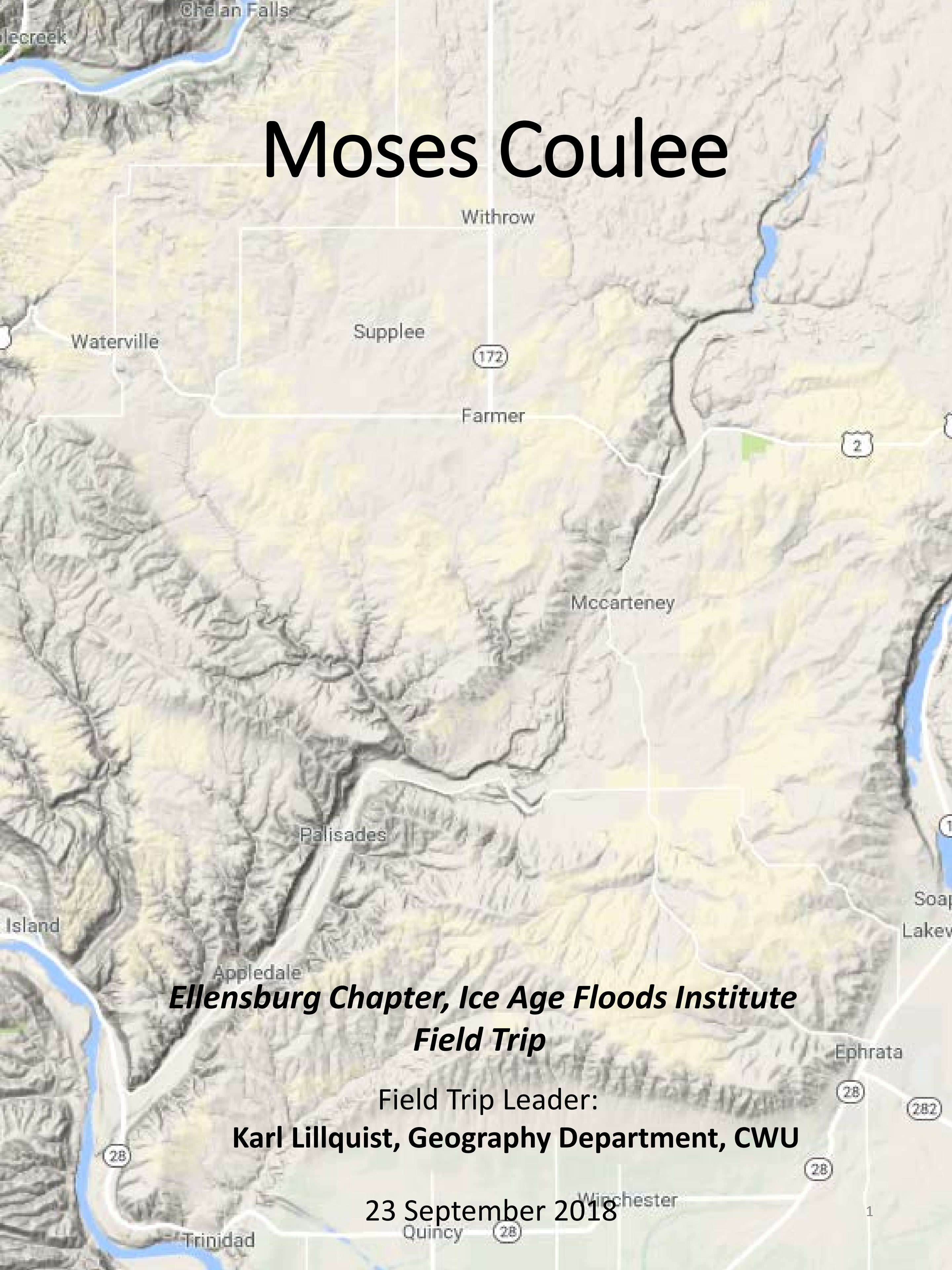
Moses Coulee



Ellensburg Chapter, Ice Age Floods Institute Field Trip

Field Trip Leader:
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23 September 2018

Field Trip Overview

Field Trip Description:

Moses Coulee is the westernmost of four, primary, ice age floodways in Eastern Washington. This 40+ mile long coulee differs from the others in the lack of a clearcut connection to the Columbia River Valley and the absence of adjacent scablands. Moses Coulee's floor is also draped by an end moraine from the Cordilleran Icesheet. We will examine the coulee from head to toe to answer the following questions: 1) what drainages were here before the floods; 2) how do we know Moses Coulee formed from ice age floods; 3) how did floods excavate the coulee; 4) what were the impacts of structures (e.g., anticlines and synclines) on the formation and evolution of the coulee; 5) how did the Cordilleran Icesheet impact Moses Coulee; 6) how many floods passed through Moses Coulee and when; and 7) how did the excavation of Moses Coulee impact the Columbia River downstream. En route, we will also consider other issues including human settlement in the area.

Tentative Schedule:

10:00am	Depart CWU
11:45	Stop 1—Jameson Lake WA DFW boat launch & parking lot (inc. pit toilets)
12:45pm	Depart
1:00	Stop 2—South of Jameson Lake, Upper Moses Coulee
2:00	Depart
2:30	Stop 3—Three Devils Grade, Lower Moses Coulee
3:15	Depart
3:45	Stop 4—Old Hwy 28, Mouth of Moses Coulee
4:30	Depart
6:00	Arrive at CWU

Our Route & Stops

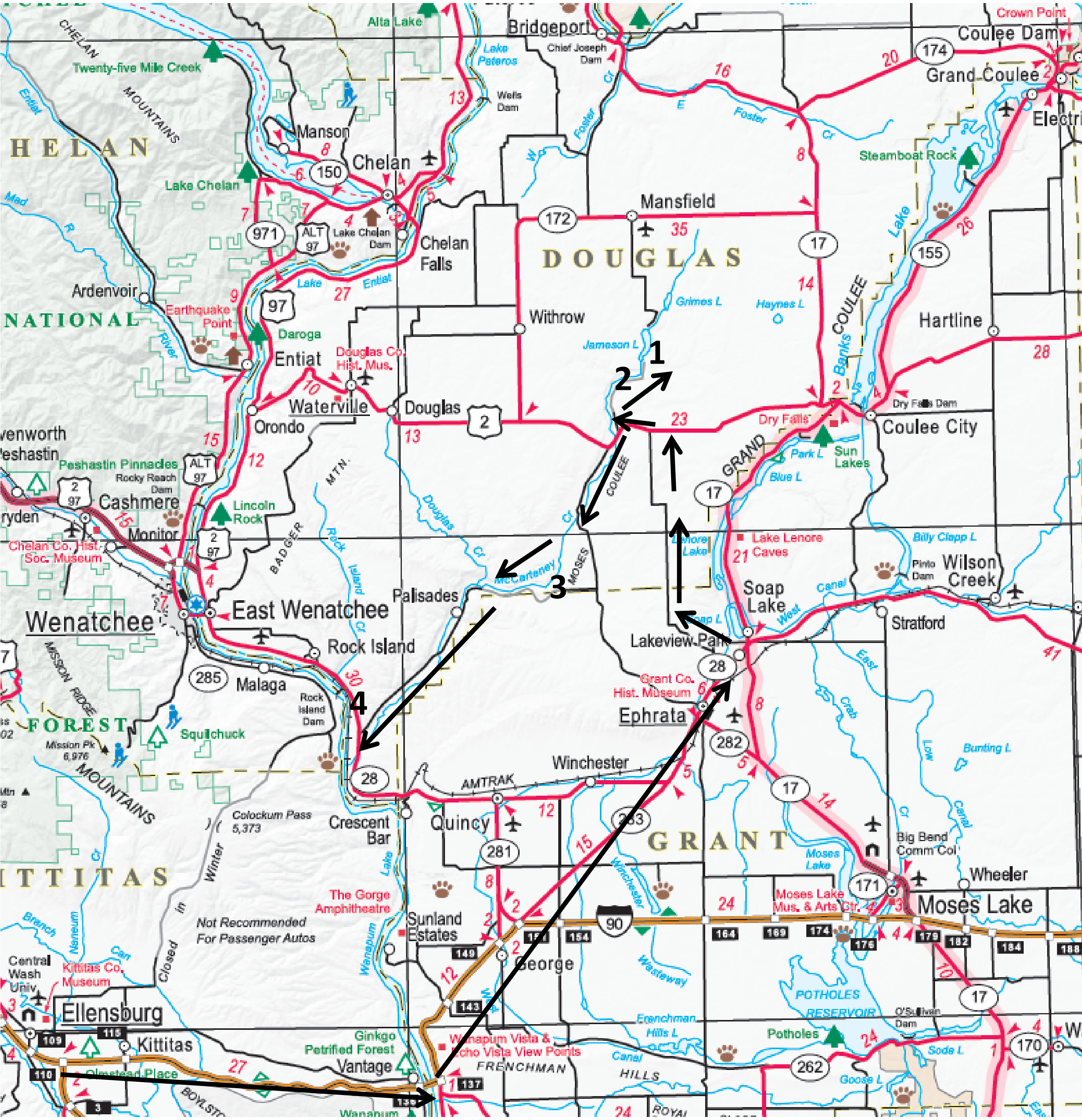


Figure 1. Our route shown with arrows and stops noted with numbers. Source: Washington State Department of Transportation http://www.wsdot.wa.gov/NR/rdonlyres/14A6187A-B266-4340-A351-D668F89AC231/0/TouristMapFront_withHillshade.pdf

Ellensburg to Ephrata

Figure 2. Topography of the Ellensburg to Quincy Basin part of our route. Source of image: Google Maps.

Ellensburg to Ephrata

Route: Part of our route to Stop 1 takes us from Ellensburg to the Quincy Basin via I-90 (Figures 1 & 2). Just beyond George, take exit 151 and follow WA 283 and WA 28 to Ephrata. Drive through Ephrata where the next leg of the trip begins.

Lithology & Structure: Ellensburg lies near the western margins of the Columbia River Basalts. Our drive from Ellensburg begins on the floor of the Kittitas Basin *syncline* with downfolded Columbia River Basalts ~4000 feet below us (Figures 3, 4, & 5). Mantling the Columbia River Basalts are volcanic sediments of the Ellensburg Formation, *alluvial fan* sediments from the surrounding mountains , Yakima River *alluvium,* and *loess*. East of Kittitas we ascend the Ryegrass *anticline* (Figure 6).

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

Missoula Floods: Descending the Ryegrass anticline, we reach the upper limit of Missoula Flood *slackwater* at ~1260 feet (Figure 7) between mileposts 133-134. Look for changes in the shrub steppe vegetation as well as thick gravel deposits to indicate that we have crossed into the area once inundated by floodwaters. Also, keep your eyes peeled for light-colored, out-of-place rocks atop the basalts in this area—these are iceberg-rafted *dropstones* (also called *erratics*) deposited by the floods. As we descend to Vantage at ~600 feet elevation on the Columbia River, recognize that floodwaters lay ~600 feet over our heads at their deepest extents. The Columbia River "Gorge" here is a result of erosion by numerous ice age floods. East of the Columbia River, the ~horizontal bench we follow until nearly entering the Quincy Basin and the Columbia Basin Irrigation Project is a *stripped structural surface* created by selective erosion of Columbia River Basalts to the level of the Vantage sandsone. Several landslides are visible atop the Vantage sandstone in the slopes to the right (east) of I-90. From here, we also have fine views of *Channeled Scablands* (to your west) that are so indicative of Ice Age flood-ravaged surfaces. Floodwaters entered the Quincy Basin from the northeast and escaped to the south and west (Figure 8).

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

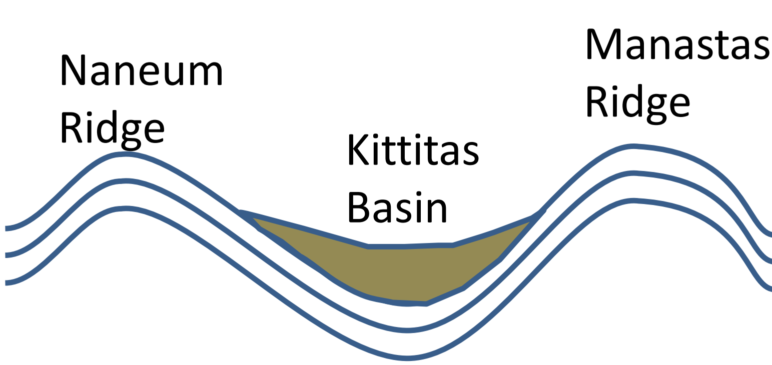


Figure 3. Location of Kittitas Basin syncline between Naneum Ridge and Manastash Ridge anticlines.

Ellensburg to Ephrata

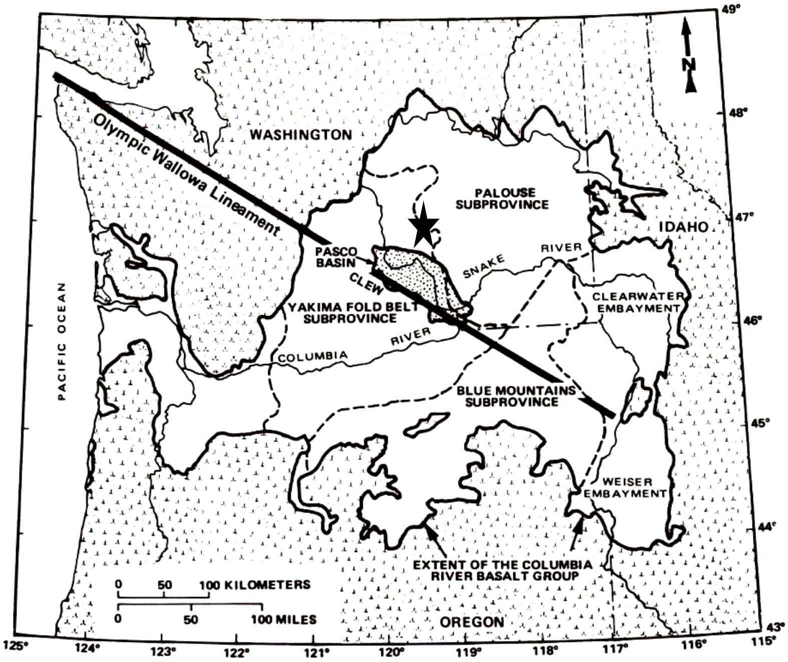


Figure 4. The Columbia Plateau and the areal extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Star indicates approximate location of Moses Coulee. Source: (Reidel & Campbell, 1989, p. 281).

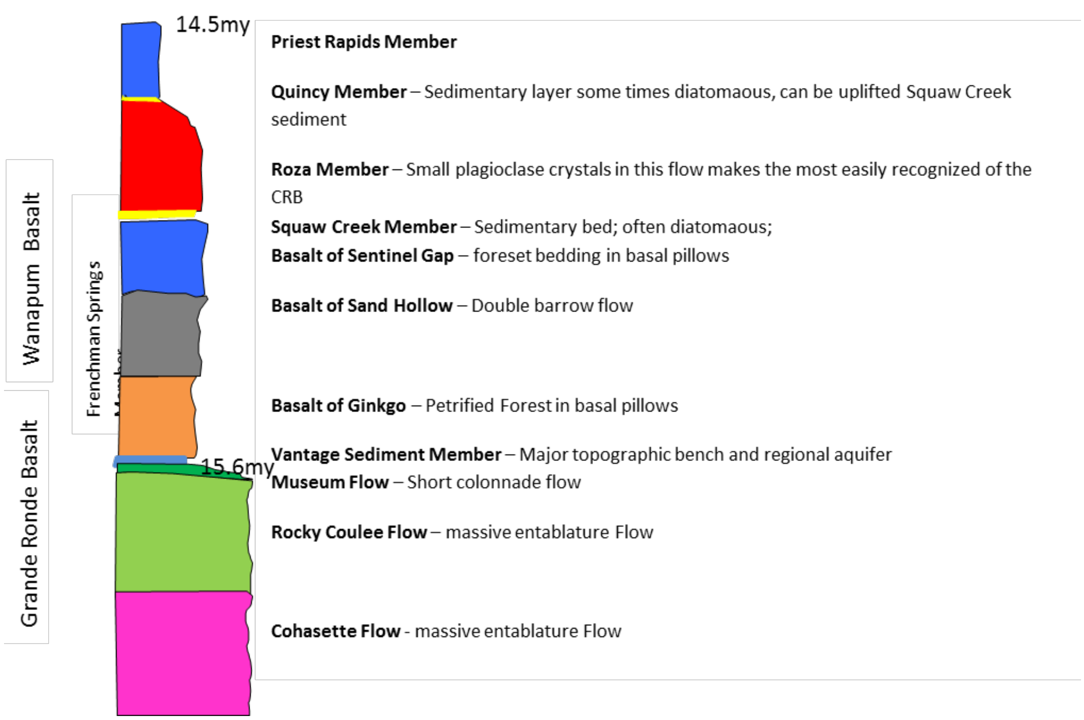


Figure 5. Stratigraphy of the Columbia River Basalt Group. Source: Jack Powell.

Ellensburg to Ephrata

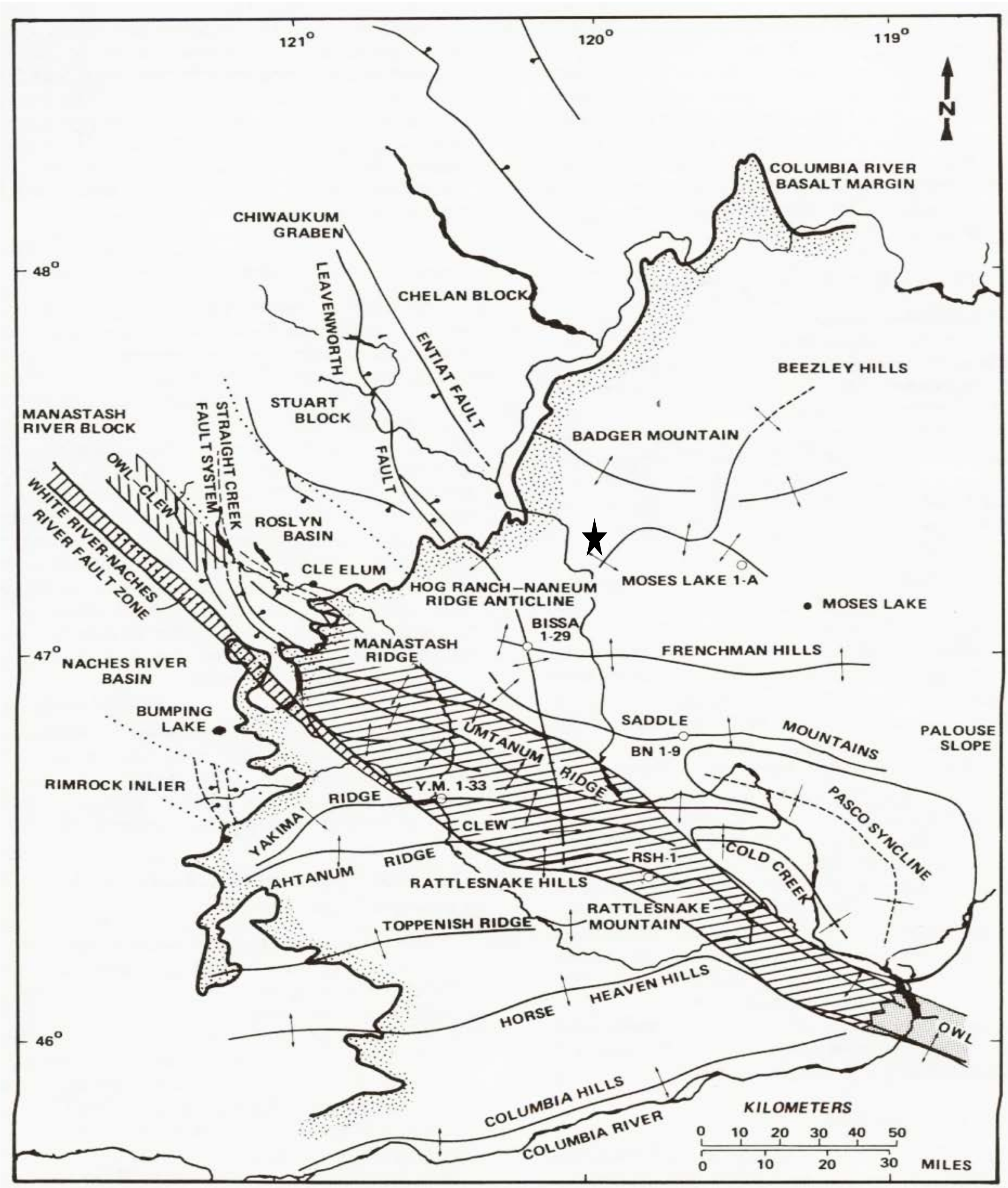


Figure 6. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Star indicates approximate location of Moses Coulee. Source: Reidel & Campbell (1989, p. 281).

Ellensburg to Ephrata

Substrate: The Quincy Basin is underlain by *Miocene* Grande Ronde and Wanapum basalts of the Columbia River Basalt group (Figures 4 and 5). The individual flows are interbedded with sedimentary units including *diatomaceous earth*, which is mined in the basin. The Ringold Formation, a mix of *Tertiary* and *Quaternary alluvial* and *lacustrine* sediments, is found in scattered exposures in the basin. Gravels, sands, and silts associated with late Quaternary Ice Age floods cover much of the basin. Loess mantles much of the slopes of the basin (Figure 10). The tan soils of the basin are low in organic matter and indicate aridity.

Structure and Flooding: The Frenchman Hills and Beezley Hills (Figure 8) are anticlines on the northwestern part of the Yakima Fold and Thrust Belt (Figure 6). These anticlines guided Ice Age floodwaters entering the basin from the northeast and east. Flood outlets from the basin were (clockwise from the northwest) at Crater Coulee, Potholes Coulee, Frenchman Coulee, and Drumheller Channels (Figure 9).

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

Flood Bars: A giant flood bar formed at the mouth of the Lower Grand Coulee and Upper Crab Creek Valley as the waters left their confines. The largest sediments were deposited near the mouth of the lower Grand Coulee as the Ephrata Fan (or Ephrata Expansion Bar). This bar impounds Soap Lake. Keep your eyes open for evidence of large, Ice Age flood-transported boulders between George and Ephrata (near milepost 10), and again between Ephrata and Soap Lake, some of which have been piled into huge stone fences. These floodwaters also left *distributary channels* throughout the basin. Ephrata lies in once such channel, aptly named the Ephrata Channel. From Ephrata, we climb to the top of the expansion bar on WA 17, then descend to Soap Lake. Note the impacts of these bar sediments on land use.

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

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

Ellensburg to Ephrata

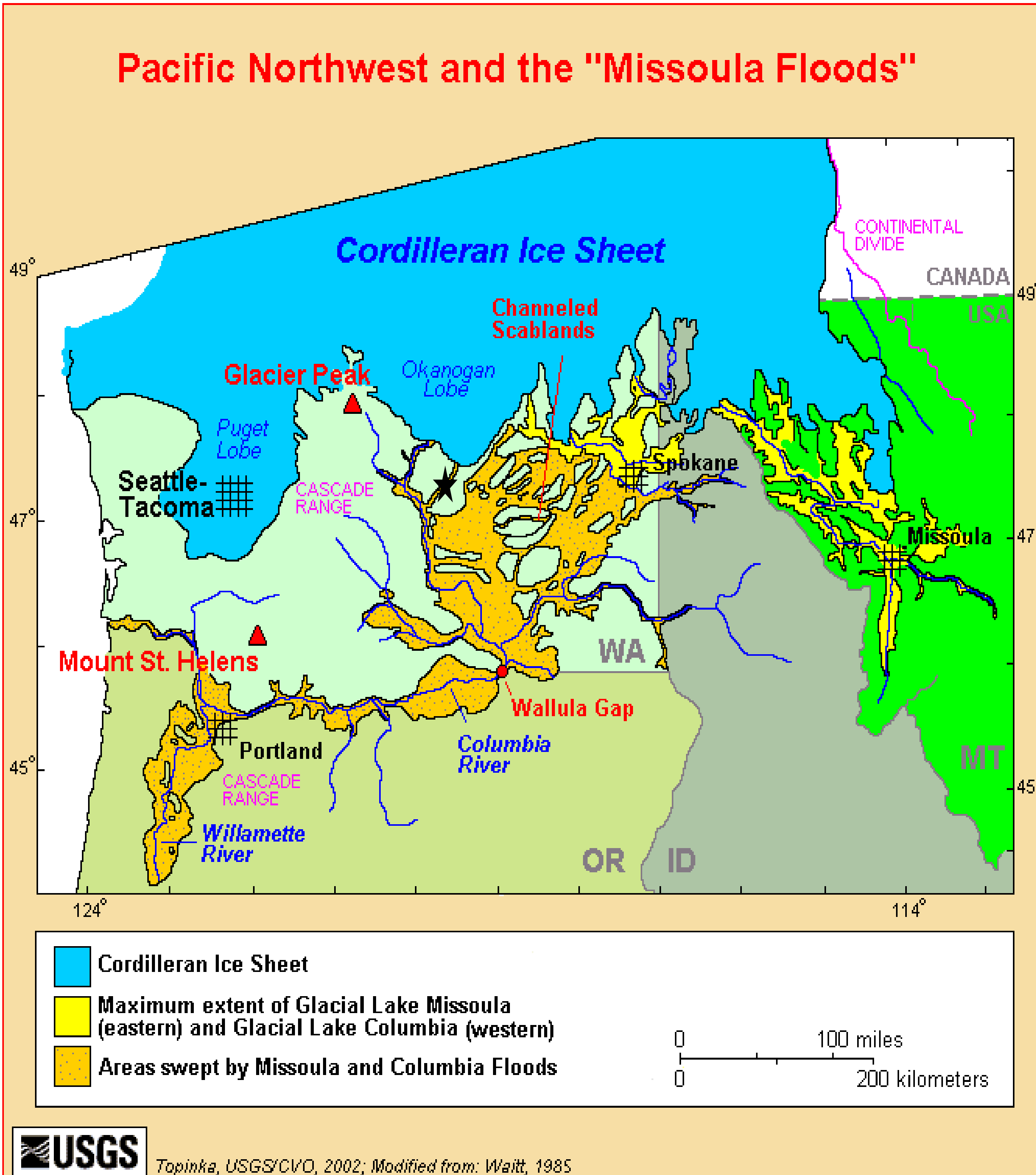


Figure 7. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Star indicates approximate location of Moses Coulee.
Source: Cascade Volcano Observatory website.

Ellensburg to Ephrata

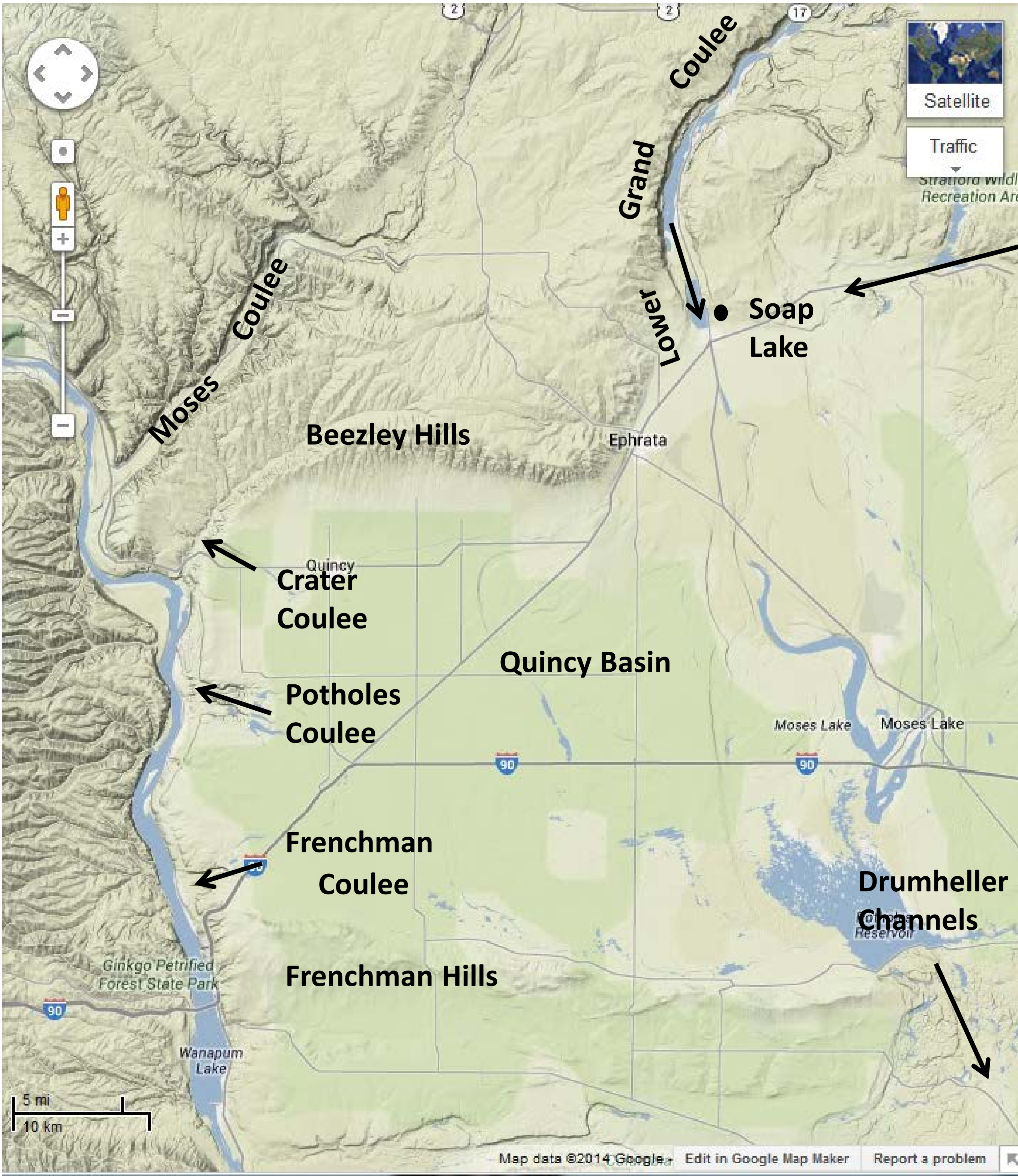


Figure 8. Topography of the Quincy Basin and adjacent areas. Arrows show direction of flood flows into, and out of, the Quincy Basin. Source of image: Google Maps.

Ephrata to Jameson Lake

Route. Just north of Ephrata, turn left onto Road B NW. Follow this north about 2.5 miles to the Sheep Canyon Road, Turn left onto the Sheep Canyon Road and follow this northwest about 3.5 miles as it climbs up onto the Waterville Plateau. At about the 6 mile mark from WA 28, turn right onto Road E NW. This road soon becomes Whitehall Road. Continue north, then jog west 1 mile, and turn north again to travel to US 2. The total length of Road E NW and Whitehall Road is about 14 miles. At US 2, turn left and head west about 2.5 miles to bottom of Moses Coulee. At the coulee bottom, turn right onto Jameson Lake Road SE and follow this good gravel road north for approximately 7 miles to the Washington Division of Fish and Wildlife boat launch site at Jameson Lake. We will park above the boat launch. This is Stop 1. Pit toilets are available here.

Ice Age Floods. Road B NW is atop the distal edge of the large expansion bar that formed at the mouth of the Lower Grand Coulee (Figures 8 & 9). Given the typically coarse nature of expansion bar sediments, it is amazing that agriculture can occur here. Ice Age floods must have also impacted the area up Sheep Canyon Road. How do we know? Ice age flood impacted surfaces are typically scoured so soils are thin to non-existent. This may also result in an abrupt soil, or even topography, boundary between flooded and non-flooded lands. Land use typically reflects this soil change. Here, that would mean rangeland on flood-impacted surfaces versus dryland agriculture on non-flooded. Further, iceberg-rafted boulders may be grounded as floodwaters recede. When these boulders are not basalts (e.g., light colored granites and quartzites) they are good evidence of flooding. Based on the change in land use from range land to dryland agriculture, the upper limit of flooding seems to have been near 1900 feet elevation.

Wind & Water. Above the Missoula Flood limit, the segment of the route from the upper Sheep Canyon Road to US 2 is dominated by the effects of wind-deposited *loess*. Loess is often deposited as a blanket over a landscape. Given this blanket and the underlying Coulee Monocline, we are on a loess-covered plateau. Loess originates where ample, fine-textured sediments are present. Such places include the outwash plains of ice sheets. That may be the case here as the Okanogan Lobe of the Cordilleran Icesheet stopped about 3 miles north of US 2. Conversely, Ice Age floods deposited great thicknesses of fine sediments in the Pasco Basin to our south. Winds may have subsequently blown those sediments here (Busacca and McDonald, 1994). Even in this dry environment, local streams (mostly ephemeral or intermittent) and *sheetwash* have eroded into this loess blanket. The most eroded areas are not suitable for farming.

Dryland Agriculture and Human Settlement. Agriculture atop the Waterville Plateau was initially mostly ranching. Dryland wheat farming followed this beginning in the late 1800's. It is so dry here (<10 inches of precipitation/year) that farmers use a summer fallow system where a particular piece of land grows grain (typically wheat) one year and lies fallow the next year to collect moisture. Further, farmers plant winter wheat (wheat is planted in late summer, grows until it is too cold in fall, goes dormant, then resumes growth in spring) as a way for plants to get a good start with the stored fallow moisture. At this time of year, you can see the land that was planted in August and earlier September as well as the straw-covered, recently harvested fields that were planted the previous year. When this area was first farmed, farms were much smaller with each covering 160 to 320 acres. This meant that there was a home every 0.5 to 1.0 mile. One room schoolhouses served the school-aged kids of the area. At least four schools operated in this area (Ogle, 1915). You can still see the Highland School just south of US 2 on Highland School Road SE. The Baird School burned in the last 20 years but the associated cemetery remains. With the changing economies of scale, the family farm has grown to several thousand acres of land farmed each year. So…fewer families live here.

Ice Age Floods…again. The impacts of Ice Age floods are again seen along US 2 where it descends into Moses Coulee, and along Jameson Lake Road SE that heads toward Jameson Lake. Ice Age floods created Moses Coulee. These floods will be the focus of much of today.

Ephrata to Jameson Lake

Figure 9. Landscape between Ephrata and Jameson Lake. First two field trip stops shown with bold numbers. Very approximate location of our route shown in red. Approximate location of Withrow Moraine shown with white line. Source: Google Earth.

Stop 1—Jameson Lake

Location. We are located at the Washington Division of Fish and Wildlife boat launch area near the south end of Jameson Lake in Moses Coulee.

Upper Moses Coulee Geology. Undifferentiated Grand Ronde basalts and the Frenchman Coulee member of the Wanapum basalts of the Columbia River Basalt Group are present here. In this area, Moses Coulee generally follows the trace of a syncline in these basalts. Well logs here show 30-80 feet of sands and gravels above the basalt bedrock (Pacific Groundwater Group, 2007). These are interpreted as flood deposits or glacial outwash. Additionally, one well shows 41 feet of silt and clay that indicates a prehistoric lake (Pacific Groundwater Group, 2007). Glacial *till* and *outwash*, flood sediments, and *talus* commonly obscure the basalts.

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.

Moses Coulee. Moses Coulee is the westernmost of four scabland tracts in Eastern Washington. Bretz (1923a, p. 600) argued that Moses Coulee is second only to the Grand Coulee in "spectacular proportions" (Figure 10). It is an S-shaped feature extending from Grimes Lake southward about 40 miles to the Columbia River. It can be subdivided into upper, middle, and lower portions (Figure 11) (Bretz, 1923a; Hanson, 1970). The upper portion begins as intermittent and ephermal, shallow channels near WA 172 about 9 miles to the north. The middle portion is an indistinct, broad basin centered on Sagebrush Flat. The lower portion is the most spectacular because its walls are up to 900 feet deep. A triple cataract up to 600 feet high separates the middle and lower portions of the coulee.

Moses Coulee Origins. While Symons (1882) was the first scientist to visit Moses Coulee, it was I.C. Russell (1893) who first recognized that it was the result of stream erosion. Bretz (1923a), based primarily on the presence of scabland features (see Stop 3) stated that a "great stream" eroded Moses Coulee. The scale of features here tells us that the floods that created Moses Coulee weren't floods of historic proportions; instead, these were great floods. We will talk more about the evidence of such floods at later stops.

Possible Floodwater Sources. The source of such great floods is not clear. Moses Coulee differs from many other scabland coulees in that its head is hardly identifiable and does not extend north to possible floodwater sources in the Columbia River Valley (Figures 11 & 12). In fact, WA 172 passes over the subtle drainages feeding into Moses Coulee near Yeager Rock (Figure x). It is possible that 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 and glacial meltwater deposited outwash) is generally thin in those areas north of the glacier margin (Hanson, 1970). Perhaps instead the Moses Coulee channel cutting event occurred during an earlier glaciation, then subsequent gaciation has obscured the upper portions of the channel. However, evidence of an earlier glaciation has not been found on the Waterville Plateau (Hanson, 1970). Perhaps Moses Coulee was eroded by water 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

Stop 1—Jameson Lake

Figure 10. Physiographic diagram of the Channeled Scablands. Note the locations of the of the four scabland tracts: A) Cheney-Palouse; B) Crab Creek-Telford; C) Grand Coulee; and D) Moses Coulee. Source: Raisz (1965).

Possible Floodwater Sources (continued)…require that Foster Coulee and Horse Lake Coulee were the delivery mechanisms of the Columbia River water onto the Waterville Plateau (Figure 13). The lack of apparent direct drainage to Moses Coulee may be explained by hydraulic ponding of this water as a large temporary lake. The main delivery channels to Moses Coulee at this time would have been the direct headwaters above Grimes Lake and Burton Draw which enters the coulee at the very south end of Jameson Lake. Another possibility is that floodwaters reached what is now Moses Coulee via tunnels within the Okanogan Lobe (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 1—Jameson Lake

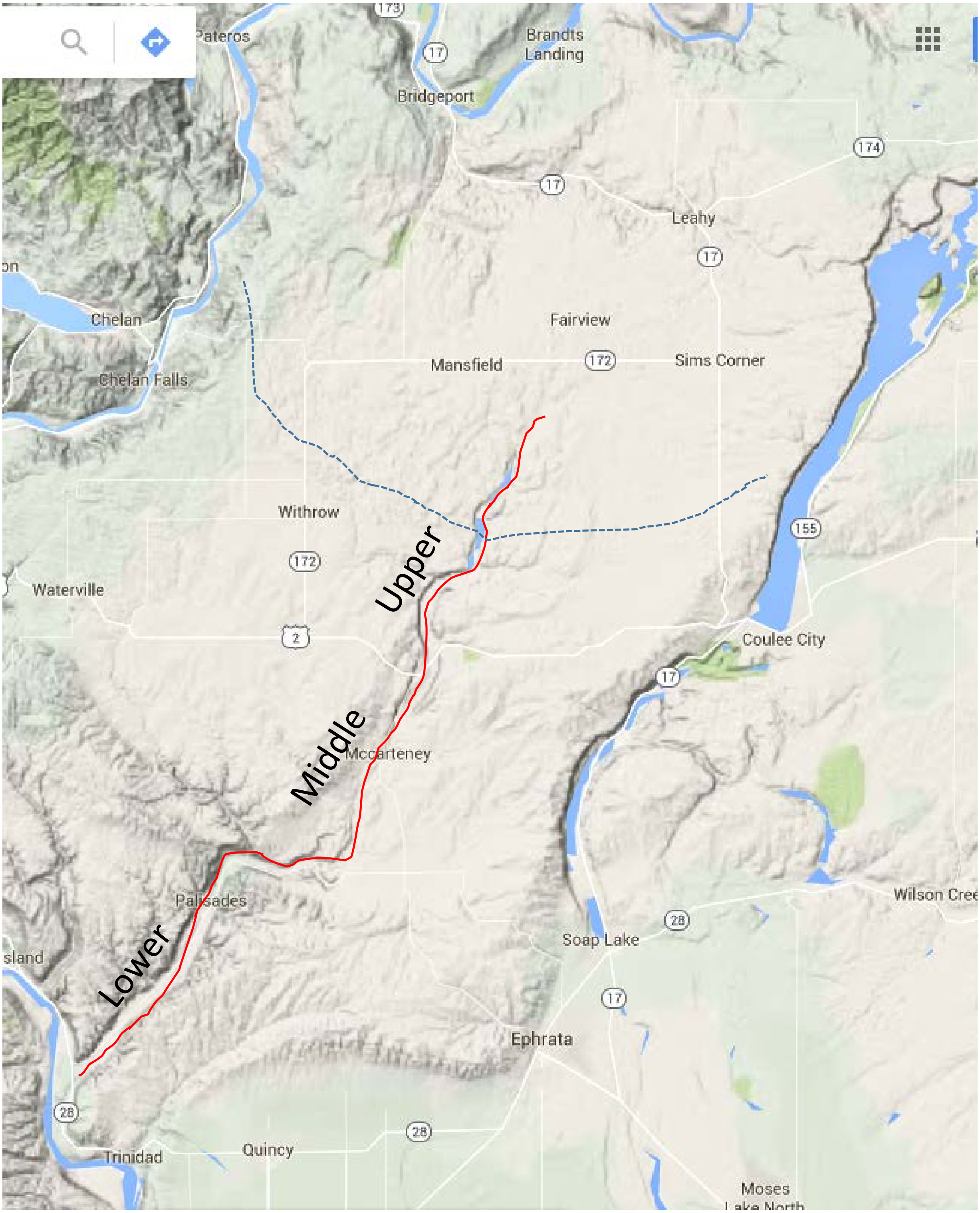


Figure 11. Moses Coulee, Washington on the Waterville Plateau. Solid red line indicates extent of Moses Coulee. Dashed blue line indicates approximate location of Withrow Moraine. Source of image: Google Maps.

Stop 1—Jameson Lake

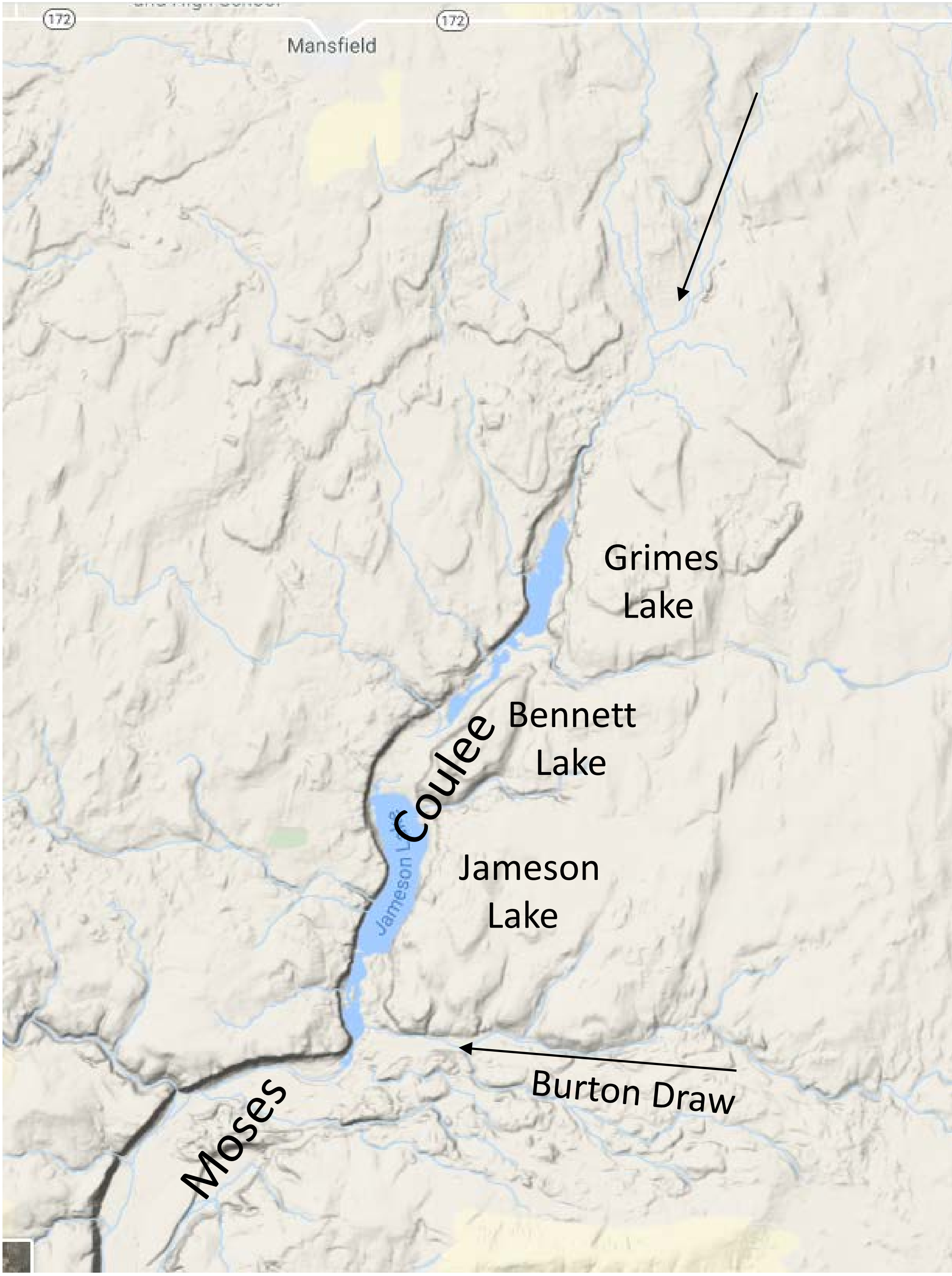


Figure 12. Jameson, Bennett, and Grimes lakes, upper Moses Coulee. Note the indistinct drainages leading into the north end of Moses Coulee and via Burton Draw. Source: Google Earth.

Stop 1—Jameson Lake

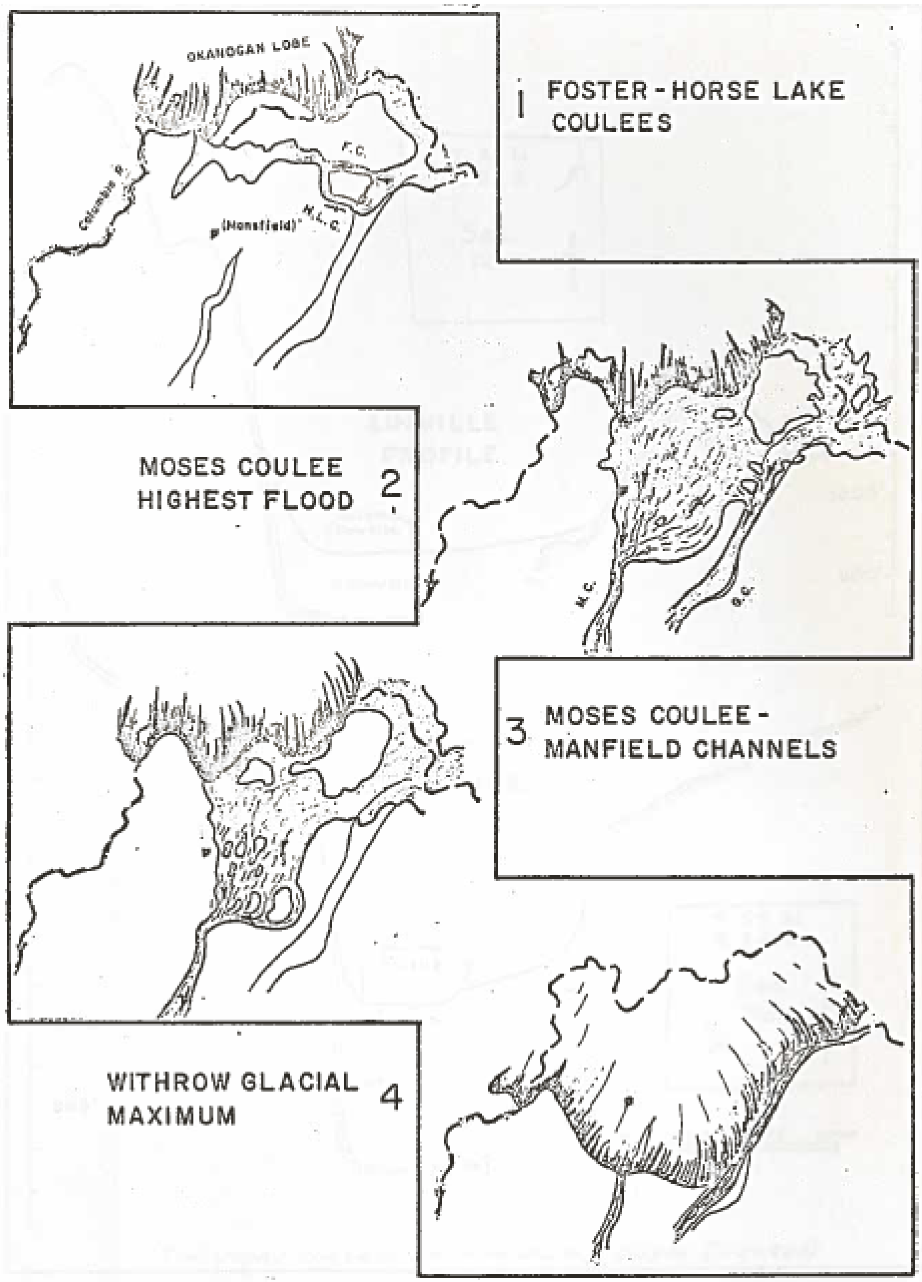
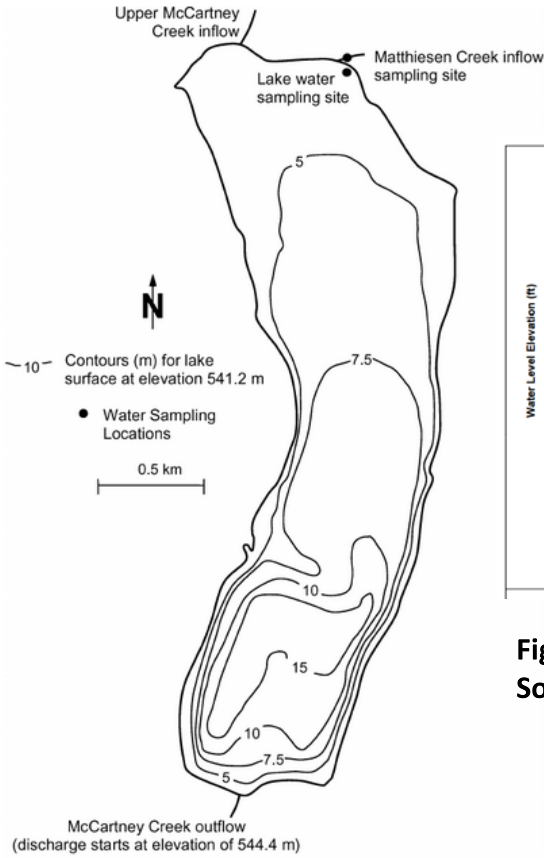


Figure 13. Hypothetical, sequential steps involved in the incision of Moses Coulee by Missoula Floodwater diverted from the Columbia River through the Foster Coulee and Horse Lake Coulee channels. Source: Hanson (1970, p. 129).

Stop 1—Jameson Lake



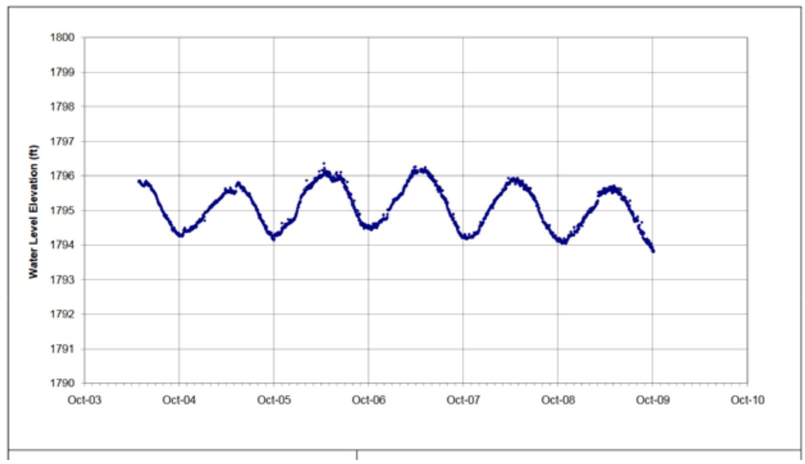


Figure 15. Jameson Lake hydrograph, 2004-2009. Source: Pacific Groundwater Group (2010).

Figure 14. Bathymetric map of Jameson Lake, Upper Moses Coulee. Depths in meters. Source: Churchill & others (2009).

Moses Coulee Lakes and Water Quality. Grimes, Bennett, and Jameson lakes are the only natural lakes in Moses Coulee (Figure 14). Because they are *hydrologically closed basins* (outflow is primarily by evaporation and subsurface seepage), they tend to be somewhat saline (Burgoon, 2005). Jameson Lake is impounded behind Okanogan Lobe end moraine in a rock basin eroded by Ice Age Floods (Figure x). It receives inputs from surface streams and groundwater. Since the 1880's Jameson Lake has doubled in area. And between 1992 and 2007 lake levels rose several feet. Some of these changes are likely due to increased snowmelt and thunderstorm-driven runoff into the basins. Some of these rises may also be attributed to agricultural land use in the watershed (Pacific Groundwater Group, 2007). Imprinted atop these longer term changes are annual fluctuations because of cool, wet winters and warm, dry summers (Figure 15). With the rising waters and associated dilution of salts of the mid-century, rainbow trout were stocked in Jameson Lake beginning in 1960. Over time, Jameson has been very productive but has periodically struggled with water quality issues (inc. extensive algal blooms) and resulting low dissolved oxygen fish kills (Burgoon, 2005). When fishing is good, Jameson and Grimes lakes are very popular—I have heard that 3,000-5,000 anglers may fish here on a given opening day under great conditions!

Stop 2—South of Jameson Lake

Location. We are located about 2.5 miles south of Jameson Lake along Jameson Lake Road NE.

Missoula Flood Bar. We are standing on a Missoula Flood bar formed following incision of Moses Coulee (Figure 16). Flood bars form sub-fluvially (i.e., at the base of the flood flow) as velocity decreases. Bars typically have blunt upvalley "heads" and long, tapering downvalley "tails". Their surfaces slope downvalley. Some have described their forms as "whalebacks", a shape very different from a dissected terrace, a form *uniformitarianists* would have preferred finding in these areas. They are composed of well to poorly sorted and bedded gravels and sands. The situation in which velocity decreases determines the type of bar (Figure 17): 1) c*rescent bars* —form on the inside bend of channels; 2) *longitudinal bars* —form in mid-channel or along a channel wall; 3) e*xpansion bars* —form where channels widens abruptly; 4) *pendant bars* —form downcurrent of mid-valley obstacle or valley-wall spur on bend; 5) e*ddy bars* —form in a valley at the mouth of a tributary; and 6) *delta bars* —form where floodwater on a high surface adjacent and parallel to a main channel encounters a transverse tributary valley where it deposits. Giant pendant bars such as this are one of the pieces of evidence geologist J Harlan Bretz used to argue for a catastrophic flood origin for the Channeled Scablands.

Okanogan Lobe End Moraine. The hummocky terrain upslope of us is the end moraine of the Okanogan Lobe of the Cordilleran Icesheet (Figures 16 & 18). It represents the southernmost extent of the Okanogan Lobe. This is often referred to as the Withrow Moraine for its type locality near Withrow, a tiny town west of Moses Coulee. The size of the moraine there suggests it occupied that position for a considerable amount of time (Freeman, 1933). Because the moraine here sits atop the flood bar, it is younger than that feature (Bretz and others, 1956). This is a nice illustration of the *Law of Superposition*. Based on its relative lack of weathering, it makes sense that this is a late Pleistocene feature. Four ^{10}Be dates from granitic boulders on the moraine date to 15,400 +/- 1400 years before present. This means that the moraine was in place and the icesheet was likely retreating by ~15,400 years ago (Balbas and others, 2017). Because of the Law of Superposition, we know that the giant pendant bar and Moses Coulee itself formed before ~15,400 years ago. Following Hanson's (1970) model (Stop 1) of Moses Coulee formation, Moses Coulee must be older than the formation of the Upper Grand Coulee. According to Balbas and others (2017), three ^{10}Be dates from granitic bedrock outcrops at Northrup Canyon in the Upper Grand Coulee indicate an age of 15,600 +/- 1300 years before present. Given the similarity in weathered appearance of Moses Coulee and the Upper Grand Coulee, it seems that these coulees are of similar ages. Therefore, it seems unlikely that Moses Coulee formed in an earlier glaciation as was suggested by Bretz (1923b, 1956, 1959), who based his estimate on the amount and degree of talus weathering in lower Moses Coulee

Glacial Outwash. Much of the remainder of upper Moses Coulee is filled with glacial outwash (Figure 16). This outwash originated from the melting of the Okanogan Lobe. Some likely came down Moses Coulee as the ice sheet receded. However, a significant portion of this probably came from glacial meltwater gathered by Dutch Henry Draw to the west of Moses Coulee. Dutch Henry Draw dumps into the west side of Moses Coulee near the end moraine (Figure 16). Burton Draw also likely brought outwash from a receding Okanogan Lobe to the east (Figure 13). Outwash is characterized by terrace-like landforms, planar bedding, and ample distributary channels on its surface. Dutch Henry Draw helps explain why an outwash plain is missing to the south of the Withrow Moraine near Withrow. The <u>northward</u> slope of lands to the south of Withrow is another reason the absence of a broad outwash plain (Easterbrook, 2003).

Stop 2—South of Jameson Lake

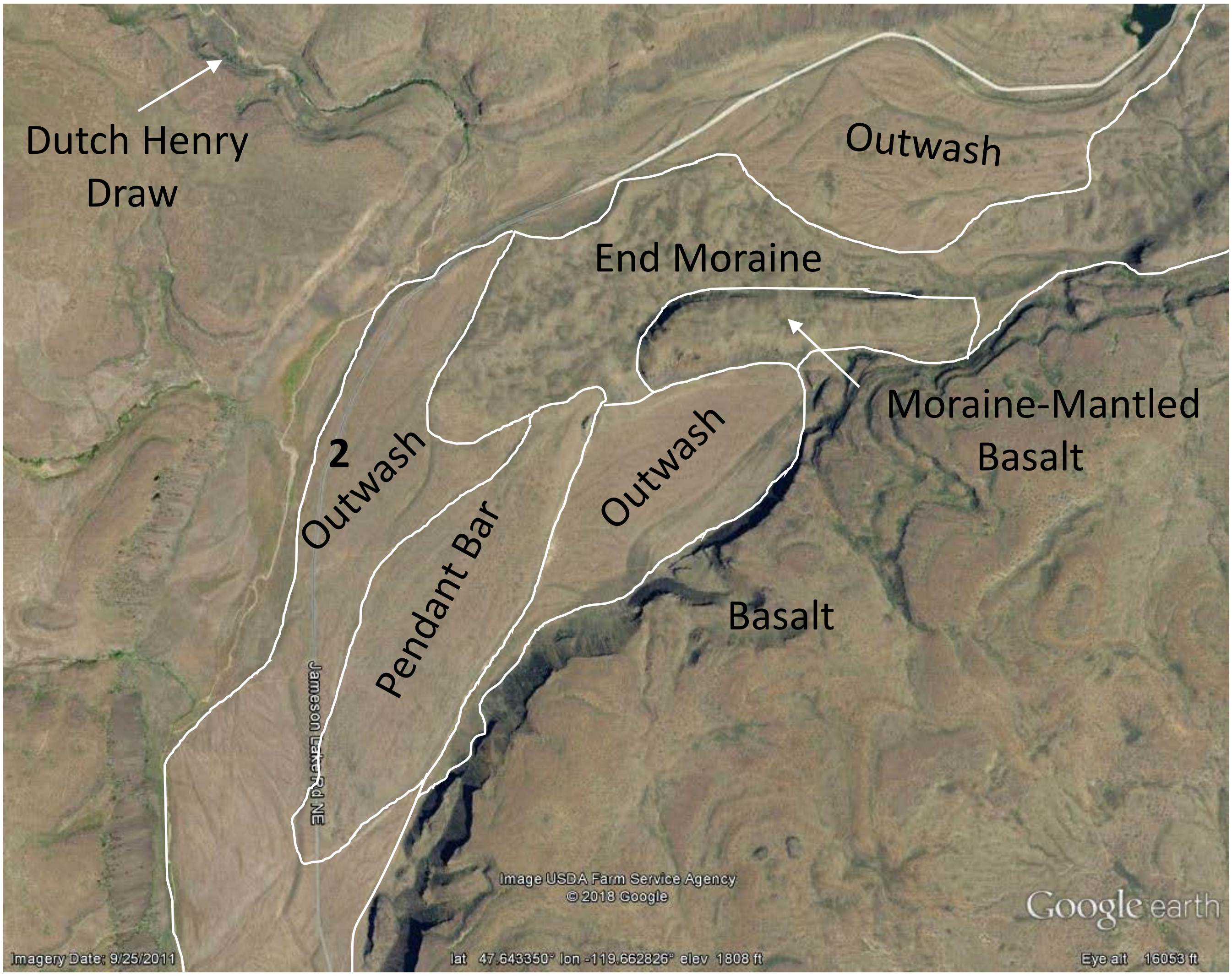


Figure 16. Surficial geology and geomorphology of the area south of Jameson Lake. Note interrelationships between giant flood bar, end moraine, and outwash. Source: Google Earth; O'Conner & others (2018).

Patterned Ground. Brief exploration of the area reveals the presence of patterned ground in the form of stone stripes and soil mounds atop the moraine and outwash features. Again, invoking the Law of Superposition, these features must be younger that the surfaces they lie on. Did these features form from a cold climate that should have characterized the area at about 15,000 years ago? Or did they form from other processes?

Stop 2—South of Jameson Lake

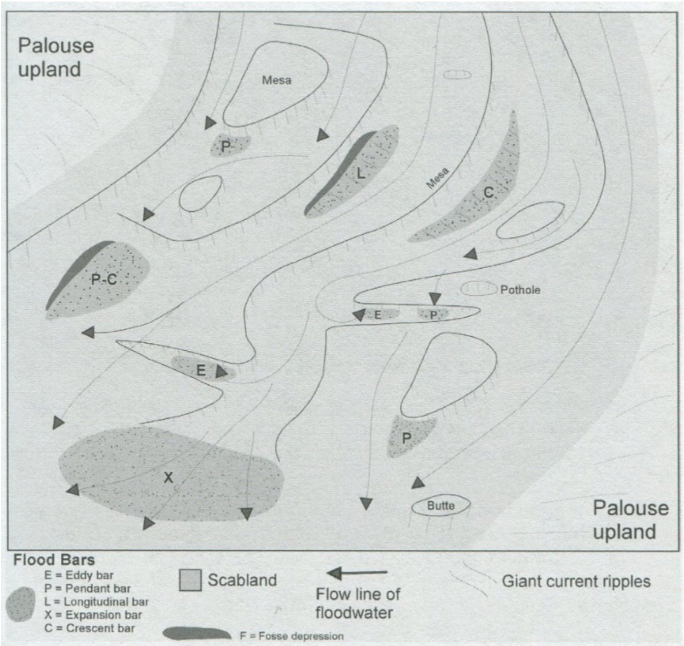


Figure 17. Types of flood bars. From Bjornstad and Kiver (2012, p. 51).

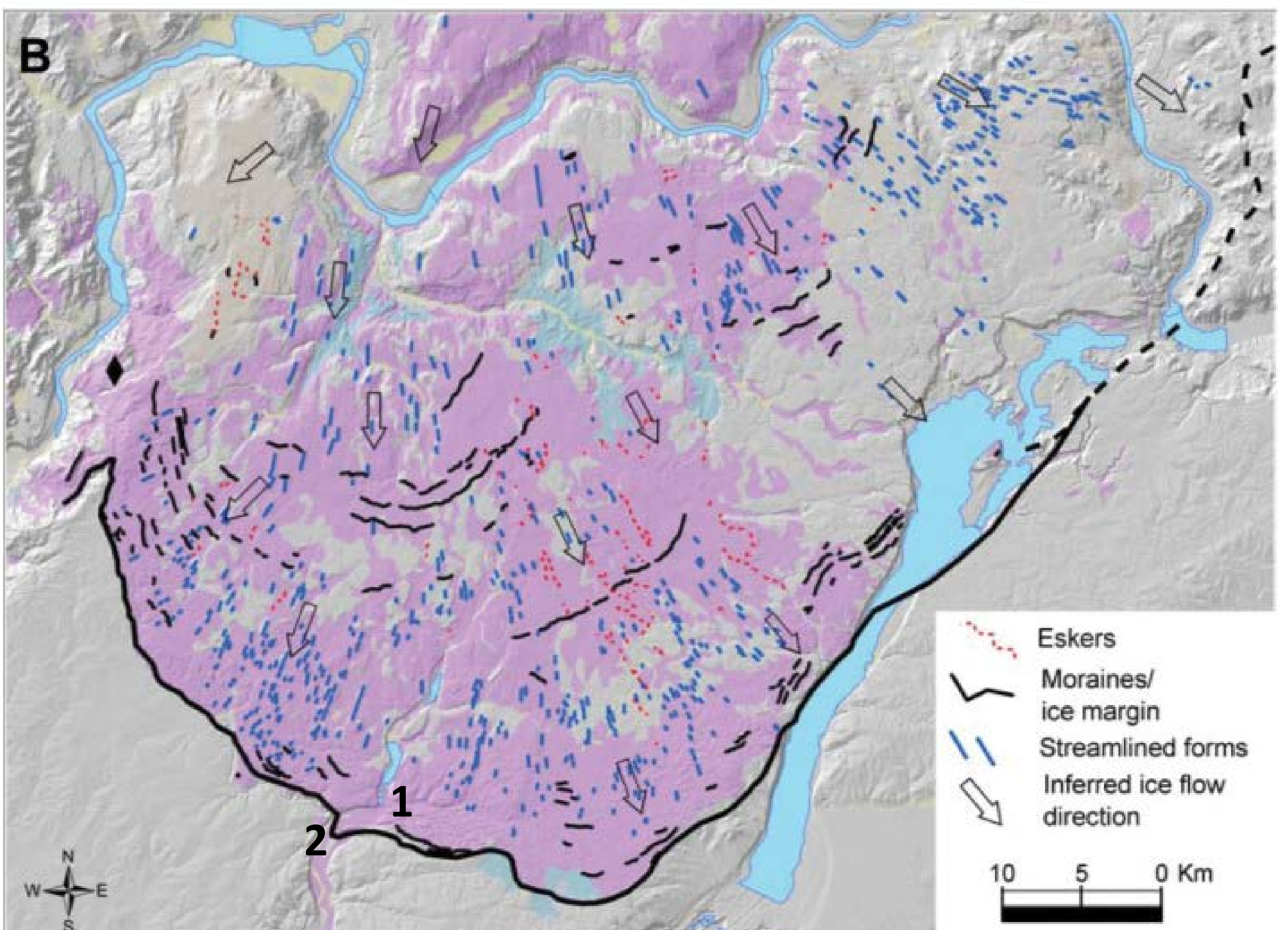


Figure 18. Withrow moraine and associated large-scale glacial landforms formed by Okanogan Lobe of the Cordilleran Ice Sheet. Bold numbers indicates approximate locations of field trip stops. Source: Kovanen and Slaymaker (2004).

South of Jameson Lake to Three Devils

Route. Return to US 2. Turn right and travel west for approximately 1 mile. Turn left onto Moses Coulee Road and head south in Moses Coulee. Follow this paved road south approximately 12 miles. Turn right onto gravel Road 24 NW and head west. Follow this about 5 miles to our stop at the Three Devils above the Billingsley Ranch.

Giant Flood Bar. As we return to US from our stop near Jameson Lake, look west at the huge flood bar (Figure 19). This is a pendant bar formed in the lee of the basalt bedrock ridge to the north. This bar is about 310 feet tall (that's a 31 story building) and 3.25 miles long! Again, this is the type of evidence Bretz used to argue that catastrophic floods shaped this landscape.

Irrigated Agriculture. South of the huge flood bar, we descend to the floor of Upper Moses Coulee. Here, irrigated agriculture occurs atop flood, outwash, and perhaps, loess deposits. The source of the irrigation water here must be the flood and outwash gravels from the receding Okanogan Lobe. Wells in the vicinity are bored in thick (up to 240 thick sequences of sands, gravels, silts, and clays—Pacific Groundwater Group, 2007). The coarser sediments are indicative of flood and outwash deposits. Additionally, several report thick deposits of silts and clays indicating prehistoric lakes occupied the area (Pacific Groundwater Group, 2007). In those areas where no agriculture is present, it must be because soils are too rocky.

Scablands and More Gravel Bars. South of this stretch of irrigation, the road ascends onto basalt scablands created by outburst flooding. This ~4.5 mile long stretch of scabland coincides with the broadening of Moses Coulee (Figure 20). Bretz (1923a) attributed it the structural geology of the area. Sagebrush Flat lies in a structural basin (Figure21). The dip of the basalts is greater than the valley floor gradient therefore the topography runs out. This is the case at Sagebrush Flat. However, prominent scablands do exist to the west and northwest of Sagebrush Flat (Figure 22). Huge gravel bars are also present in select places within these scablands as well as on the edge of Sagebrush Flat. We pass over one particular large expansion bar on Road 24 NW west of the Moses Coulee Road (Figure 23).

Rimrock Meadows. You may notice the scattered RV's, outbuildings, and even a few houses on the scabland landscape here. This is Rimrock Meadows, a recreational development. According to their website, 1-2 acre lots sell for approximately $4500. While no water, sewer, or electricity is available at the lots, these can be found at the formal camping facilities and clubhouse for the development (http://www.rimrockmeadows.com/). Perhaps such a lot may be in your future?

Dryland Agriculture. From the scablands, we descend onto Sagebrush Flat, an area that once must have been covered with sagebrush but which is now an area of dryland agriculture. Apparently, there is not sufficient groundwater here to irrigate crops.

S-Shaped Moses Coulee. The bend near the bottom of the middle coulee gives Moses Coulee an S-shape. Why does this bend occur here? Flood flows appear to have followed the axis of a syncline to the west before cutting across the Badger Mountain anticline (Bretz, 1923a; Gulick, 1990).

South of Jameson Lake to Three Devils

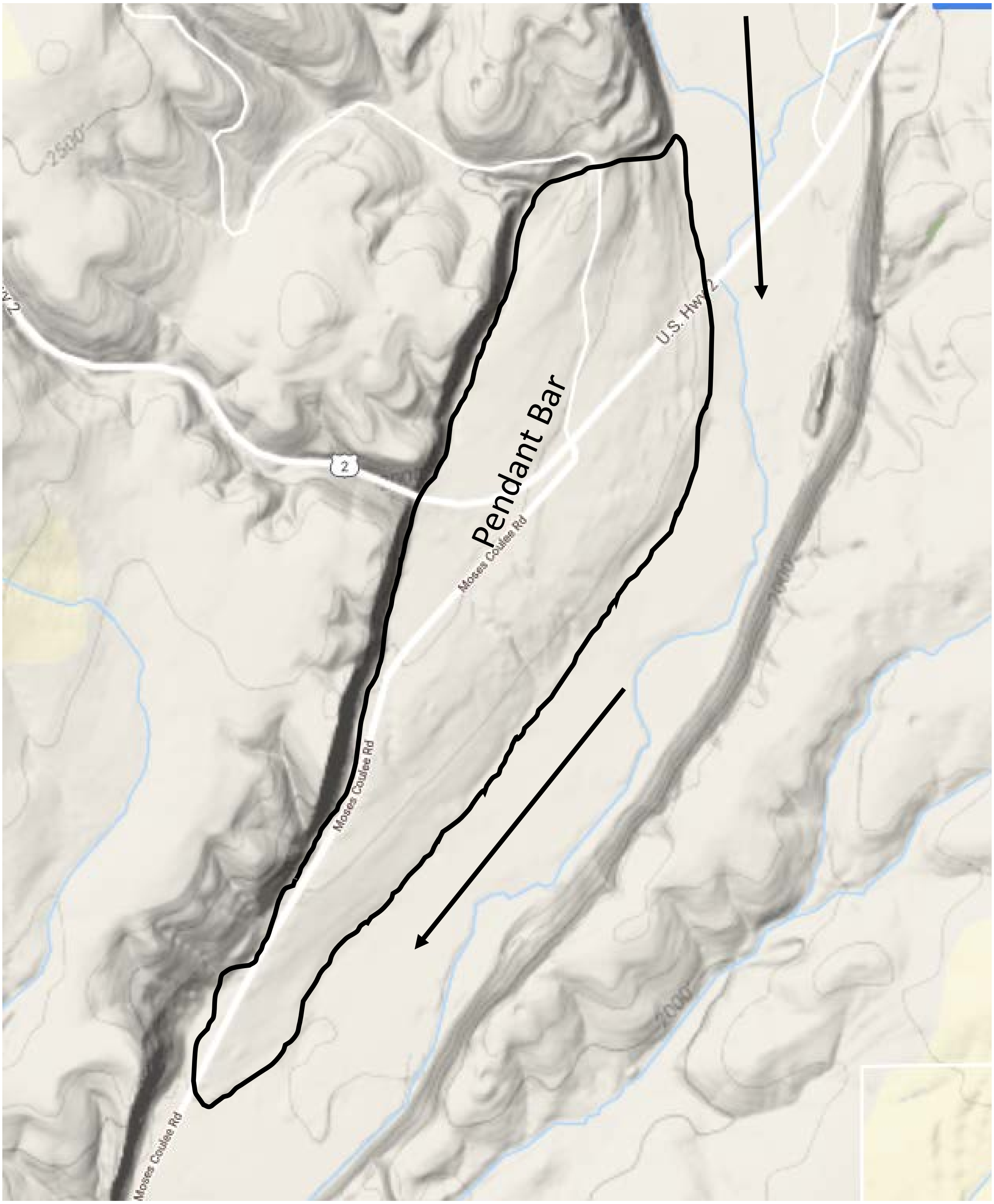


Figure 19. Giant pendant bar in upper Moses Coulee. Arrows indicate direction of flood flow. Source: Google Maps.

South of Jameson Lake to Three Devils

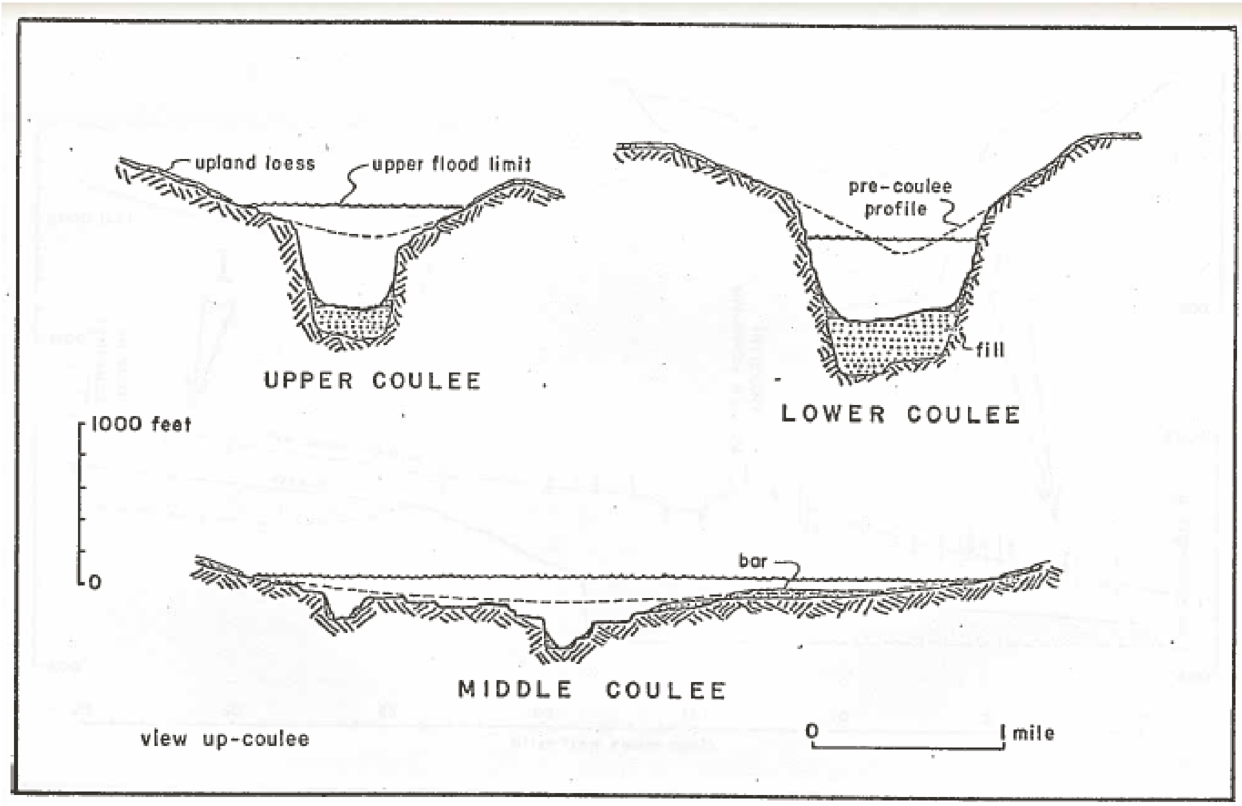


Figure 20. Typical channel cross sections for Moses Coulee. Source: Hanson (1970, p. 122).

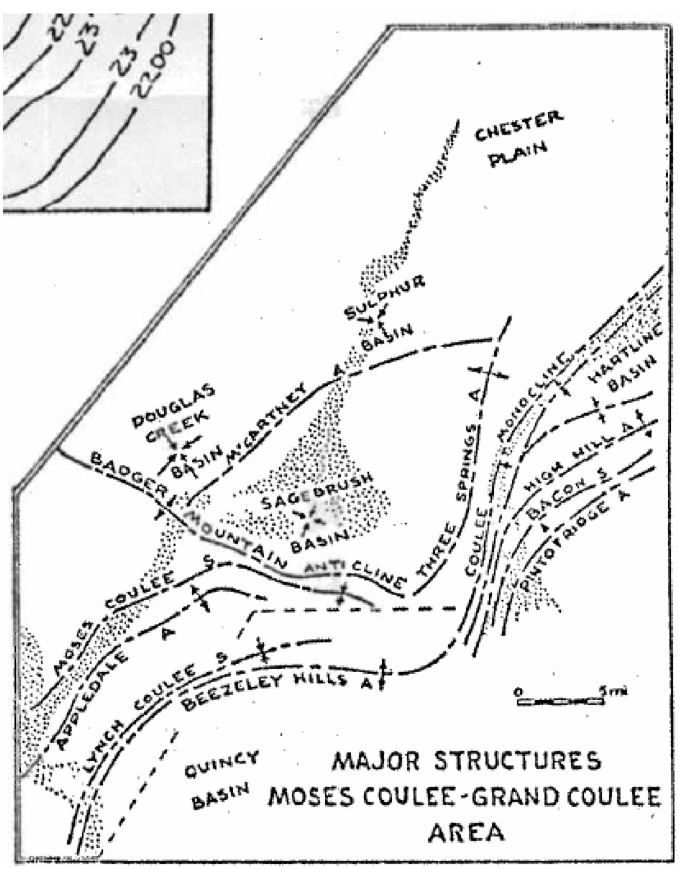


Figure 21. Major structures of the Moses Coulee-Grand Coulee area, Washington. Source: Hanson (1970, p. 117).

South of Jameson Lake to Three Devils

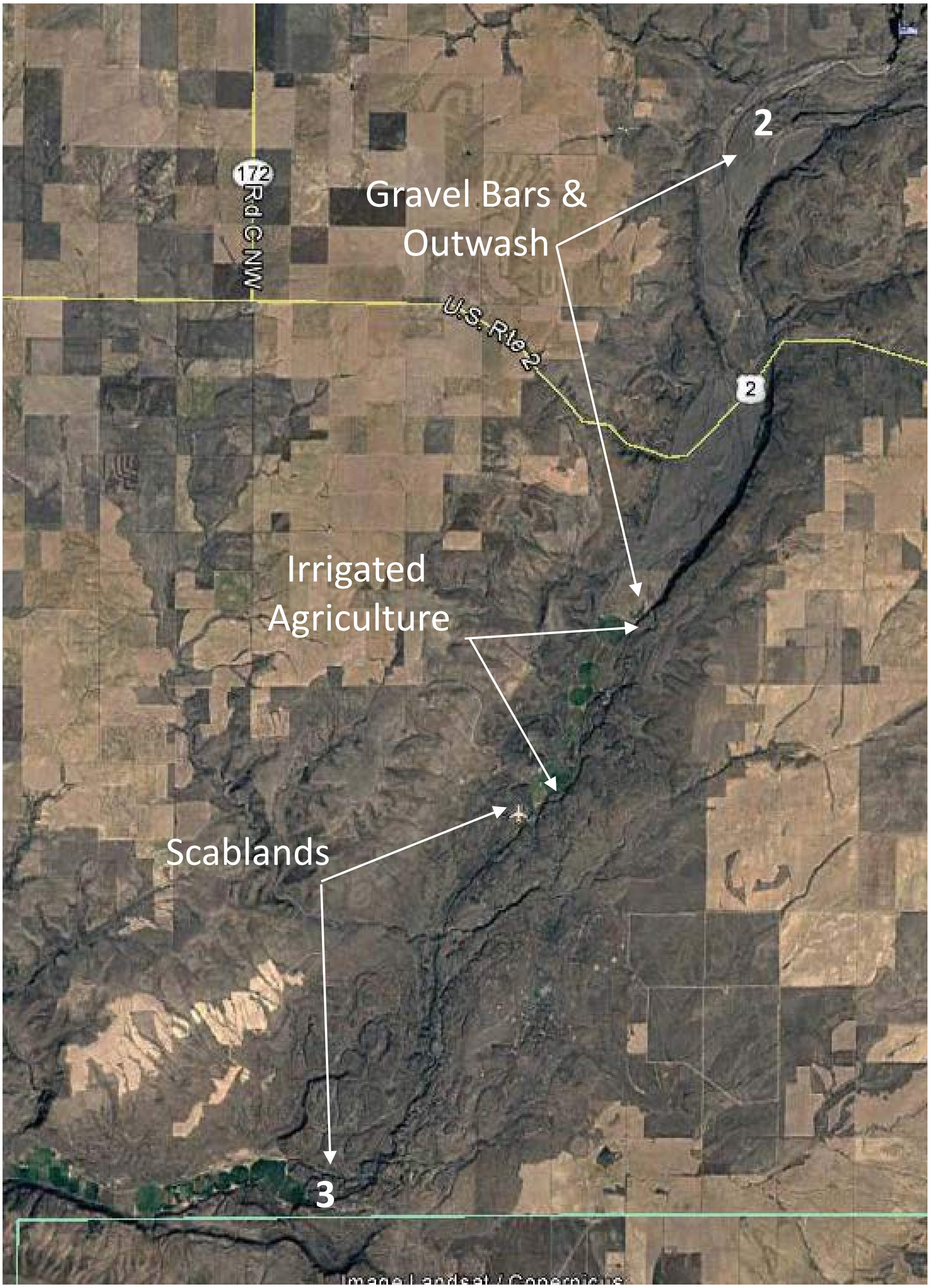


Figure 22. Landscape from Jameson Lake area to Three Devils. Bold numbers indicate approximate locations of field trip stops. Source: Google Earth.

South of Jameson Lake to Three Devils

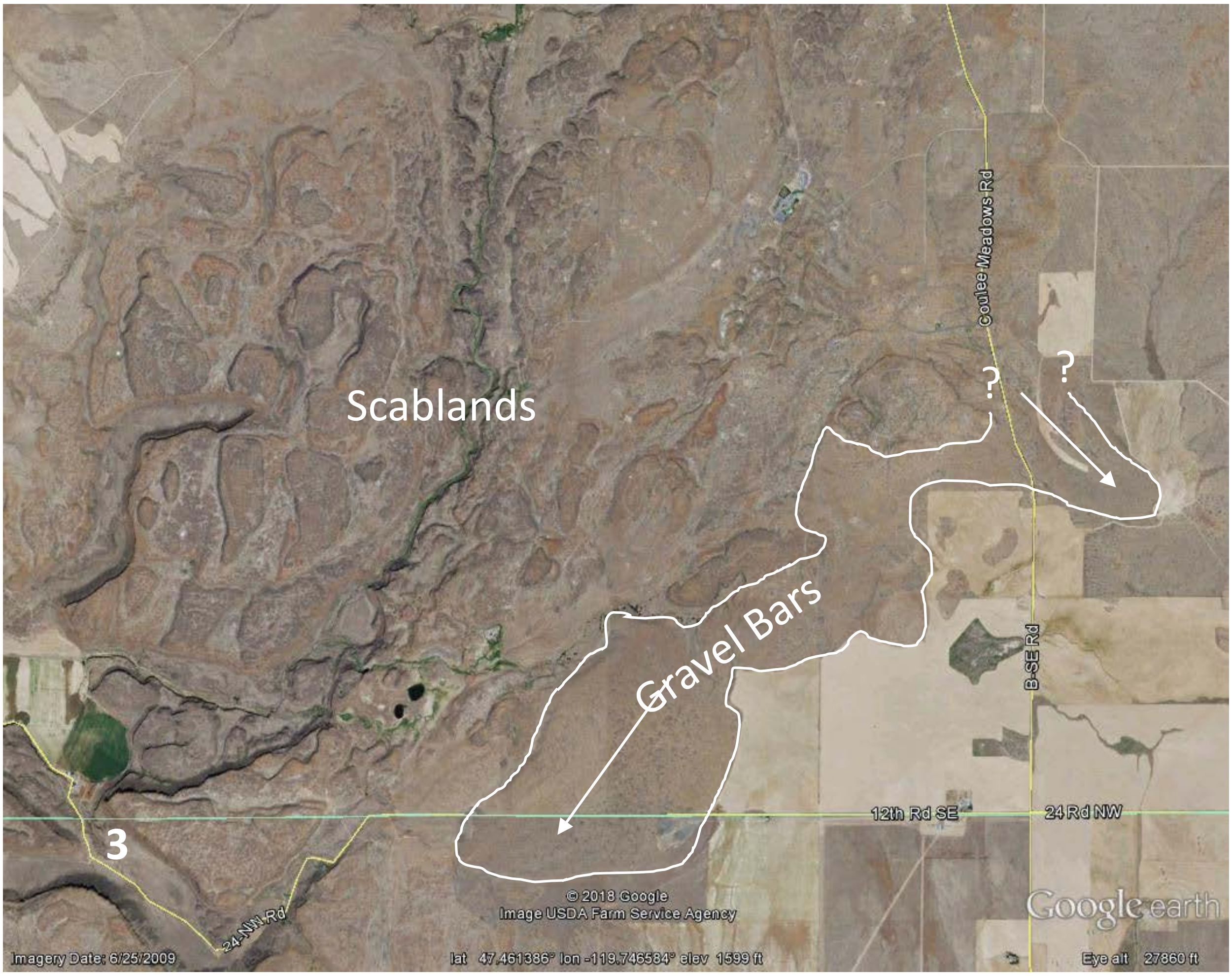


Figure 23. Scablands and giant gravel bars of Sagebrush Flats. Bold number indicates field trip stop. Source: Google Earth.

Stop 3—Three Devils

Location. We are located in the Three Devils Scabland along Road 24 NW above the Billingsley Ranch (Figure 23).

Cataracts and Flood Erosion Bretz (1923a, p. 600) described this area as follows:

Here it [the lower coulee] abruptly ends at the foot of a cliff across the coulee. Two great castellated buttresses face down the coulee, with lesser walls connecting them. This notched cliff clearly was a waterfall, and before the deep notching it was comparable in height to Grand [Dry] Falls at Coulee City. From this transcoulee cliff to the lower end of the upper canyon is a tract, 5 or 6 miles long and nearly as wide, where the basalt floor of the syncline was widely overrun by a great stream which formed a complex of anastomosing channels with rock-basins and cataracts, leaving isolated knobs and buttes irregularly disposed in a perfect maze.

Cataracts are waterfalls inundated by large volumes of water. In the Channeled Scablands, cataracts formed from massive erosion that occurs vertically and headwardly. Rapidly rotating vortices known as *kolks* form in fast-moving, deep floodwaters (Figure 24). These vortices *plucked* basalt chunks from the exposed basalt flows creating deep, steep-sided potholes. Basalt columns were preferentially plucked (Figure 25). The kolks moved downstream with the floodflows creating strings of potholes that connected to form coulees. Cataract formation also occurs headwardly, especially from an initial waterfall. Given the nature of lower Moses Coulee, it makes sense that a waterfall was once present near the mouth of Moses Coulee and headwardly retreated to the position of the Three Devils. Three cataracts are present here, each of which received water from the scablands in the middle portion of Moses Coulee. The maximum drop of each of the cataracts ranges from 480 feet in Dry Coulee to 360 feet in Three Devils. Incomplete stripping of basalt flows resulted in *buttes* and *mesas*. These features differ only in size—butte diameters are less than or equal to their heights. Mesa diameters are greater than their heights. The unnamed hill to our west is a mesa as is Steamboat Rock (Figure 24). The elevations at the heads of each of the three cataracts suggests that Dry Coulee and the Three Devils went dry before the lower center cataract. Again, based on elevation, the arm of Three Devils to our west went dry before the main channel of Three Devils that we are standing in. Given the different levels of the lower and middle/upper coulee it makes sense that headward erosion was occurring simultaneously in the lower and upper coulee. Headward erosion of the lower coulee effectively ended at the tops of the three cataracts. The stepped nature of Dry Coulee and Three Devils likely reflects the basalt flows

Flood Sizes. We often assume that it must have been truly huge floods that created the coulees of the Channeled Scabland. Ice Age flood size (or discharge) is often estimated as the amount of water required to fill a particular coulee "brim-full". However, plucking results in the incision, therefore lowering, of coulees over time therefore successively larger floods are required to keep successive floods brim-full. Additionally, could glacial ice have stored as much water as is required by the high flow models? And would the high flows predicted by brim-full models suspend rather than deposit the sediments found in the huge bars?

Stop 3--Three Devils

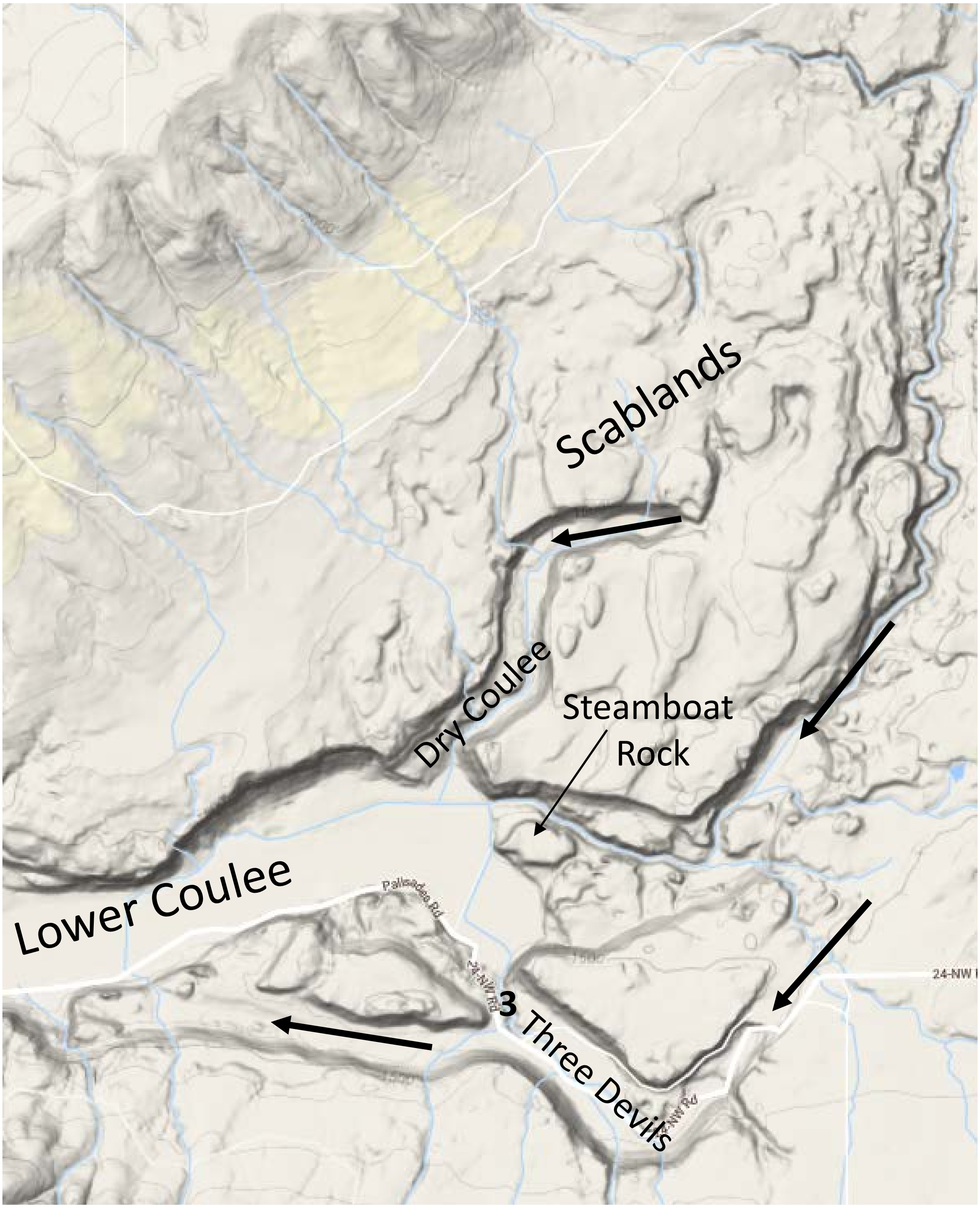


Figure 24. Middle Moses Coulee scabland. Arrows indicate flood flow directions. Bold number indicates field trip stop. Source: Google Maps.

Stop 3—Three Devils

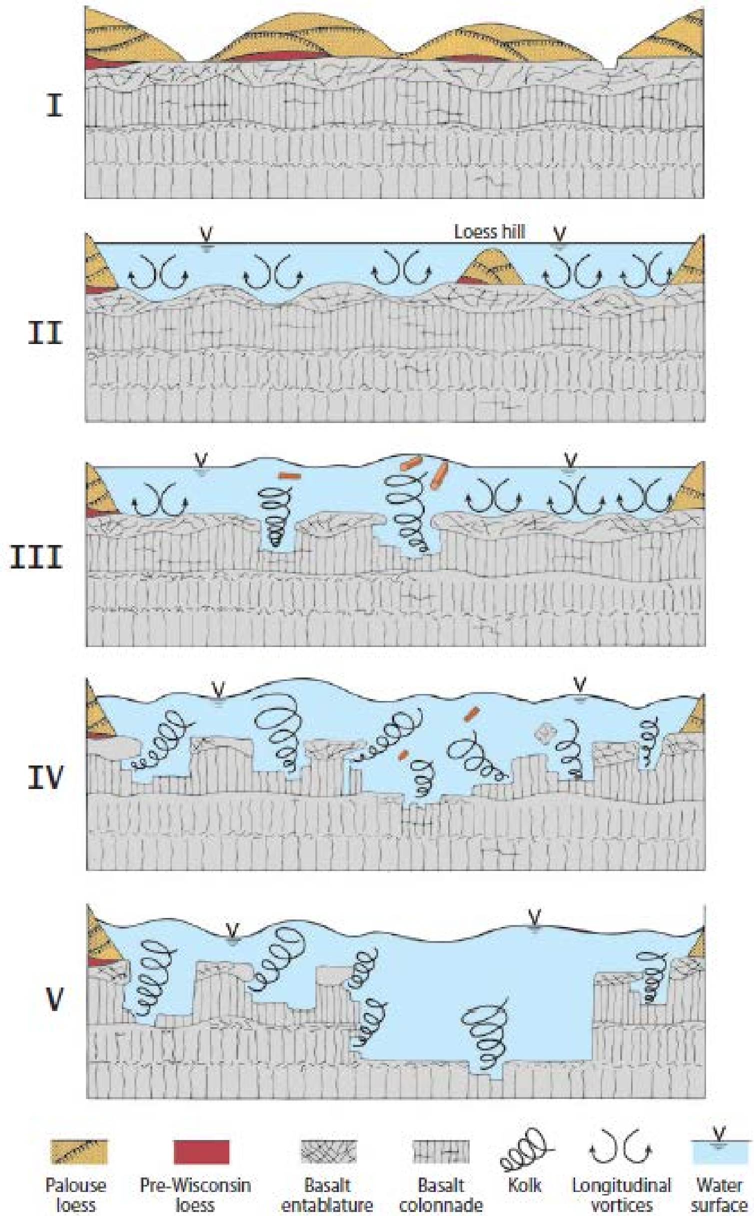


Figure 25. Inferred sequence of erosion for Channeled Scabland. Source: Baker (2009).

Flood Sizes (continued)…So, could progressive incision by numerous smaller floods accomplish the same landscape as fewer, large floods? According to stream modelling by Larsen and Lamb (2016), it is possible to create Moses Coulee. Essentially, they developed and tested a model that showed the minimum *discharge* (i.e., flow) to erode the channel and to inundate several large flood bars in the coulee. The results of their research show that, according to their assumptions, discharges of 0.6×10^6 m^3/sec. Such a "smaller flood" is still three times the average flow of the Amazon River today! This pales in comparison with the of 3.0×10^6 m^3/sec flow predicted by the brim-full model. This flow would be approximately 14 times the average discharge of the Amazon River.

Three Devils to Mouth of Moses Coulee

Route. From the Three Devils continue on Three Devils Grade Road SW for about a mile to the Billingsley Ranch where it becomes Palisades Road. Follow Palisades Road approximately 18 miles to its junction with WA 28. At this junction, turn right and head north for just over 2 miles. Pull off onto an old section of WA 28. This is Stop 5.

Old Lakes & Flat Topography. As we descend Three Devils Grade to the Billingley Ranch, note the flat nature of the Billingsley Ranch irrigatied farmland. This extends downvalley approximately three miles. Bjornstad and Kiver (2012) speculate that this represents a lake at the end of the last Ice Age flood that was impounded by the alluvial fan of Douglas Creek and a large crescent flood bar near the fan.

The Great Northern & Moses Coulee. About 4 miles below the Billinglsey Ranch, Douglas Creek enter the valley from the north. On the northwest wall of the coulee, a gently sloping "road" heads up toward Douglas Creek Canyon. This is actually the abandoned railbed of the Mansfield Branch line of the Great Northern Railway, (which later became the Burlington Northern Railroad). The Great Northern Railway completed a 61 mile long branch line from the Columbia River to Mansfield, partially following Moses Coulee (Figure 25), in 1909. The train made regular stops at Palisades, Alstown, Douglas, Supplee, Withrow, Touhey, and Mansfield (Figure 25). The primary purpose of this branch line was to efficiently move wheat off the plateau rather than first hauling it to the Columbia River or Coulee City via wagons to steamboats(Meinig, 1968). Additionally, it transported passengers and other necessary goods. Great Northern ran the line until 1970 when it was taken over by the Burlington Northern Railway. Trains continued to operate on the line until 1985 when boxcars were no longer an efficient way to transport wheat, and when truck transportation was more economical (https://en.wikipedia.org/wiki/Mansfield_Branch_(Great_Northern_Railway).

Lower Moses Coulee Topography. Below Douglas Creek, Moses Coulee is characterized by steep basalt walls punctuated by hanging valleys. These valleys represent drainages to a pre-Moses Coulee trunk stream that was incised far less than present-day lower Moses Coulee (Figure 26). Alluvial fans formed at the mouths of many of the hanging valleys. Talus from rockfall mantles lower coulee walls. Landslides have also accumulated at the bases of some of the coulee walls. The floor of the coulee is blanketed with flood sediments including giant gravel bars. One of these bars is covered with giant current ripples (Figure x). An intermittent meandering stream channel is incised into the sediments of the floor of Moses Coulee.

Irrigated Agriculture and Valley Floor Sediments. Irrigated agriculture occurs over much of lower Moses Coulee's bottom presumably where soil and water availability allow. In addition to the alfalfa that we saw in upper Moses Coulee, feed corn and several types of fruit are also grown here. This occurs over loess or perhaps prehistoric lake deposits atop outburst flood gravels and sands. To get a sense of the depth of the coulee floor fill, A well near Appledale is bored in 300 feet of gravel (Bretz, 1923a).

Three Devils to Mouth of Moses Coulee

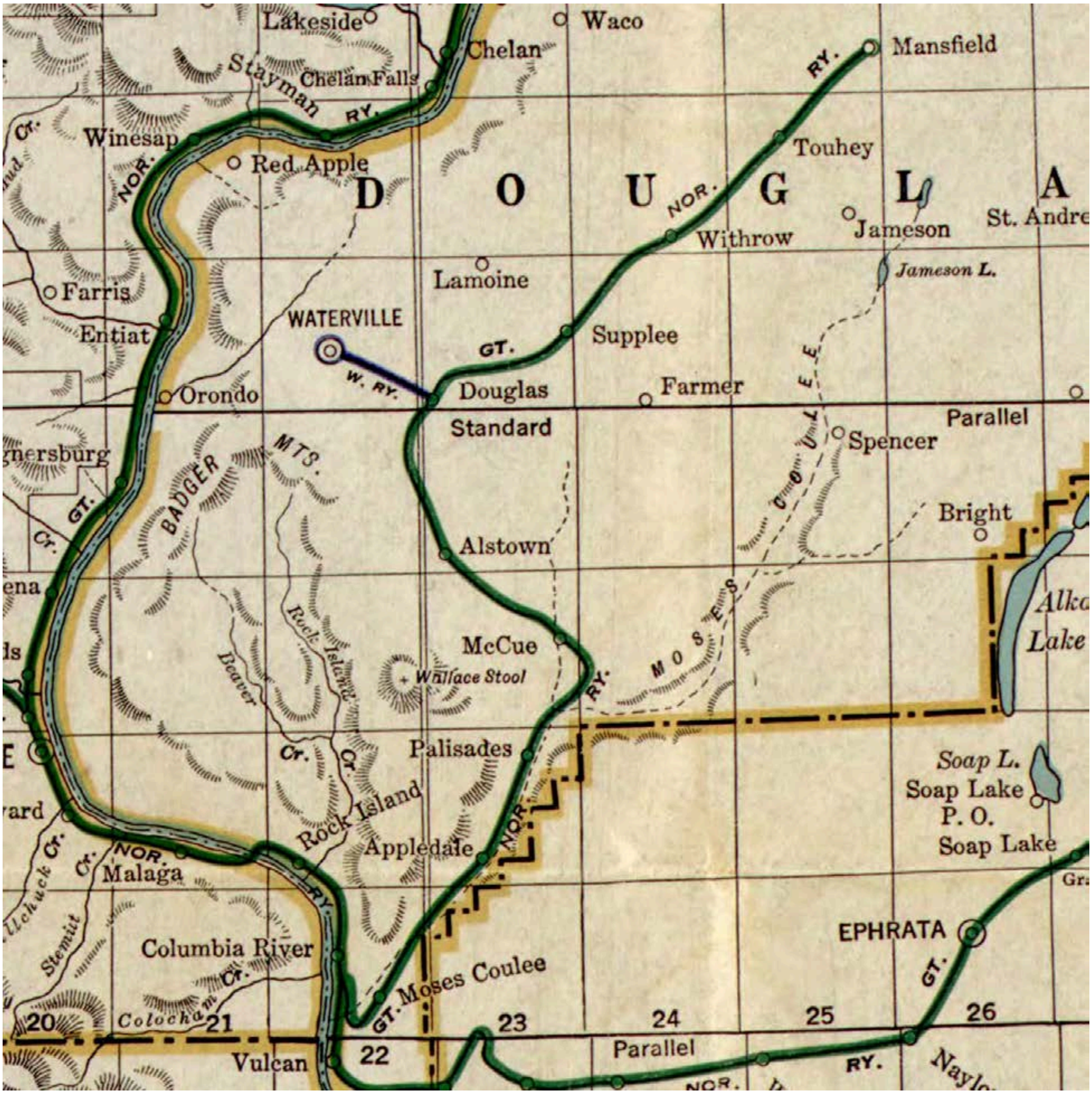


Figure 26. Route of the Mansfield Branch of the Great Northern Railway from the Columbia River onto the Waterville Plateau. Source: http://ndarrin97.blogspot.com/2014/12/1928-map.html

Three Devils to Mouth of Moses Coulee

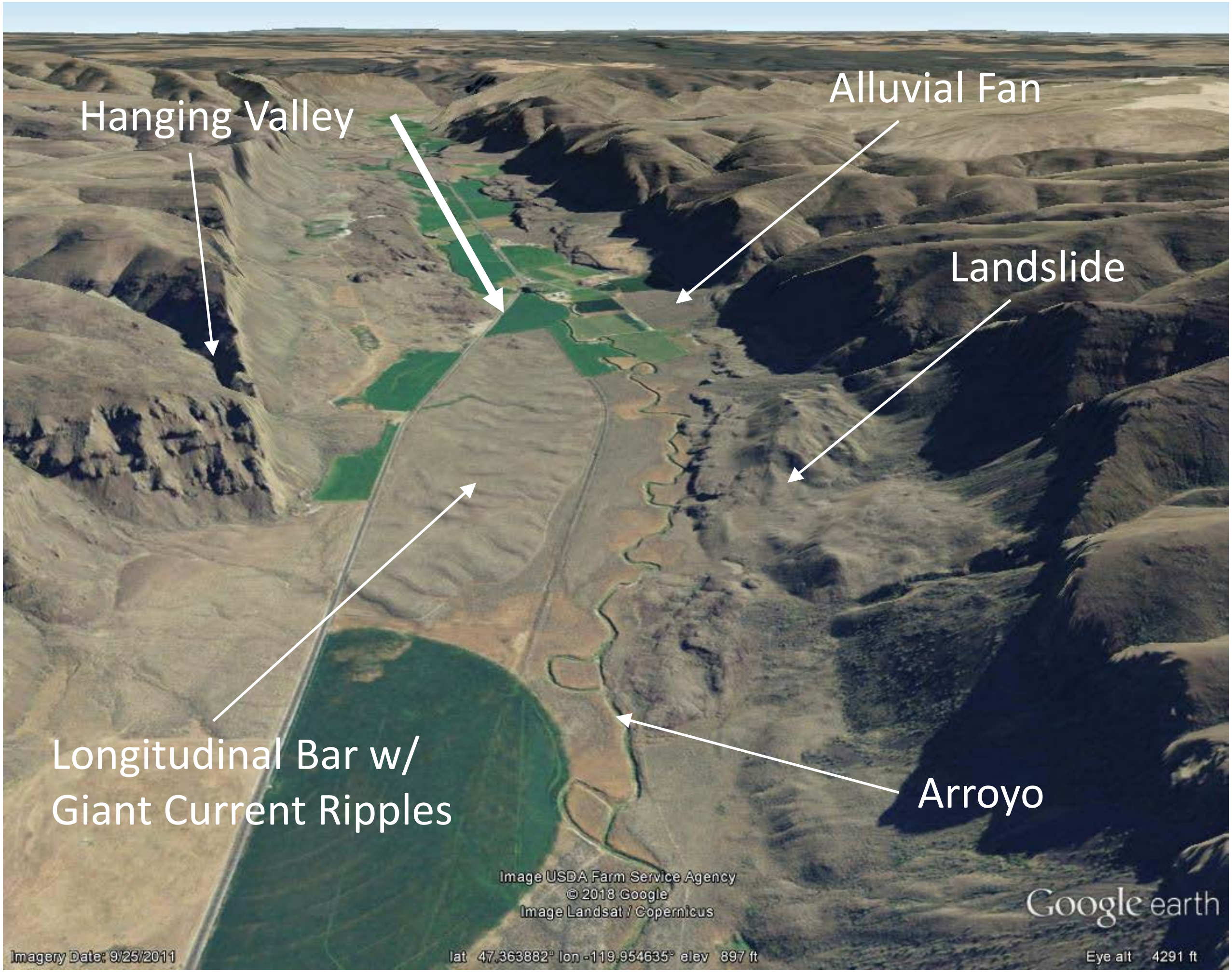


Figure 27. Oblique view upvalley at valley wall and valley floor landforms in Moses Coulee. Bold arrow indicates flow flow direction. Source: Google Earth.

Stop 4—Mouth of Moses Coulee

Location: We are standing on a former segment of WA 28 on the east side of the Columbia River and at the northern end of the giant Moses Coulee expansion bar.

Moses Coulee Bar. On the ground and on Figure 28, we can see how giant, paleoflood bars dominate the geomorphology of the Middle Columbia River. The Moses Coulee flood bar is a huge expansion bar that formed as floodwaters exited Moses Coulee into a mostly dry Columbia River Valley, building outward across the valley, downstream, and upstream (Figure 29). Its upper surface lies at an elevation of ~920 feet. Construction of the bar pushed the main channel of the Columbia westward (Bretz, 1930). The upstream portion of the bar/fan extends just upstream of Rock Island Dam (Waitt, 1977). Bretz attributed the origin of the bar to Moses Coulee rather than to a Columbia River source because basalts compose >90% of the bar sediments. As a comparison, crystalline rocks typically form >50% of Columbia River sediments. On a previous field trip, we explored the huge basalt boulders scattered around the bar surface and the large, subrounded, basalt boulders that compose the interior of the bar (Figure 30). Both pieces of evidence indicate a Moses Coulee origin for the bar. Apparently, the bar was sufficiently large to dam the Columbia River (Bretz, 1930) as indicated by overlying silt deposits (Hanson, 1970). Some of these silty lake deposits are present here. Hanson (1970) and Waitt (1977) tentatively linked these silts with rhythmites in the lower Wenatchee River Valley (Porter, 1969).

Moses Coulee Floods. How many Moses Coulee floods occurred? Waitt (2017) identified five basalt gravel-dominated, upvalley-dipping beds in Rock Island Bar just upstream of us. These beds fine upward with basal portions consisting of basalt-dominated gravels that are overlain by sands and silts. They resemble *rhythmites* seen elsewhere in the Channeled Scablands with each *couplet* interpreted as a separate flood. Because of the basalt-dominated composition and the upvalley dipping nature of the couplets, Waitt interprets these as huge floods that came down Moses Coulee, then ascended the Columbia River Therefore, at least five floods eroded Moses Coulee. We see the last flood couplet here (Figure 32).

Quincy Basin Backfloods. The sediments atop the last flood couplet here are rhythmites with ample mica within (Figure 33). Mica is an indication of crystalline rocks like granite rather than basalt. Because of this composition, they cannot be from Moses Coulee; instead, they represent floods from the Upper Grand Coulee that exited the Quincy Basin at Crater, Potholes, and Frenchman coulees (Figure 8). Upon exiting the basin, they ascended the Columbia River at least as far upstream as this site. Waitt indentified 21 distinct couplets here and another 15 or so less distinct couplets. This means that this site records approximately 36 floods that descended the Grand Coulee, and ascended the Columbia River Valley to here! Why did they ascend rather than descend? Sentinel Gap was not sufficiently large to handle all of a particular Quincy Basin flood so water backed up. Upstream may have also been a path of least resistance.

Giant Current Dunes (Ripples) & Columbia River Flood: Like West Bar downstream, Moses Coulee's upper surface is covered by asymmetric, giant current ripples (i.e., dunes) (Figure 29 & 31). These asymmetric features indicate formation by floods descending the Columbia River Valley. Waitt (1977, 1980; Waitt, 2017) interpreted this as evidence of one large flood from Glacial lake Columbia descending the Columbia River Valley after the retreat of the Okanogan Lobe. In addition to leaving giant current ripples on the surface of the Moses Coulee Bar, the large Columbia River flood(s) incised through the bar opening a channel downvalley, and also built bar into the mouth of Moses Coulee (Waitt, 1977, 1980; Waitt and others, 2009) (Figure 29). Columbia River Flood(s) also created a large, low gradient bar on the downstream side of the Moses Coulee Bar (Waitt, 1977).

Stop 4—Mouth of Moses Coulee

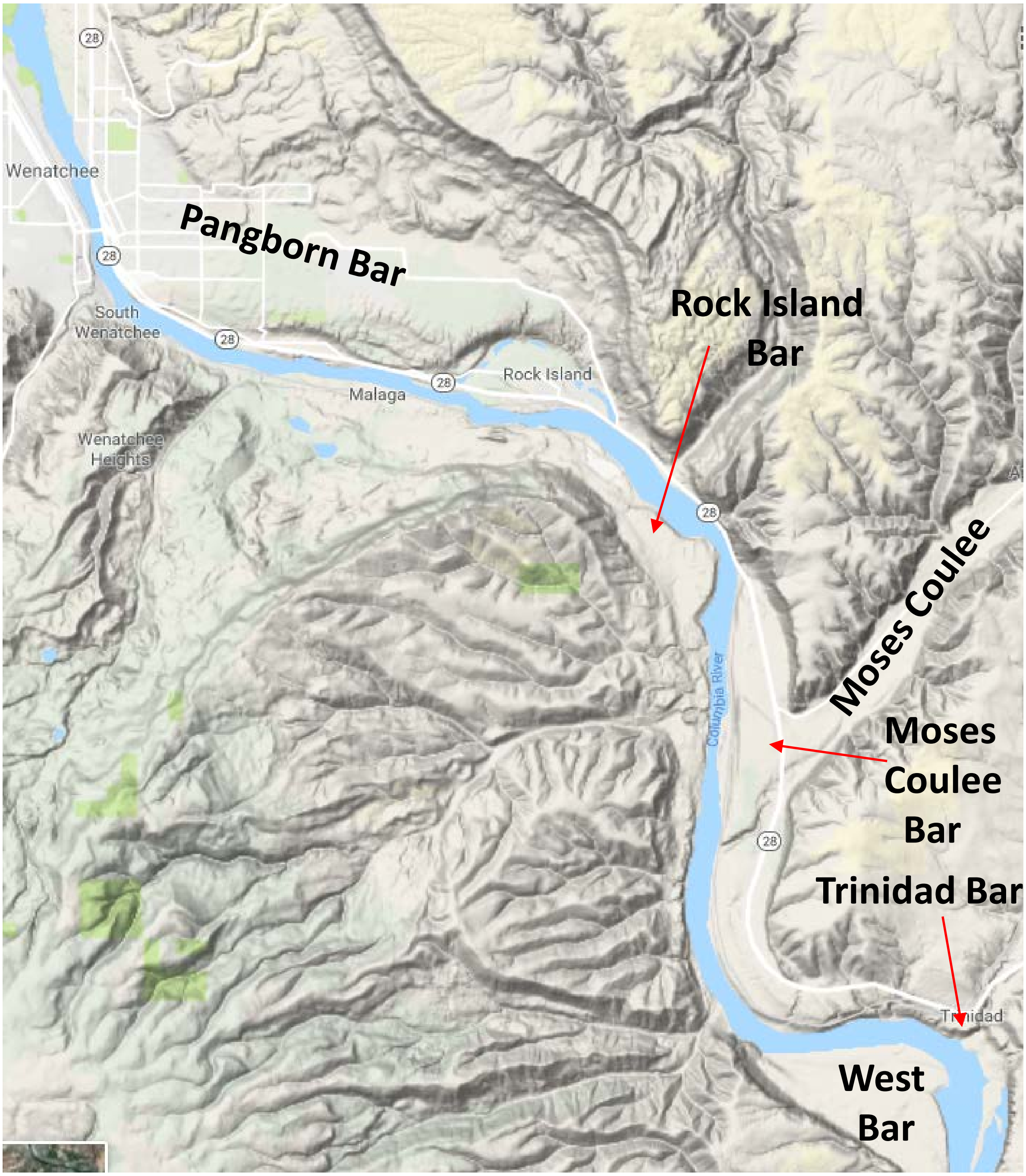


Figure 28. Topography and significant Ice Age flood features of the Columbia River beteween Wenatchee and Trinidad. Red number indicates field trip stop. Source of image: Google Maps.

Stop 4—Mouth of Moses Coulee

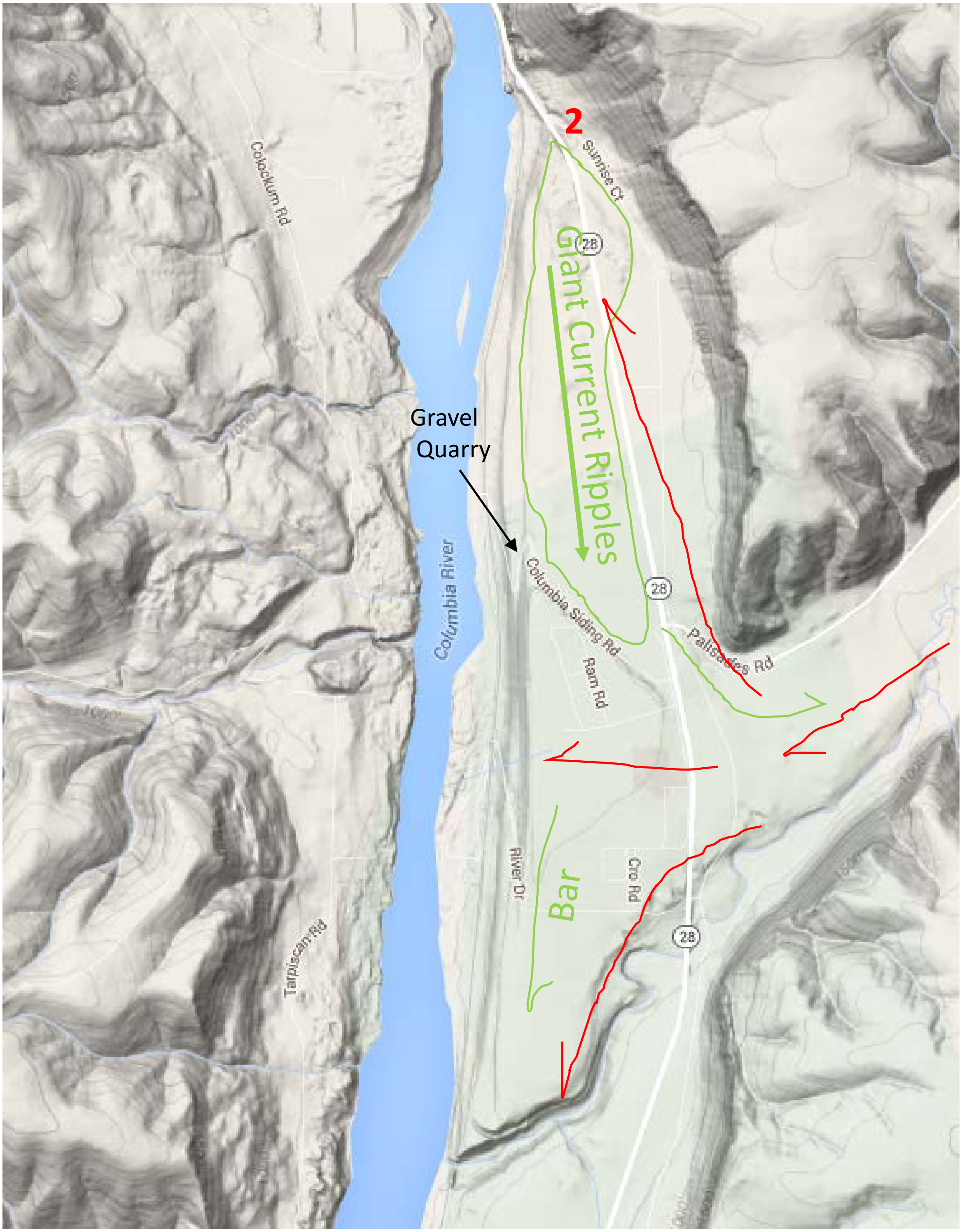


Figure 29. Part of the Moses Coulee bar. Original bar extended off map upstream (north) and downstream(south). Red arrows indicate initial Moses Coulee flows that created bar. Green arrows indicate subsequent Columbia River Valley floods that reshaped bar. Approximate extent of giant current ripples outlined in green. Source: Google Maps.

Stop 4—Mouth of Moses Coulee

Figure 30. Basalt boulders on surface and in interior of Moses Coulee Bar in gravel quarry shown on Figures 29 & 31. Source: author.

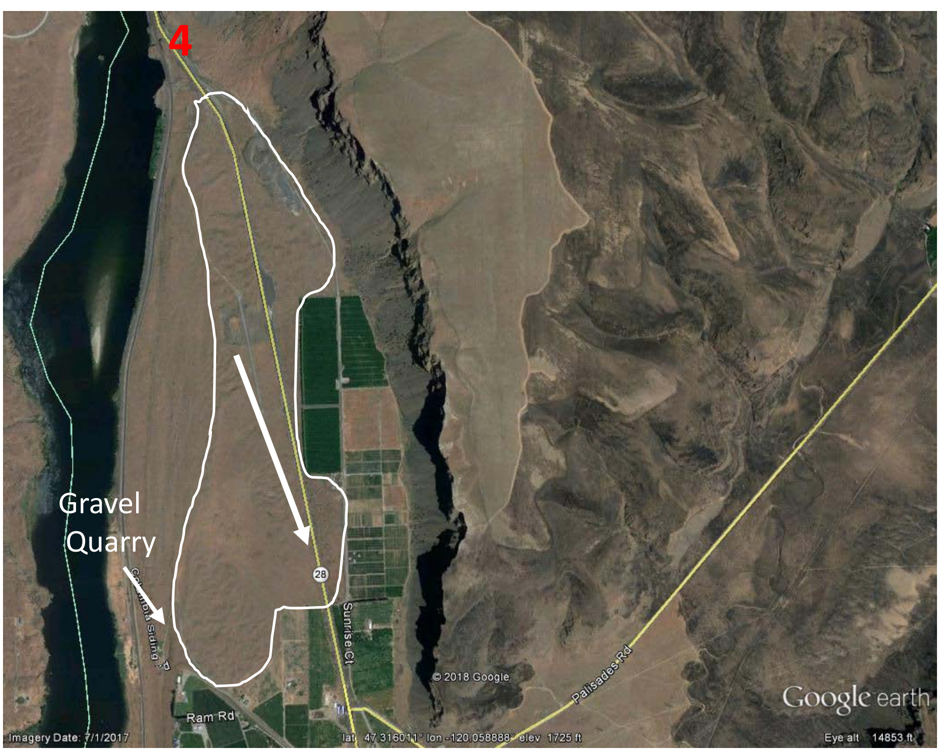


Figure 31. Area of giant current ripples on surface of Moses Coulee Bar. Number indicates field trip stop. White outline is area of giant current ripples. Heavy arrow indicates the Columbia River Valley source that created them. Source: Google Earth.

Stop 4—Mouth of Moses Coulee

Figure 32. Stratigraphic evidence of the last great flood to descend Moses Coulee. The flood couplet consists of two units. The dark unit is basalt gravel indicative of high energy conditions. Lighter beds above are low energy, slackwater deposits. Note folding shovel for scale. Source: Author photo.

Wrap-up

Today, we have had the opportunity to examine Ice Age flood and glacial evidence, and the impacts of these floods and glaciers on the landscapes of the Waterville Plateau and the Middle Columbia River Valley. I hope this field trip has helped you understand the complex, intertwining nature of Ice Age Floods and glaciers, and the tools and techniques used to understand these past events. Further, I hope you now have a better appreciation of a field that has been studied for over 100 years that keeps getting re-examined as new techniques come along.

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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