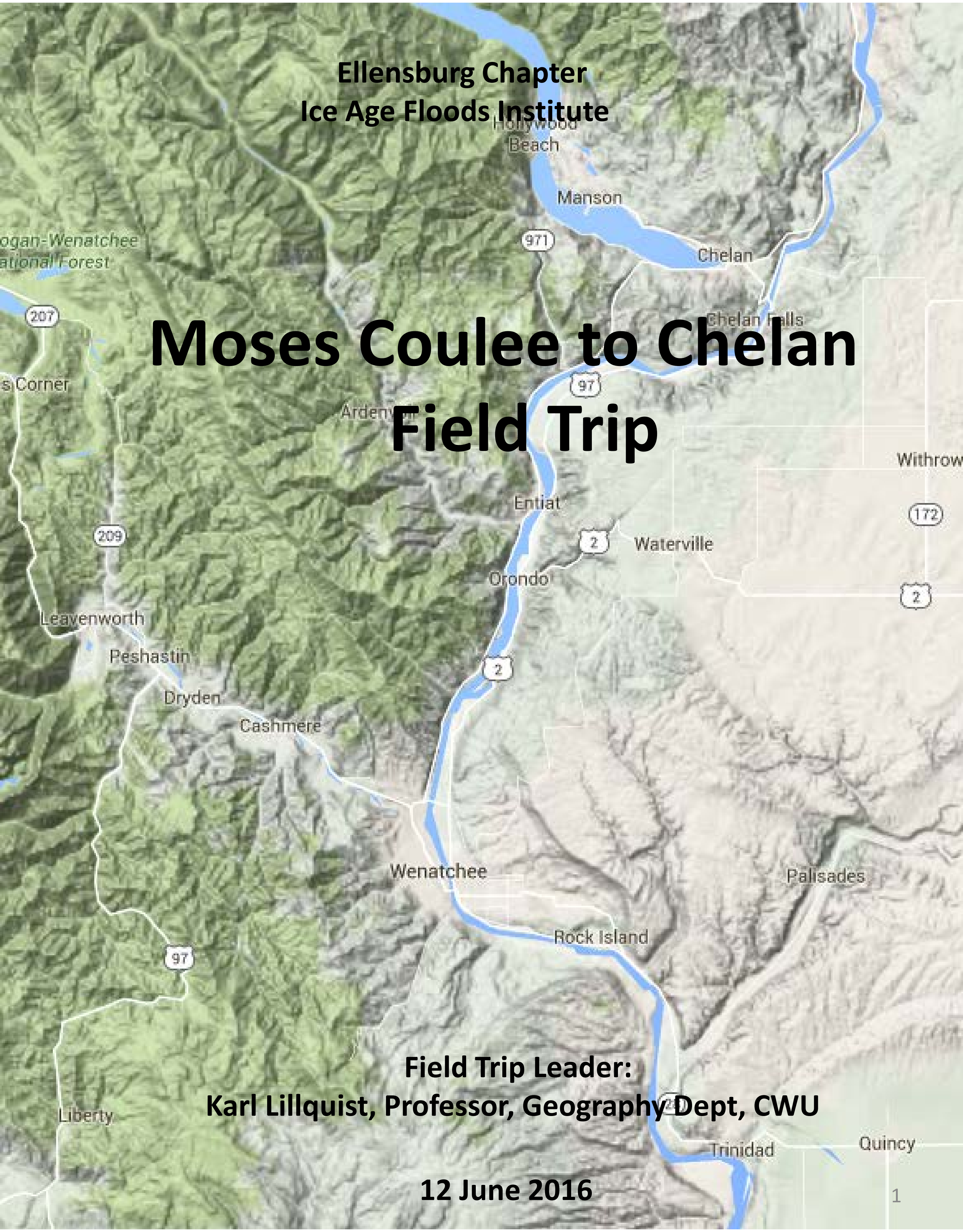
Ellensburg Chapter
Ice Age Floods Institute

# Moses Coulee to Chelan Field Trip




**Field Trip Leader:**
**Karl Lillquist, Professor, Geography Dept, CWU**

**12 June 2016**

# Preliminaries

## Field Trip Overview

The Mid-Columbia River between Moses Coulee and Chelan lies at a key natural boundary. Geology, physiography, climate, and vegetation change dramatically from west to east along this boundary. To the wetter west, lies the coniferous forest-shrouded Cascade Range and associated crystalline rocks of the Swakane and Chelan Mountains terranes. To the east, we see more arid, shrub steppe of the Columbia Plateau and underlying Columbia River Basalts. The northern portion of this area was shaped directly by the late Pleistocene Okanogan Lobe of the Cordilleran Icesheet while ice age floods impacted areas to the south. Our trip will focus on evidence for these intermingled glaciers and floods in this distinctive boundary environment. Stops will focus on key features of the flood and glacial story between Moses Coulee and Chelan.

### Tentative Schedule

| | |
|---|---|
| **9:30 am** | **Depart CWU** |
| **10:30** | **Stop 1—Quincy Valley Rest Area** |
| **10:45** | **Depart** |
| **11:00** | **Stop 2—Moses Coulee Bar** |
| **11:45** | **Depart** |
| **12:15** | **Stop 3—Pangborn Bar** |
| **12:45** | **Depart** |
| **1:30** | **Stop 4—Knapp Coulee** |
| **2:00** | **Depart** |
| **2:15** | **Stop 5—Lake Chelan** |
| **2:45** | **Depart** |
| **3:00** | **Stop 6—Great Terrace** |
| **3:30** | **Depart** |
| **3:45** | **Stop 7—Beebe Springs** |
| **4:30** | **Depart** |
| **6:30** | **Arrive at CWU** |

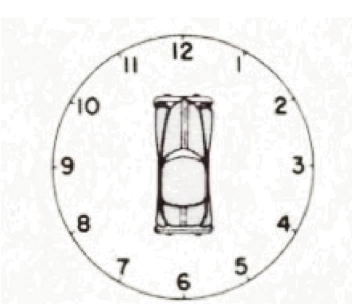



**Figure 1. Relative bearings using a clock. Assume that the bus is always pointed to 12 o'clock. Source: Campbell (1975, p. 1).**

# Our Route & Stops

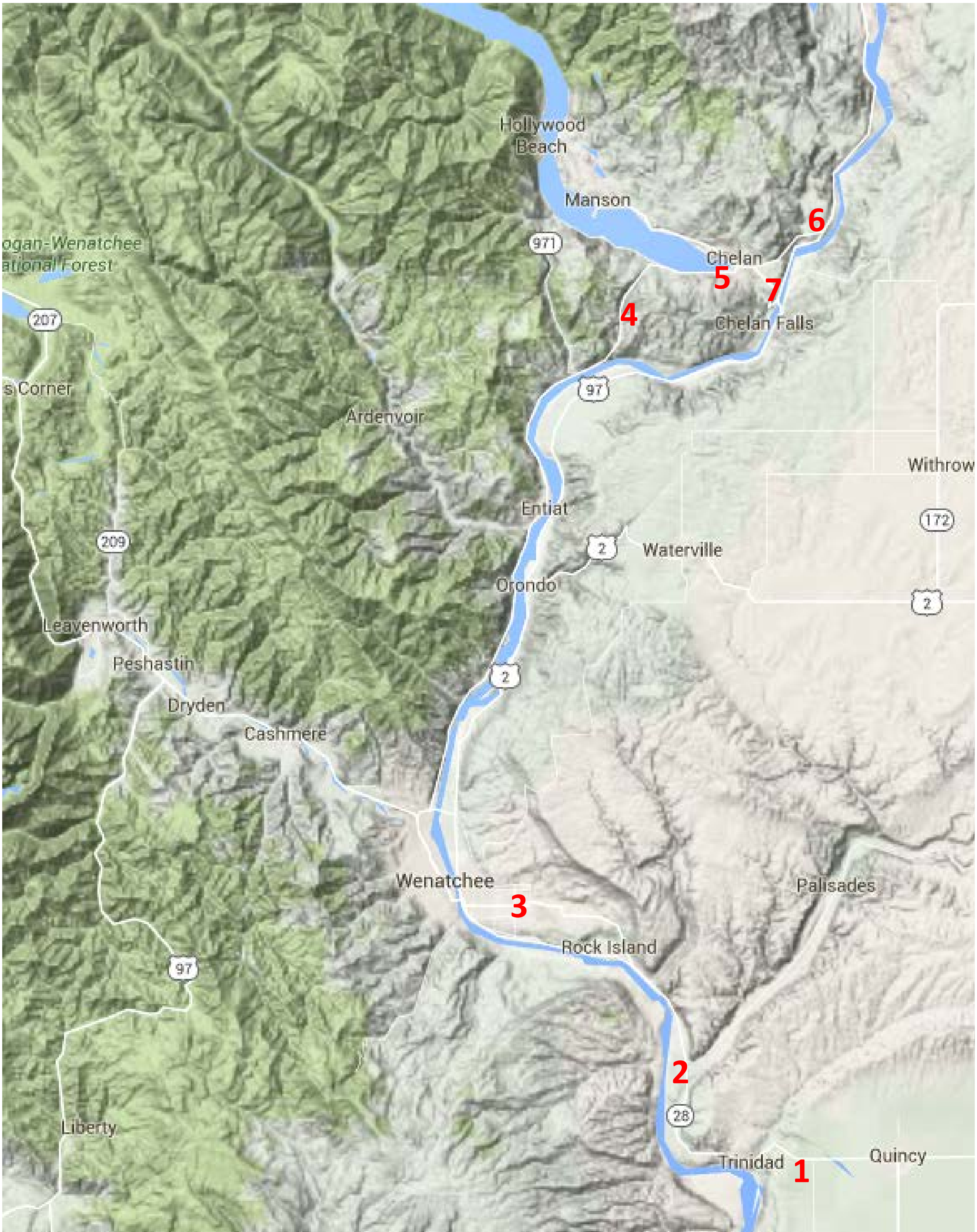





**Figure 2. Route map for field trip. Approximate locations of stops shown with red numbers. Source: Google maps.**

# Ellensburg to Quincy Valley Rest Area

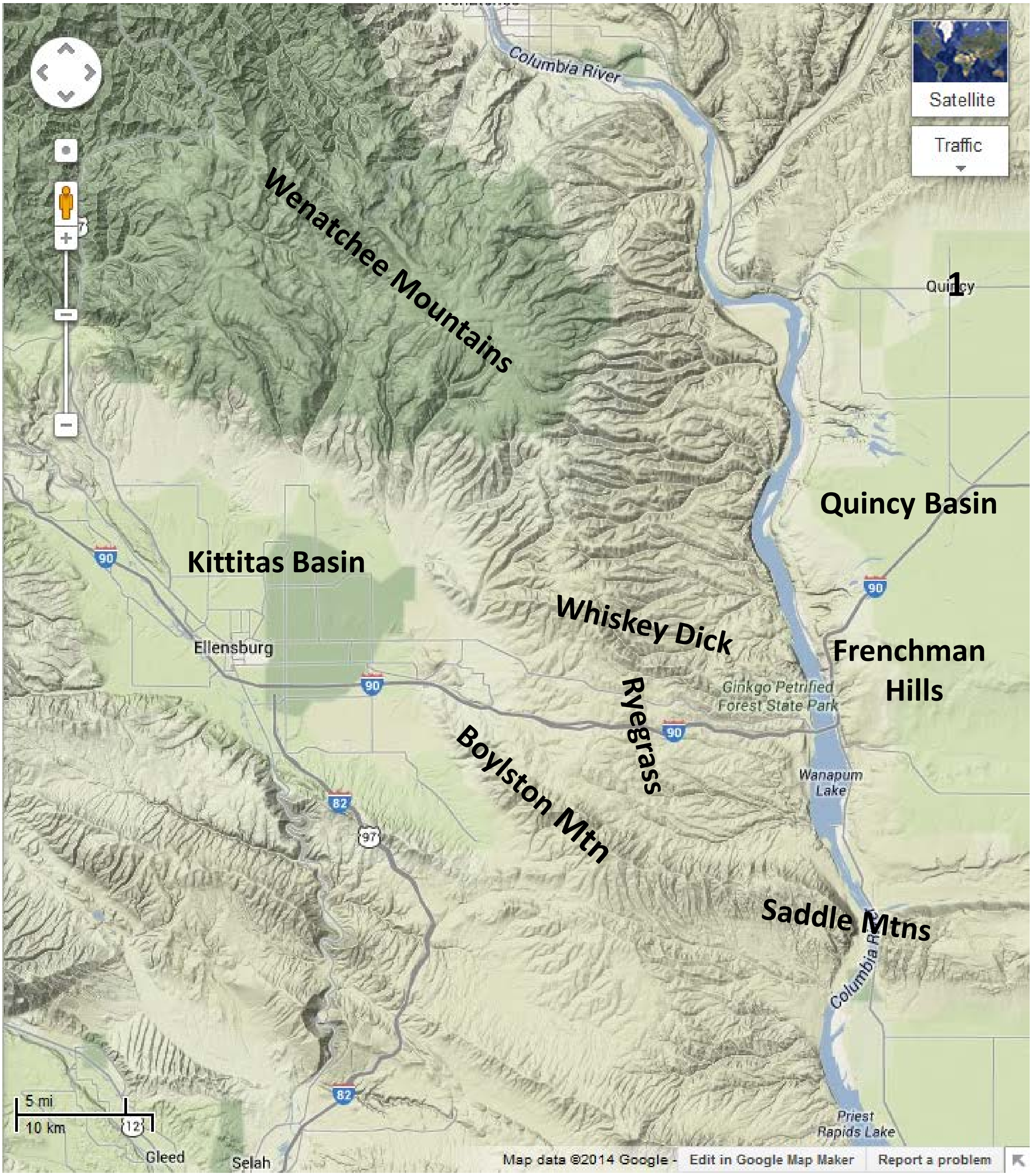



**Figure 3. Topography of the Kittitas Basin area part of our route. Source: Google Maps.**

# Ellensburg to Quincy Valley Rest Area

**Route & Directions:** Our route to Stop 1 takes us from Ellensburg to the Quincy Valley Rest Area in the Quincy Basin via I-90, WA 281, White Trail Road, and WA 28 (Figures 2 & 3). We enter the Quincy Basin essentially where I-90 reaches its high point before descending to the Silica Road exit. We continue east on 1-90 from the Silica Road Exit to George. Take Exit 149 at George, and head north on WA 281 to Quincy. Approximately, 5 miles north of George, turn left (west) onto White Trail Road and follow it west, then north to its intersection with WA 28. Turn left (west) onto WA 28, and travel less than 1 mile to Quincy Valley Rest Area. This is Stop 1.

**Kittitas Basin Lithology & Structure:** Ellensburg lies near the western margins of the Miocene-aged 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 & 7). Mantling the Columbia River Basalts are volcanic sediments of the Ellensburg Formation, *alluvial fan* sediments from streams exiting the surrounding mountains , Yakima River *alluvium,* and windblown *loess*. East of Kittitas we ascend the upfolded Ryegrass *anticline* (Figure 7).

**Kittitas Basin Climate:** 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, fine textured 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 *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 the Wanapum *Basalts* and the Vantage sandstone *interbed* to the resistant Grande Ronde basalts. Several landslides formed with the failure of overlying Wanapum Basalts atop the incompetent Vantage sandstone in the slopes to the right (east). From here, we also have fine views of Channeled Scablands (to your west) that are so indicative of Missoula Flood-ravaged surfaces. Floodwaters entered the Quincy Basin from the northeast and escaped to the south and west (Figure 9).

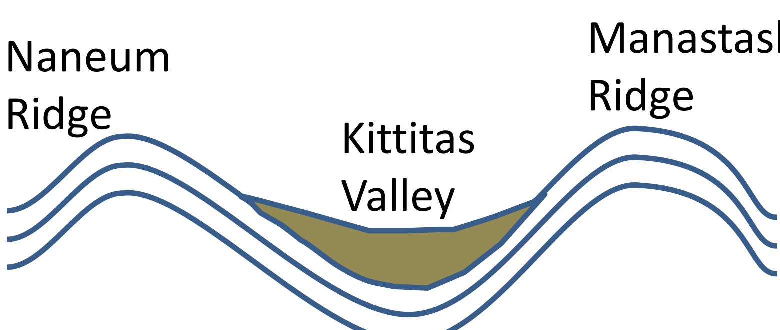



**Figure 4. Location of Kittitas Basin syncline between Naneum Ridge and Manastash Ridge anticlines. Source: Jack Powell.**

# Ellensburg to Quincy Valley Rest Area

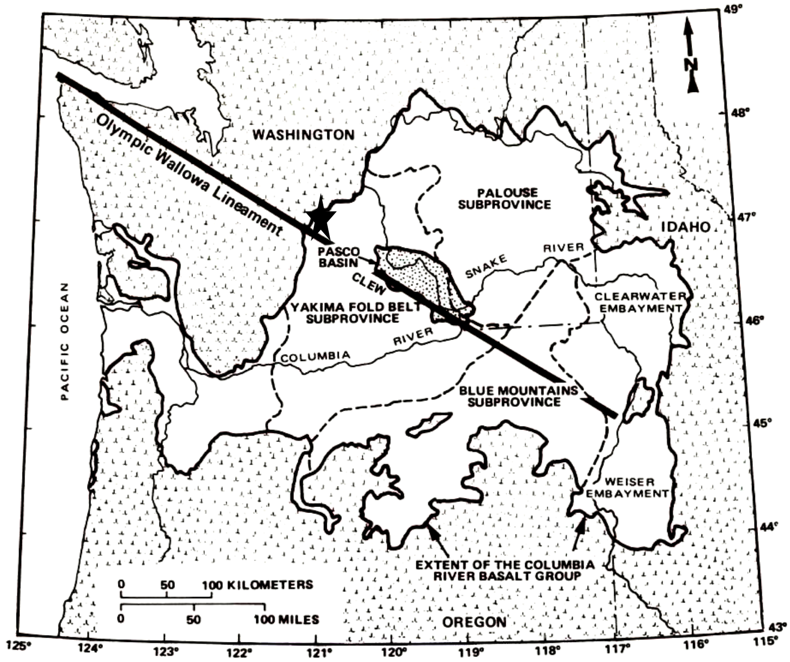



**Figure 5. The Columbia Plateau and the spatial extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Star indicates approximate location of Ellensburg. Source: Reidel & Campbell (1989, p. 281).**

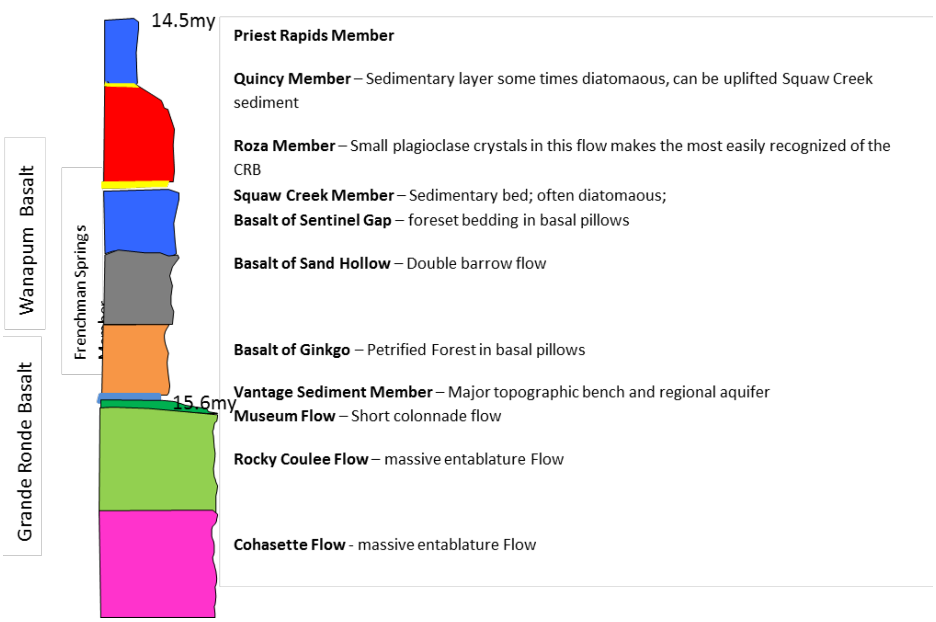



**Figure 6. Stratigraphy of the Columbia River Basalt Group. Source: Jack Powell.**

# Ellensburg to Quincy Valley Rest Area

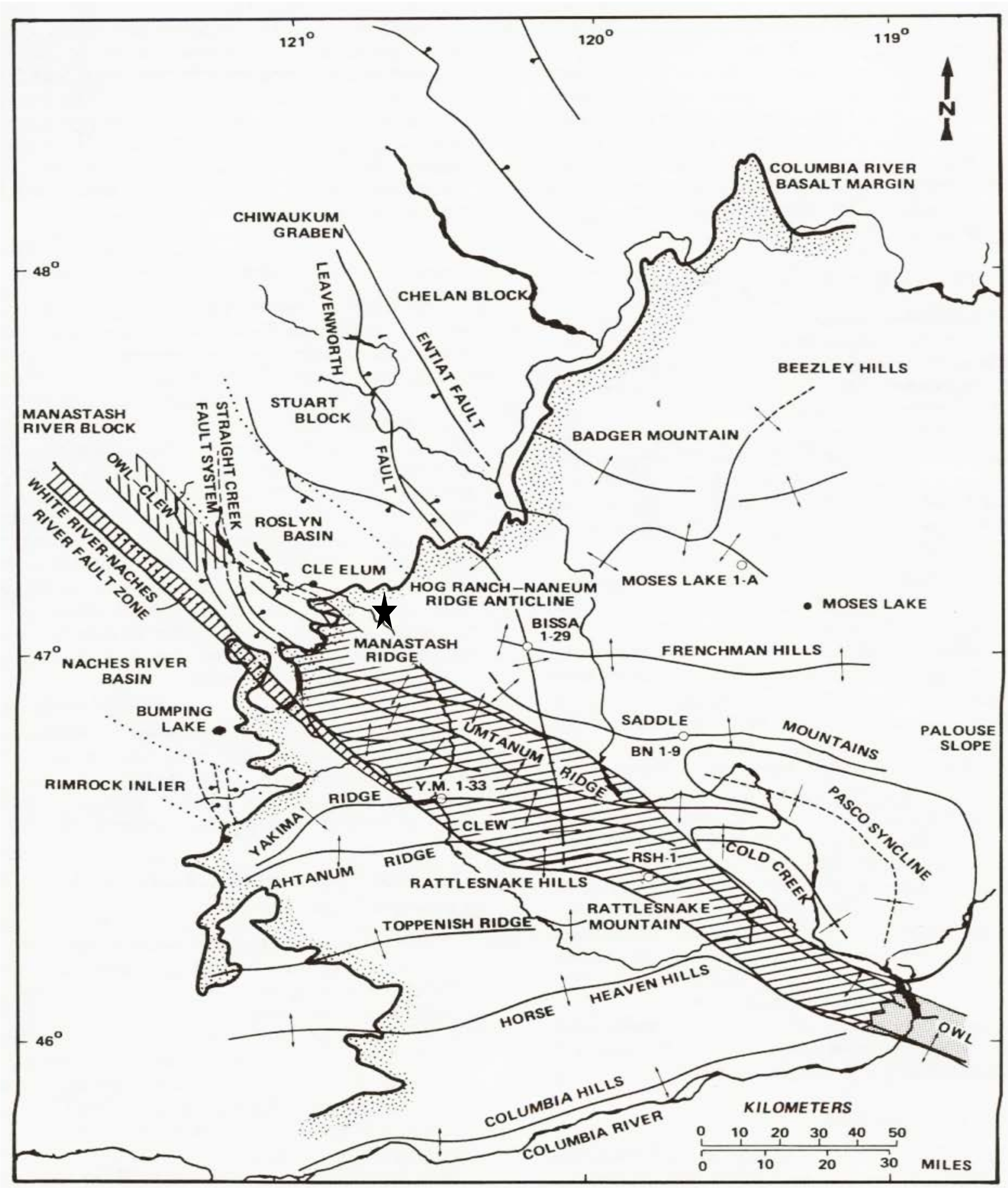



**Figure 7. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Star indicates approximate location of Ellensburg. Source: Reidel & Campbell (1989, p. 281).**

# Ellensburg to Quincy Valley Rest Area Quincy

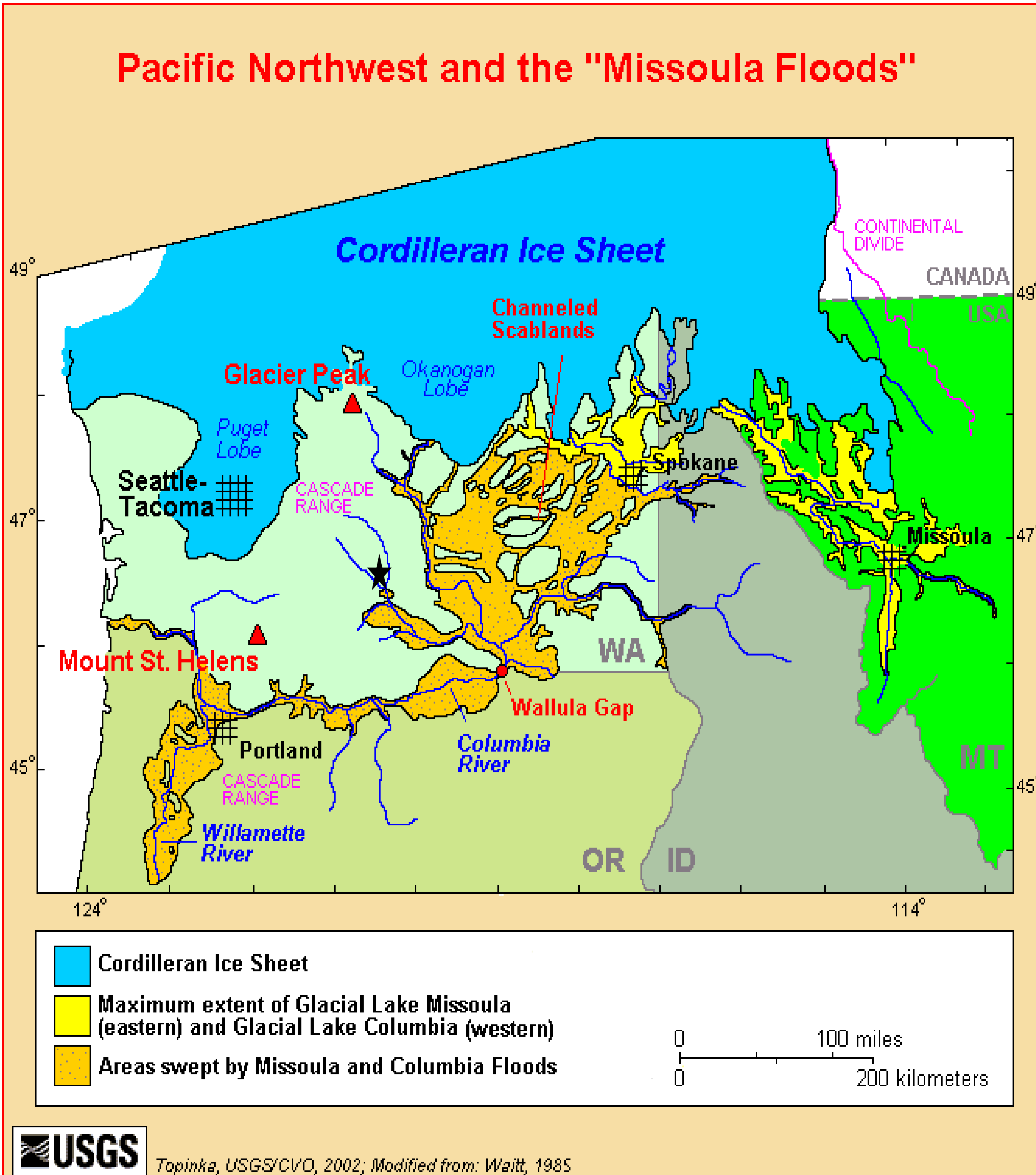



**Figure 8. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Star indicates approximate location of Ellensburg. Source: Cascade Volcano Observatory website.**

# Ellensburg to Quincy Valley Rest Area

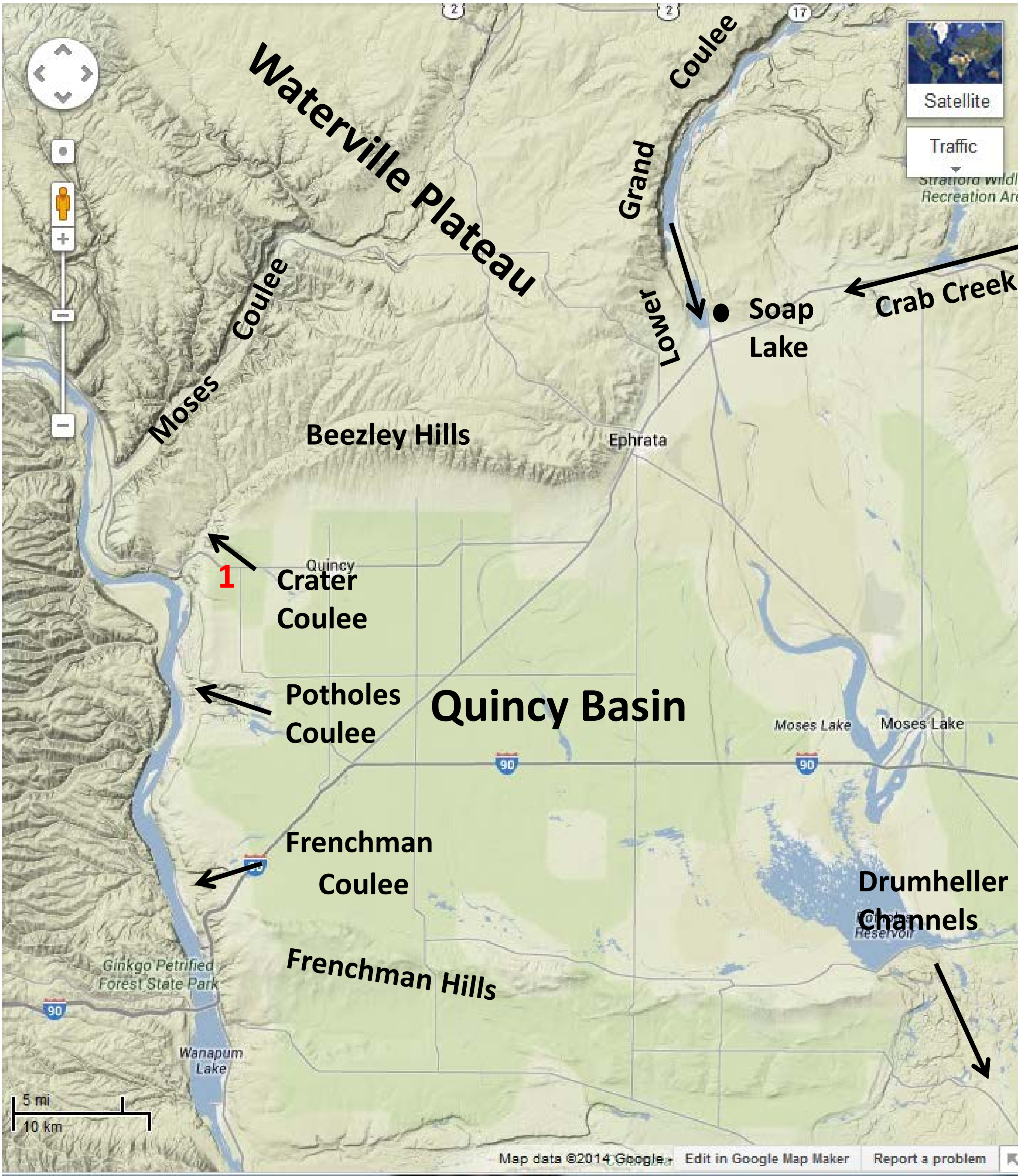



**Figure 9. Topography and significant features of the Quincy Basin. Arrows show direction of flood flows into, and out of, the Quincy Basin. Source of image: Google Maps.**

# Ellensburg to Quincy Valley Rest Area

**Quincy Basin Substrate:** The Quincy Basin is underlain by Grande Ronde and Wanapum basalts (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 surrounding slopes of the basin. The tan soils of the basin are low in organic matter and indicate aridity. In places along White Trail Road, you will see white rock-like material in roadcuts. This is *caliche*, a calcium carbonate soil layer, that accumulated in the soil over time. It tells us that soils pre-dating the late *Pleistocene* floods are still present in places in the basin.

**Quincy Basin Area Geologic Structure:** The Frenchman Hills and Beezley Hills (Figure 9) are anticlines on the northwestern part of the Yakima Fold and Thrust Belt (Figure 7) that bound the southern and northern margins of the Quincy Basin. These anticlines guided floodwaters entering the basin from the northeast and east.

**Quincy Basin Cover Sand and Topography:** Windblown sand originating from the Columbia River and from wind reworking of distal Missoula Flood deposits covers much of the basin floor. 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. Where measureable relief exists in the western Quincy Basin, it is often shaped by underlying Missoula Flood erosional or depositional forms.

**Columbia Basin Irrigation Project:** The Quincy Basin is a vastly different place now than in 1952. Prior to that time, it was a dry, sand-covered basin characterized by ranching and meager attempts at dryland and small-scale irrigated farming. Columbia River water was first delivered to the area from Lake Roosevelt (behind Grand Coulee Dam) via Banks Lake and a series of canals and siphons in 1952. Now the Columbia Basin Irrigation Project boasts over 60 different crops. Our route from near Silica Road to the Quincy Valley Rest Area takes us through a variety of crops.

# Stop 1—Quincy Valley Rest Area

**Location:** We are located in Quincy's East Park.

**Restrooms:** This is our only official bathroom stop until this afternoon. We will also use this as a meeting place for field trippers joining us from the Wenatchee and Moses Lake areas.

# Quincy Valley Rest Area to Moses Coulee

**Route:** From the rest area, turn left (west) onto WA 28. Follow WA 28 for approximately 9 miles to the mouth of Moses Coulee (Figure 10). Turn left (west) onto Nelson Siding Road. Follow this paved road for less than 0.25 mile, then turn right (west) onto Columbia Siding Road. Follow this good gravel road for approximately 0.5 mile. Park along the side of the road making sure to leave enough room for vehicles to safely pass. We will walk a short distance to the overlook and outcrop.

**Wenatchee Mountains**: The Wenatchee Mountains are the ridge on skyline to our west. These mountains are the most prominent of the anticlines of the Yakima Fold Belt. This prominent ridge diverted the Columbia River from its basalt-margin location seen north of Wenatchee to its cross-basalt path to the south (Waitt, 1977).

**Quincy Basin Outlets**: WA 28 descends toward the Columbia River between two of the three key, Western Quincy Basin outlets of the Missoula Floods—Crater Coulee to the north and Potholes Coulee to the south (Figure 9). Potholes Coulee is a double cataract that is 1.4 miles wide and 380 feet, both dimensions comparable to the better known and more visited Dry Falls at the head of the Lower Grand Coulee.

**Flood Bars:** WA 28 takes us over Trinidad Bar. This huge *eddy bar* formed as floodwaters descended the Columbia River Valley, rounded the large bend to the west, and eddied back to the north (Waitt and others (2009). This bar is 2 miles long, stretching up Lynch Coulee to near Crater Coulee's mouth, and is composed of more than 300 feet of sand and gravel. Approximately 19 separate floods are recorded in the rhythmic sediment units of the bar. Mount St. Helens S tephra dated at ~13,500 $^{14}$C yr BP (~15,500 calendar years) is found midway down through the stack of *rhythmites* giving us a sense of the age of the flooding (Waitt and others, 2009). West Bar lies across the river and ~100-200 feet below us. It is a giant *crescent bar* (some would say *point bar*) formed on the inside of the channel where velocities were lower. *Giant current dunes* (i.e., ripples) cover the surface of the bar, and are so large they are visible from the window of a commercial aircraft. Dune wavelengths average ~360 feet while heights average ~24 feet (Bjornstad and others, 2007). Bretz used giant current dunes as a key piece of his evidence of huge floods rather than uniform flow shaping the landscape. The lower elevation of West Bar compared to Trinidad Bar suggests that West Bar is the younger of the two features (Bretz, 1930). The bar itself likely formed from Missoula Floods. The size, shape, orientation, and location of the giant current ripples indicate that they formed in one of the last ice age floods to descend the Columbia River Valley. However, the source was probably not from Glacial Lake Missoula; rather, it was likely from the breakup of the Okanogan Lobe and the release of Glacial Lake Columbia (Bretz, 1969; Waitt, 1994) and/or from floods from Glacial Lake Kootenay (Waitt and others, 2009).

**Railroads**: We have been following the route of the Burlington Northern-Santa Fe rail line from the Quincy Basin. This route was originally constructed for James J. Hill's Great Northern on the "Empire Builder" route. Because of the elevation difference between the Quincy Basin and the Columbia River, the railroad maintains its gentle grade with a tunnel and a very large switch back into the mouth of Lynch Coulee.

**Coulees**: In this part of the world, *coulees* are typically steep sided, flat floored valleys eroded in basalts. Ridges are often truncated by coulees and tributary valleys are left "hanging" on their margins. They are often fairly straight in planimetric (i.e., overhead) view. Note how well Moses Coulee fits this description as we cross its mouth.

# Quincy Basin to Moses Coulee

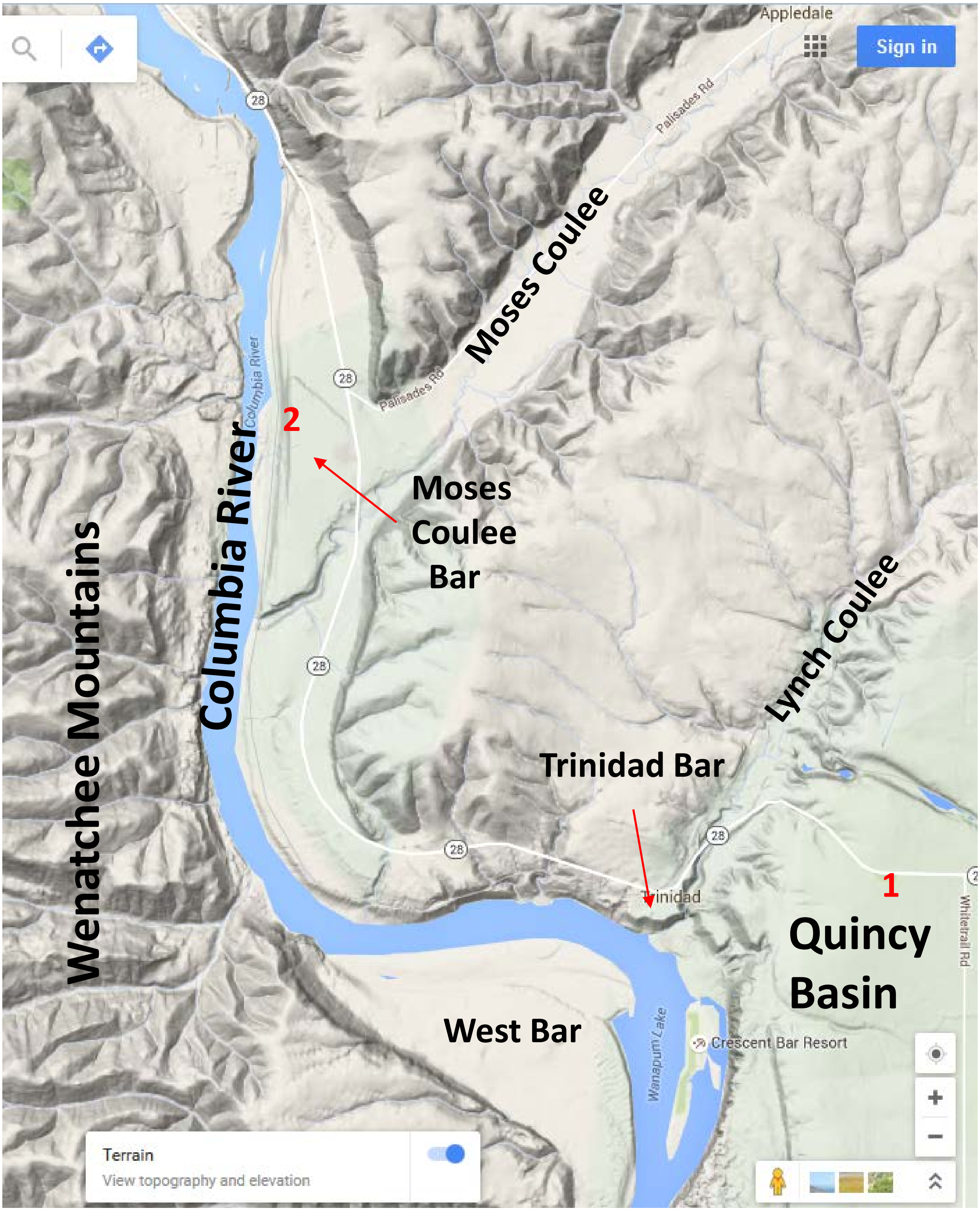



**Figure 10. Topography and significant features of the route from the Quincy Basin to the mouth of Moses Coulee. Red numbers indicate field trip stops. Source of image: Google Maps.**

# Stop 1—Moses Coulee Bar

**Location:** We are standing on the riverward edge of the Moses Coulee Bar on Columbia Siding Road.

**Pre-Flood Douglas Creek:** Prior to catastrophic flooding (see below), the shallow, gentle-sided, southwest-trending stream valley of Douglas Creek flowed from the Waterville Plateau to the Columbia River near here. This is indicated by the presence of tributary valleys that hang on the walls of present-day Moses Coulee (Figure 11) (Bretz, 1923a; Hanson, 1970).

**Moses Coulee**. At its mouth, Moses Coulee is approximately 0.8 mile wide and 700-800 feet deep. It is so impressive that Bretz (1928) described it as one of the four main scabland tracts in eastern Washington (along with Grand Coulee, Crab Creek-Telford, and Cheney-Palouse). Moses Coulee has been described as having three segments (Bretz, 1923b) subsequently described as the upper, middle, and lower coulee (Hanson, 1970). Our stop is just beyond the lowermost portion of the lower coulee. The lower coulee abruptly ends and the middle coulee begins ~16 miles upstream at the triple cataract of Rattlesnake Springs. Moses Coulee differs from many other scabland coulees in that its head is hardly identifiable. One drives across this very subtle feature when travelling between Sims Corner and Mansfield on WA 172 (Figure 12).

**Origin of Moses Coulee**: Moses Coulee formed when the Okanogan Lobe of the Cordilleran Icesheet advanced south to block the Columbia River Valley (Figure 13) near present-day Grand Coulee dam. This blockage created Glacial Lake Columbia whose waters were diverted over what is now the Waterville Plateau forming the "Mansfield Channels" and coalescing into McCartney Creek. Missoula floodwaters that rushed into Glacial Lake Columbia were also diverted down this route. The combination of Glacial Lake Columbia waters and Missoula floodwaters eroded Moses Coulee. Floodwaters racing down the McCartney Creek Valley merged with the relatively meager flow from Douglas Creek to reach the Columbia River Valley. These flows downcut and also *headwardly eroded* upstream (Bretz, 1923b). Based on Manning equation calculations, flood velocities likely approached 50 mph at the height of flooding in the coulee (Hanson, 1970)!

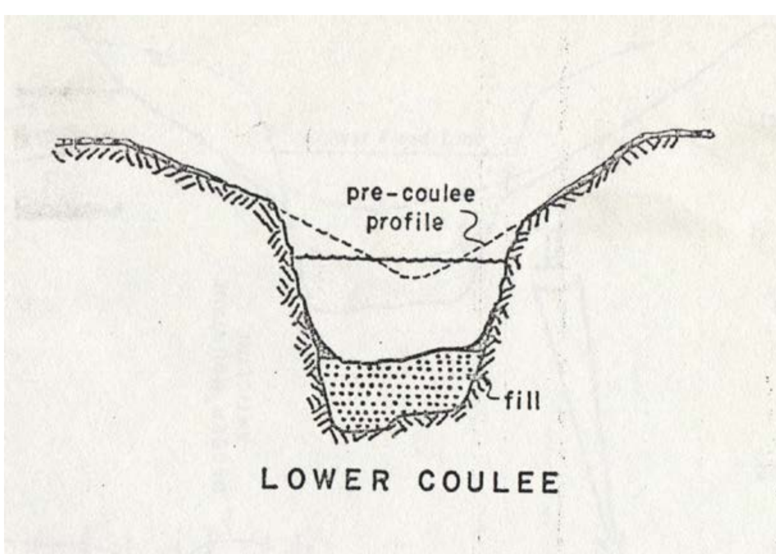



**Figure 11. Pre-coulee and coulee profiles, lower coulee of Moses Coulee. Source: Hanson (1970, p. 122).**

# Stop 1—Moses Coulee Bar

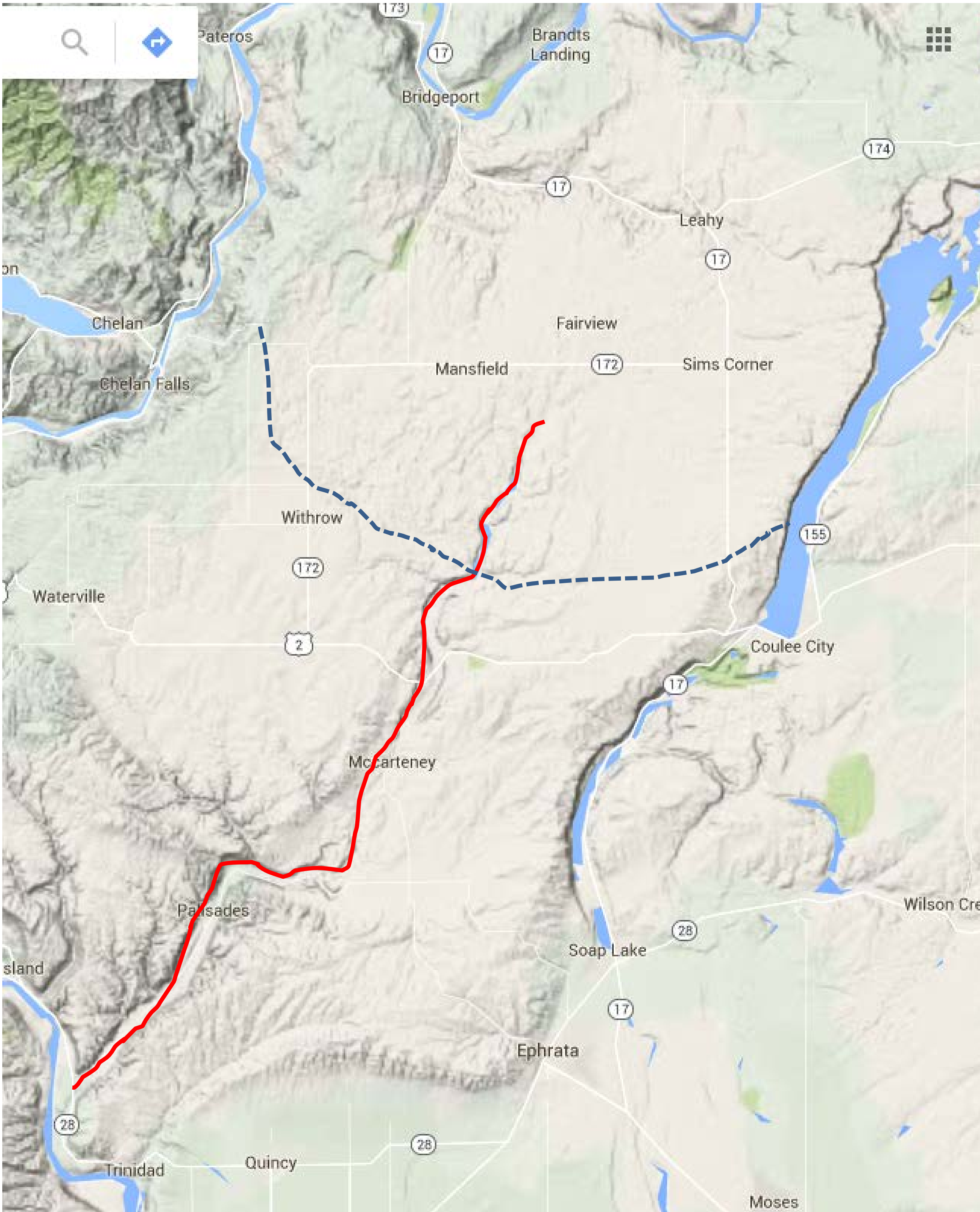



**Figure 12. Moses Coulee, Washington on the Waterville Plateau. Solid red line indicates extent of Moses Coulee. Dashed blue line indicates approximate location of Withrow Moraine. Source of image: Google Maps.**

# Stop 1—Moses Coulee Bar

**Age of Moses Coulee:** Because the end moraine of the Okanogan Lobe crosses Moses Coulee just south of Jamison Lake, we can safely say that Moses Coulee formed prior to the maximum advance of the Okanogan Lobe. However, beyond that, its age is not clear. Bretz (1923b, 1956, 1959), based on the amount and degree of weathering of talus in the Moses Coulee, thought that it formed before the last glaciation. In more detailed work throughout the coulee, Hanson's (1970) work suggests that Moses Coulee formed in the late Pleistocene just prior to the advance of the Okanogan Lobe fully onto the Waterville Plateau.

**Flood bars**: A massive bar developed at the mouth of Moses Coulee. This deposit formed sub-fluvially (i.e., at the base of the flood flow) as velocity decreased. 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 14): 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 flood bars such as this are one of the pieces of evidence Bretz used to argue for a catastrophic flood origin for the channeled scablands.

**Moses Coulee Bar**. This is an 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 15). 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 is seen 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 of a 90-99% basalt composition. Crystalline rocks typically form >50% of Columbia River sediments. At this site you can see the <u>huge</u> basalt boulders scattered around the bar surface (Figure 16). You can also see the subrounded, large basalt boulders that compose the interior of the bar at the gravel pit here (Figure 16). 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, p. 70). You can see these deposits to the right of WA 28 on the north end of the bar. Hanson (1970) and Waitt (1977) tentatively linked these silts with rhythmites in the lower Wenatchee River Valley (Porter, 1969).

**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 17). These asymmetric features indicate formation by floods <u>descending</u> the Columbia River Valley. Waitt (1977, 1980; Waitt and others, 2009) interpreted this as evidence of one or more floods from Glacial lake Columbia descending the Columbia River Valley <u>after</u> 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 15). Columbia River Flood(s) also created a large, low gradient bar on the downstream side of the Moses Coulee Bar (Waitt, 1977).

# Stop 1—Moses Coulee Bar

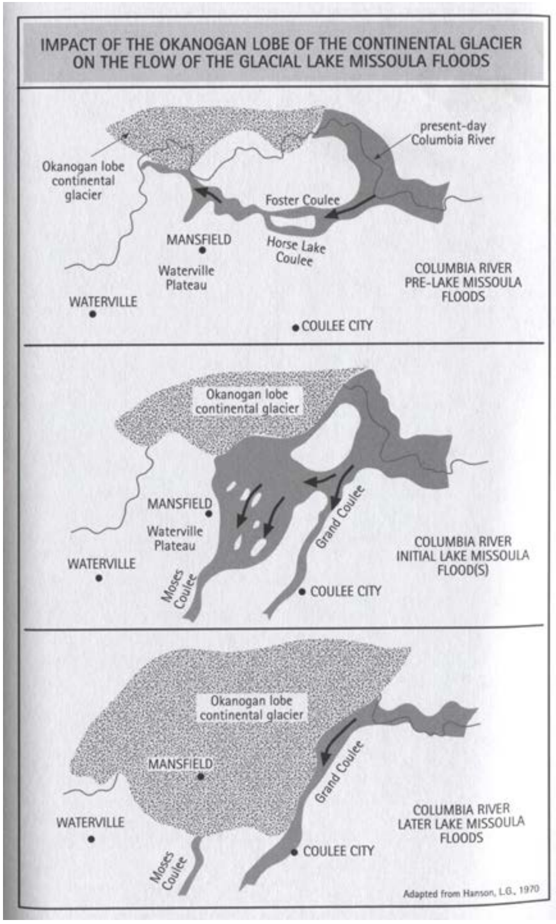



**Figure 13. The sequential development of flood channels on and adjacent to the Waterville Plateau. Source: Mueller and Mueller, 1997, p. 143 who redrafted figure from Hanson (1970).**

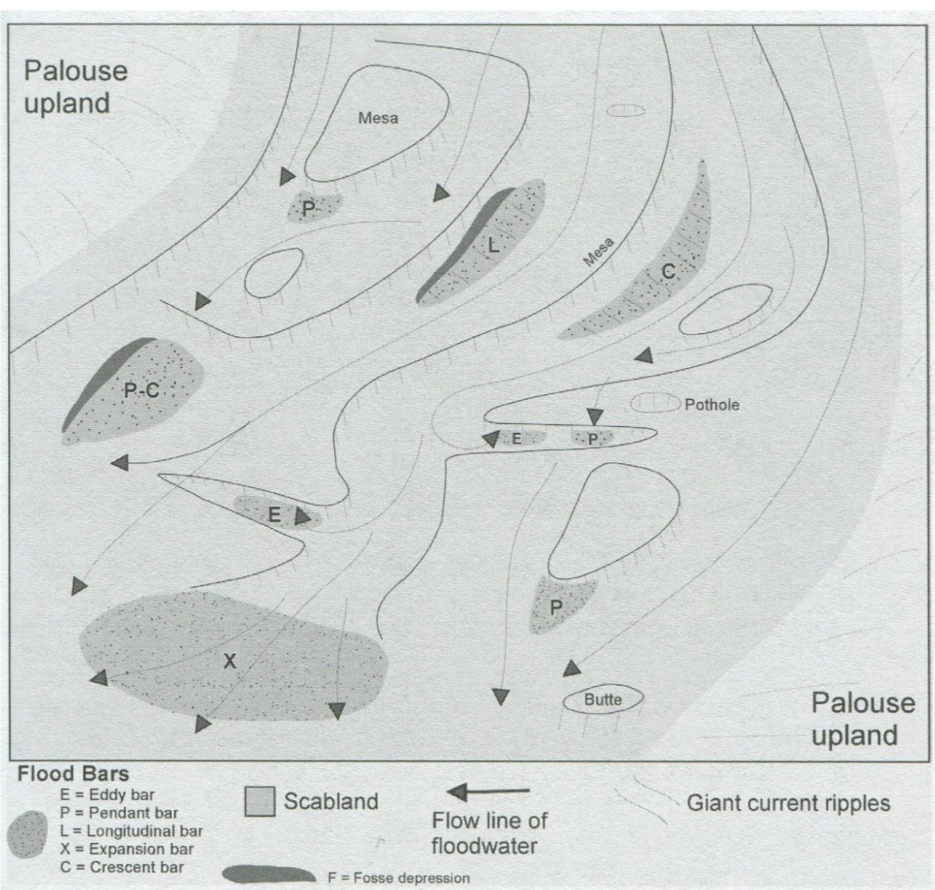



**Figure 14. Types of flood bars. From Bjornstad and Kiver (2012, p. 51).**

# Stop 1—Moses Coulee Bar

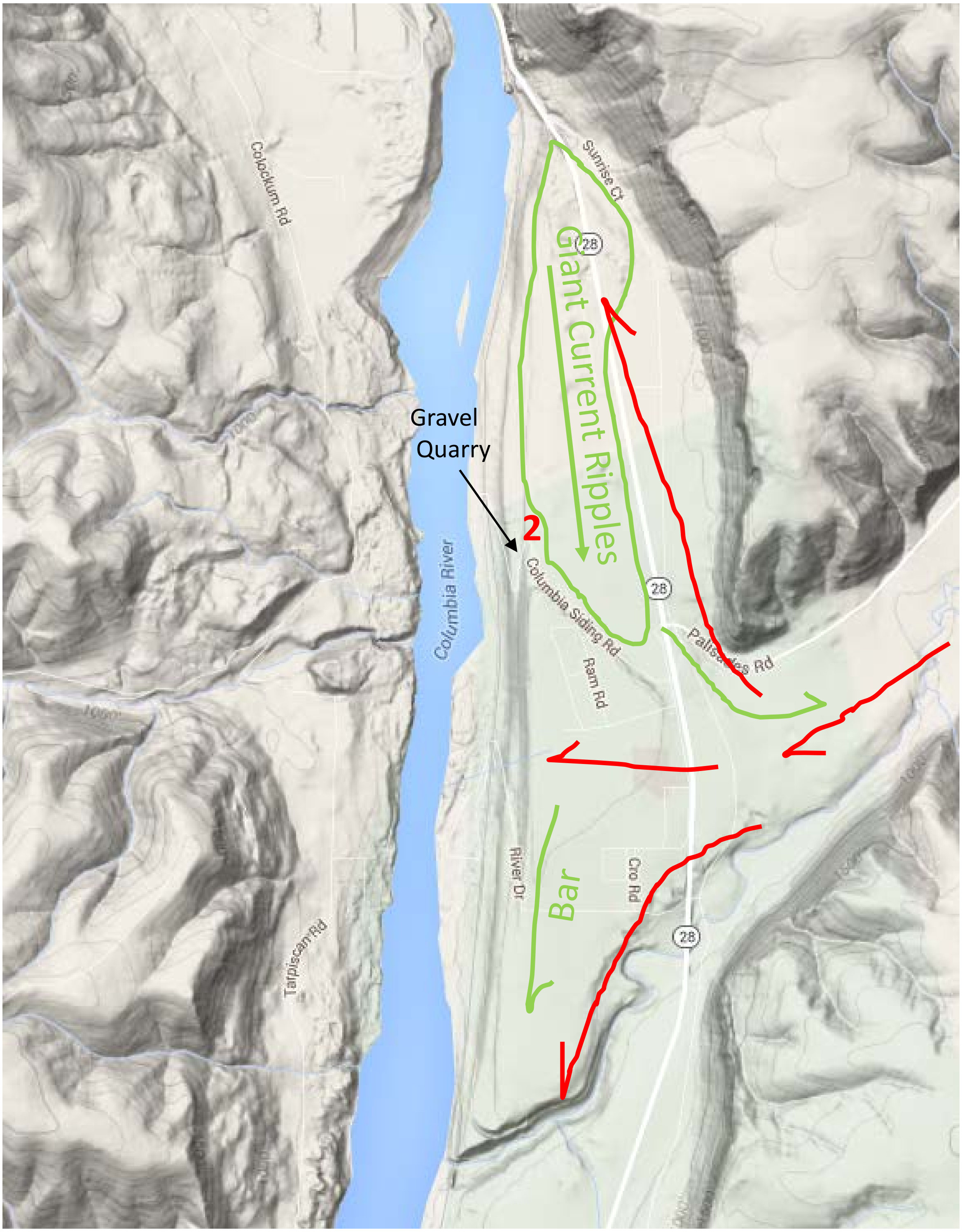



**Figure 15. Part of the Moses Coulee bar. Original bar extended off map upstream (north) and downstream(south). Red arrows indicate initial Moses Coulee flows that created bar. Green arrows indicate subsequent Columbia River Valley floods that reshaped bar. Approximate extent of giant current ripples outlined in green. Source: Google Maps.**

# Stop 1—Moses Coulee Bar

**Figure 16. Basalt boulders on surface and in interior of Moses Coulee Bar in gravel quarry shown on Figures 15 & 17. Source: author.**


**Figure 17. Area of giant current ripples on surface of Moses Coulee Bar. Number indicates field trip stop. Red outline is area of giant current ripples. Arrow indicates the Columbia River Valley source that created them. Source: Google Earth.**

# Moses Coulee to Pangborn Bar

**Route:** From Stop 1, turn around and return to WA 28. Turn left and head north on WA 28. Approximately 1.5 miles north of Rock Island Dam, turn right (north) onto Battermann Road. Follow this road north and west as it changes to 4th Street SE, Vanwell Street, and Grant Road. Just West of Pangborn Field, turn left (south) from Grant Road onto South Union Avenue. Follow this road south approximately 0.75 mile to 5th Street Southeast. Turn left (east) onto 5th Street Southeast and follow it around the Coca-Cola Bottling Company. Because there should be little if any traffic here today, we will park in the right lane of this quiet street near where it joins back with South Union Avenue (Figure 19).

**Rock Island Bar**: Rock Island Bar is visible on the opposite side of the river. Like the Moses Coulee Bar, its surface is covered with giant current ripples that indicate they were created by flood flows descending the Columbia River Valley.

**Rock Island Rapids & Dam**: Prior to 1933, a prominent set of rapids were present here on the Columbia River. Rock Island Rapids were serious impediments to river travel (Figure 18). The *City of Ellensburgh* and her sister ship the *Thomas L. Nixon* were the first sternwheelers to pass through Rock Island Rapids. Legendary sternwheeler captain William Gray piloted the *City of Ellensburgh* on this maiden enroute from Pasco to Wenatchee in the 1880's. These sternwheelers worked the Columbia River between Wenatchee and the mouth of the Okanogan River for many years. Other sternwheelers followed them until the Great Northern ran a branch line from Wenatchee upriver to Oroville. Rock Island was the first dam to completely span the Columbia River. The first stage of Rock Island Dam was completed in 1933. Power generation was increased in the early 1950's and again in the late 1970's.

**Landslides**: A huge slide from Jump Off Joe Ridge west of the river (Figure 19) may have blocked the Columbia upstream of Rock Island Rapids as evidenced by blocks of basalt on the east side of the river. Because the landslide deposits lie beneath flood-deposited bars, the slide occurred prior to catastrophic flooding (Waitt, 1977). This cumulative slide area is nearly 30 mi$^2$! The proximity of these large landslides to high flood evidence suggests that saturated conditions caused by catastrophic flooding may have caused the landslides (Porter, 1969).


**Figure 18. Rock Island Rapids in 1925. View downriver. Moses Coulee Bar in the background. Source: Spokane Public Library.**

# Moses Coulee to Pangborn Bar

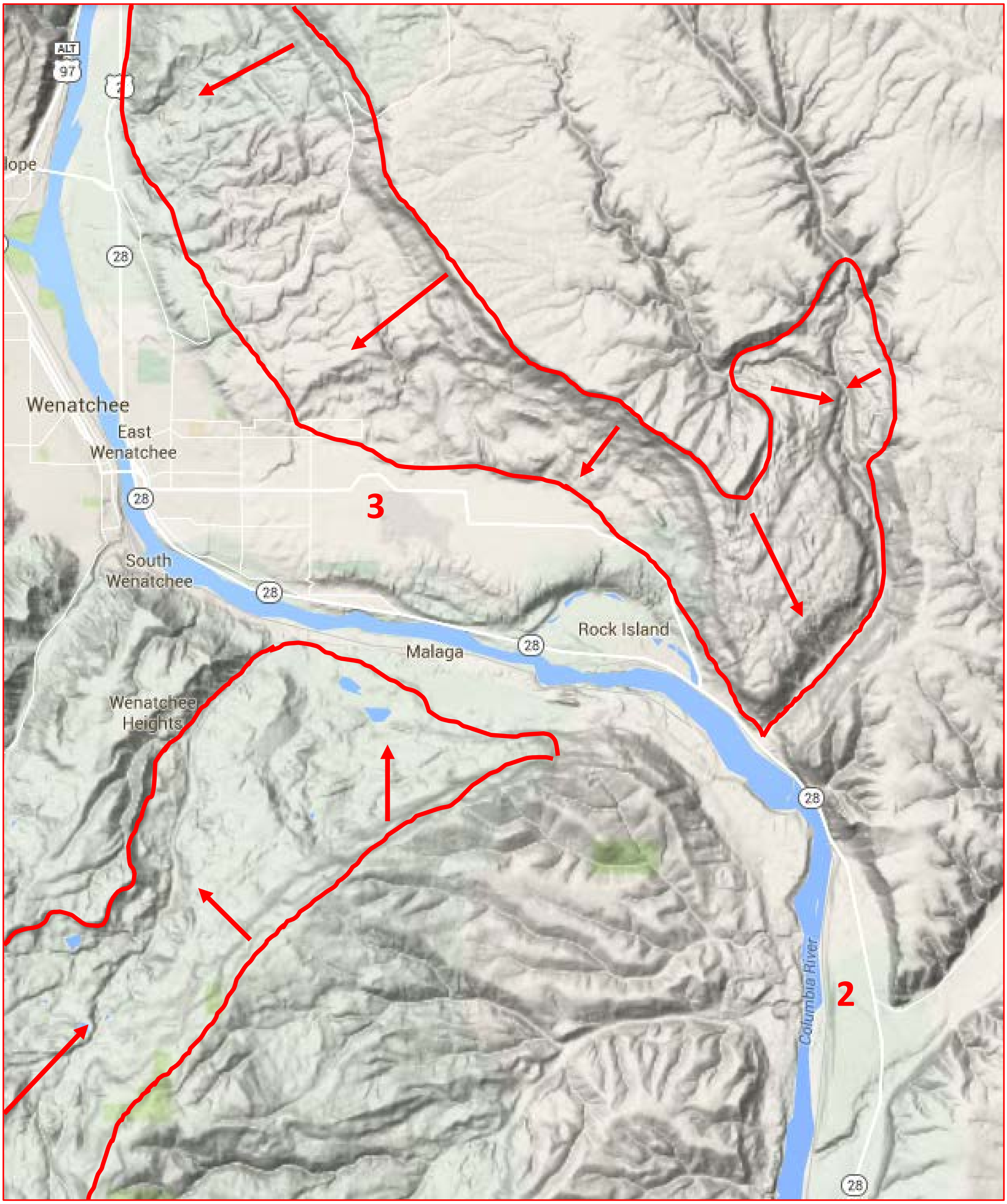



**Figure 19. Topography between Stop 2 and Stop 3. Stops noted in red. Note large red outlined areas of mass wasting approximated from Waitt (in Tabor and others, 1982). Red arrows indicate general mass movement directions. Source of map: Google Maps.**

# Stop 2—Pangborn Bar

**Location**: We are located just west of Pangborn Field on Pangborn Bar in East Wenatchee at an approximate elevation of 1180 feet.

**Landslides:** Ancient landslides are common in the Columbia River Basalts along this stretch of the river (Figures 19 & 20). From our field stop, we can see the basalt escarpment and hummocky deposits of a huge (>28 $mi^2$!) landslide complex that formed on the west flanks of Badger Mountain. Given the *anti-dip slope* of this portion of Badger Mountain, this complex is likely a series of rotational slides (Figure 21). Large landslides here and elsewhere on the margins of the Columbia River Basalts form best where dipping Columbia River Basalts overlie sedimentary *interbeds* in steep terrain (Waitt in Tabor and others, 1982; Lillquist, 2001). This complex is covered with iceberg-rafted, crystalline boulders up to 1590 feet elevation (1100 feet above the modern level of the Columbia River) indicating that the slides pre-date the last great flood(s) that passed down the Columbia River Valley following the demise of the Okanogan Lobe ice dam and the release of Glacial Lake Columbia (Waitt, 1977; Waitt and others, 2009).

**Pangborn Bar**: Giant flood bars with their relatively horizontal upper surfaces are great places to locate airports such as Pangborn Field. Pangborn Bar is a huge crescent (i.e., point) bar that formed on the slower, inside bend of floodwaters descending the Columbia River. It formed prior to the blocking of the Columbia River by the Okanogan Lobe. Evidence for the age of the bar is seen in gravel quarries and other exposures on its surface. That the bar is a late Pleistocene feature is indicated by the absence of well-developed soils on its surface. However, a layer of windblown sandy silt (likely derived from the Columbia River floodplain) and 11,600 year old Glacier Peak ash (Mehringer and Foit, 1990; Kuehn and others, 2009) on its surface indicate that it formed prior to the last great floods that came down the Columbia River following the break up of the Okanogan Lobe. Upriver, Glacier Peak ash is missing from the surfaces of several high bars indicating that the bars (and the floods) formed after the deposition of the Glacier Peak ash.

**Giant Current Dunes**: Very high velocity flows created giant current dunes that "embellish" (Waitt's term) the surface of the Pangborn Bar. Dune crest spacing in the vicinity averages approximately 700 feet. They are composed of mixed basalt and crystalline rock lithology. This, combined with the steeper downstream faces of the dunes indicates that these features formed from floods coming down the Columbia River Valley rather than from floodwaters out of Moses Coulee (Waitt, 1980; Waitt and others, 2009). Giant current dunes here are subtle because of a thick soil cover and orchard land uses. If you look carefully in the orchards as we return to Grant Road you can see the gentle undulations of the giant current dunes.

**Significant Archaeology**: A spectacular collection of Clovis points were unearthed from a cache near here in 1988 and 1990. These huge projectile points are from Clovis-age (~11,000 years before present) people who hunted large mammals in the area. A grain of Glacier Peak ash was found on one of the blades indicating that with these points (and associated people) were here after the last great floods descended the Columbia River Valley and after the ~11,600 years old Glacier Peak eruption (see Waitt and others, 2009).

# Stop 2—Pangborn Bar

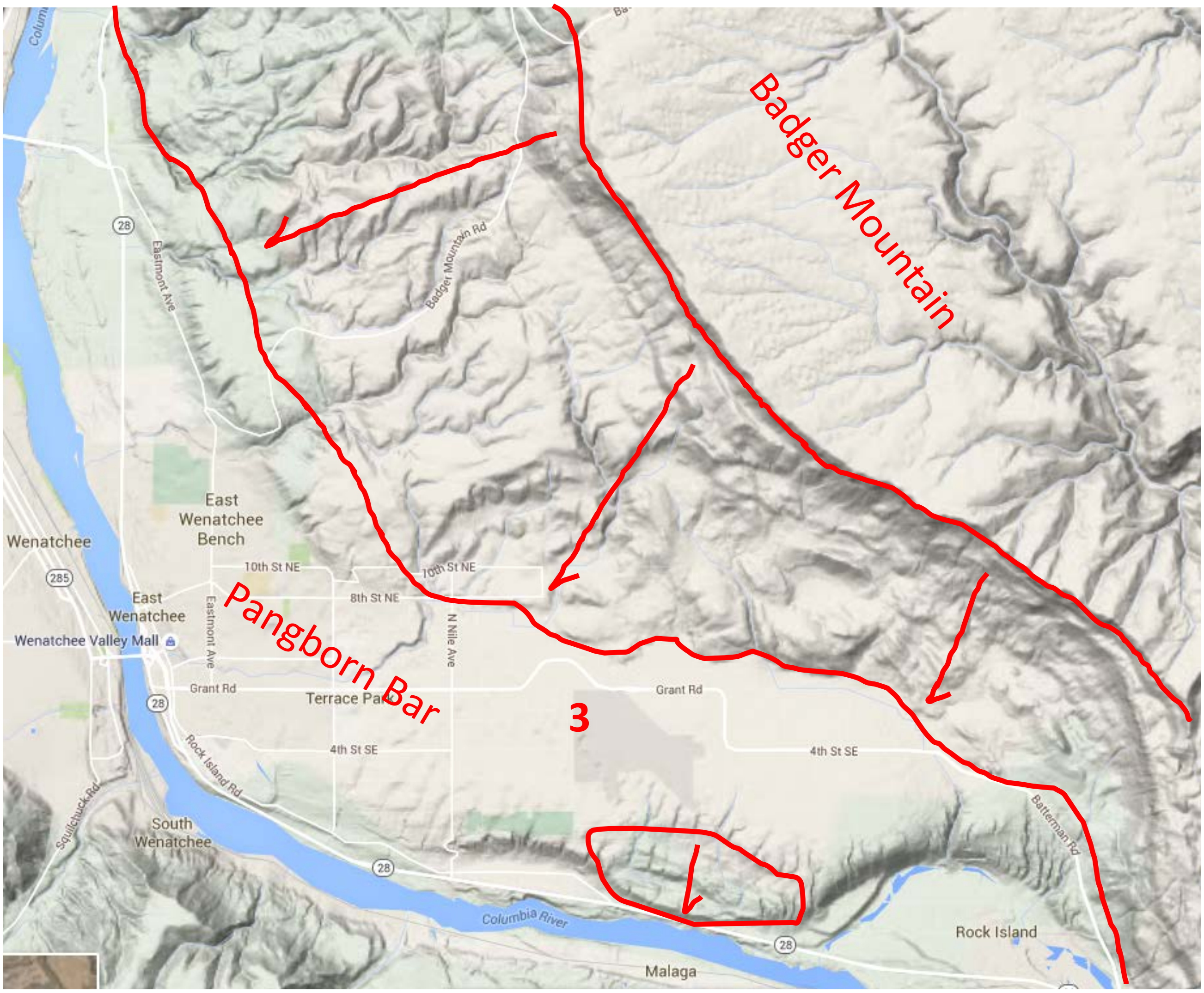
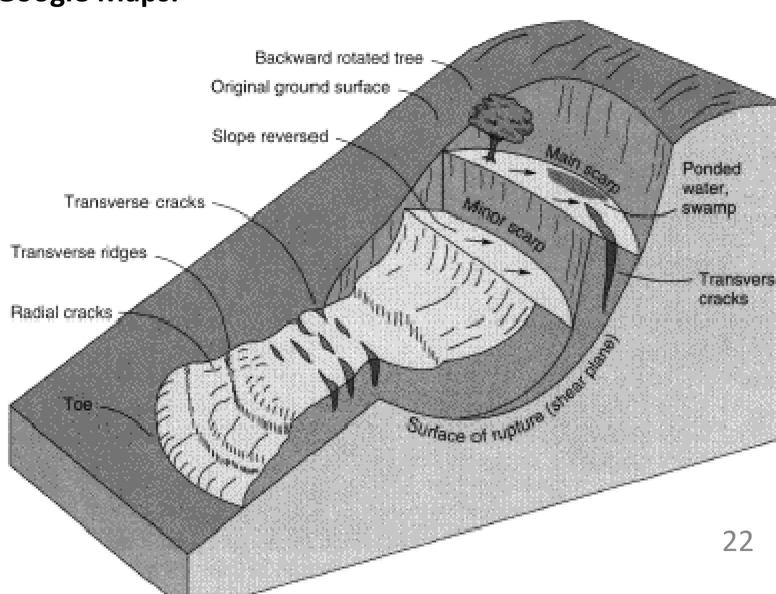



**Figure 20. Pangborn Bar and adjacent landslides. Red number indicates location of field trip stop. Source: Tabor and others, 1982; Google Maps.**

**Figure 21. Model of a rotational slide. From http://www.ussartf.org/landslides.htm**



# Pangborn Bar to Knapp Coulee

**Our Route**: From Stop 2, turn right (north) onto South Union Avenue and follow it back to Grant Road. There, turn left (west) onto Grant Road and follow this approximately 2.5 miles west to its junction with Eastmont Avenue. Turn right (north) onto Eastmont Avenue and follow it approximately 4 miles north to its junction with WA 28 and US 2/97. Go straight through this intersection onto US 2/97 and cross the Columbia River. Take the US 97A exit just after crossing the Columbia River and head north on US 97A toward Chelan. Our route will take us through Entiat. North of Entiat, US 97A ascends through a tunnel and into Knapp Coulee. Follow the lead vehicle and park on the far right shoulder of US 97A. This will be Stop 3.

**Geology**: We are following the boundaries of two geologic and two physiographic provinces. Columbia River Basalts generally lie to our east while crystalline rocks of the Swakane, Mad River, and Chelan Mountains terranes lie to our west. These include gneiss, tonalite, and migmatites. Note the pegmatite dikes that intrude the Swakane Biotite Gneiss from just north of Wenatchee to nearly Entiat (Tabor and others, 1987).

**Hydropower**: We pass Rocky Reach Dam, owned by Chelan County PUD. The first stages of this dam were completed in 1961. Like Rock Island Dam, its primary purpose is generating hydropower. This dam impounds Lake Entiat which submerged Entiat Rapids. While not as treacherous as Rock Island Rapids, Entiat Rapids claimed at least one sternwheeler (Figure 22).

**Physiography and Geomorphology**: Physiographically, the landscapes east and west of the river appear very different from each other with the more planar landscapes of the Columbia Plateau to our east and the rugged mountains of the Northeastern Cascades to our west. Much of the drive up the west side of the Columbia River follows metamorphic and igneous bedrock. Where US 97A is not on or next to bedrock, the substrate is primarily alluvial fans that formed from the steep tributaries to our west or bars formed by the Columbia River at higher levels. Large, low bars formed just north of Swakane Canyon and just north of the Entiat River. A large gravel pit is present on the Swakane Bar indicating the importance of fluvial sediments to the sand and gravel industry. Large boulders litter the north end of the Entiat bar suggesting that it was formed by very high velocity flows. Are these evidence of historic or prehistoric floods? In scattered places, dune sands outcrop next to the Columbia River

**Earthquakes:** Just north of Entiat and just before milepost 219, we pass Earthquake Point, the site of the December 1872 magnitude 6.8 Earthquake. This was the largest historical earthquake in Washington state and was felt throughout the Pacific Northwest. It may have caused the Ribbon Cliff landslide that blocked the Columbia River for hours as well as other landslides throughout the Cascade Range (US Geological Survey, n.d.)

University of Washington Libraries, Special Collections Division. PH Coll 548

**Figure 22. The wreck of the W.H. Pringle sternwheeler in the Entiat Rapids, April 1907. Source: University of Washington Libraries, Special Collections Division.**

# Pangborn Bar to Knapp Coulee


**Figure 23. Route map along the Columbia River from Pangborn Bar to Knapp Coulee. Source: Google Maps.**

# Stop 4—Knapp Coulee

**Location**: We are located along US 97A near the middle of Knapp Coulee. Our elevation is approximately 1400 feet.

**Coulee's II**: The term *coulee* implies formation by flowing water. Knapp Coulee's appearance is very different from scabland coulees present on the Columbia Plateau. Coulees take their form from the bedrock of the area and the erosional processes that created them. Knapp Coulee formed in migmatite, a rock that responds to erosion very differently than the nearby basalts. Migmatites are mixtures of igneous and metamorphic materials. They form when metamorphic rock partially melts then crystallize into igneous rocks. This migmatite is found around much of the lower part of Lake Chelan. It is part of the late Cretaceous Chelan Complex that also includes other intrusive igneous and metamorphic rocks. Knapp Coulee is one of four prominent coulees present in the vicinity of Chelan including Navarre to the west, and Antoine, and Alta coulees to the northwest (Figures 24 & 25). Various hypotheses have been proposed for coulee origins in the area—e.g., glacial ice (Dawson, 1898), landslides (1898, 1900), and ice marginal streams (Smith and Calkins, 1904). Navarre and Knapp are unique in that they are oriented perpendicular to Lake Chelan.

**Navarre Coulee Origin**: Navarre Coulee originated as an outlet for Glacial Lake Chelan water when the Okanogan Lobe blocked the lower end of the Lake Chelan Basin. This blockage created a lake that extended up to 1800 feet above sea level (~700 feet above present day Lake Chelan). This deep lake first overtopped a drainage divide and eroded a pre-existing channel which drained to the Columbia River. An amphitheater near the head of Navarre Coulee is the remnant of a past waterfall in the drainage (Figure 24).

**Knapp Coulee Origin**: Later in the late Pleistocene as the Okanogan Lobe receded and the level of Glacial Lake Chelan receded, ~4.5 mile long Knapp Coulee formed as Glacial Lake Chelan waters overtopped a divide at ~1430 feet (Runner, 1921; Waters, 1933; Waitt and Thorsen, 1983; Cunderla and others, 2011) (Figures 23 & 26). The initial cause of Glacial Lake Chelan was the Okanogan Lobe. Later, as the lobe receded, the Columbia River may have been dammed by moraine and outwash (Waitt and others, 2009). Erosion likely occurred <u>downward</u> with the overtopping, and <u>headward</u> back toward the drainage divide. Terraces formed at lake level on the walls of the Lake Chelan Basin extend up to this level (Figure 27). The north end of the floor of Knapp Coulee is ~1400 feet elevation and the south end is ~1200 feet. However, elevations rise on the channel floor to ~1540 feet near the north end, and a large depression is present near the middle. The south half now flows down to the Columbia River while the north end drains into Lake Chelan. Post-glacial weathering, erosion, and deposition (including the presence of numerous alluvial fans on the channel floor) are the likely causes of much of this odd channel floor relief. The lower (south) end of Knapp Coulee, like that of Navarre Coulee is filled with Great Terrace sediments (see Stop 6) (Waitt, 1980) (Figure 24).

# Knapp Coulee to Lake Chelan

**Route**: Follow US 97A through Knapp Coulee, past its junction with WA 971, and to Lakeside, the very small "suburb" of Chelan. Here, US 97A becomes Woodin Avenue. On the western edge of Lakeside, turn left (north) onto Johnson Place (it may also be called Terrace Avenue) and enter the City of Chelan Lakeside Park. Parking spots are available around the edge of the park and in small lots on both sides of Woodin Avenue just east of the park. Take a parking spot wherever you can. Restrooms are available in the center of the park. We will meet on the lake's edge.

**If There Is No Parking**: Because we will be visiting on a Sunday in the early summer, there is a chance that we will not be able to find sufficient parking for our group. If this is the case, we will return to Woodin Avenue and continue east into Chelan. Immediately after crossing the bridge over the Chelan River, turn right onto East Trow Avenue and travel 2 blocks east. Turn right (south) onto South Navarre Street and travel ~1 block to the community softball/baseball fields. Restrooms are available here. We can cover the same material here plus talk about the Chelan River and a nice outcrop.

# Stop 4—Knapp Coulee

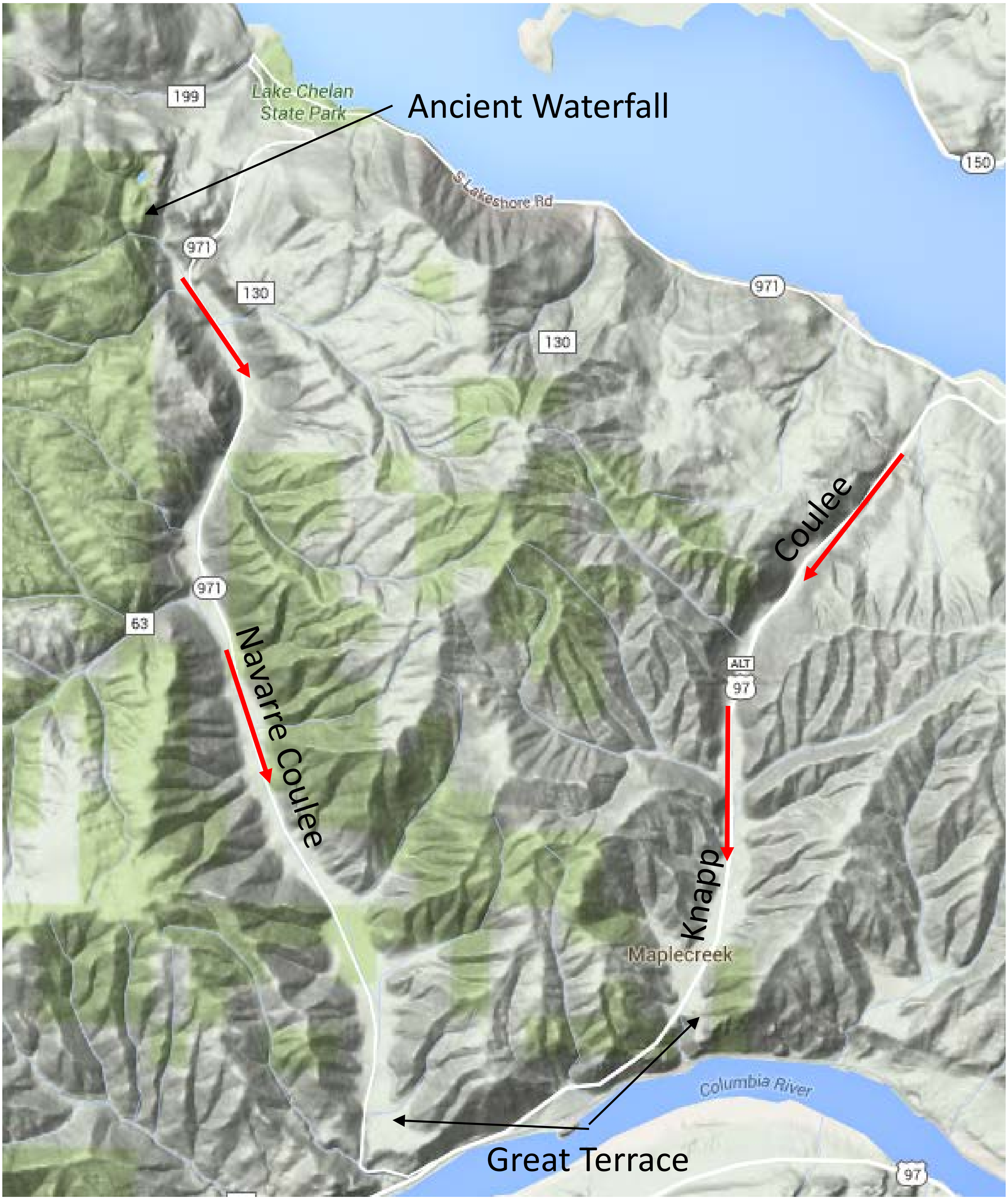



**Figure 24. Knapp and Navarre Coulees. Late Pleistocene water flow directions indicated with arrows. Source: Google Maps**

# Stop 4—Knapp Coulee

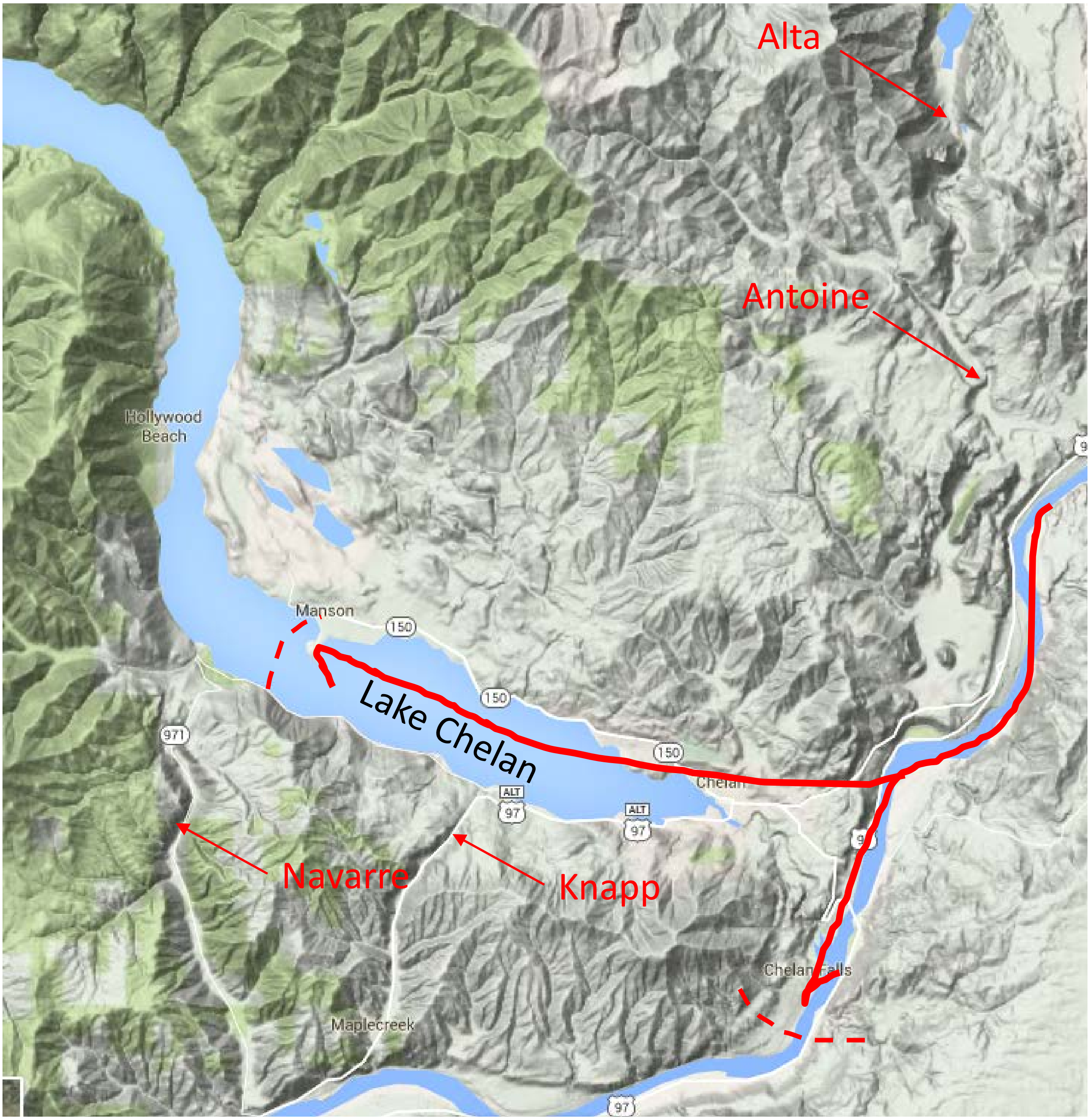



**Figure 25. Coulees in the vicinity of Lake Chelan—Alta, Antoine, Knapp, and Navarre. Paths of Okanogan Lobe in Columbia River Valley and Lake Chelan basin shown with heavy red arrows. Very approximate limit of Okanogan Lobe in the Columbia River Valley and Lake Chelan basin shown with red dashed line. Source: Google Maps**

# Stop 4—Knapp Coulee


**Figure 26. Oblique view of Knapp Coulee. Arrow indicates Late Pleistocene flow direction through coulee. View north toward Lake Chelan. Source: Google Earth.**

**Figure 27. Knapp Coulee from Lake Chelan. Red dashed line shows height of terraces in relationship to the height of the coulee. Source: Author photo.**

# Stop 5—Lake Chelan

**Location**: We are located at Lakeview Park on Lake Chelan.

**Basics**: Lake Chelan is 50 miles long and at a maximum depth of 1459 feet, is the third deepest lake in North America (Cunderla and others, 2011) behind Crater Lake (1949 ft) and Lake Tahoe (1644 ft). Bedrock beneath the lake floor sediment cover is at least 800 feet below sea level (Cunderla and others, 2011).

**Lake Basin Topography**: The lake may be divided into three topographic basins—Stehekin, Lucerne, and Wapato (Figures 28 & 29). Stehekin, the uppermost, formed in *gneiss* (a hard metamorphic rock). The result of this is that the lake is relatively shallow there and is surrounded by steep, resistant rock walls. The central part of the lake, Lucerne, is the deepest because it was eroded into softer bedrock (including *schist*, a soft metamorphic rock). Wapato Basin resulted from the deposition of Okanogan Lobe sediments at the downstream end of the lake (Whetten, 1967; Cunderla and others, 2011).

**Glaciers, Glaciation, and the Lake Chelan Basin**: The cross sectional and planimetric topography of the Lake Chelan basin is largely the result of repeated glacial erosion and deposition (maybe 9 or 10 times) in the past 1 million years (Cunderla and others, 2011). While alpine glaciers were present in numerous *cirques* (i.e., amphitheater-shaped, glacier-eroded basins) and tributary valleys above the upper end of the lake (Freeman, 1944), they likely played little if any role in shaping the actual Lake Chelan Basin. Instead, the Skagit Lobe (a part of the Okanogan Lobe of the Cordilleran Icesheet) split from the main part of the Okanogan Lobe in the upper Similkameen River Valley in British Columbia, advanced into the Skagit River drainage, then into the Lake Chelan Basin by passing over Fisher and Rainy passes, and down Bridge Creek (Figure 28). Because the Cordilleran Icesheet created low temperatures, high barometric pressure that blocked the westerlies, and resulting low precipitation, alpine glaciers were in retreat while the Skagit Lobe advanced into the Lake Chelan Basin (Jon Reidel, personal communication, 27 May 2016). Icesheets, because they are larger also respond more slowly to climate changes. It was the Skagit Lobe which flowed to the southeast shaping a somewhat linear, glacial trough (Cunderla and others, 2011). The depth of the Lucerne Basin and the height of glacier-altered terrain on the walls of the trough indicates that this glacier was over 1 mile thick (Freeman, 1944; Whetten, 1967)! The other source of glacial ice—another portion of the Okanogan Lobe–entered the <u>downvalley</u> end of the Lake Chelan Basin (Dawson, 1898; Runner, 1921) (Figure 28). The evidence for the Okanogan Lobe in the Lake Chelan Basin is the presence of basalt erratics—there is no basalt bedrock in this basin therefore the erratics had to come from the Columbia River Basalts to the east (Dawson, 1898). Basalt erratics suggest that this glacier moved at least as far upvalley as Manson (Cunderla and others, 2011). Unusual sublacustrine topography in the Wapato Basin supports this (Whetten, 1967). Elevations of the lateral moraines deposited by the Okanogan Lobe also decline upvalley as the ice thinned (Waitt and others, 2009).

# Stop 5—Lake Chelan

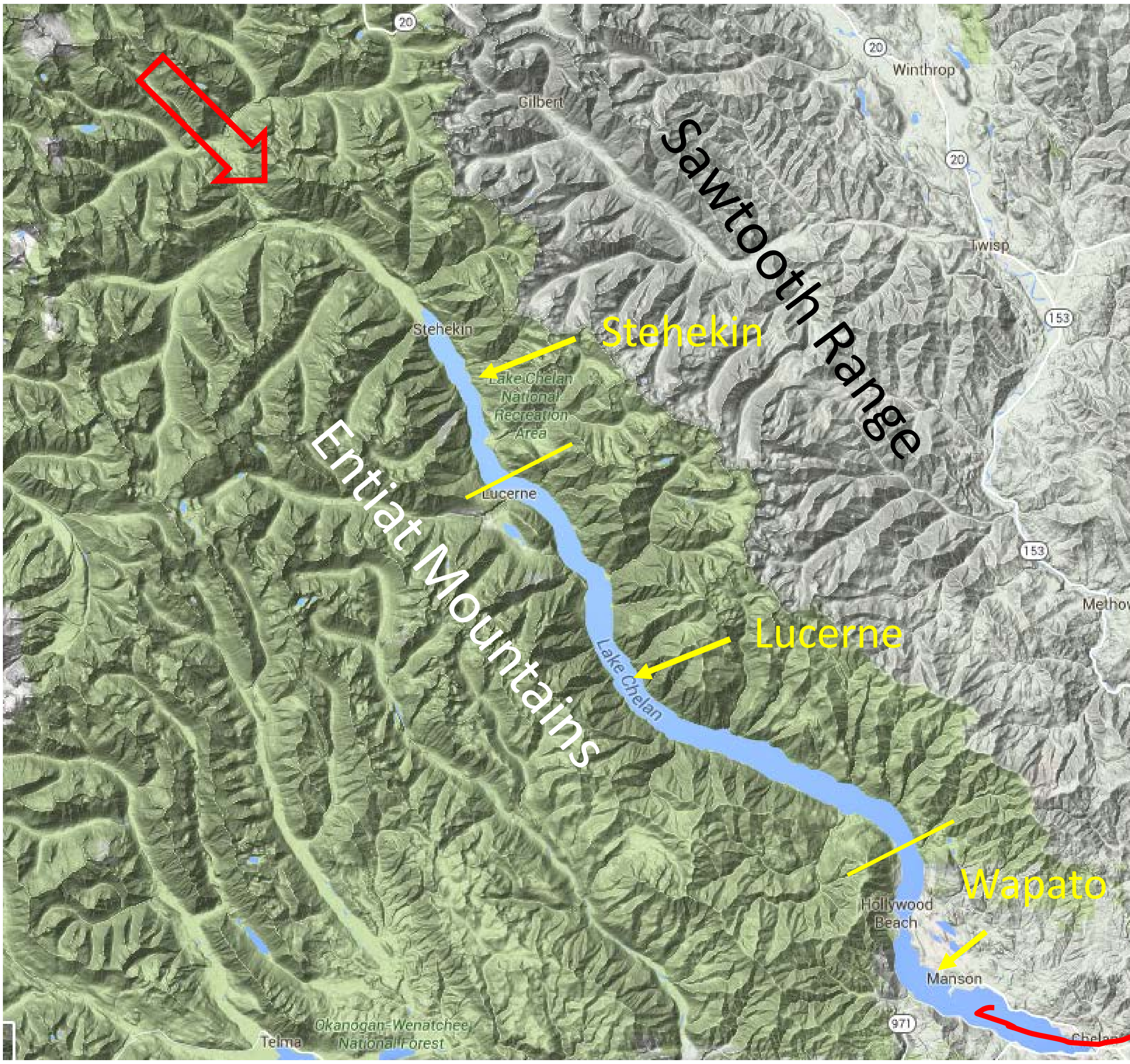



**Figure 28. Lake Chelan. Yellow lines delineate the three topographic basins of the lake—Stehekin, Lucerne, and Wapato. Broad red arrow is the Skagit Lobe entering from the west and the narrow red arrow is the Okanogan Lobe entering the basin from the east. Both are interpretations based on Cunderal and others (2011). Source of map: Google Maps.**

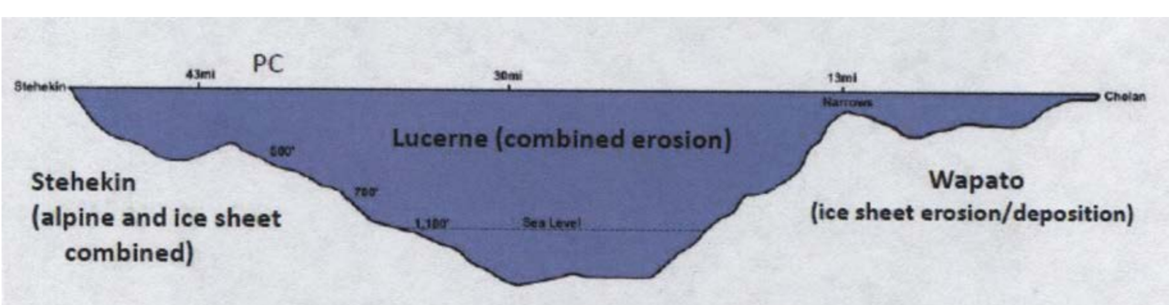



**Figure 29. Stehekin, Lucerne, and Wapato basins of Lake Chelan, and the glacier types and actions that formed them. Source: Cunderla and others (2011).**

# Stop 5—Lake Chelan

**Chelan River Outlet**: With the melting of the Okanogan Lobe and subsequent lowering of Glacial Lake Chelan to about 1100 feet, the new outlet of the basin became the low point in the glacial *drift* (i.e., glacial till and outwash) dam on the east end of the lake (Figure 30). This drift here is about 400 feet thick (Runner, 1921) thus raising the level of Lake Chelan 400 feet above the underlying bedrock. As Cunderla and others (2011) note, the Wapato Basin part of Lake Chelan would not exist without this drift dam. A hydroelectric dam was installed on the Chelan River in Chelan in the 1920's that raised the level of the lake another 20 feet (Cunderla and others, 2011).

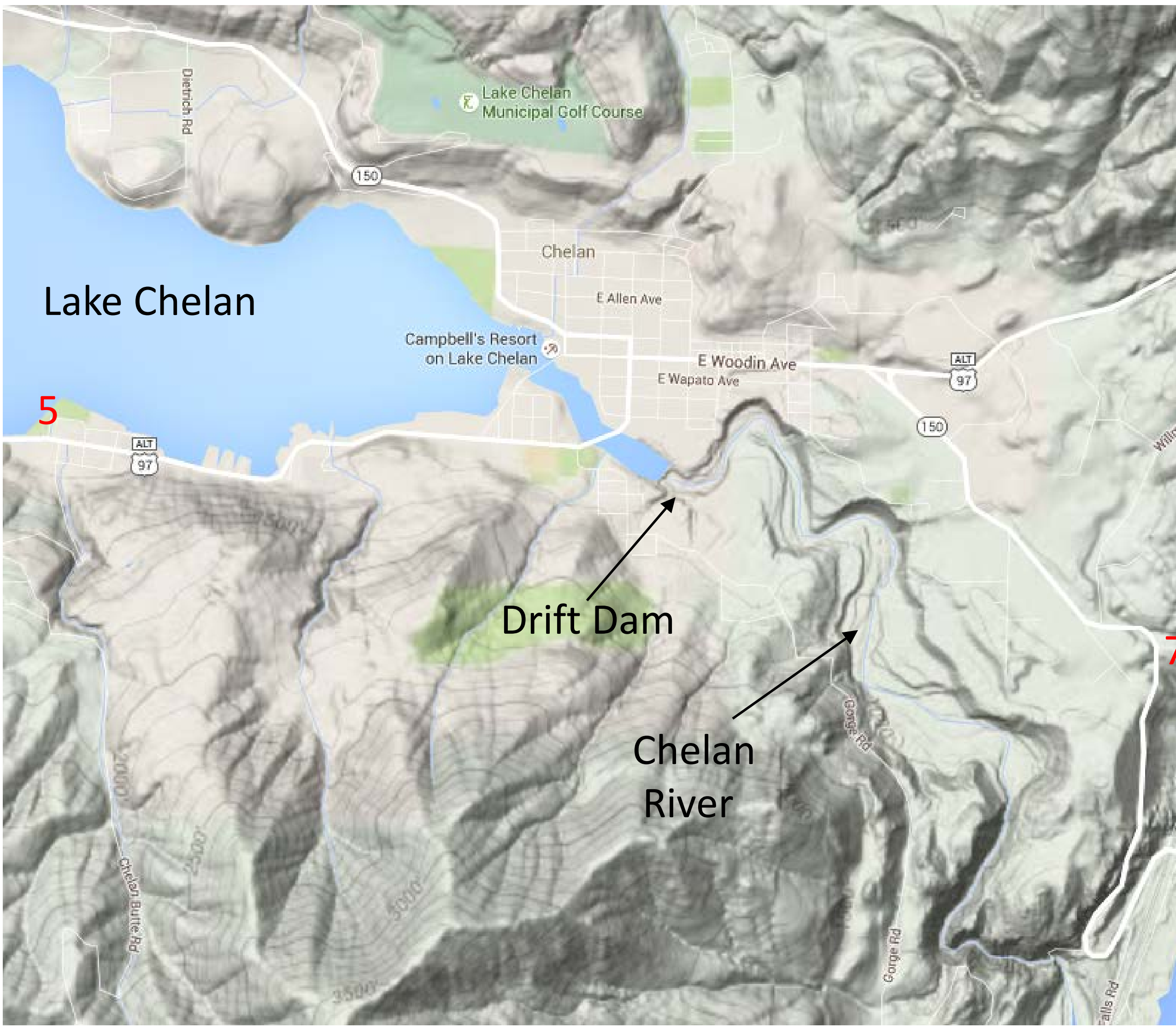



**Figure 30. Lake Chelan outlet and Chelan River. Red numbers shows location of Stops 5 and 7. Source: Google Maps.**

# Lake Chelan to Great Terrace

**Route:** Return to Woodin Avenue and continue east, then north into downtown Chelan. At a prominent intersection, turn right (east), continuing to follow Woodin Avenue as it becomes US 97A. Follow US 97a approximately 2 miles to the northeast to the Lake Chelan Airport. Take a left onto Apple Acres Road, then a nearly immediate right onto Airport Way. We will park on the side of the road near the south end of the airstrip.

# Stop 6: The Great Terrace

**Location**: We are standing near Lake Chelan Airport on a nearly horizontal bench (Figure 31). The elevation here is ~1200 feet above sea level.

**History of study**: Terraces are common features in the vicinity of Chelan. Our focus at this stop is the most prominent of them all--the "Great Terrace" or the "Great Terrace of the Columbia" (named by Russell, 1893, 1898). Over time, a veritable "who's who" of geologists have studied the Great Terrace of the Columbia (e.g., Russell, 1893, 1898, 1900; Dawson, 1898; Waters, 1933; Flint, 1935; Waitt, 1980; Waitt and Thorson, 1983; Waitt in Tabor and others, 1987; Waitt and others, 2009). Descriptions of the feature and interpretations of its origin vary.

**Description:** The Great Terrace extends discontinuously on both sides of the Columbia River from downstream of Entiat upriver to its junction with the Nespelum River, and up the Okanogan River Valley to north of Tonasket (Flint, 1935; Waitt, 1980). In places, it is as much as 1.5 miles wide (Russell, 1900). The surface ranges from being quite uniform in slope throughout its length (Russell, 1900) to sloping downvalley (Dawson, 1898) to being quite irregular (Waters, 1933). The surface in places is relatively featureless while in others it is pitted (Russell, 1900) or scarred with old channels (Waters, 1933). The top of the Great Terrace ranges above 600 feet above river level (Russell, 1893). Composition is typically bedded sands and silts with limited gravels (Waters, 1933; Flint, 1935).

**Possible Origins of the Great Terrace**: Possible origins of the Great Terrace include: 1) stream deposition into the Columbia River Valley followed by partial stream erosion (Russell (1893); 2) deposition as a delta into a large lake (Lake Lewis) in the Columbia River Valley and subsequent partial erosion (Russell, 1893, 1898); 3) river deposition (Dawson, 1898); 4) deposition as *kame terraces* along the downwasting lateral margins of the glacier (Flint, 1935); and 5) glacial outwash deposition as an *outwash train* into a lake or series of lakes formed as the glacier retreated (Waters, 1933; Waitt and Thorsen, 1983). This latter model required a dam—likely outwash train and possibly moraine—to form a lake--Lake Brewster. This dam was located downstream of Chelan Falls (Waitt and Thorsen, 1983). It is likely that elements of each of these models are valid depending on the location. Downstream of Chelan Falls, most of the fill is coarse outwash while above there are more lake sediments (Waters, 1933). With any of these models as much as ~600 feet of sediment accumulated in the Columbia River Valley in the vicinity of Chelan in the late Pleistocene! The massive size of the Great Terrace suggests that sediment deposition occurred over a long period. The common 1150-1200 feet elevation of the Great Terrace in the vicinity of Chelan suggests that the Knapp Coulee outlet controlled the elevation of the Great Terrace (Waitt and others, 2009).

**Modifications to the Great Terrace**: The highly dissected nature of the Great Terrace suggests that tributary streams have incised into this fill as they attempted to remain graded to the Columbia River. Where coarse gravels compose the Great Terrace, they appear to have originated from tributary streams (Flint, 1935; Waitt, 1972). In places, alluvial fans have been constructed atop the Great Terrace (Waters, 1933). Pitting may have been caused by buried ice (Flint, 1935) or differential settling of sediments (Russell, 1900).

# Stop 6: The Great Terrace

**Nearby Coulees**: Meltwater from the receding ice masses in the Okanogan and Methow valleys had to find a way south and did so on the western side of the downwasting Okanogan Lobe. In doing so, these flows eroded notches across drainage divides. These *trenched spurs* eventually formed coulees (or *ice marginal channels*) such as Alta and Antoine coulees to the north (Figure 32). These coulees delivered water into the Lake Chelan Basin that initially spilled to the ice-free Columbia River Valley immediately south of Chelan via Navare Coulee and later Knapp Coulee (Waters, 1933; Waitt and Thorsen, 1983).

**Missoula Floods and the Great Terrace:** Waters (1933) was the first to recognize that huge, late glacial floods overtopped the Great Terrace in places. He used the similar elevations of the terrace and the presence of numerous kettles on the surface as evidence of past flooding. Waitt in Tabor and others (1987) noted that floods reached to approximately 700 feet above the Columbia River in the vicinity of Chelan. Further evidence of huge flood(s) includes giant current dunes and large boulders atop the surface of the Great Terrace (Waitt and others, 2009).

# Great Terrace to Beebe Springs Natural Area

**Route**: Return to Apple Acres Road. Turn right (south) onto US 97A and head toward Chelan. At about 1.25 miles, turn left (south) onto Willmorth Drive. Follow this south for about 1.25 miles to its junction with WA 150. At this junction, turn left. Within less than 0.25 miles, you will see the Beebe Springs Natural Area on your left. If you have a Discover Pass, pull in and park in the parking lot. If not, park along the shoulder of WA 150 and carefully make your way to the parking lot—this can be a busy highway at times!

# Stop 6—Great Terrace

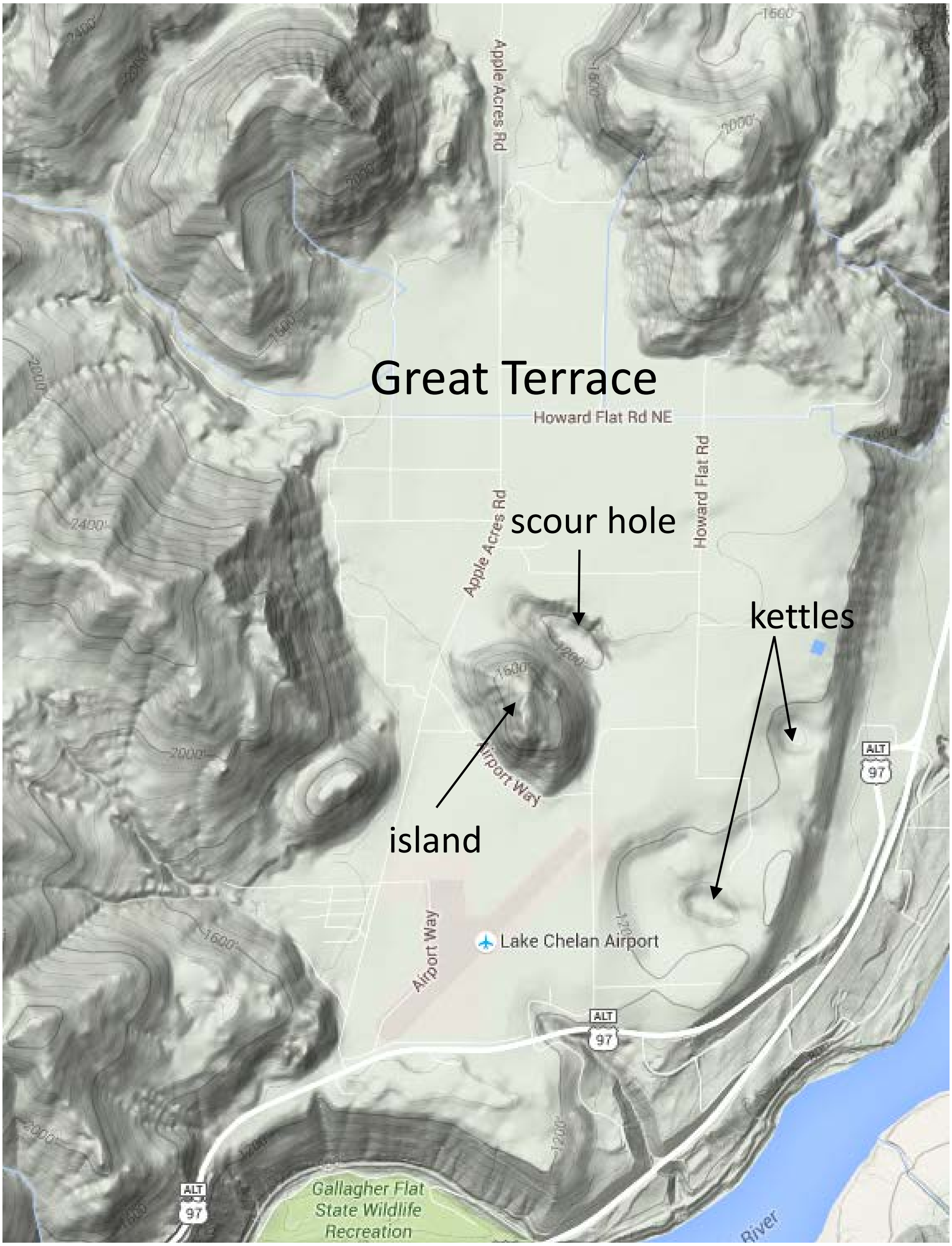



**Figure 31. Great Terrace at Howard Flats, northeast of Chelan. Note large kettles, scour hole, and large island in terrace. Source: Google Maps.**

# Stop 6—Great Terrace

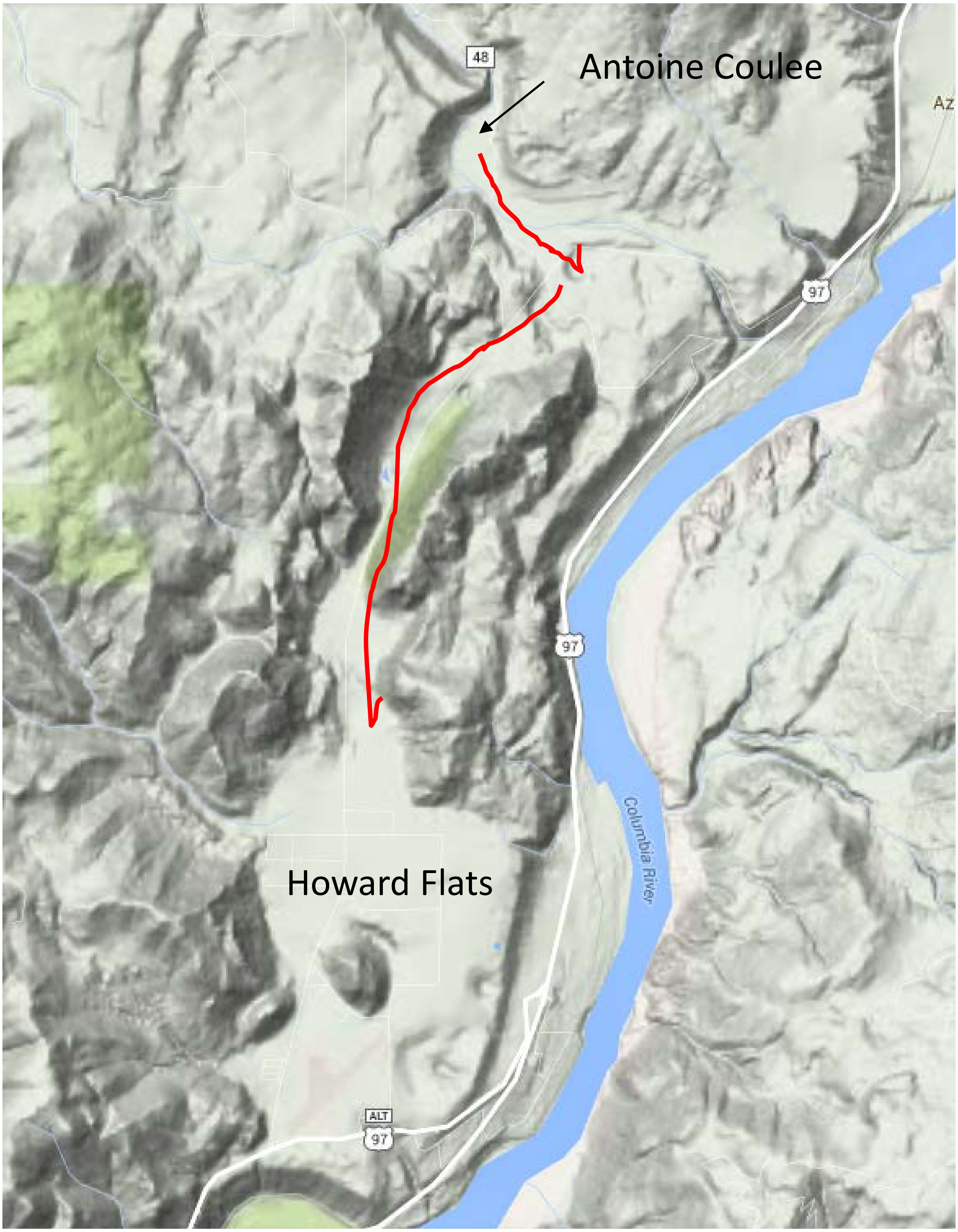



**Figure 32. Unnamed coulee (i.e., ice marginal channel) extending from near the mouth of Antoine Coulee to Howard Flats. This coulee likely delivered water into the Lake Chelan basin when the Okanogan Lobe occupied the Columbia River Valley. Source: Google Maps.**

# Stop 7—Beebe Springs Natural Area

**Location**: We are located at Beebe Springs Natural Area east of Chelan but well above the Columbia River (Figure 30).

**Glacial Erosion**: The initially most striking feature of this site is the glacially polished and striated migmatite of the bedrock knobs immediately south and east of parking lot (Figure 33). Glaciers erode by *abrasion* and *plucking*. Because glacial ice is typically softer than bedrock, it is the rocks that are embedded in the ice that are the effective abrasion agents on the underlying bedrock that result in overall sculpted forms, *polish*, and *striations*. You can feel the polished surface of the migmatite. Superimposed on that polished surface are striations that were etched by larger rocks embedded in the base of the glacial ice. The long axes of striations indicate ice movement directions. The orientations of these striations tell us that the glacier that created these—the Okanogan Lobe--was moving into the Lake Chelan Basin. Larger, whale-back shaped features known as *roche moutonee* (or rock sheep) may form from abrasion on the upglacier end of an outcrop and plucking on the downglacier end. Abrasion occurs on the upglacier end where pressure is greatest and melting occurs. Plucking results in a steeper form on the downglacier end because pressure lessons and the glacier freezes to the bedrock. These features can also be ice movement indicators.

**Glacial Lake Sediments**: To the north of the parking lot is an exposure of thinly bedded, fine grained sediments that contain occasional gravel lenses. These have been interpreted by Cunderla and others (2011) as representing a small lake that formed between the retreating Okanogan Lobe occupying the Columbia River Valley and the bedrock valley side. Such lake sediments are common throughout the area because of similar situations—i.e., glaciers block off drainages leading to ponding of water and sediments.

**The Big Picture**: At this final stop, it's good to look at the big picture. We can do this by walking up onto the bedrock knobs east of the parking lot. From here, we can see the: 1) migmatites overlain by Columbia River Basalts on the east side of the Columbia River Valley; 2) a Columbia River Valley that was occupied by the Okanogan Lobe in this vicinity; 3) the Great Terrace that formed as the Okanogan Lobe receded (Figure 34); 4) a Columbia River Valley that was shaped by large floods from Glacial Lake Missoula, Glacial Lake Columbia, and Glacial Lake Kootenay, before and after the Okanogan Lobe occupied the area.

# Stop 7—Beebe Springs Natural Area

**Figure 33. Glacially sculpted migmatite. Beebe Springs Natural Area. Source: Author photo.**


**Figure 34. The Great Terrace (river left) just downstream of Chelan Falls. View to the southeast from Beebe Springs Natural Area. Source: Author photo.**

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