. Source: https://www.usgs.gov/centers/oregon-water-science-center/science/columbia-river-basalt-stratigraphy-pacific-northwest#multimedia; Andy Miner, written communication, November 3, 2021.

Preliminaries

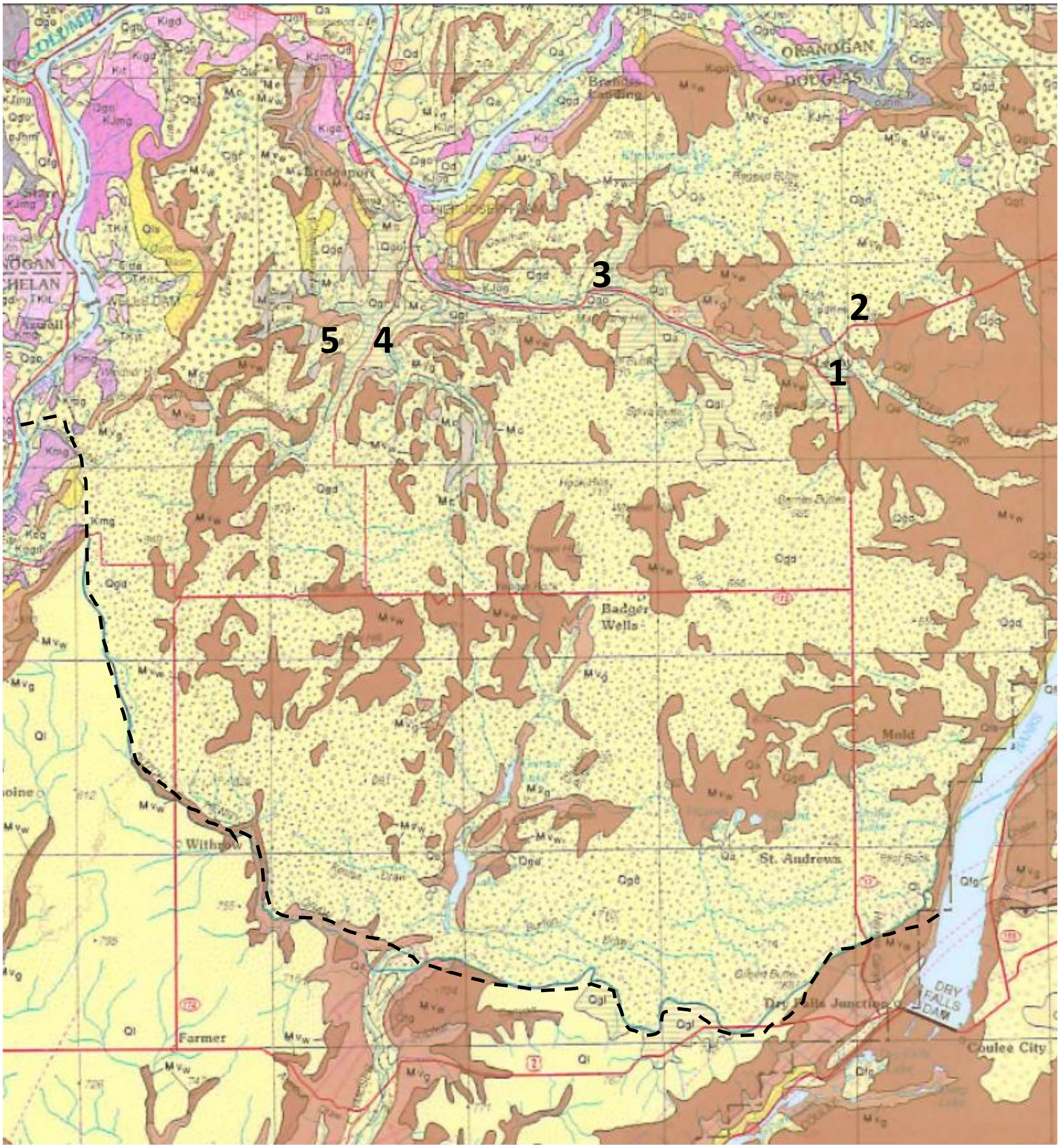
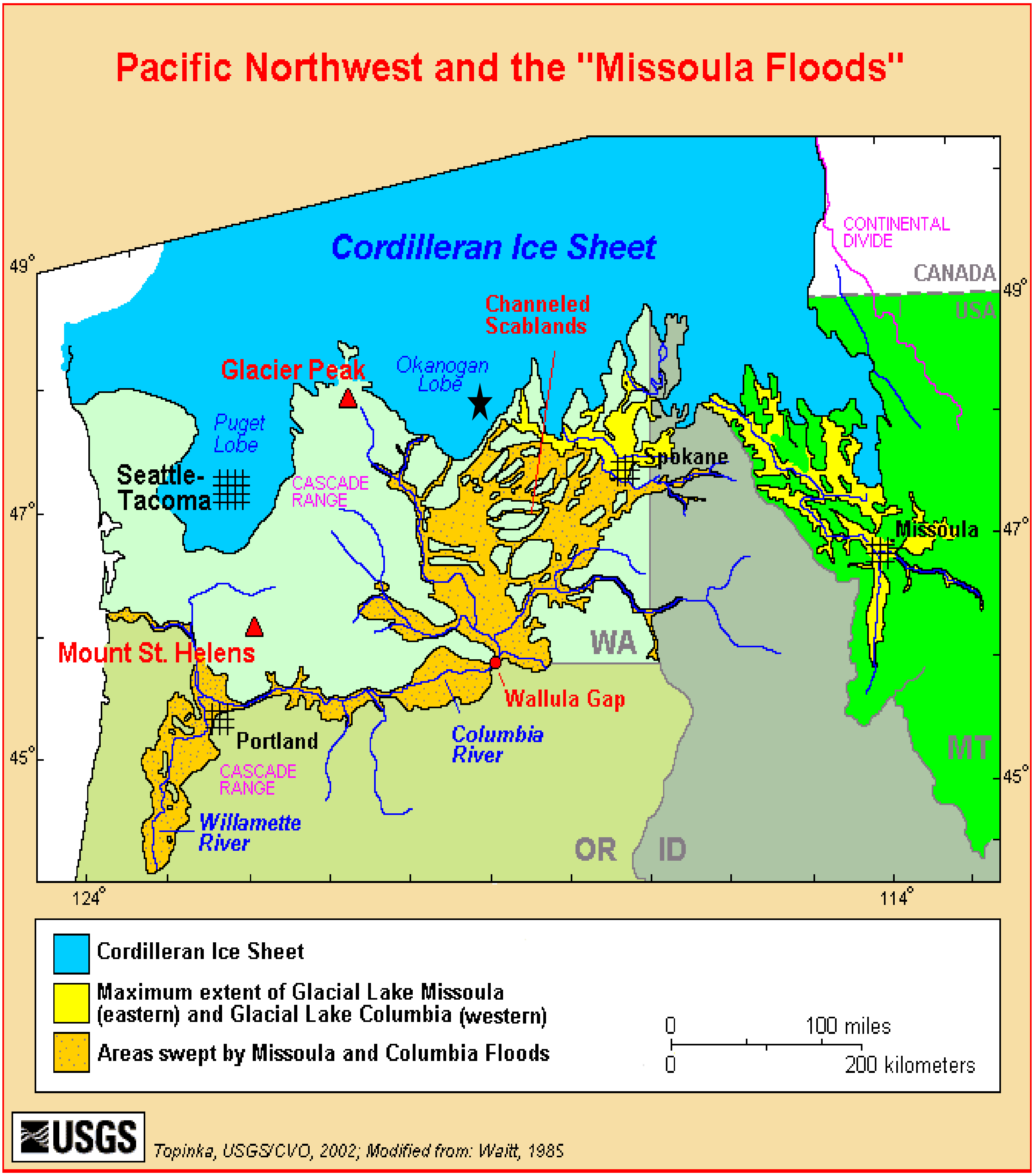


Figure 4. Geologic map of a portion of the Waterville Plateau covered by our field trip. Bold numbers indicate approximate locations of field trip stops. Dashed line indicates approximate position of Withrow moraine. Stippled yellow area north of dashed line is glacial "drift" (i.e., various glacial deposits). Solid yellow area south of stippled area is loess. Brown is Columbia River Basalt. Source: Stoffel & others (1991) + see Gulick & Korosec (1990).

Preliminaries



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

Figure 5. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Star indicates approximate location of the Foster Creek Watershed. Source: Cascade Volcano Observatory website.

Preliminaries

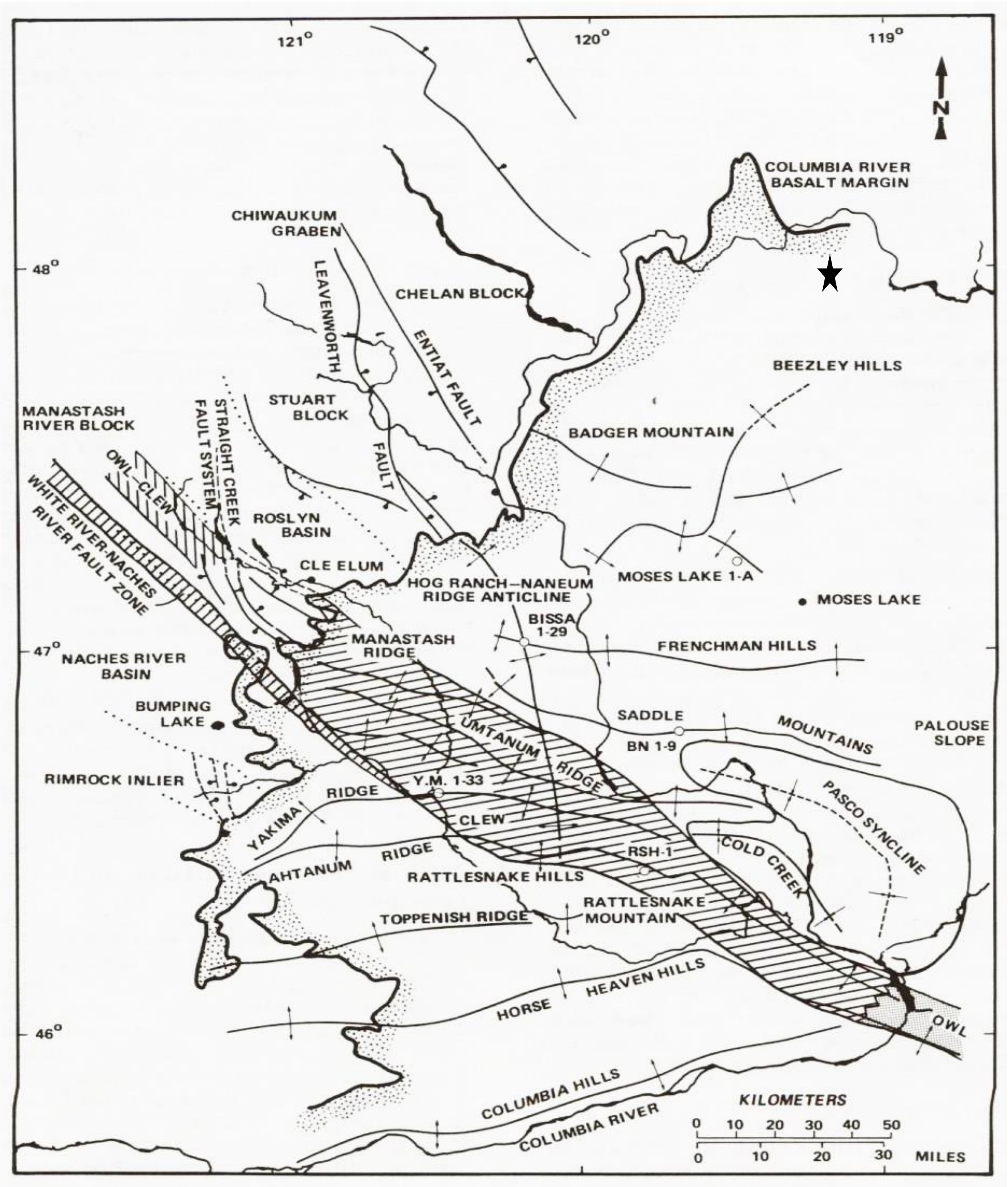


Figure 6. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Star indicates approximate location of the Foster Creek Watershed. Source: Reidel & Campbell (1989, p. 281).

Preliminaries

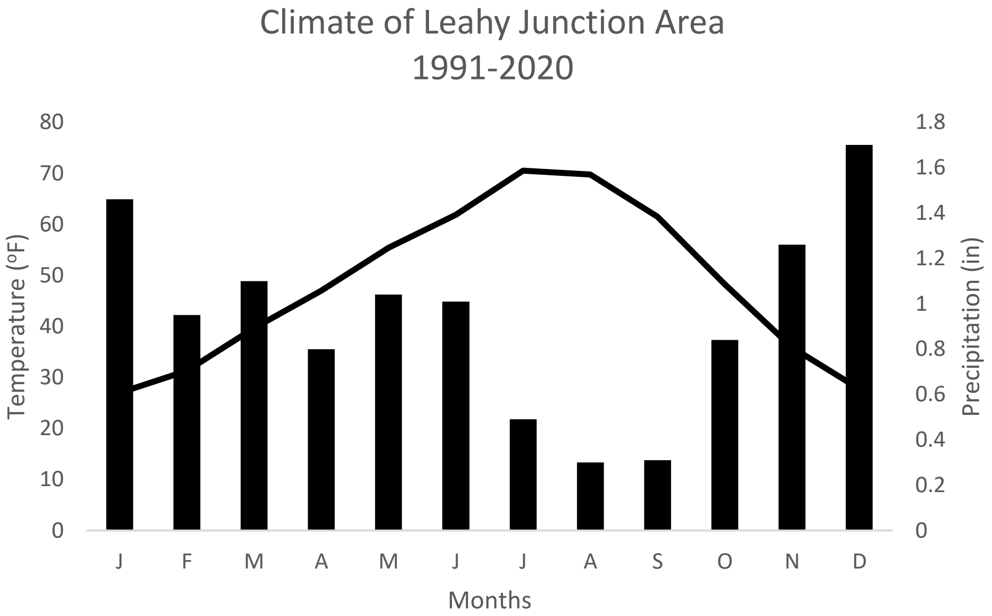


Figure 7. Modelled temperature (line graph) and precipitation (bars) for the Leahy Junction area, Waterville Plateau over the 1991-2020 climate normal. From PRISM Climate Group website (https://www.prism.oregonstate.edu/).

Stop 1—Foster Coulee (South of Leahy)

Getting our bearings: We are located near the northeastern margin of the Waterville Plateau (**Figure 1**). Specifically, we are at a small gravel pit in Foster Coulee on road 20 NE about a mile south of Leahy Junction. GPS coordinates: 47.911562° N, 119.378518° W.

What is the physical geography of Waterville Plateau? The Waterville Plateau is an elevated area defined by Banks Lake on the east, the Columbia River on the north and west, and the Quincy Basin to the south. The bedrock consists of Cretaceous to pre-Jurassic metamorphic rocks overlain by Miocene Columbia River Basalts (**Figures 2, 3 & 4**). The limit of the last glaciation is about 16 miles south of here. Glacial drift covers much of the plateau north of US 2. We are also located in an area that was shaped by Missoula Floods (**Figure 5**). Our focus area today, the northern Waterville Plateau, is north of the Yakima Fold and Thrust Belt (**Figure 6**). The

Stop 1—Foster Coulee (South of Leahy)

What is the physical geography of Waterville Plateau? (continued)… climate here is semi-arid with an average of about 11 inches of precipitation/year (**Figure 7**). Vegetation here is dominated by shrubs and grasses (i.e., shrub-steppe). Soils reflect the grasses (mollisols) and relative aridity (aridisols). Surface water consists of numerous ephemeral to perennial ponds and streams. East Fork Foster Creek (just north of our stop) is one such perennial stream. The presence of water and the valley topography likely played a role in the Native American, fur trader, and cattle drive trails that followed the East and West Forks of Foster Creek (Anglin, 1995).

What is Foster Coulee? Foster Coulee extends from the western edge of the Upper Grand Coulee westward to about Leahy Junction. In Washington, the term *coulee* is used to denote a steep sided, relatively flat floored valley eroded into basalt bedrock by floodwaters. Previous researchers have noted a fluvial (i.e., flowing water) origin for Foster Coulee (e.g., Hanson, 1970). It is one of at least three enigmatic channel systems on the Waterville Plateau. Foster Coulee, like Horse Coulee, is unique in that it ends abruptly on the west wall of the Upper Grand Coulee (**Figure 8**). Today, East Fork Foster Creek originates in Foster Coulee and flows west to ultimately join the Columbia River near Bridgeport. Foster Coulee may follow a channel that originated east of Steamboat Rock in the Upper Grand Coulee and flowed west (Bjornstad and Kiver, 2012). Such an origin for East Foster Coulee would need to have occurred before the excavation of the Upper Grand Coulee. Later, Foster and Horse Lake Coulees formed as “typical scabland surfaces” by the spilling of Glacial Lake Columbia (including Columbia River and Missoula Floods) waters over a divide but still prior to the formation of the Upper Grand Coulee and the maximum advance of the Okanogan Lobe of the Cordilleran Icesheet on the Waterville Plateau (Hanson, 1970) (**Figure 9)**. Later still, during the recession of the Okanogan Lobe, meltwater in a short segment of East Foster Coulee flowed east into the Upper Grand Coulee depositing a small fan delta (Hanson, 1970). The same occurred in Horse Lake Coulee.

What is the evidence of glaciation here and who first figured this out? We are standing on and are surrounded by glaciated terrain. In fact, the hill here with the gravel pit is a kame that was created by a sediment-laden meltwater stream depositing those sediments in a void in the Okanogan Lobe (**Figure 5**). The early government and university geologists and geographers who explored the Waterville Plateau included I.C. Russell (1893), Roland Salisbury (1901), George Garrey (1902), J Harlan Bretz (1923, 1928), Otis Freeman (1932), Aaron Waters (1933), and Richard Foster Flint (1935). They used the presence of erratics (including “haystack rocks”, “hummocky” terrain that included hills and basins (that held lakes in the wet months), linear features (e.g., grooves on

Stop 1—Foster Coulee (South of Leahy)

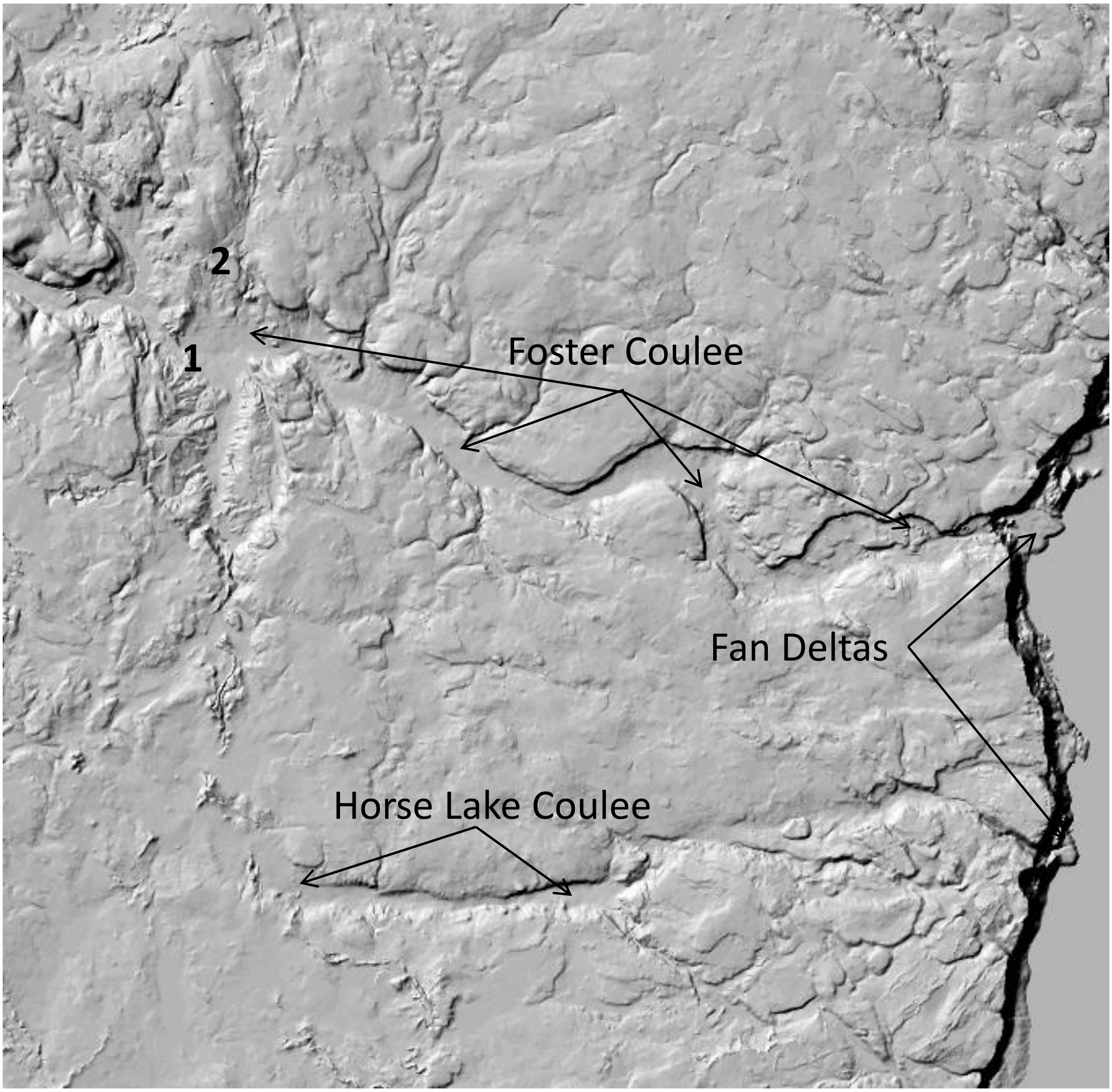


Figure 8. Shaded relief view of Foster Coulee in relation to Horse Lake Coulee. Stops 1 & 2 shown with numbers. Source: Caltopo.com.

Stop 1—Foster Coulee (South of Leahy)

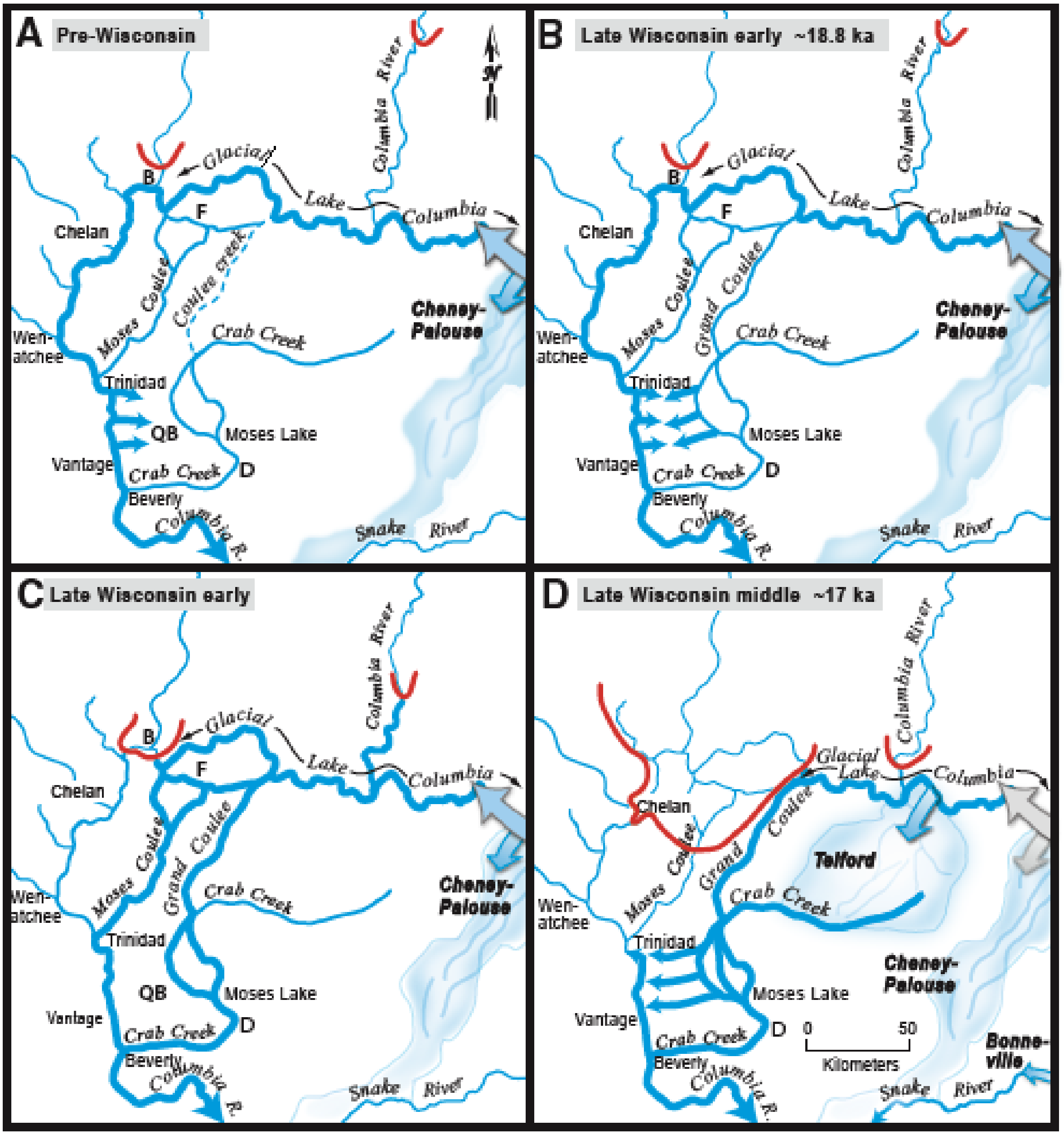


Figure 9. Hypothetical, sequential steps affecting floodwater routing on the Columbia Plateau including Foster Coulee (F). From Waitt (2021).

Stop 1—Foster Coulee (South of Leahy)

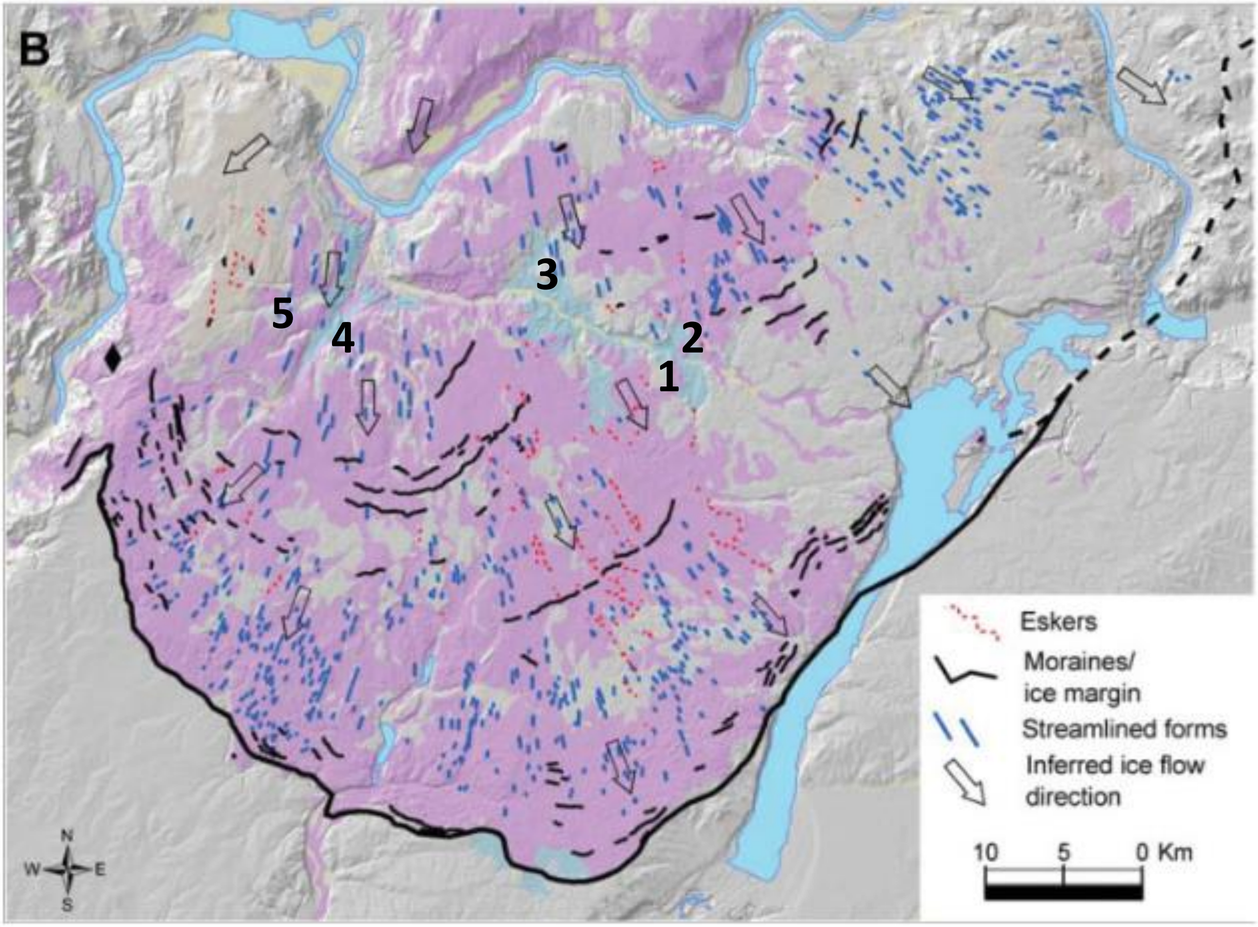


Figure 10. Glacial map of the Waterville Plateau. Approximate extent of Glacial Lake Foster shown in light blue (Kovanen and Slaymaker, ????). Approximate locations of field trip stops shown in bold numbers.

What is the evidence of glaciation here and who first figured this out?... bedrock and lines of boulders), and sinuous deposits ("eskers") as indicators of past icesheet glaciation (**Figure 10**).
What was the origin of the ice sheet here? While the Waterville Plateau can be cold and snowy in the winter months, and was colder and perhaps snowier in the Late Pleistocene Ice Ages, it was not sufficiently so to create glaciers <u>here</u>. The Okanogan Lobe that shaped this landscape formed in the colder and snowier Coast Mountains and Rocky Mountains of British Columbia, then moved south to here. As it grew, it flowed away from its mountain sources into adjacent valleys. In addition to the Okanogan Lobe, four other lobes existed--Puget, Columbia River, Purcell Trench, and Flathead.

Stop 1—Foster Coulee (South of Leahy)

Is glaciation associated with lakes? If you drove to Stop 1 from the south or from the east, you encountered many ponds and lakes. An aerial perspective via Google Earth Pro will show how much of the glaciated area is dotted with lakes and ponds. Many of these lakes are kettles, formed in depressions in glacial till. Some are scabland lakes formed in depressions eroded in basalts by floodwaters associated with a diverted flow from Glacial Lake Columbia, the Columbia River, and Missoula Floods.

Pleistocene lake evidence: We are located within the area once covered by Glacial Lake Foster. The first mention of this lake was by I.C. Russell in 1893 who noted the "fine white silt and clay" deposits in the valley floors. He noted that these deposits extended 125 feet above the valley floors. Hanson (1970) attributed this lake to damming by the retreating Okanogan Lobe as it receded west. This recession and the associated meltwater formed a long-lived lake whose surface was at about 2100 feet elevation. Further, he noted that a lake at ~2100 feet elevation would have drained into the Upper Grand Coulee. CWU Geography undergraduate Knud Martin (2001) mapped different lake levels based on on the receding ice.

Paleolakes may leave a variety of evidence depending on their areas, depths, longevity, and the surrounding environment. Unlike long-lasting paleolakes in places like the Great Basin of the Western U.S., this Pleistocene lake did not leave obvious shorelines. This likely reflects the difficult-to-erode basalts, the relatively short time the lake was present, or both. Instead, the evidence for this lake here is primarily its sediment. Glacial lake sediments are often light colored and are deposited in layers. I assume that a thick sediment fill was deposited throughout the basin by Glacial Lake Foster. Subsequent erosion by water and wind has removed all but scattered remnants of these sediments along the steep, unstable walls of Foster Coulee. At its highest levels, Glacial Lake Foster stood about 180 feet over our heads at this site.

Foster Coulee to WADOT Gravel Pit

From here: We will return to WA 17 and head north to Leahy Junction. At the junction, turn right (east) and proceed about 1.25 miles to the large WADOT gravel pit on the right (south) side of WA 174. We will open the gate and drive into the south end of the gravel pit, and park. Please do not enter this pit without the permission of WADOT.

Foster Coulee to WADOT Gravel Pit

Change in geology. In the short ~2 mile drive from Stop 1 to Stop 2 there are several items of interest. First, note the bedded, white lake sediments in several roadcuts on WA 174. Second note that, in the westernmost road cuts, lake sediments drape over Columbia River basalts. As we get closer to Stop 2, the lake sediments drape over the underling metamorphic rocks. We call geologic contacts between very different aged geologic units unconformities.

Stop 2—WADOT Gravel Pit (East of Leahy)

Getting our bearings: We are parked near the southern end of the WADOT gravel pit (**Figure 11**). GPS coordinates for the site are: 47.925131° N and 119.369629° W.

What is the big picture here? From here, you have a good view to what would have been an embayment to the south where floodwaters in Horse Lake Coulee would have spilled into Foster Coulee (**Figure 12**). Note the prominent ~horizontal bench on the eastern shore of this embayment. I interpret this as a remnant of the lake silts that once formed a ~continuous cover in the basin. A horizontal line at our approximate elevation is also present on the thinly mantled basalt wall to our south. This may be an erosional shoreline formed by wave action that removed the lake sediment and glacial deposits.

What is this landform? Hanson (1970) first mentioned the presence of deltas near the western end of Foster Coulee associated with Glacial Lake Foster. This was likely one of the deltas he saw (**Figure 11**). Deltas (or fan deltas) in the area indicate that there must have been ample meltwater associated with the retreating Okanogan Lobe. That meltwater would have been loaded with sediments. The gravels and sands dropped out when the meltwater stream encountered the ~still waters of Glacial Lake Foster. With the shifting position of the stream or streams (i.e., distributaries) entering the lake, the deposits would take on a roughly triangular shape when viewed from above (**Figure 11**). Such a scenario would have resulted in the development of a fan delta over time. Rapid deposition of these sediments into a lake rather than a dry basin is indicated by the abrupt outer edges of the features. I interpret the top of this fan delta (at ~2135 feet) to represent the top (or nearly so) of the Glacial Lake Foster. Most of the fan deltas in the eastern portion of the Foster Creek basin have surface elevations within 35 feet of this. Two other fan deltas are readily seen on **Figure 13**.

Stop 2—WADOT Gravel Pit (East of Leahy)

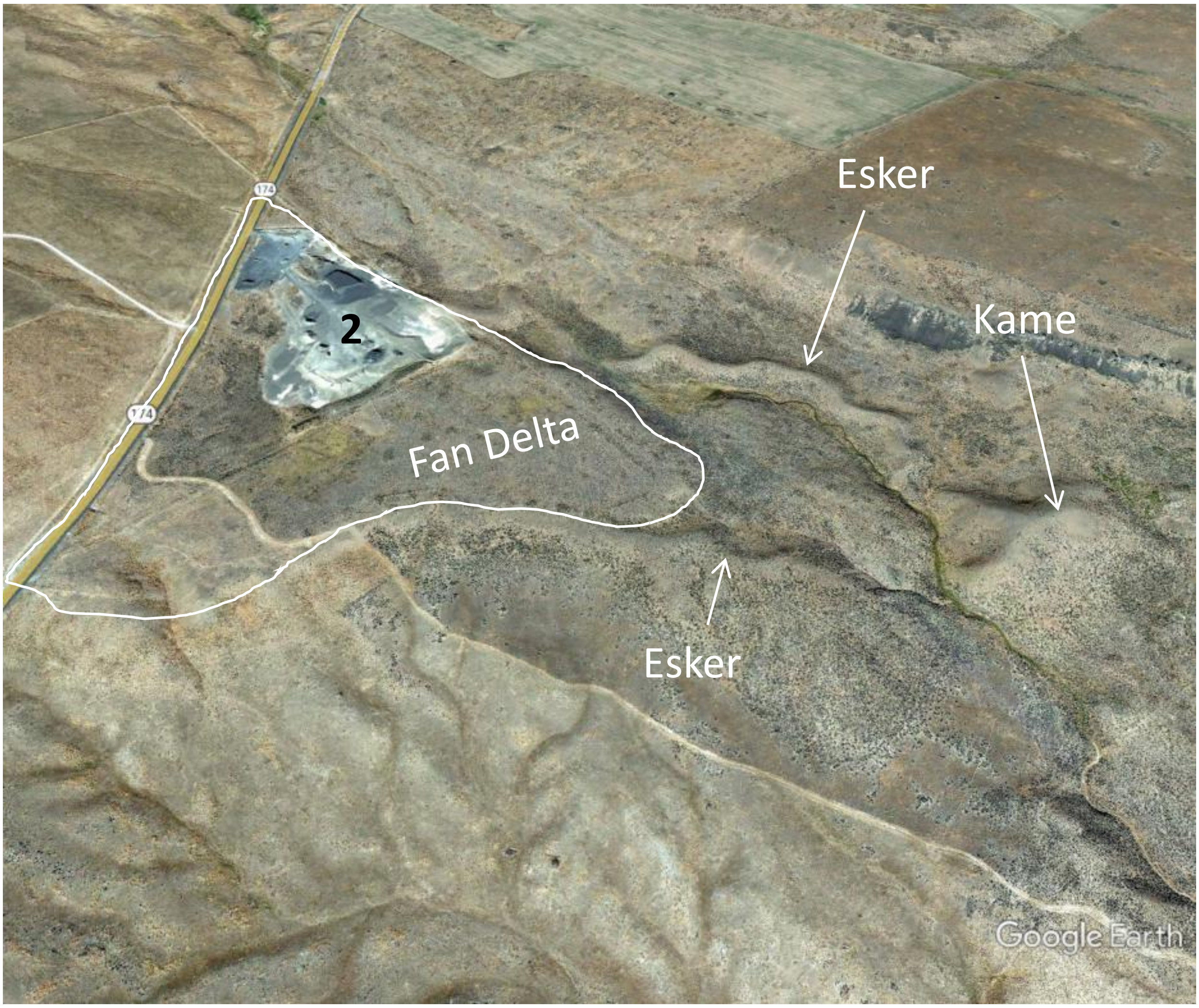


Figure 11. Oblique aerial view of fan delta at Stop 2. Approximate outline of fan delta shown in white. Bold number indicates approximate parking area. View to the northeast. Note prominent eskers to the east and south, and the kame on the south. Source: Google Earth Pro, 09/13/2011.

How old is the fan delta? The short answer is "I don't know"! The long answer is two-fold: 1**)** three attempts at dating sediments here via OSL methods have yielded the following ages—2970 +/- 290, 19,930 +/- 1270, and 25,595 +/- 880 calendar years before present (cal yr BP). A sample of Glacial Lake Foster sediments in a gravel pit at 2137 feet elevation about 4 miles south of Leahy Junction had an OSL date of 15,730 +/-1340 calendar years before present. Based on other dates collected from the basin, I think this is a more reasonable age for the fan delta.

Stop 2—WADOT Gravel Pit (East of Leahy)

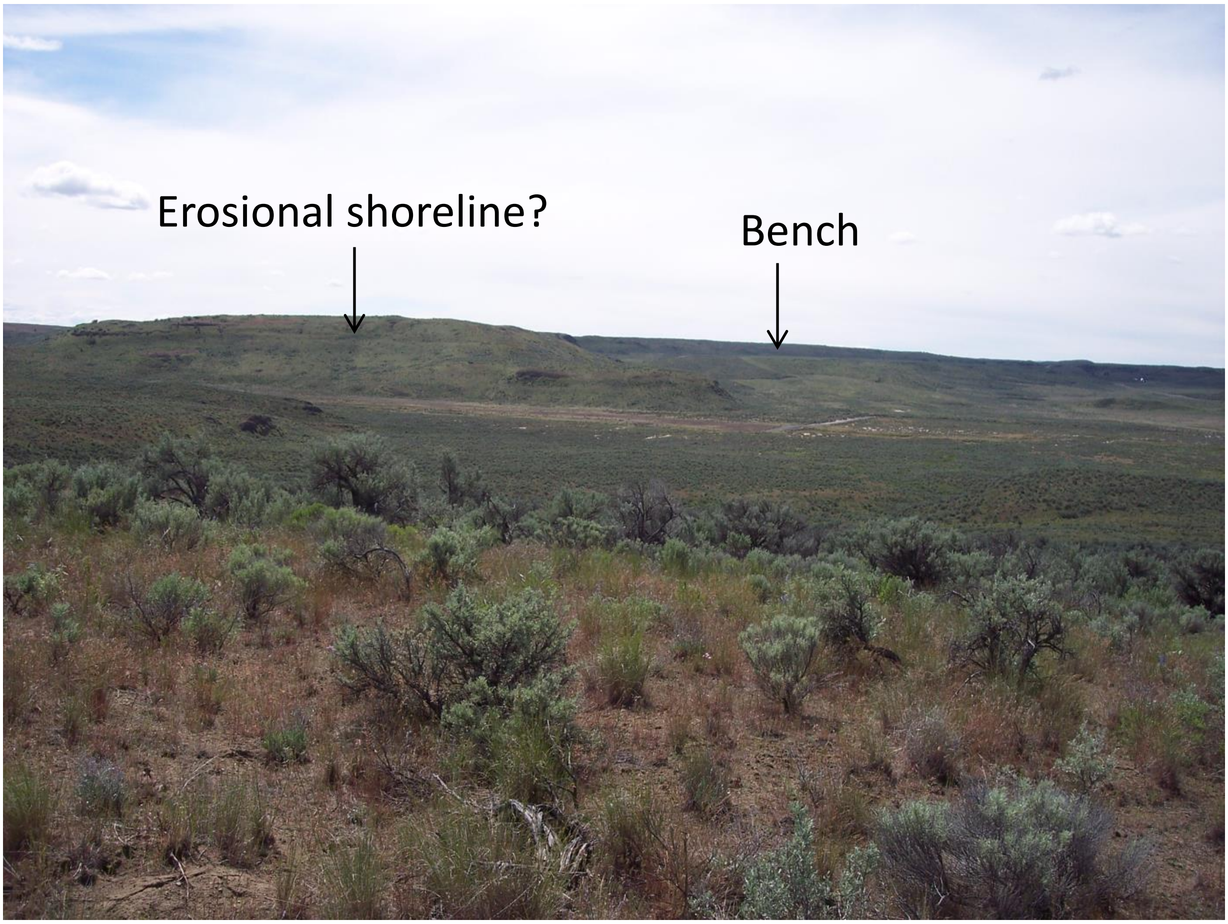


Figure 12. View south of Foster Coulee (near) and embayment (far and right). Note bench on the eastern side of the embayment the top of which is slightly lower than the DOT fan delta (~2070 feet vs. 2135 according to Google Earth Pro). This bench represent fine-textured lake sediments like those at Stop 3.

What are those squiggely things? Figure 11 shows that the relationship between the fan delta, two eskers, and a kame. I interpret the easternmost esker as being a pre-Glacial Lake Foster feature deposited by meltwater channels beneath the Okanogan Lobe. I base this on the vertical relationships between the fan delta and the easternmost esker which appears to be overlain by the fan delta at its northern extent. I am less clear on the age relationships between the fan delta and the southern esker and kame. Given that I have seen no other evidence in the basin of glacial landforms overlying (therefore post-dating) lake features, I tentatively assign the eskers and kame here to be predate Glacial Lake Foster.

Stop 2—WADOT Gravel Pit (East of Leahy)

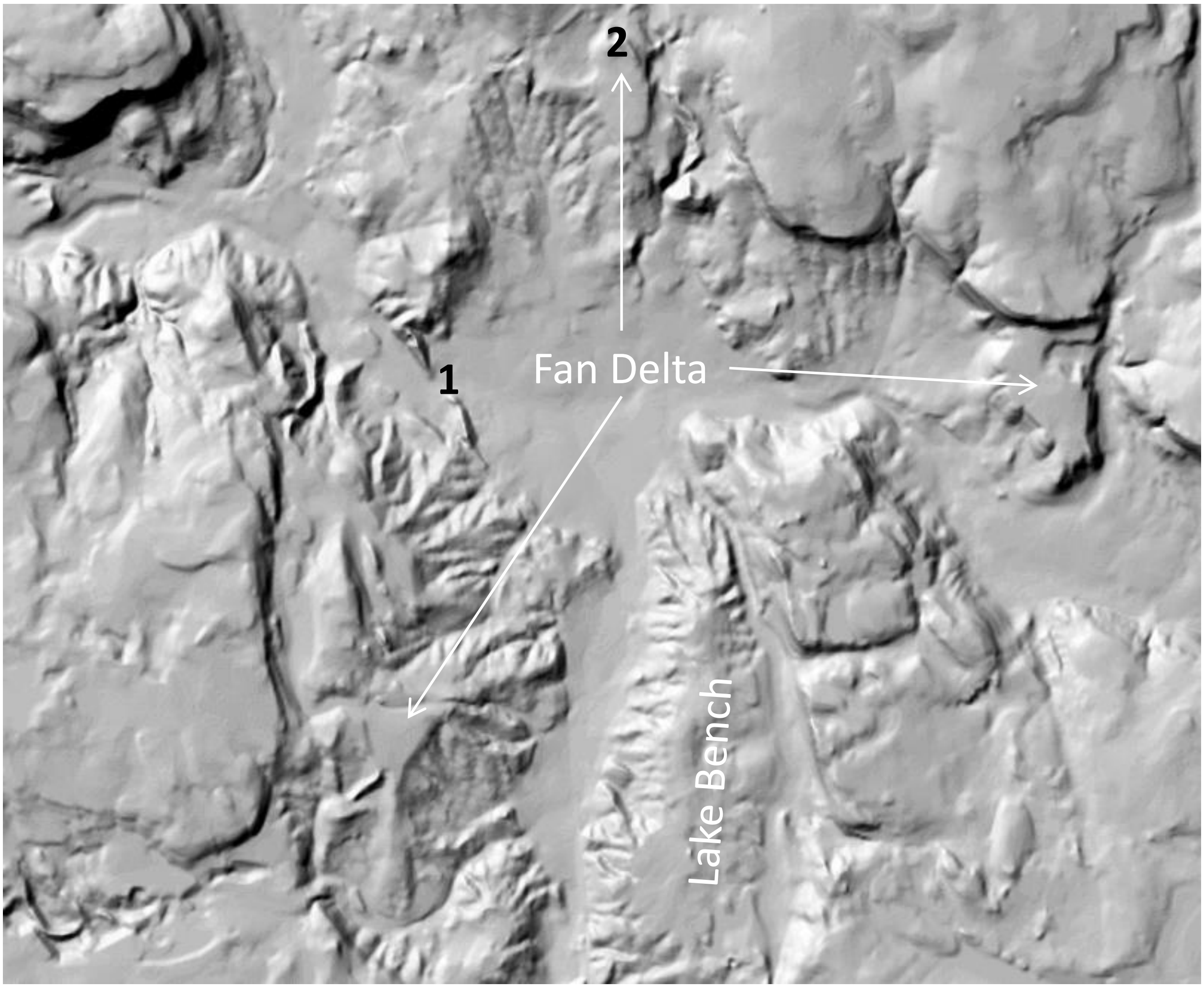


Figure 13. Shaded relief image of vicinity of Stops 1 & 2 (see bold numbers on image). Note the prominent fan deltas, and the bench is the southern embayment. Source: Caltopo.com.

East of Leahy to Chalk Hills

From here: From the DOT gravel pit, head west on WA 174 until it joins with WA 17 at Leahy. Continue west on WA 17 down East Foster Creek about 6.5 miles to its junction with Chalk Hills Road NE. Turn right (north) onto Chalk Hills Road NE (i.e., Road K NE) and drive north about 0.25 mile. Turn right (east) on Road 24 NE and park along side this road. The property on the north and south sides of the road here are privately owned. You will need to obtain permission to access this land if you return.

East of Leahy to Chalk Hills

What is that hummocky terrain? Bedded basalts are prone to landslides, especially when the bedding planes are tilted. A landslide is present on the nose of the basalts just north of Leahy Junction. It extended out to the present day junction, and may be the reason the junction is where it is. Watch for similar features as we descend the East Fork Foster Creek.

What is the relationship between the Okanogan Lobe and Glacial Lake Foster? Just west of Leahy Junction a roadcut reveals glacial lake sediments atop glaciofluvial sediments. The glaciofluvial sediments are likely in a kame deposited beneath a stagnating Okanogan Lobe. This supports the relative ages discussed at Stop 2—i.e., Glacial Lake Foster formed after the Okanogan Lobe retreated.

Where did the basalts go? The basalt walls lining the route are initially well-exposed but become increasingly obscured by glacial till, as well as glaciofluvial and glacial lake sediments as we descend to the west.

East Fork Foster Creek. This creek forms in Foster Coulee upstream of Stop 1. It is but one of a handful of perennial streams on the semi-arid Waterville Plateau. West of Leahy Junction ranchers have long taken advantage of the wet meadows created by this perennial flow. Beaver dams have also played a role in shaping these wet meadows. Watch for large beaver dams and associated large ponds/wetlands as we descend to the west.

Glacial lake sediments. Westward, we increasingly see glacial lake sediments. Sometimes they subtly mantle the landscape. In others, they are very prominent. As we near Stop 3, the lake sediments take on the forms of hills. These are the Chalk Hills and they are the foci of Stop 3.

Stop 3: Chalk Hills

Getting our bearings: We are parked near two of the Chalk Hills (**Figure 14**). The GPS coordinates are: 47.956266° N, 119.512020° W.

What are these white sediments? Glacial Lake Foster was a deep lake in the central and western parts of the Foster Creek Basin. Here, ~midway down the East Fork Foster Creek, Glacial Lake Foster was approximately 380 ft deep (2127 feet at top of fan delta to the north of us to 1746 feet at a bench mark on WA 17). Deep lakes are known for the deposition of light colored, fine textured, and bedded (i.e., layered) sediments. Further, glacial lakes are known for generating varves which are couplets of light colored, coarser sediment deposited in summer and darker (more organic rich

Stop 3: Chalk Hills

Figure 14. Vertical aerial view of the Chalk Hills. North is toward the top of the image. Bold 3 indicates approximate location of Stop 3.

What are these white sediments?: (continued)… sediment deposits under ice in winter). We see all of those characteristics here (**Figure 15**). If we assume that the prominent bench (elevation ~1880 feet) on the valley side to the south represents the bottom of the lake, ~135 ft of lake sediments are present here (**Figure 16**). This thick stack of sediments suggests that the inflow to the lake was very sediment laden and that deposition occurred over a significant time period. I have not found any molluscs or clams in the deep lake sediments here suggesting that water conditions were too turbid and/or too cold for benthic

Stop 3: Chalk Hills

What are these white sediments? (continued)… organisms. There appear to be sufficient clays in these sediments that some swelling occurs when they are wet, and contraction cracking occurs when they are dry (**Figure 17**).

What are the hills? The Chalk Hills are remnants of a once continuous cover of fine-textured lake sediments that extended up to at least 1880 feet elevation (**Figure 16**). Following the draining of the lake, the fill was dissected by small channels (i.e., rills) that became larger channels (i.e., gullies or arroyos) over time. The eroded sediments were flushed downstream and likely into the Columbia River near present-day Bridgeport. The hills that remain are examples of badland topography, such as is found in places like Badlands National Park. It just occurs here on a much less extensive scale. Shrub-steppe vegetation does not offer much protection for the fine-textured sediments from direct precipitation and snowmelt. This water erosion continues as evidenced by the recent rills on Chalk Hills slopes (**Figure 18**). Water and wind erosion was probably the reason that lands in the Chalk Hills are no longer farmed (**Figure 19**). According to Web Soil Survey, the soils of the Chalk Hills are silt loams or silty clay loams that have severe to very severe limitations because of erosion.

Why are stones present in the white sediments? Proglacial lakes often have icebergs floating on them and those icebergs may be mantled by boulders as well as smaller sediments. Glacial Lake Foster appears to have had ample debris-covered icebergs based on the amount of rock debris found around the remnant hills (**Figure 20**). Basalts are the dominant dropstone here reflecting nearby sources; however, one may also encounter intrusive igneous rocks such as granite, and metamorphic rocks such as gneiss and quartzite.

In addition to the dropstones, calcareous concretions are also abundant around the bases of individual hills (**Figure 20**). These concretions form in various shapes from elongate to circular but are generally less than 0.25 inch thick. In glacial lake sediments elsewhere, they are thought to have formed as a result of calcite precipitation in the voids of host sediments. Their thickness is often dictated by thinly bedded lake sediments. Over time, the concretions harden to become rocks. (Wu and Others, 2021).

Stop 3—Chalk Hills

Figure 15. Bedded nature of Glacial Lake Foster sediments in the Chalk Hills. Note the alternating light and dark tones of the sediment layers. I interpret this as indicating annual deposition forming varve couplets. Author photo, May 2022.

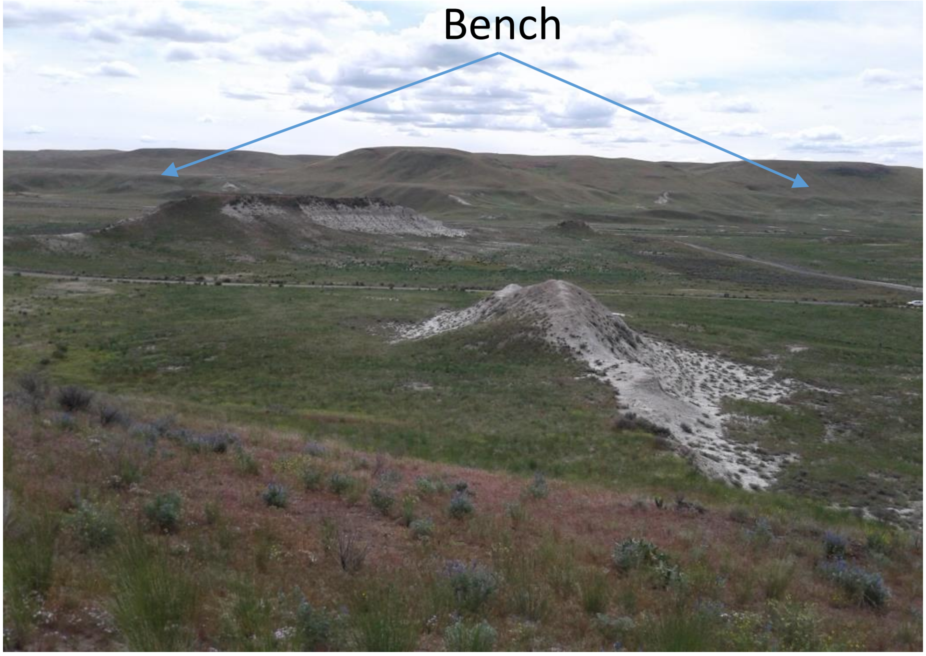


Figure 16. The Chalk Hills, view to the south. Note the bench on the valley wall to the south. I interpret this to represent the former level of the fine-textured lake sediment fill in the area.. Author photo, May 2022.

Stop 3—Chalk Hills

Figure 17. Mud cracks in the Chalk Hills lake sediments. Author photo, May 2022.

Figure 18. Rills formed on the slopes of one of the Chalk Hills. Author photo, November 2015.

Stop 3—Chalk Hills

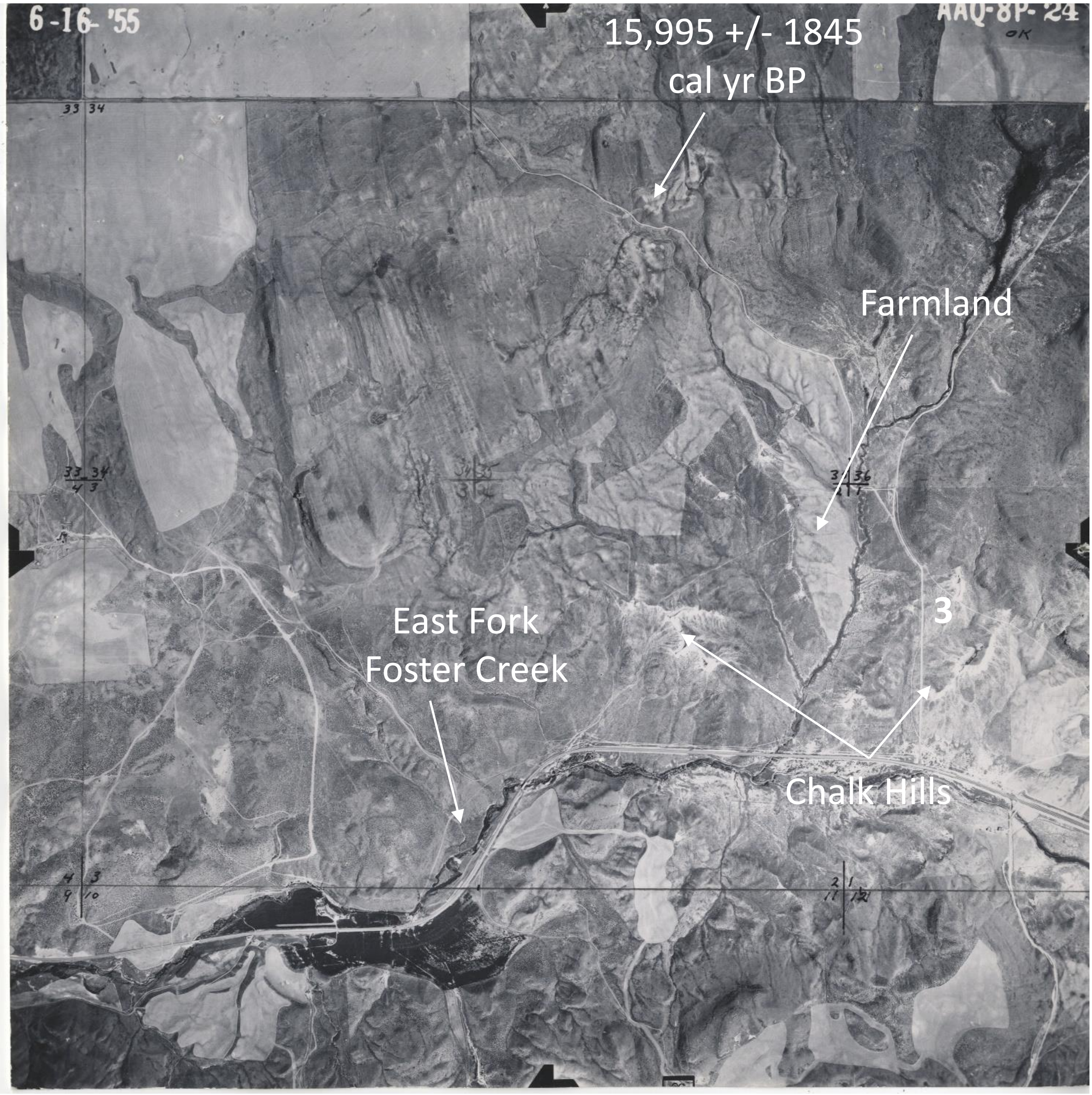


Figure 19. Chalk Hills and vicinity as of 1955. The bare hills show up as bright white. Patches of farmland display as lighter colors. Bold 3 indicates approximate location of Stop 3. Also note site and age of fan delta north of Stop 3. Photo AAQ-8P-24, June 16, 1955. Photo courtesy of Central Washington Historical Aerial Photograph Project https://www.gis.cwu.edu/geog/historical_airphotos/.

Stop 3—Chalk Hills

Figure 20. Dropstones (larger, rounder, dark colored rocks) and calcareous concretions (smaller, flatter, lighter colored rocks) are common at the eroded bases of Chalk Hills. Author photo, May 2022.

How old are the lake sediments in the Chalk Hills? I don't know of any dates on the Chalk Hills lake sediments. However, a pebbly sand near the top of a fan delta at 2143 feet elevation 1.3 miles northwest of Stop 3 has an OSL date of 15,995 +/- 1845 cal yr BP. This is in the ballpark with the OSL date from south of Stop 1.

Chalk Hills to West Foster Creek

From here to there. From the Chalks Hills return to WA 17. Turn right (west) and follow WA 17 7 miles to its junction with the Bridgeport Hill Road (which lies near the junction of East and West forks of Foster Creek. Turn left (south) onto the Bridgeport Hill Road and follow it about 2 miles up the West Fork Foster Creek to a pullout just after the bridge over Smith Draw. The pullout is just left (east) of the road. Park here.

Stream incision. From the Chalk Hills to Stop 4, East Fork Foster Creek and West Fork Foster Creek are each deeply incised. It is such an issue in terms of sediment load in the East Fork that the Natural Resources Conservation Service (NRCS) has installed an erosion prevention structure just upstream of Chalk Hills Road NE, and a sediment retention structure several miles downstream. Numerous beaver dams on the East Fork also serve as sediment retention structures. Keep your eyes open for their telltale ponds.

Wildfire. The Pearl Hill fire raged through this area on September 7, 2020. It might be more accurately described as a “firestorm” driven by high winds and low humidity. It was devastating to the human property as well as the shrub-steppe landscape here (**Figures 20 & 21**). Of particular note are the debris flows which came from the easily eroded lake sediments in the surrounding, burned uplands.

Substrate and terraces. As we descend East Foster Creek, and near its junction with West Foster Creek, glacial lake sediments diminish and sands and gravels increase. The landscape also takes on a terraced appearance. We descend through at least four terraces mostly sand and gravel terraces here (**Figure 22**). The grade of WA 17 also steepens as we descend the creek junction. What is the origin of these terraces? According to Hanson (1970) they are dissected kame terraces associated with the receding Okanogan Lobe. Conversely, they may represent valley fill that poured into Lower Foster Creek from a late Ice Age flood that descended the Columbia or possibly Okanogan River valleys. This fill may have been dissected by the still ample meltwater in the Foster Creek drainage.

In ascending the Bridgeport Hill Road, note evidence of sand in several roadcuts and bare areas caused by the Pearl Hill fire. This is an indication of more sand present in the sediments of the West Fork. What is the source of these sands? Also note in the incised walls of lower West Foster Creek oxidized sediments that look to have a lake origin. These oxidized sediments are old—i.e., they have been mapped as Miocene Ellensburg Formation (Gulick and Korosec, 1990).

Chalk Hills to West Fork Foster Creek

Figure 21. Pre-Pearl Hill fire landscape just downstream of Chalk Hills. Note farmstead and vegetation cover indicated by black speckled pattern. Google Earth Pro image, July 27, 2019.

Chalk Hills to West Fork Foster Creek

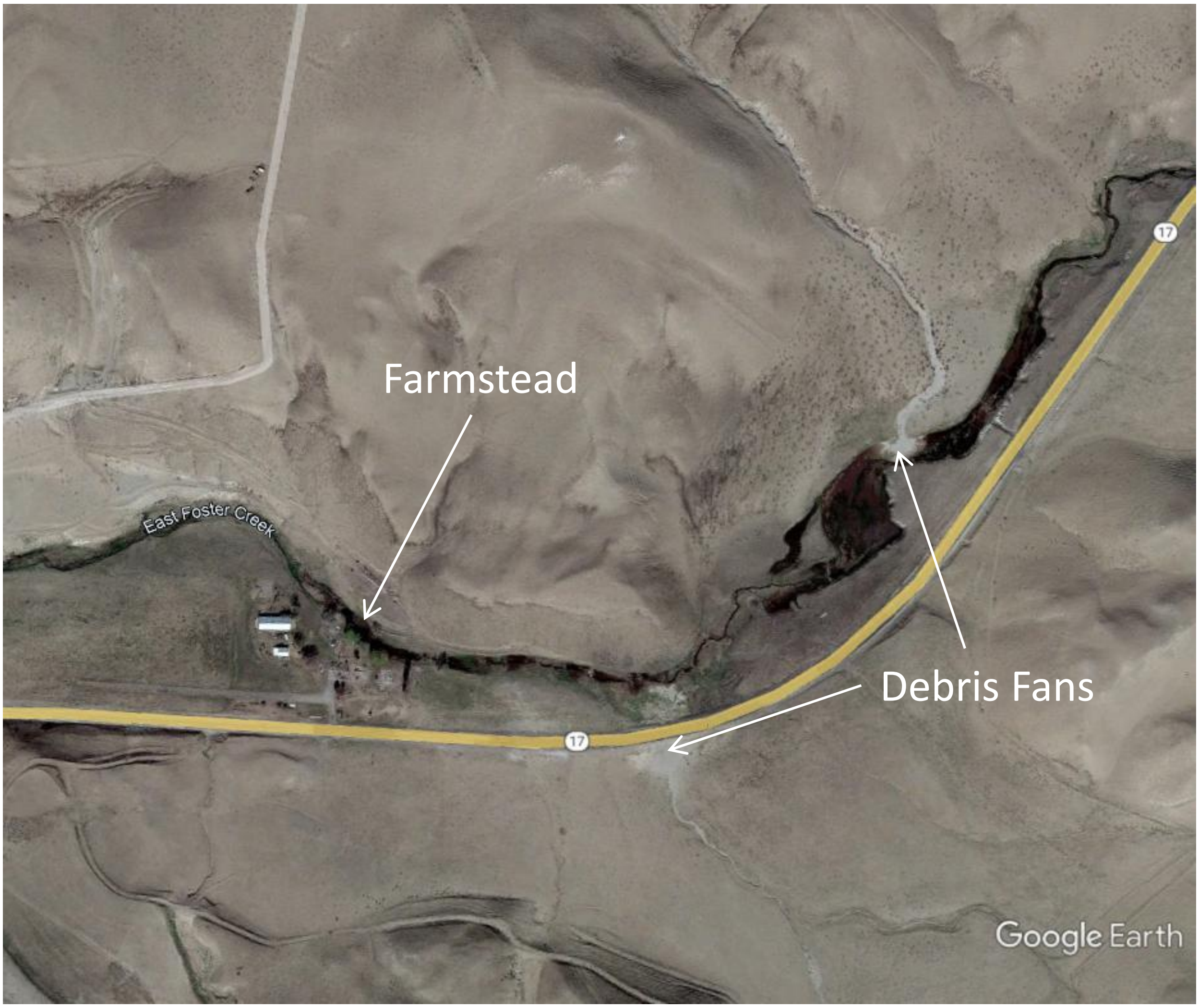


Figure 22. Post-Pearl Hill wildfire landscape just downstream of Chalk Hills. Note the burned farmstead, and the post-fire debris flows. Google Earth Pro image, April 18, 2021.

Chalk Hills to West Fork Foster Creek

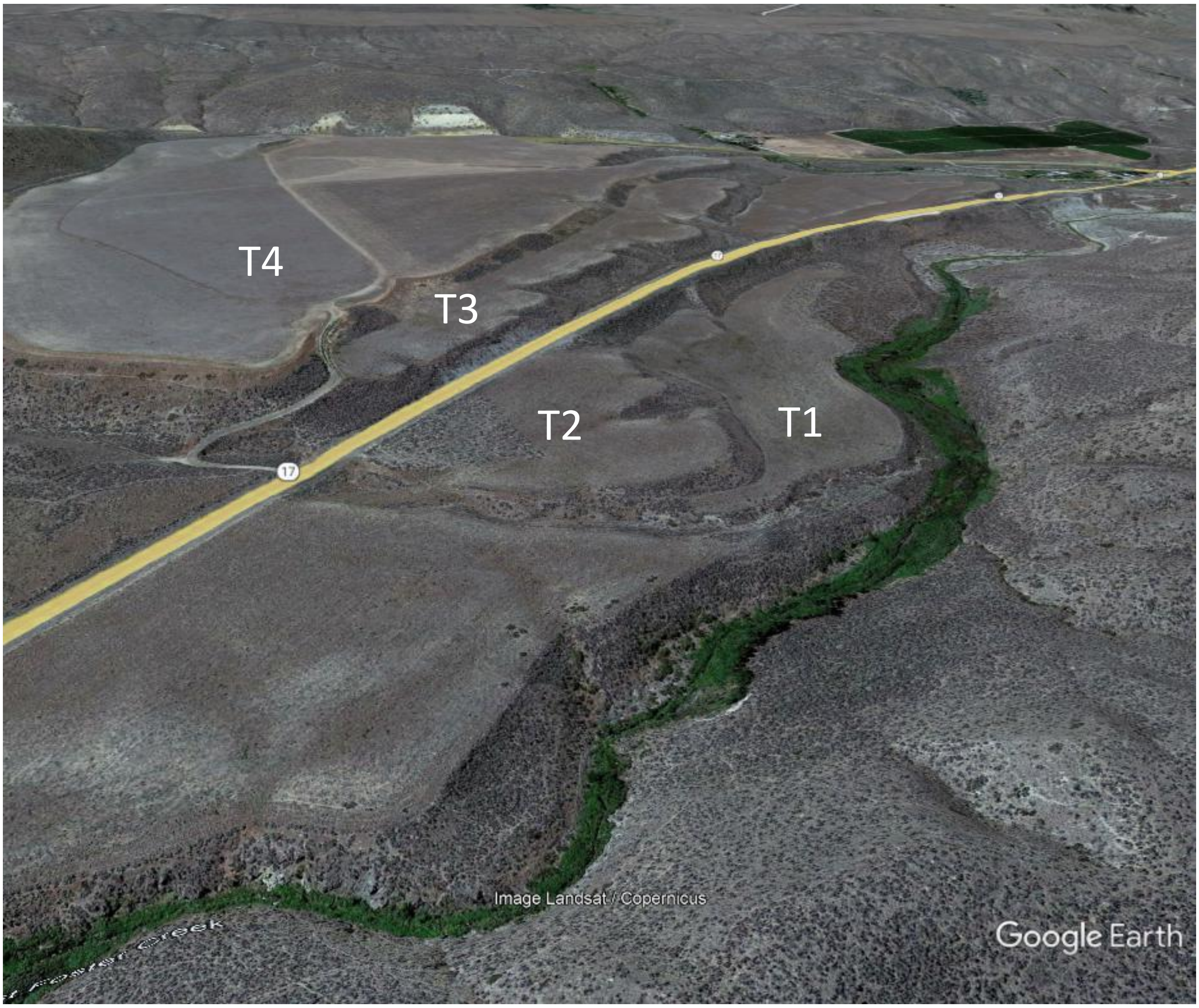


Figure 22. Oblique view toward the northwest of the terrace sequence near the junction of the East and West forks of Foster Creek. Terraces are indicated (from highest to lowest) as T1, T2, T3, and T4. Google Earth image, July 27, 2019.

Stop 4: West Fork Foster Creek

Getting our bearings: We are located near the junction of the West Fork Foster Creek and Smith Draw along the Bridgeport Hill Road. The GPS coordinates are: 47.941043° N, 119.668095° W.

Why do streams incise?. We are perched above a steep walled, ~flat floored stream channel incised in "soft" sediments (**Figure 23**) Such channels are known as gullies or arroyos. Such features are present around Central Washington (e.g., Baird Springs north of Quincy, Hansen Creek on the Yakima Training Center, and Park Creek east of Kittitas are three that come to mind) and around the semiarid Western U.S. In the Southwestern U.S., the period 1865-1915 has been identified as a period of arroyo incision. The incision was especially prominent in the 1880's (Cooke and Reeves, 1976). Hypothesized causes for arroyo incision have centered on land use and weather/climate patterns. Grazing, farming, timber harvest, and road development have all been identified as potential causes of arroyo incision (Cooke and Reeves, 1976). Each results in a loss of vegetation (and associated root strength) and an increase in soil compaction (so less water infiltrates during a rain). Weather and climate causes include wetter than normal conditions, drier than normal conditions (i.e., drought diminishes vegetation, reduces water infiltration, and increases storm runoff), and increased rainfall intensity associated with convective thunderstorms (Cooke and Warren, 1976). Given that many of the factors listed above involve vegetation removal prior to incision, it also follows that fire (either human- or lightning-caused) may also play a role in incision as may the removal of beaver from a drainage.

CWU Resource Management graduate Paul Blanton's master's thesis focused on historical patterns of channel incision in the West Foster Creek Watershed (Blanton, 2004). His historical document- and field-based research determined that incision in the watershed was associated with high magnitude, spring and summer precipitation events and perhaps land use shifts towards more farm land (**Figure 24, Table 1**).

Note the old position of the Bridgeport Hill road here. This pattern of road undercutting is typical downstream and upstream of us resulting in the county moving the road upslope (**Figure 25**).

Beaver removal and reintroduction. West Foster Creek was only about 14 miles from Fort Okanogan, an early 19th century fur trading post near the mouth of the Okanogan River. It makes sense that beaver were mostly trapped out of the basin by the early 1800's. I suspect that floods would have then removed the abandoned dams thereby steepening the West Fork's gradient and resulting in stream incision. Of course, this is all conjecture without solid

Stop 4—West Fork Foster Creek

Figure 23. Incised nature of West Fork Foster Creek channel near Stop 4 Google Earth image, September 13, 2011.

Evidence. And solid evidence is hard to find. The earliest aerial photographs here are from 1939, and radiocarbon dating does not give much better than half a century precision. Historical ground photographs have not yet been located for the West Fork. Beaver have been making a comeback here for at least 25 years (Dan Peterson, oral communication, June 6, 2022). In one ~200 yard long stretch downstream of the Smith Draw bridge, I counted four beaver dams in May 2022 (**Figure 25**). Each of these dams, if actively maintained, has the potential to trap sediments. Over time, these sediments will raise the bed of the stream and help fill in the incised drainage.

Stop 5—West Fork Foster Creek

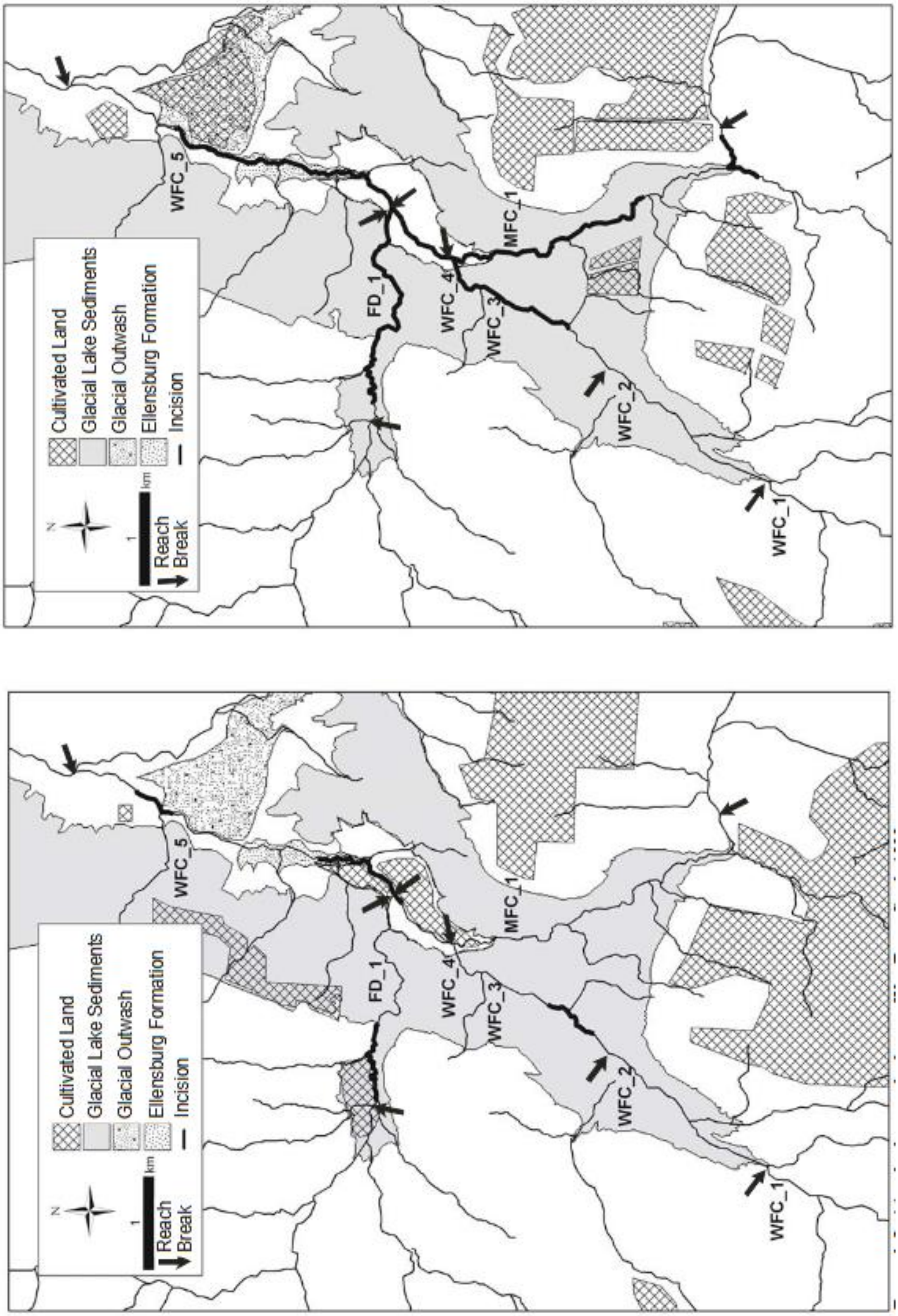
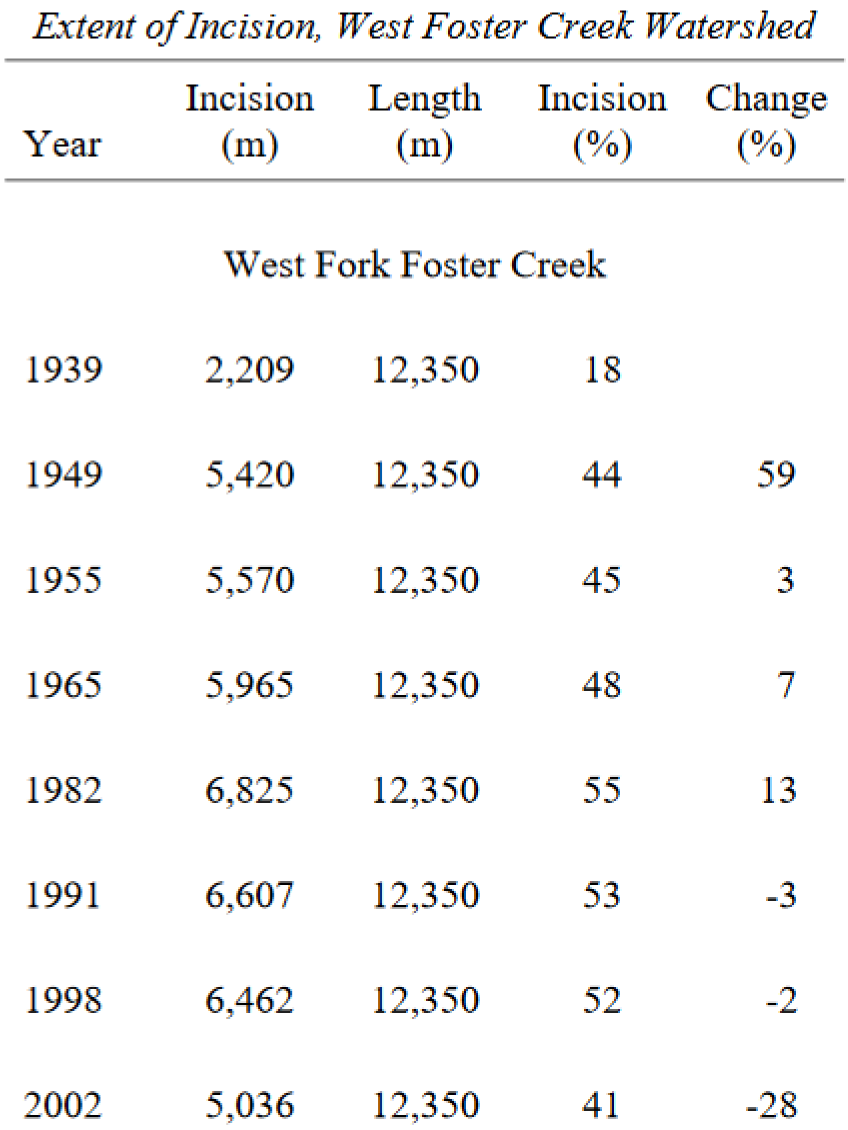


Figure 24. Incision in West Foster Creek Watershed in 1939 (left) and 2002 (right). WFC = West Fost Creek and FD = Smith Draw.

Stop 4—West Fork Foster Creek



Extent of Incision, West Foster Creek Watershed

Year	Incision (m)	Length (m)	Incision (%)	Change (%)
West Fork Foster Creek				
1939	2,209	12,350	18	
1949	5,420	12,350	44	59
1955	5,570	12,350	45	3
1965	5,965	12,350	48	7
1982	6,825	12,350	55	13
1991	6,607	12,350	53	-3
1998	6,462	12,350	52	-2
2002	5,036	12,350	41	-28

Table 1. Extent of channel incision in West Foster Creek. From Blanton (2004, p. 59).

Stop 4: West Fork Foster Creek

Figure 25. West Fork Foster Creek at its junction with Smith Draw. Note the remnants of the former Bridgeport Hill Road (solid heavy white lines where road is exposed and dashed where it is obscured). Also, note the beaver dams (white arrows) and associated ponds in this reach of West Foster Creek. Google Earth Pro image, July 27, 2019.

West Fork Foster Creek to Smith Draw

From here… Return to the Bridgeport Hill Road and continue uphill for ~1.5 miles. Turn right (west) onto N Oil Road (a gravel road). Follow N Oil Road west then north for about 1.7 miles. Turn left on an unmarked road onto private property. Park along side this road.

More erosion? As we ascend the Bridgeport Hill Road and West Fork Foster Creek, see ample evidence of fine textured sediments. These sediment are especially well exposed where we turn off the Bridgeport Hill Road onto N Oil Road.

A higher terrace. As we follow N Oil Road to the north, we soon ascend to the top of a moderately well-defined terrace. This terrace is another several hundred feet higher than the four terraces identified near the junction of the East and West forks of Foster Creek. We will see part of the interior of this terrace at Stop 5.

Stop 5—Upper Smith Draw

Getting our bearings…We are on Alex McLean's farm land. Please do not access his land without his permission. GPS coordinates: 47.942538° N, 119.688901° W.

When and why was arroyo created? The arroyo incision here is as spectacular as any within the Foster Creek Watershed (**Figure 26**). Part of what makes it so impressive is the fact that the original homesteaders'—the Mertens--house and various outbuildings were on the south side of the arroyo and the granary was on the north side (**Figure 27**). Assuming the buildings were all part of one homestead, this does not make practical sense—i.e., it would be very complicated and cumbersome accessing the granary from the house side of the arroyo. Therefore, I assume that when the Mertens' homestead was established prior to 1915 (Ogle, 1915) the arroyo was not here. The 1939 USDA airphotos indicate that it was here by then.

So what caused the arroyo incision here? According to Dan Hammond, son-in-law of Alex McLean "farming the area around Smith Draw (and the subsequent removal of the natural vegetation that protected the meadow & creek) was the major cause of the channel incision in Smith Draw. By 1915 there were more than a half dozen homesteads in the area farming that meadow (maybe eight

Stop 5—Upper Smith Draw

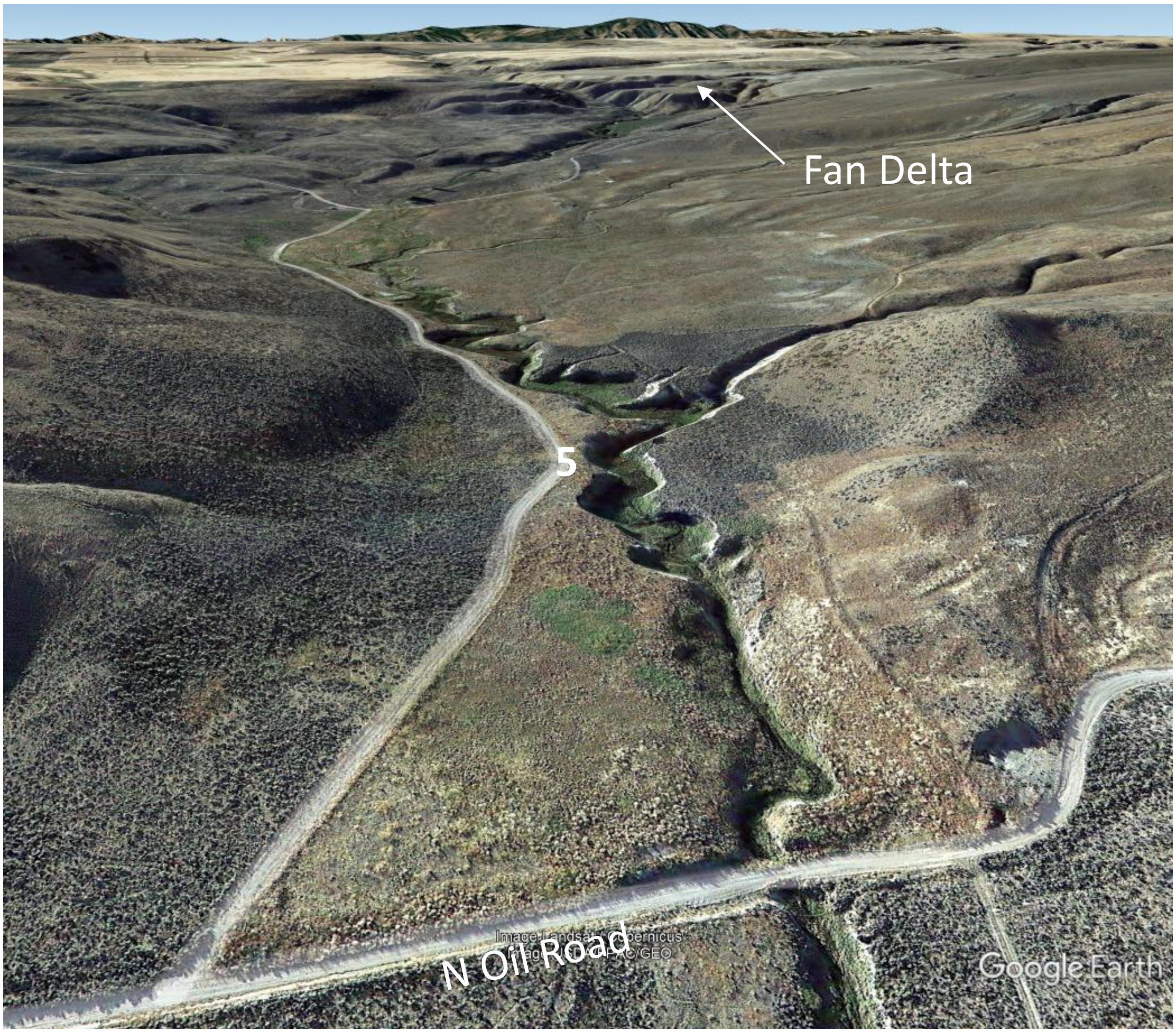


Figure 26. Oblique aerial view west of Smith Draw and the Mertens' Homestead site (near the bold white 5 which also indicates the field trip stop site). Note fan delta in the upper portion of the draw. Google Earth Pro image, September 13, 2011.

When and why was arroyo created?... homesteads?). The meadow was literally farmed to the edges of the little creek bed...I don't believe there was any natural vegetation to protect the channel from further eroding. Then came the 'flood of '48. But there apparently were several more heavy, water run-off events between '48-'55…It seems that anytime there was a heavy, spring run-off, there was further incision with no natural protection."

Stop 5—Upper Smith Draw

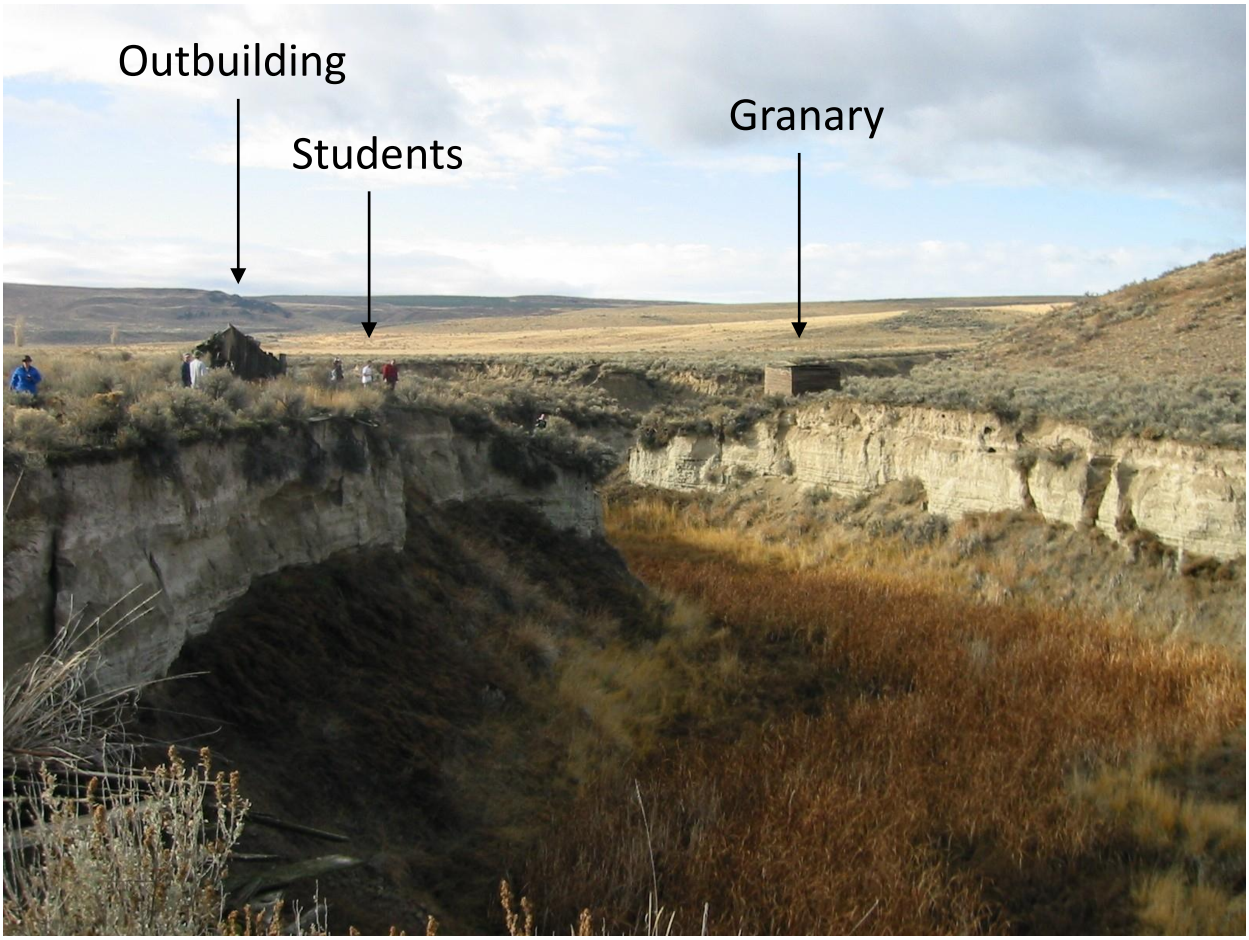


Figure 27. View toward the west and up Smith Draw. Merten homestead outbuilding (left or south side of arroyo) and granary (right side of arroyo). Students for scale. Author photo, November 2008.

When and why was arroyo created?... More from Dan Hammond: "There used to be a dirt road that ran from the meadow up through Smith Draw all the way to Division (the county road on top of the draw). It passed two homesteads in that draw (one of which was the Smith homestead where Alex McLean's mother was born). I suspect that major portions of this road washed out between '48-'55. I do know that Smith sold his homestead to the Wainscotts in 1941, so I suspect the road was navigable then."

Stop 5—Upper Smith Draw

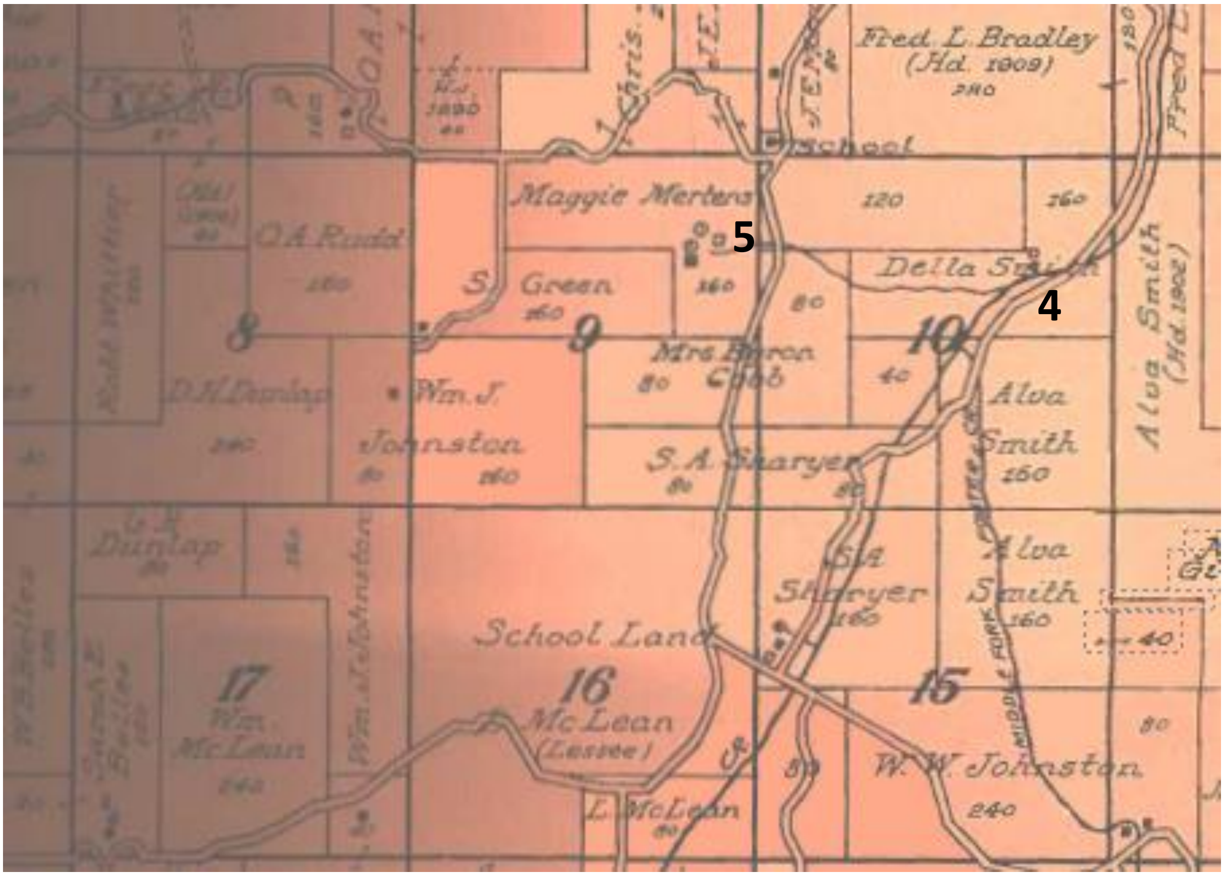
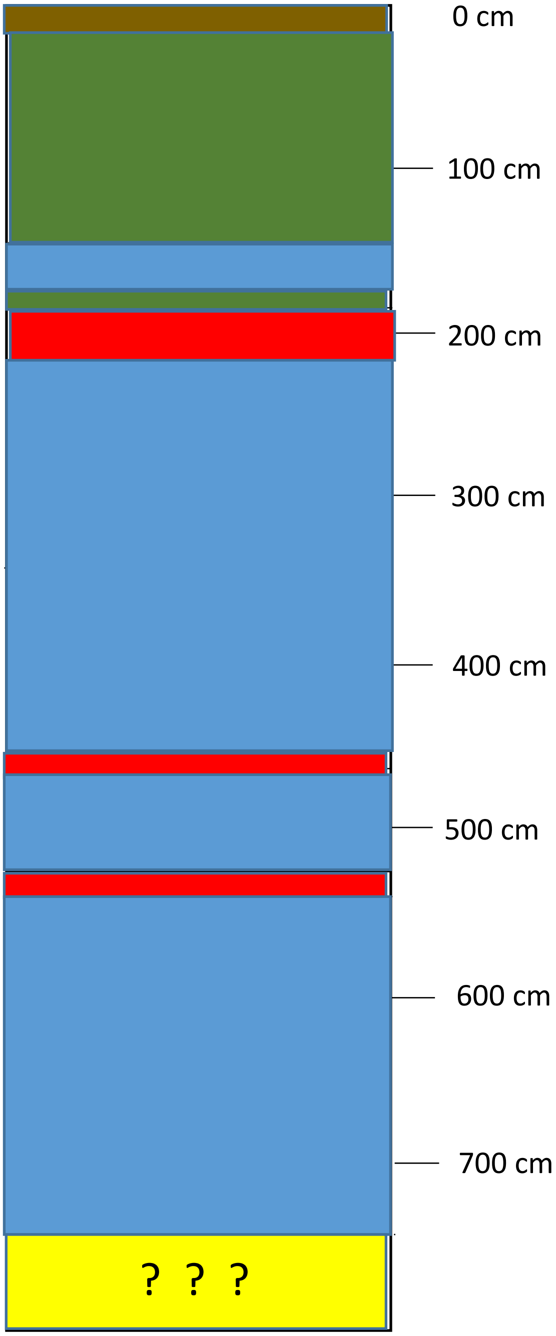


Figure 28. 1915 map of land ownership in West Foster Creek and Smith Draw area. Bold numbers 4 & 5 indicate locations of field trip stops. From Ogle (1915)

What is the stratigraphy of the walls of Smith Draw arroyo? The walls of Smith Draw offer >15,000 years of plateau history. Take a look and see if you can identify different geologic units. I identified several different units here including glacial outwash or till, three tephras, lake sediments, wetland sediments, and loess (**Figure 29**). Glacial outwash or till forms the base of the geologic units shown here. Glacial Lake Foster sediments lying immediately above the till have an OSL date of ~15,850 . Two tephra layers separated by 60 cm occur within the Glacier Lake Foster sediments. Microbeam analysis determined both to be Glacier Peak Tephra Layer G which were deposited about 13,410-13,710 cal yr BP. Above that are more lake sediments, wetland sediments, Mazama tephra (7470-7620 cal yr BP), and loess.

Stop 5—Upper Smith Draw



0-15 cm—Fine bed, massive--**loess**

15-150 cm—Fine bed, massive--**lake or wetland sediments**

150-175 cm—Alternating fine & coarse beds--**lake sediments**

175-185 cm—Silty sand with molluscs—**wetland or lake sediments**

185-210—Fine bed, massive--**Mazama tephra; 7470-7620 cal yr BP**

210-340 cm—Fine seds w/molluscs—**lake sediments– 7850-8010 cal yr BP**

340-460 cm—Alternating fine & coarse beds—**lake sediments—9120-9420 cal yr BP**

460-470 cm—Course to fine sand—**Glacier Peak tephra-- 13,410-13,710 cal yr BP**

470-520 cm—Alternating fine & coarse beds—**lake sediments**

520-530 cm—Course to fine sand—**Glacier Peak tephra--13,410-13,710 cal yr BP**

530-730 cm—Alternating fine & coarse beds--**lake sediments**

730 m—Fine sand layer—**lake sediments—15,850 +/- 1140**

>730 cm—Cobbly sandy layer—**glacial outwash/till**

Figure 29. Composite stratigraphic section, Merten Homestead, Smith Draw. Based on author's observations, sampling, and dating. Glacier Peak tephra ages based on Kuehn and others (2009) and Mazama tephra age based on Hallett and Clague (1997).

Stop 5—Upper Smith Draw

Table 2. Dates on arroyo wall sediments at Merten homestead, Upper Smith Draw.

	Sampled Sediments	Depth of sediments (cm below surface)	Type of Date	Age (cal yr BP)
WA-ChJo-09-16-2010-06	Tephra	185-210	Microbeam	7,470 - 7,620 (Mazama O)
WA-ChJo-09-16-2010--07	Molluscs	210-230	AMS	7850 - 8010
WA-ChJo-14-06-2011-04	Molluscs	395-405	AMS	9120 - 9420
WA-ChJo-13-11-2013-01	Tephra	460-470	Microbeam	13,410-13,710 (Glacier Peak-G)
WA-ChJo-13-11-2013-01	Tephra	520-530	Microbeam	13,410-13,710 (Glacier Peak-G)
WA-ChJo-13-11-2013-03	Lake sands & silts	730	OSL	15,850 +/- 1140

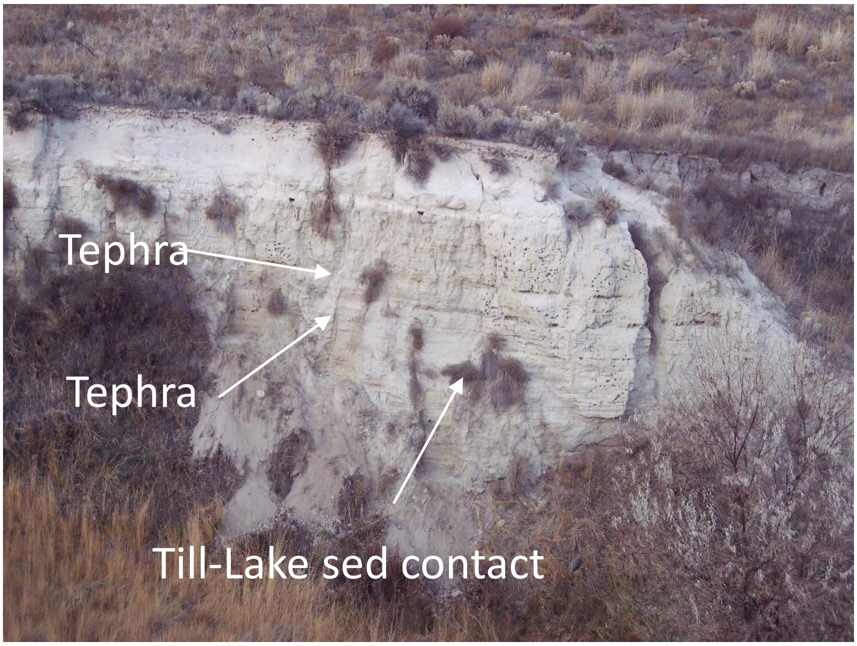


Figure 30. Arrows point to tephra sample sites on north wall of Smith Draw arroyo homestead site. Subsequent analysis identified these samples as Glacier Peak G eruption with a date of 13,410-13,710 calendar years before present and till-lake sediment contact to be 15,850 +/- 1140 calendar years before present. Author photo, November 13, 2013.

Stop 5—Upper Smith Draw

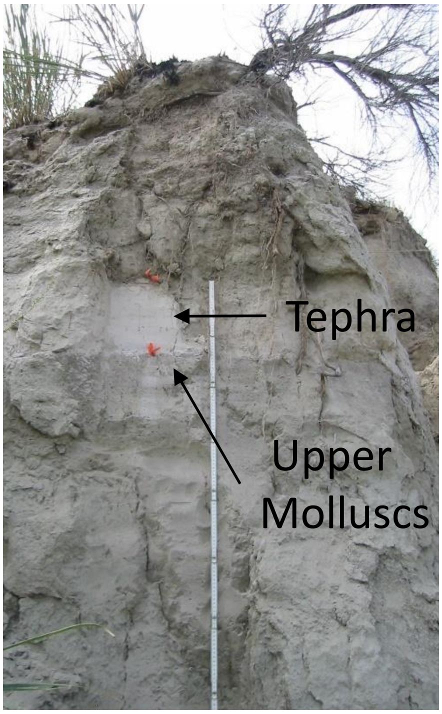


Figure 31. Stratigraphy of part of south wall of Smith Draw arroyo homestead site. Subsequent analysis identified tephra as Mazama 7470-7620, upper molluscs as 7850 – 8010, and lower molluscs as 9120 – 9420 (all calendar years before present). Lower mollusc layer just out of photo. Author photo, September 16, 2010.

How deep and old was the lake here? The fan delta upstream of us (**Figure 26**) has a surface elevation of about 2150 feet which means the lake over our parking area was nearly 350 feet deep! The 2150 feet elevation is pretty close to that of the lake elevations identified in East Fork Foster Creek. This suggests that Glacial Lake Foster was present in the East and West forks. The date at the glacial outwash/till and glacial lake interface indicates that the lake was here about 15,850 +/- 1140. This date is also in line with other high shoreline or near high shoreline dates in the basin (**Figure 32**). Unfortunately, two attempts at dating the fan delta upstream have yielded wildly different results—11,900 +/- 910 and 33,365 +/-2610 cal yr BP, neither of which fits the chronology elsewhere in the basin.

Wrap-up

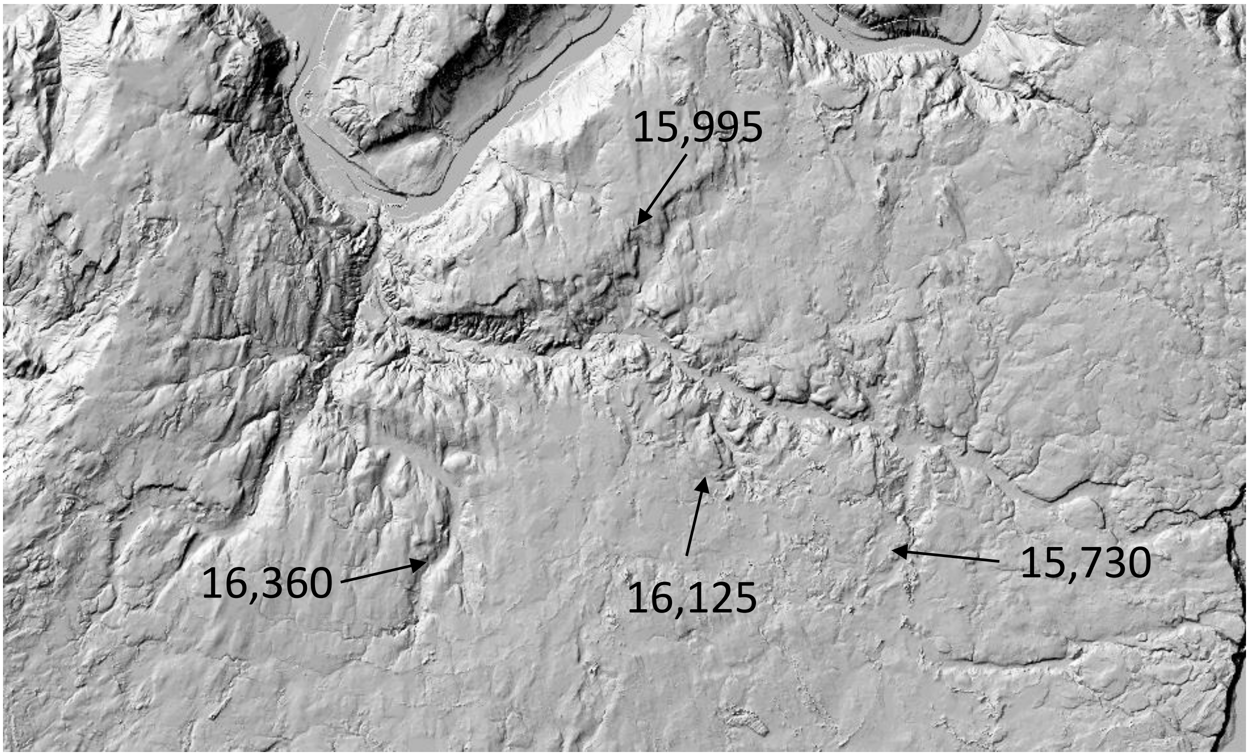


Figure 32. Summary map showing high or near high shoreline OSL dates for Glacial Lake Foster. All dates from author and reported as calendar years before present.

Glacial Lake Foster occupied part of the Foster Creek Watershed during the most recent Ice Age. The lake likely formed from the effects of a receding Okanogan Lobe blocking water outlets. We know that it reached an elevation of at least ~2150 feet throughout the watershed. It appears that this high level was reached ~15,000-16,000 cal yr BP. The later story of the lake is less clear. A lake appears to have occupied Smith Draw and the West Fork until after the deposition of the Mazama tephra at 7470-7620 cal yr BP; however, we do not know how deep it was at that time. As Martin (2001) hypothesized, perhaps the thinning ice resulted in a lowering of subsequent lake levels over time. In addition to the effects of lakes on the landforms and sediments, this watershed has also been shaped by volcanic eruptions, landslides, streams/floods, and glaciers. Humans (especially farmers and ranchers) and beaver activity has also played a role in shaping these landscapes.

Thanks for supporting the activities of the Ellensburg Chapter of the Ice Age Floods Institute. I hope you have enjoyed your time with us today. If you have questions or comments about his field trip feel free to contact me at lillquis@cwu.edu or (509) 963-1184. Hope to see you on our next trip!

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