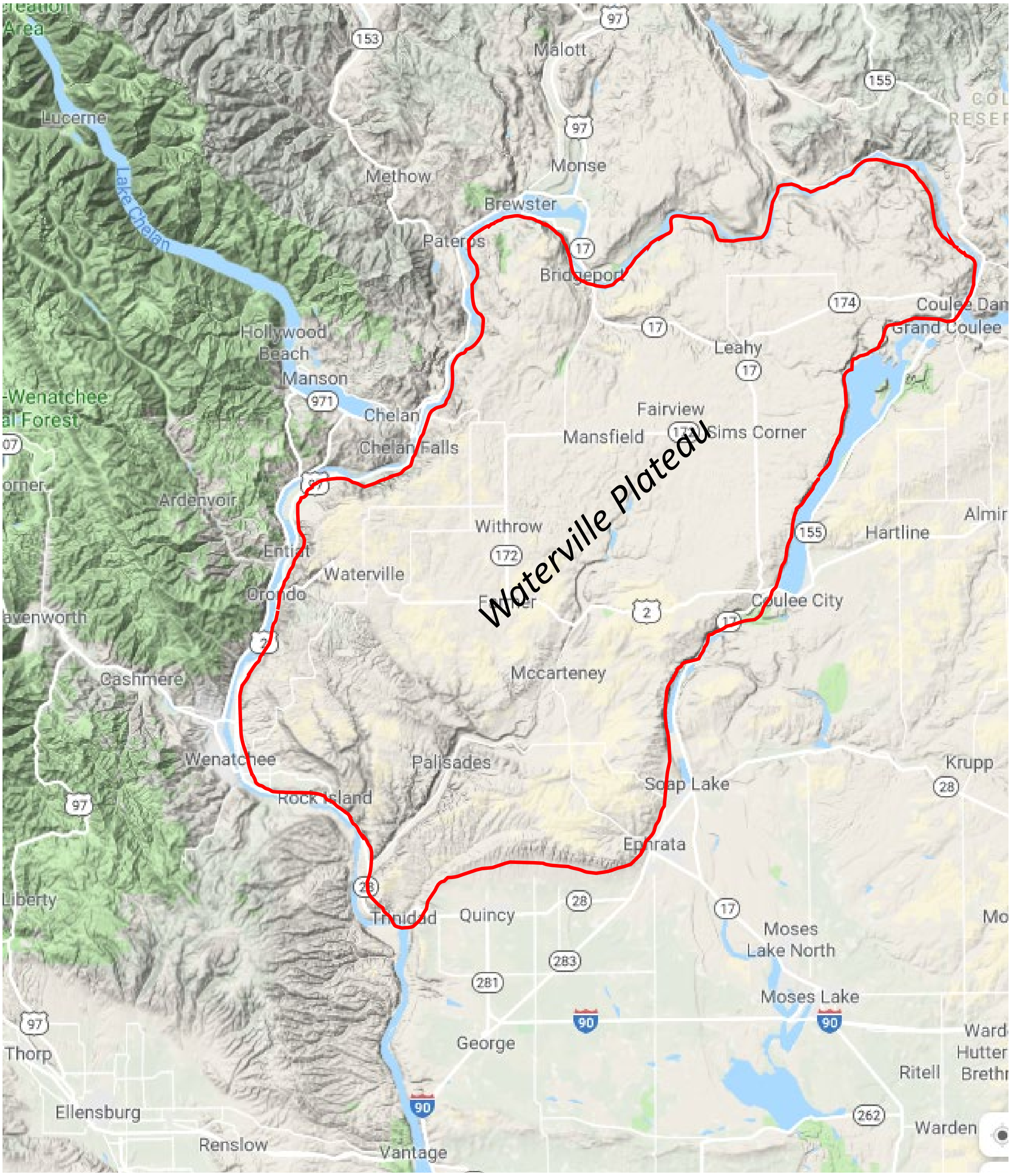
Ellensburg Chapter -- Ice Age Floods Institute Field Trip

Across the Waterville Plateau



Field Trip Leader:
Dr. Karl Lillquist
Geography Department, Central Washington University

29 September 2019

Introduction

Glaciers are the engines of tremendous landscape change. I have been fascinated by the glacial evidence of the Waterville Plateau for nearly 40 years. Today's field trip focuses on glaciation of the Waterville Plateau by the Okanogan Lobe of the Cordilleran Ice Sheet. Along the way, we will address the relationship between glacial advance, stillstand, and retreat on landforms and sediments, weather and climate, water, vegetation, and human land use. We will enter the glaciated area from the Columbia River Valley near Chelan Falls. Our first stop will at the terminal position of the Okanogan Lobe. Here, we will explore the source of the ice sheet and the formation of the terminal moraine. We will also ponder the plight of the glacial meltwater and the origin of the loess on the adjacent unglaciated surfaces. From there, we will head east to examine landform evidence (flutes and drumlins) for the active movement of ice before the formation of the terminal moraine. Continuing east, we will look at huge erratics quarried by the ice sheet, and discuss potential water sources for Moses Coulee (the focus of our September 2018 field trip). Eastward, we will examine the Pot Hills, a feature that has perplexed scientists for years. Is it a glacial till or glaciofluvial deposit? Or is it even a deposit? Our final stop will focus on stagnant ice features including eskers, kames, and kame deltas.

Tentative Schedule

9:00am	**Depart from Hebeler Hall Parking Lot, CWU**
11:30	**Stop 1: Road F NW** (**Terminus of Okanogan Lobe)**
12:15pm	**Depart**
12:30	**Stop 2–Road 11 NE (Drumlins & Flutes)**
1:15	**Depart**
1:45	**Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)**
2:15	**Depart**
2:30	**Stop 4—WA 172 (Pot Hills)**
3:15	**Depart**
3:30	**Stop 5—Road 14** NE--east of **Sims Corner(Kame Deltas & Eskers)**
4:15	**Depart**
6:30	**Arrive in Ellensburg**

Our Route & Stops

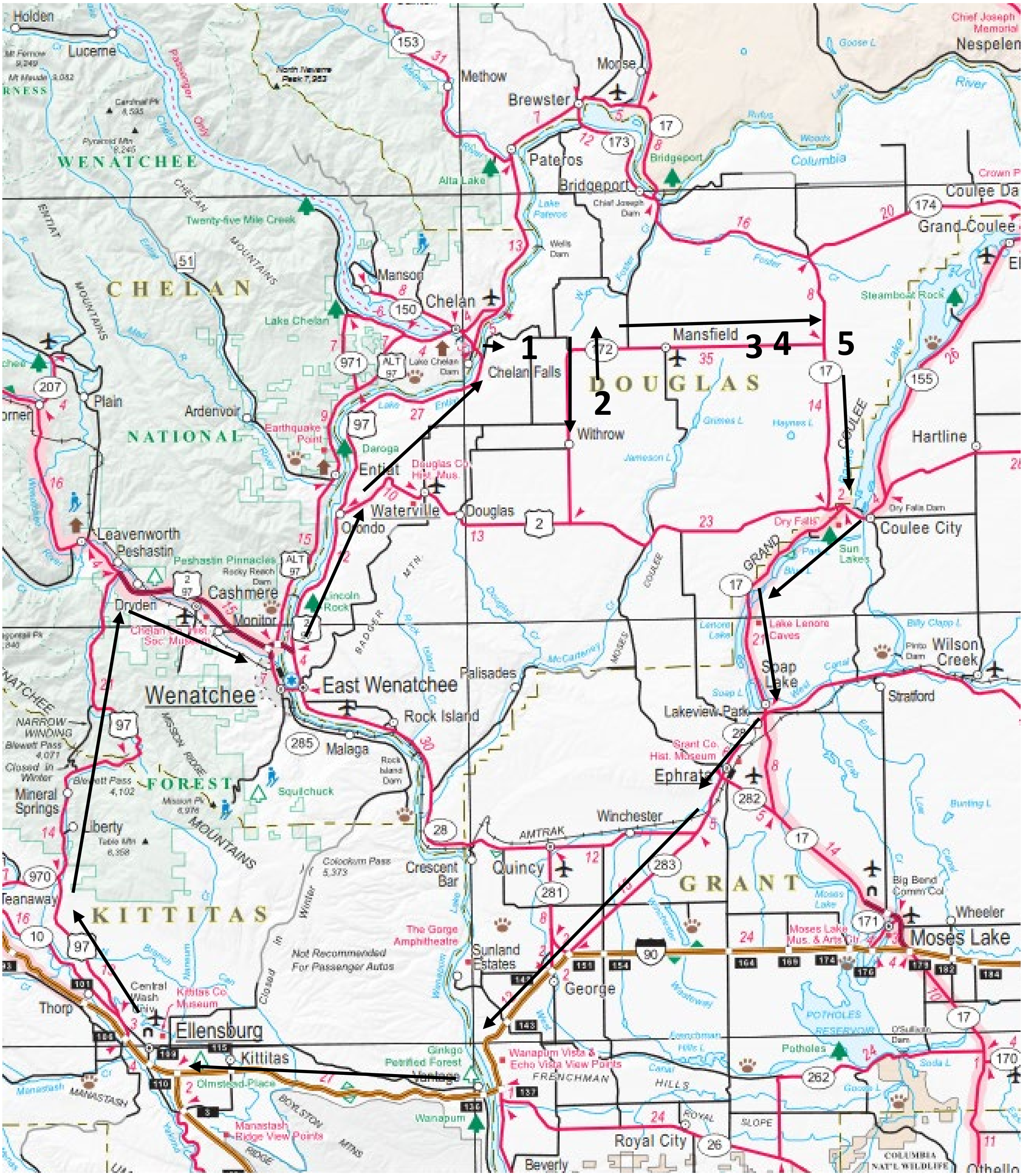


Figure 1. Our route shown with arrows. Stops denoted with bold numbers. Source: Washington Department of Transportation.

Ellensburg to Junction of US 97 & US 2

Route. From Ellensburg, head north on US 97 (**Figures 1 & 2**). Follow US 97 to its intersection with WA 970 at Lauderdale Junction. Turn east (right) and continue on US 97 over Blewett Pass to its junction with US 2.

Geology. From Ellensburg to US 2, US 97 passes through sedimentary, igneous, and metamorphic rocks ranging in age from *Jurassic* to *Miocene* (**Figure 2 & 3**) (Walsh & others, 1982; Dragovich & others, 2002). Early on, the road follows recently deposited *Quaternary alluvium*, *alluvial fans*, and landslide deposits. As we near the junction of US 97 and WA 970, we pass through Miocene Columbia River Basalts. These basalts originated from fissure eruptions in southeastern Washington, northeastern Oregon, and western Idaho. From Lauderdale Junction to Blewett Pass, we generally parallel Swauk Creek on the valley floor and the high, western edge of the Columbia River Basalts. This basalt edge is littered with large landslides and rockfalls. US 97 passes through early Eocene Swauk Formation sedimentary rocks, and middle Eocene Teanaway Formation volcanic rocks. The Swauk Formation originated as streams and lakes. The Teanaway Formation formed as a variety of eruptive features including round cones and linear *dikes*. So many dikes are present in the vicinity, they are often referred to as a “dike swarm”. Because the Teanaway Formation dikes are harder than the surrounding sedimentary rocks, they form many of the ridges of the drainage. Often, the reddish basalts of these ridges are sparsely vegetated.

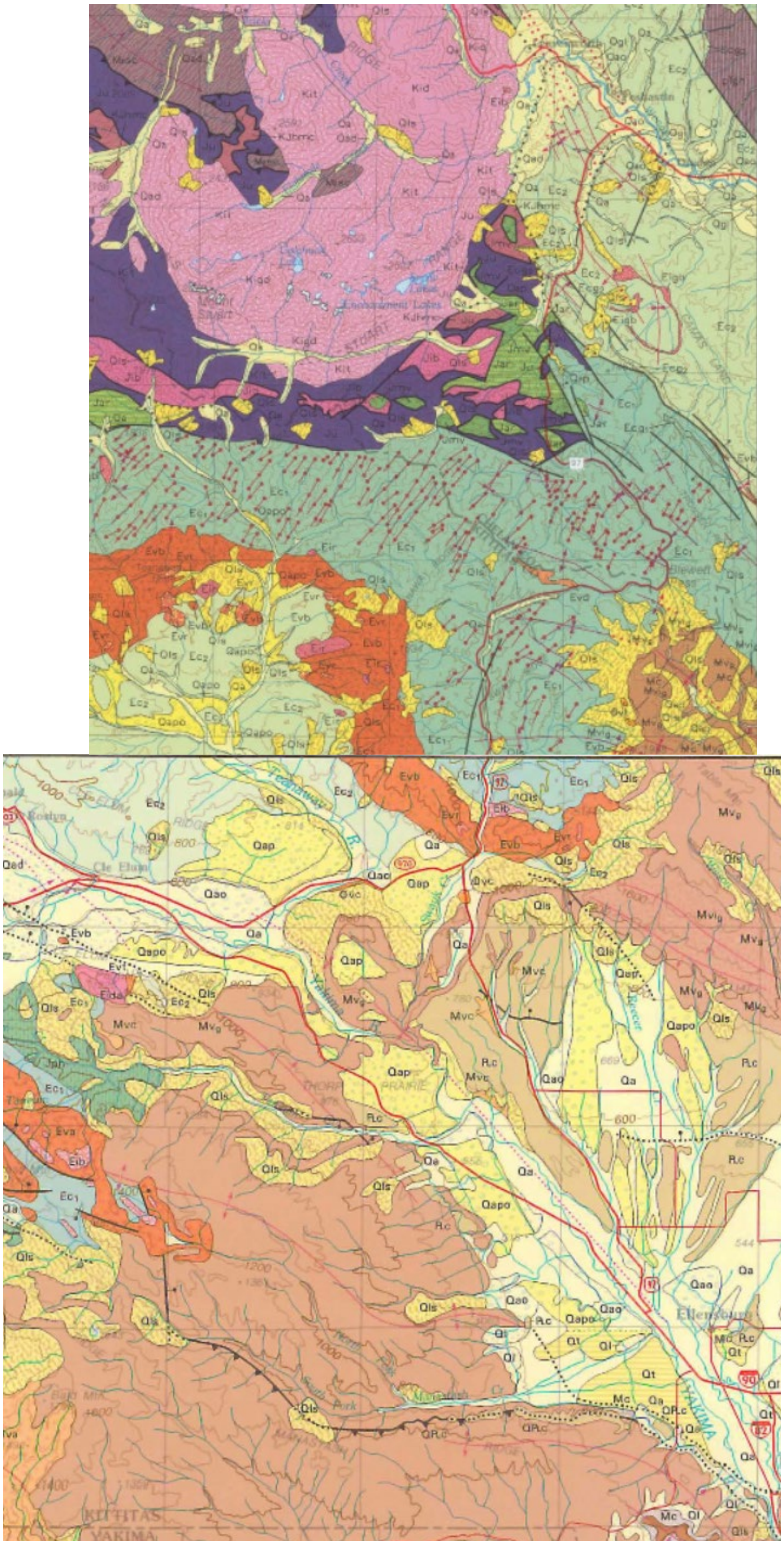
From Blewett Pass, we descend the Peshastin Creek drainage (**Figures 2 & 3**). If you look up on this part of the route, you may be able to see part of the Late *Cretaceous* Mount Stuart *batholith* in the distance. Around milepost 171, we cross from the Swauk Formation onto the Jurassic Ingalls Tectonic Complex, an *ophiolite complex* consisting of mafic and ultramafic rocks (including *serpentinite*), that originated in a large, marginal basin or open ocean, then accreted to the edge of the continent as a *terrane*. You can also see *serpentinite barrens* through this area where the vegetation cover is drastically reduced because of the chemistry of the serpentinite. A large active landslide is present near the southern boundary of this unit. Below the junction of Peshastin Creek and Ingalls Creek, US 97 crosses the Leavenworth Fault and we enter the Eocene continental sedimentary rocks of the Chumstick Formation.

Near the junction of Peshastin Creek and Ingalls Creek, US 97 crosses the moraine remnants of a Pleistocene alpine glacier that descended Ingalls Creek (**Figures 2 & 3**). This glacier formed in the cirques in the headwaters of Ingalls Creek (including Ingalls Lake, the north-facing cirques of the Wenatchee Range, and even south-facing cirques in the Stuart Range. High elevation source areas (as high as Mt Stuart at 9416 feet) and locations closer to the Cascade Crest (~17 miles at Ingalls Lake) helps explain why glaciers formed there and not in the Swauk Watershed.

Ellensburg to Junction of US 97 & US 2

Figure 2. Topography of route from Ellensburg to US 2 near Peshastin. Source: Google Maps.

Ellensburg to Junction of US 97 & US 2



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- 🟨 Landslides
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Figure 3. Geologic map for route from Ellensburg to US 2 near Peshastin. Source: Walsh & others, 1987; Dragovich & others, 2002.

Junction of US 2 & US 97 to Stop 1

Route. From the junction of US 97 and US 2, head east on this combined route through the north end of Wenatchee and across the Columbia River (**Figure 4**). Continue north. At Orondo, US 2 splits off and heads east toward Waterville. Continue north on US 97 to Beebe Bridge Park. Across US 97 from the park entrance, turn north (right) onto McNeill Canyon Road. This steep, paved road ascends ~2300 feet in about 8 miles! As you reach the top of the Waterville Plateau, the road will bend south for about 1 mile, then begin to bend east. Just before this corner you will see a sign to Waterville. Follow the sign and turn west (right) onto unmarked Road F NW (i.e., Logan Road). Follow this road for less than 0.5 miles and park on the side of the road <u>before</u> the crest of the rise. The south side of the road has the widest shoulder so it is best if you turn around and park there rather than on the north side. Make sure that your automobile is outside the white line on the road. This is stop 1. GPS coordinates for our parking spot are 47°49'48.03"N, 119°52'9.07"W.

Geology & Topography: From the junction of US 2 and US 97 to Stop 1, we again pass through a variety of rock and landscapes (**Figures 4 & 5**). From this junction to Wenatchee, we are in the Chiwaukum structural low that is filled with sedimentary rocks of the Chumstick Formation. The Wenatchee River follows this structural low. Because of the river's past here, we are also travelling through Quaternary alluvium. As we near Wenatchee, we are also increasingly in Ice Age Flood deposits.

At Wenatchee, we head up the Columbia River Valley. Columbia River Basalts form the rim above us on the east side of the river. Landslides have formed along much of the edge of these basalts creating hummocky terrain. The Columbia River generally follows this geologic margin. Crystalline rocks of the Swakane Biotite Gneiss underlie the basalts south of Orondo while gneiss and granite of the Entiat pluton underlie the basalts further north. Much of our route from Wenatchee northward is on Ice Age flood deposits including a giant flood bar north of Orondo. Stabilized dunes are present on this bar. Alluvial fans have formed at the mouths of most canyons that drain from the uplands of the Waterville Plateau.

As we climb the McNeill Canyon Road, two pieces of evidence indicate that we have moved into the area once covered by glaciers--terraces and "haystack rocks". Waitt (1994) attributes the series of six terraces seen here to "inwash" against the Columbia Valley ice tongue, a sublobe of the Okanogan Lobe, as it gradually melted. The numerous, "haystack rocks" (huge basalt boulders) were deposited by this sublobe. Above, we pass out of the glaciated area and see Columbia River Basalt flow and an interbed near the top of the climb. On top, haystack rocks indicate we have passed into the area covered by the Okanogan Lobe. Its complicated here!

Junction of US 2/US 97 to Stop 1

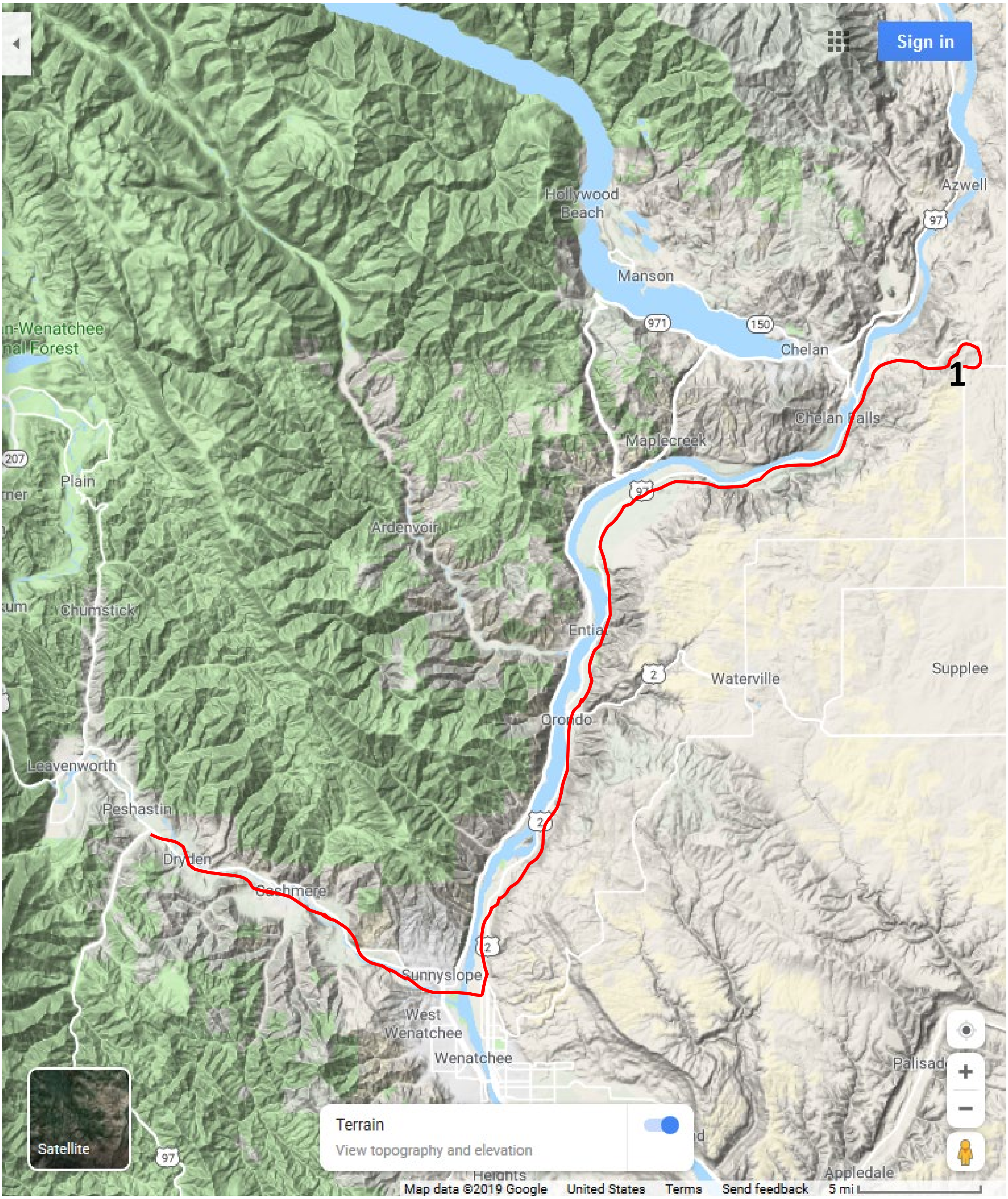

Figure 4. Topography of route from junction of US 2 & US 97 to Stop 1. Red line is approximate route. Bold number is Stop 1. Source: Google Maps.

Junction of US 2/US 97 to Stop 1

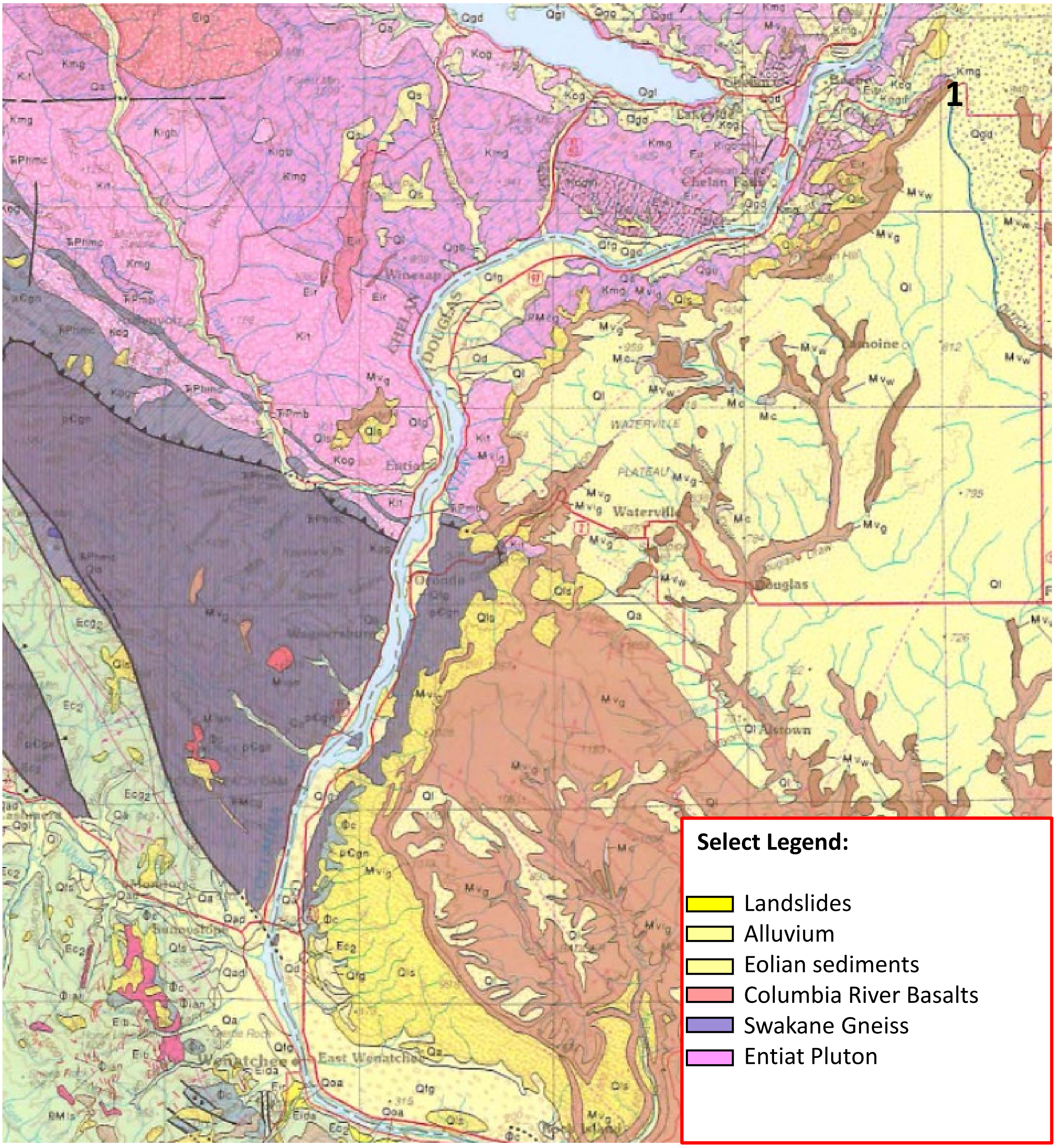

Figure 5. Geologic map for route from junction of US 2 & US 97 to Stop 1. Source: Stoffel & others (1991).

Stop 1—Road F NW (Terminus of Okanogan Lobe)

Location. We are located near the western edge of the Waterville Plateau just off the McNeill Canyon Road on Road F NW (**Figures 6, 7, & 8**). This is privately owned land. Please treat it with respect.

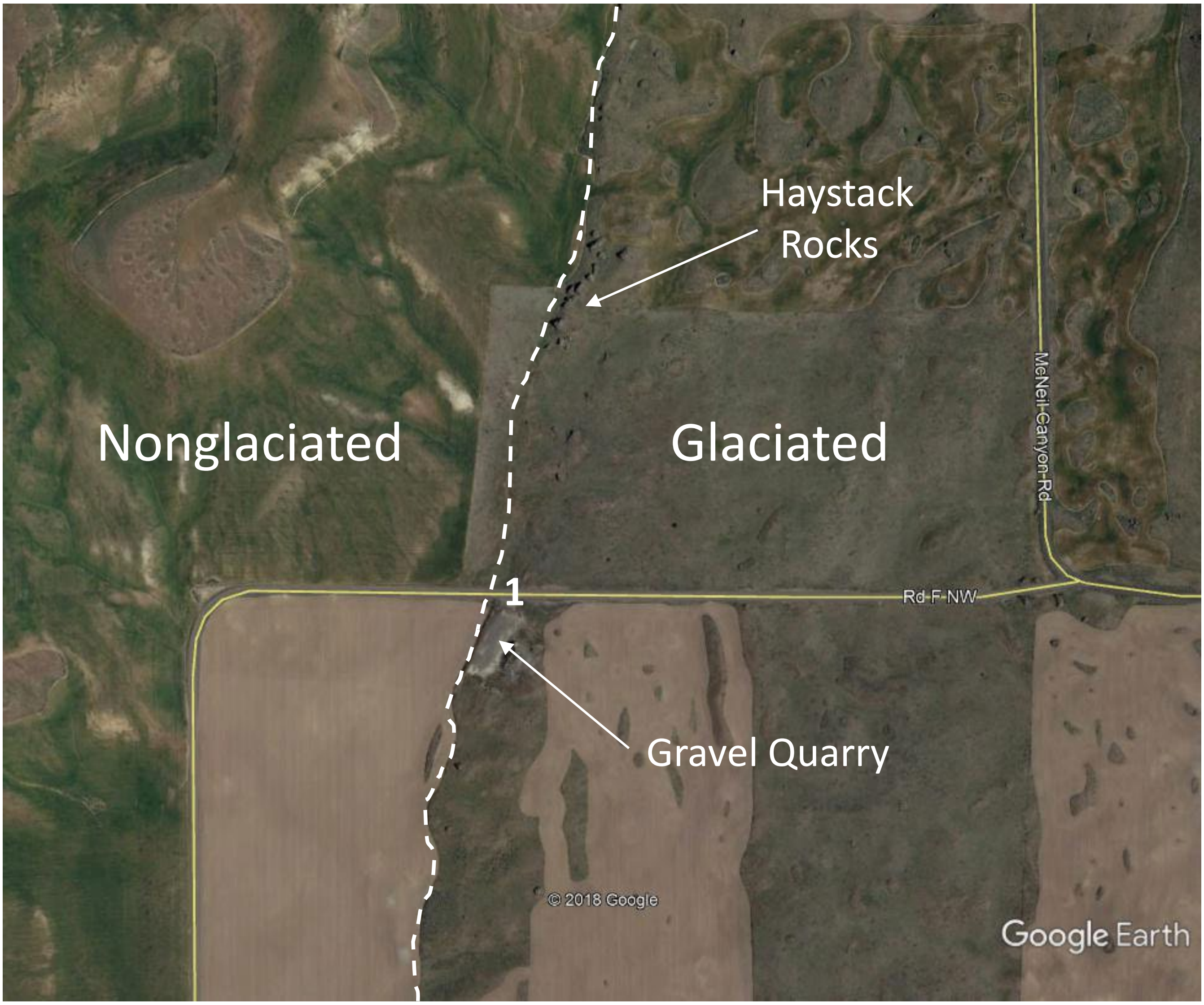

Figure 6. Location of Stop 1 (bold number). Dashed line separates glaciated from nonglaciated surfaces. Note the haystack rocks on the surface of the moraine and the boulder-free state of the non-glaciated surfaces. Also, note the hummocky nature of the glaciated vs. nonglaciated surface. Source: Google Earth.

Stop 1—Road F NW (Terminus of Okanogan Lobe)

What is the evidence of glaciation here and who first figured this out? We are standing at the border of glaciated and non-glaciated terrain. The early government and university geologists and geographers who explored this area 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 haystack rocks, “hummocky” terrain that included hills and basins filled with water in the wet season, linear features (e.g., grooves on bedrock and lines of boulders), and sinuous deposits as indicators of past ice sheet glaciation. **Figure 9** is the earliest map (Bretz, 1923) I know of that shows the extent of glacial ice on the Waterville Plateau.

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 here. The ice sheet that shaped this landscape formed in colder and snowier places in the Coast Mountains and Rocky Mountains of British Columbia, then moved here. As it grew, it flowed away from its mountain sources into adjacent valleys. Enroute to here via the Okanogan Valley, sediments were transported atop, within, and at the base of the ice. The entire ice sheet is known as the *Cordilleran Ice Sheet* and it consisted of five lobes—Puget, Okanogan, Columbia River, Purcell Trench, and Flathead. This area was impacted by the *Okanogan Lobe* (**Figure 10**).

What is the Okanogan Lobe end moraine and how did it form? When the Okanogan Lobe reached here, its advance stalled leading to the formation of this ridge, known as an *end moraine*. 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. 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, hummocky ridge that represents 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 11**). This moraine is often referred to as the “Withrow Moraine” for its type locality near Withrow, a tiny town about 9 miles south of here. Near Withrow, the moraine is over 200 feet high and 2 miles wide. The size of the moraine suggests it occupied that position for a considerable amount of time (Freeman, 1933; Easterbrook & Rahm, 1970). Kovanen and Slaymaker (2004) estimated that the ice sheet terminus was over 700 feet thick!

Stop 1—Road F NW (Terminus of Okanogan Lobe)

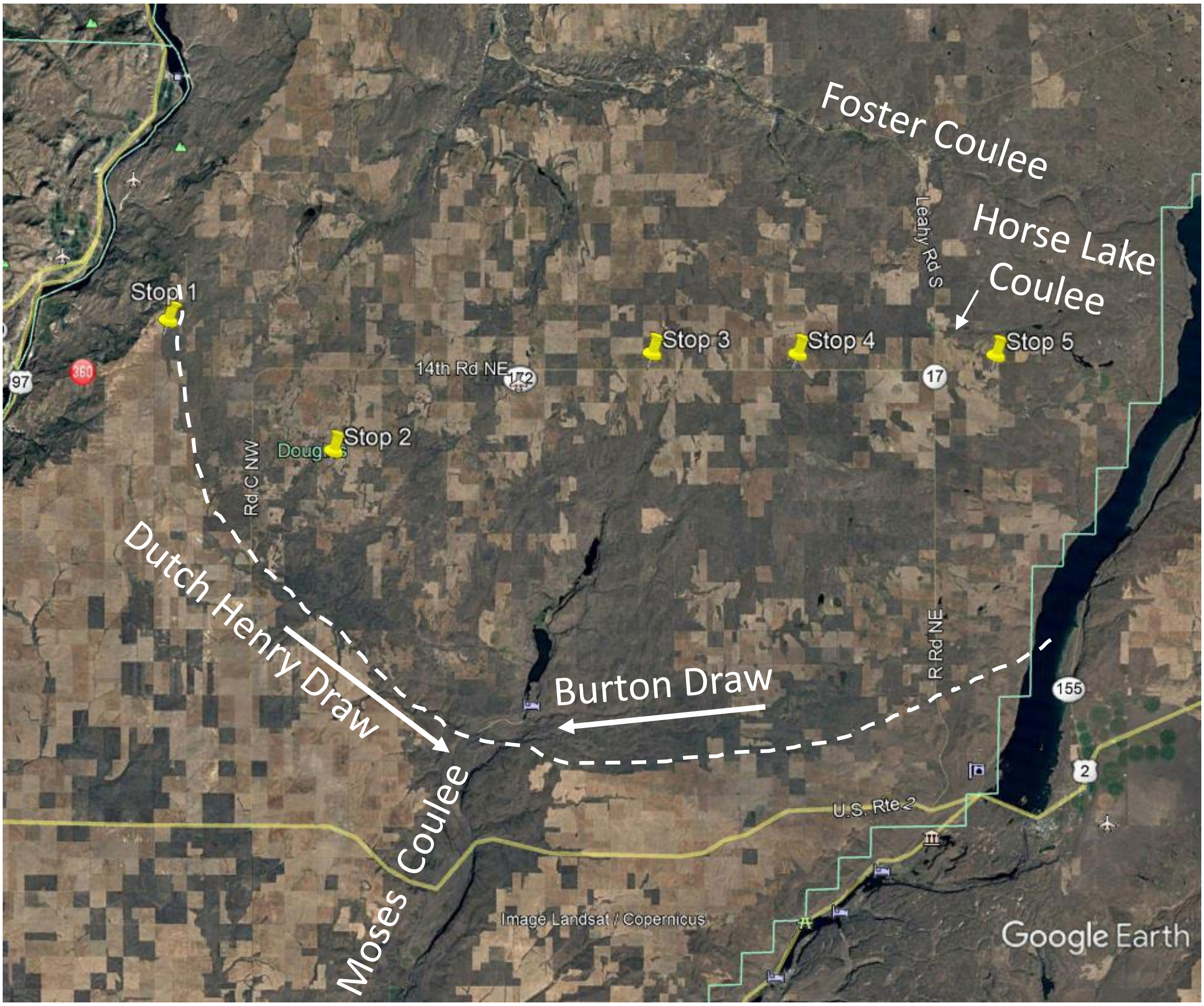

Figure 7. Physiographic map of the portion of Waterville Plateau covered by our field trip. Pins indicate field trip stops. Dashed line indicates approximate position of Withrow moraine. Note land use change at this boundary. Heavy arrows indicate path of glacial meltwater from Dutch Henry Draw and Burton Draw into Moses Coulee. Foster Coulee and Horse Lake Coulee are Ice Age flood channels. Source: Google Earth.

How do we know this is an end moraine? Topographic and compositional evidence indicates this is a moraine. First, note the change in slope. As we approached Stop 1 from the east, the topography sloped gently down toward us. From the stop, the topography slopes steeply down to the west and south. Moraines are often asymmetrical. We are therefore on the crest of a ridge. Second, note the presence of haystack rocks and how they don't extend west or southwest from the base of the ridge (**Figure 11**). Third, note how the land use differs from the glaciated to non-glaciated. We will talk more about this later.

Stop 1—Road F NW (Terminus of Okanogan Lobe)

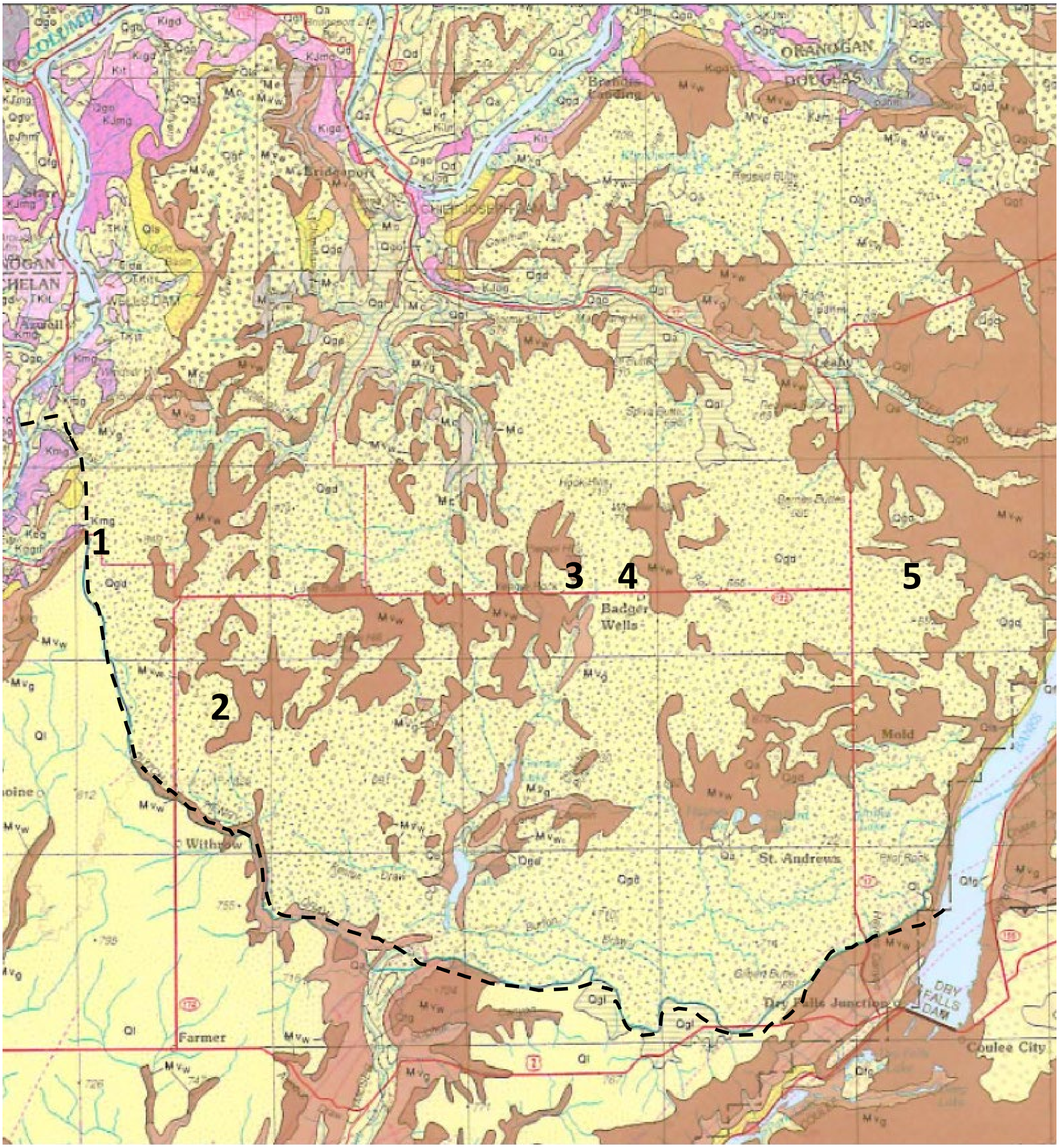

Figure 8. Geologic map of a portion of the Waterville Plateau covered by our field trip. Bold numbers indicate approximate locations of field trip stops. Dashed line indicates approximate position of Withrow moraine. Stippled yellow area north of dashed line is glacial "drift" (i.e., various glacial deposits). Solid yellow area south of stippled area is loess. Brown is Columbia River Basalt. Source: Stoffel & others (1991).

Stop 1—Road F NW (Terminus of Okanogan Lobe)

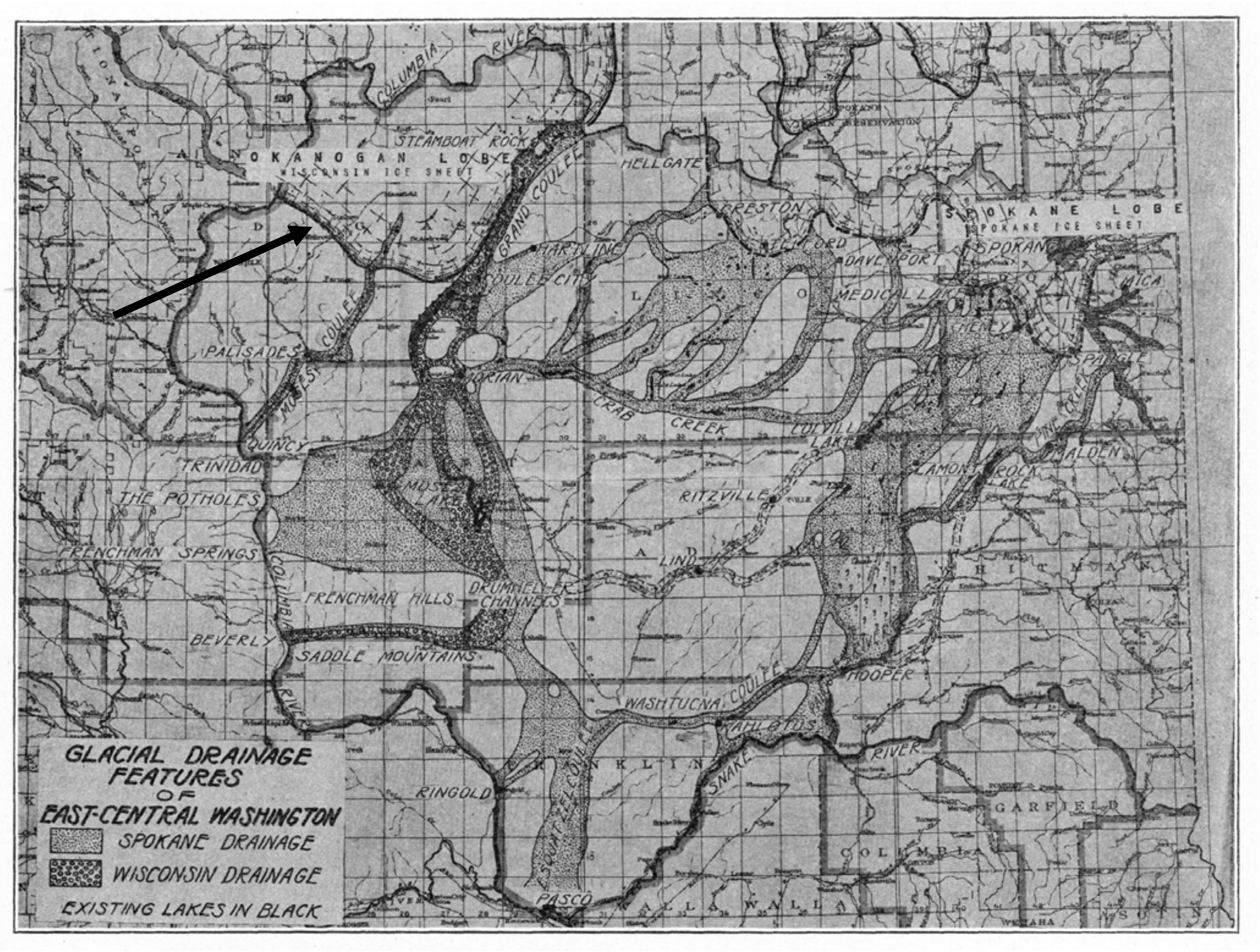

Figure 9. Earliest map of the extent of the Okanogan Lobe, northwest Waterville Plateau. Bold arrow denotes Withrow moraine. Source: Bretz (1923).

Where did the meltwater go? A lobe of an ice sheet should generate much meltwater and sediments (i.e., *outwash*) therefore requiring a large channel. This didn't seem to be the case with the Okanogan Lobe (e.g., Waters, 1933; Flint, 1935). Dutch Henry Draw, on the southwestern margin of the Withrow Moraine, likely transported some of the meltwater and associated outwash east to Moses Coulee (**Figure 6**). Burton Draw to the east of Moses Coulee likely did the same. However, neither are large drainages capable of transporting significant amounts of water over time (Hanson, 1970). So where did the rest of the meltwater go? Did some evaporate or sublimate (Flint, 1935)? Did some generated north of the terminus flow directly into the Columbia River Valley (Flint, 1935)?

Stop 1—Road F NW (Terminus of Okanogan Lobe)

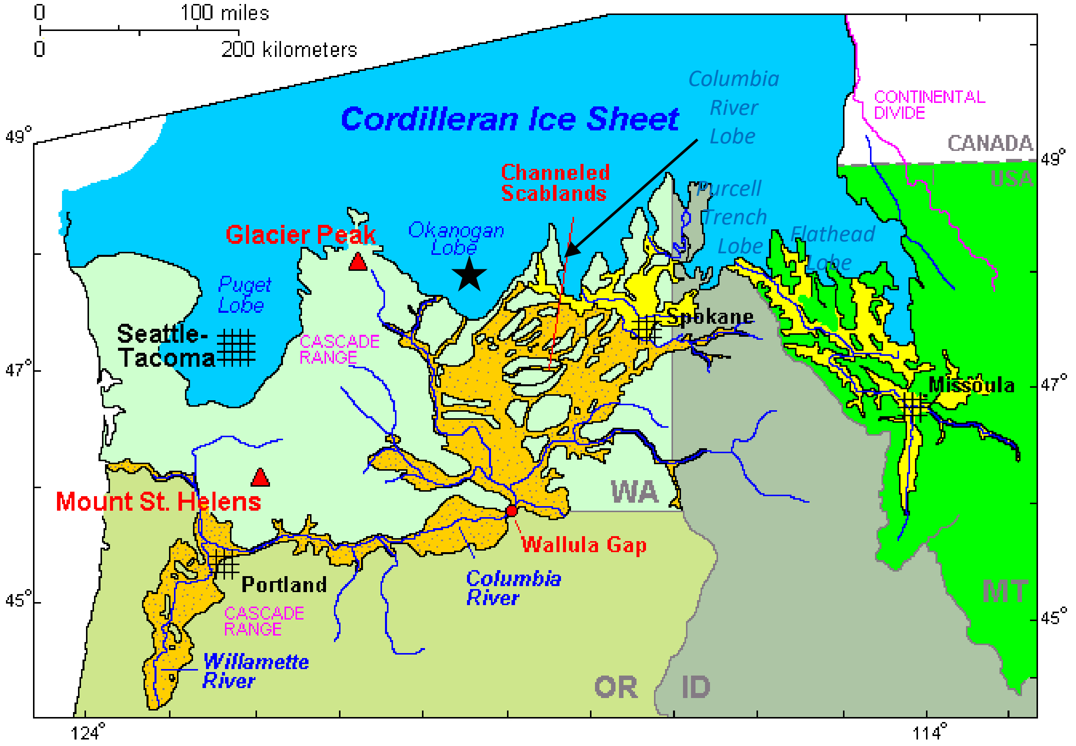

Figure 10. Map of the late Pleistocene Cordilleran Ice Sheet and Missoula Floods in the Pacific Northwest. Star indicates the approximate location of Mansfield. Source: Cascade Volcano Observatory website.

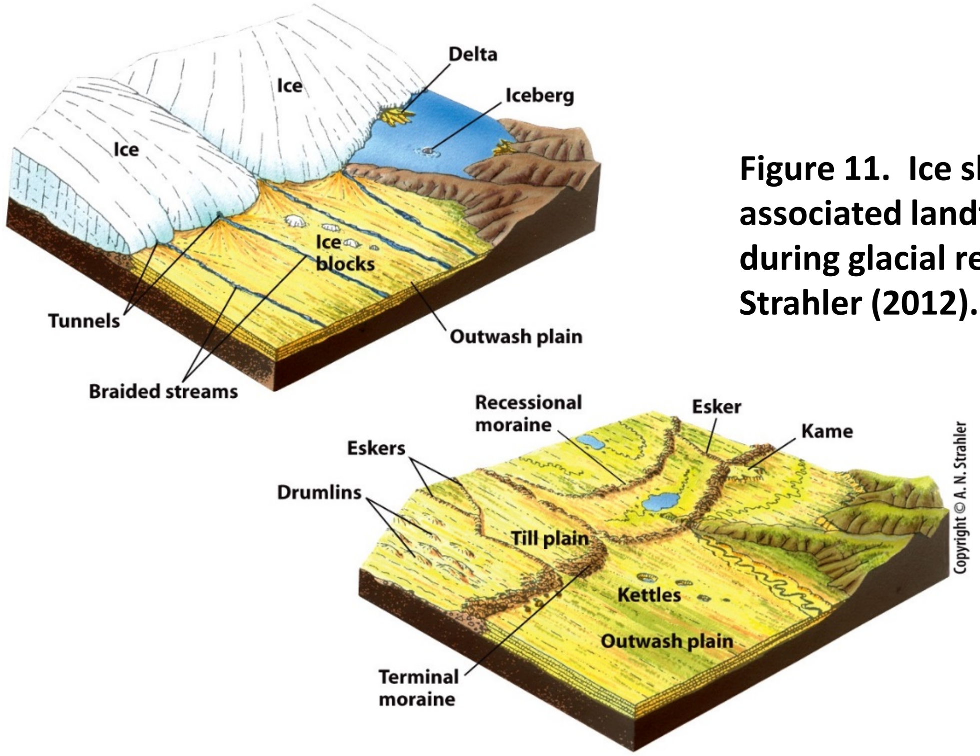

Figure 17.16

Figure 11. Ice sheet and associated landforms exposed during glacial retreat. Source: Strahler (2012).

Stop 1—Road F NW (Terminus of Okanogan Lobe)

Origin of the loess. The smooth, largely rock-free farm fields to the west and south west reflect their loess origins (**Figure 13**). What was the source of this loess? We often think of glaciers and glacial outwash as the source for loess. Previous researchers have approached this question by measuring loess thickness and loess texture at various places on the Columbia Plateau. Likely because of different sampling strategies each came to different conclusions as to the sources: 1) local glacial outwash (Markham, 1971); 2) outwash in Moses Coulee (Busacca and McDonald, 1994); and 3) slackwater deposits in the Columbia River Valley (Dalman, 2007). All likely played a role in depositing loess atop the non-glaciated as well as the glaciated surfaces.

What were the impacts of the Okanogan Lobe on land use? Here, and throughout our day on the plateau, note the impacts of glaciation of human land use. Land use on the plateau is primarily dryland wheat agriculture and cattle ranching. Dryland agriculture involves farming a particular parcel of land one year, then leaving that same parcel fallow the following year to gather moisture. Generally, land is better for farming in the unglaciated areas because of the lack of glacial erratics and often deeper soils. There, the farmers are farming in *loess*—i.e., windblown sediments. Over time, farmers farming the *till* and overlying loess of glaciated terrain have removed rocks from the fields or farmed around them. As a result of the latter, farm fields on the glaciated portion of the Waterville Plateau are often irregular in shape. Waters (1933, p. 785) said "*West of the Grand Coulee the basalt underlying the southern part of the Waterville Plateau is covered by a thick mantle of aeolian soil which permits wheat farming. On the other hand, the northern half of the district is a broad expanse of rocky waste, most of which either still preserves its primeval sagebrush covering or is spotted with abandoned, weed-covered farms*".

Figure 12. Haystack rocks marking the boundary of glaciated terrain just north of Stop 1. Source: Karl Lillquist (2019)

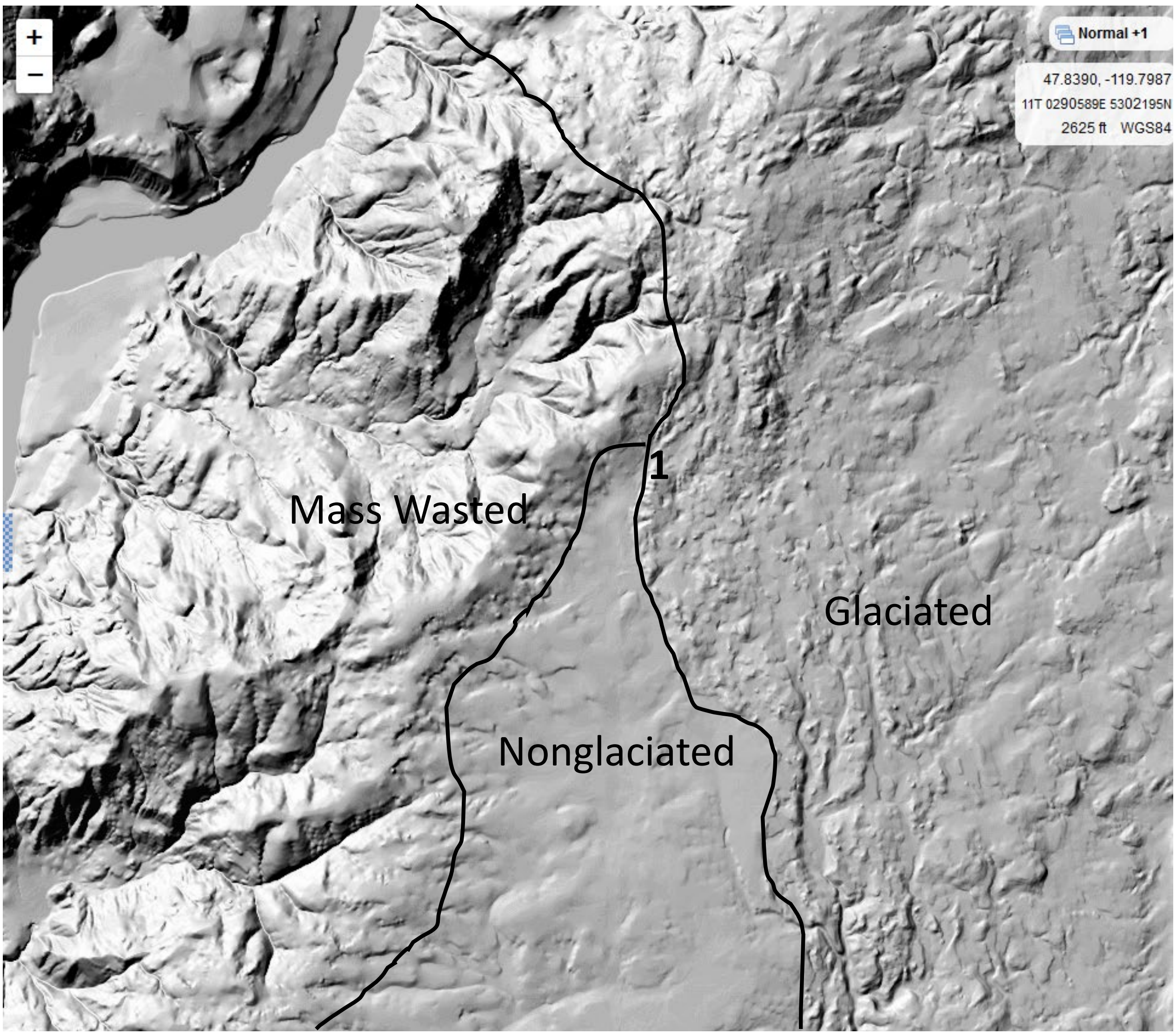

Figure 13. Shaded relief image of the northwestern Waterville Plateau. Note the irregular surface of the till-covered, glaciated portion, irregular surface of colluvium-covered, mass wasted portion, and the smooth surface of the loess-covered, nonglaciated portion. Bold number is approximate location of Stop 1. Source: Caltopo.com

To Stop 2

Route. Return to the McNeil Canyon Road. Continue east and south on it for approximately 3.5 miles to its junction with WA 172. Here, turn south (right) and drive approximately 4 miles south on WA 172. Turn east (left) onto road 10 NW and follow this for 2 miles. Turn north (left) onto road A NW and proceed for ~1 mile. Turn right onto road 11 NE and proceed for ~0.2 miles to Stop 3. GPS coordinates for our parking spot are: 47°46'18.98"N, 119°46'0.25"W.

Stop 2—Road 11 NE (Drumlins & Flutes)

Location. From our parking spot on Road 11 NE, we will walk several hundred yards through a winter wheat field to a linear ridge. This ridge is located just north of the Withrow Moraine crest (**Figure 14**). This is privately owned land.

How do ice sheets move? As noted at Stop 1, glaciers advance because of their mass and the underlying slope. This movement occurs because of internal deformation of the ice (i.e., *flow*) and by sliding on their bases (i.e., *basal sliding*). Basal sliding results in the formation of small to large subglacial landforms. The orientation of these features may also indicate the direction of that past movement.

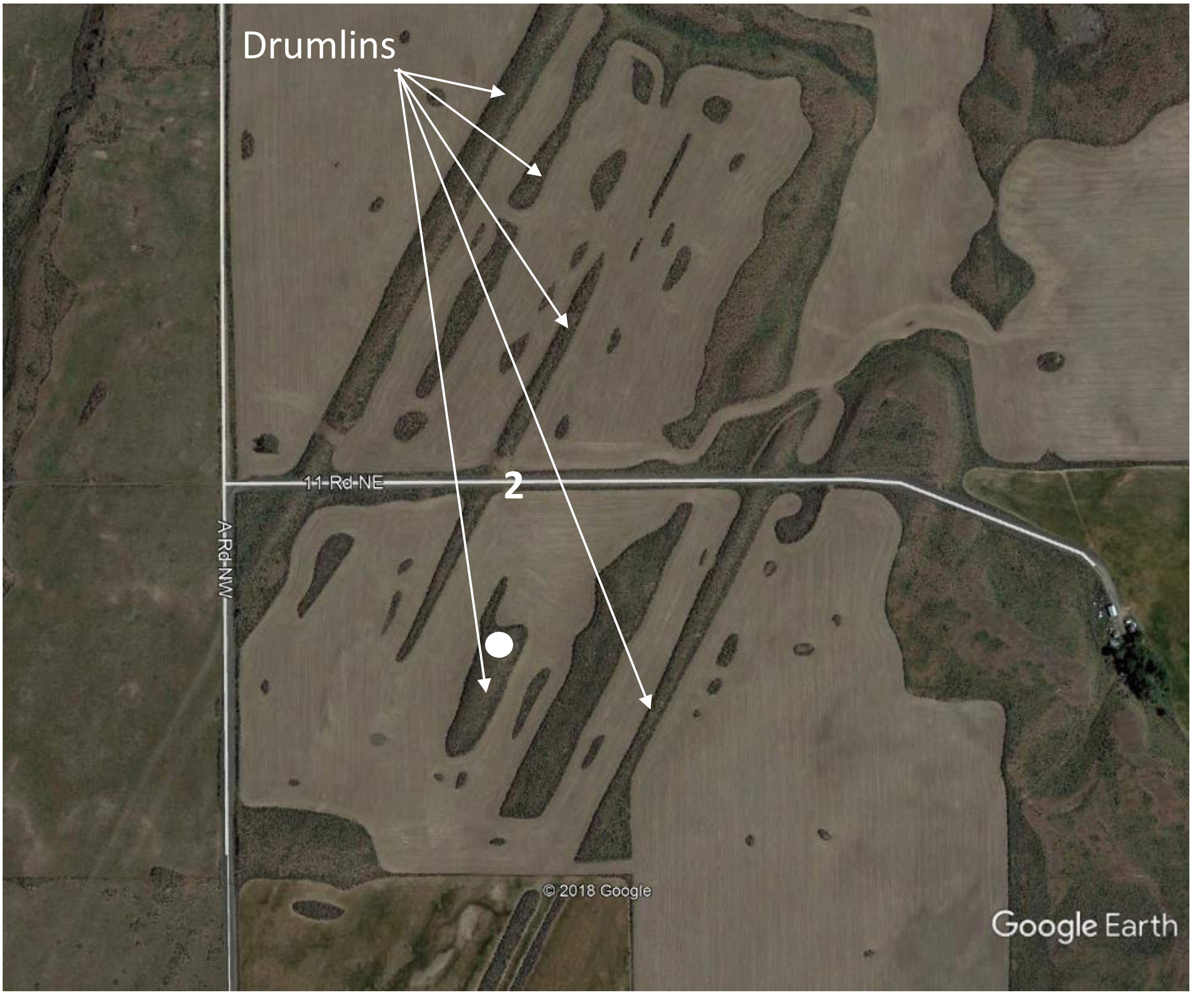

Figure 14. Location of Stop 2 (white dot) atop drumlin. Note other drumlins indicated by land use. Source: Google Earth.

Stop 2—Road 11 NE (Drumlins & Flutes)

What landforms indicate glacier directional movement? Glacier directional indicators include features that range in scale from inches to a few feet (e.g., *striations* and *flutes*) to hundreds of feet (e.g., *drumlins*) (**Figure 11**). All are linear features that form parallel to ice movement. Striations form when rock, embedded in the base of a glacier, gouges the underlying bedrock. This results in a linear groove that is typically less than an inch wide and ranges up to several feet long. Striations are apparently widespread on basalt outcrops on the plateau (e.g., Russell, 1893; Easterbrook & Rahm, 1970; Ringe, 1976) although I only know of one area of them. Flutes are narrow, low, streamlined ridges formed as overlying ice deforms saturated sediment into a streamlined form. This often occurs in the lee of an obstruction, like a bedrock knob (Benn and Evans, 1998). Drumlin is derived from a Gaelic word meaning "rounded hill" (Benn and Evans, 1998). Drumlins are larger, rounded and streamlined hills with upglacier ends typically blunt and wider than the gently tapering downglacier ends. They have been described as looking like inverted spoons. Most often, they are composed of unconsolidated sediments—e.g., till and/or outwash. Sometimes, they are partially composed of bedrock. Drumlins may form from erosion, deposition, or a combination of both. Their formation appears to be enhanced by sediment layers of different strengths, therefore mobilities—i.e., strong sediments will remain in place while weak sediments will be more mobile forming the streamlined features (Benn and Evans, 1998). Others have proposed that catastrophic subglacial megafloods may form drumlins (e.g., Shaw, 1983), again through erosion or deposition. This is a reminder of the basic geomorphic concept of *equifinality*—i.e., different processes may result in similar features.

What features are here? Using Google Earth, I interpret the feature we are standing on as a drumlin. I based this interpretation on the fact that it is a streamlined ridge that has a blunt upglacier end and a gently tapered downglacier end. Land use helps tremendously with this interpretation. The thin, dry soils of the ridges are not farmed while the deeper, moister soils of the swales are farmed. Rahm and Easterbrook (1975) suggest that such features form as till is molded by overlying ice (remember that the ice here was over 700 feet thick). I interpret the ridges as indicating the direction of ice movement as it slid and flowed across the underlying surface. The drumlins and flutes of the area are remarkably similar in their orientation. A quick azimuth measurement of a half-dozen of the drumlins reveals orientations from 205-208° suggesting that was the direction of ice movement as the Okanogan Lobe advanced to its southernmost extent a few miles south of here. This orientation is perpendicular to the former ice margin. Examine **Figure 13** to see how this orientation changes as we move east across the Waterville Plateau.

Stop 2—Road 11 NE (Drumlins & Flutes)

When was the ice sheet here? Researchers mention the likelihood of several glaciations here (e.g., Bretz, 1923; Richmond and others, 1965). The most recent glaciation appears to have been the most extensive therefore obscuring evidence for earlier glaciations (Easterbrook and Rahm, 1970). The most recent glacial advance began after 17,500 ^{14}C yr BP (Fulton and Smith, 1978; Clague & others, 1980). Radiocarbon dates plus varved lake sediments in the San Poil River Valley upstream of Grand Coulee Dam suggest the Okanogan Lobe had advanced sufficiently south to impound Glacial Lake Columbia from ~15,550 +/- 450 to 13,050 +/-650 ^{14}C yr B.P. Further, it appears that the Okanogan Lobe occupied its maximum position for about two centuries at around 14,800 +/- 375 ^{14}C yr B.P. Four cosmogenic isotopes (^{10}Be) dates from granitic boulders on the moraine in Moses Coulee (about 15 miles southeast of here) date to 15,400 +/- 1400 years before present. This means that the moraine was in place and the ice sheet was likely retreating by ~15,400 years ago (Balbas and others, 2017). The presence of ~11,600 ^{14}C yr BP Glacier Peak tephra in the southern Okanogan Valley near Malott indicates that the Okanogan Lobe had retreated to there by that time (Porter, 1978; Kuehn & others, 2009).

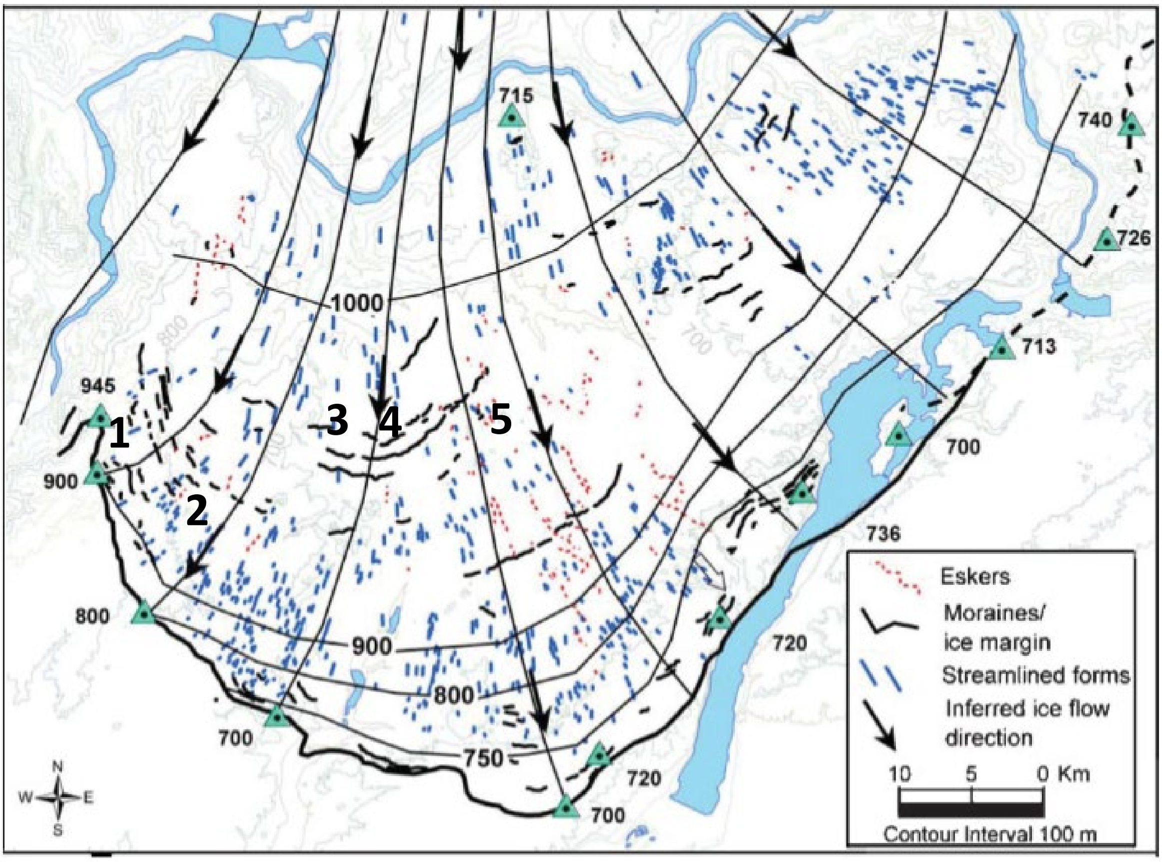

Figure 15. Withrow moraine and associated large-scale glacial landforms formed by Okanogan Lobe of the Cordilleran Ice Sheet. Bold numbers indicate approximate locations of field trip stops. Source: Kovanen and Slaymaker (2004, p. 561).

To Stop 3

Route. From Stop 3, we will return to the junction of road 11 NE and road A NW. Here you have a choice: Option A. The road north is "pretty good" gravel and will work fine for pickups and SUV's, and passenger cars with care. The vegetation in the center of the road will scour the bottom of passenger cars but it should be passable to them. If you choose this route, it is ~3 miles of gravel to the paved, east-west trending WA 172. From there it is about 6 miles to Mansfield and another nearly 4 miles to Stop 3; and Option B. Retrace your steps over 2 miles of really good gravel and another mile of pavement to north-south trending WA 172. At WA 172, turn north (right) and follow it about 4 miles north to the junction with McNeil Canyon Road. Remain on WA 172, going through the bend and heading east toward Mansfield. It is about 8 miles from the bend to Mansfield, and another nearly 4 miles to Stop 3. Stop 3 is at a very large, graffiti-covered boulder on the north side of the road just east of Road I NE. Pull off the south side of the highway as much as you can, or park a few hundred yards west on Road I NE. The GPS coordinates for the site are: 47°48'56.19"N, 119°33'10.95"W.

What is the surface we are driving through? Much of what you are driving through is *ground moraine* which is characterized by a rolling rather than hummocky topography. There is also a large amount of glacial scoured and perhaps meltwater eroded basalt bedrock in view of the pretty good gravel road. Once you are heading east, WA 172 skirts around the base of a large,hill known as Lone Butte. Like the drumlins to the south, this hill is oriented at about 210^{o}. Another prominent, similarly oriented hill is Burke Hill which lies about 2 miles southeast of Lone Butte. Who did these prominent features form?

What is Mansfield? Mansfield owes its origin to wheat farming. From 1909 to 1985, it was served by a branch line of the Great Northern (and later Burlington Northern) railroad. The main purpose of the railroad was to haul wheat off the plateau and equipment and supplies to the plateau. Over time, the town's population has declined with the increasing size of farms and associated mechanization. However, the town continues on as does its K-12 school (team mascot "Kernels"). The trend toward depopulation in these areas of dryland agriculture distant from cities is a trend that is so different from much of the rest of Washington state.

Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)

Location. We are located at Yeager Rock along WA 172 nearly 4 miles east of Mansfield (**Figures 7, 8 & 16**). This is privately owned land.

What is an erratic? Yeager rock is a classic example of a haystack rock (**Figure 17**). This large boulder, like others on the Waterville Plateau, was likely *plucked* by the Okanogan Lobe from nearby, underlying basalt bedrock, transported, then deposited here. Plucking occurs when moving glacial ice temporarily freezes to the underlying bedrock. The continued movement of ice plucks the bedrock

Figure 16. Location of Stop 3 (bold number) at Yeager Rock amidst dryland wheatfields east of Mansfield. Note the numerous other rocks and rock piles in the wheat fields. This is characteristic ground moraine terrain here. Source: Google Earth.

Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)

What is an erratic? (continued)…(**Figure 18**). Plucking is enhanced by jointing (i.e., fractures) in a rock. Basalt is notorious for its jointing patterns (**Figure 19**). The layered Columbia River Basalts that form the boundary of the Waterville Plateau would have been an ideal place for glacial plucking as the ice sheet passed over it (Russell, 1893; Freeman, 1932; Waters, 1933; Hanson, 1970). The interbeds separating the different flows may have also enhanced the plucking of large boulders (Hanson, 1970). As with Ice Age flood-related plucking, one would expect that columnar joints are more readily plucked than the entabulature jointing; however, that is not the case here—Yeager Rock is composed of entabulature. Some geologists and geographers would also refer to this as an *erratic*—i.e., a boulder that was transported here from elsewhere by glacial ice. Others would say that an erratic needs to be different in composition from the underlying rock. In that case, this is not an erratic as the area is underlain by basalt bedrock. However, you don't have to look far to find true erratics here. What can you identify?

What's that stuff under Yeager Rock?. Yeager Rock sits atop glacial till (**Figures 17 & 20**). This till, like most, is unsorted and unstratified meaning that all sizes of material from clay to boulders, are mixed together in a non-layered pile. An immature soil has formed in the till, and was perhaps enhanced by deposition of loess atop the till. It is immature because there is little soil horizon development evident. Most evident is the calcium carbonate that has moved from the surface down into the soil and shows up as a white band (**Figure 20**). This carbonate is indicative of the semi-arid climate here (probably average about 10" of precipitation/year). Atop the till is rock fall from disintegrating Yeager Rock (**Figure 20**). The well-jointed basalt is susceptible to frost action weathering.

Figure 17. Yeager rock, a popular haystack rock east of Mansfield. Note the glacial till beneath rock. Source: Karl Lillquist (2012).

Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)

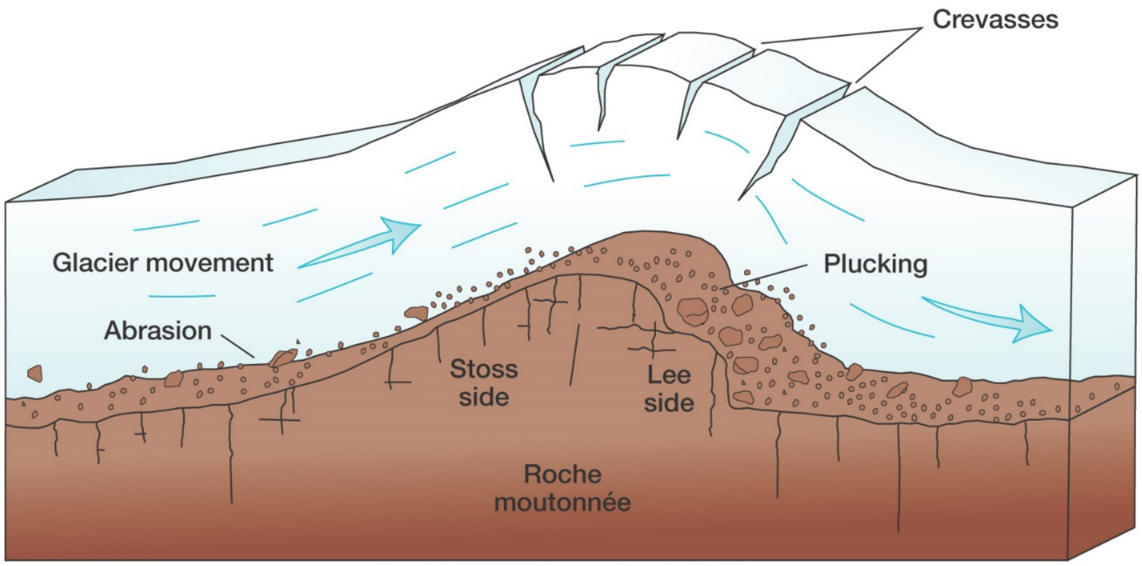

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Figure 18. Abrasion on the higher pressure, melting stoss side, and plucking on the lower pressure, freezing lee side. Source: http://web.gccaz.edu/~lnewman/gph111/topic_units/glacial/19_16.jpg

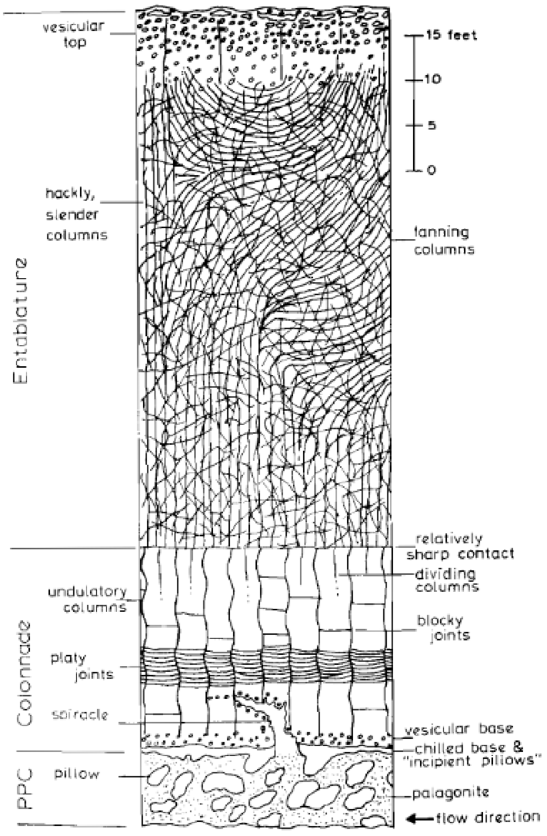

Figure 19. Typical cross section of Columbia River Basalt flow. Source: Swanson (1967)

Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)

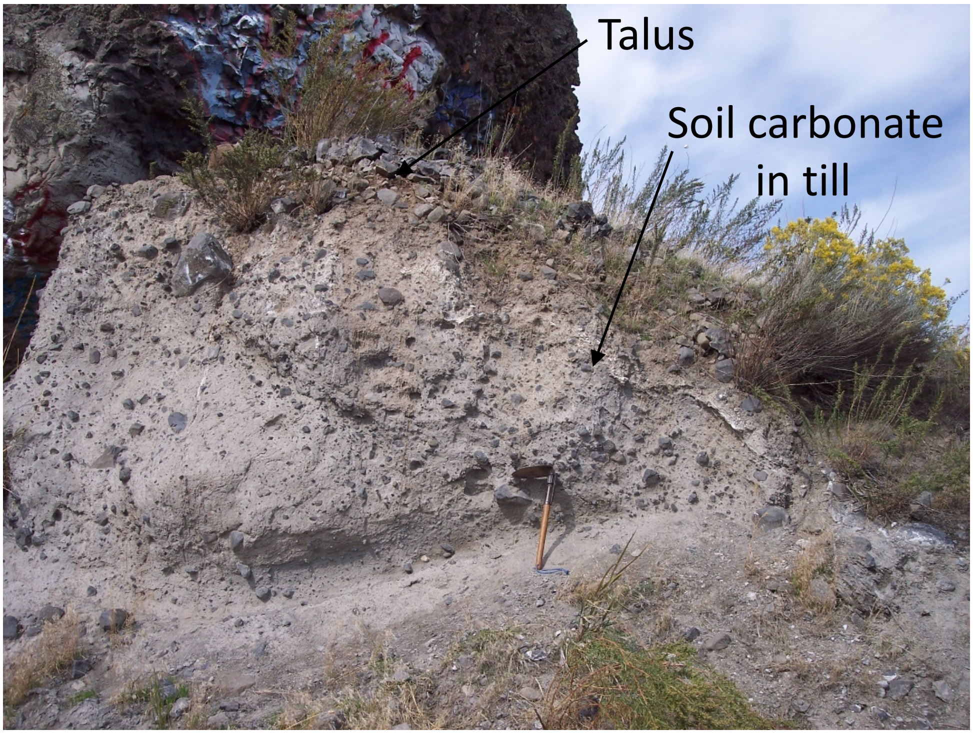

Figure 20. Glacial till beneath Yeager rock. Note the dense, unsorted nature of the till. Also note the limited soil development beneath the rock indicating its geologically recent history. Source: Karl Lillquist (2012).

Figure 21. View down into the subtle drainages leading to Moses Coulee. Source: Karl Lillquist (2019).

Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)

Headwaters of Moses Coulee? We are located in the headwaters of Moses Coulee (**Figure 21**) about 5 miles north of the head of the coulee. Our September 2018 field trip followed Moses Coulee from Jameson Lake south to its mouth. There is little question that floodwaters eroded Moses Coulee. However, what was the source of those floodwaters? Glacial meltwater from Dutch Henry Draw (to the west) and Burton Draw (to the east) (**Figure 7**)may have played a minor role but neither appear to have been formed by floodwaters coming from Glacial Lake Columbia or Glacial Lake Missoula. Moses Coulee differs from many other scabland coulees in that its head is hardly identifiable and does not clearly extend north to possible floodwater sources in the Columbia River Valley (**Figures 7, 8, & 22**). Several possibilities exist: 1) subsequent glaciation obliterated or partially obliterated such a channel after it formed (Bretz and others, 1956; Bretz, 1959; Hanson, 1970). However, glacial *drift* (i.e., directly deposited till <u>and</u> glacial meltwater deposited outwash) is generally thin in those areas north of the glacier margin (Hanson, 1970); 2) the Moses Coulee channel cutting event occurred during an earlier glaciation, then subsequent glaciation has obscured (through erosion and deposition) the upper portions of the channel. However, evidence of an earlier glaciation has not been found on the Waterville Plateau (Hanson, 1970); 3) floodwater was initially diverted from the Columbia River by the advance of the Okanogan Lobe. Such a diversion would require that the Grand Coulee had not yet formed. Further, it would require that Foster Coulee and Horse Lake Coulee were the delivery mechanisms of the Columbia River water onto the Waterville Plateau (**Figure 7**). Perhaps the floodwaters did not originate from the Glacial Lake Columbia or Glacial Lake Missoula. Instead, they reached what is now Moses Coulee via tunnels within the Okanogan Lobe from the Okanogan Valley (Neff in Hanson, 1970). Jerome Lesemann, at a recent presentation to the Ellensburg Chapter of the IAFI, argued for subglacial meltwater from the Okanogan Lobe and points north providing the necessary flows for Moses Coulee.

Stop 3—WA 172 (Yeager Rock & Moses Coulee Head)

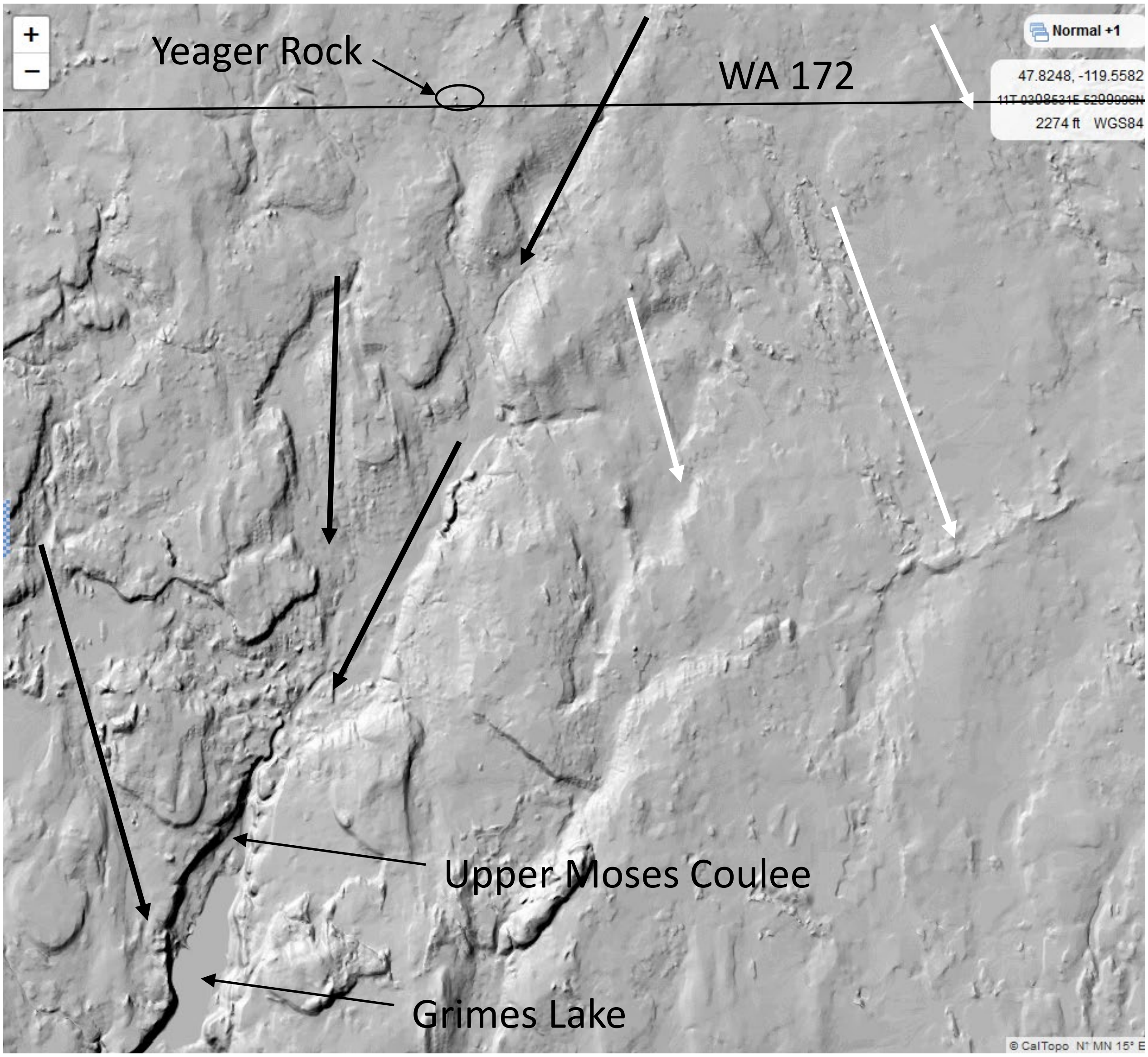

Figure 22. Shaded relief image of the Yeager Rock area. Note the several drainages (bold, black arrows) that empty into the head of Moses Coulee. Also, note the different orientation of drumlins and flutes here (bold, white arrows) versus those at Stop 2. Source: Caltopo.com.

To Stop 4

Route. From Stop 4, we will continue east on WA 172 for nearly 4 miles. Turn north (lef) onto gravel Road M NE. Very soon after, turn east (right) onto anunmarked old, paved highway. Drive nearly 0.5 miles and park. This is Stop 4. GPS coordinates are 47°49'8.92"N, 119°27'44.47"W.

What is this surface? Nearly 2 miles east of Stop 4, WA 172 passes through an unfarmed area. Unfarmed areas on the Waterville Plateau are usually that way because of poor soils. These soils may be shallow, rocky, or poorly drained (therefore wet). Any of these conditions may lead to rangeland rather than farmland land use. A large gravel quarry located just south (right) of the road suggests that the area is underlain by sorted stream deposits. Examination of Google Earth suggests this is a very extensive, braided stream deposit. Erratics and eskers mantle part of these deposits. This is but one of many such features on the plateau. It seems likely that this feature formed as the ice margin retreated. Might it have fed water into the Moses Coulee? If so, it would likely have done so via Burton Draw, rather than into the head of the coulee.

Stop 4—WA 172 (Pot Hills)

Location. We are located in the Pot Hills east of Mansfield and west of Sims Corner. This is state of Washington land and we are parked on an old version of WA 172. **What are the characteristics of the Pot Hills?** The Pot Hills are a NW-SE trending series of hills that is intersected by WA 172 (**Figure 23**). The entire area is about 1.1 mile long by ~0.6 mile wide at its widest. Easterbrook (1977) described them as a "complex of rounded, conical hills". USGS topographic map and Google Earth analysis suggests that the terrain takes on a linear aspect as well. The linear features have two different orientations—225^o in the southern portion and 275^o in the northern portion (**Figures 23 & 24**). Easterbrook (1977) notes the relationship of the Pot Hills with *eskers* (i.e., sinuous ridges composed of glaciofluvial sediments) and with streamlined features (e.g., flutes or drumlins) (**Figure 23**). Large haystack rocks are also present in the Pot Hills. Further, the overall elongation of the Pot Hills is similar to that of the drumlins and the eskers.

Stop 4—WA 172 (Pot Hills)

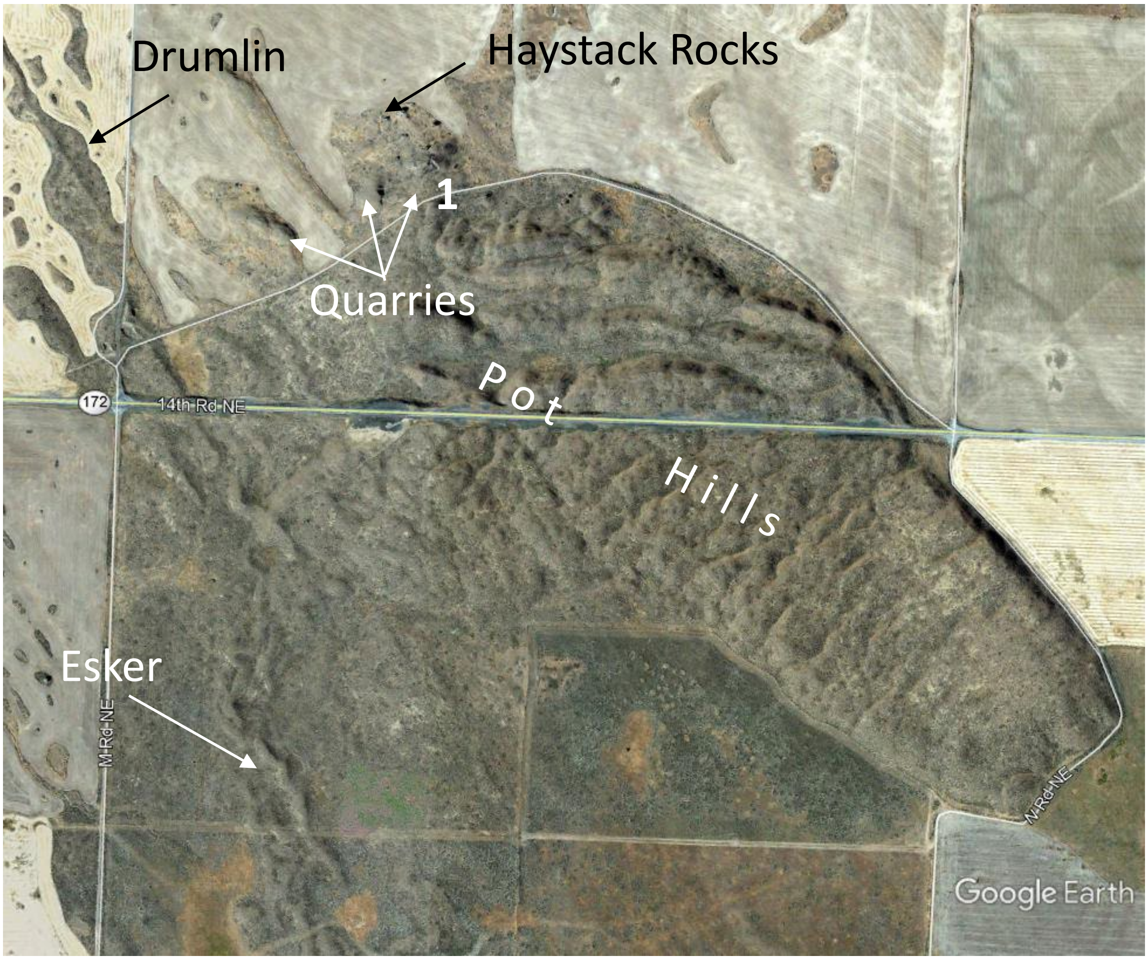

Figure 23. Stop 4 in the Pot Hills (bold number) and surrounding environs. Source: Google Earth.

Figure 24. Aligned nature of the Pot Hills. View to southeast. Source: Karl Lillquist (2019)

Stop 4—WA 172 (Pot Hills)

What are the possible origins of the Pot Hills? Several origins have been put forth for the Pot Hills. Freeman (1932) proposed that the hills are crevasse fillings. In this model, crevasses on the ice surface would fill with sorted glaciofluvial debris. With the stagnation of ice, the fillings would be left as ridges. Easterbrook (1977, 1979) referred to them as *kames*. Kames are typically round hills composed of glaciofluvial sediments that were deposited in cavities within glacial ice. Upon melting, the kames occur as hills. However, kames are typically composed of glaciofluvial sediments therefore are the sites of gravel quarries. There are several quarries in the Pot Hills (**Figure 23**) but none seem to include glaciofluvial sediments. Also, their common orientations seem odd for kames. Instead, perhaps they represent a large mass of basalt bedrock that was "dislocated" along its joint pattern as the Okanogan Lobe passed over (Hanson, 1970). What remains is a mix of jointed bedrock and rubble. If this is the case, why doesn't the feature display linear trends reflecting ice movement? Finally, might they represent a large mass of basalt plucked and transported to the area by the Okanogan Lobe? Could this also be the origin of Lone Butte and Burke Hill (Waitt, 1994)?

What is a recessional moraine? When glaciers retreat, they don't often do so in a uniform fashion. Rather, they may retreat, pause, and retreat. Retreat is not like a conveyor belt in reverse; instead, it involves the melting the front and top of the ice so the ice lobe gets shorter and thinner. Recessional moraines may be deposited as the ice pauses in a new position. These moraines occur behind (or upglacier) of the Withrow terminal moraine. Like the Withrow moraine, they parallel the ice front so they are perpendicular to ice flow and subglacial meltwater direction. They are composed primarily of unsorted till therefore they typically do not have gravel quarries in them. Early researchers recognized recessional moraines on the Waterville Plateau (e.g., Waters, 1933). At least 13 major recessional moraines and an equal number of minor recessional moraines are present across the Waterville Plateau (Hanson, 1970). These are spaced about 1-2 miles apart, range up to 50 feet high, and may be several hundred feet wide. They are constructed of unstratified as well as stratified sediment. An extensive recessional moraine lies just south of the Pot Hills (Easterbrook, 1979) (**Figure 25**).

Stop 4—WA 172 (Pot Hills)

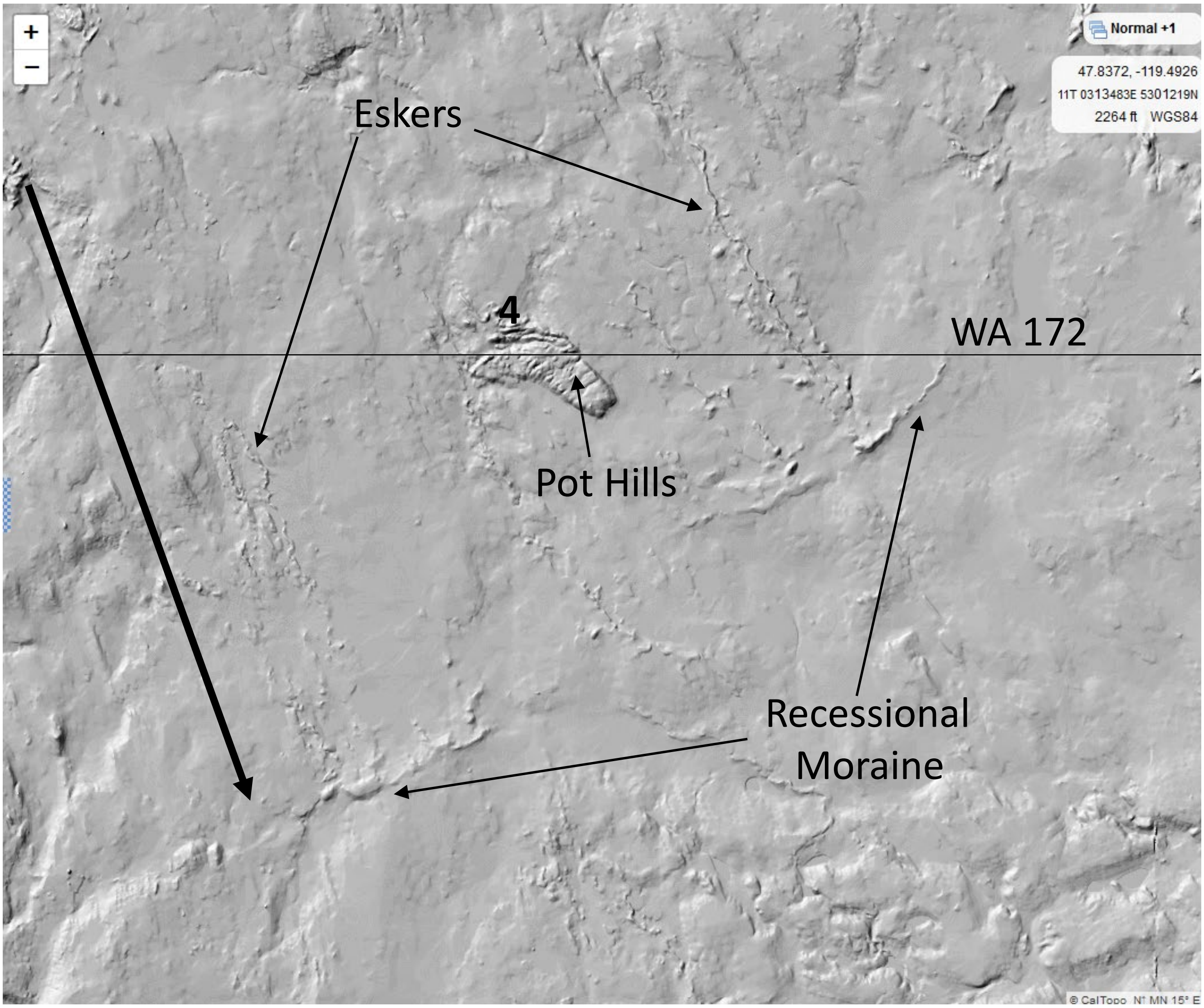

Figure 25. Shaded relief image of Pot Hills and vicinity. Note the prominent eskers that terminate at the recessional moraine. Bold black arrow indicates predominant ice flow direction here. Note how different this is from our observations at Stop 2. This shows how ice sheet flow is often radial when relatively unconstrained by topography. Source: Caltopo.com.

To Stop 5

Route. Continue east on WA 172 approximately 4.5 miles to the junction of WA 172 with WA 17. This is known as Sims Corner. Cross WA 172 and continue east on gravel Road 14 NE for approximately 1.75 miles. Park near the gravel pit on the left. GPS coordinates are 47°48'54.21"N, 119°19'28.04"W.

Stop 5—Road 14 NE (Kames Deltas & Eskers

Location. We are located about 1.75 miles east of Sims Corner (**Figures 7, 8 & 26**). This is State of Washington land.

Why does ice stagnate? As glacial ice melts from the end and top, it thins to a point it no longer has the mass to advance. When this occurs, the ice wastes or stagnates in place resulting in stagnant ice features. These include kames, kame terraces, kame deltas, kettles, and eskers.

What are stagnant ice features? Between Stop 4 and here, we passed through a subtle, yet amazing, area of stagnant ice features. In fact, this area, and an area just north of us, was proposed for National Natural Landmark designation as the

Figure 26. Esker, kame delta, and various other stagnant ice deposits, east of Sims Corner. Note the pimpled surface of the kame delta. Source: Google Earth.

Stop 5—Road 14 NE (Kame Deltas & Eskers)

What are stagnant ice features? (continued)…Sims Corner Esker and Kames, and Sims Corner West Esker sites (Scott, 1978). Two key, stagnant ice features here are eskers and kames (Hanson, 1970; Easterbrook, 1979; May, 1988; Kovanen & Slaymaker, 2003). Both form in contact with glacial ice. *Eskers* are sinuous channel fillings formed at the base of glacial ice (**Figure 11**). As channel fillings, they are composed of sorted and stratified sands and gravels. Eskers in the area often terminate at recessional moraines or kame deltas (Hanson, 1970) (**Figure 25**). *Kame deltas (*sometimes called *delta-kames, delta-moraines, ice-contact deltas, and ice marginal fans)* form at the downstream ends of eskers where meltwater streams exited the ice and deposited into proglacial lakes (**Figure 11**) . They typically take on a Greek delta (i.e., triangle) or fan shape, have steep margins, and flat tops. Their surfaces are often pitted with kettles. Kame deltas often display erratics on their near-glacier ends where debris was directly deposited from the ice onto the feature. The near-glacier ends are often slumped and irregular because of the subsequent melting of the ice.

What are the stagnant ice features here? We are parked at the base of a large kame delta which formed at the end of an esker (**Figure 26**). The esker is certainly a sinuous ridge and is likely composed of glaciofluvial sediments (based on the nearby gravel pit) (**Figure 27**). It is nearly nearly 5.25 miles long! Others on the plateau are as long. The kame delta has a fan-like shape with steep sides, a relatively flat surface that is cut several *distributary channel*, and a deformed section near where the ice once stood (**Figure 28**). It measures ~3,100 feet at its widest along the former ice front while the central portion extends nearly 1,000 feet outward from the esker. Within the deformed section there are numerous depressions that may be kettles.

What do the stagnant ice features indicate? The well-developed eskers, kames, and kame deltas suggest that the Okanogan Lobe stagnated for a significant period here (Freeman, 1932). Why did so many of these features form on the eastern portion of the Waterville Plateau rather than the western portion? The kame delta indicates that a proglacial lake was present here with a depth of at least 30 feet. This is corroborated by the kame delta immediately to our south which as the same surface elevation (**Figure 29**). What impounded this lake? How large was it? Where and when did it drain? Third, the preservation of the eskers and kame deltas here indicates that the ice sheet did not readvance after their deposition or they would have been destroyed. Instead, the eskers are "like great dying serpents that give their final testimony to the stagnation of the Okanogan Lobe" (Easterbrook and Rahm, 1970, p. 132). In addition to their unique shapes, eskers and kame delta sediments (i.e., clean sand and gravel) are tremendous economic resources here and in other stagnant ice areas. They can often be identified by the gravel and sand quarries (like the one's here) on their surfaces.

Stop 5—Road 14 NE (Kame Deltas & Eskers)

Figure 27. Surface of esker representing old stream channel. View toward northwest. Source: Karl Lillquist (2019)

Figure 28. Steep front of kame delta that indicates sediments were deposited into a lake. Source: Karl Lillquist (2019)

Stop 5—Road 14 NE (Kame Deltas & Eskers)

Ice Age Floods. Stop 5 lies just south of Horse Lake Coulee and associated scabland terrain (**Figure 30**) which is a possible Ice Age floods pathway onto the Waterville Plateau and a glacial meltwater pathway off the plateau. Ice Age floods may have been diverted onto the Waterville Plateau by the Okanogan Lobe prior to the formation of the Grand Coulee (Bretz, 1932; Flint, 1935; Hanson, 1970). These floods would have flowed down the Foster Creek drainage to the northwest (Hanson, 1970). The presence of a fan-delta at the eastern mouth of Horse Lake Coulee in the Upper Grand Coulee also indicates that glacial meltwater flowed east into the Grand Coulee where it was deposited into Glacial Lake Columbia (Bretz, 1932).

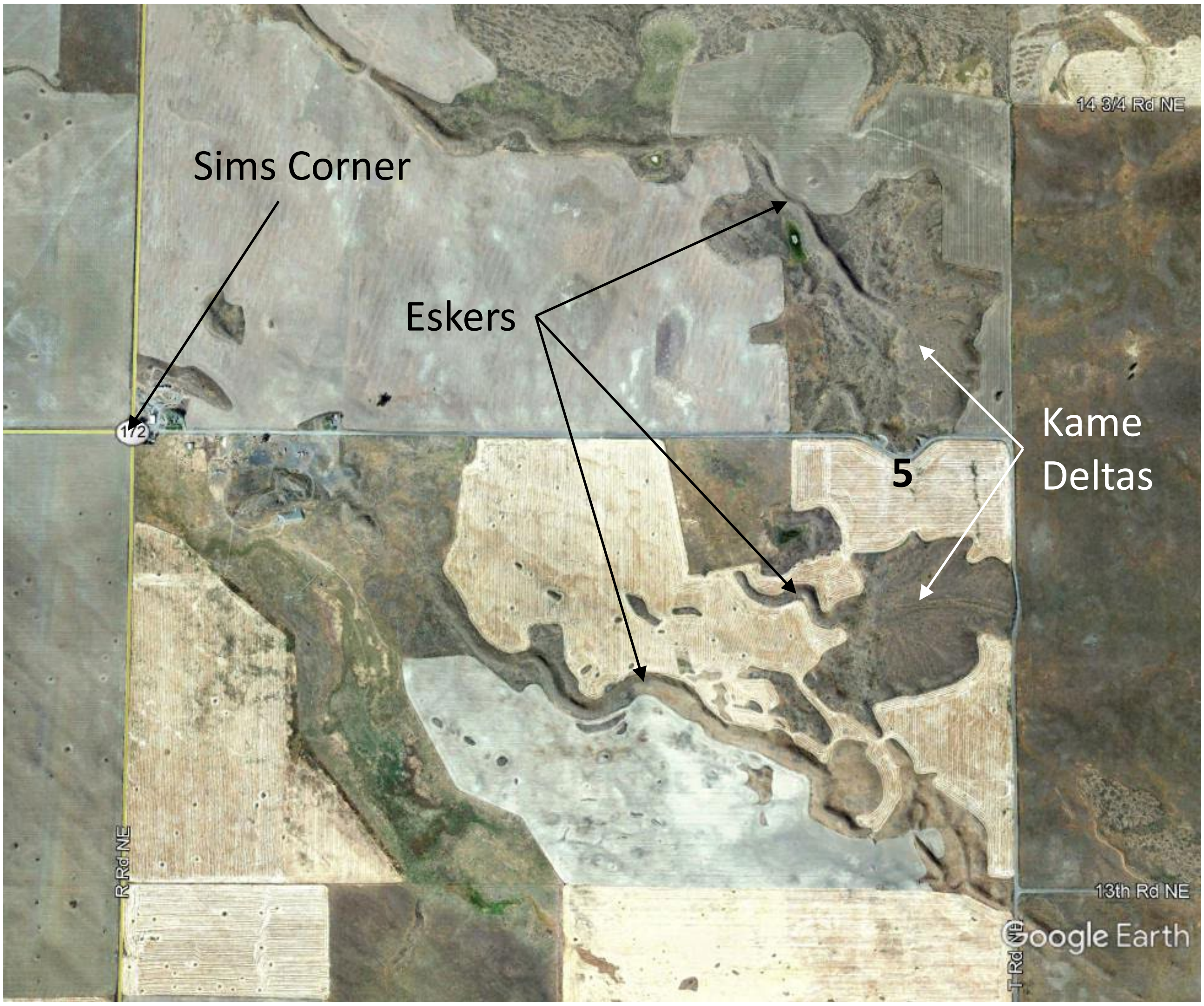

Figure 29. Stop 5 (bold number) amidst kame deltas and eskers east of Sims Corner. Source: Google Earth.

Stop 5—Road 14 NE (Kame Deltas & Eskers)

What is the pimpled appearance of the kame delta surface? Note the pimpled appearance of the surface of the kame delta at Stop 5 (**Figure 30**). This is patterned ground in the form of shallow, subtle soil mounds We have previously seen these on a variety of surface types and ages in Central Washington. Invoking the Law of Superposition, these features must be younger than the kame delta they lie on. Did these features form from a cold climate that should have characterized the area in the late Pleistocene or did they form from other processes—e.g., selective deposition of loess, selective erosion of loess, burrowing rodents?

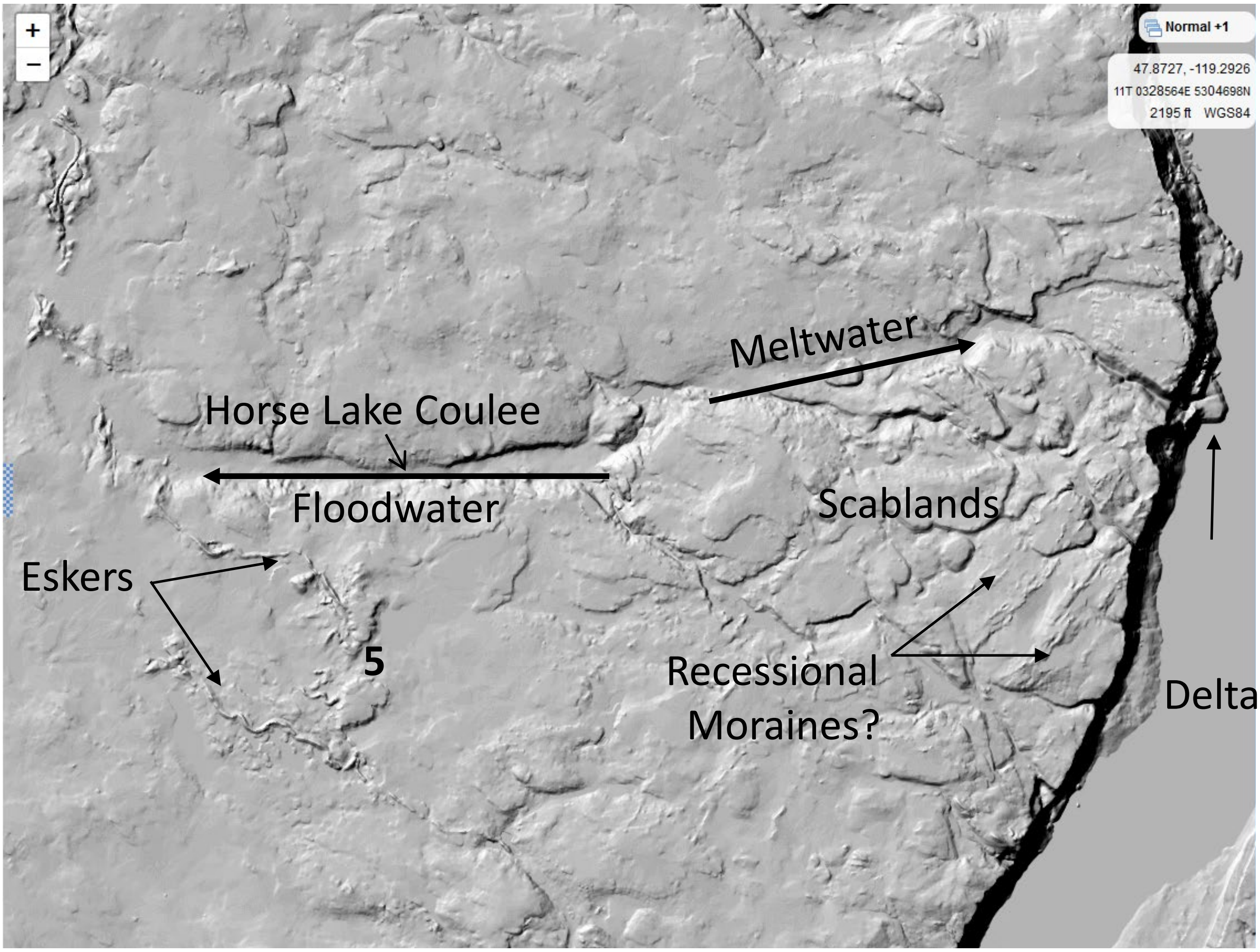

Figure 30. Shaded relief map of Stop 5 (bold number) and surroundings including eskers, kame deltas, possible recessional moraines as well as the Horse Lake Coulee scablands and fan-delta. Source: Caltop.com.

Wrap-up

While we did not see glacial ice today, we saw the effects of ice sheet glaciation in a place where the evidence is well-exposed. Drumlins and flutes indicate ice sheet advance into the area, the Withrow Moraine shows the southernmost terminus of the Okanogan Lobe, kames, kame deltas, and eskers highlight where the ice stagnated in place for a significant time, and erratics reflect the overall ground moraine deposition that occurred here. This area has been described as “a museum of glacial landforms magnificently preserved in the arid climate” (Easterbrook, 2003, p. 153). In my experience, it is indeed rare to see such a variety of well-preserved landforms in one small area. All of this may have occurred over less than a ~6,000 year period—i.e., the most recent glacial advance began in Canada about 17,500 years ago but we don’t know when the glacial ice advanced onto the Waterville Plateau. By ~11,600 years ago, the ice sheet had retreated to the southern Okanogan Valley north of Brewster.

To Home

From here, you can take several paths to return to Ellensburg: 1) retrace out steps; 2) drive down Moses Coulee; or 3) or head toward Coulee City. The CWU van will take the Coulee City route stopping briefly at Dry Falls for a restroom break. To do this, we will return to Sims Corner where we will turn south (left) and follow WA 17 to its junction with US 2. At US 2, turn east (left) and follow this for several miles to its junction with WA 17 (again). Turn south (right) onto WA 17. Dry Falls and its restrooms will be on the south (left). Continue following WA 17 to Soap Lake. From there, you can take WA 28 and WA 282 back to I-90 near George, and I-90 back to Ellensburg.

Thanks!

Thank you for your support of the Ice Age Floods Institute—Ellensburg Chapter, and Central Washington University. I hope this has been an educational and enjoyable field trip for you. Don’t hesitate to contact me with questions or comments about this field trip or associated Ice Age Floods issues.
Thanks for participating! Karl karl.lillquist@cwu.edu & (509) 963-1184.

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