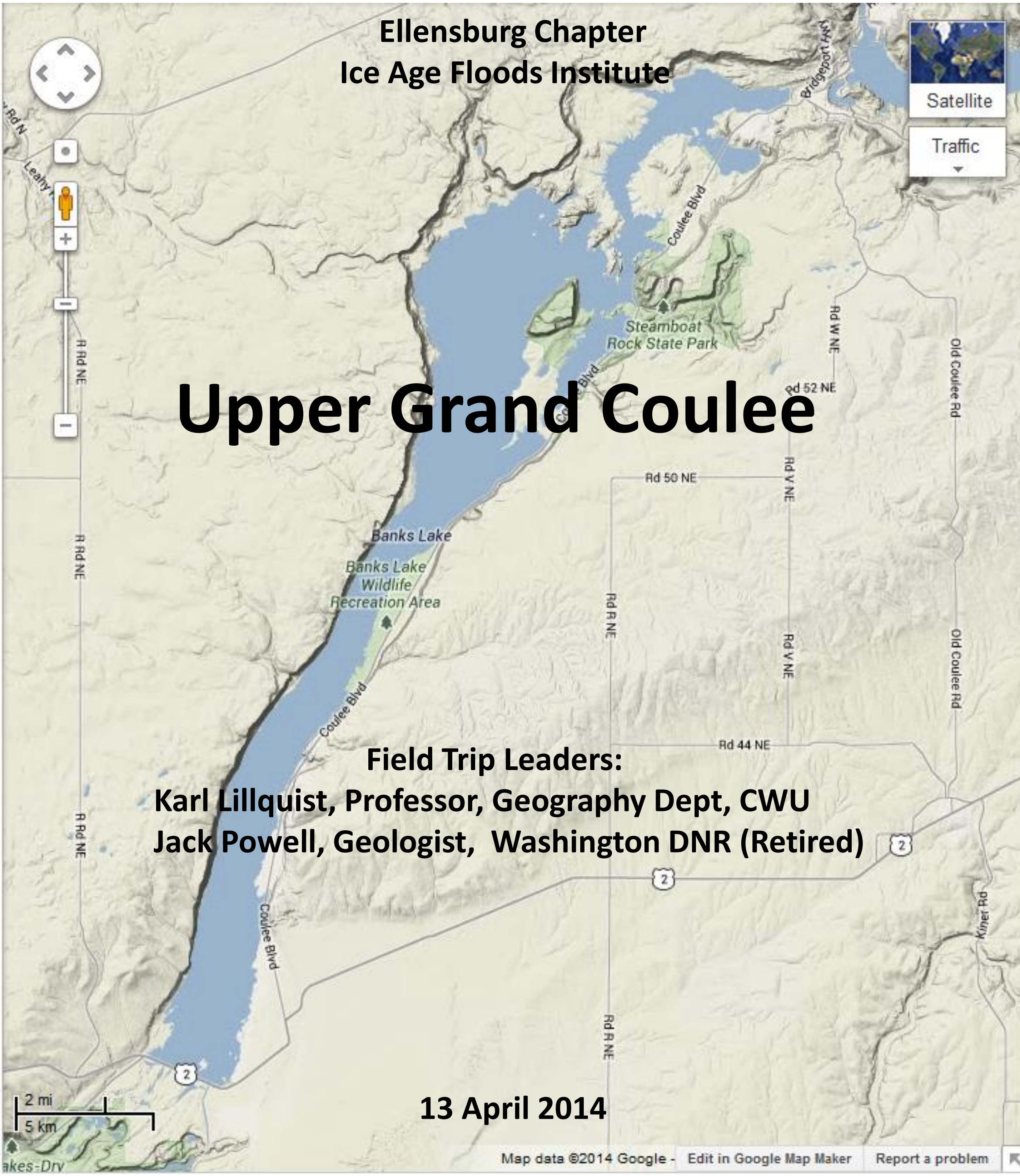
Ellensburg Chapter
Ice Age Floods Institute

Upper Grand Coulee

Field Trip Leaders:
Karl Lillquist, Professor, Geography Dept, CWU
Jack Powell, Geologist, Washington DNR (Retired)

13 April 2014



Preliminaries

Field Trip Overview

Our route will take us from Ellensburg to George, Ephrata, Soap Lake, Coulee City, Electric City, and Grand Coulee. Our driving tour and field trip stops will focus on: the magnificent erosional landscape of Dry Falls at the junction of the Lower and Upper Grand Coulees; ancient lake sediments in the mid-Upper Grand Coulee and their potential causes; late Cenozoic Columbia River basalts and associated interbeds; Steamboat Rock as an erosional remnant of a huge recessional cataract; post-flood talus; Mesozoic and early Cenozoic intrusive igneous and metamorphic rocks; ecotones and "geotones" of Northrup Canyon; large-scale hydropower irrigation development; and the Cordilleran Icesheet and its relationship to glacial lakes and catastrophic floods.

Tentative Schedule

8:00 am	Depart CWU
10:00	**Stop 1—Dry Falls (inc. restrooms)**
10:45	Depart
11:00	**Stop 2—Million Dollar Mile**
11:30	Depart
11:45	**Stop 3—Paynes Gulch (inc. restroom)**
12:30 pm	Depart
12:45	**Stop 4—Steamboat Rock State Park Day Use Area (inc. lunch & restrooms)**
1:45	Depart
2:00	**Stop 5—Northrup Canyon (inc. restroom)**
2:30	Depart
2:45	**Stop 6—Crown Point Vista**
3:15	Depart
4:00	**Stop 7—Dry Falls (inc. restrooms)**
4:15	Depart
6:00	Arrive at CWU

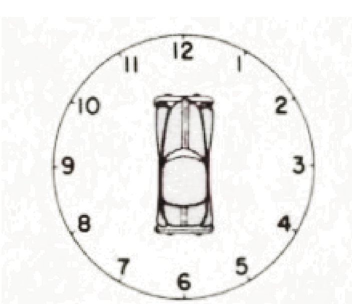


Figure 1. Relative bearings using a clock. Assume that the bus is always pointed to 12 o'clock. Source: Campbell (1975, p. 1).

Our Route & Stops

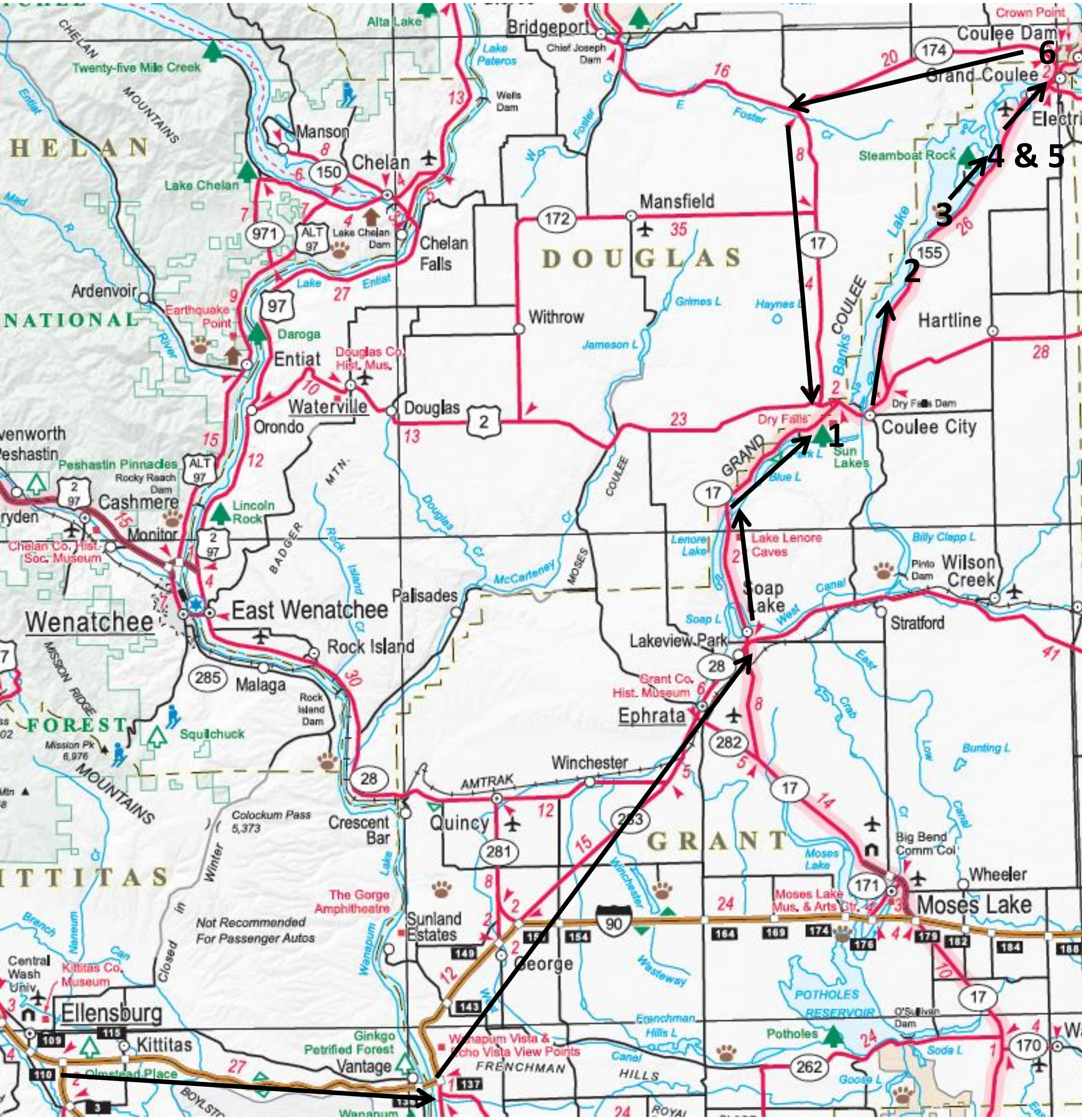


Figure 2. Our route shown with arrows and stops noted with numbers. Source: Washington State Department of Transportation http://www.wsdot.wa.gov/NR/rdonlyres/14A6187A-B266-4340-A351-D668F89AC231/0/TouristMapFront_withHillshade.pdf

Ellensburg to Quincy Basin

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

Ellensburg to Quincy Basin

- **Route:** Part of our route to Stop 1 takes us from Ellensburg to the Quincy Basin via I-90 (Figures 2 & 3).
- **Lithology & Structure:** Ellensburg lies near the western margins of the Columbia River Basalts. Our drive from Ellensburg begins on the floor of the Kittitas Basin *syncline* with downfolded Columbia River Basalts ~4000 feet below us (Figures 4, 5 & 6). 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 7).
- **Climate in the Kittitas Basin:** The wind towers of the Wildhorse and Vantage Wind Farm remind us of the regularity and strength of winds on the eastern margins of the basin. The thick deposits of *loess* that blanket the Badger Pocket area in the southeastern part of the Kittitas Basin are a reminder of the importance of wind over time as well.
- **Missoula Floods:** Descending the Ryegrass anticline, we reach the upper limit of Missoula Flood *slackwater* at ~1260 feet (Figure 8) between mileposts 133-134. Look for changes in the shrub steppe vegetation as well as thick gravel deposits to indicate that we have crossed into the area once inundated by floodwaters. Also, keep your eyes peeled for light-colored, out-of-place rocks atop the basalts in this area—these are iceberg-rafted *dropstones* (also called *erratics*) deposited by the floods. As we descend to Vantage at ~600 feet elevation on the Columbia River, recognize that floodwaters lay ~600 feet over our heads at their deepest extents. The Columbia River "Gorge" here is a result of pre-Missoula Flood, Missoula Flood, and post-Missoula Flood erosion. East of the Columbia River, the ~horizontal bench we follow until nearly entering the Quincy Basin and the Columbia Basin Irrigation Project is a *stripped structural surface* created by selective erosion of Columbia River Basalts to the level of the Vantage sandsone. Several landslides are visible atop the Vantage sandstone in the slopes to the right (east) of our bus. From here, we also have fine views of *Channeled Scablands* (to your west) that are so indicative of Missoula Flood-ravaged surfaces.
- **Climate in the Vantage Area:** In Vantage, we are in a very different climate from that of Ellensburg. Because we are ~900 feet lower than Ellensburg, temperatures are likely 4-5^{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.

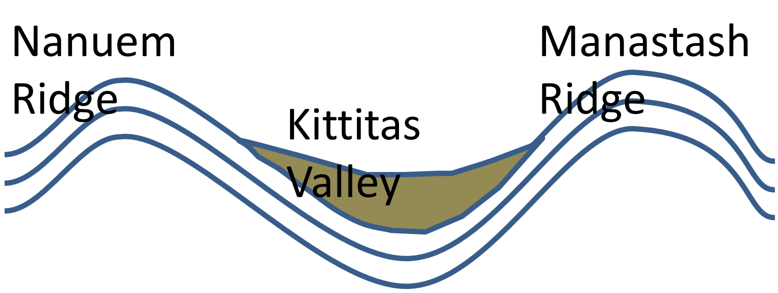


Figure 4. Location of Kittitas Basin syncline between Naneum Ridge and Manastash Ridge anticlines.

Ellensburg to Quincy Basin

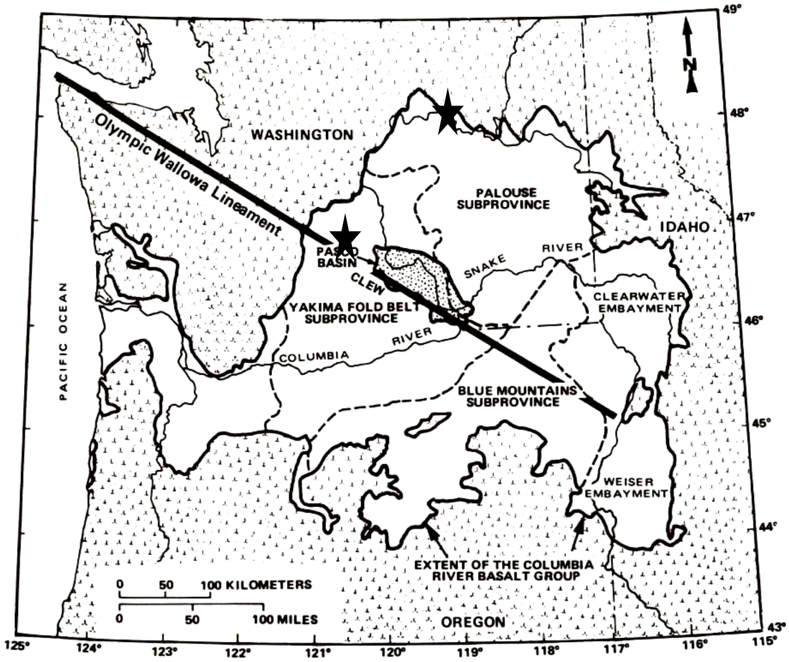


Figure 5. The Columbia Plateau and the areal extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Stars indicate locations of Ellensburg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

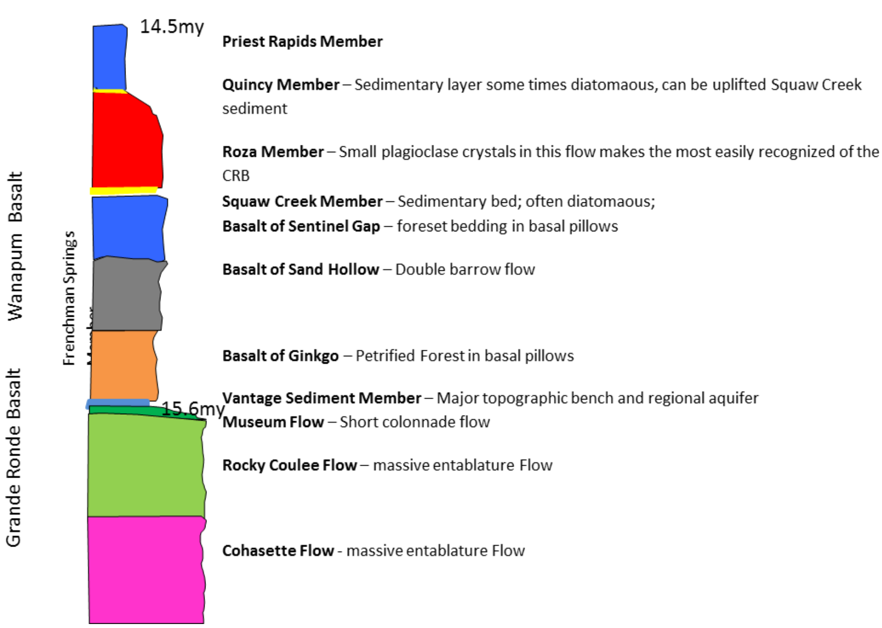


Figure 6. Stratigraphy of the Columbia River Basalt Group.

Ellensburg to Quincy Basin

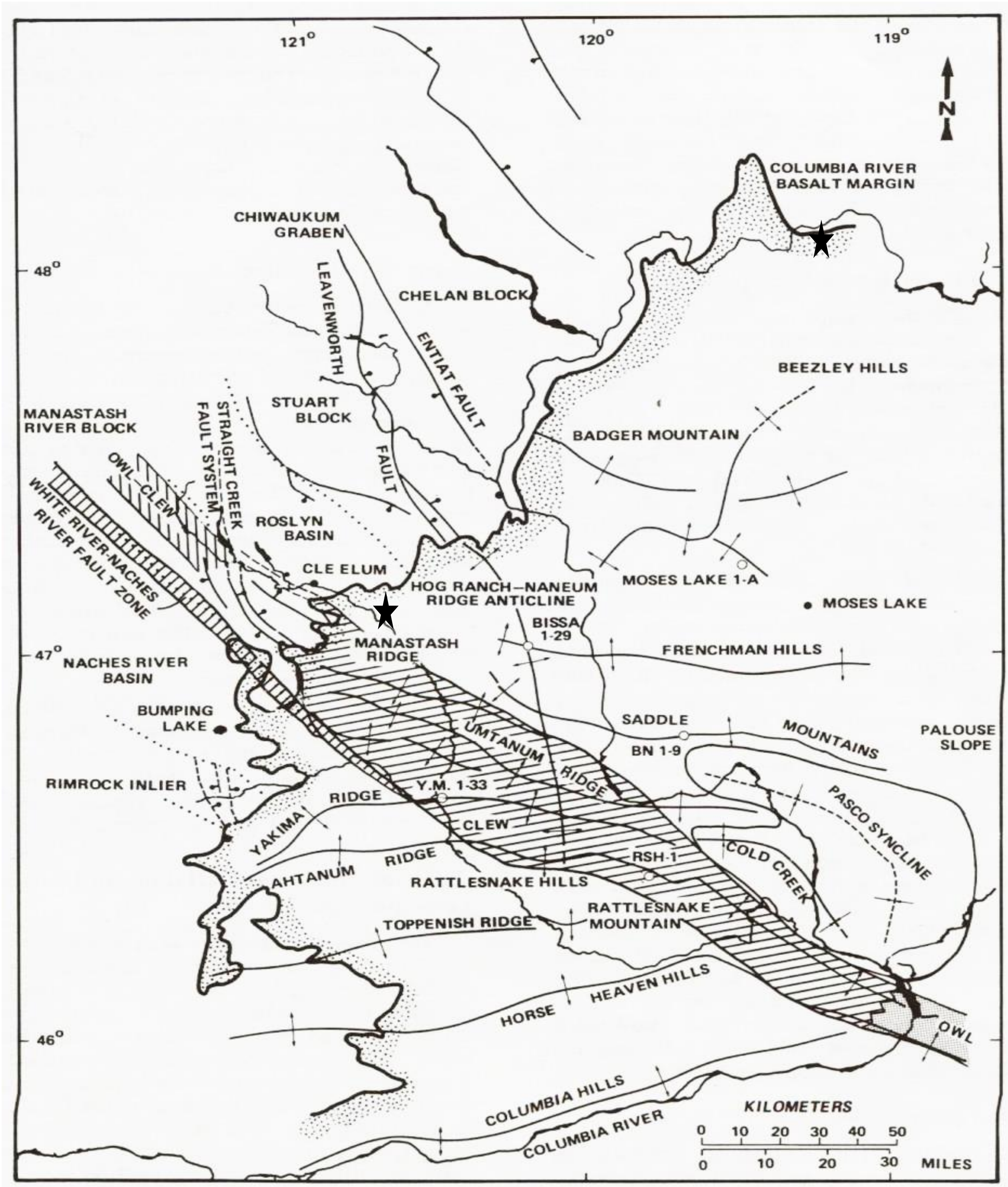


Figure 7. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Stars indicate locations of Ellensburg and the town of Grand Coulee. Source: Reidel & Campbell (1989, p. 281).

Ellensburg to Quincy Basin

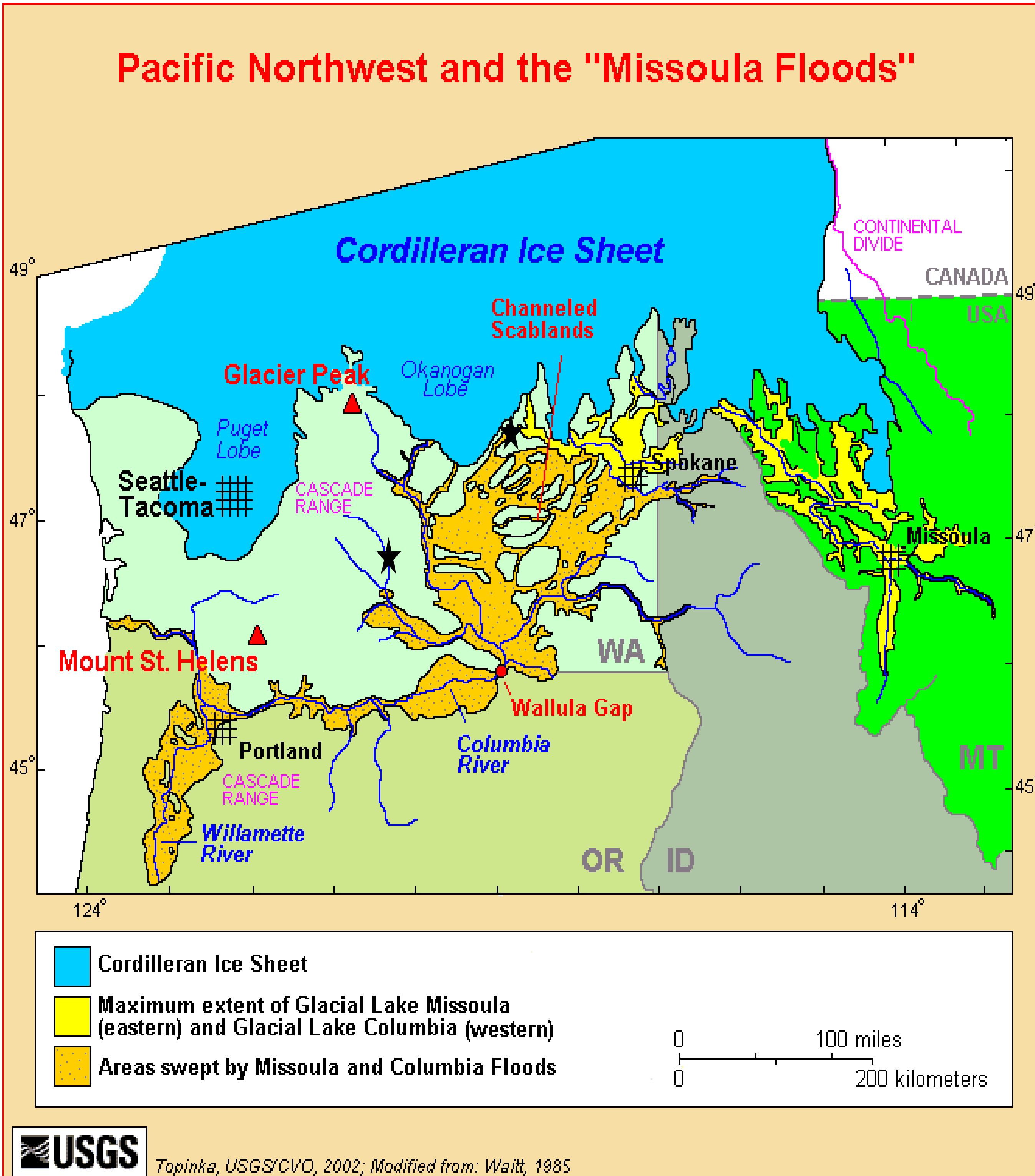


Figure 8. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Stars indicate locations of Ellensburg and the town of Grand Coulee. Source: Cascade Volcano Observatory website.

Quincy Basin to Lower Grand Coulee

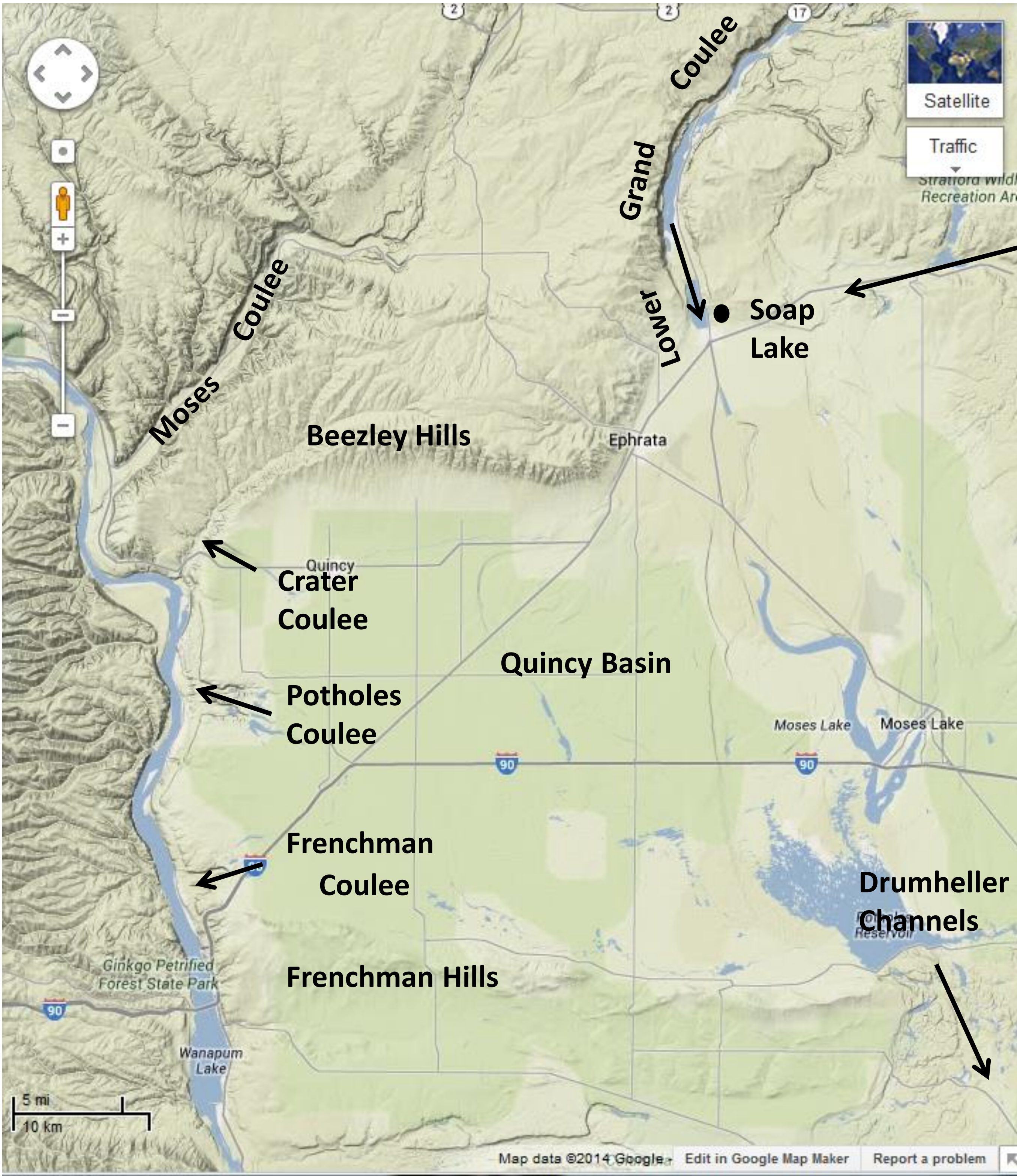


Figure 9. Topography of the Quincy Basin to Lower Grand Coulee part of our route. Arrows show direction of flood flows into, and out of, the Quincy Basin. Source of image: Google Maps.

Quincy Basin to Lower Grand Coulee

- **Route:** This leg of the route takes us across the Quincy Basin to the mouth of the Lower Grand Coulee. (Figures 2 & 9). On I-90, then WA 283. We enter the Quincy Basin essentially where I-90 reaches its high point before descending to the Silica Road exit.
- **Substrate:** The Quincy Basin is underlain by *Miocene* Grande Ronde and Wanapum basalts of the Columbia River Basalt group (Figures 5 and 6). The individual flows are interbedded with sedimentary units including *diatomaceous earth*, which is mined in the basin. The Ringold Formation, a mix of *Tertiary* and *Quaternary alluvial* and *lacustrine* sediments, is found in scattered exposures in the basin. Gravels, sands, and silts associated with late Quaternary Missoula Floods cover much of the basin. Loess mantles much of the slopes of the basin (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 9) are anticlines on the northwestern part of the Yakima Fold and Thrust Belt (Figure 7). These anticlines guided floodwaters entering the basin from the northeast and east. Flood outlets from the basin were (clockwise from the northwest) at Crater Coulee, Potholes Coulee, Frenchman Coulee, and Drumheller Channels (Figure 9).
- **Columbia Basin Irrigation Project:** The Quincy Basin is a vastly different place now than in 1952 when Columbia River water was first delivered to the area via the Columbia Basin Irrigation Project. Prior to that time, it was a dry, sand-covered basin characterized by ranching and meager attempts at dryland farming. Now it boasts over 60 different crops. Water for these crops reach the Quincy Basin from Lake Roosevelt via Banks Lake Reservoir and a series of canals and siphons.
- **Flood Bars:** A giant flood bar formed at the mouth of the Lower Grand Coulee Upper Crab Creek Valley as the waters left their confines (Figures 11 & 12). 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, 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 Missoula Flood deposits covers much of this bar. Unlike the deposits near Moses Lake, these deposits take on the flatter form of cover sand rather than dunes, perhaps reflecting the lower amount of sand available. These sands are a main parent material for the basin's soils.
- **Patterned Ground:** Patterned ground appears as pimple-like features on the gravelly to bouldery Missoula Flood deposits as we near Ephrata. If you look closely, you can also see patterned ground on the Beezely Hills. Given the position of these features, they must have formed following the floods in the latest *Pleistocene* or *Holocene*. Are they cold climate phenomena, the result of water or wind erosion, seismic activity, burrowing rodents, or something else?

Quincy Basin to Lower Grand Coulee

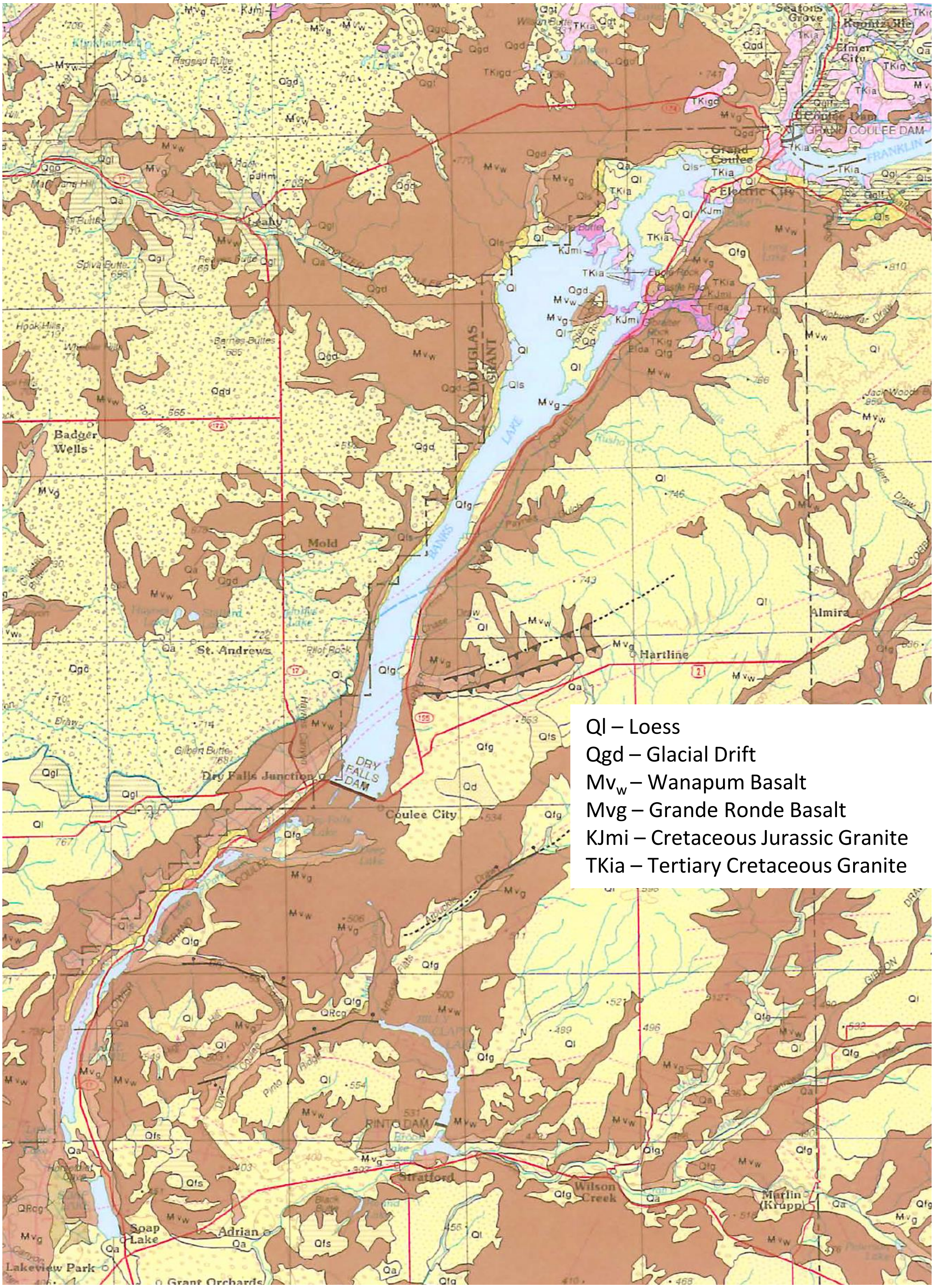


Figure 10. Geologic map for the Grand Coulee area.

Quincy Basin to Lower Grand Coulee

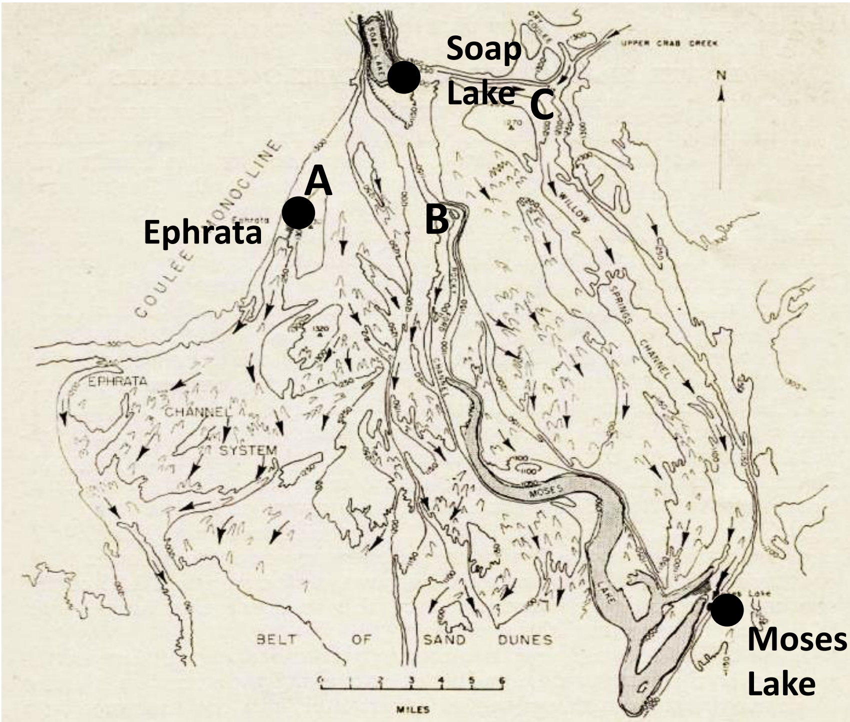


Figure 11. Quincy Basin distributary channels. Note three main distributaries from west to east—Ephrata (A), Rocky Ford (B), and Willow Springs (C). Note origins of dis-tributaries at apex of Ephrata Fan (i.e., expansion bar). Source: Bretz (1959, p. 33).

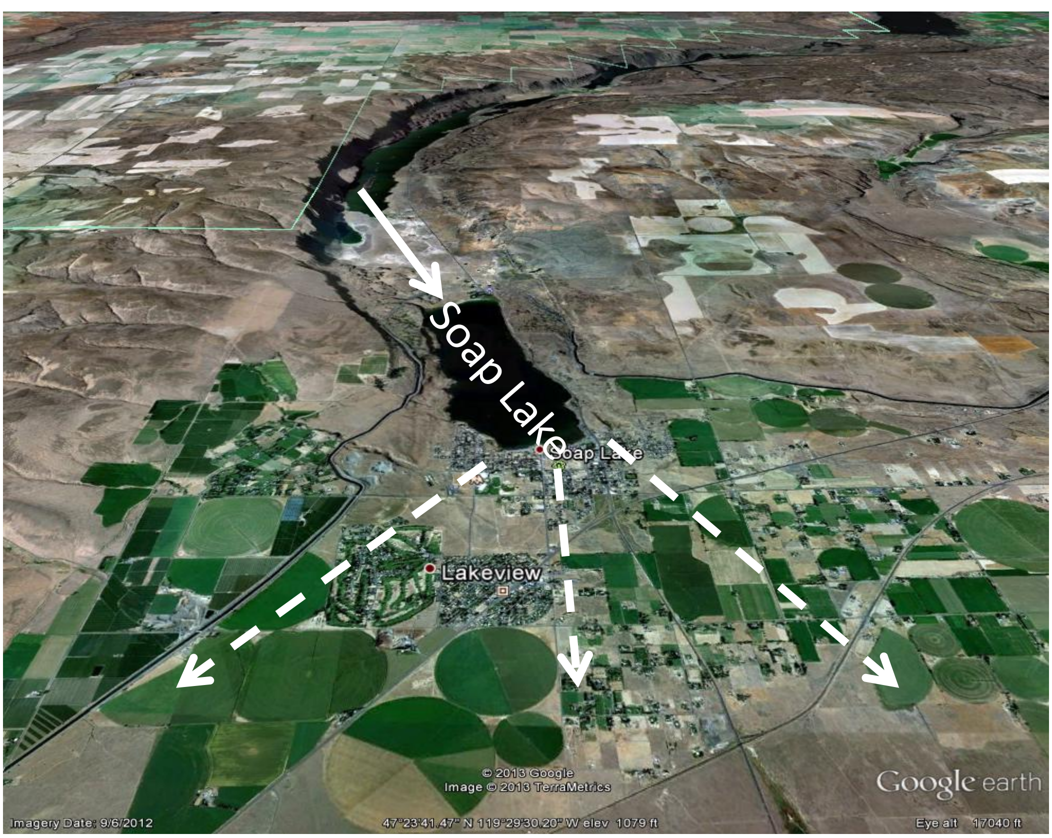


Figure 12. Oblique view of Soap Lake at the terminus of the Lower Grand Coulee. Solid arrow shows flood flows. Dashed arrows show development of explansion bar. Source: Google Earth.

Lower Grand Coulee to Dry Falls

Figure 13. Topography of the Lower Grand Coulee and vicinity. Blue Lake rhinocerus site shown with star. Source of image: Google Maps.

Lower Grand Coulee to Dry Falls

- **Route:** Our route from the mouth of the Lower Grand Coulee to Dry Falls follows the Lower Grand Coulee and WA highway 17 to Dry Falls. (Figure s 2 & 13).
- **Substrate:** Much of the substrate that we see in the Lower Grand Coulee is Grande Ronde and Wanapum basalt of the Columbia River Basalt Group (Figures 5, 6 & 13). Missoula Flood gravels and Paleolake Bretz sands, silts, and clays also outcrop on the coulee floor (see below). Quaternary, post-flood talus mantles slopes below cliffs throughout the coulee. The structure of the Lower Grand Coulee is dominated by the Coulee Monocline.
- **Geologic Structure & Missoula Floods:** Geologic structure dictated the paths of Glacial Lake Columbia water and Glacial Lake Missoula floodwaters in the Lower and Upper Grand Coulees. The Lower Grand Coulee follows the Coulee Monocline for much of its path. *Monoclines*, like their name implies, are single incline folds associated with compression. The Coulee Monocline extends from Ephrata at least as far east as Hartline . You can see evidence of it in the tilted basalts of the numerous *hogback islands* present in the lakes on the floor of the coulee (Figure 14). Flood flows coming over the Coulee Monocline in the Upper Grand Coulee in the vicinity of Coulee City migrated to the southwest to follow the topographic low created by the Coulee Monocline and the flanks of the High Hill anticline. Floodwaters followed the base of the monocline, exploiting the folded and crushed rocks here to erode the Lower Grand Coulee. In the vicinity of Lake Lenore, floodwaters also excavated the synclinal valley of Unnamed Coulee. (Figure 15). In each case, floodwaters exploited the less resistant of the uptilted beds leaving behind *homoclinal ridges* and valleys that are further eroded to become *hogbacks* and *cuestas.* The result of the flooding and associated erosion of the monocline was that the cataract receded headwardly (i.e., upvalley) from near present-day Soap Lake 17 miles to near Dry Falls (Figure 16).
- **Evidence for Flooding**: Evidence for the rapid, flood erosion of the Lower Grand Coulee can be seen in the *hanging valleys*, especially evident on the west side of the coulee. Uniform river processes result in valleys that join at essentially the same level. This is the *Law of Accordant Junctions* (or Playfair's Law). Other evidence of huge floods through the Lower Grand Coulee include the giant flood bars deposited in the lee of obstructions. Look for lighter sediments and changes in vegetation to help you identify these. Evidence can also be seen in the chaotic landscape east of the Grand Coulee where channels go every which way, including uphill!
- **Paleolake Bretz**: Flood gravel-capping silts south and north of present-day Soap Lake suggest that a once-deeper lake existed here to an elevation of ~1150 feet (Waitt, 1994). WSU Anthropologist Roald Fryxell's student Jerry Landye (1973) named this Lake Bretz, and suggested it was a Late Pleistocene lake formed following the passage of the last Missoula Floods through the coulee. The high point of this lake was about 5 feet below the lowest point on the expansion bar (~1155 feet) impounding the lake south of the present day intersection of WA 28 and 17. Glacial Lake Bretz extended upcoulee nearly to Dry Falls Lake. To our knowledge, no one has dated the abundant molluscs in these lake sediments to determine the timing of the lake.

Lower Grand Coulee to Dry Falls

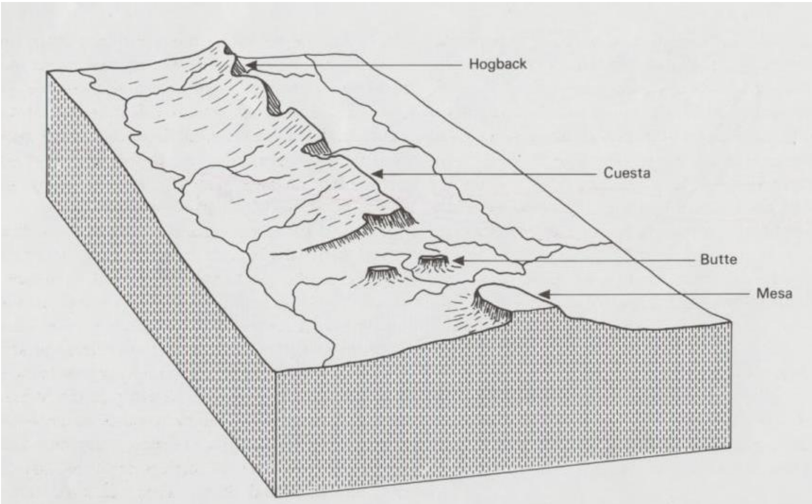


Figure 14. Butte & basin topography associated with horizontal strata versus cuestas and hogbacks associated with increasingly tilted strata. From: Summerfield (1991, p. 408)

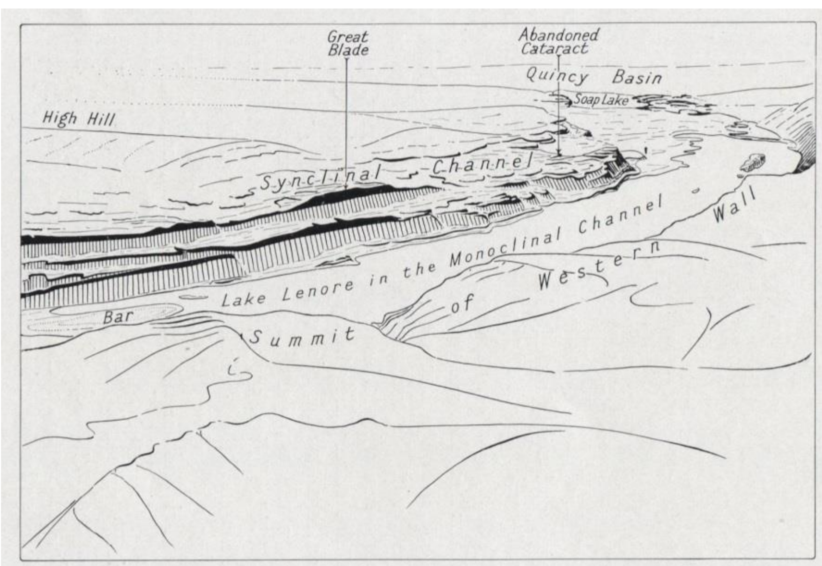


Figure 15. Synclinal and monoclinal channels of the Lower Grand Coulee. View to the southeast from the west rim of the Lower Grand Coulee. From Bretz (1932).

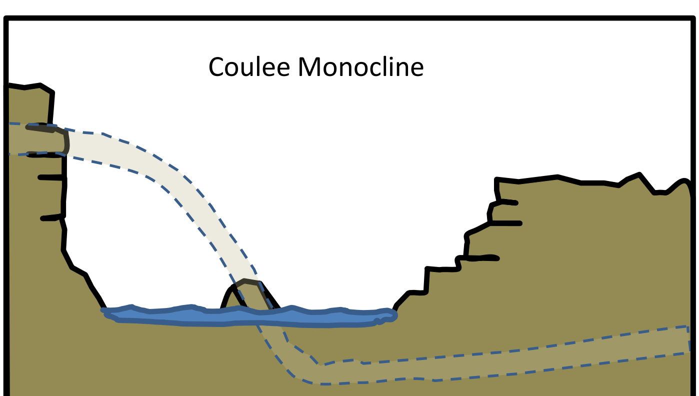


Figure 16. Relationship of floodwaters to the Coulee Monocline.

Lower Grand Coulee to Dry Falls

- **Contemporary Lakes**: Along our route, we pass a chain of lakes. Soap Lake is the terminal lake of this chain and has no outlet. In arid to semi-arid settings, water loss from such *closed basin* lakes occurs primarily because of evaporation which concentrates minerals in the remaining water. Closed basin lakes therefore tend to be saline and/or alkaline, and because of its terminal position, Soap Lake is the most saline and alkaline of the Lower Grand Coulee lakes (Bennett, 1962). The soapy appearance of Soap Lake on a windy day (hence the name) comes from the mineral-rich waters (primarily Sal Soda--Na_2CO_3). Soap Lake has a long history of human use tied to the purported healing powers of the lake waters that extends from Native American use to present (Fiege, n.d.).
- **Blue Lake Rhino**: The eight foot long, one ton, Blue Lake rhinoceros died 14.5 million years ago. Its bloated body was lying among some fallen trees in a shallow water body (Figure 17). The pillow complex of the advancing Priest Rapids Basalt Flow lifted up and encased the trees and the rhino carcass. It was found in 1935 along the west wall of Jasper Canyon at Blue Lake when hikers entered a small cavern which turned out to be the rhino's body cast containing a few silicified bone fragments. The presence of the rhino plus pollen samples suggests that approximately 14.5 million years before present the climate of what is now central Washington was similar to that of the southeastern United States—i.e., warm and moist (Kaler, 1988).

Figure 17. Artists rendition of the burial of the Blue Lake rhinoceros.
Source: www.justgetout.net

Stop 1—Dry Falls

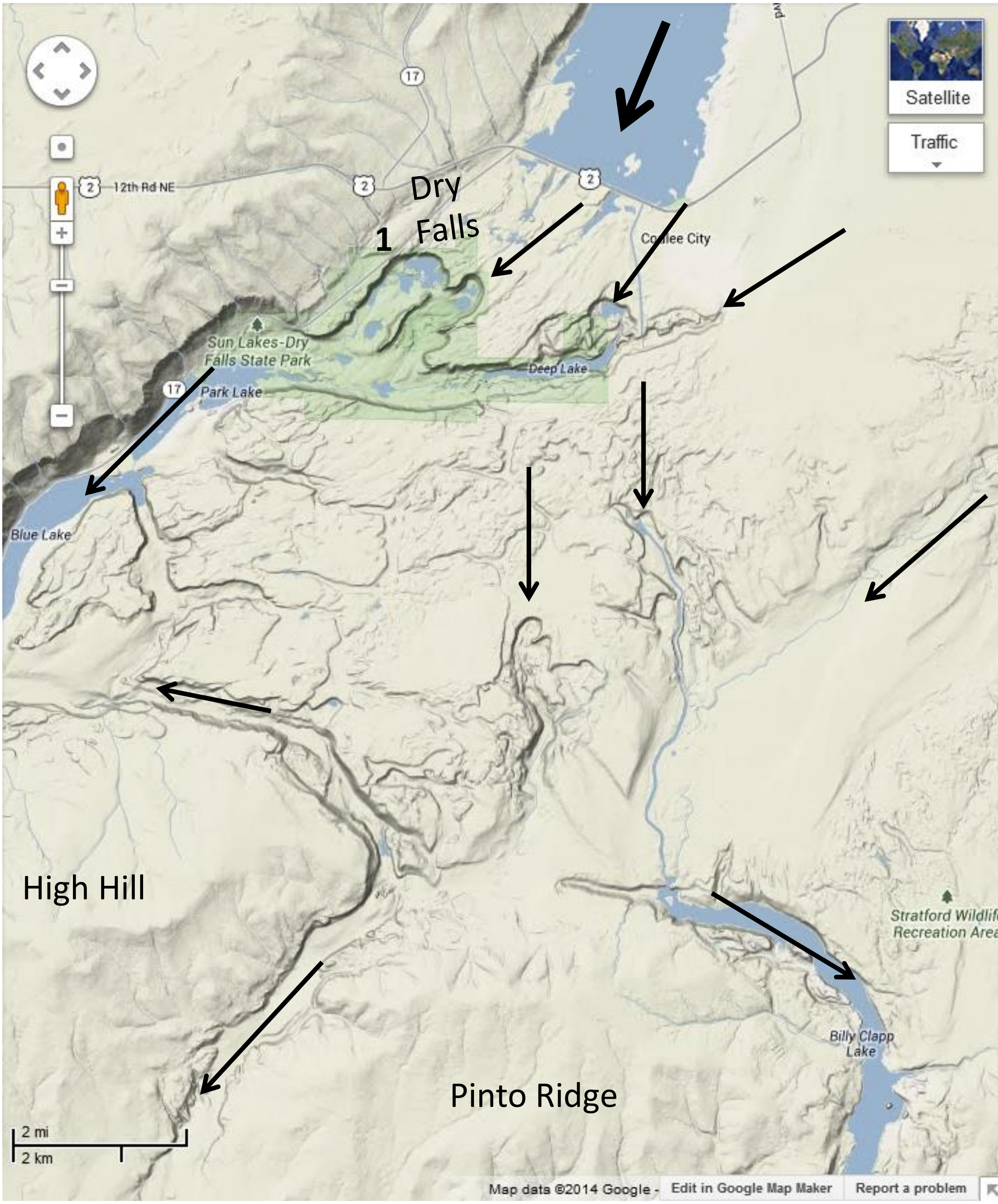


Figure 18. Map of topography in vicinity of Dry Falls and Coulee City. Heavy arrow indicates flood flow down Upper Grand Coulee. Lighter arrows are flood paths below Coulee City. Number indicates field trip stop. Source: Google Maps.

Stop 1—Dry Falls

- **Location:** We are at Dry Falls at the head of the Lower Grand Coulee (Figure 18) . This is an information and restroom stop.
- **Glacial Lake Missoula and its Floods**: The floods that shaped this landscape came from Glacial Lake Missoula in western Montana (Figure 8). Glacial Lake Missoula originated when the Purcell Trench Lobe of the Cordilleran Icesheet blocked the mouth of the Clark Fork River near Lake Pend Oreille and Sandpoint creating Glacial Lake Missoula. At its maximum, it held 530 mi^3 of water which is about one-half the volume of modern day Lake Michigan. It was 2000 feet deep at its ice dam. Periodically, the ice dam failed releasing lake waters as glacial outburst floods or *jokulhlaups* that swept across northern Idaho and into northeastern Washington. Floodwater velocities reached nearly 70 mph in places (Baker, 1987). Much of the path of these floods was scoured to basalt bedrock and descriptively named the *Channeled Scablands* (Figure 19). The Channeled Scablands can be divided into three large scabland tracts—Cheney-Palouse, Telford-Crab Creek, and Grand Coulee (Figure 19). We are located in the most prominent of them all—the Grand Coulee. The Upper Grand Coulee formed when the Okanogan Lobe of the Cordilleran Icesheet blocked the Columbia River Valley near Grand Coulee thus creating Glacial Lake Columbia (Figure 8). This lake spilled to the south as did Missoula Floods that entered the lake. Floods down the Upper Grand Coulee could follow multiple paths to arrive in the Quincy Basin (Figure 18) because of the shear volume of water exiting the Upper Grand Coulee and the lack of the topographic confinement there. Perhaps as many as 90 floods of varying magnitudes passed through the Upper Grand Coulee during the late Pleistocene. Many more may have come through during earlier glacial periods.
- **Dry Falls Origins:** Dry Falls is the upvalley position of the cataract that receded approximately 17 miles from Soap Lake. It is in this location only because the floodwaters that created it were shut off by the retreat of the Okanogan Lobe thus opening the Columbia River Valley to Columbia River as well as Missoula Flood flow. Dry Falls is over four miles wide and nearly 400 feet high (Figure 21). It stretches from here to Castle Lake (Figure 18). It is so large, it is referred to as a *cataract* (Figure 20*).* Deep (~500 feet deep), fast flows have great erosive power, setting up vertical vortices called *kolks* that exploited the columnar joints of the basalts (Figures 22 & 23), especially in the zone of the weakened rock at the base of the Coulee Monocline. These kolks combined with abrasion and cavitation to erode the Lower Grand Coulee. It is difficult to imagine approximately 17 miles of erosion in hard basalt bedrock; however, with many floods in the late Pleistocene and perhaps many more earlier floods, the amount of recession per flood could have been a "reasonable" several hundred feet for each flood (Waitt, 1994).
- **Dry Falls Landforms:** Dry Falls is characterized by a variety of distinctive landforms. Dry Falls Lake, Red Alkali Lake, Green Lake, and Castle Lake (Figure 21) all occupy *plunge pools* in the Dry Falls cataract. Umatilla Rock is a *goat island* --i.e., a remnant between the flood flows that created Dry Falls Lake and Red Alkali Lake/Green Lake. Large bars are present on the floor of the Dry Falls cataract including one that impounds Perch Lake. Large boulders on the floor of the Dry Falls cataract may be *bedload* of the floods or post-flood rockfall. Longitudinal grooves like those above Dry Falls are present where the flood flow moved kolks downstream (Figure 21).

Stop 1--Dry Falls

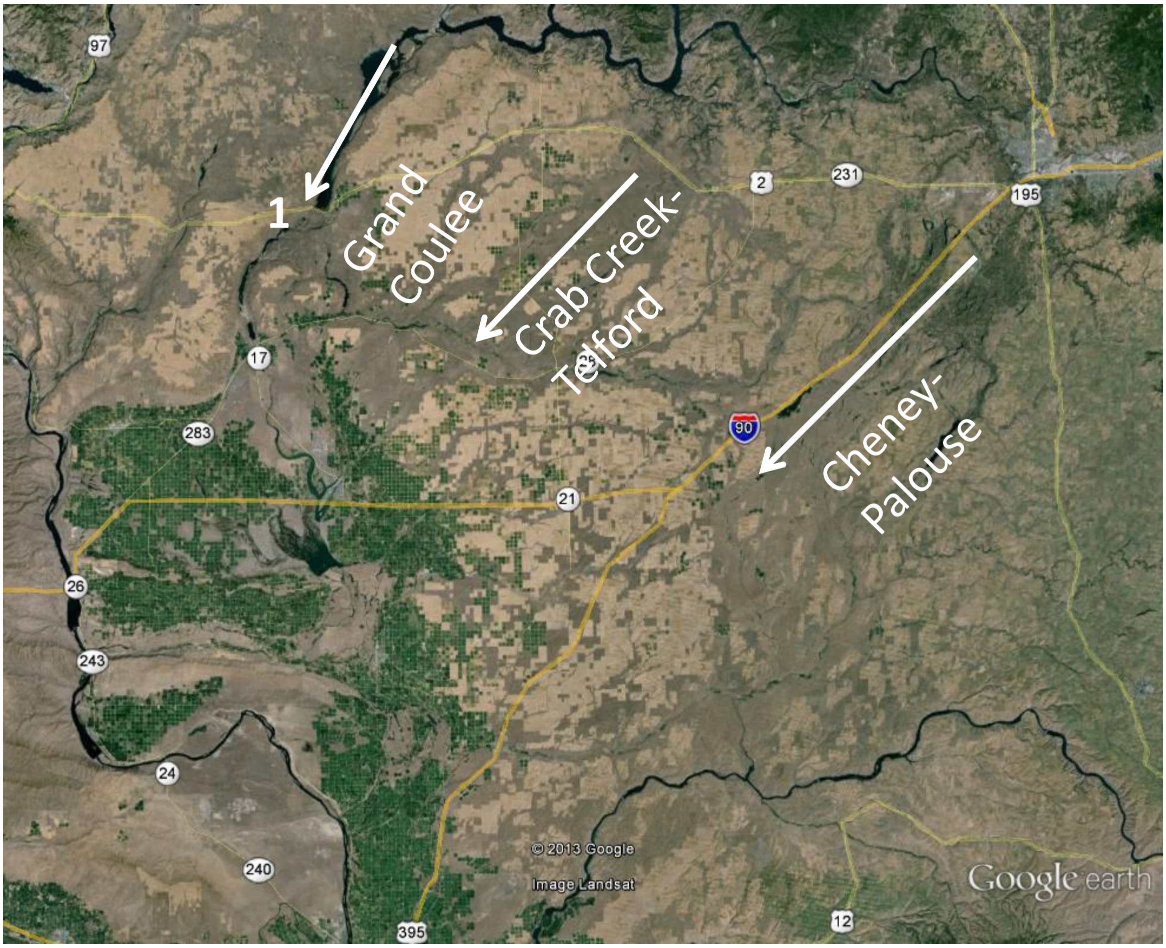


Figure 19. Channeled scablands tracts of central Washington state. Scablands are the darker areas. Number indicates field trip stop. Source: Google Earth.

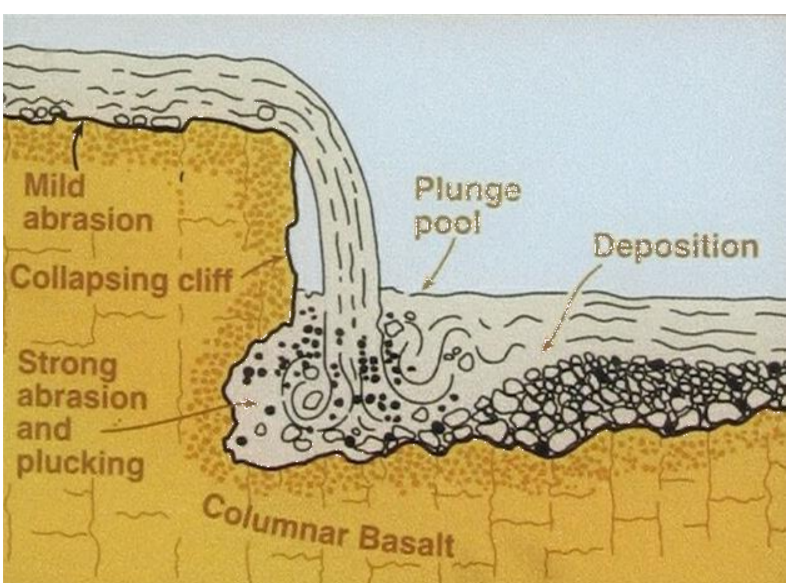


Figure 20. Diagram of waterfall and plunge pool development. Adapted from Weis and Newman (1982).

Stop 1—Dry Falls

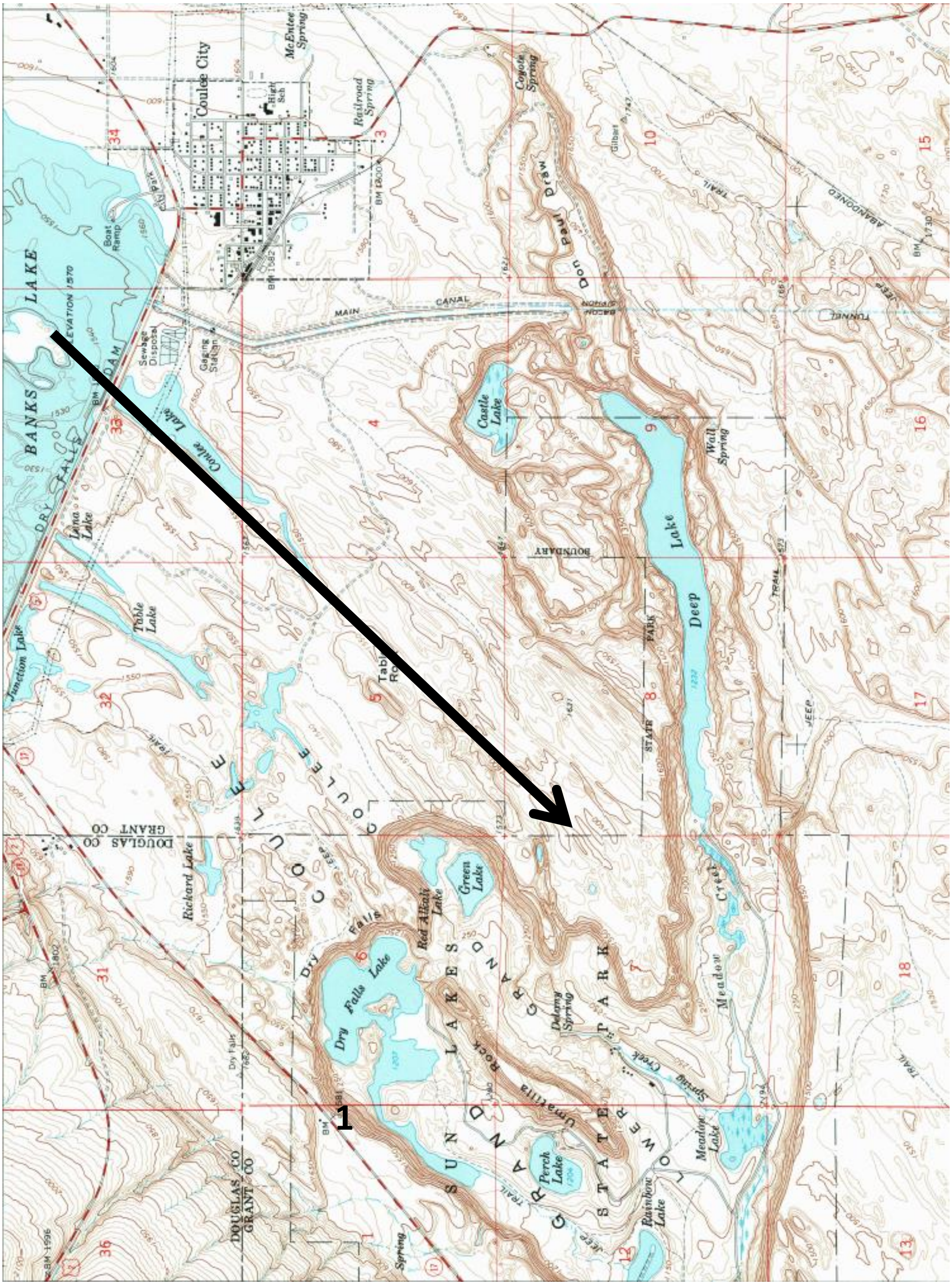


Figure 21. Topographic map view of Dry Falls cataract. Arrow indicates primary flood flow direction. Note longitudinal grooves north of Dry Falls. Number indicates field trip stop. Source: U.S. Geological Survey Coulee City 7.5' quadrangle.

Stop 1—Dry Falls

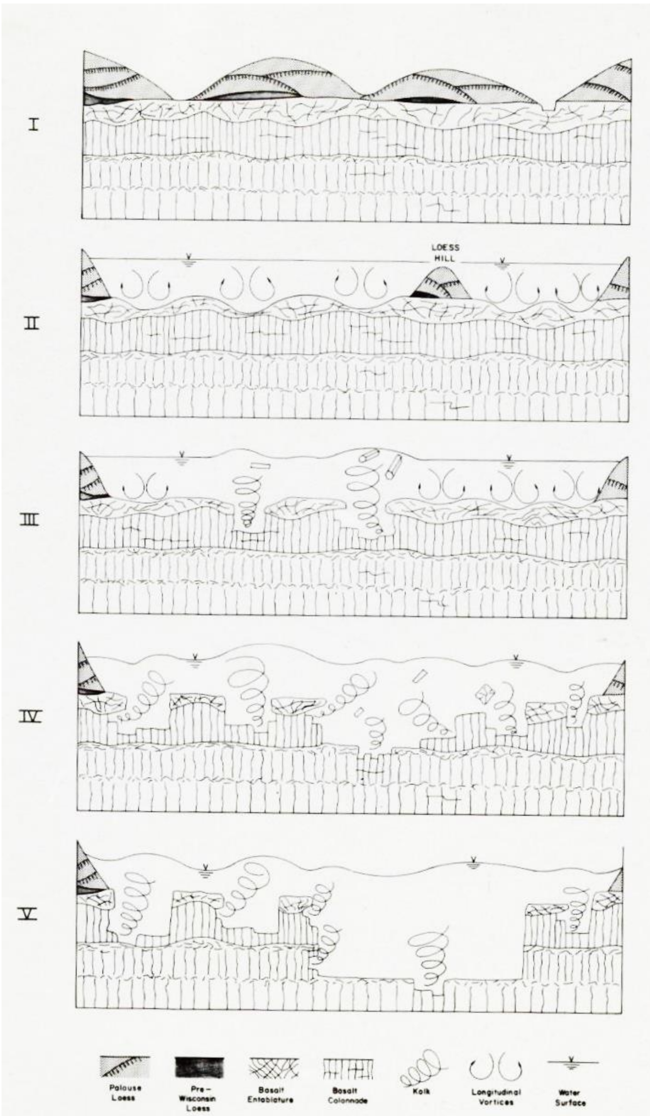


Figure 22. Illustration of kolk-based erosion in columnar jointed basalts. From Baker (1978, p. 105).

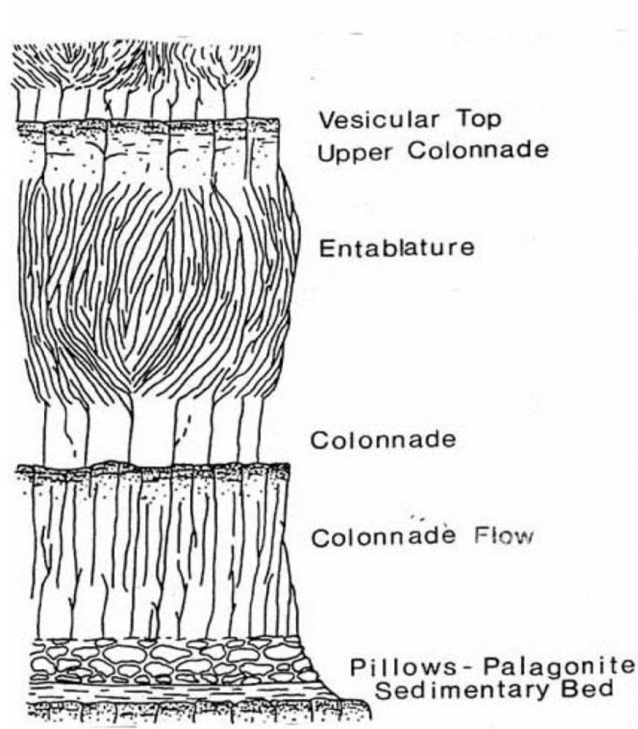


Figure 23. Typical Columbia River Basalt flow cross-section. Source: Jack Powell sketch.

Dry Falls to Million Dollar Mile

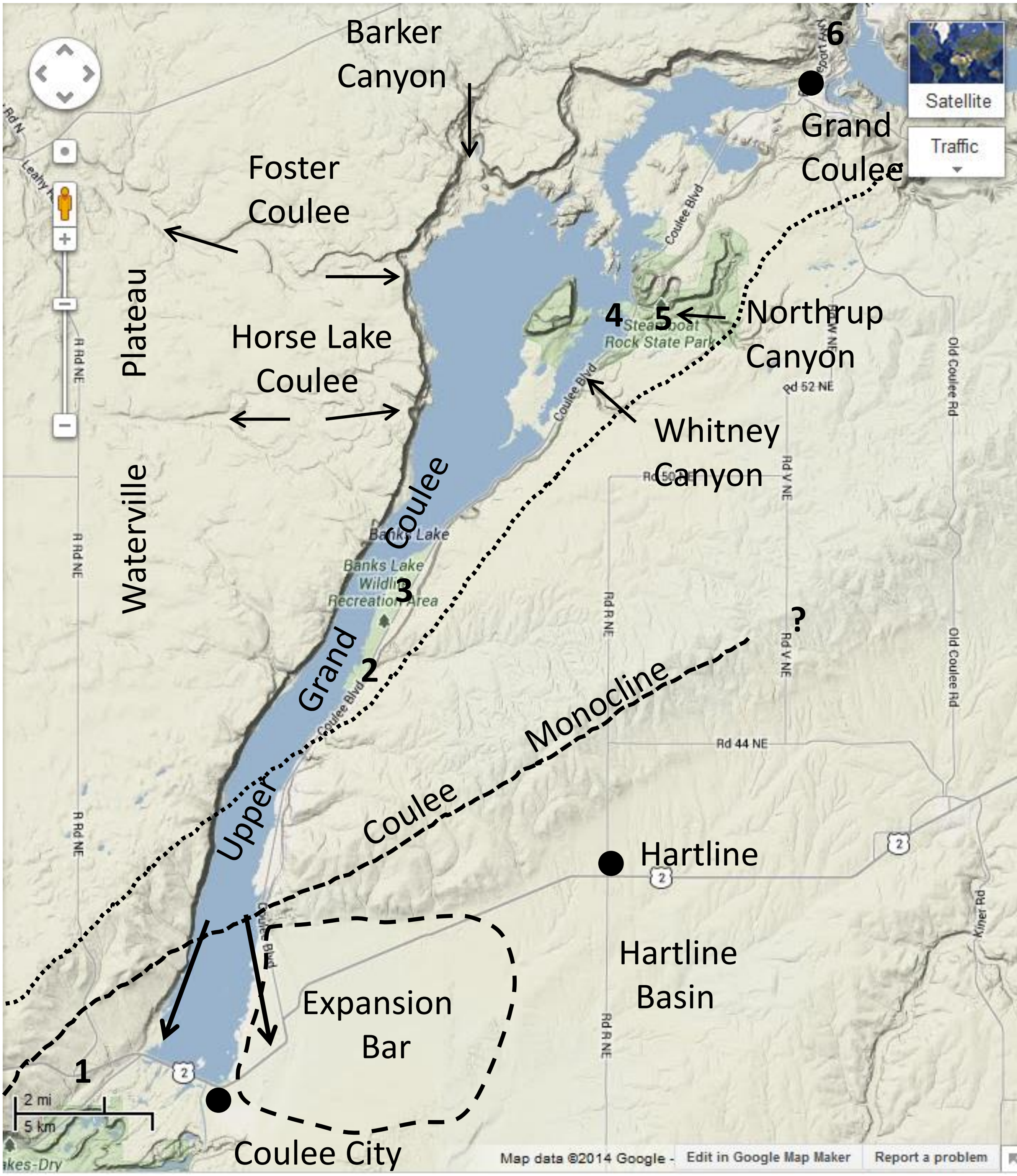


Figure 24. Topography of the Upper Grand Coulee and vicinity. Dashed line indicates approximate edge of expansion bar remnant. Dotted line indicates the approximate (actual & inferred) position of the Withrow Moraine. Numbers indicate field trip stops. Source: Google Maps.

Dry Falls to Million Dollar Mile

- **Route:** From Dry Falls we continue north for several miles on WA 17, east on U.S. 2, and north on WA 155 (Figures 2 & 24).
- **Upper Grand Coulee:** The Upper Grand Coulee is a recessional cataract that began where floodwaters crossed the Coulee Monocline at nearly right angles north of Coulee City (Figure 24). According to Bretz (1959), U.S. Bureau of Reclamation personnel found at least 300 feet of gravel below the basalt scabland coulee floor immediately downstream of the cataract origin near Coulee City. This gravel suggests that this area was a huge plunge pool.
- **Banks Lake:** Banks Lake is a reservoir in the Upper Grand Coulee impounded here by the South Dam is dam as well as the North Dam on its north end. Water filling the lake is pumped up from the Columbia River (impounded as Lake Roosevelt). Banks Lake water is then released via the Main Canal at Coulee City to flow south providing the irrigation water for the 670,000 acre Columbia Basin Irrigation Project focused on the Quincy Basin, Royal Slope, and Pasco Basin.
- **Coulee City:** Coulee City is a town that owes its origins and continued existence to water, agriculture, the U.S. government, and transportation. The town formed here because of the presence of McEntee Springs. Since 1952, Banks Lake has been a source of recreation, hence tourism dollars for the town. The town has long served as an agricultural center and is the nearest railhead for area farmers. Coulee City was initially located at the junction of a trail that travelled the length of the Upper Grand Coulee and one leg of the Caribou Trail that ascended the Coulee Monocline onto the Waterville Plateau (Anglin, 1995). During the construction of Grand Coulee Dam, it was a rail junction for a line that ran north to the town of Grand Coulee. More recently, it lies near the junctions of US 2, WA 17, and WA 155.
- **Coulee City Expansion Bar:** An abrupt escarpment parallels US 2 and then WA 155 before the highway enters the Upper Grand Coulee. This escarpment is not in basalt; rather, it is the eroded edge of a large *expansion bar* that occupies the Hartline Basin (Figure 24). The escarpment indicates that larger floods created the bar and subsequent smaller floods eroded the edge of the bar. The expansion bar formed as large floods exited the confines of the Upper Grand Coulee, lost velocity, and deposited their coarse textured load. Bjornstad and Kiver (2012) argue that this 300 foot tall (extending to 1850 feet elevation) expansion bar once spread from the Hartline Basin west to the west wall of the Upper Grand Coulee, helping impound the south arm of Glacial Lake Columbia. They argue that this bar catastrophically failed in the late Pleistocene sending a Missoula Flood-like torrent of Glacial Lake Columbia water down the Lower Grand Coulee. The remants of this bar are primarily confined to the Hartline Basin. Because of the coarse nature of the bar sediments, much of the bar land is not suitable for dryland farming; rather, crops require irrigation on these coarse textured parent materials.
- **Coulee Monocline Hogbacks**: Several miles north of the junction of US 2 and WA 155, we cross the Coulee Monocline and enter the Upper Grand Coulee. The Coulee Monocline here is indicated by prominent hogbacks seen to the east of the bus (Figure 24). The hogbacks formed from weathering and erosion of the less resistant strata . North of the hogbacks, basalt flows are more horizontal. Kolks have preferentially stripped the colonnades leaving horizontal stripped structural surfaces as terraces.

Stop 2—Million Dollar Mile

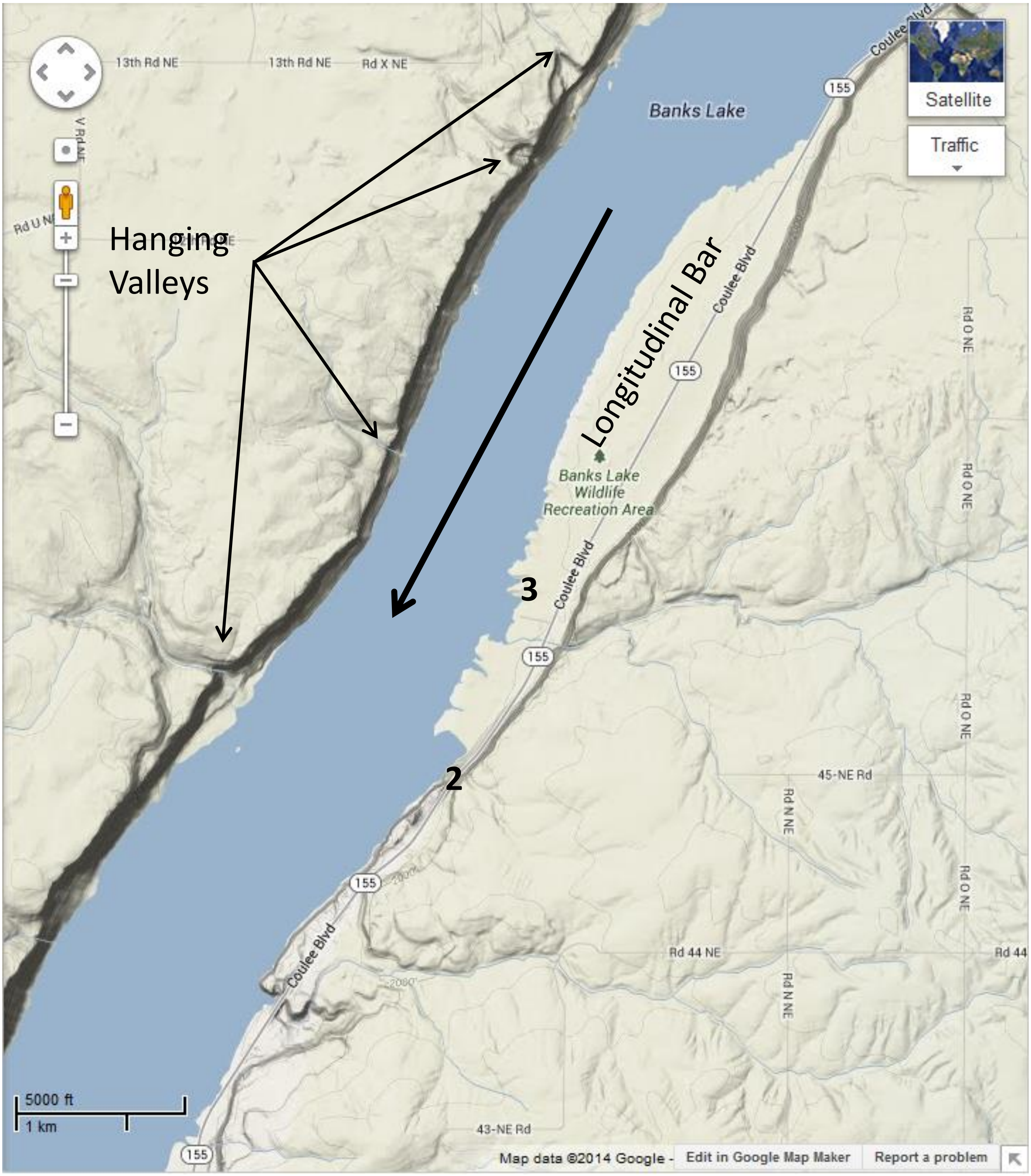


Figure 25. Topography in vicinity of Million Dollar Mile and Paynes Gulch, Upper Grand Coulee. Heavy arrow indicates flood flow. Numbers indicate field trip stops. Source: Google Maps.

Stop 2—Million Dollar Mile (North End)

- **Location:** We are parked at a pullout along WA 155 on the north end of the Million Dollar Mile. Our view here toward the north along the Upper Grand Coulee (Figure 25).
- **Million Dollar Mile:** The Coulee City to Grand Coulee highway was moved from the floor of Banks Lake to the east side of the Upper Grand Coulee in the early 1950's. In this area, construction crews had to blast through basalts to remain above Banks Lake. The costly construction linked to this blasting gives this stretch of the road its name.
- **Substrate & Structure:** The coulee is eroded in Grande Ronde and Wanapum basalts of the Columbia River Basalt group (Gulick and Korosec, 1990) (Figure 10). Missoula floods and associated kolks have especially exploited the colonnade portions of these flows leaving shallow caves known to archaeologists as *rock shelters.* Many rock shelters in the Channeled Scabland served as seasonal occupation sites for early Native Americans.
- **Upper Grand Coulee:** The Upper Grand Coulee here is about 1.25 miles wide and 700 feet deep. This coulee is larger than the Lower Grand Coulee because essentially all floodwaters were confined to it rather than only transporting part of the flood flow as was the case with the Lower Grand Coulee. In the distance up the coulee, we can see the isolated island of Steamboat Rock. Steamboat Rock will be the focus of our discussion at Stop 4.
- **Flood Bars:** The large surface on the floor of the coulee in the foreground is a longitudinal (Atwater (1987) says point) flood bar that is over 2 miles long. Large basalt and granite boulders are present on the bar. Bars form sub-fluvially as velocity decreases. They 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 those favoring a non-catastrophic origin for the Channeled Scablands 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 26): 1) c*rescent bar* forms on the inside bend of channels; 2) *longitudinal bar* forms in mid-channel or along a channel wall; 3) e*xpansion bar* forms where channels widens abruptly; 4) *pendant bar* forms downcurrent of mid-valley obstacle or valley-wall spur on bend; 5) *eddy bar* forms in a valley at the mouth of a tributary; and 6) *delta bar* forms where floodwater on a high surface adjacent and parallel to a main channel encounters a transverse tributary valley where it deposits. As noted earlier, bars are often differentiated from adjacent bedrock by not only their shapes but also vegetation cover—i.e.., typically bars are more vegetated or vegetated with more grass than is adjacent bedrock. The bar in our view is a longitudinal bar. If the light is right, you may notice multiple parallel channels eroded into the flood bar. These reflect the ready erodibility of the lake sediments that overtop the bar. These sediments will be the topic of Stop 3.
- **Okanogan Lobe:** The Okanogan Lobe of the Cordilleran Icesheet terminated west and north of here (Figure 27). If you look closely on the top of the western wall of the Upper Grand Coulee, you can see large haystack rock *erratics* deposited by the Okanogan Lobe. It is unclear how many times the Okanogan Lobe advanced into the area but it appears that the last time was the most extensive.
- **Talus:** Post-flood *talus* mantles the lower coulee walls. The thickness and lateral extent of the talus indicates the amount of weathering and rockfall that has occurred since the last large floods scoured the coulee walls.

Stop 2—Million Dollar Mile (North end)

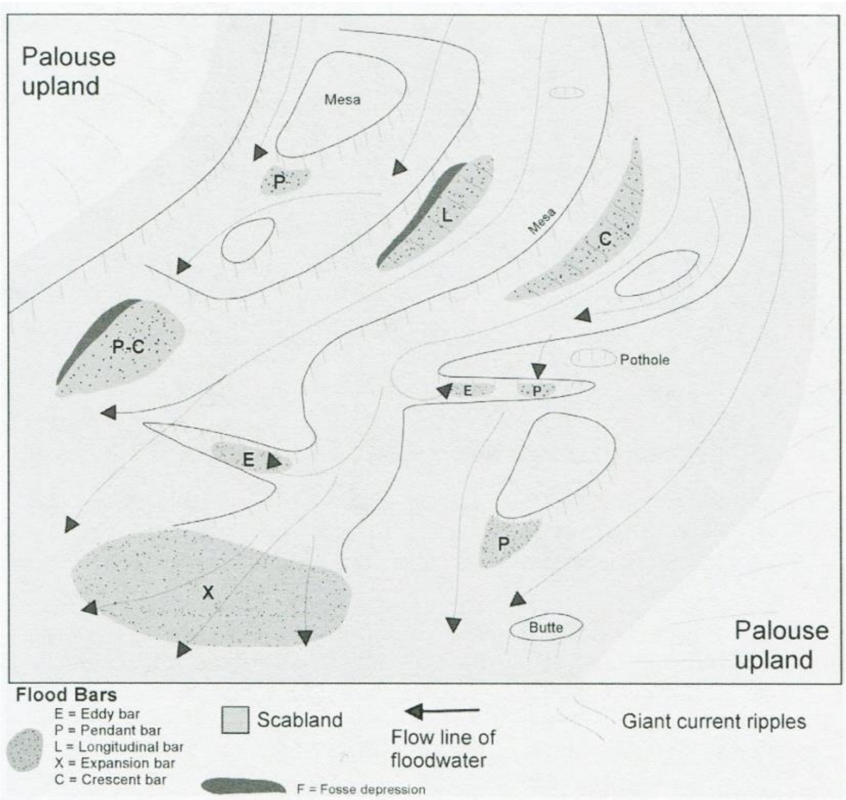


Figure 26. Types of flood bars. Source: Bjornstad and Kiver (2012, p. 51).

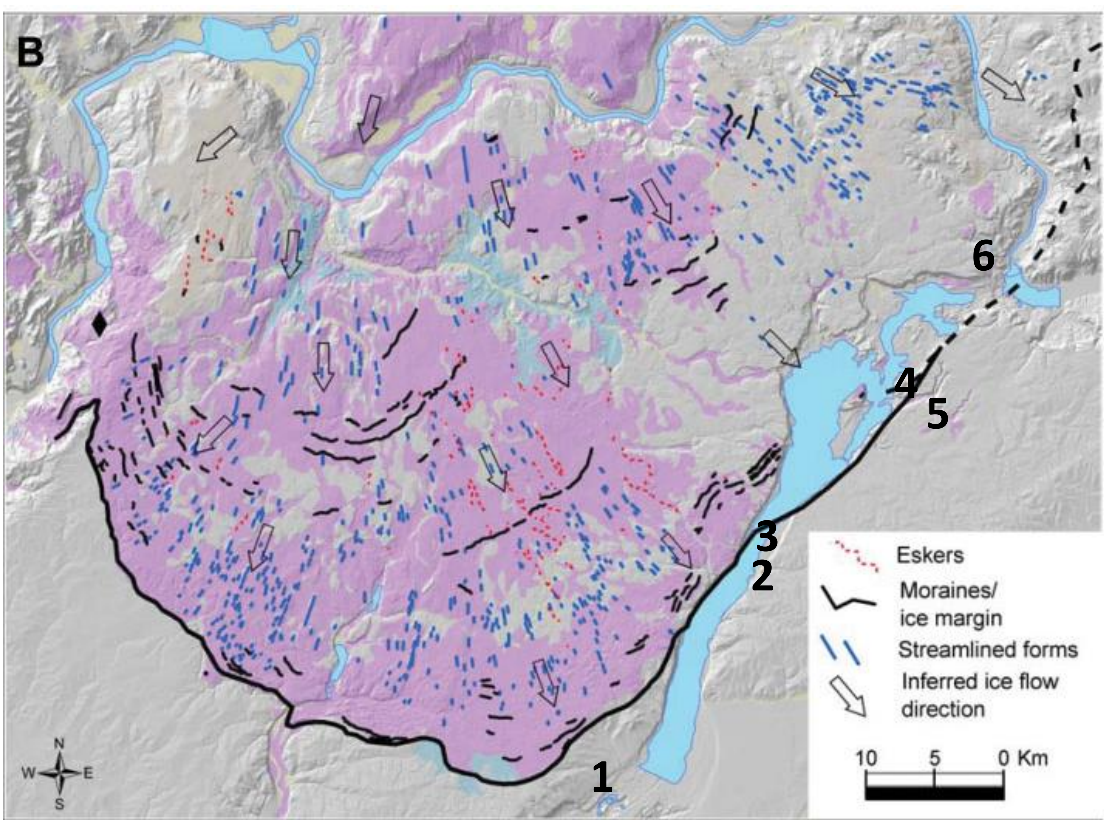
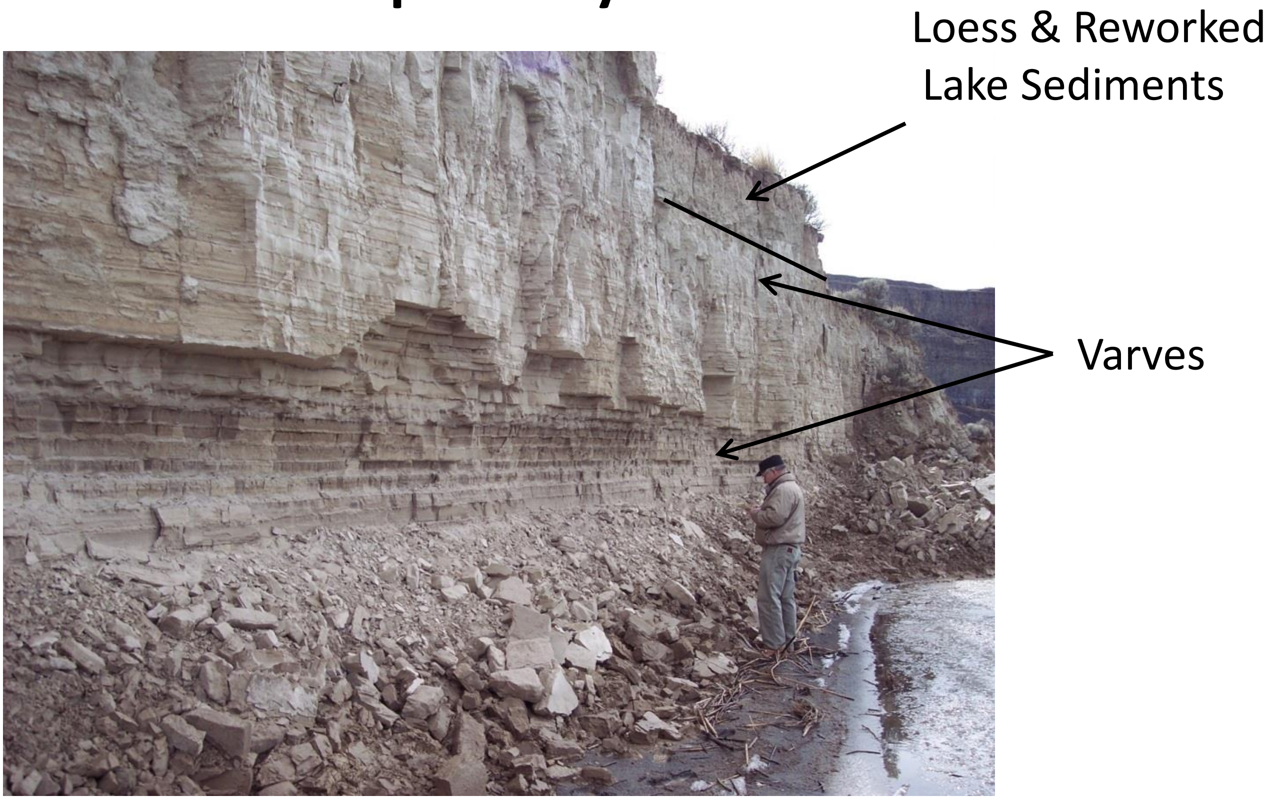


Figure 27. Position of the Okanogan Lobe relative to the Upper Grand Coulee. Numbers indicate field stop locations. Source: Kovanen and Slaymaker (2004, p. 561).

Stop 3—Paynes Gulch

- **Location:** We are parked at the boat ramp on the large bar north of the Million Dollar Mile (Figure 25). This is Brian Atwater's Paynes Gulch field site for his paper on Glacial Lake Columbia (1987).
- **Nespelum Silt as Paleolake Sediments:** Pardee (1918) named the thinly bedded, fine-textured, pale -colored sediments in north central Washington the Nespelum formation or the Nespelum Silt. Bretz (1932) and Flint (1935) first identified these and others in the Upper Grand Coulee as paleolake sediments.
- **Glacial Lake Columbia**: As noted earlier, Glacial Lake Columbia formed behind the Okanogan Lobe as it blocked the Columbia River Valley near present-day Grand Coulee Dam. This lake extended upriver to near the present-day mouth of the Spokane River. According to Waitt (1983), the maximum level of Glacial Lake Columbia was 2360 feet prior to the breaching of the drainage divide . Following the breaching, an arm of Glacial Lake Columbia extended into the Upper Grand Coulee where maximum levels were at about 1540 feet. This lake stretched to near Coulee City where it was either impounded by the large Coulee City expansion bar (Bjornstad and Kiver, 2012) or by a bedrock sill near present-day Coulee (implied by Waitt, 1994). This sill might have been enhanced by isostatic depression at the north end of the Upper Grand Coulee . Waitt (1994) notes about 90 feet of subsequent isostatic rebound in the Upper Grand Coulee. Lake sediments continue sporadically through the divide that separates the Upper Grand Coulee from the Columbia River Valley. Therefore, these represent a continuation of Glacial Lake Columbia. This lake was actually a "lake or very sluggish river" (Bretz, 1932; Atwater, 1987) that was flowing slowly through the upper Grand Coulee, over Dry Falls and down the Lower Grand Coulee to the Quincy Basin. That this lake exhibited flow is indicated by ripples of very fine sand. More lake-like conditions are seen in the clays that mantle these ripples.
- **Paynes Gulch Exposure and Glacial Lake Columbia:** Approximately 18 feet of paleolake sediment is exposed here over bar sediments (submerged at high lake level) (Figures 28 & 29). We know these are paleolake sediments because of their fine textured, thinly bedded structure. The rhythmic changes in color and texture indicate that these are forms of *rhythmites* called *varves*. Varves consist of pairs or couplets of alternating course and fine textured sediments that indicate annual deposition. Coarse -textured and often light-colored sediments are typically deposited in spring and summer months characterized by ample snowmelt and runoff. Conversely, fall and winter deposition is typically fine-textured and often dark-colored. Because varves indicate annual deposition, one may count them to indicate the number of years of sedimentation. Atwater (1987) counted 180 varves here. This, combined with the lack of evidence of catastrophic flooding, indicates that the Okanogan Lobe remained in place and Glacial Lake Columbia existed for at least 180 years after the last Glacial Lake Missoula flood came through the Grand Coulee. The descent of the top of the Nespelum Silt from the Columbia River Valley down the Grand Coulee combined by the presence of the hanging deltas at the mouths of Foster Coulee and Horse Lake Coulee on the west side of the coulee indicate that *isostatic rebound* has raised the northern Upper Grand Coulee approximately 90 feet above the lowest outlet at Coulee City.

Stop 3—Payne Gulch



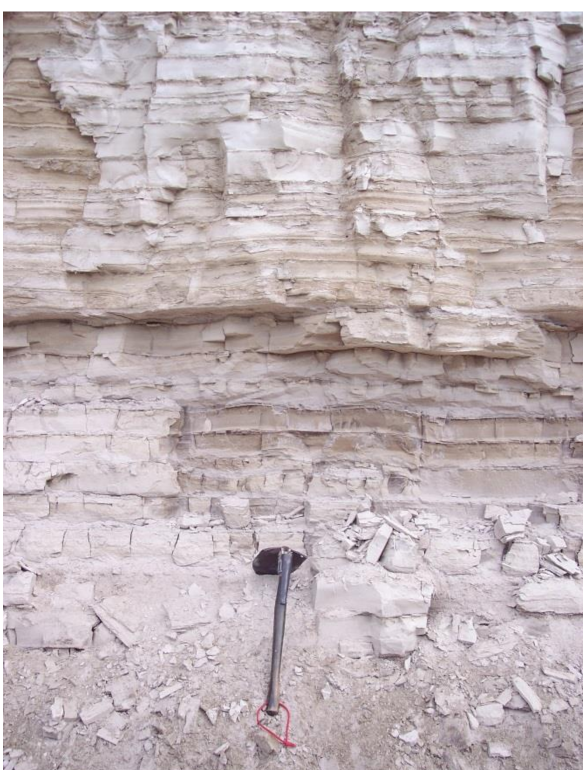


Figure 28. Sediments exposed at Paynes Gulch.

Figure 29. Close-up of individual varves exposed at Paynes Gulch, each of which indicates one year of deposition.

Paynes Gulch to Steamboat Rock

- **Route:** Our route from Paynes Gulch to Steamboat Rock follows WA 155 through the Upper Grand Coulee. (Figures 2 & 24)
- **Talus:** Thick accumulations of talus mantle the lower coulee walls here. In a few places where the talus has slid to reveal its internal structure, you can see a layer of white sediment. According to Waitt (1994), this is the 6850 yr BP Mazama tephra overlain by about 3 feet of talus. Given the amount of post-flood talus present, this suggests that talus production has dramatically slowed over time.
- **Hanging Valleys and Waterfalls:** Also, note the hanging valleys in the coulee. These valleys terminate in muddy waterfalls during snowmelt and after thunderstorms. These valleys indicate rapid downcutting in the main valley (Upper Grand Coulee) at a pace that could not be matched by the tributary valley. These were one of Bretz' lines of evidence for a flood origin of the Upper Grand Coulee. In winter, the frozen waterfalls of these hanging valleys are commonly used by ice climbers.
- **Coulee Widening:** As we near Steamboat Rock, the Upper Grand Coulee broadens abruptly from to over 3.5 miles. Bretz (1932) attributed this widening to two factors: 1) increased discharge in floodwaters when Steamboat Falls had retreated from the Coulee Monocline to this point; and 2) the floods' encounter with more resistant intrusive igneous rocks that lie below the Columbia River Basalts. Intrusive igneous rocks like granite were much more resistant to Missoula Flood erosion than were Columbia River Basalts because the intrusives lacked bedding and much of the vertical columnar jointing that floodwaters could exploit. You might think of the granitics as being akin to the entabulature of basalt flows.
- **Pre-Banks Lake Lakes:** The U.S. Bureau of Reclamation began filling Banks Lake sometime in the late 1940's and early 1950's. By 1951, irrigation water was flowing out of Banks Lake via the Main Canal. However, numerous lakes were likely present in the Upper Grand Coulee following the demise of Glacial Lake Columbia and the development of Banks Lake. According to a 1949 airphoto set (Figure 30), lakes occupied parts of the Upper Grand Coulee prior to Banks Lake. Most were present in the southern portion of the coulee. They were likely fed by seasonal runoff from snowmelt and rainfall as well as groundwater. Most must have been closed basin lakes and the airphotos suggest most were shallow and saline. As a result of their salinity and ephemeral nature, the coulee bottom adjacent to these lakes appeared to be little developed for agriculture. Devils Lake in the vicinity of Steamboat Rock was an exception. It was fed by perennial flow from Northrup Creek and was sufficiently fresh to be used for irrigation in the bottom of the coulee.
- **Ring Dike Structures**: It is in the east wall of the Upper Grand Coulee in this stretch of WA 155 that Windy Jaeger has found evidence of ring dike structures like those found in the Odessa area to our south (Keszthelyi et al, 2009). She attributes these to the rising of lava around a phreatic (i.e., wet) eruptive vent. These features were a focus of our April 2013 field trip to the Odessa area.

Paynes Gulch to Steamboat Rock

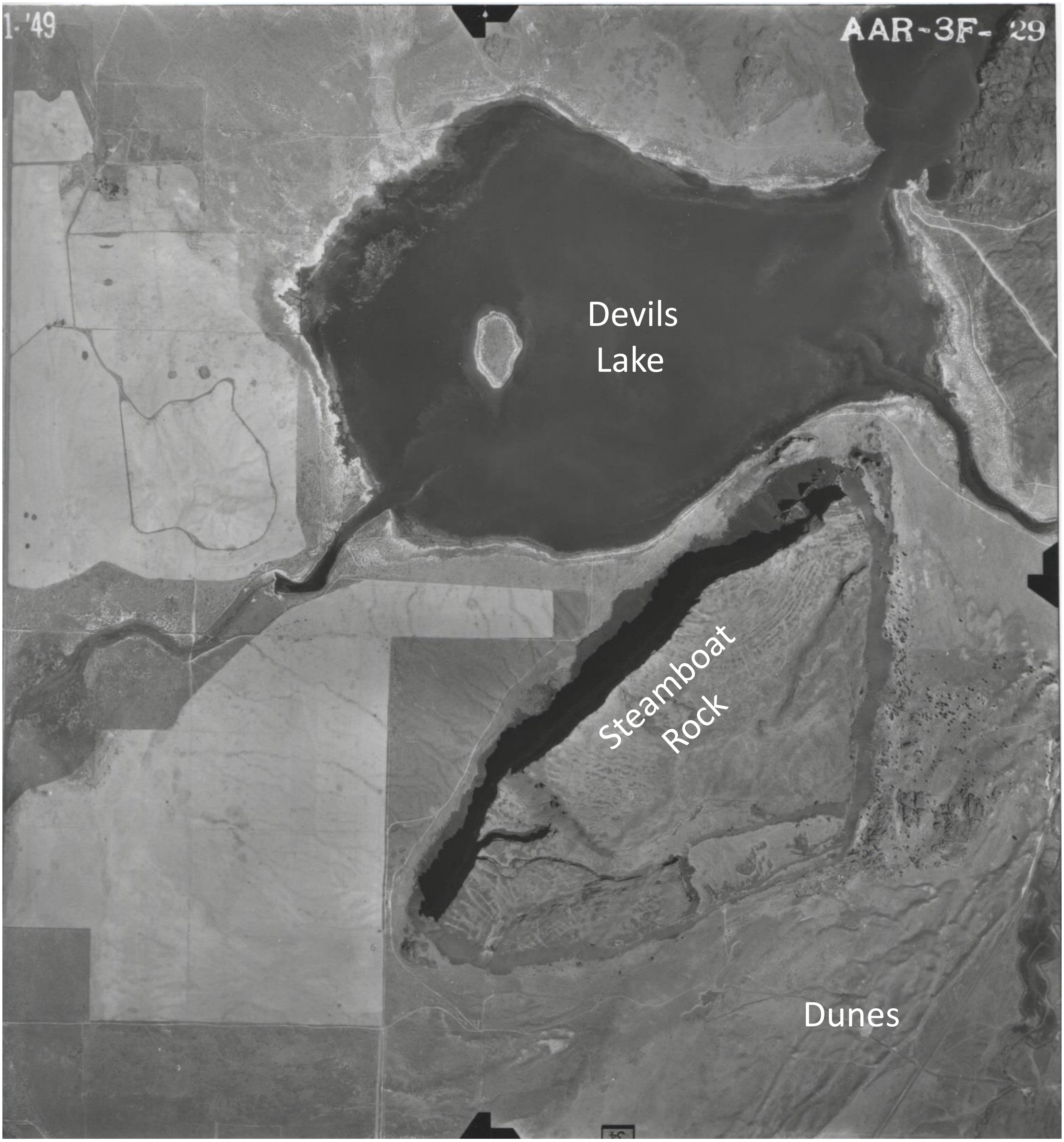


Figure 30. Steamboat Rock, Devils Lake in the Upper Grand Coulee. Note the parabolic dunes to the southeast of Steamboat Rock. Source: USDA –Production and Marketing Adminstration, Grant County, July 1949.

Stop 4—Steamboat Rock

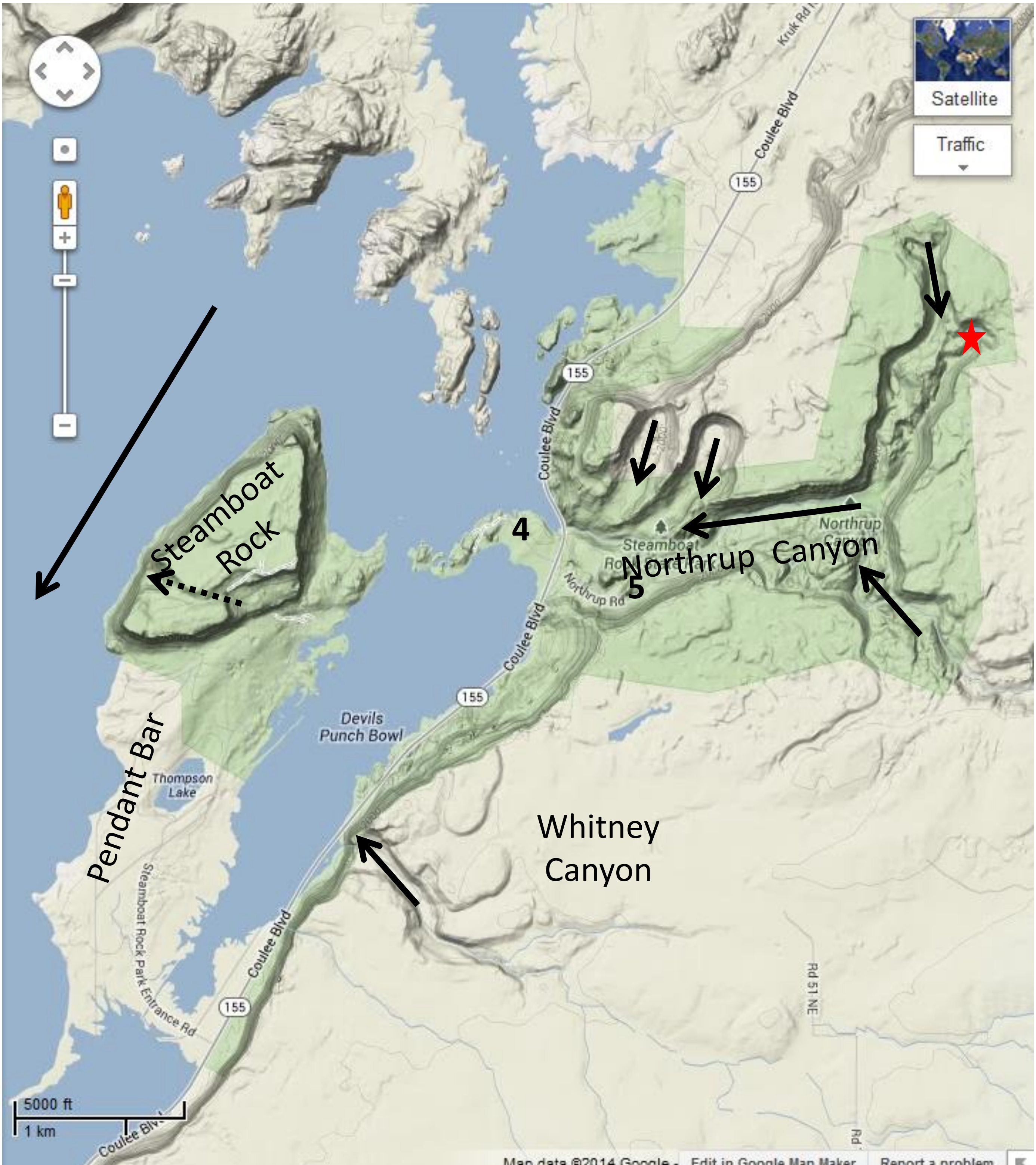


Figure 31. Topography in the vicinity of Steamboat Rock and Northrup Canyon, Upper Grand Coulee. Arrows indicate flood flow directions. Star indicates Northrup Lake. Source: Google Maps.

Stop 4—Steamboat Rock

- **Location:** Our stop is at the Steamboat Rock State Park boat launch east of Steamboat Rock and west of the mouth of Northrup Canyon (Figure 28). This is a lunch , restroom, and information stop.
- **Steamboat Falls & Steamboat Rock:** Steamboat Rock sits about 800 feet above the coulee floor. Its top generally matches the elevation of the coulee walls to the east and west. It is an erosional remnant of a once-continuous cover of Columbia River Basalts. In fact, the area where Steamboat Rock sits could be considered the pre-flood Waterville Plateau. As nearly 5 mile wide Steamboat Falls retreated headwardly, it left behind Steamboat Rock. Eventually, the falls retreated through the drainage divide separating the Upper Grand Coulee from the Columbia River leaving behind the goat island known as Steamboat Rock. J Harlan Bretz (1932) used Niagara Falls and Victoria Falls as current examples of retreating waterfalls to illustrate what happened to create the Upper Grand Coulee and Steamboat Rock. However, the scale of cataract recession in the Upper Grand Coulee is hard to visualize—7 times the width and 5 times the height of Niagara! Once the lowering of the divide occurred, the Upper Grand Coulee became the lowest outlet of the three scabland tracts ; therefore, it became the primary route of the Missoula Floods until they ended.
- **Steamboat Rock Evolution:** We haved added to Crosby and Carson's (1999) steps in the Pleistocene evolution of Steamboat Rock to present a Miocene through present evolution of the setting:

1. *Cretaceous and early Tertiary*
   Intrusion and metamorphism
2. *Mid-Tertiary*
   Erosion
3. *Miocene*
   Flood basalts of the Columbia River Basalt Group
4. *Pleistocene*
   A. Huge jökulhlaups produce large-scale topography
   B. Complete glaciation of summit of Steamboat Rock
   C. Huge jökulhlaups sweep over Steamboat Rock but leave a few erratics from earlier glaciation
   D. Glaciation of the northern third of Steamboat Rock results in moraines
   E. Moderate jökulhlaups surround but do not overtop Steamboat Rock
4. *Late Pleistocene to Holocene*
   A. Dunes form near base of Steamboat Rock
   B. Talus collects due to rockfall from Steamboat Rock
   C. Sackung develops near summit
5. *Late Holocene*
   Manmade dams result in Banks Lake

Stop 4—Steamboat Rock

- **Latest Pleistocene Floods:** The latest Pleistocene floods of Crosby and Carson (1999) may be represented by an exposure in paleolake sediments southwest of Steamboat Rock that reveal s 13 upwardly fining beds. Atwater (1987) interpreted these rhythmites (but not varves!) to be successively smaller (but still significant) floods that passed through the Upper Grand Coulee. These flood deposits are located stratigraphically below the lake sediments seen at Paynes Gulch further supporting the idea that flooding ended decades before Glacial Lake Columbia, hence the Okanogan Lobe, disappeared from the area. The prominent pendant bar on the downstream side of Steamboat Rock may have formed during several of these smaller floods (Figure 31).
- **Drainages into the Upper Grand Coulee**: Horse Lake, Coulee, Foster Coulee, Barker Canyon, Northrup Canyon, and Whitney Canyon all flowed into the Upper Grand Coulee and all likely flowed into Glacial lake Columbia (Figure 24). Prominent fan deltas are still present at the mouths of Horse Lake Coulee, Foster Coulee, and Barker Canyon representing glacial outwash flow into Glacial Lake Columbia.

Stop 5—Northrup Canyon

- Location: From Stop 5, we cross WA 155 and drive up Northrup Road to its gated end. We are standing just above the mouth of Northrup Canyon near the Steamboat Rock State Park parking lot and trailhead (Figure 31).
- **Ecotones**: We are in an *ecotone* where the vegetation communities change from shrub steppe to eastside forest, primarily as a result of increased precipitation and slightly cooler temperatures. Coulee Dam had a mean annual temperature of nearly 50^{o}F and averaged nearly 11 inches of precipitation/year over the 1981-2010 climate normal. Conversely, Ephrata had a nearly 51^{o}F MAT and averaged approximately 8 inches of precipitation/year.
- **Geotones:** This area is a *geotone* because of the change from basalt to intrusive igneous (primarily granite). The granite we see was emplaced in the Eocene (Gulick and Korosec, 1990). We are very near the northern extent of the Columbia River basalts in the area. Note the rounded granite knobs here and how they look so different from the basalts. This difference in appearance is not solely due to color; rather, it is also the result of how the two rocks weather. Abundantly jointed basalts weather along parallel lines preserving cliff faces and leading to rockfall and talus accumulating at the base of those cliffs. Granite knobs weather through the process of *exfoliation*, which proceeds parallel to the exposed surface . This results in onion skin-like slabs of rock being removed from a surface thus forming and ultimately preserving rounded surfaces. Coarse textured granite weathers rapidly leading to coarse parent material for soil development As a result, soils formed from granite are coarse, well-drained, and have a tendency to be droughty.

Stop 5—Northrup Canyon

- **Missoula Flooding in Northup Canyon:** Northrup Canyon consists of former channels that were formed by Missoula Flood waters. They formed from headward recession in the basalts, and to a lesser degree, in the granitics. Evidence for a flood origin of the canyon includes the abrupt, steep ends of two of these channels that head almost at the east wall of the Upper Grand Coulee (Bretz, 1932). Northrup Lake occupies the plunge pool of one of the northern canyons. Large bars in and at the mouth of the canyon also indicate a flood origin.
- **Settlement History in Northrup Canyon:** Northrup Canyon is now part of Steamboat Rock State Park. It was named after the Northrup family, who first settled the canyon in 1889. Over time, John Northrup and his descendants raised a variety of vegetables, fruits, and livestock in the canyon. The main road in the canyon leads to the Northrup farmstead. The road that heads up the talus on the south side of Northrup Canyon is known as the Scheibner Grade, built by the Scheibner brothers for the U.S. Army as a link in the road from Almira to Brewster (Northrup, 2003). The Scheibners lived about midway up the canyon and operated a sawmill and had a small farm in the canyon. A third family, the Sanfords, lived up the southern-most canyon of Northrup Canyon. These homesteaders remind us of the importance of water in this environment—Northrup Creek is one the few perennial streams in the area thus providing water for domestic as well as irrigation and livestock uses. The continued existence of each of the homesteading families depended on Northrup Creek.

Northrup Canyon to Crown Point

- **Route**: From Northrup Canyon, we return to WA 155 and follow it to the junction with WA 174. We follow WA 174 to the Crown Point Vista road. We take the Crown Point Vista Road to its terminus (Figures 2 & 24).
- **Flood Bar Sediments**: Just before reaching WA 155 on Northrup Road, we see a gravel quarry in the bar to our north. Waitt (1994) identified six thick gravel beds in this "composite bar" exposure that each indicate a flood.
- **Glacial Lake Columbia Sediments**: North of Northrup Canyon, we pass through a housing development and an area of agriculture. These land uses sit atop Glacial Lake Columbia sediments like those seen at Paynes Gulch. These pale sediments can be seen in outcrops along the road as well as in their drainage pattern evident from the air.
- **Breached Divide**: At the town of Grand Coulee, we are essentially in the divide that was breached by the retreat of Steamboat Falls (Figure 32). This breach allowed lesser floods more ready access to the Upper Grand Coulee and allowed for a much larger Glacial Lake Columbia that stretched nearly to present-day Coulee City.

Crown Point

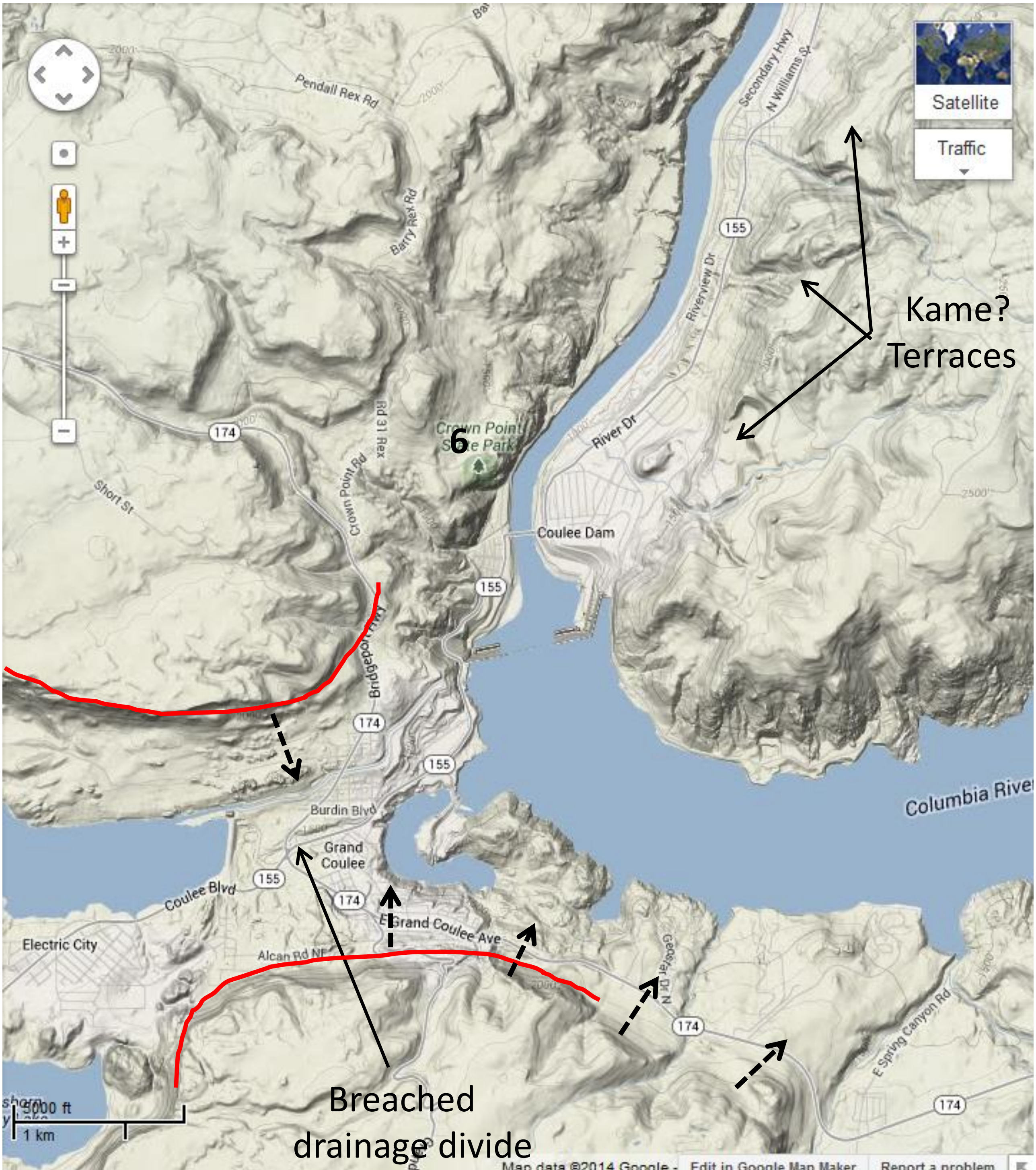


Figure 32. Topography in the vicinity of Grand Coulee, Coulee Dam, and Crown Point. Number indicates field trip stop. Dashed arrows indicate large, old landslides in the Columbia River Basalts. Source: Google Maps.

Stop 6—Crown Point

- **Location**: We are located at the Crown Point Vista above the Columbia River and Grand Coulee Dam (Figure 32). This vista is a large sun dial. Sun shines through a hole in the roof allowing a beam of sunlight to fall onto one of 12 concrete beams.
- **Grand Coulee Dam**: From here, we can see Grand Coulee Dam the lynchpin in the Columbia Basin Irrigation Project and in hydroelectric power generation in the Pacific Northwest. Water from Lake Roosevelt, impounded behind Grand Coulee Dam, is pumped uphill into a canal that feeds Banks Lake (Figure 32). Grand Coulee Dam has a total generating capacity of 6809 mW making it the largest electric power producting facility in the U.S.
- **Okanogan Lobe**: The advance of the Okanogan Lobe resulted in a damming of the Columbia River and a successive development of channels to the south and east. The first channel s to develop were likely Foster Coulee and Horse Lake Coulee, followed by Moses Coulee. The Upper Grand Coulee likely formed last in this sequence. Grand Coulee Dam lies west of the distal position of the Okanogan Lobe of the Cordilleran Icesheet (see Waitt and Thorsen, 1983). Evidence for the Okanogan Lobe includes erratics and possilble *kame terraces* on the hillside across the Columbia River to the east and north of here. *Striations* eroded in the rocks here also indicate the past present of glacial ice.
- **Glacial Lake Columbia**: Like Grand Coulee Dam, the Okanogan Lobe blocked the path of Columbia River causing it to back up to the Spokane area. The resulting lake was nearly 1500 feet deep at its maximum (pre-Grand Coulee breach). Breaching resulting in a new spillway approximately 800 feet lower (Waitt and Thorsen, 1983) (Figure 32). Lake waters apparently did not rise sufficiently high to cause the Okanogan Lobe to “self-dump” as the Purcell Trench Lobe did repeatedly with Glacial Lake Missoula. As a result, Glacial Lake Columbia was a long-lived feature in the late Pleistocene, serving as a long-term repository of ice age flood history. Evidence for 89 catastrophic floods from Glacial Lake Missoula are found in the sediments at Manila Creek, a tributary of the San Poil River upstream of Grand Coulee Dam (Atwater, 1987).
- **Landslides:** From here, we can also see steep escarpments along the basalts to the south and east of the town of Grand Coulee (Figure 32). These escarpments are the head scarps of large landslides that occurred along bedding planes within the basalts and associated interbeds. Most of these features post-date glaciation and Glacial Lake Columbia as indicated by their relatively “fresh” appearance. These slides are the causes of the scalloped nature and the recession of the of basalt walls. Large post-Grand Coulee Dam and –Lake Roosevelt slides have also occurred, more commonly in the Glacial Lake Columbia sediments. These formed with the filling of Lake Roosevelt beginning in the 1930’s and with the seasonal fluctuations of the lake level. Daily fluctuations in releases of Columbia River flow from Grand Coulee Dam has also caused landslides downstream (Jones , Embody and Peterson, 1961).

Crown Point to Dry Falls

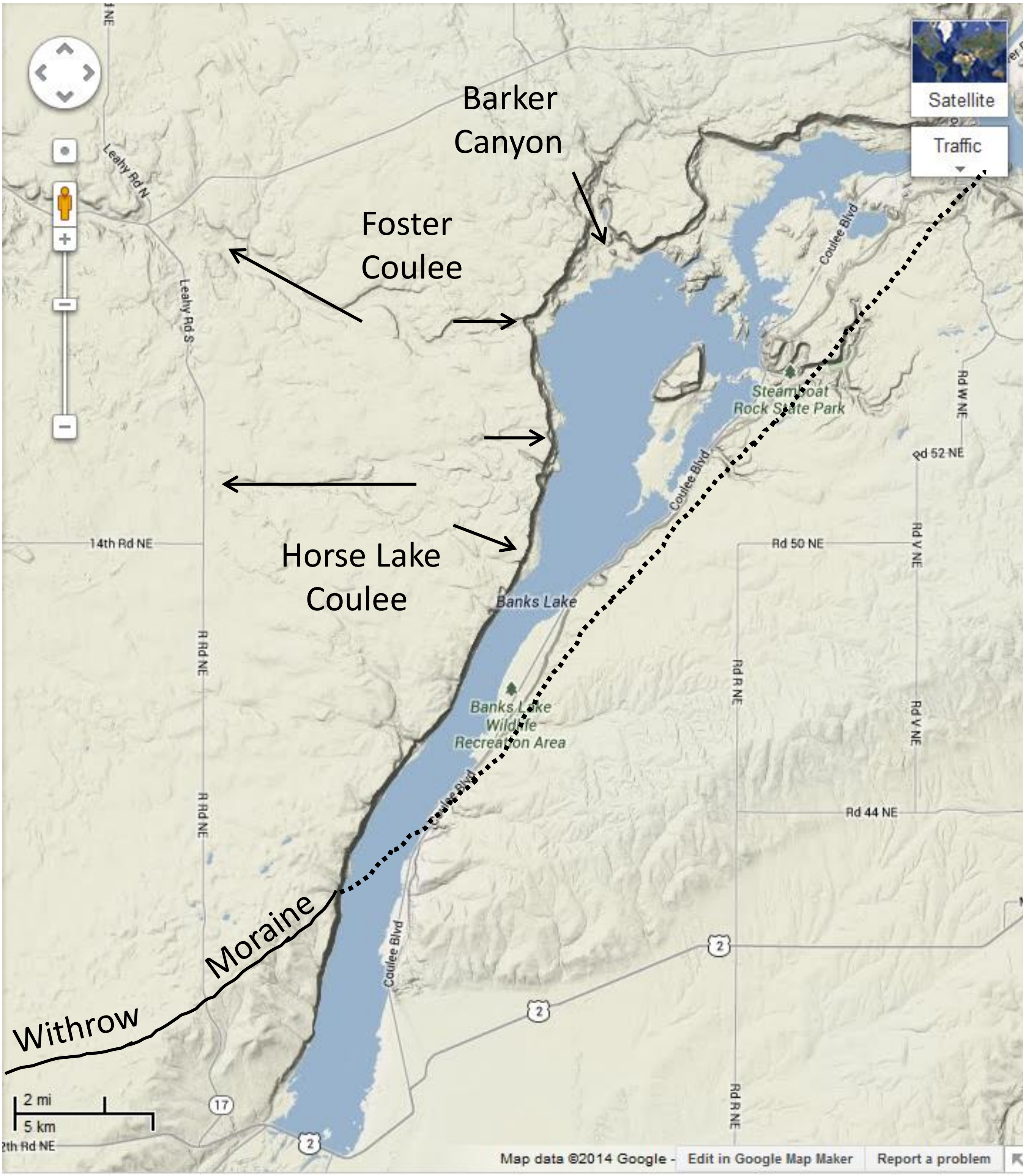


Figure 33. Topography from Crown Point to Dry Falls via the Waterville Plateau. Source: Google Maps.

Crown Point to Dry Falls

- **Route:** Time permitting, we will drive back to Dry Falls over the Waterville Plateau on WA 174 and WA 17 (Figures 2 & 33). If we are running behind our schedule, we will retrace our steps down the Upper Grand Coulee.
- **Flood- & Glacier-Scoured Basalts**: The basalt surfaces traversed by WA 174 are scablands thinly mantled, at best, by post-flood soils. Barker Canyon, a prominent flood channel, is accessed off this road (Figure 33). This surface was also glaciated by the Okanogan Lobe as indicated by the prominent southeast-trending *fluted terrain* that is most evident from the air. The area is littered with erratics (including huge, basalt haystack rocks) and wetland ponds and lakes which are especially common in the spring. Their spring occurrence reflects spring snowmelt and rains, and accumulation in closed depressions created by flooding or glaciation.
- **Glacial Lake Foster**: As we descend into Foster Coulee, we again see pale, bedded sediments in roadcuts. These were deposited in Glacial Lake Foster. This lake (or series of lakes) formed in each of the three branches of Foster Creek likely as the result of the receding Okanogan Lobe blocking off the mouth of the drainage. Lillquist has an optically stimulated luminescence (OSL) date for Glacial Lake Foster sediments south of Leahy Junction that indicate that the Okanogan Lobe had retreated north of here and that a deep proglacial lake had formed by this lake was here ~15,730 +/-1340 years before present. The large WA DOT gravel pit immediately south of WA 174 and just east of Leahy Junction is excavated in a huge fan delta formed where a prominent meltwater stream flowed into Glacial Lake Foster. This is but one of many large fan deltas formed in similar situations in Glacial Lake Foster.
- **Foster Coulee**: At Leahy Junction (Junction of WA 174 and WA 17) in Foster Coulee (Figure 33), we turn south onto WA 17. Foster Coulee is a former channel of the Columbia River/Glacial Lake Columbia as the Okanogan Lobe advanced to the south. Given the lack of large flood bars and hanging valleys in this coulee, it is doubtful that Missoula Floodwaters were diverted down this.
- **Okanogan Lobe**: South of Leahy, we rise above the maximum level of Glacial Lake Foster (~2140 feet) onto an undulating plain primarily shaped by the Okanogan Lobe. Prior to the development of Glacial Lake Foster, glacial meltwater flowed <u>east</u> into Glacial Lake Columbia. While not readily apparent to us as we whiz by in a bus, many of the ~round hills are *kames* and the sinuous ridges *eskers* formed subglacially by glacial meltwater. The numerous ponds in this area are *kettles* formed in glacial drift. South of the former villages of Mold and St. Andrews, we rise onto the crest of the Withrow Moraine, the southernmost extent of the Okanogan Lobe (Figure 33).
- **Missoula Floods:** From the moraine, we descend several miles to the junction of WA 17 and US 2. During this descent, we cross the upper limit of Missoula Flood waters above Dry Falls.

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