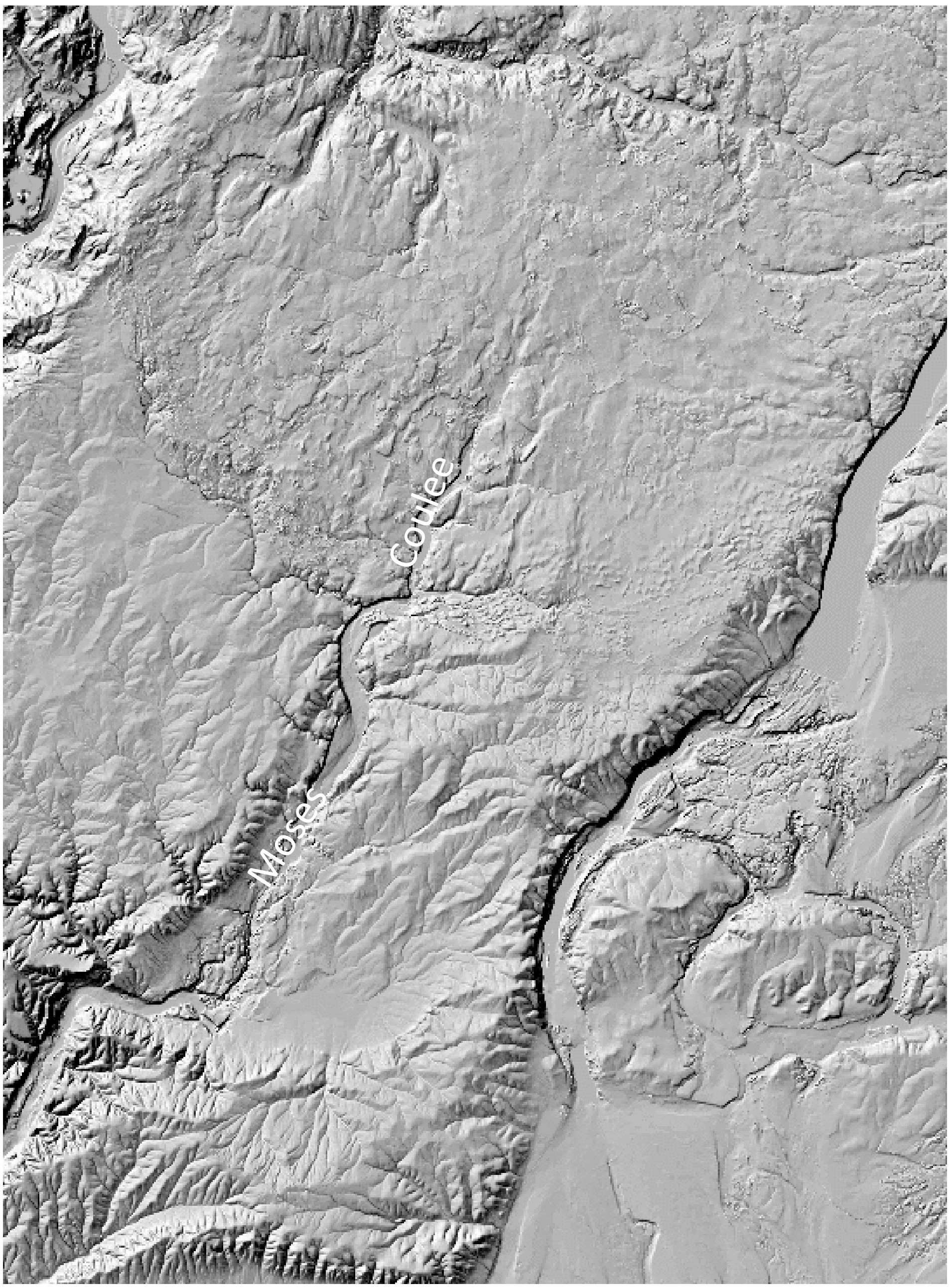
IAFI Field Trip

East of Moses Coulee:

Ice Ages to Present



Field Trip Leader:

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Introduction

The East of Moses Coulee field trip occurs on a common “stage” of Eastern Washington--Columbia River Basalts and a semiarid climate. Despite these commonalities, the landscape east of Moses Coulee and west of the Grand Coulee differs greatly from south to north, and from west to east. It has also changed markedly over the past 20,000 years. These landscape differences result from glaciation, associated meltwater, and windblown sediments. Imprinted atop this landscape are human settlement patterns that historically have been associated with dryland agriculture and grazing. Settlement and agriculture changes followed patterns of deluge and drought, as well as government programs and economic conditions. U.S. involvement in World War II brought military bombing and strafing ranges to the area. Now, climate change and Washington state’s response to that is promoting green energy development in the area.

Tentative Schedule

10:00am	Stop 1—Big Picture, Dry Falls Interpretive Center
10:45	Depart
11:00	Stop 2—End Moraine & Pilot Rock, Road 5 NE & S NE
11:45	Depart
12:00pm	Stop 3—Glacial meltwater & Burton Draw, Road L NE
12:45	Depart
1:00	Stop 4—Historic settlement & Highland, Highland School Road
1:45	Depart
2:00	Stop 5—Wind & soils, Old US 2
2:45	Depart
3:15	Stop 6—Ephrata Pattern Bombing Range, Whitehall Road
4:00	Depart

Our Field Stops

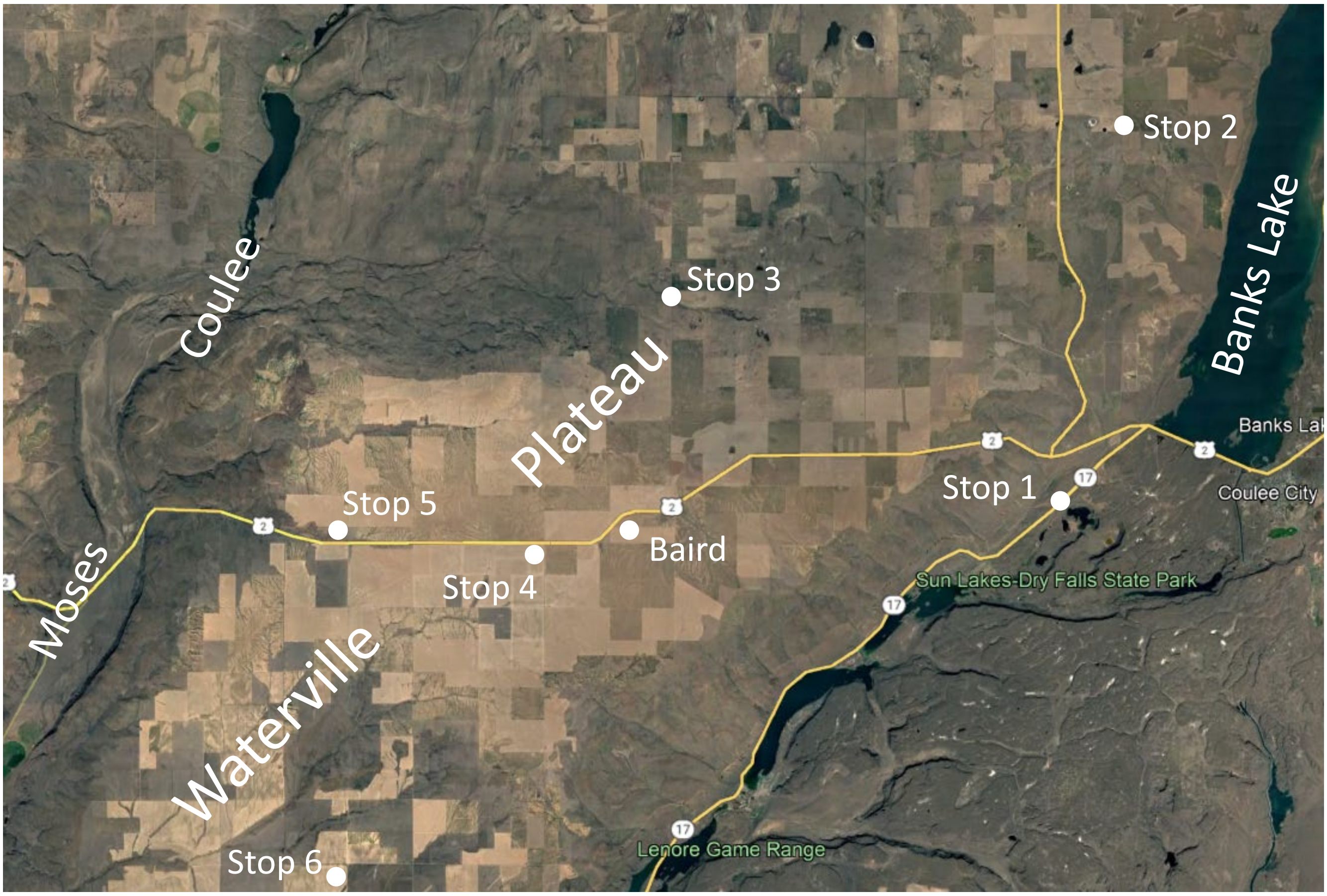


Figure 1. The approximate locations of Waterville Plateau field trip stops noted with white dots. Source: Google Earth Pro, 04/18/2021.

Stop 1—Big Picture at Dry Falls

Location: We are located at the Dry Falls Interpretive Center along WA 17 ~2 miles south of its junction with US 2. GPS coordinates for the site are 47.606742°N and 119.364093°W. The interpretative center sits at the head of the magnificent Lower Grand Coulee (Figure 1) . This is an information <u>and</u> restroom stop.

Stop 1—Big Picture at Dry Falls

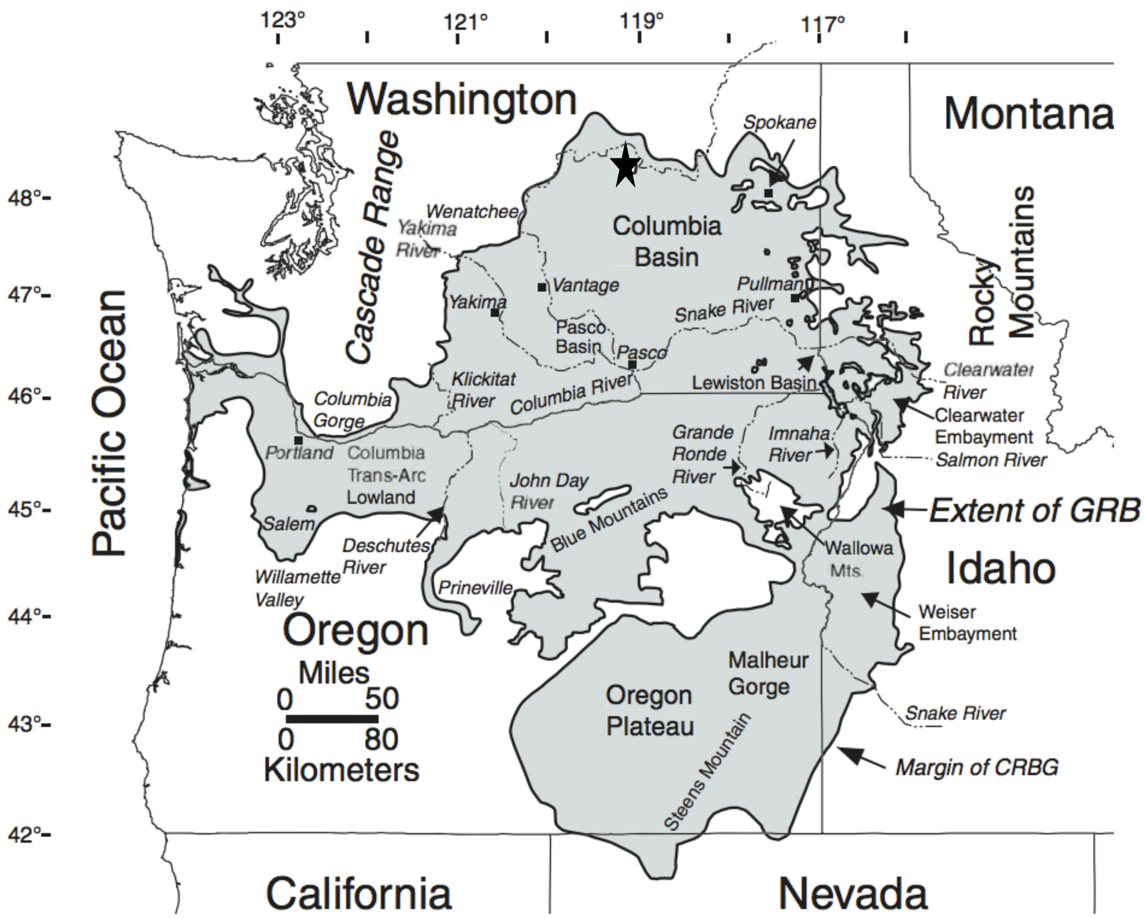


Figure 2. The extent of the Columbia River Basalt Group in Washington, Oregon, Idaho, and northern Nevada. Star indicates approximate location of field trip area. Source: USGS Cascade Volcano Center (https://www.usgs.gov/media/images/columbia-river-basalt-group-map-shows-main-regions-basalt-exposu).

Bedrock Geology. The bedrock geology of our field day is Columbia River Basalt. These dark, dense, volcanic rocks characterize much of central and eastern Washington (Figure 2). More specifically, much of our day will be spent atop the Grande Ronde and Wanapum Basalts. Of the Wanapum Basalts, we will be among the Priest Rapids, Roza, and Frenchman Springs members (Figure 3) (Gulick and Korosec, 1990). Each member is a different basalt flow, and as you can see by Figure 3, there are many flows composing the entire Columbia River Basalt Group.

Stop 1—Big Picture at Dry Falls

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
Middle			**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	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	
			Member of Slack Canyon		
			Member of Field Springs		N_2
			Member of Winter Water		
Lower			**Member of Umtanum**		
		Prineville Basalt	**Member of Ortley**		
			Member of Armstrong Canyon		
			Member of Meyer Ridge		
			Member of Grouse Creek		R_2
			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		
			Member of Rogersburg		R_1
			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.

Stop 1—Big Picture at Dry Falls

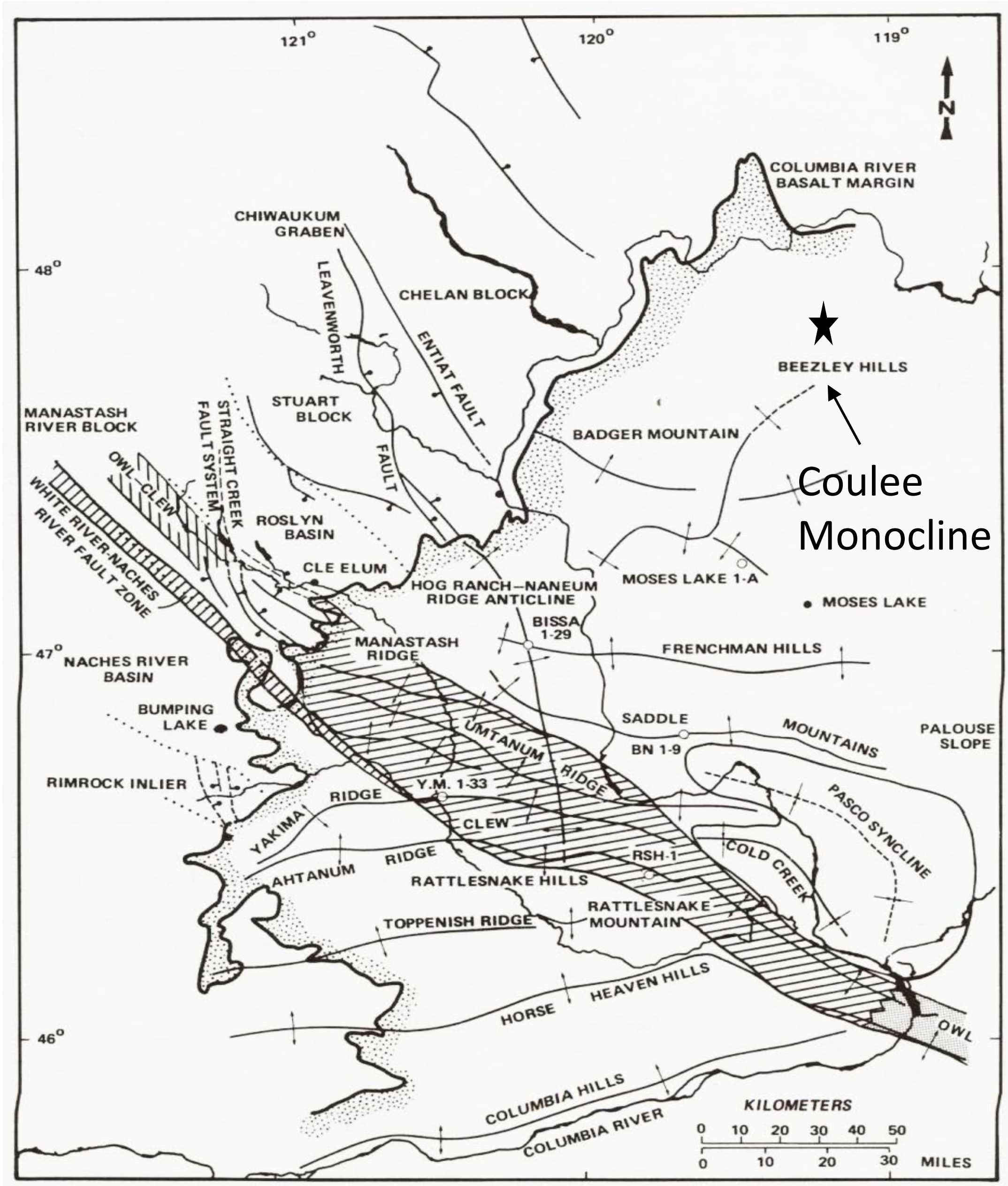


Figure 4. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Star indicates approximate location of field trip area. Source: Reidel & Campbell (1989, p. 281).

Structural Geology. The basalts were initially deposited horizontally or nearly so. Since deposition, they have been folded and faulted on the distal edges of the Yakima Fold and Thrust Belt (Figure 4). The ridge to our northwest—the Coulee Monocline-- is one of those folds. Floods down the Lower Grand Coulee followed the weakened rocks of this fold.

Stop 1—Big Picture at Dry Falls

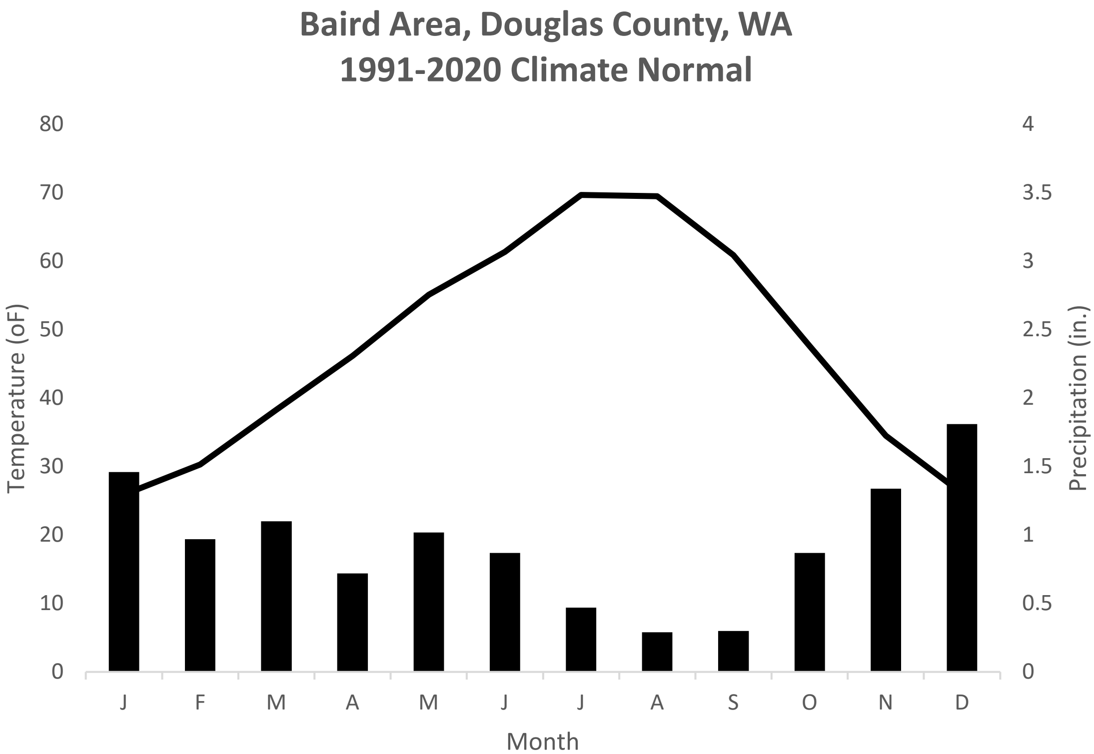


Figure 5. Modelled temperature (line graph) and precipitation (bars) for the Baird area on the Waterville Plateau over the 1991-2020 climate normal. Note the sharp contrast between winter and summer temperatures, and the marked low summer precipitation. From PRISM Climate Group website (https://prism.oregonstate.edu/explorer/).

Climate. The climate of the area may be characterized as a mid-latitude, dryland (Figure 5). The mid-latitude and inland location means that summers are hot and winters are cold. The relatively elevated location at Baird (~2400 feet) (Figure 1) leads to a cooler mean annual temperature (~47^{o}F) than adjacent lower sites like Coulee City. The location in the rainshadow of the Cascade Range results in overall dry conditions (~11 inches of precipitation/year). Most precipitation occurs in the cooler months (October-March)and is associated with the passage of mid-latitude cyclones. Wind is common throughout the year with northwest winds dominating in the winter and southwest winds in the summer. Given the dry and windy setting, potential evapotranspiration is likely twice that of precipitation (Donaldson and Ruscha, 1975).

Stop 1—Big Picture at Dry Falls

Glacial Lake Missoula and its Floods: The floods that shaped this landscape came from Glacial Lake Missoula in western Montana (Figure 6). Glacial Lake Missoula originated when the Purcell Trench Lobe of the Cordilleran Icesheet blocked the mouth of the Clark Fork River near present-day Lake Pend Oreille and Sandpoint creating Glacial Lake Missoula. At its maximum, it held 530 mi^3 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. Floodwater velocities reached nearly 70 mph in places. Much of the path of these floods was scoured to basalt bedrock and descriptively named the "Channeled Scablands" (Figure 6). We are located in the most prominent of them all—the Grand Coulee. Another very prominent coulee—Moses Coulee—forms the western boundary of this field trip. See Bretz (1969), Baker & others (2016), and Waitt & others (2021) for excellent summaries of the Ice Age flood history here.

Coulees. Key features of the Channeled Scablands are "coulees". Coulee is a French term meaning "to flow". It refers to a variety of landforms across North America. It has been used to refer to steep-sided channels or valleys in the northern U.S. In the southwestern U.S., it may be synonymous with "arroyo", "dry gulch", "dry channel", and "wadi" (Fairbridge, 1968). Here, it refers to steep-sided, ~flat-floored, ~straight valleys eroded into basalt bedrock by the waters of Ice Age floods.

Stop 1—Big Picture at Dry Falls

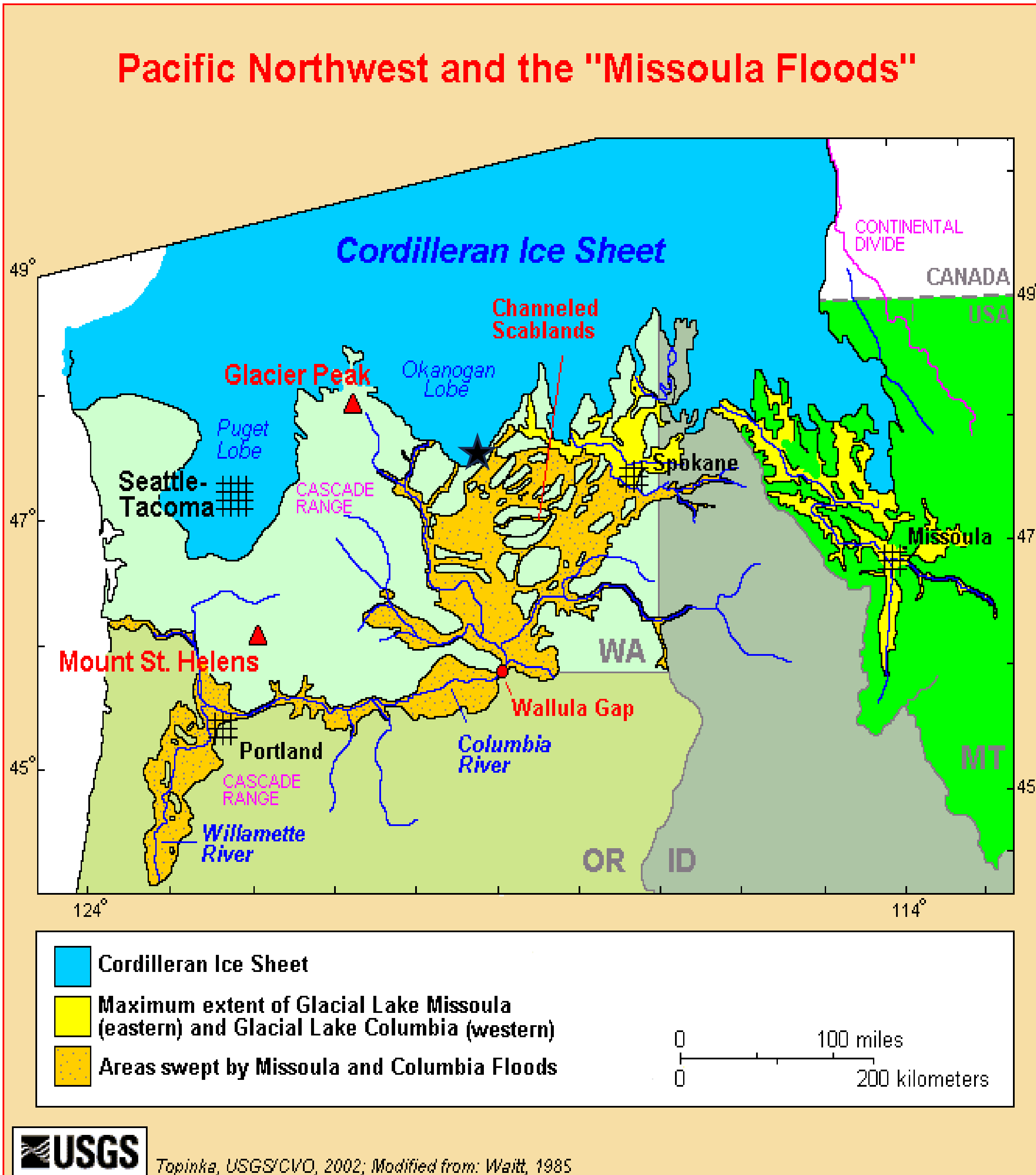
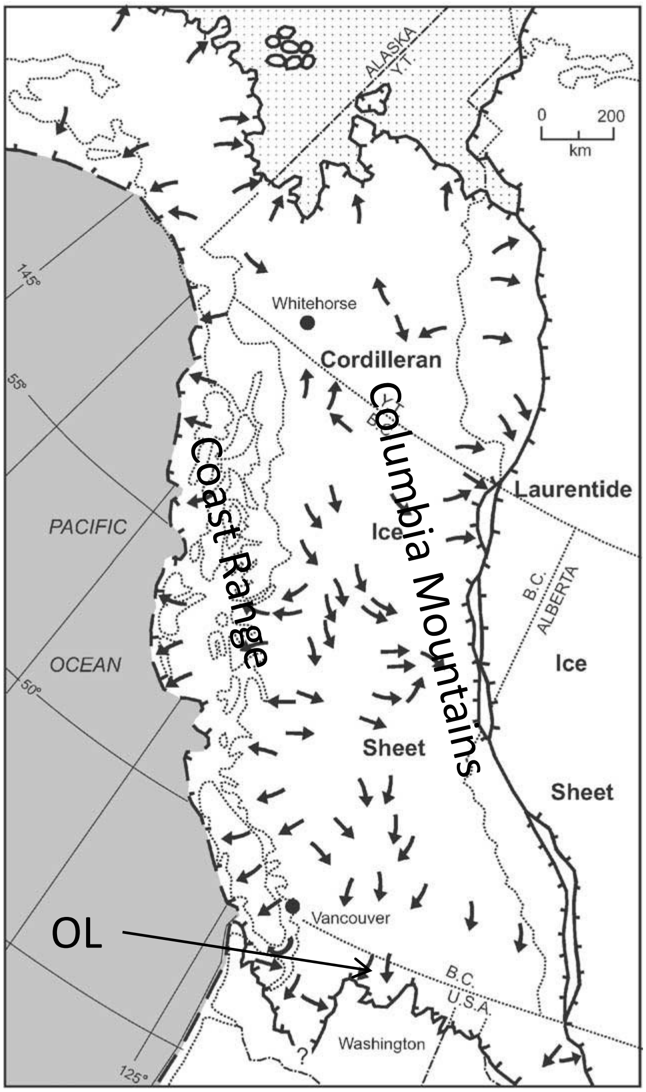


Figure 6. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Star indicates approximate location of the field trip. Source: Cascade Volcano Observatory website, https://www.usgs.gov/media/images/pacific-northwest-and-missoula-floods.

Stop 1—Big Picture at Dry Falls



Okanogan Lobe. 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 near here (Bretz, 1923; Clague and James, 2002) (Figure 7). As it grew, it flowed away from its mountain sources into adjacent valleys. In addition to the Okanogan Lobe, four other lobes existed—Puget (to the west), and the Columbia River, Purcell Trench, and Flathead to the east.

Figure 7. Cordilleran Icesheet. Okanogan Lobe is indicated by an arrow and OL. From Clague and James (2002).

Okanogan Lobe of the Cordilleran Icesheet & the Upper Grand Coulee. The Upper Grand Coulee formed when the Okanogan Lobe of the Cordilleran Icesheet blocked the Columbia River Valley near the present-day towns of Grand Coulee and Coulee Dam thus creating Glacial Lake Columbia (Figure 6). This lake spilled to the south as did Missoula Floods entering the lake. Floods down the Upper Grand Coulee could follow multiple paths to arrive in the Quincy Basin because of the shear volume of water exiting the Upper Grand Coulee and the lack of the topographic confinement there. Dry Falls and the Lower Grand Coulee is the most prominent of these paths. Numerous (perhaps as many as 90 floods) of varying magnitudes passed through the Upper Grand Coulee during the late Pleistocene. Many more may have come through during earlier glacial periods (Waitt & others, 2021)

Enroute to Stop 2

Route: Our next stop is in the vicinity of Pilot Rock. From Dry Falls, head north for 2 miles on WA 17 to its junction with US 2. WA 17 parallels the Coulee Monocline to this junction. At the WA 17-US 2 junction, turn left onto US 2 and head west for 1.6 miles climbing onto the Coulee Monocline. Turn right onto WA 17 and head north nearly 5 miles. As you ascend WA 17, you will cross the indistinct upper limit of Ice Age floods that descended the Upper Grand Coulee and the more distinct southern limit of the Okanogan Lobe. The latter can be seen near where the large powerlines crosses WA 17. At road 5 NE, turn right and head east 1 mile. Park on the side of road 5 NE or turn left (north) onto road S SE and park in the small parking lot of the cell tower. GPS coordinates: 47.684632° N & 119.341514° W.

Stop 2—End Moraine Near Pilot Rock

Location: We are parked near the junction of roads 5 NE & S NE (Figure 8). The lands surrounding this intersection are private property. Do not access these without permission.

What is an end moraine and how does it form? When the Okanogan Lobe reached just south of here, its advance stalled leading to the formation of a broad ridge (or series of closely-spaced ridges). Such features are known as end moraines (Figure 9). The ice stalled because it was sufficiently warm here to melt the glacial ice as fast as it arrived from the north. End moraines form when moving ice pauses in one location allowing debris that is on, within, and under the ice to be deposited as the ice melts. This is especially true of the debris atop the ice. Glacier surfaces are rarely clear of debris; rather, they are often covered with rock debris that fell on the ice from higher surrounding terrain upglacier—e.g., Coast Range, Rocky Mountains, and Okanogan Highlands. The conveyor belt-like movement of the ice delivers that debris to the front of the glacier. The rock debris that was on the ice sheet rolled, fell, and was washed off leaving a ~linear, broad, hummocky ridge that represents the southernmost extent of the Okanogan Lobe. Because this is the southernmost and outermost of the Okanogan Lobe moraines, it is also termed a *terminal moraine* (or *terminal end moraine*) (Figure 9). This moraine is often referred to as the “Withrow Moraine” for its type locality near Withrow, a tiny town about 22 miles west of here. Near Withrow, the moraine is over 200 feet high and 2 miles wide. East of Moses Coulee it is wider (ranging up to nearly 4 miles wide) and lower (typically lower than 100 feet) (Figure 10). The size of the moraine suggests it occupied that position for a considerable amount of time (Freeman, 1933; Easterbrook & Rahm, 1970). The ice sheet terminus was likely over 700 feet thick (Kovanen and Slaymaker, 2004)!

Stop 2—End Moraine Near Pilot Rock

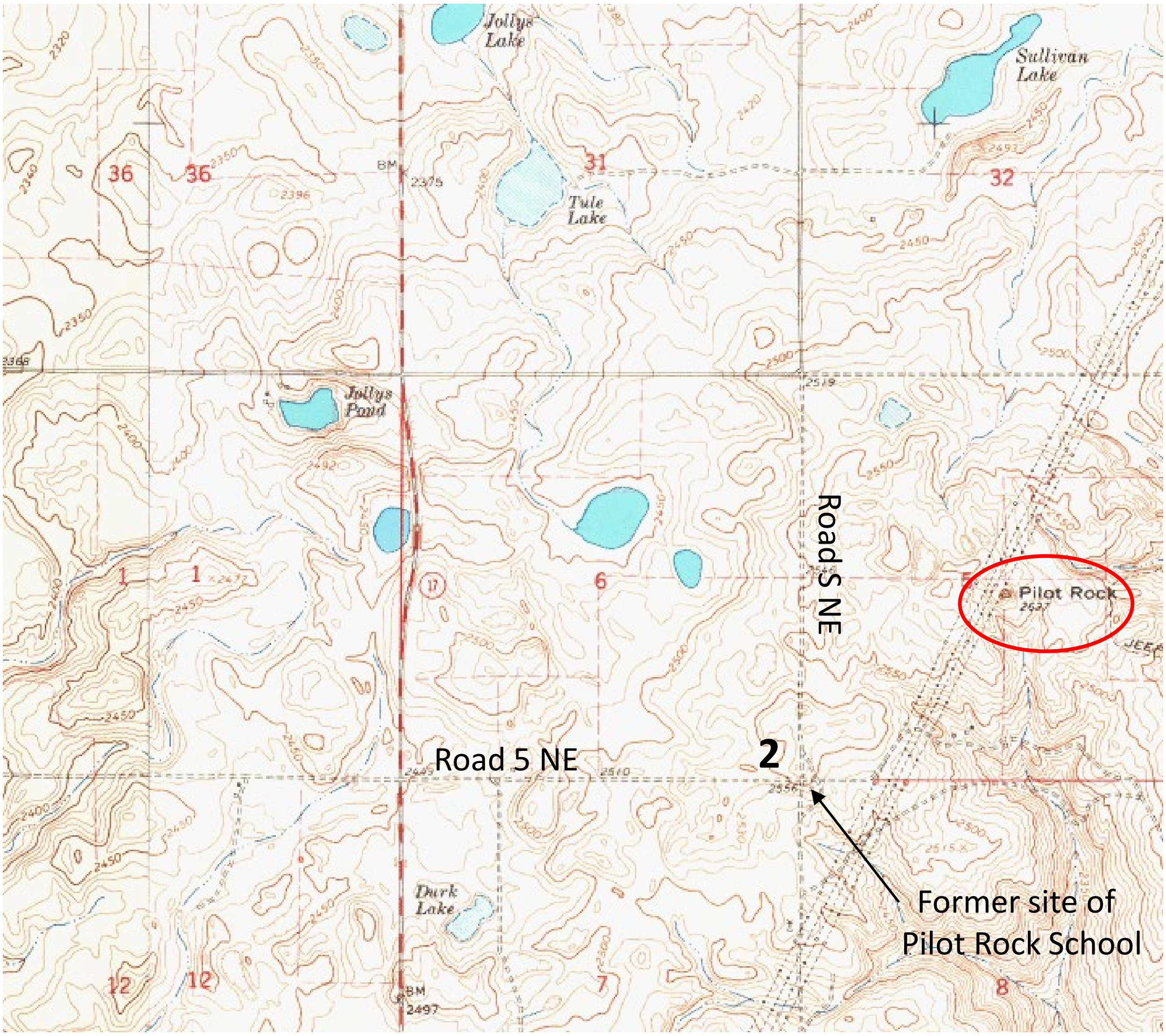


Figure 8. End moraine topography at and around Stop 2 (indicated by a bold 2). Note the poorly integrated drainage that results in numerous ponds. Also, note the location of Pilot Rock (red circle) and former location of Pilot Rock School. Source: Caltopo.com and Ogle (1915).

Stop 2—End Moraine Near Pilot Rock

How do we know this is an end moraine? Topographic and compositional evidence indicates this is a moraine. End moraines often consist of "hummocky" (i.e., lots of topographic ups and downs) and rocky terrain (Figures 8, 10 & 11). The hummocks are often arranged in a crude alignment. East of Moses Coulee, the end moraine consists of a closely-spaced, southwest to northeast trending ridges (Figure 10). Ponds are often present in the topographic depressions of the hummocks, especially following the wetter winter season. The hummocky nature of the terrain results in a poorly developed drainage pattern. The rocky nature of the terrain may be seen in roadcuts or in the farm fields (Figure 12). Some of those rocks are larger than tiny houses and have long been referred to as "haystack rocks" for their resemblance to haystacks (Figure 13). Often glacial terrain is characterized by rocks that have been transported for many miles. These are known as "erratics". The uneven, rocky terrain of end moraines often results in grazing rather than farmland in areas conducive to agriculture. That pattern is not as clear here—we see a mix of farm and range land. As one moves north and west onto the "ground moraine", farmland generally becomes more common.

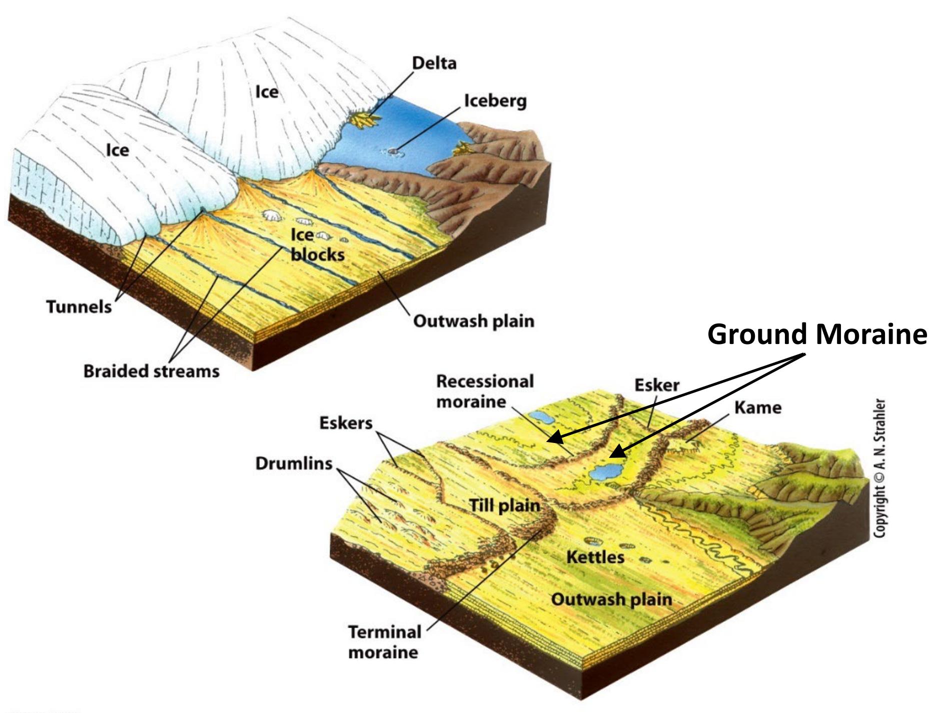


Figure 9. Ice sheet and associated landforms exposed during glacial retreat. Terminal moraine means the outermost end moraine. Source: Strahler (2013).

Stop 2—End Moraine Near Pilot Rock

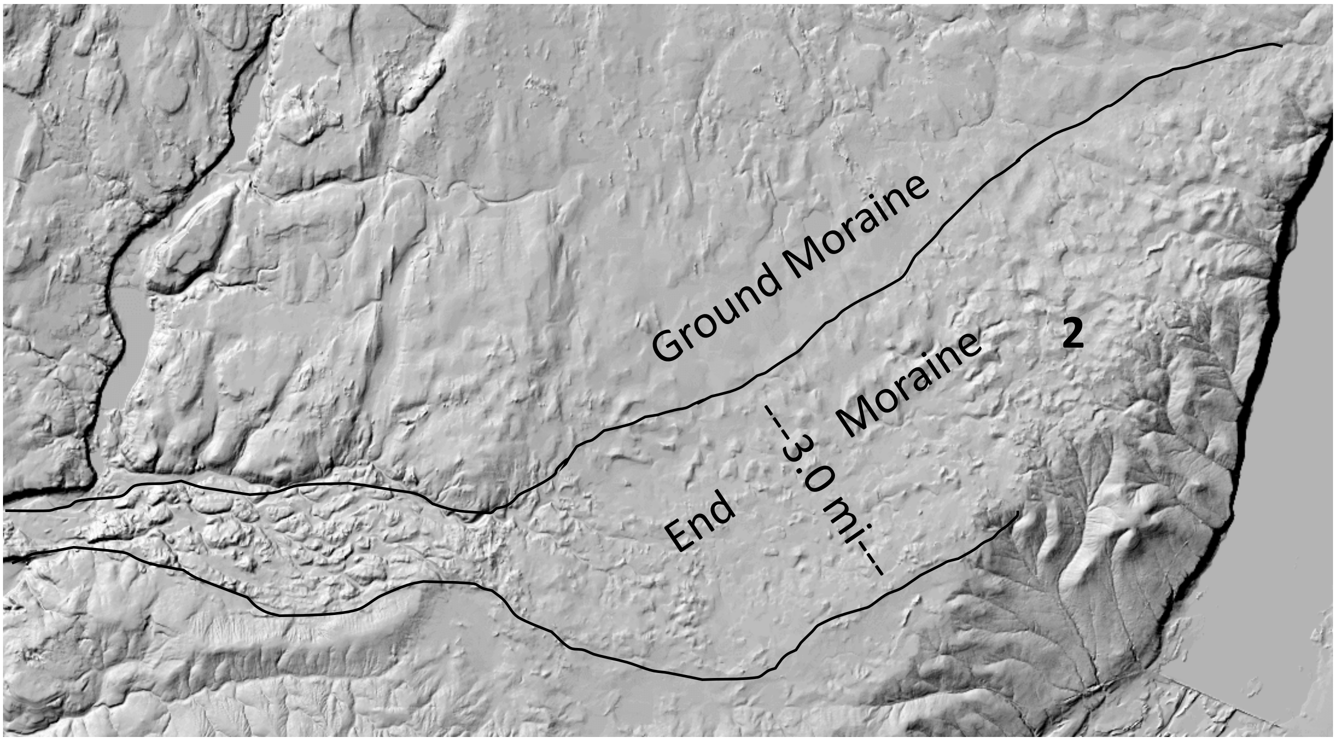


Figure 10. Shaded relief map of broad end moraine zone. Bold number indicates approximate location of Stop 2. Source: Caltopo.com.

Figure 11. Hummocky end moraine landscape. View south from intersection of roads 5 NE and S NE. Source: author, 09/10/2023.

Stop 3—End Moraine Near Pilot Rock

Figure 12. Soil formed in glacial till and loess visible in roadcut just north of intersection of roads 5 NE and S NE. Note the rocks throughout, and the poorly formed, white calcium carbonate accumulations (Bk horizon?). Poor soil development overall indicates relative youthfulness of soil. Note shovel (red circle) for scale. Author photo, 09/10/2023.

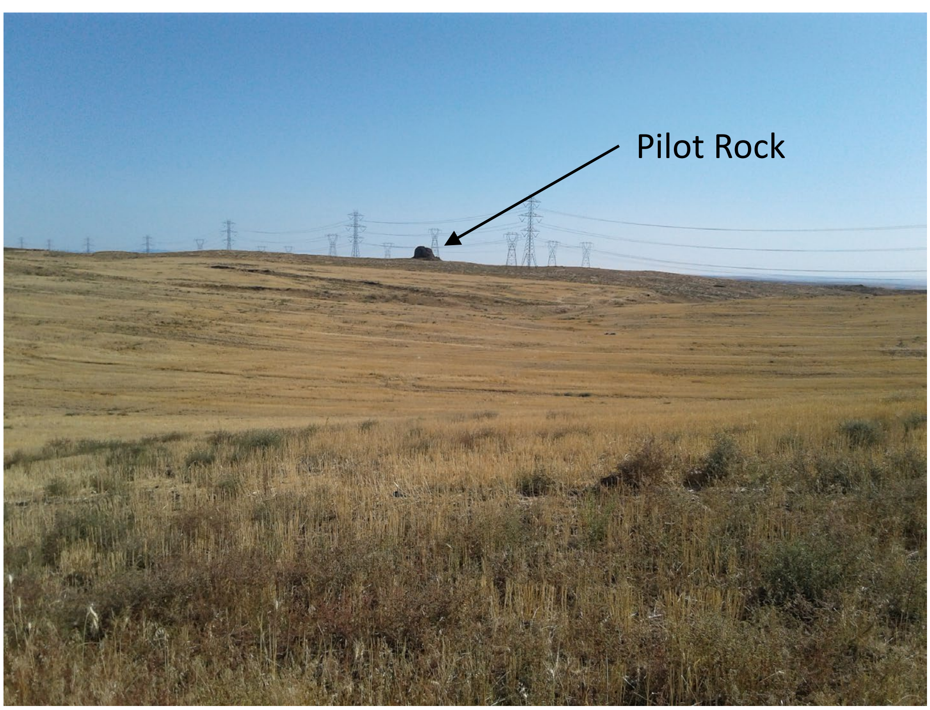


Figure 13. Pilot rock as an example of a haystack rock erratic. Northeast of intersection of roads 5 NE and S NE. Source: author, August 2023.

Stop 2—End Moraine Near Pilot Rock

What is Pilot Rock? Pilot Rock is a nearby, famous haystack rock that served as a guidepost to early explorers and settlers in the area (Figures 8 & 13). Here's what one early settler wrote of it (Steele and Rose, 1904, p. 594-95): *"Pilot Rock, Washington, stands on the west wall of the Grand Coulee, eight miles from Coulee City, Douglas County, and is the finger post marking the gateway to the Big Bend country and pointing the way to the fertile plains lying within the embrace of the greatest river of the great northwest. Long before you get into the Big Bend proper, and while you are puzzling out the intricacies of the scab rock country beyond Davenport, you will see that rock silhouetted against the horizon, and you will know that it stands on the only spot where it is practicable to cross the Grand Coulee, at any point with the length of sixty miles, with a wagon. And if you are a wise man you will know that this is the point you should aim for, since beyond lies the land for the homemaker. Later you will see that rock outlines against the snowy summits of the Cascade mountains, with Glacier Peak glistening like a day star over Lake Chelan."*

How old is this moraine? Moraines in semi-arid areas such as the Waterville Plateau are difficult to date by traditional methods such as radiocarbon—i.e., datable carbon is typically lacking. A newer surface exposure method involving ^{10}Be on erratics deposited on the Withrow Moraine near Withrow indicates that the Okanogan Lobe had reached its maximum southern extent and was beginning to retreat by ~15,400 years ago (Balbas and others, 2017).

Recessional moraines. As the Okanogan Lobe receded from this end moraine, it periodically stalled and deposited low ridges of glacial till. These are "recessional moraines". Note the recessional moraines as heavy black lines on Figure 14 indicating past positions of the Okanogan Lobe as it retreated after about 15,400 years ago. Hanson (1970) identified 13 major, transverse ridges north of the Withrow Moraine. Some of these features are shown in Figure 13.

Stop 2—End Moraine Near Pilot Rock

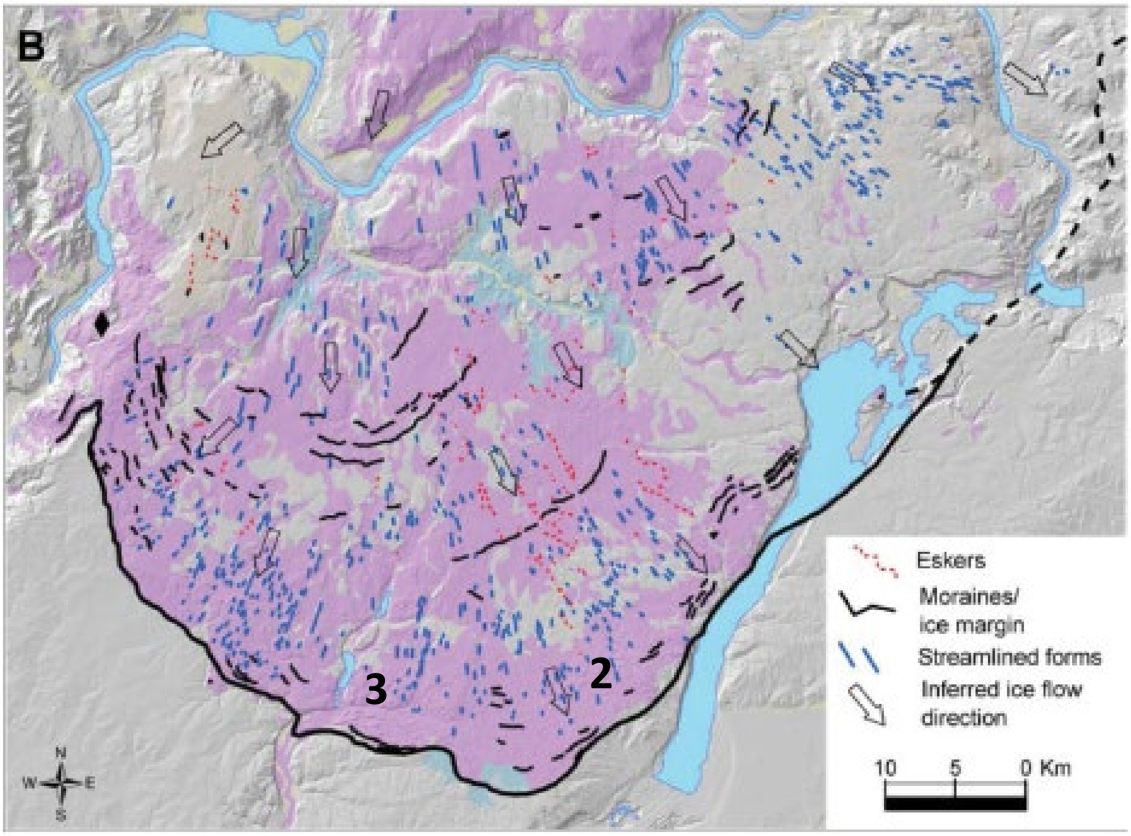


Figure 14. Distribution of prominent glacial landforms associated with the Okanogan Lobe of the Cordilleran Icesheet. Note the successive ice margins indicated by recessional moraines shown with heavy, black lines. Bold numbers indicate approximate locations of stops 2 & 3. Source: Kovanen and Slaymaker (2004, p. 553)

How has this landscape changed in the past century? Many more Euroamericans lived here in the early 1900's than do now. This area even boasted a school—Pilot Rock—just each of the road intersection here (Figure 15). Large powerlines came from Grand Coulee Dam in the 1940's (Figures 11 & 13) and cell towers arrived more recently. Conventional tillage is slowly being replaced by no-till farming. The latest change is green energy. The Washington Clean Energy Transformation Act of 2019 requires that the state's utilities transition to carbon-free energy sources by 2045. This has led to an influx of solar and wind power projects in Eastern Washington. The Waterville Plateau is ideal to serve this need given its large number of sunny and windy days. The end moraine's high elevation and proximity to large transmission lines make it a potential place for renewable energy projects. Stay tuned.

Stop 2—End Moraine Near Pilot Rock

Figure 15. Pilot Rock School which was located on the southeast corner of the intersection of roads 5 NE and S NE. The school operated at least as early as 1915 (Ogle, 1915) and at least as recently as 1933 (McGrath, 1989). Source: Les Lillquist, 1960's.

Enroute to Stop 3

Route: Our next stop is north of Baird (Figure 1). Head north on road S NE one mile to its junction with road 6 NE. Here, turn left and head west for one mile on road 6 NE to its junction with WA 17. Cross WA 17 and continue west on road 6 NE (i.e., St. Andrews Road East) for 3 miles on gravel, then on pavement to St. Andrews. Continue west on paved St. Andrews Road West for another 3 miles to its junction with road L NE (Heritage Road NE). At this junction, turn left onto gravel Road L NE and head south for ~3.5 miles to Stop 3. GPS coordinates: 47.653043°N & 119.491720°W.
Glaciation. Once you have travelled a mile or so west of WA 17, the road passes through "ground moraine" behind the end moraine of the Cordilleran Icesheet (Figures 9 & 10). Note the low relief terrain that is only punctuated by haystack rocks. Some of the numerous depressions may contain ponds. The best time of year to see these ponds is in early to mid-Spring.

Enroute to Stop 3

St. Andrews: The community at the junction of St. Andrews W road and St. Andrews S road is not surprisingly...St. Andrews! The first settlers arrived here around 1889 (Steele and Rose, 1904). The first post office opened in 1890 (Forte, n.d.). The small community was named after Captain James Saint Andrews, the first postmaster here and a Civil War veteran (Meany, 1923). Prior to the railroad coming to Mansfield in 1909, the Darby Hotel in St. Andrews was a resting point on the wheat hauling route between Mansfield and Coulee City (McGrath and Jayne, n.d). St. Andrews was also on the mail route between Coulee City, Mansfield, and Brewster (Ramsey, 1973). The school operated from before 1912 until at least 1948 (McGrath, 1949) and the post office operated here until 1957 (Forte, 1957). The St. Andrews Cemetery lies 1.5 miles southeast and the Danish Cemetery lies 1 mile southwest of St. Andrews. As you can see now, little remains beyond two houses and the St. Andrews Grange Hall. The Grange Hall sits where the 2 room school sat (McGrath, 1989).

Stop 3—Meltwater at Burton Draw

Location: We are located along road L NE just south of its junction with 3 Road NE. One channel of Burton Draw lies to our immediate north and the other lies to the south. The lands on either side of the road are private property. Do not access these without permission.
Terrain: The drive south from St. Andrews West Road has brought us from ground moraine back into end moraine (Figures 10 & 16). Notice how the terrain has become more hummocky and land use suggests that soils are not as good here as in parts of the ground moraine. These poor soils are especially the case to the west. In addition to glacial till deposition, meltwater erosion likely played a role here and to the west in soil quality.
Meltwater: A key question regarding icesheets is where does the icesheet meltwater go? Given our proximity to the Lower Grand Coulee, one might think that most of the meltwater flowed outward from the glacier terminus and into the Lower Grand Coulee. That does not appear to be the case here as elevations actually increase toward the Lower Grand Coulee's wall. Instead, in this area, most meltwater flowed west into Moses Coulee via Burton Draw. North of here, another drainage--Long Canyon-- also delivered water westward to Moses Coulee. And south of here, Sulfur Springs Canyon may have transported meltwater to Moses Coulee (Figure 16). Much of the remainder flowed into depressions and formed ephemeral lakes and ponds.

Stop 3—Meltwater at Burton Draw

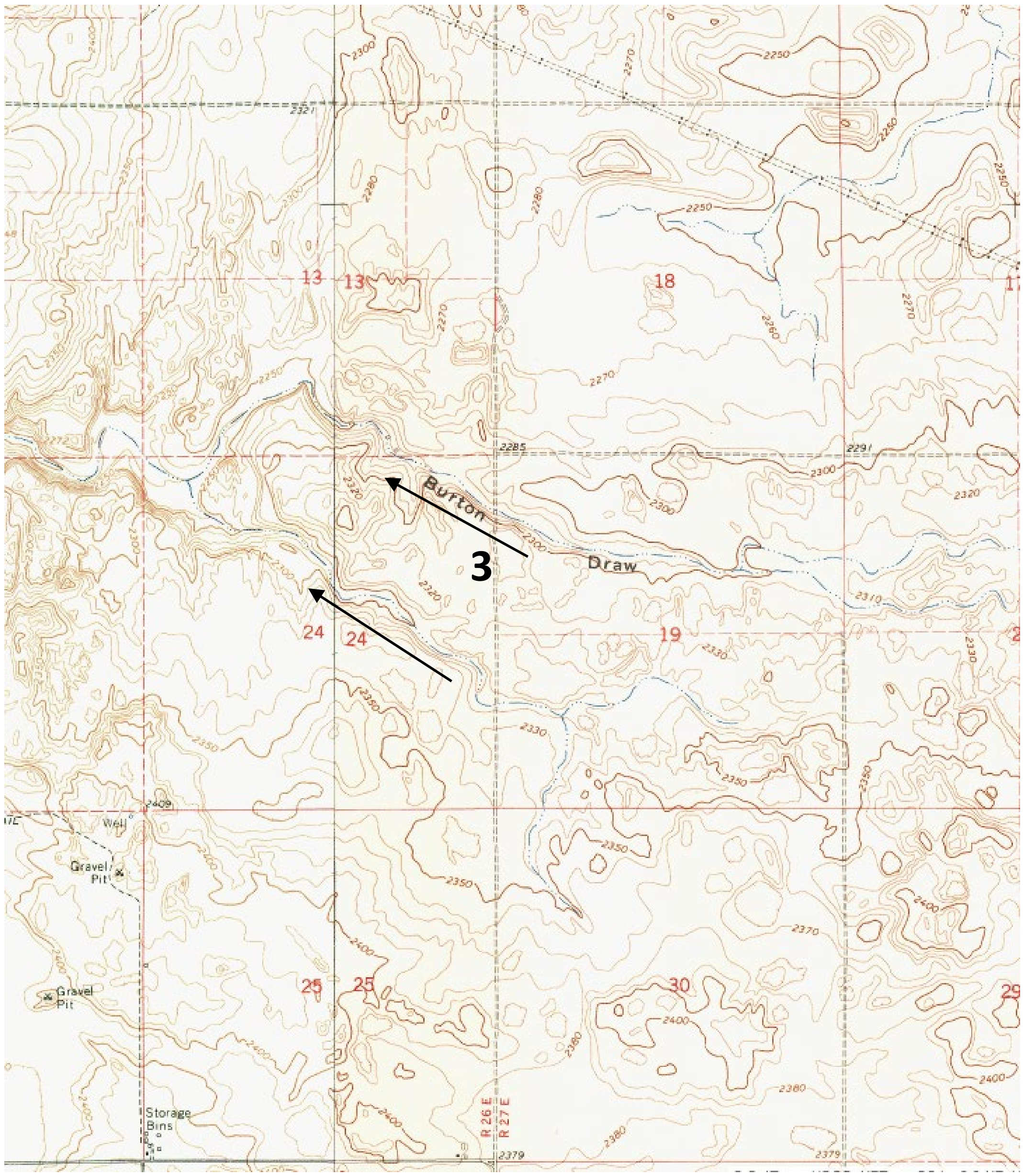


Figure 16. Hummocky terrain of end moraine at Stop 3. Note headwaters of Burton Draw. Approximate location of Stop 3 shown with a bold 3. Heavy arrows indicate direction of water flow. Source: Caltopo.com.

Stop 3—Meltwater at Burton Draw

Burton Draw. The area of our field stop including Burton Draw to its mouth in Moses Coulee has been mapped at a small scale as "glacial drift" which includes glacial till (i.e., debris deposited by ice) and glacial outwash (i.e., debris deposited by meltwater) associated with moraines, till plains, and meltwater channels and terraces (Hanson & others, 1979). A seismic test along the axis of Burton Draw near its mouth indicates a sediment fill of about 65 feet atop the basalt bedrock (Hanson, 1970). This fill must represent the glacial drift noted above.

Burton Draw was a main channel delivering meltwater to Moses Coulee. Near where we are parked, the draw is actually two channels—the one we are standing above and another approximately 0.5 mile south (Figure 16). The channel we are standing above is the better developed of the two with steep sides and a channel floor about 20 feet below the surrounding terrain. The channel width is nearly 200 feet. This "draw" is eroded into glacial drift here but it changes dramatically to the west (Figure 17). There, it is largely eroded into basalt so the landscape has a scabland appearance similar to that between Dry Falls and Banks Lake. In fact, Hanson (1970, p. 53) describes the draw as having a "typical scabland-like character". In that portion of Burton Draw, the channel is up to 600 feet wide and 80 feet deep. The entire Burton Draw scabland ranges up to 1.8 miles wide (Figures 18 & 19).

Implications: Clearly, a large amount of water flowed through Burton Draw at some time in the past. Was this meltwater from the Okanogan Lobe or from early Missoula Floods that were not confined to the Upper Grand Coulee? If the former, was there sufficient discharge to create scablands in resistant basalt? If the latter, the channels that led to Burton Draw have been obscured by glacial drift. If the latter, the location of Burton Draw suggests a Missoula Flood origin for at least some of the waters that shaped Moses Coulee. This finding runs counter to recent thoughts on the origins of Moses Coulee (Lesemann & Brennand, 2009; Gombiner, 2022).

Stop 3—Meltwater at Burton Draw

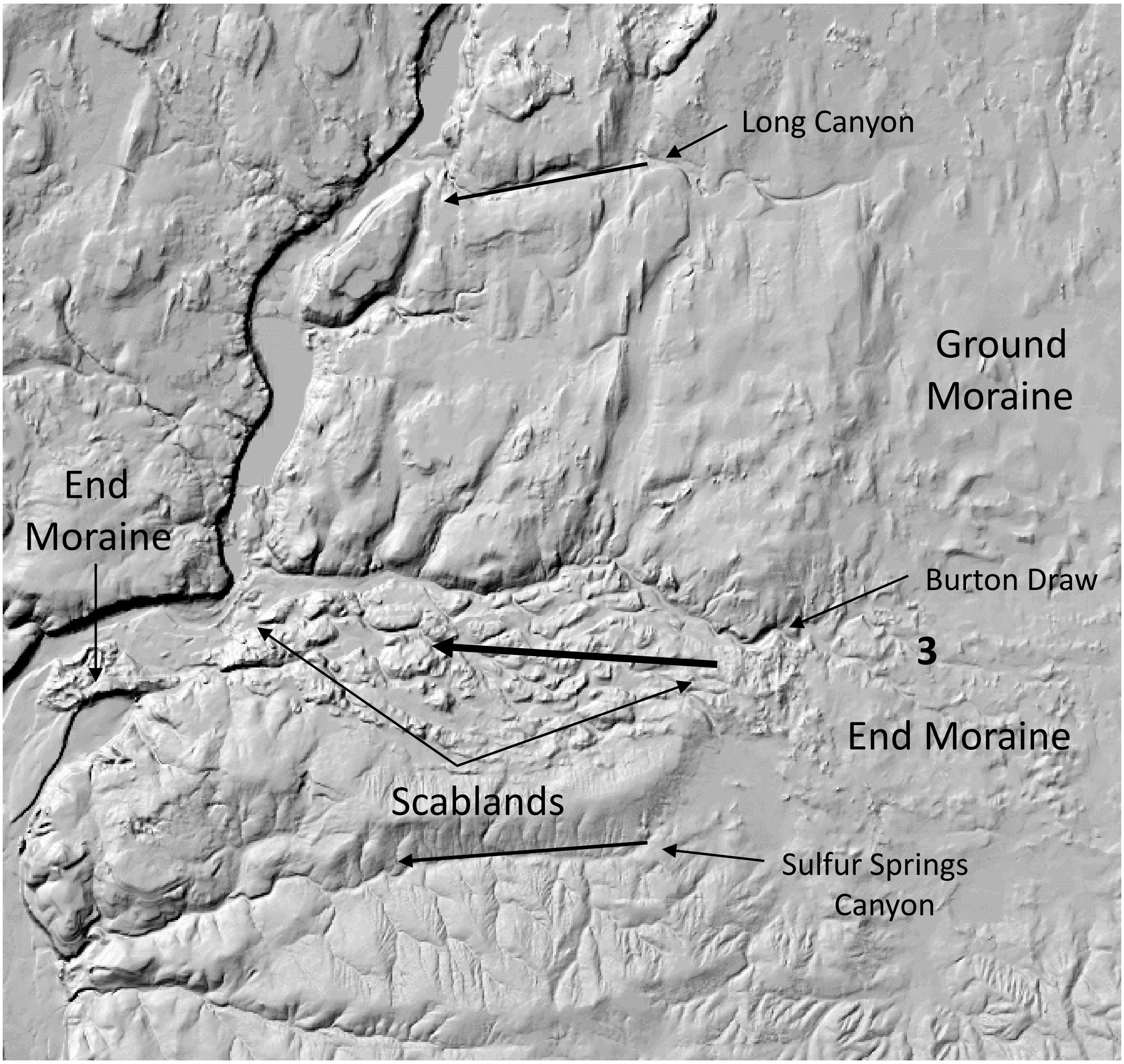


Figure 17. Burton Draw's, Long Canyon's, and Sulfur Springs Canyon's paths to upper Moses Coulee. Bold 3 indicates approximate location of Stop 3. Note the scablands of Burton Draw and the hummocky terrain of the end moraine in the vicinity of Stop 3. Heavy arrow indicates direction of flow. Source: Caltopo.com.

Stop 3—Meltwater at Burton Draw

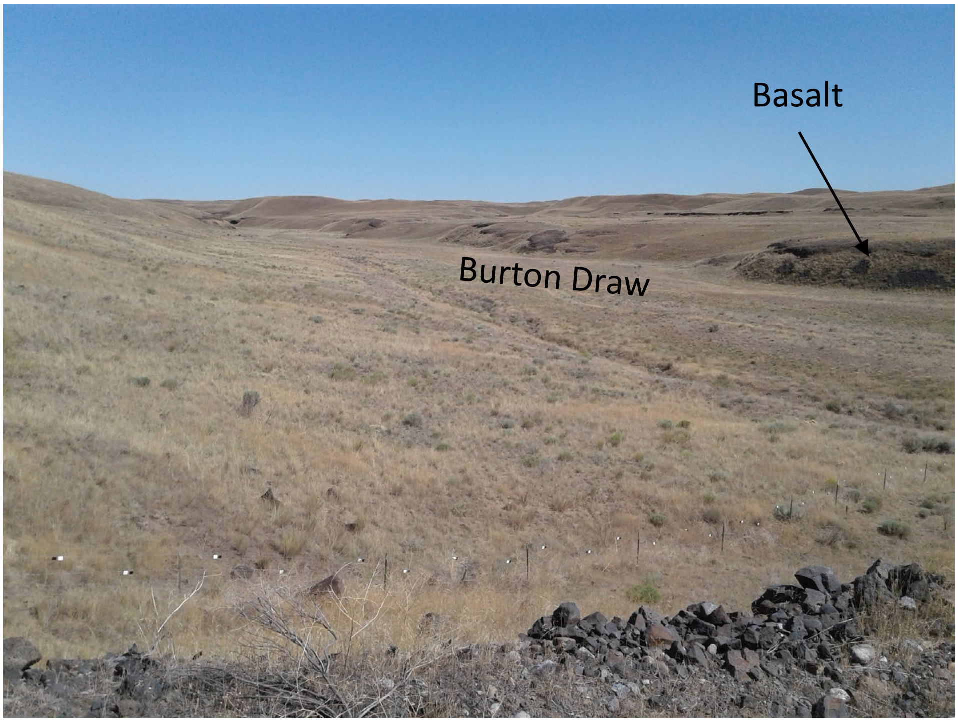


Figure 18. View up (east) Burton Draw from near Jamison Lake. Note broad channel eroded in basalt. Source: Author photo, July 2023.

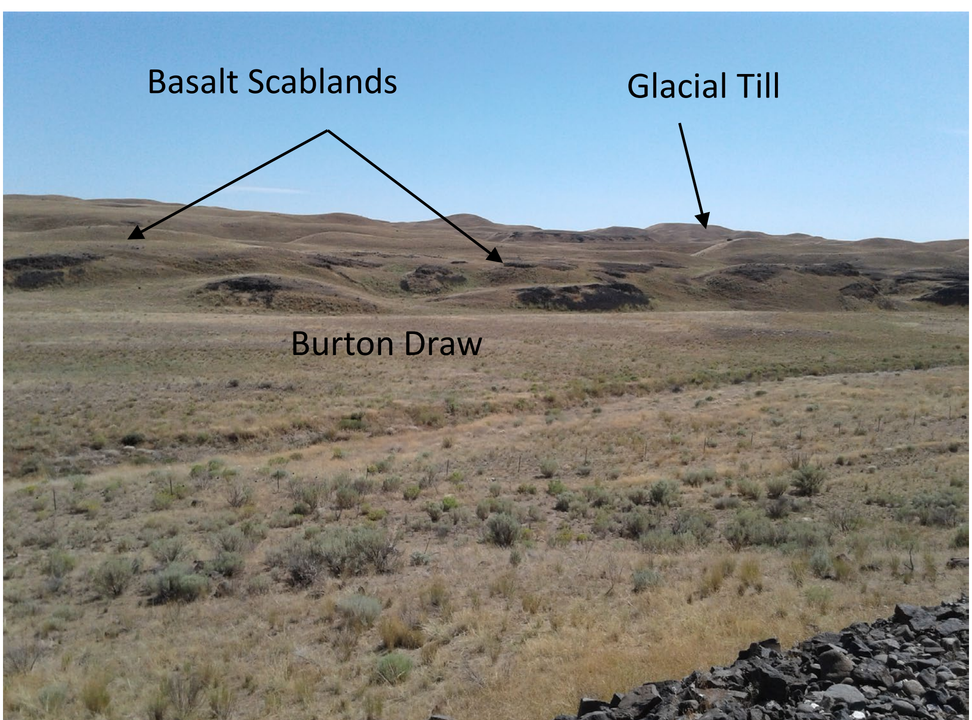


Figure 19. View across (southwest) Burton Draw near Jamison Lake. Note broad channel, scablands, and glacial till of the end moraine atop basalts. Source: Author photo, July 2023.

Stop 3—Meltwater at Burton Draw

Oddity: West of Moses Coulee, Dutch Henry Draw formed on the south (downglacier) side of the Withrow Moraine. This draw appears to have delivered much of the Okanogan Lobe's meltwater eastward to Moses Coulee. Burton Draw formed on the north (upglacier) side of the Withrow Moraine, then delivered water westward to Moses Coulee (Figure 17). Why the difference?

Ponds and Lakes. The depressions of the hummocky terrain are ideal places to store water during wet seasons, years or during deglaciation. Indeed, in the June 2019 Google Earth image, there were at least 8 ponds within 0.75 miles of where we are parked (Figure 20). Were an early spring 2019 image available that number may double. Atkins Lake (approximately 2 miles south) is an ephemeral lake that forms on the distal edge of the end moraine. Such lakes, when formed during deglaciation, are termed "proglacial". The presence of lake sediments shown on geologic maps and soil surveys for the area suggest that Atkins Lake has existed on and off for a very long period and its basin may indeed have held a proglacial lake. Contemporary Atkins Lake, at its maximum extent, is approximately 240 acres (0.38 mi^2). It forms from severe runoff associated with a rapid thaw when deep snow is on frozen ground. This is especially prominent in conventionally tilled fields unless they are deeply tilled (i.e., subsoiled). The placement of lands around the basin into the USDA's Conservation Reserve Program (CRP) has helped reduce such rapid runoff (Sharon Davis, written communication, 08/30/2023). The Conservation Reserve Program pays farmers to take land out of agricultural production and plant it with more native types of vegetation. This year round vegetation cover greatly reduces soil erosion plus provides excellent habitat for wildlife. As of September 2023, the lands west of the intersection at Stop 2 and west of the road at Stop 3 are CRP lands.

Stop 3—Meltwater at Burton Draw

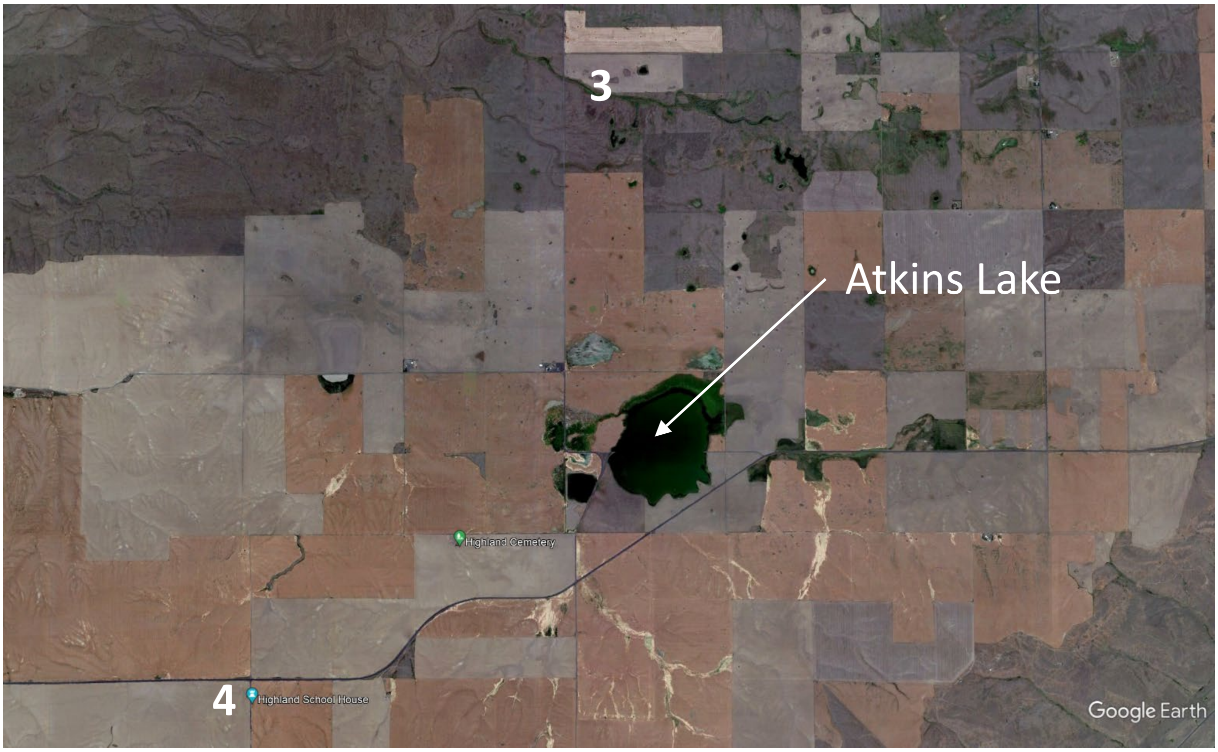


Figure 20. Ephemeral Atkins Lake occurs in a likely proglacial lake basin. Stops 3 and 4 are shown with bold numbers. Note the other dark areas that represent smaller ponds and wetlands. Source: Google Earth Pro, 07/27/2019.

Enroute to Stop 4

Route: Continue south on road L NE for ~3.4 miles to US 2. Note that this road will curve around part of the Atkins Lake basin. At the junction of road L NE and US 2, turn right onto US 2. Follow US 2 west for 2.2 miles. Turn left onto road J SE (Highland School Road SE) and proceed to the Highland School. Turn around and park on the east side of this road if there is room GPS coordinates: 47.598124°N, 119.533166°W.

Stop 4—Historic Settlement at Highland

Location. We are located on Road J SE (Highland School Road) just south of its junction with US 2 (Figure 21). Baird lies 3.3 miles to the northeast. We passed out of the glaciated area just north of US 2.

Highland: This area is referred to as "Highland" because of its relatively high elevation (~2500 ft) compared to the surrounding terrain. Recall that these high elevations prevented much of the Okanogan Lobe's meltwater from flowing south into the Lower Grand Coulee.

Native Americans. Native American use of this portion of the Waterville Plateau was likely seasonal occurring mainly in spring and early summer. Camas digging would have occurred in the thin soils on the margins of the coulees. Waterfowl and wetland plants were also likely exploited in and around the numerous ponds of the glaciated area north of here (Anglin, 1995).

Early Euroamerican settlements in the area. The earliest written account of the area by Lieutenant Thomas Symons of the U.S. Corps of Engineers in 1881 stated "The land between the two coulees (Grand Coulee and Moses Coulee) is mostly rich and covered with bunch grass" (Symons, 1967, p. 120). This bunch grass likely first attracted stockmen to the area after about 1883. Particularly harsh winters (e.g., 1880-81 and 1889-90) and overall dire economic conditions (1893) limited the influx of settlers. However, at least three hardy farm and stock raising families were in the area by 1892 (Steele and Rose, 1904).

J. Harry Noonan said of Highland..."*Lying at such an altitude as to overlook the greater part of Douglas county, the giant country of the Evergreen State, and much of the higher portions of Washington, as well as points in Idaho, Oregon, and British Columbia, rests the beautiful Highland country, the home ideal of numbers of happy, enterprising, and self-sustaining tillers of the soil....This country being highly elevated the crops are not subject to severe frosts like that of the lower lands, and the higher elevation insures us sufficient snow and rain during the year to saturate the ground, and being a brown clay soil and wonderfully adapted to the retention of moisture, good crops could be raised without a drop of water from May until August."* (Steele and Rose, 1904, p. 604).

In addition to its physical amenities, settlement of the area was driven by railroads (Northern Pacific in Coulee City by 1890 and Great Northern in Ephrata by 1892) (Meinig, 1968). Homesteaders had four ways to acquire land from the federal government: Homestead Act, preemption, Timber Culture Act, and Desert Land Act. The Homestead Act granted 160 acres to the head of a family if the land was resided on continuously for 5 years. Preemption permitted the head of a family to purchase an additional 160 acres for $1.25/acre after 6 months of occupation. A further 160 acres could be obtained via the Timber Culture Act by planting and maintaining 40 acres of trees. The Desert Land Act permitted a farmer to obtain an additional 160 acres at $1.25/acre if the land was irrigated (Meinig, 1968). Given the lack of precipitation and available surface water in many years, it is likely that the Timber Culture Act and the Desert Land Act were less commonly used in this area than the Homestead Act and preemption.

Stop 4—Historic Settlement at Highland

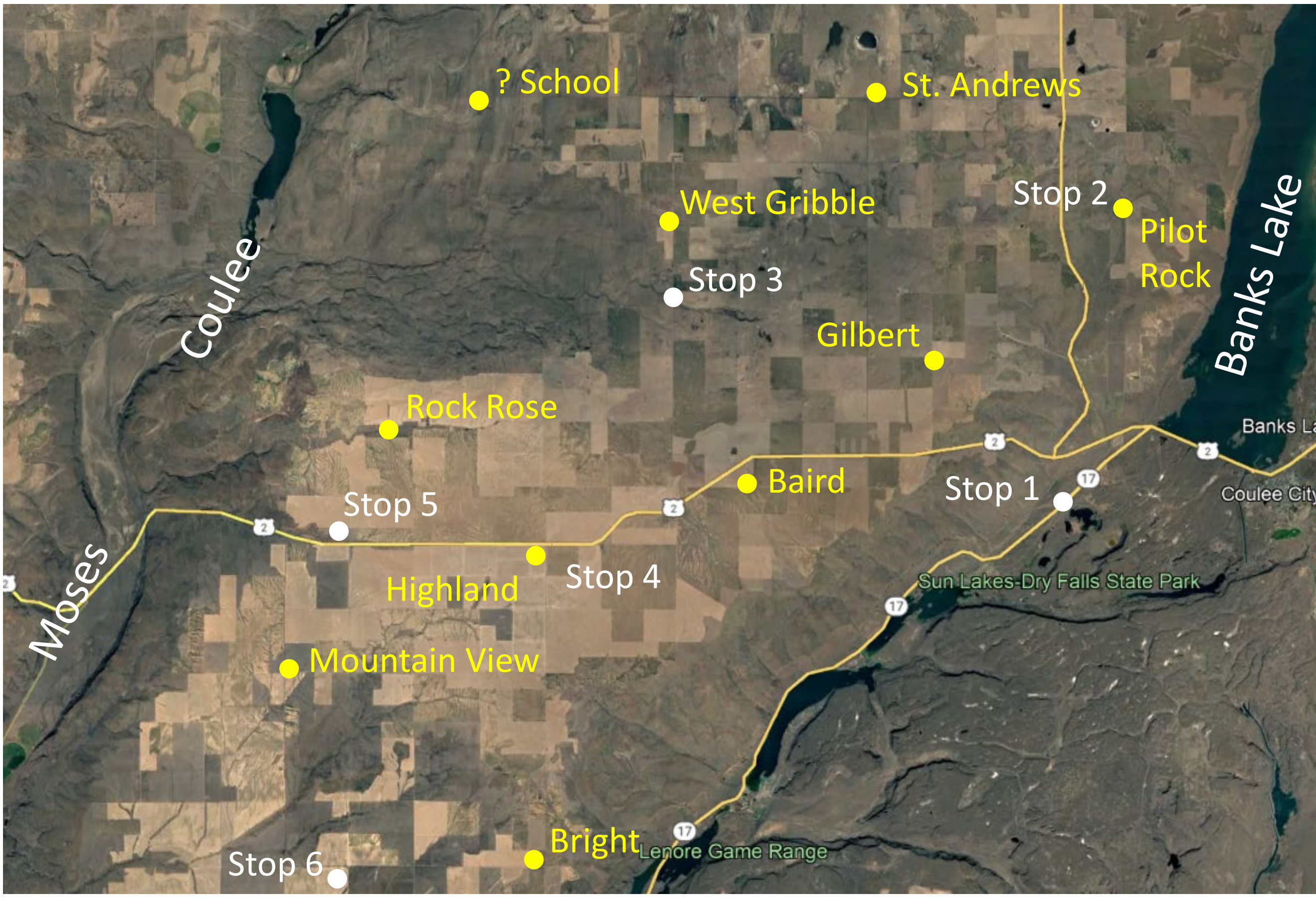


Figure 21. Yellow dots indicate locations of schools as of 1915. Baird is the location of a school and the climate data in Figure 5. Pilot Rock and Highland are field trip stops and school sites. "? School" means a school was located near the yellow dot but I don't know its name. The approximate locations of Waterville Plateau field trip stops noted with white dots. Source: Google Earth Pro, 04/18/2021 and G.A. Ogle & Co (1915).

Highland School. The Highland School was one of nearly 100, public, schools in Douglas County (McGrath, 1989) (Figures 21 & 22). Within our general field trip area, there were at least 10 small schools including Pilot Rock, St. Andrews, Baird, Gilbert, Highland, Bright, West Gribble, and Rock Rose. Most, if not all, of these were "1 room schools" with a mix of grades taught in that one room. There is actually a second room in the Highland School that may have been the "teacherage"—i.e., where the teacher lived (McGrath, 1989). The first Highland School likely opened in 1893 serving the several families in the area. It is not known when this version of the Highland School was built but it closed in Spring 1944. The last teacher there, Mary (Cox) Nutt earned $1500 for the nine-month academic year (McGrath, 1989).

Stop 4—Historic Settlement at Highland

Figure 22. Highland School. Cistern in foreground. Source: Author photo, March 1998.

Figure 23. Baird School as of March 2000, view northeast. This structure apparently dates back to before 1915 when it was located 1.75 miles east. Source: Author photo.

Stop 4—Historic Settlement at Highland

Baird. Highland School is about 3 miles southwest of Baird, a small farm community that was first settled by ranchers and farmers in the early 1890's (Steele and Rose, 1904) (Figure 21). A school and post office was located in section 32 immediately southeast of seasonal Atkins Lake as of 1915 (Ogle, 1915). The first postmaster, James Baird, is the namesake of the community (Meany, 1923). The post office operated from 1896 to 1934 (Jim Forte, n.d). It is unclear when the school opened at Baird. By 1933, it appears to have closed because of consolidation with Highland School (Figure 22). In 1944, the Baird School House was moved ~1.75 miles west to the Highland Cemetery where it sat (Figure 23) until burning in 2002 (Sharon Davis, written communication, 08/30/2023).

Depopulation. Over time, the numbers of individual farms ebbed and flowed because of years of deluge and years of drought, crop prices, and overall economic conditions (e.g., Great Depression). Wet (i.e., deluge) years initially attracted homesteaders and dry years drove them away. Note the drought years in the ~120 year Palmer Drought Severity Index (Figure 24). Dry years are especially problematic when they are grouped as in the mid-1920's through the early 1930's. As a result, schools in the area came and went as farm families moved in and out (McGrath, 1989). Recall that a family in those early years might farm 160-320 acres/year (i.e., 160 acres from the Homestead Act and 160 acres from preemption) using horses in all aspects of the farming. Now, it is common for an individual farmer to cultivate several thousand acres per year. Mechanization of agriculture and associated economies of scale have played a large part in this change. The results today are far fewer individual farms therefore far fewer people on the land. This then helps explain the loss of schools, post offices, and businesses here.

Stop 4—Historic Settlement at Highland

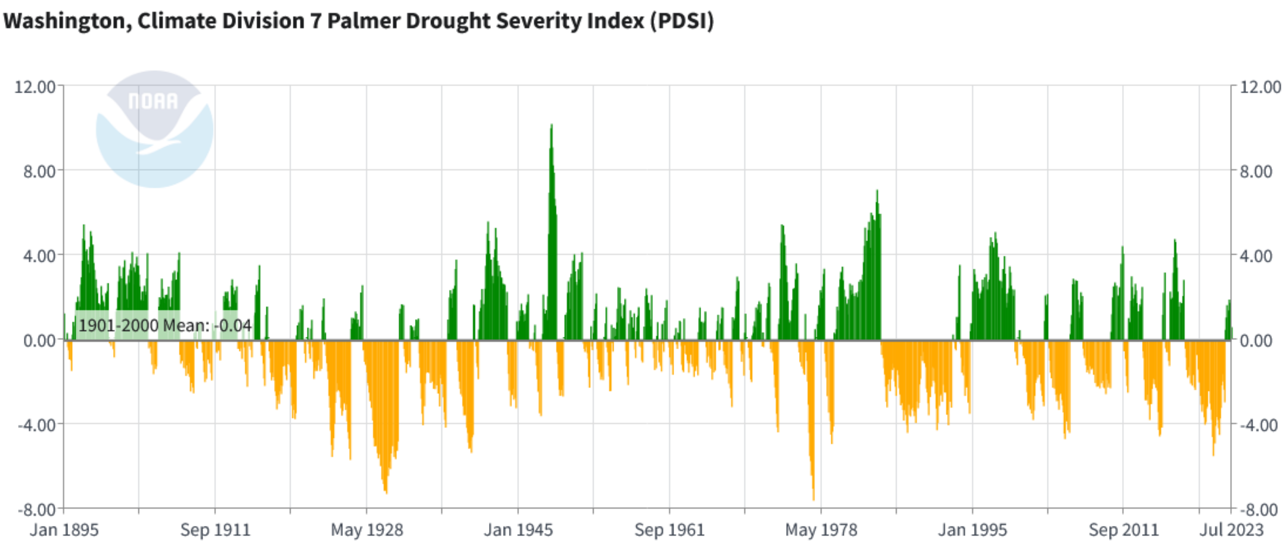


Figure 24. Palmer Drought Severity Index for the Okanogan Big Bend climate division of Washington state. "Deluge" years are shown in green and drought years in orange. Severe drought may be seen as strongly negative numbers (e.g., ~1977) as well as a lengthy, consecutive period of moderately negative numbers. Note the severe droughts of the teens through the 1930's, 1970's, and in the past ~30 years. Source: NOAA—National Centers for Environmental Information (https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/divisional/time-series/4507/pdsi/all/7/1895-2023?base_prd=true&begbaseyear=1901&endbaseyear=2000).

Enroute to Stop 5

Route: Return to US 2. Turn west onto US 2 and head west 3 miles to G Road SE. Turn right on G Road NE and drive north ~0.1 mile. Park on the side of the road. GPS coordinates: 47.600796° N & 119.598414° W.

Stop 5—Wind & Soils Along Old US 2

Location. We are located just north of US 2 and west of G Road SE. To reach the site, walk about 270 yards west of G Road SE on old US 2 (Sunset Highway). The site is an old quarry on the side of old US 2. The lands here are private property. Do not access these without permission.

Wind, water and soils. We are located less than 3 miles south of the end moraine of the Okanogan Lobe. This means that soils were not shaped directly by glaciation. Instead, wind and liquid water has played a major role in the soils here and on our drive south to Stop 6. The loess (i.e., windblown sediments) of the site are characterized by silt-sized sediments but also often includes some fine sand and clay. Silt is intermediate in size to sand and clay. Its interactions with water and nutrients are also intermediate to sand and clay. This means that silt will allow water infiltration (unlike clay-rich soils) but will slow percolation (unlike sand-rich soils). These characteristics are ideal for agriculture in a semiarid setting. Additionally, loess often leads to deep soils that store more water in the rooting zone than do shallow deposits. Water has extensively eroded these deposits (Figure 25). Because of the extensive stream channel development and associated water erosion, we can say that the area south of the end moraine is a "mature" landscape as opposed to the glaciated area (Figure 26).

Where did the loess originate? We typically think of loess as forming downwind of glacial outwash plains. When glacial meltwater slows, it deposits its transported sediments. Once those sediments have dried, they become susceptible to the pervasive winds that characterize areas adjacent to glacier fronts. The problem here is that there doesn't appear to have been a major outwash plain to serve as a significant source of loess. In a very limited study, Markham (1971) did find a decrease in loess texture away from the Withrow moraine suggesting that there was enough outwash to supply local loess deposits. However, more recent and extensive studies show that loess thickness and grain size declines east and north of the Pasco Basin (Busacca & McDonald, 1994) (Figure 27); therefore, much of the loess of the Waterville Plateau likely came from the Pasco Basin which temporarily held ice age floodwaters that descended the scablands to the north. Clearly, more research needs to be done on this issue on the Waterville Plateau.

Quarry exposure. The upper 5-6 feet of the quarry cut shown in Figure 28 is loess. Notice the lack of rocks in this exposure. Such would not be the case in soils exposed north of the end moraine. Using very brief field observations, and Web Soil Survey, it appears that two soils formed in this loess "parent material" over time. The upper and more recent soil includes three horizons—an organic-rich A horizon, a clay-rich Bt horizon, and a calcium carbonate-rich Bk horizon. Over time, water infiltrating the soil moved clays and calcium carbonate down where they accumulated at different levels. An earlier soil appears to have formed below (2Bkqm). It is important to note that it takes significant time for the formation of Bkqm horizons in this semi-arid environment. By the "significant", I mean well longer than since ~15,000 years ago. Such soils should characterize areas south of the Okanogan Lobe which should have been stable for well longer than 15,000 years. The soil horizons sit atop a reddish, coarse textured interbed and a Columbia River Basalt flow.

Stop 5—Wind & Soils Along Old US 2

Figure 25. Loess landscape in the vicinity of Stop 4 (see bold 4). Note the "dendritic" drainage pattern (i.e., it looks like the branches of a tree) that characterizes uniform substrate while the frequency of these dendritic channels suggests that the substrate is easily erodible. Further, this well-developed dendritic drainage pattern indicates that this is a mature landscape (i.e., it is older than that of stops 2 & 3). Source: Google Earth Pro.

Stop 5—Wind & Soils Along Old US 2

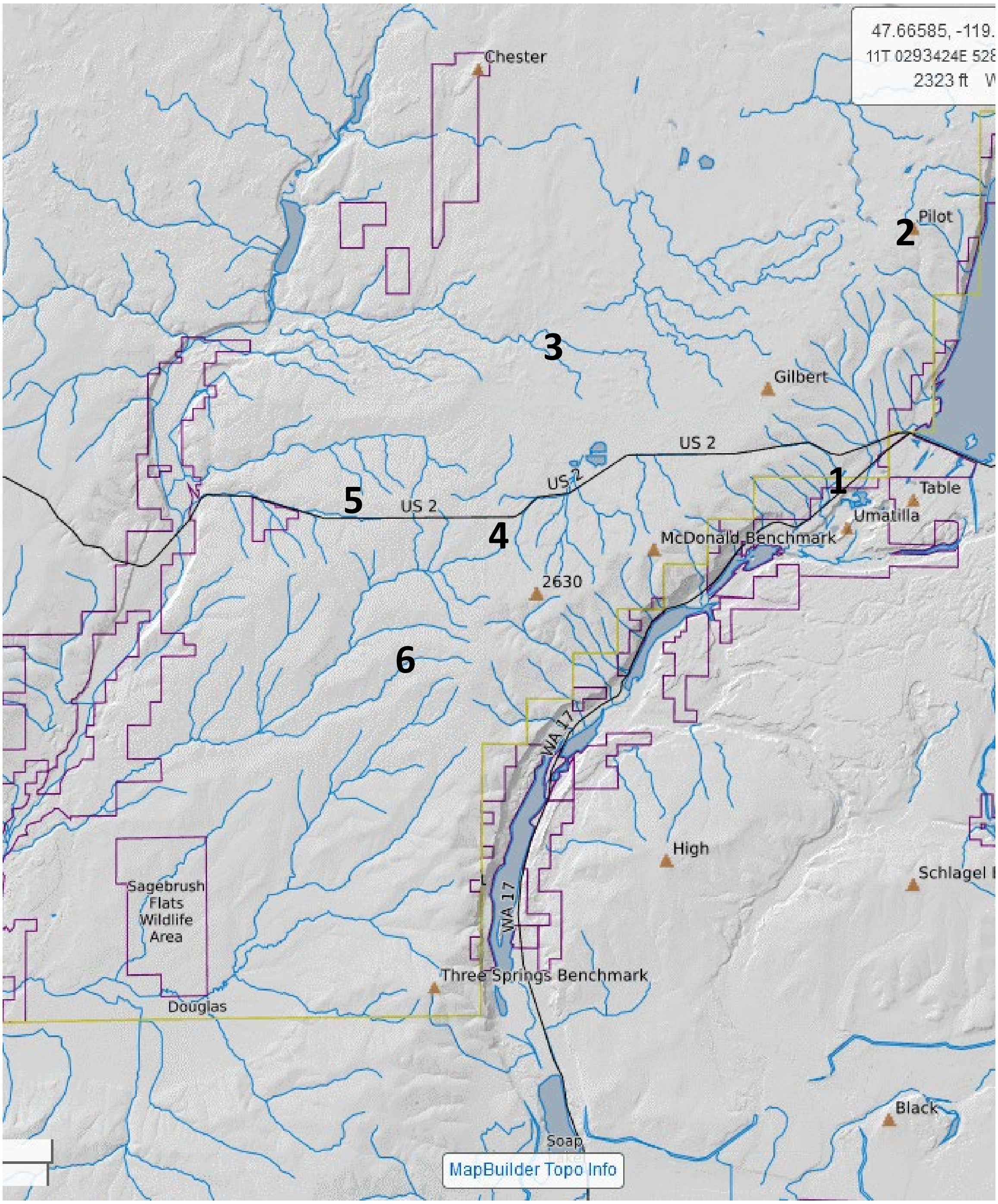
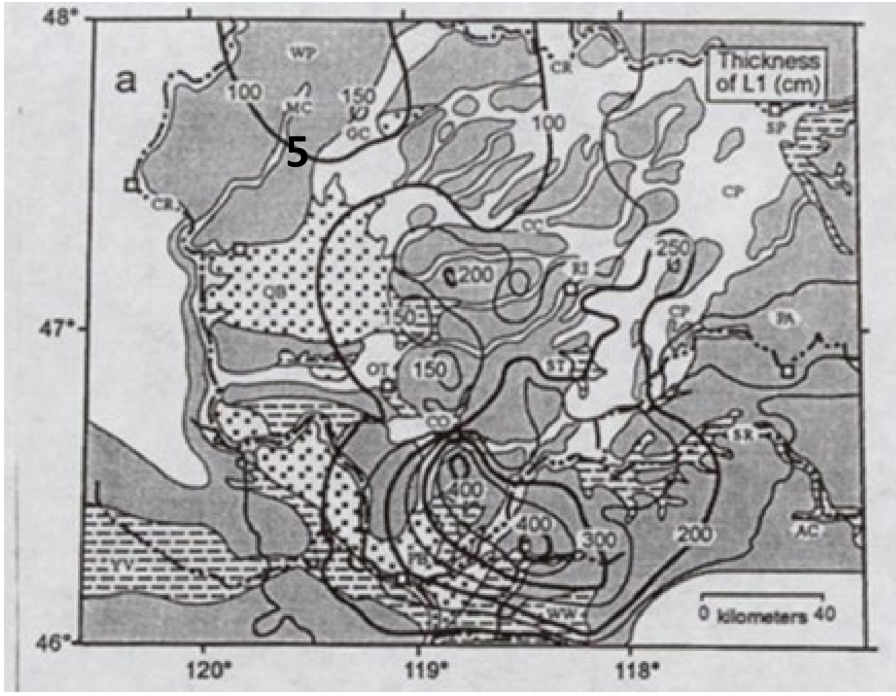


Figure 26. Contemporary drainage patterns on the Waterville Plateau east of Moses Coulee. Note how they differ north and south of US 2 which approximates the boundary between glaciated and un-glaciated areas. Bold numbers indicate approximate locations of field trip stops. Source: Caltopo.com.

Stop 5—Wind & Soils Along Old US 2

A



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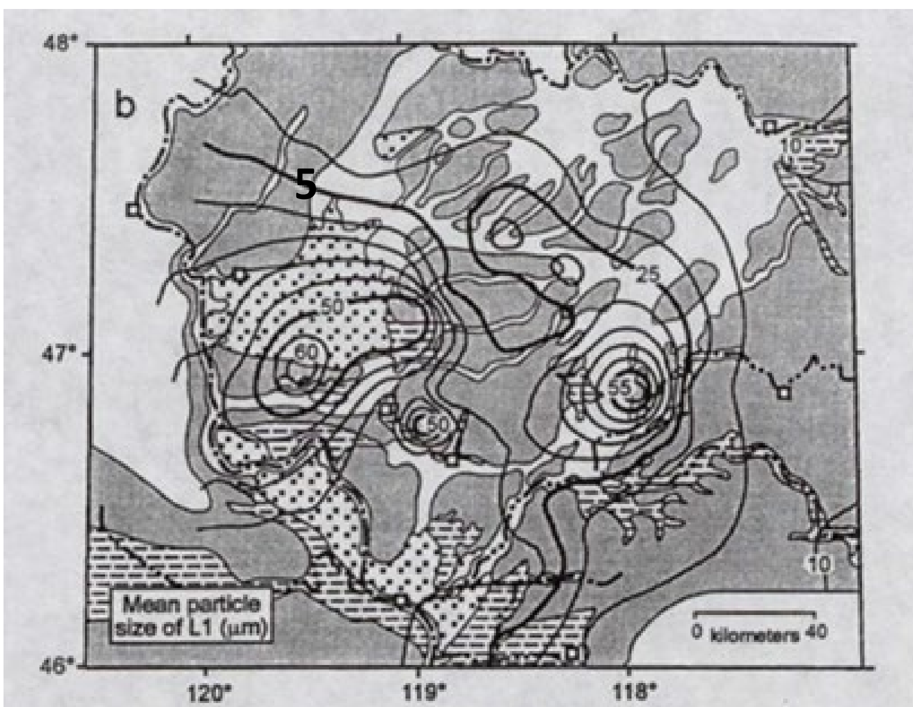

Figure 27. A. Contour map of loess thickness for L1 (more recent) loess (above). Bold contours are 100 cm intervals, thin contours are 50 cm intervals. B. Mean particle size for L1 loess (below). Bold contours are 25 micrometer intervals. Thin contours are 5 micrometer intervals. Places shown on the map include: WP = Waterville Plateau, MC = Moses Coulee, GC = Grand Coulee, PB = Pasco Basin, YV = Yakima Valley, and PA = Palouse. Approximate location of field trip stop is shown with a bold 5. Source: Busacca & McDonald (1994).

Stop 5—Wind & Soils Along Old US 2

Figure 28. Soil exposure in quarry just north of old US 2 and west of G Road SE. Quaternary soil lies above solid white line. Based on very brief field observations and examination of Web Soil Survey (Selah and Benwy soil series), I have assigned the outcrop 4 soil horizons. See text for details. Soil lies over sedimentary interbed (SI) and basalt (B). Note ~20" long folding shovel (red circle) for scale. Source: Author, July 2023.

Enroute to Stop 6

Route: Return to US 2. Turn right and head 1 mile west to Whitehall Road. Turn left and head generally south for about 6.5 miles on paved Whitehall Road across a southwest sloping, dissected loess plain. The road will make a couple of turns before Stop 6 including a 90^{o} turn to the east and another 90^{o} turn to the south in the final 1.25 miles. The GPS coordinates for Stop 6 are: 47.523148°N & 119.598499° W. Park along the side of the road.

Stop 6—Ephrata Pattern Bombing Range, Whitehall Road

Location. We are located ~0.25 mile south of the junction of Whitehall Road and 6 Rd SE (i.e., Highland School Road SE). This is Washington DNR land farmed by a local farmer.

What was the U.S. military doing in Central Washington? Central Washington was a hotbed of military activity during World War II. U.S. Army air bases were present in Ellensburg, Yakima, Ephrata, Moses Lake, Walla Walla, and Spokane (Figure 29). The nearest of these bases—Ephrata-- was developed as the Ephrata Army Air Base in 1942 to provide training at nearby bombing and gunnery ranges in the area. It served heavy bombers (mainly B-17's) until 1943. In 1944, it was reassigned to the Fourth Air Force who used it to train P-39 and P-38 fighter pilots (Kershner, 2010).

Air bases are often associated with bombing and strafing sites, especially in semi-arid areas with sparse human populations. Central Washington fit this description well in the 1940's. At least two bombing areas were present here in the 1940's. Both were used by airplanes flying out of Ephrata. One area consisted of four targets south of Ephrata and north of the Saddle Mountains and Crab Creek. The other area consisted of at least three targets on the Waterville Plateau (Figure 30).

Where were the Waterville Plateau military sites? Waterville Plateau sites were mostly located on landscapes that were marginal for agriculture because of glaciation (Bombing sites 1 & 2, and landing strip) or ice age floods (Bombing site 3 and Strafing site). This site (Bombing stie 4) is the exception--i.e., it is well south of the glacial limit and was not covered by ice age floods; however, part of the site lies on shallow soils directly underlain by basalt (Figure 31). The site was located on 2,460 acres of leased land from 1943 until 1946 (USACE, 2021). I suspect the site was chosen because part lies on Washington state land, the other part lies on poor quality, private farm land, its sparse human population, and its proximity to Ephrata.

What remains of the bombing activity here? Because of farming activity west of Whitehall Road, and dense shrub steppe vegetation cover east of the road, the prominent bomb target is no longer visible. Perhaps the portion of the target east of Whitehall Road will be detectable once Lidar coverage is available in this area. What does remain here are portions of bombs that were dropped for practice (Figure 32). The practice bombs I have seen at Bombing Range 1 were filled with sand. Because the bomb fragments present here were probably farmed over and later removed from the farm field by farmers, the sand filling is long gone. Given the time frame this site operated (1943-46), I assume that these bombs were dropped by P-38 and P-39 aircraft. We can see remnants of these bombs in the farm field (look for chunks of metal) as well as in the adjacent scab patch. Because there are suspected munitions here, the site is slated for cleanup at some point in the next several decades (USACE, 2021); however, it is considered a a low risk site with unlimited access (Propublica, n.d.).

Stop 6—Ephrata Pattern Bombing Range, Whitehall Road

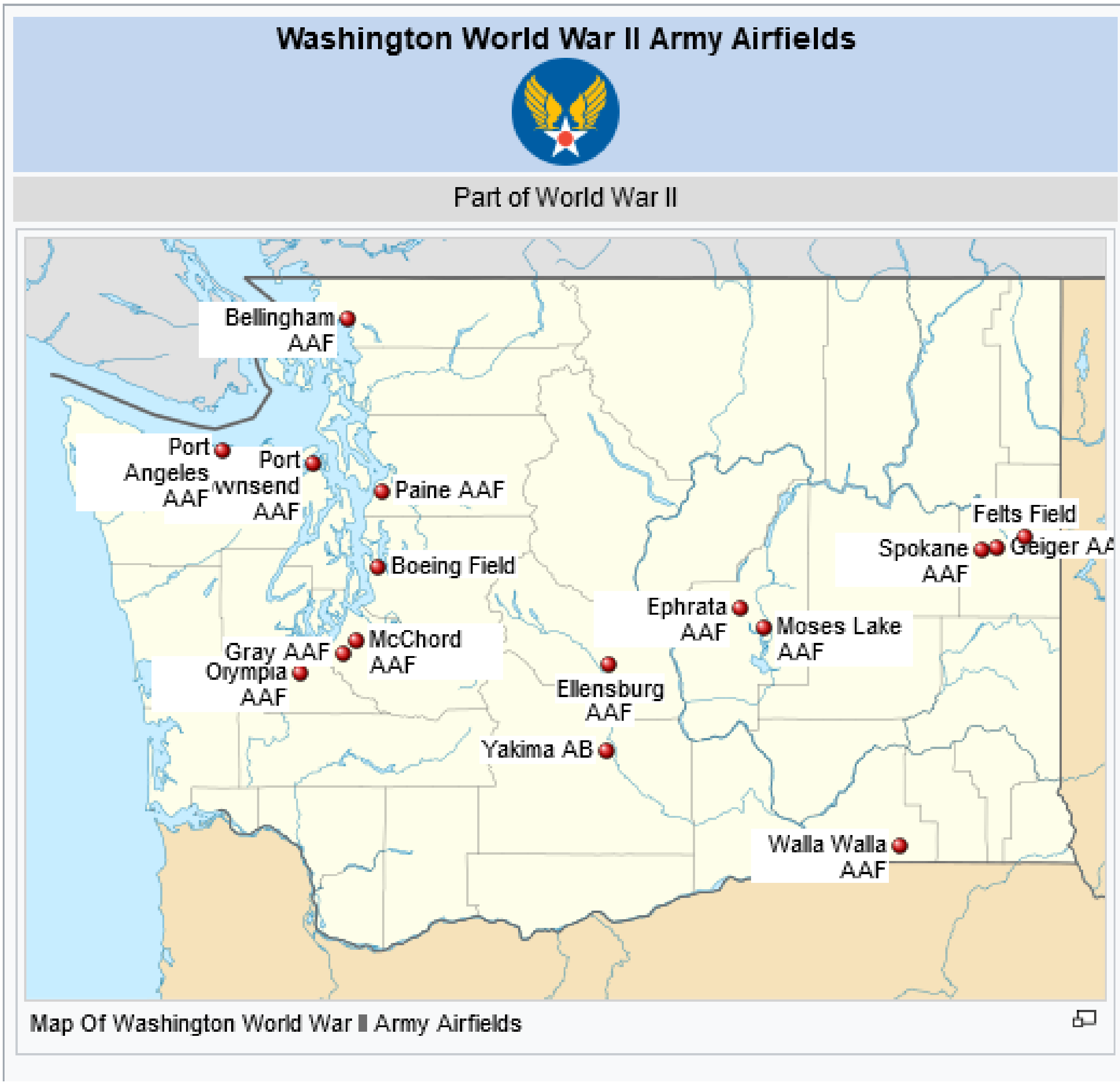

Figure 29. U.S. Army airfields in Washington state during World War II. Source: https://en.wikipedia.org/wiki/Washington_World_War_II_Army_Airfields

Stop 6—Ephrata Pattern Bombing Range, Whitehall Road

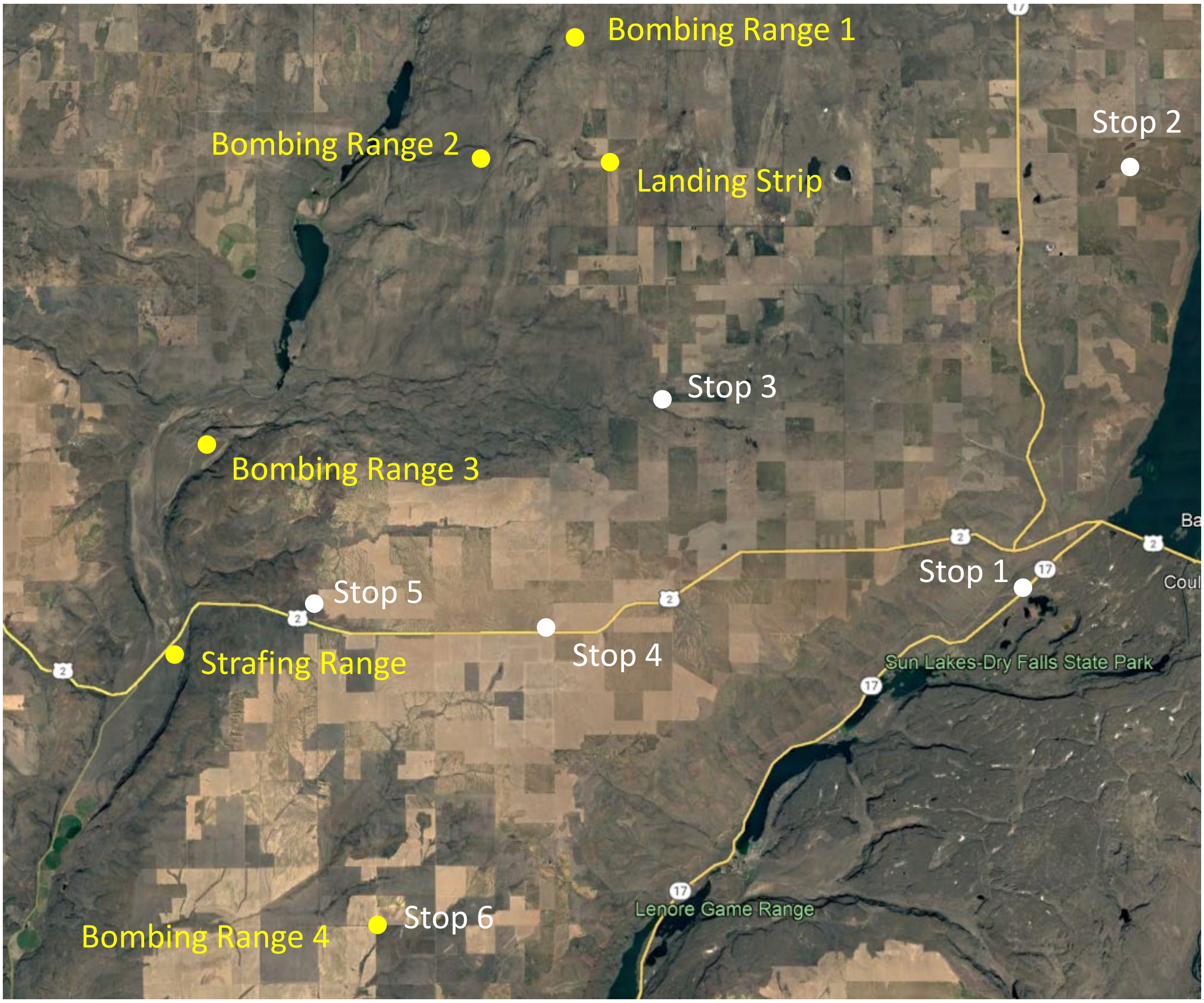

Figure 30. World War II-era, Army Air Corps bombing, strafing, and landing sites on the Waterville Plateau. Bombing ranges, 1, 2, and 4 are visible on USDA 1949 airphotos. Bombing site 3 (proposed) from Propublica Bombs in our Backyard Series (https://projects.propublica.org/bombs/installation/WA09799F3260009799#b=47.3085471753576,-119.96733993669582,47.714822345349226,-119.07195419450832&c=shrink). Landing strip and strafing range from Sharon Davis (written communication, 12/01/2021 & 01/05/2022).

Stop 6—Ephrata Pattern Bombing Range, Whitehall Road

Figure 31. Ephrata Pattern Bombing Range (Bombing Range 4 on previous figure), Whitehall Road, southern Douglas County, Washington. Approximate location of parking area for Stop 6 is shown with a bold 6. 1949 USDA Douglas County, Washington airphotos available from Douglas County, Washington GIS Department.

Stop 6—Ephrata Pattern Bombing Range, Whitehall Road

Figure 32. Deformed practice bomb dropped by P-38's or P-39's during 1944-45 at the Ephrata Pattern Bombing Range on Whitehall Road. Source: Author photo, July 2023.

Recent Waterville Plateau bombing range proposals: The establishment of bombing and strafing ranges on the Waterville Plateau during World War II seems reasonable given the state of the world in the 1940's and the sparse population of the plateau. However, the U.S. Navy proposed in 1974 to use 5,900 acres (9.2 mi^2) of the northern Waterville Plateau as a target training range. Given the size of the proposed range and that another 33,000 acres (51.6 mi^2) would have been subject to restrictions, this would have impacted 30 families living in the area (Rinker, 1976). Local farmers worked with members of Congress to squash the idea (Lee Hemmer, oral communication, 07/2023)

Wrap-up

The portion of the Waterville Plateau lying east of Moses Coulee has undergone tremendous environmental changes over the past ~15,000 years from deglaciation to torrents of meltwater, wind deposition of loess, water erosion of that loess, Native American occupation, Euroamerican settlement and agriculture, Euroamerican depopulation, military use, and now, wind and solar energy development. What will the future bring? Has the trend of Euroamerican depopulation reversed and will we increasingly see people escaping the cities to live here? Or will this land continue to empty out? Time will tell.

To Home

From here, you can take several paths paths to home, wherever it may be. You may choose to retrace the path to US 2, then head east or west. You may also choose to head south to Ephrata by following Whitehall Road south. Once in Ephrata you can head east, south or west.

Thank you!

Thank you for supporting these field trips since 2007. And thank you for supporting Central Washington University. I hope this has been an education and enjoyable field trip for you. Don't hesitate to contact me with questions or comments about this field trip or others that I have led in the past (see my website). Thanks for participating! Karl lillquis@cwu.edu & 509 963-1184.

References

Anglin, R. 1995. *Forgotten Trails: Historical Sources of the Columbia's Big Bend Country*. WSU Press, Pullman.

Baker, V.R., B.N. Bjornstad, D.R. Gaylord, G.A. Smith, S.E. Meyer, P. Alho, R.M. Breckenridge, M.R. Sweeney and M. Zreda. 2016. Pleistocene megaflood landscapes of the Channeled Scablands. In R.S. Lewis and K.L. Schmidt, eds., *Exploring the Geology of the Inland Northwest*. Geological Society of America Field Guide 41, p. 1-73.

Balbas, A.M., A.M. Barth, P.U. Clark, J. Clark, M. Caffee, J. O'Connor, V.R. Baker, K. Konrad & B. Bjornstad. 2017. 10Be dating of late Pleistocene megafloods and Cordilleran Ice Sheet retreat in northwestern United States. *Geology* 45 (7): 583–586.

Brady, N.C. and R.R. Weil. 2010. *Elements of the Nature and Properties of Soils* (3rd edition). Prentice Hall. Boston.

Bretz, J H. 1923. Glacial drainage on the Columbia Plateau. *Bulletin of the Geological Society of America* 34: 573-608.

Bretz, J H. 1969. The Lake Missoula Floods and the Channeled Scabland. *Journal of Geology* 77 (5): 505-543.

Busacca, A.J. & E.V. McDonald. 1994. Regional sedimentation of late Quaternary loess on the Columbia Plateau: Sediment source areas and loess distribution patterns. Regional Geology of Washington State, *Washington Division of Geology and Earth Resources Bulletin 80*: 181-190.

References (continued)

Clague, J.J. & T.S. James. 2002. History and isostatic effects of the last ice sheet in southern British Columbia. *Quaternary Science Reviews* 21: 71-87.

Donaldson, W.R. and C. Ruscha. 1975. Washington Climate for Chelan, Douglas and Okanogan Counties. EM 3889. Cooperative Extension Service, Washington State University.

Easterbrook and Rahm, 1970. *Landforms of Washington: The Geologic Environment*. Western Washington State College, Bellingham.

Fairbridge, R. 1968. *The Encyclopedia of Geomorphology*. Dowden, Hutchinson & Ross ; New York.

Forte, Jim. N.d. Postal History. Post Offices, Washington, Douglas County. https://www.postalhistory.com/postoffices.asp?task=display&state=wa&county=Douglas

Freeman, O.W. 1933. Stagnation of the Okanogan Lobe of the Cordilleran Ice Sheet and the resulting physiographic effects. *Northwest Science* 7: 61-66.

Gombiner, J.H. 2022. The Okanogan Lobe and Moses Coulee During the Last Glaciation. PhD Dissertation. University of Washington.

Groeger, L., R. Jones & A. Lustgarten. 2017. Bombs in our backyards. Propublica https://projects.propublica.org/bombs/#b=45.8485607518245,-123.32398837578125,49.09963783390812,-116.16090243828125&c=shrink

Gulick C.W. and M.A. Korosec. 1990. Geologic Map of the Banks Lake 1:100,000 Quadrangle. *Washington Division of Geology and Earth Resources Open File Report* 90-6.

Hanson, L.G. 1970. The Origin and Development of Moses Coulee and Other Scabland Features on the Waterville Plateau, Washington. PhD Dissertation, University of Washington.

Hanson, L.G., E.P. Kiver, J.G. Rigby & D.F. Stradling. 1979. Surficial geologic map of the Ritzville Quad, Washington. *Washington Division of Geology and Earth Resources Open File Report OF 79-10.*

Kershner, J. 2010. The Ephrata Army Air Base switches from heavy bomber training to fighter pilot training on April 1, 1944. History Link.Org. https://www.historylink.org/file/9289.

Kovanen, D.J. & O. Slaymaker. 2004. Glacial imprints of the Okanogan Lobe, southern margin of the Cordilleran Ice Sheet. *Journal of Quaternary Science* 19 (6): 547-565.

References (continued)

Leseman, J. E. & T.A. Brennand. Regional reconstruction of subglacial hydrology and glaciodynamic behaviour along the southern margin of the Cordilleran Ice Sheet in British Columbia Canada and northern Washington state, USA. *Quaternary Science Reviews* 28: 2420-2444.

McGrath, M.P. 1989. *Country Schools, Douglas County*. Empire Publishers.

McGrath, M.P. and H.W. Jayne. n.d. *Mansfield: The Town at the End of the Rails*. Self-published.

Meany, E.S. 1923. *Origin of Washington Geographic Names*. University of Washington Press, Seattle.

Meinig, D.W. 1968. *The Great Columbia Plain: A Historical Geography, 1805-1910*. University of Washington Press. Seattle.

Ogle, G.O. & Co. 1915. *Standard Atlas of Douglas County, Washington*. Geo. A. Ogle & Co Publishers & Engravers. Chicago.

Ramsey, G.R. 1973. *Postmarked Washington: Chelan, Douglas, and Kittitas Counties*. Wenatchee World.

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.

Rinker, H. 1976. Farms threatened by bombing range. Pp. 254-55 in Grand Coulee Dam Bicentennial Association, *From Pioneers to Power: Historical Sketches of the Grand Coulee Dam Area*. A Project of the Bicentennial Association. RMA Printing and Graphics, Nespelem, WA.

Schillinger, W.F. and R.I. Papendick. 2008. Then and now: 125 years of dryland wheat farming in the inland Pacific Northwest. *Agronomy Journal* 100 (Supplement): S166-S182.

Steele, R.F. and A.P. Rose. 1904. *An Illustrated History of the Big Bend Country Embracing Lincoln, Douglas, Adams, and Franklin Counties*. Western Historical Publishing Company.

Strahler, A. 2013. *Introducing Physical Geography* (6th edition). Wiley, New York.

Symons, T. W. 1967. *The Symons Report on the Upper Columbia River and the Great Plain of the Columbia.* Ye Galleon Press, Fairfield, WA.

U.S. Army Corps of Engineers. 2021. Ephrata Pattern Bombing Range: Formerly Used Defense Sites Program Management Action Plan. US Army Corps of Engineers, Environmental Programs.

Waitt, R.B., B.F. Atwater, K. Lehnigk, I.J. Larsen, B.N. Bjornstad, M.A. Hanson & J.E. O'Conner. 2021. Upper Grand Coulee: New views of a channeled scabland megafloods enigma. In A.M. Booth & A.L. Grunder, eds., From *Terranes to Terrains: Geologic Field Guides on the Construction and Destruction of the Pacific Northwest*. Geological Society of America Field Guide 62, p. 1-56.