Ice Age Floods Institute

Western Quincy Basin Field Trip

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

23 April 2017

Preliminaries

Field Trip Overview

Ice Age floods entered the Quincy Basin from the northeast and east. Some of this water drained from the basin through the Drumheller Channels to the south. The remainder flowed west, exiting the basin through Frenchman Coulee, Potholes Coulee, and Crater Coulee on the western edge of the Quincy Basin. We will examine the landform and sediment evidence for late Ice Age catastrophic flood origins and evolution of the western flood outlets. Along the way, you will see giant basalt columns, dry falls, potholes, plunge pools, buttes, mesas, flood bars, dunes, and more. Additionally, we will examine evidence of earlier Ice Age floods into the Quincy Basin from the Columbia River Valley.

Tentative Schedule

10:30 am	**Depart Ellensburg**
11:15	**Stop 1—Frenchman Coulee** (inc. pit toilet)
1:15 pm	**Depart**
1:30	**Stop 2—George Gravel Pit**
2:15	**Depart**
2:45	**Stop 3—Potholes Coulee** (inc. pit toilet)
4:45	**Depart**
6:00	**Arrive at Ellensburg**

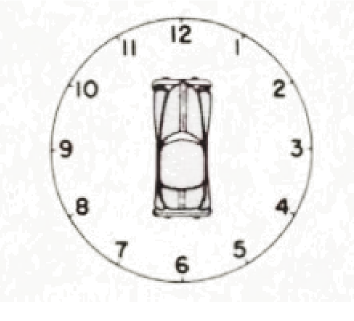


Figure 1. Relative bearings using a clock. Assume that the vehicle is always pointed to 12 o'clock. Source: Campbell (1975, p. 1).

Our Route & Stops

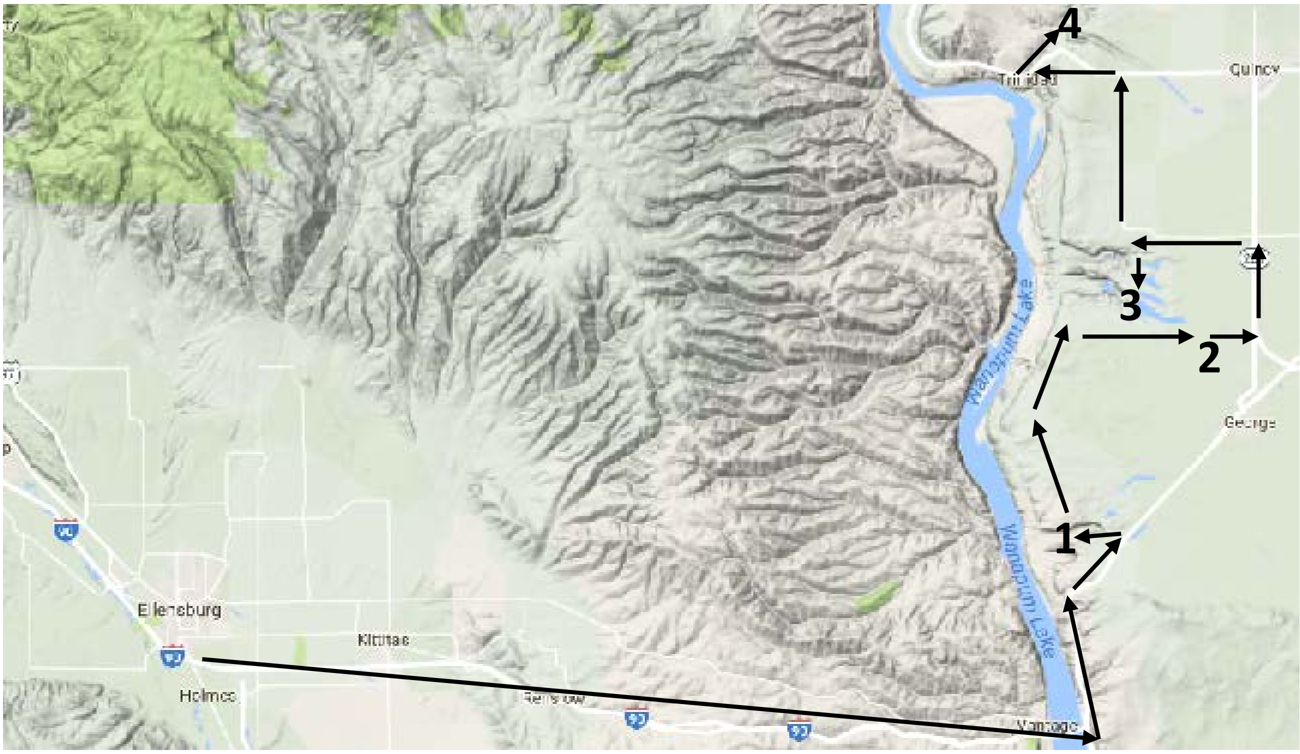


Figure 2. Route map for field trip. Approximate locations of stops shown with numbers. Source: Google maps.

Ellensburg to Frenchman Coulee

Route & Directions. Our route to Stop 1 takes us from Ellensburg to Frenchman Coulee on the southwestern margin of Quincy Basin via I-90, Silica Road, and Vantage Road (Figure 2). From Ellensburg, proceed east on I-90 past Vantage and across the Columbia River. I-90 bends north then east from the Columbia River. We enter Quincy Basin essentially where I-90 reaches its high point before descending to the Silica Road exit (Exit 143). Take this exit. At the stop sign at the base of the off-ramp, turn left and follow Silica Road for ~1 mile. Turn left onto Vantage Road and descend into Frenchman Coulee for about a mile before reaching a parking lot and single restroom mid-Coulee. Find a parking spot in or near this lot. You will need a Washington Discover Pass or a Washington Department of Fish and Wildlife vehicle access pass in Frenchman Coulee. This is Stop 1.

Ellensburg to Frenchman Coulee

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 3, 4, & 5). 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 6).

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 Flood Slackwater Deposits. Descending the Ryegrass anticline, we reach the upper limit of Missoula Flood *slackwater* at ~1260 feet (Figure 7) between mileposts 133-134. Look for changes in the *shrub steppe* vegetation as well as thick gravel deposits to indicate that we have crossed into the area once inundated by floodwaters. Also, keep your eyes peeled for light-colored, out-of-place rocks atop the basalts in this area—these are iceberg-rafted *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* overlying 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.

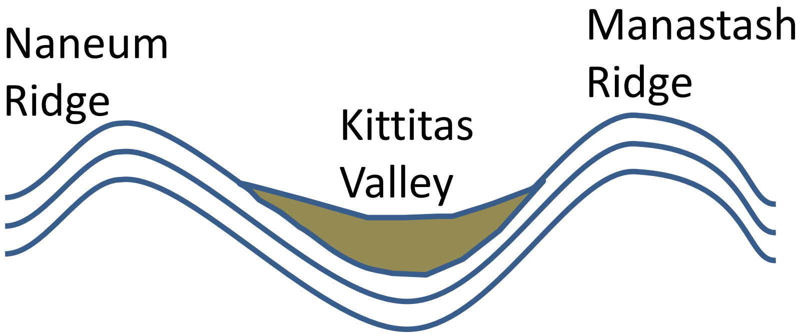


Figure 3. Location of Kittitas Basin syncline between Naneum Ridge and Manastash Ridge anticlines. Source: Jack Powell.

Ellensburg to Frenchman Coulee

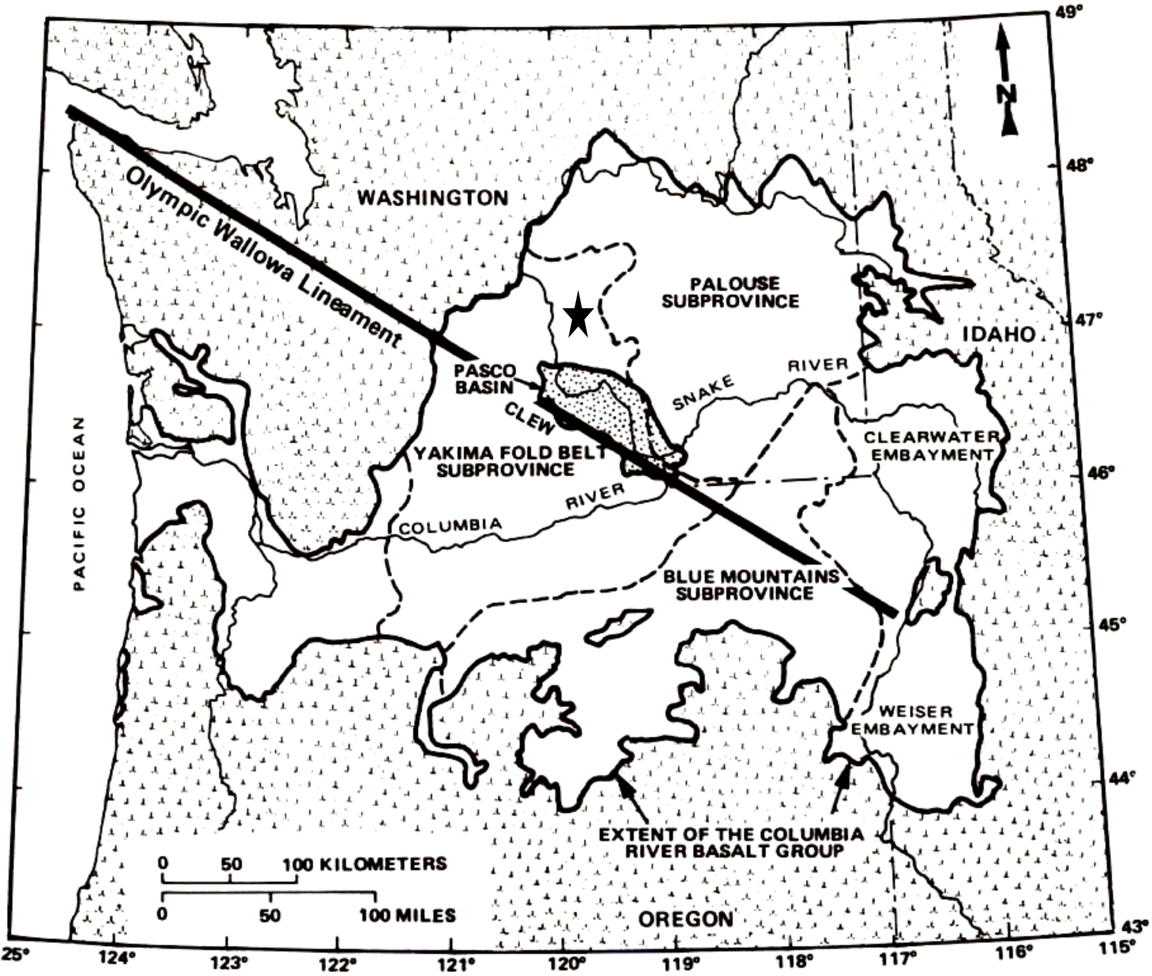
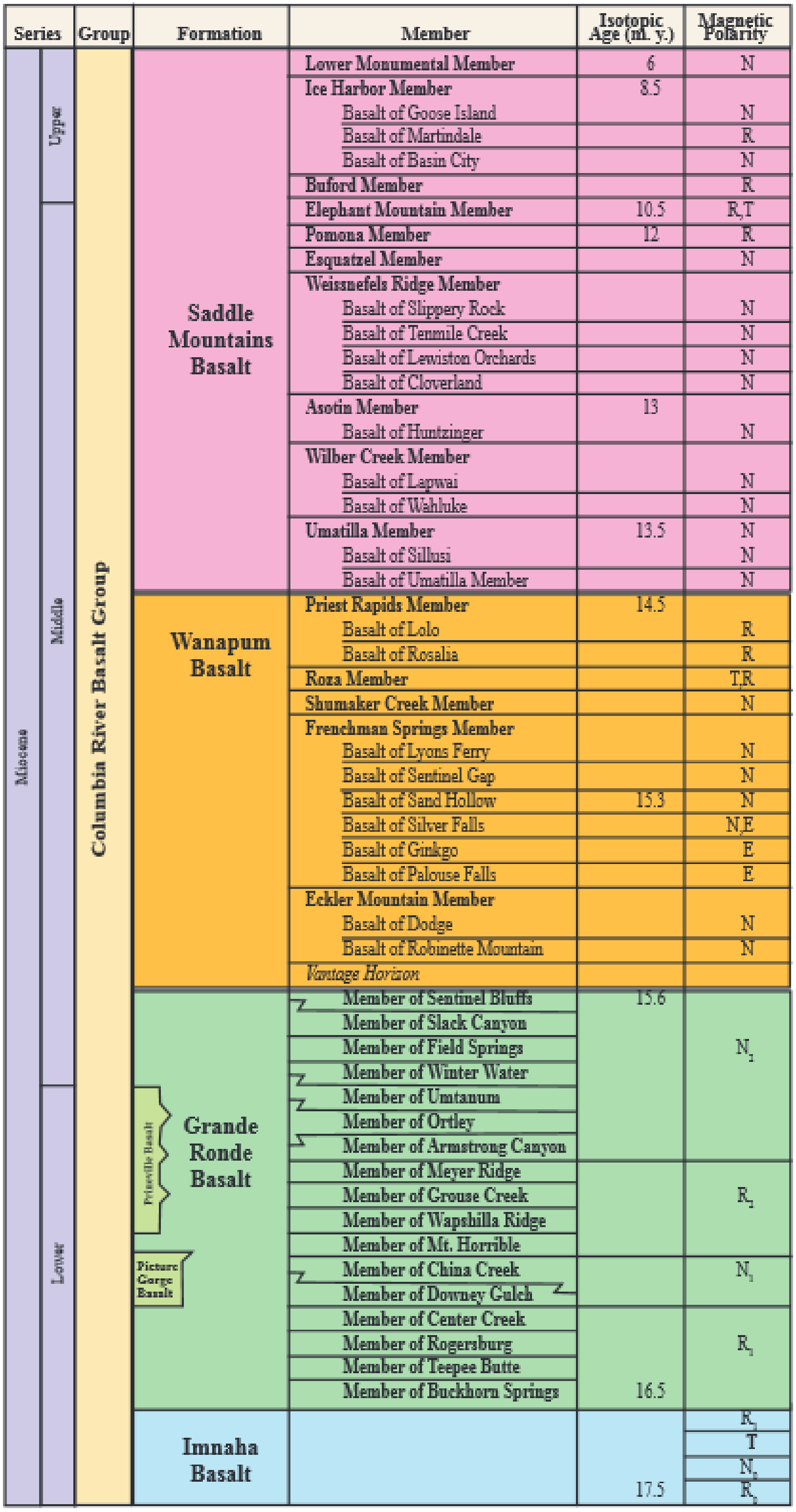


Figure 4. The Columbia Plateau and the spatial extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Star indicates approximate location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

Ellensburg to Quincy Basin



Series		Group	Formation	Member	Isotopic Age (m. y.)	Magnetic Polarity
Miocene	Upper	Columbia River Basalt Group	Saddle Mountains Basalt	Lower Monumental Member	6	N
				Ice Harbor Member	8.5	
				Basalt of Goose Island		N
				Basalt of Martindale		R
				Basalt of Basin City		N
				Buford Member		R
	Middle			Elephant Mountain Member	10.5	R,T
				Pomona Member	12	R
				Esquatzel Member		N
				Weissnefels Ridge Member		
				Basalt of Slippery Rock		N
				Basalt of Tenmile Creek		N
				Basalt of Lewiston Orchards		N
				Basalt of Cloverland		N
				Asotin Member	13	
				Basalt of Huntzinger		N
				Wilber Creek Member		
				Basalt of Lapwai		N
				Basalt of Wahluke		N
				Umatilla Member	13.5	N
				Basalt of Sillusi		N
				Basalt of Umatilla Member		N
			Wanapum Basalt	Priest Rapids Member	14.5	
				Basalt of Lolo		R
				Basalt of Rosalia		R
				Roza Member		T,R
				Shumaker Creek Member		N
				Frenchman Springs Member		
				Basalt of Lyons Ferry		N
				Basalt of Sentinel Gap		N
				Basalt of Sand Hollow	15.3	N
				Basalt of Silver Falls		N,E
				Basalt of Ginkgo		E
				Basalt of Palouse Falls		E
				Eckler Mountain Member		
				Basalt of Dodge		N
				Basalt of Robinette Mountain		N
				Vantage Horizon		
			Grande Ronde Basalt	Member of Sentinel Bluffs	15.6	N_2
				Member of Slack Canyon		
				Member of Field Springs		
				Member of Winter Water		
	Lower		Prineville Basalt	Member of Umtanum		
				Member of Ortley		
				Member of Armstrong Canyon		
				Member of Meyer Ridge		R_2
				Member of Grouse Creek		
				Member of Wapshilla Ridge		
				Member of Mt. Horrible		
			Picture Gorge Basalt	Member of China Creek		N_1
				Member of Downey Gulch		
				Member of Center Creek		R_1
				Member of Rogersburg		
				Member of Teepee Butte		
				Member of Buckhorn Springs	16.5	
			Imnaha Basalt			R_1
						T
						N_0
					17.5	R_0

Figure 5. Stratigraphy of the Columbia River Basalt Group.
Source: https://or.water.usgs.gov/projs_dir/crbg/

Ellensburg to Quincy Basin

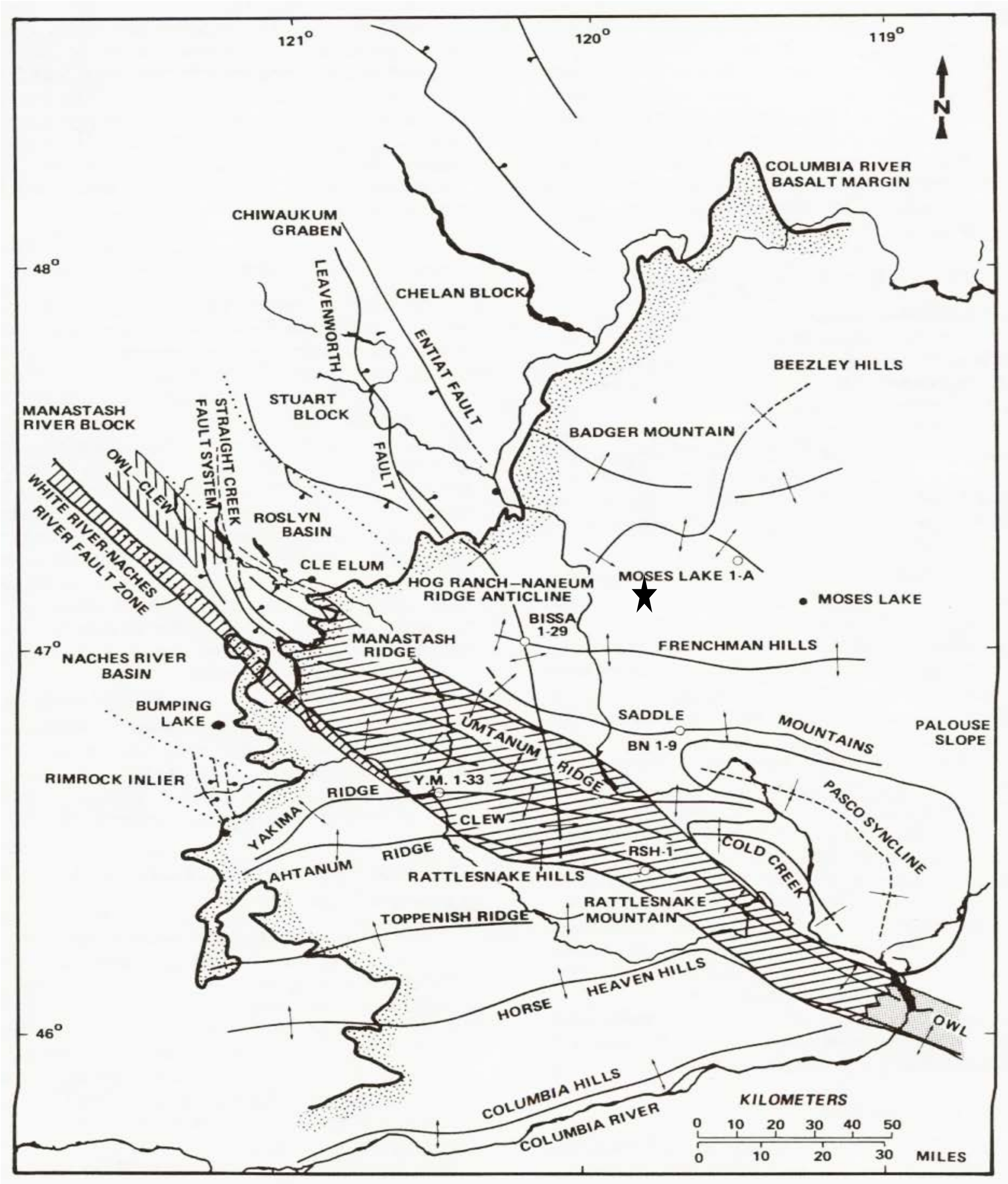
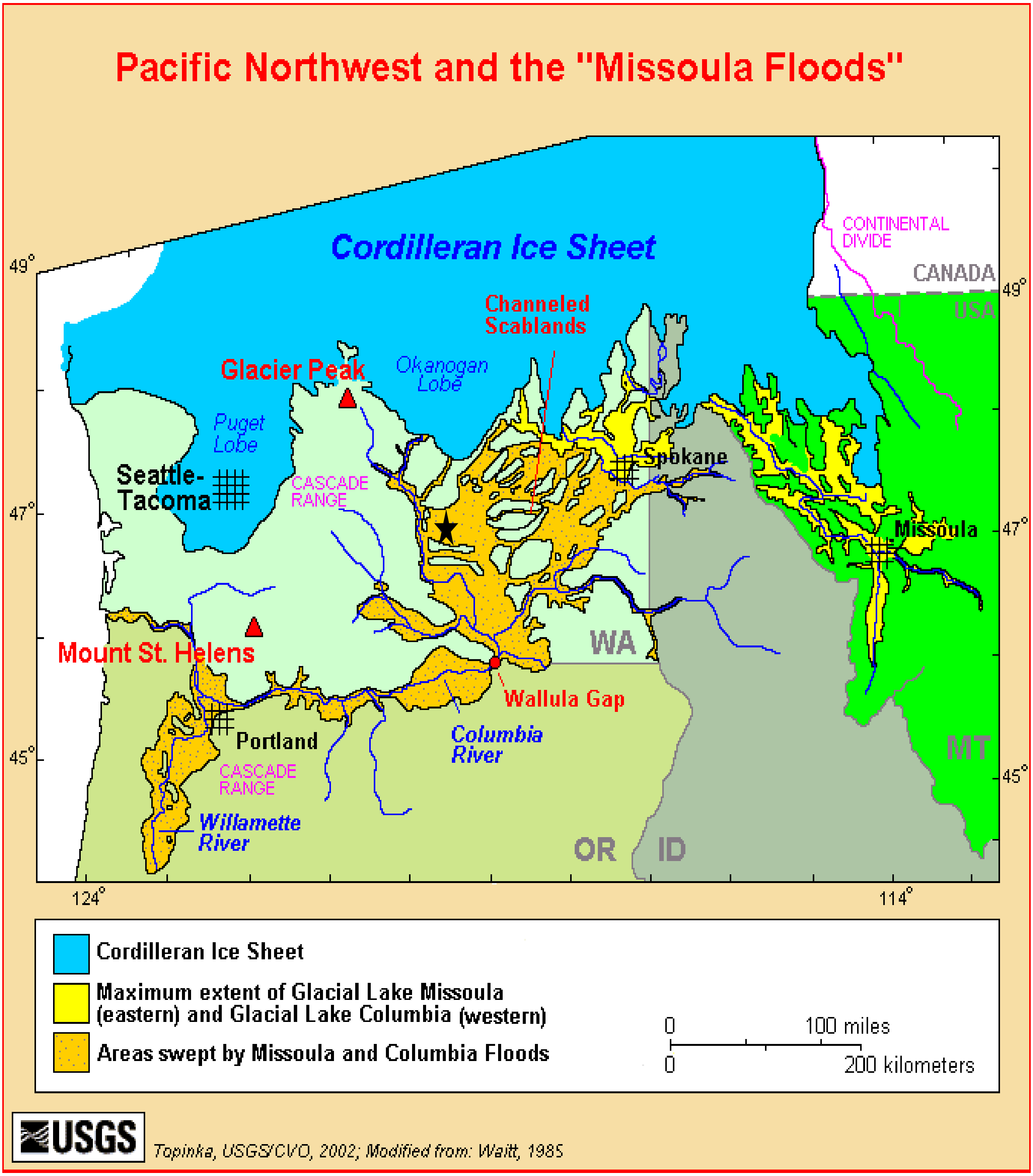


Figure 6. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Star indicates location of Quincy Basin. Source: Reidel & Campbell (1989, p. 281).

Ellensburg to Quincy Basin



Topinka, USGS/CVO, 2002; Modified from: Waitt, 1985

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

Quincy Basin

Quincy Basin Defined. Originally called “Quincy Valley”, the more appropriately named “Quincy Basin” is bounded by the Beezley Hills to the north and the Frenchman Hills to the south (Figure 3). The eastern margins are the higher elevations east of Moses Lake while Babcock and Evergreen ridges form the western margins (Schwennesen and Meinzer, 1918).

Quincy Basin Geology. Quincy Basin is underlain by Miocene (~16.5-~14.5 million year old) Grande Ronde and Wanapum basalts of the Columbia River Basalt group (Figures 3, 4, 5 & 9). These basalts cover much of Central Washington and northern Oregon. The individual flows are interbedded with sedimentary units including *diatomaceous earth* which is mined in the basin. The Quincy Diatomite, lying between parts of the Roza Member of the Wanapum Basalt, represents ancient Quincy Lake (Menicucci and others, 2016). The Ringold Formation, a mix of *Pliocene* and *Pleistocene* (~8.5-3.4 million year old alluvial (i.e., river) and lacustrine (i.e., lake) sediments (Grolier and Bingham, 1978: Bjornstad, 2006), is found in scattered exposures in the basin. Gravels, sands, and silts associated with Pleistocene (i.e., 2.6 million to 11.6 thousand years before present) catastrophic floods cover much of the basalt, Quincy Diatomite, and Ringold Formation on the basin floor. *Holocene* (i.e., 11,600 years to present) windblown sediments mantle much of the surrounding slopes of the basin. Windblown sand originated from the Columbia River and from wind reworking of the Ephrata Fan (an Ice Age flood deposit to the north) (Petrone, 1970; Bandfield and others, 2002). Near Moses Lake and Potholes Reservoir, these windblown deposits occur commonly as dunes. Westward, most of this sand is flatter “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.

Quincy Basin Area Geologic Structure. The Frenchman Hills and Beezley Hills are anticlines on the northwestern part of the Yakima Fold and Thrust Belt that bound the southern and northern margins of the Quincy Basin (Figures 6 & 8) . The intervening lower Quincy Basin is a downfolded syncline. The anticlines and syncline guided Ice Age floodwaters entering the basin from the northeast and east (Figure 3). The folding began after 10.5 million years and has continued in the Quaternary (i.e., past 2.6 million years) (Tolan and others, 2009). A *thrust fault* is also present along the steep northern flanks of the Frenchman Hills (Figure 6).

Quincy Basin Climate. The climate of Quincy Basin is characterized by cold, wet winters and hot, dry summers (Figure10). At Quincy, the mean annual temperature is ~51^{o}F and precipitation averages ~8 inches/year (Western Regional Climate Center, n.d.). Much of the precipitation falls between October and March. A secondary precipitation occurs in May and June. It is this secondary precipitation which is so important for dryland agriculture efforts. Large variations in annual precipitation, including drought, characterize arid areas such as Quincy Basin. Warm and windy conditions lead to average *potential evapotranspiration* (i.e., the amount of water that could be evaporated in this climate if water was unlimited) of nearly 27 inches/year (U.S. Weather Bureau, 1962). Based on wind data for Ephrata and Moses Lake, it is likely that Quincy’s dominant winds are from the west but its unclear whether they are more like Ephrata (northwest) or Moses Lake (southwest) (Donaldson, 1979). This is a continental dry climate even though it is only ~200 miles from the Pacific Ocean. The Cascade Range casts a distinct *rainshadow* that results in the Quincy Basin occupying some of the driest portions of Washington state. East of Quincy Basin, precipitation begins to increase again, reaching approximately 17 inches/year in Spokane.

Quincy Basin

Figure 8. Key features in and adjacent to the Quincy Basin. Heavy arrows indicate inflow of floodwaters. Numbers indicate approximate upper elevation (in feet) for the breach of the basin margin (from Bretz, 1928b). Source: Google Maps.

Quincy Basin

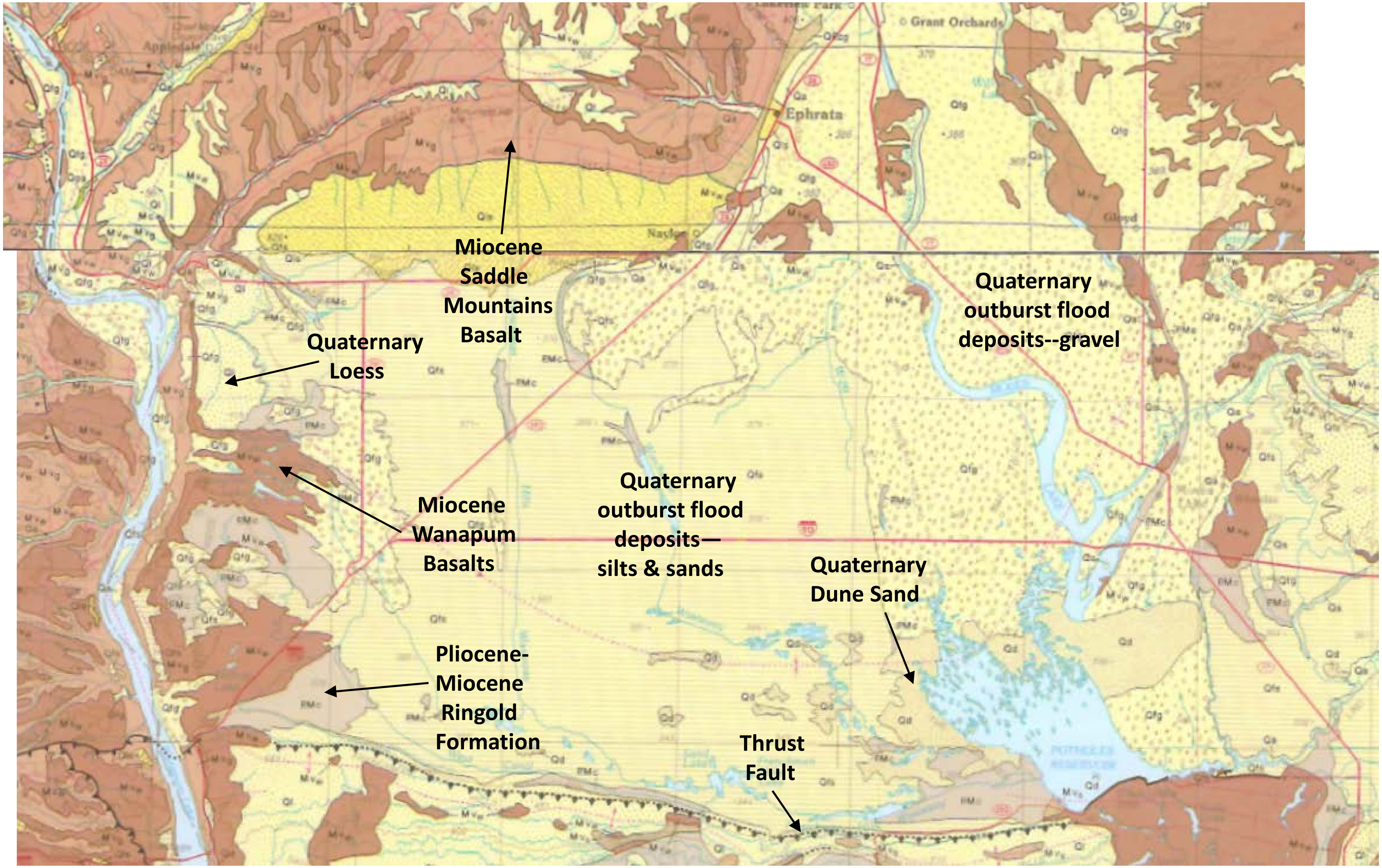


Figure 9. Parts of the Geologic Map of Washington--Northeastern Quadrant and Geologic Map of Washington --Southeastern Quadrant (Stoffel and others, 1991; Schuster and others, 1997).

Quincy Basin

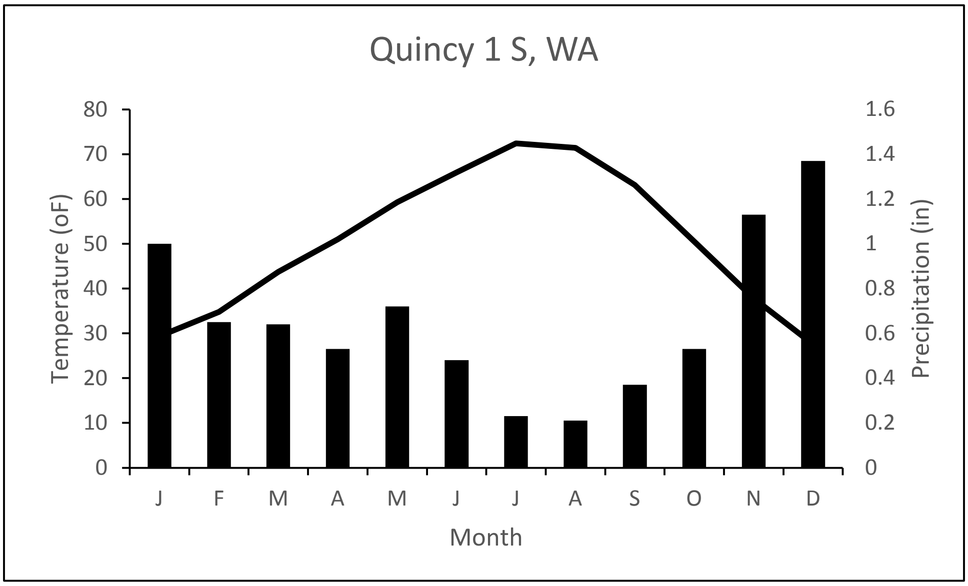


Figure 10. Climate data for Quincy 1 S site, 1981-2000. Temperature shown with line graph and precipitation representation by bars. Source: Western Regional Climate Center (n.d.).

Natural Vegetation. The natural vegetation that is so well adapted to the semi-arid to arid conditions of the Quincy Basin is known as shrub steppe. It is characterized by a shrub, which, depending on the soil and microclimate may be sagebrush, rabbitbrush, bitterbrush or greasewood, and a variety of bunch grasses (i.e., steppe). As we may see on our hikes today, there may also be a variety of wildflowers. The native grasses attracted cattle ranchers to the area before 1900.

Missoula Floods in Quincy Basin. Many Ice Age floods from Glacial Lake Missoula entered Quincy Basin from the three main scabland "tracts"—Grand Coulee, Crab Creek-Telford, and Cheney-Palouse, and five major coulees to the north and east—Grand Coulee, Crab Creek, Rocky Coulee, Bowers-Weber Coulee, and Lind Coulee (Figures 8, 11 & 12). J Harlen Bretz (1923a, 1923b, 1927, 1928a, 1928b, 1928c, 1959, 1969) and Bretz and others (1956) built a tremendous case for the passage of Ice Age floods through the area. According to Waitt (2016), Missoula Floods occurred between 19,000-15,400 calendar years before present. Several dozen of the floods passed through the Grand Coulee and emptied into Quincy Basin. Much of the basin is filled with a huge sand and gravel *expansion bar* (i.e., "Ephrata Fan") that was deposited where the Grand Coulee and Crab Creek flood channels spilled into Quincy Basin (Figure 12). Three *distributary channel* systems incise this bar—Ephrata, Rocky Ford, and Willow Springs. The maximum depth of the expansion bar deposits is nearly 130 feet (Bretz, 1969).

Soils. Quincy Basin soils reflect their geologic histories and climate. Soil textures range from coarse (over Ice Age Flood bars), to medium (over dune sand) to fine (over loess). Depths are deep (over sedimentary fill) to shallow (over basalts stripped by flooding). Natural soils here are universally light colored because of the lack of organic inputs and higher salt content reflecting

Quincy Basin

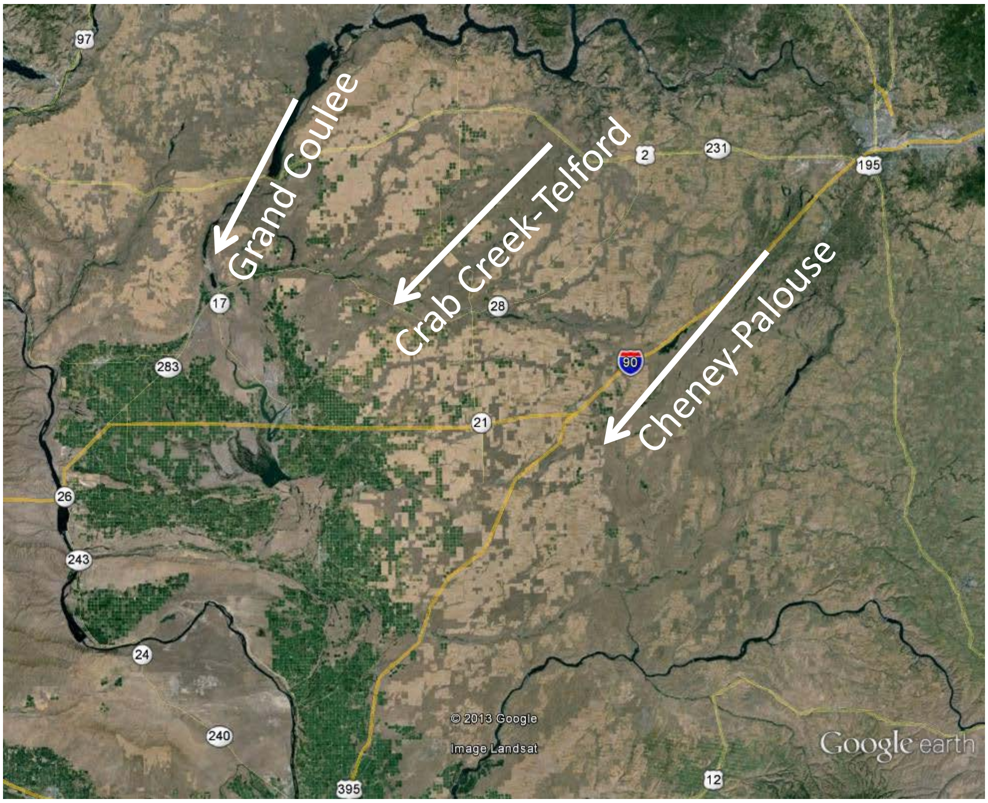


Figure 11. Channeled scabland tracts of central Washington state. Scablands are the darker areas. Source: Google Earth.

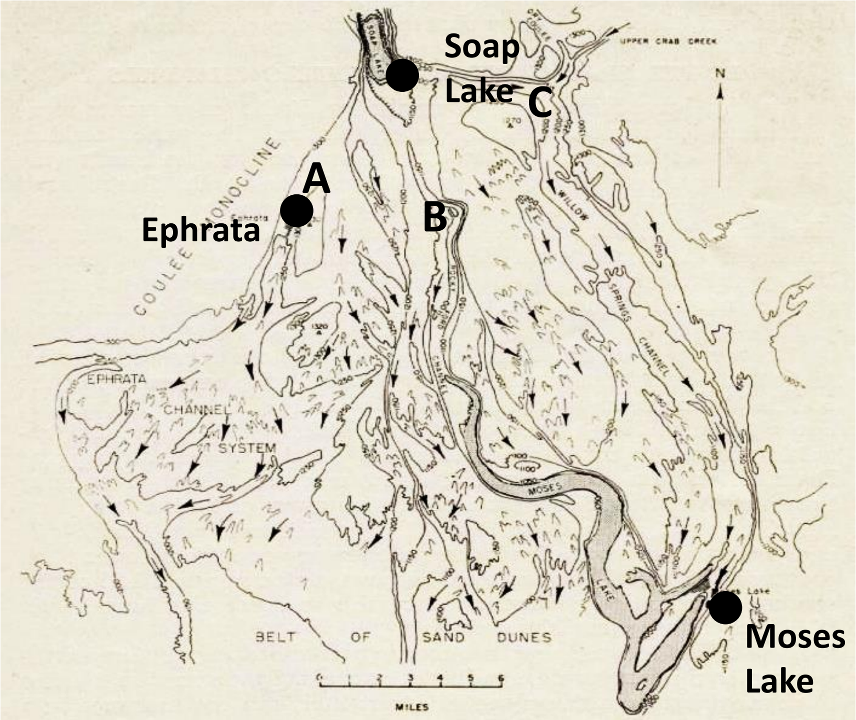


Figure 12. Quincy Basin distributary channels. Note three main distributaries from west to east—Ephrata (A), Rocky Ford (B), and Willow Springs (C). Note origins of distributaries at apex of Ephrata Fan (i.e., expansion bar). Source: Bretz (1959, p. 33).

Soils (continued). … the aridity of the area. All characteristics were key in shaping attempts at agriculture here over time. These soils have been mapped primarily as *aridisols* (reflecting the arid climate) and *entisols* (formed in dynamic cover and dune sand areas) (Gentry, 1984).

Quincy Basin

Native Americans. Native Americans were in the vicinity of Quincy Basin by the latest Pleistocene as indicated by the discovery of the Ritchey-Roberts Clovis site in East Wenatchee. This occupation occurred ~13,100-12,800 calendar years before present, ~2,000-2,500 years after the last Missoula Floods and Glacial Lake Columbia floods passed through the area (Waitt, 2016). The Lind Coulee site near Warden in the eastern Quincy Basin was occupied by Native Americans approximately 10,000 ^{14}C years before present (Huckleberry and others, 2003). Likely no tribes occupied the Quincy Basin year-round; instead, the area was occupied seasonally by root gatherers and traders. The Sinkiuse (i.e., Columbia) tribe of the Southern Plateau Culture most frequently used the area (Anglin, 1995). By the early 1700's, horses had made their way into the Southern Plateau culture (Haines, 1938). Winter camps for this tribe stretched along the Columbia River from present-day Wenatchee south to the vicinity of present-day Beverly. Here, temperatures were less severe and driftwood was plentiful for fires and longhouses. In Spring, groups would move to Tuc-Ta-Hyaspum (present-day Ephrata) which served as a base for groups radiating outward to harvest and process the roots of *Lomatium canbyi* (or Tsuka-lo-tsa). From here the groups moved a few miles eastward to Rocky Ford Creek (Entapas-Noot) to trade with various northwest tribes. Later, they headed north to an encampment on the south side of Badger Mountain to harvest the later ripening Bitterroot (*Lewisia redivivia*). Some of the Sinkiuse would then go to the Northern Great Plains to hunt buffalo while others focused on hunting young ducks and geese in the lakes and marshes of the Grand Coulee, and yet others headed to the Columbia and Wenatchee rivers to fish salmon. By late Summer, most Sinkiuse were hunting and berry picking in the Eastern Cascades. As the days shortened and the nights got colder, the Sinkiuse returned to the encampments along the Columbia River (Washington, 1956)

Early Euroamericans in the Quincy Basin. Early explorers in Eastern Washington skirted the margins of the Quincy Basin. These included members of the Lewis and Clark Expedition in 1805-06 (well south), David Thompson of the North West Company and a party of the Pacific Fur Company led by David Stuart in 1811, and George Simpson of the Hudsons Bay Company in 1824 (west on the Columbia River). Beginning in 1826, annual fur "brigades" moved down the Columbia River. At about the same time, overland trails developed following Crab Creek through the Moses Lake area to fur trading posts, and later to mines in British Columbia (Anglin, 1995) (Figure 13). One early traveler through the area referred to the Columbia Plain (of which the Quincy Basin is a part) as the "Great Columbia Desert" (Meinig, 1968). U.S. Army Corps of Engineers Lieutenant T.W. Symons, following an exploration of the area in Fall 1881, described the eastern Quincy Basin as "It is a desert, pure and simple, an almost waterless, lifeless desert" (Symons, 1882). Until the coming of the Great Northern Railroad (see below), the only Euroamericans living in Quincy Basin were ranchers, and these were most likely focused on water sources, especially Crab Creek and Moses Lake (Anglin, 1995). Animals were grazed on the open range year round with little to no hay put up for winter. Drought and competition with wild horses—perhaps as many as 25,000 in what became Grant County—made for a tough go here. Hard winters in 1880-81 and 1889-90 made it even tougher. Perhaps as many as 100,000 cattle died in the Big Bend Region in 1880-81 alone (Lewis, 1926).

The Railroads. Three railroads crossed Quincy Basin—the Great Northern, Northern Pacific, and the Chicago, Milwaukee and St. Paul. The Great Northern route through the northern part of the basin was completed in 1892 but little development occurred until 1900 because of the 1890's

Quincy Basin

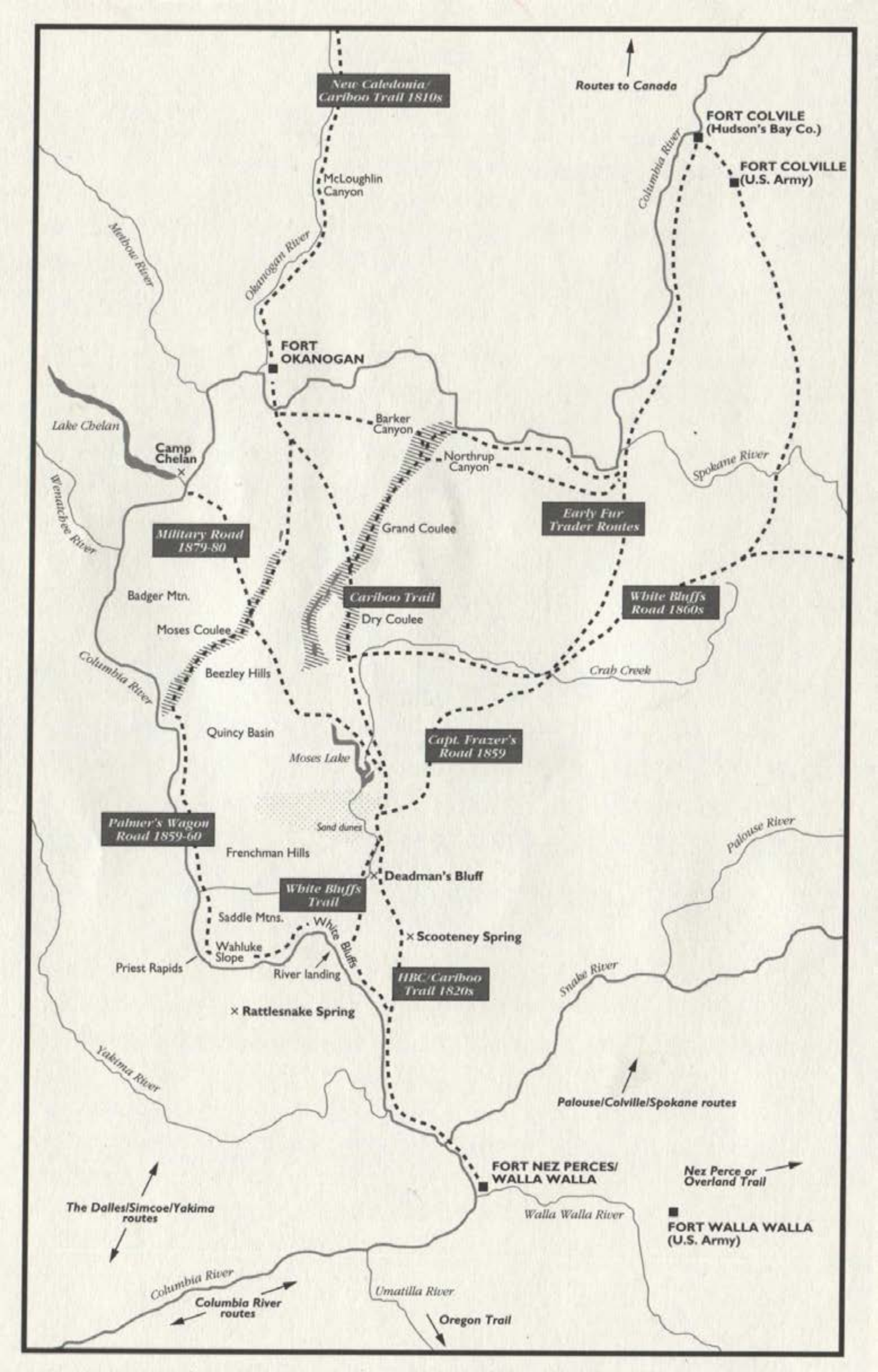


Figure 13. Key routes through the Big Bend region of Central Washington until about 1880. Source: Anglin (1995).

Quincy Basin

Railroads (continued)**.** …economic depression. By 1901, Ephrata had been established and Quincy was platted in 1902. A spur of the Northern Pacific ran south from Coulee City to Adrian (east of Soap Lake) in 1903. Subsequently, the spur was extended across the eastern edge of Quincy Basin to the mainline at Connell. The Chicago, Milwaukee and St. Paul passed along the eastern and southern margins of the Quincy Basin, and had extended a spur to Moses Lake by 1913 (Meinig, 1968).

Early Dryland Farming in Quincy Basin. The Great Northern Railroad brought a flood of homesteaders into Quincy Basin. Homesteaders took up 160 acre parcels. The coming of the railroads, fencing, and farms put an end to the open range. Wild and domesticated horses were a big part of the open range in the area. In April 1906, about 5,000 horses were rounded up in the area, herded to Ephrata, loaded onto Great Northern railcars, and shipped to North Dakota (McIntyre, 1906; Anglin, 1995). By 1913, nearly all farmable lands had been claimed. Wheat was the major crop grown on these lands. Quincy, with 400 residents, was the principle service center for the western portion of the basin (Mangum and others, 1913). However, the sandy soils needed precipitation or irrigation to hold them in place against the strong winds, especially when the native vegetation was removed. Drought wreaked havoc with farms, the families that settled the farms, and the communities that developed around the farms. The dry years that began in 1908 and persisted until 1913 ruined the wheat crops, lowered the wells, and ultimately drove many of the homesteaders away. Approximately 100,000 acres of Quincy Basin was sold for delinquent taxes in 1917 (Morris, 1976).

Early Irrigation Efforts. Early settlers recognized that irrigation was needed if the Quincy Basin was ever to bloom agriculturally. Approximately 3,300 acres were irrigated from wells in 1916. Most of these were in vicinity of Soap Lake, Quincy, and Winchester. They consisted mostly of apples and alfalfa. This included more than 500 acres of irrigated apple orchard in the Winchester area by 1914 (Schwennesen and Meinzer, 1918; Morris, 1976). An additional 700 acres was irrigated near Moses Lake by pumping from the lake. Availability of water as well as soil characteristics and proximity to transportation routes limited the development of irrigation. It was estimated that groundwater combined with Moses Lake waters could irrigate up to 15,000 acres) (Schwennesen and Meinzer, 1918).

Government & Irrigation. A government team surveyed the basin for irrigation as early as 1903. The nearby Columbia River was to be the water source. In 1907, the Quincy Power and Irrigation Company formed and proposed using an artesian well to irrigate the area. In 1908, another group of private citizens proposed the Quincy Valley Irrigation Project (Morris, 1976). This proposal generated a study by a group of Washington state scientists who identified the Wenatchee River near Lake Wenatchee as the water source for a project that would irrigate at least 435,000 acres (Landes and others, 1912). It would have been quite an engineering feat to have delivered water 65 miles from west of the Columbia River by way of canals, tunnels, and siphons! The proposal also led to the completion of a soil survey in the area recognizing that most of the land in the Quincy Basin had the potential to be good to excellent farmland if irrigation water was supplied (Mangum and others, 1913). A bond on this project was brought before voters in 1914 but was defeated because of its high cost (Morris, 1976). The U.S. Geological Survey also completed a groundwater survey on the area in 1918 (Schwennesen and Meinzer, 1918). Without irrigation, much of the basin was best used for grazing (Schwennesen

Quincy Basin

Figure 14. Abandoned farmhouse 1 mile east of Quincy. Dorothea Lange photograph, August 1939. Library of Congress Reproduction Number LC-DIG-fsa-8b15481. Accessed at: http://www.loc.gov/pictures/item/fsa2000003950/PP/.

Government and Irrigation (continued). ... and Meinzer, 1918). By 1941, writers for the Works Project Administration wrote "*This part of the Columbia Basin is both a land of promise and a graveyard of hope. Despite the lightness of precipitation, which is seldom more than six inches annually, there are productive farms and flourishing stock ranches on the deep soil, rich in nitrates, lime, and magnesium. Scattered along the highway are ghost farms with their deserted houses, weather-beaten barns, and uprooted skeletons of fruit trees, a tragic residue left by settlers, who, at the turn of the century, hopefully broke the land and waited for the promised irrigation to materialize. The dream which they dreamed too soon is now about to become a reality* (p. 330) (Figure 14).

Irrigation Today. The Quincy Basin is a vastly different place now than in 1941. 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 irrigates over 670,000 acres and boasts over 60 different crops.

Stop 1—Frenchman Coulee

Location. We are located approximately midway down Frenchman Coulee at the Washington Department of Fish and Wildlife parking area (Figure 15). A pit toilet is available at this site. The paved road here is a remnant of old U.S. 10, also known as the Sunset Highway. From here we will hike approximately 1.4 miles round trip on the Frenchman Coulee Rib Trail (Bjornstad, 2006).

Columbia River Basalts. The dark colored bedrock you see here is basalt of the Columbia River Basalt (CRB) group. In particular, you can see the gigantic, well-formed columns of the Roza member of the Wanapum Basalts. These columns are a result of basalt flow cooling, and are part of a sequence of colonnade-entabulature-colonnade typical of many CRB flows (Figure 16). The Roza columns just east of our parking area are locally known as "The Feathers" and are very popular with rock climbers.

Channeled Scablands. As we neared Frenchman Coulee, you may have seen bare, basalt bedrock outcropping along our route. These basalts are eroded into a confusing array of channels, closed depressions, and steep-sided hills (Figure 15). These features are characteristic of the *Channeled Scablands*. Scabland has long been a very descriptive term for this harsh landscape. J Harlen Bretz added "channeled" to scabland to emphasize the preponderance of channels within these scablands (Bretz, 1923a).

Coulees. Key features of the Channeled Scablands are *coulees*. Coulee is a French term meaning "to flow". It refers to a variety of landforms across North America. It has been used to refer to steep-sided channels or valleys in the northern U.S. In the southwestern U.S., it may be synonymous with *arroyo*, dry *gulch*, dry channel, and *wadi* (Fairbridge, 1968). Here, it refers to steep-sided, ~flat-floored, ~straight valleys eroded into basalt bedrock by the waters of Ice Age floods. Frenchman Coulee is actually two parallel coulees (Figure 15). The upper ends of some coulees end in steep-walled amphitheaters. That's the case here.

Erosion, Scablands, Coulees, and Cataracts. Ice Age floods eroded the landscape by *abrasion*, direct hydraulic action, *cavitation*, and the action of large, rapidly rotating, vertical vortices known as *kolks*. These vortices *plucked* basalts (especially columns) from the exposed basalt flows creating deep, steep sided *potholes* (Figure 17). Adjacent to the potholes are erosional remnants known as *buttes* and *mesas*. The cumulative name for this landscape is *butte and basin topography* and is a very common feature of the Channeled Scablands. Kolks tended to travel in a linear fashion, exploiting weaknesses in the basalts. These linear paths subsequently became coulees. "Headward erosion" associated with waterfall recession also played a major role in coulee formation.

Frenchman Coulee Origins. Schwennesen and Meinzer (1918) first recognized that Frenchman Coulee and the Potholes to the north were *cataracts* created by flowing waters from a Columbia River that had been diverted down the Grand Coulee. Bretz (1923a) agreed adding Crater Coulee as a third floodwater outlet in the Western Quincy Basin. Water exited the Quincy Basin here because water overtopped a low point in Evergreen Ridge, a continuation of the Wenatchee Range across the Columbia River Valley. (Bretz and others, 1956). Water flowing from Frenchman Coulee dropped ~660 feet into the Columbia River Valley creating a significant waterfall. As a comparison, modern-day Palouse Falls is just over 180 feet high (Carson and others, 1987). Frenchman Coulee likely formed through headward erosion as floodwaters spilled over, and eroded, the Columbia River Valley wall. Over time, this waterfall receded headwardly

Stop 1—Frenchman Coulee

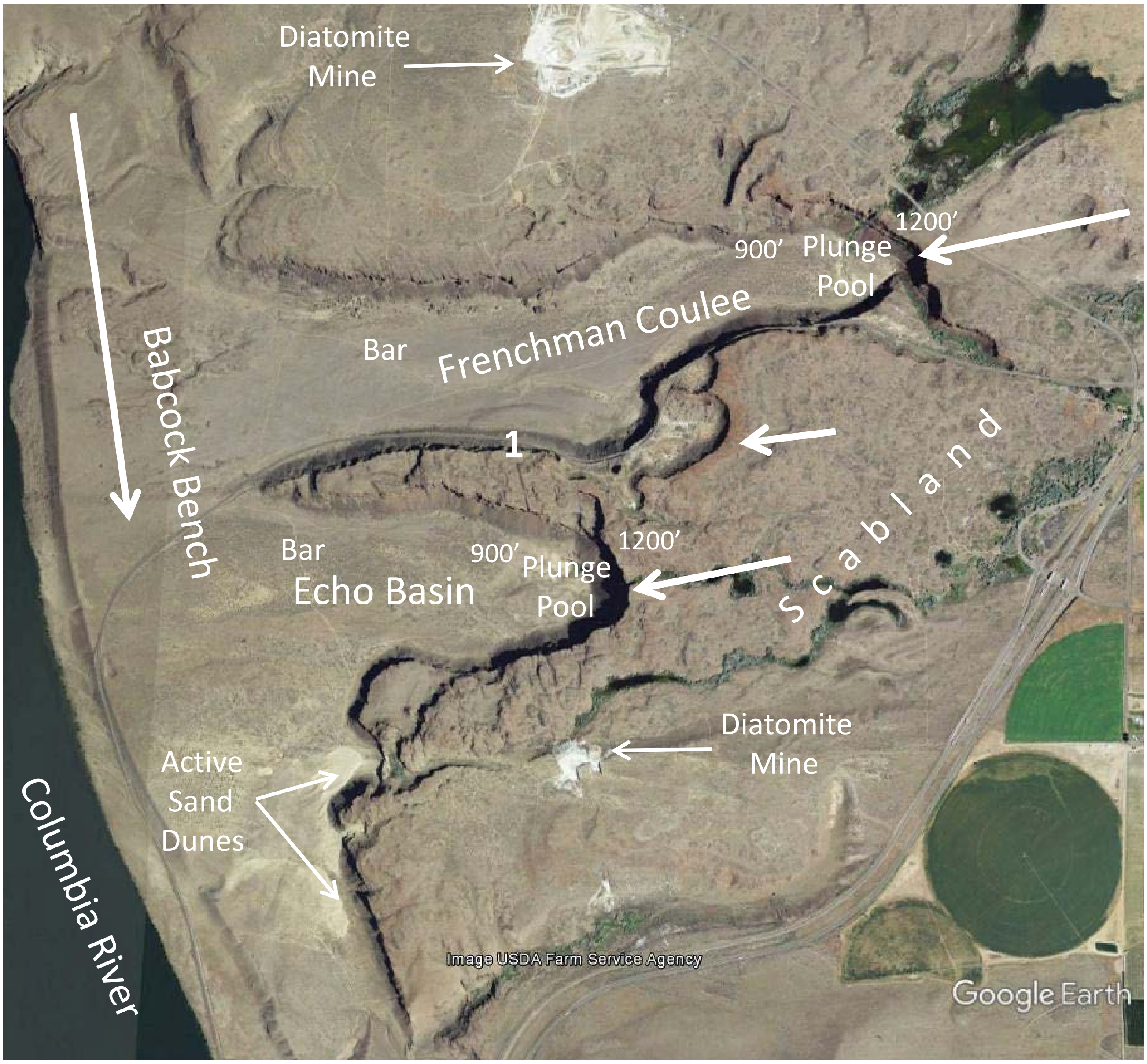


Figure 15. Frenchman Coulee including Echo Basin. Bold arrows indicate floodwater flow direction from Quincy Basin and down the mainstem of the Columbia River. Approximate elevations indicated with small numbers. Bold number indicates approximate location of Stop 1. Source: Google Earth.

Frenchman Coulee Origins (continued). **…**approximately 2 miles to its present position. Plunge pools lie at the foot of each of the falls at the heads of each of the coulees. The plunge pool here is more than 165 feet deep at the base of its cliff (Carson and others, 1987). Likely by chance, the linear mesa (or *blade*) separating the northern and southern arms of Frenchman Coulee escaped complete erosional removal. The lower elevation of the northern coulee's inlet indicates that it operated more recently than did the southern cataract (Bretz, 1923b).

Stop 1—Frenchman Coulee

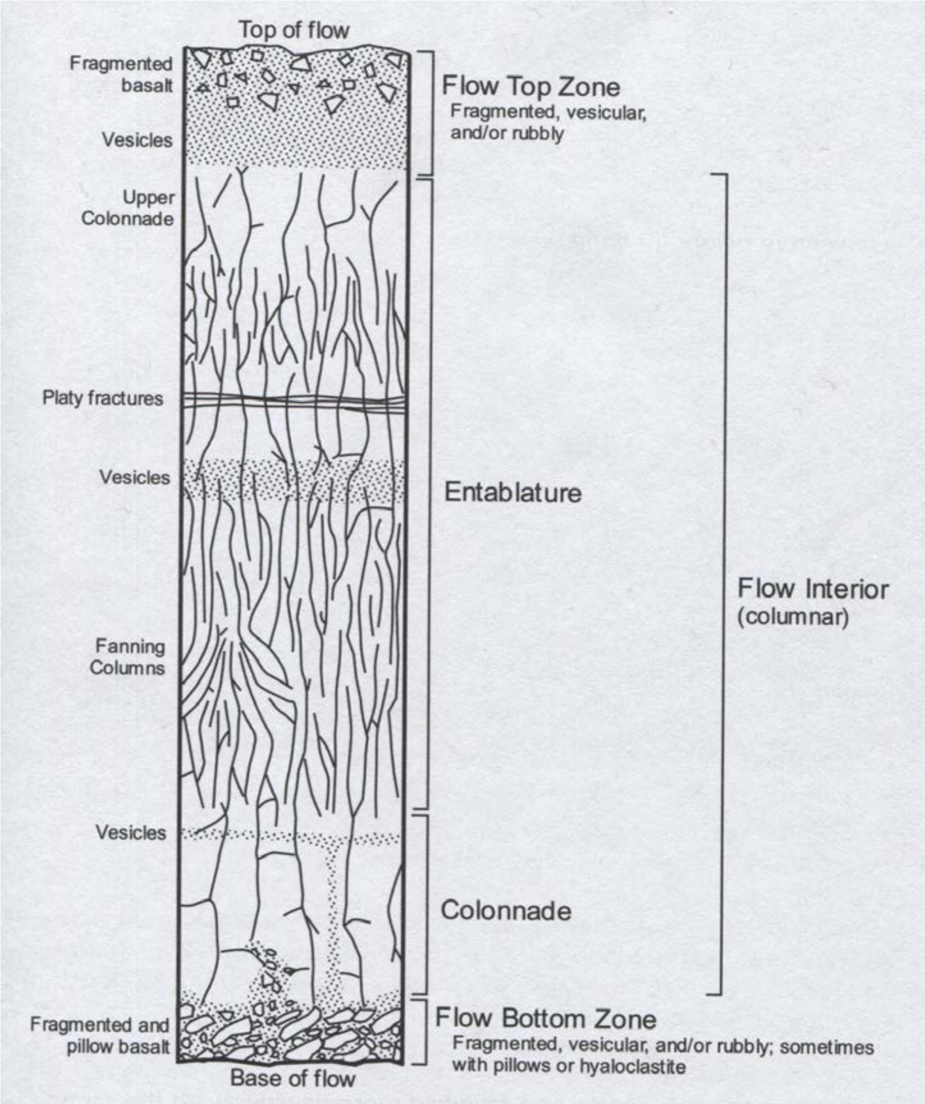


Figure 16. Cross section of idealized Columbia River Basalt flow showing structural features important to flood erosion. The fragmented and pillow basalt, and upper colonnade are not present with all flows. Source: Bjornstad (2006, p. 15).

Stripped Structural Surfaces. The basalt bench forming Babcock Bench is a *stripped structural surface* mostly formed in the entabulature of the Sentinel Bluffs member of the Grand Ronde Basalts (Bjornstad, 2006) (Figure 15). It is “stripped” in that the lava flows above this were eroded by Ice Age floods. It is “structural” in that it represents the resistant upper portions of a lava flow.

Flood Deposits. Flood deposits cover the basalt floors of both coulees of Frenchman Coulee (Figure 15). These include *longitudinal* and *crescent bars* formed parallel to the coulee walls and to the direction of flood flow down coulee (Figures 15 & 18). The trench-like feature separating a bar from a coulee wall is a *fosse* (Bretz, 1928).

Stop 1—Frenchman Coulee

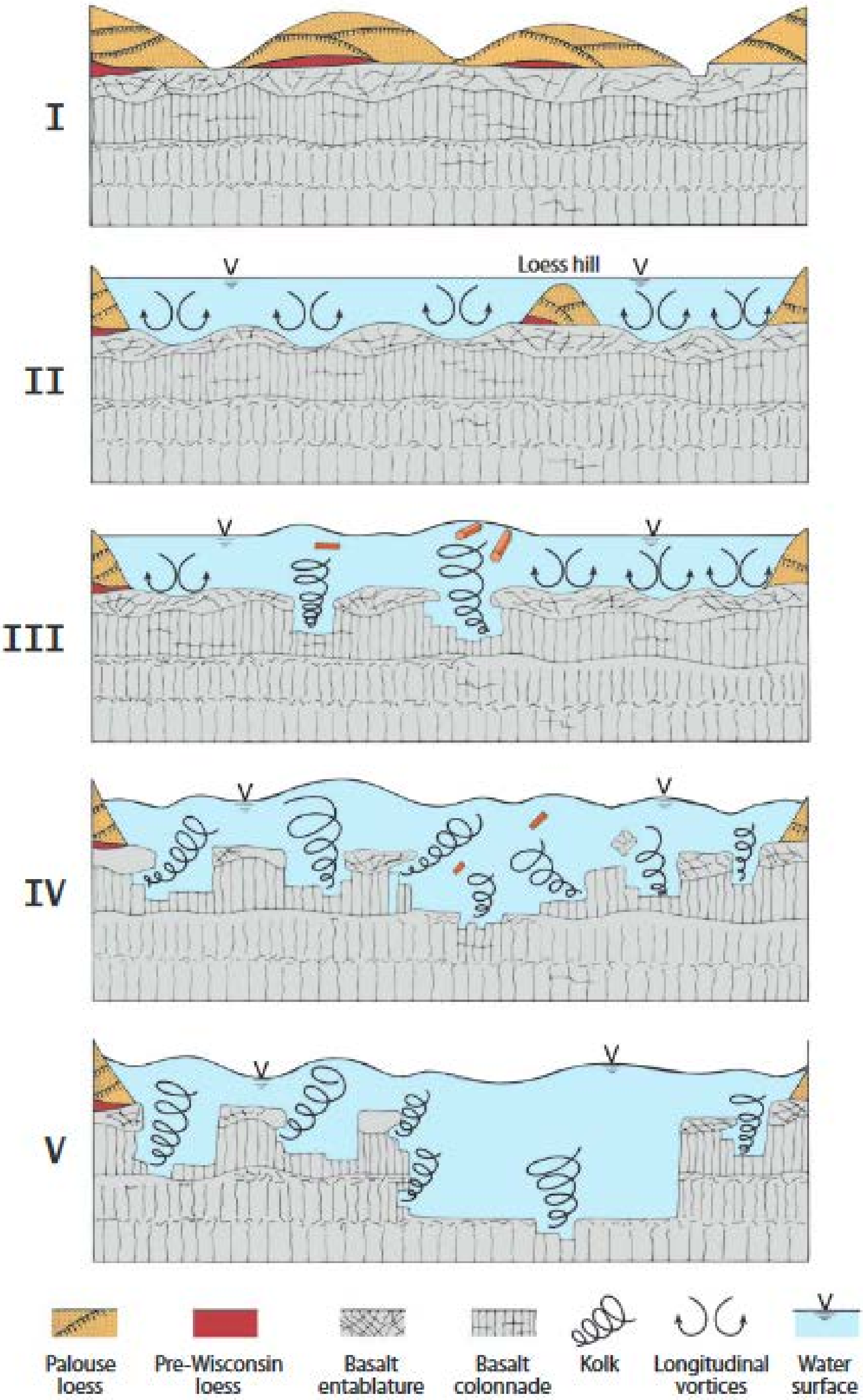


Figure 17. Inferred erosion sequence (I-V) for the Channeled Scablands illustrated by schematic cross section views. Source: Baker (2009).

Stop 1--Frenchman Coulee

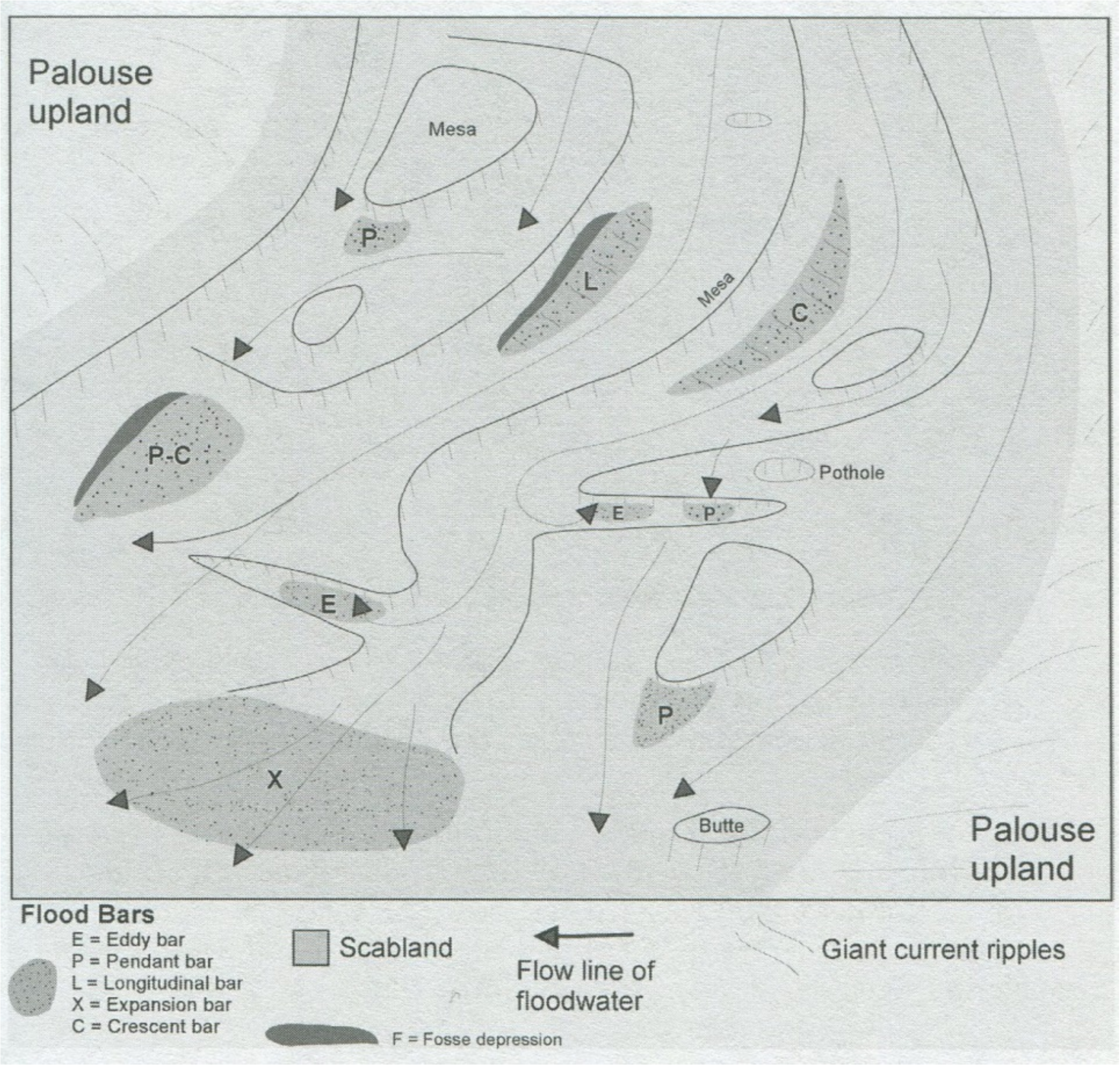


Figure 18. Types of flood bars. From Bjornstad and Kiver (2012, p. 51).

Stop 1—Frenchman Coulee

Sand Dunes. A small dunefield is present in the southern coulee (i.e., Echo Basin) and south of the southern coulee of Frenchman Coulee (Figures 15 & 19). The sand source for these dunes was the Columbia River floodplain to the west. They indicate generally westerly winds in the area. The dunes are active (vegetation-free) and inactive (vegetation-covered). Dune shapes are confusing because of the interaction between winds and the basalt cliffs, and the impacts of vegetation cover. Active dunes are *climbing dunes*—i.e., climbing up the scabland channels incised in Evergreen Ridge. Stable dunes are mostly *parabolic* in form indicating that the arms (or horns) were anchored by vegetation while the centers (*deflation hollows*) remained vegetation free and active. These deflation hollows remain the least vegetation-covered. Since the completion of Wanapum Dam in 1963, the old Columbia River floodplain has been mostly submerged; therefore, the sand supply has been largely cut off. This has led to stabilization of most dunes in the area.

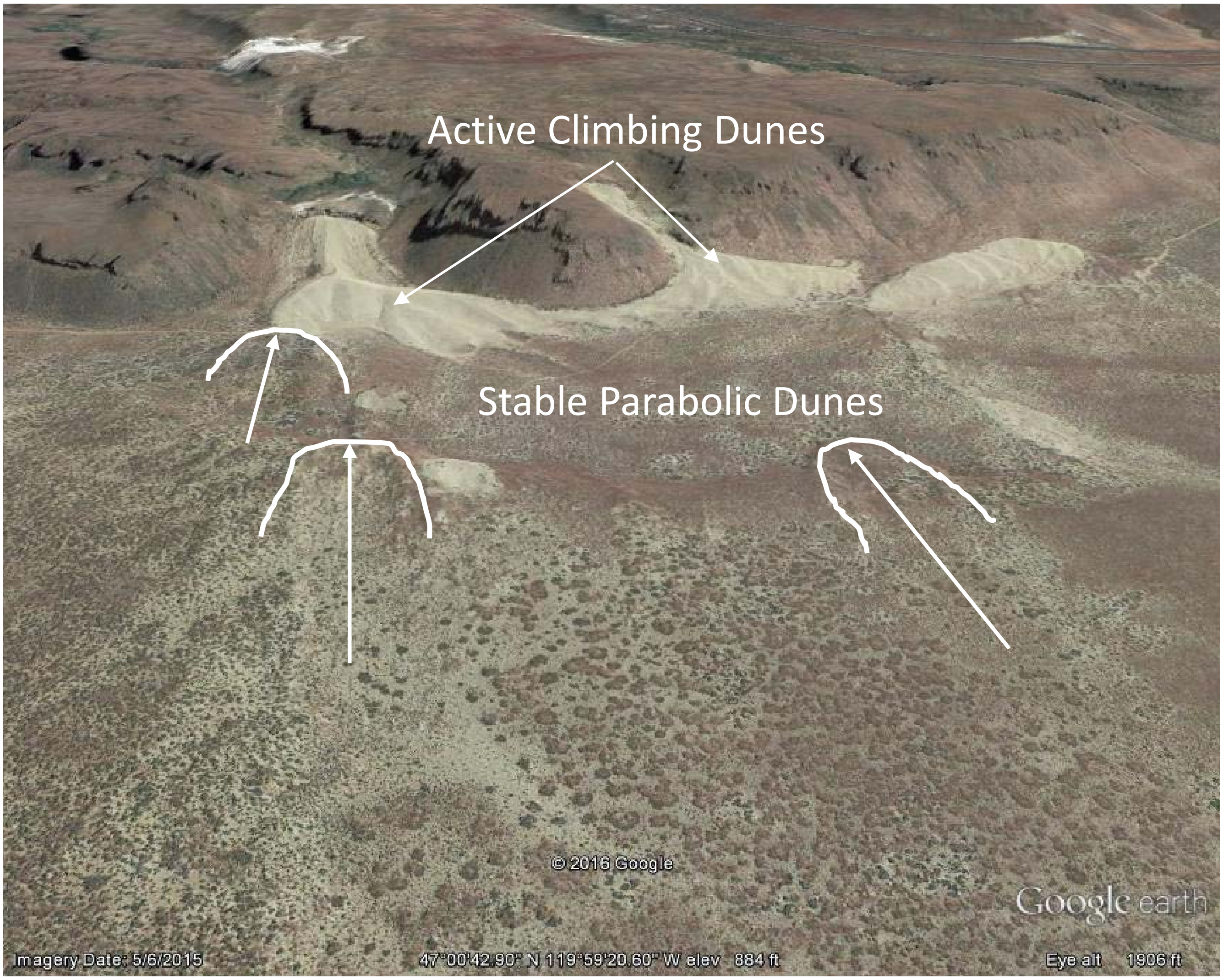


Figure 19. Dunefield of active and stable dunes south of the southern coulee (i.e., Echo Basin) of Frenchman Coulee. Arrows indicate the general wind direction that shaped the stable parabolic dunes in the foreground. View southeast. Source: Google Earth.

Frenchman Coulee to George Gravel Pit

Route and Directions. Return to Silica Road and follow it north for about 6 miles to 1 NW. Note the large diatomaceous earth mines along Silica Road. Also, near the junction of Silica Road and 1 NW, note the location of the world famous Gorge Amphitheatre. Turn right onto 1 NW and follow this east about 5 miles to the George Gravel Pit. Park at the abandoned George Drop Box building parking lot or on the right side of the road.

Stop 2—George Gravel Pit

Location. We are located at the George Gravel Pit site (Figure 20). Cross a fence and walk into the abandoned gravel pit. The geological significance of this site was first noted by G.E. Neff, a longtime geologist for the U.S. Bureau of Reclamation (Bretz and others, 1956).

Flood Gravels. In the walls of the pit here, we are looking at gravels deposited by Ice Age floods. We know they are flood deposited by their subrounded, poorly size sorted, and poorly bedded nature. Poorly developed *foreset bedding* may be seen in places dipping down to the ~south. Foreset beds dip down in the flow direction of water that deposited them (Webster and others, 1976). These gravels are mostly basalt in composition and range from cobbles to boulders in size. Some of the boulders reach 5.5 feet in diameter (Bretz and others, 1956)! Crystalline rocks are also scattered about in these deposits telling us that the floods came from well to the north or northeast.

Caliche. *Caliche* (also known as *calcrete* or *hardpan*) caps these flood deposits. Caliche forms as calcium carbonate dissolved by precipitation moves down from the soil surface. Eventually, the water is evaporated leaving behind these salts in the soil. Over time, caliche development proceeds from scattered, faint carbonate coatings to massive, cemented laminations (Figure 21). Caliche formation typically occurs at depth in a soil, in what is termed the “B” horizon. Excavation associated with the gravel pit and/or the landfill removed the overlying soil horizons but the caliche that remains is impressive. It is 2 to 4 feet deep with the uppermost portion *laminated* (i.e., thinly layered) and cementing the gravels, and the lowermost only cementing the gravels. In places, carbonate coatings on the undersides of cobbles extend to 11 feet deep! Because of the thick, laminated, cemented nature of the caliche here, this must be an old soil.

Old Floods from the Columbia River Valley. Several characteristics of these gravels are odd in comparison to most other Ice Age flood deposits in the Quincy Basin—the presence of caliche atop the flood gravels, deeply weathered basalt cobbles, chunks of Vantage Formation, and the dip of these gravels. The stage IV caliche (Figure 21) lying atop the flood gravels suggests that the floods that deposited them are much older than late Pleistocene. An earlier Pleistocene origin is also supported by the presence of deeply weathered basalt cobbles to a depth of five feet (Webster and others, 1976). Webster and others (1976) estimated that it is a “pre-Bull Lake” age soil. Bull Lake is a term from the Rocky Mountains meaning it is pre-late Pleistocene in age; the flood gravels below that are even older. Based on the similarity of this caliche with a *paleomagnetically* dated soil in Old Maid Coulee to the southeast, the caliche may be Early Pleistocene in age (>780,000 years old) (Bjornstad and others, 2001). This is the oldest of two pre-late Pleistocene flood episodes identified by Neff in the Quincy Basin (Webster and others,

Stop 2—George Gravel Pit

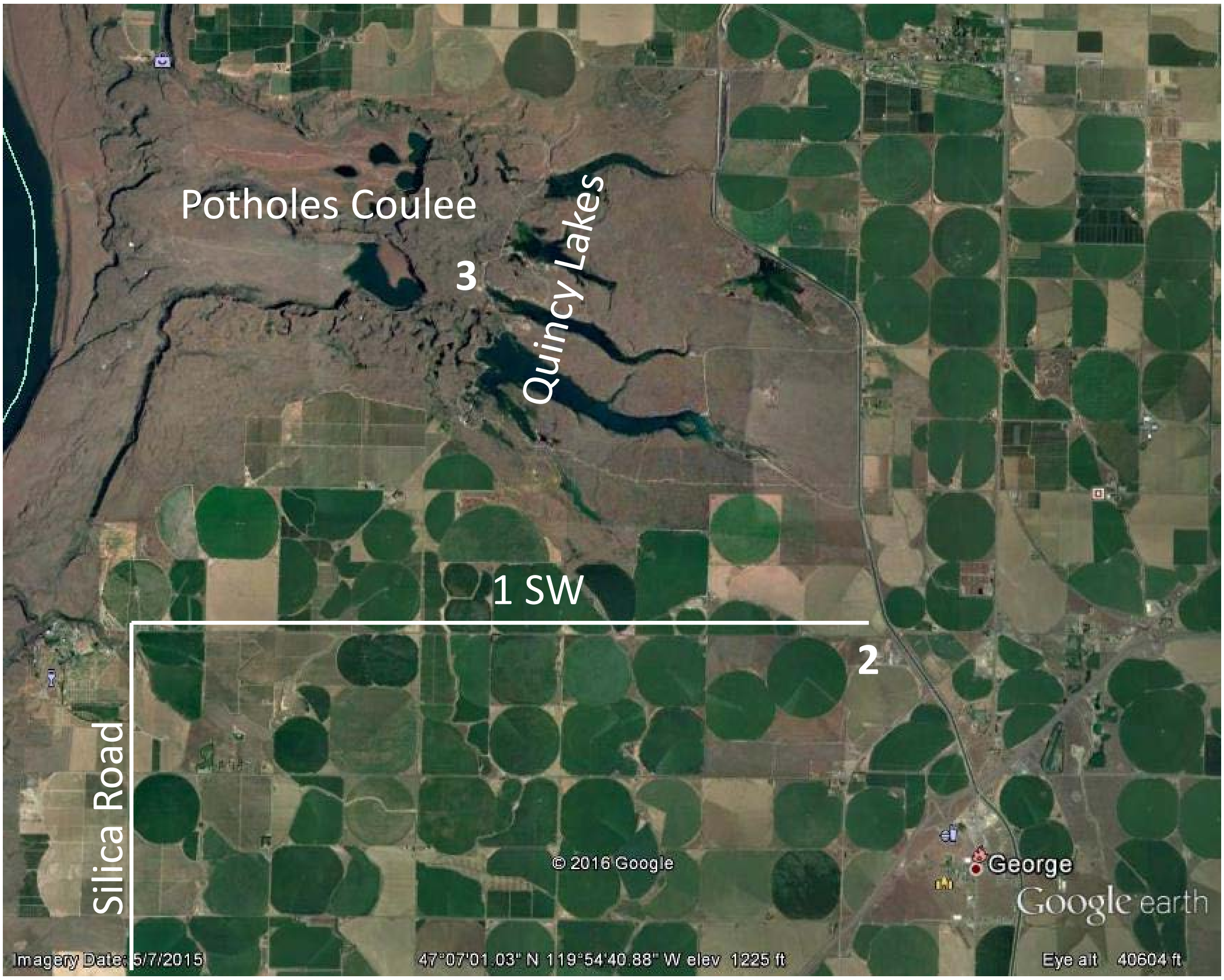


Figure 20. George gravel pit (Stop 2). Note location of Potholes Coulee in relation to George Gravel Pit. White line indicates route from Stop 1 to Stop 2. Also, note the circle indicating central pivot irrigation systems. Source: Google Earth.

Stop 2—George Gravel Pit

Increasing Age

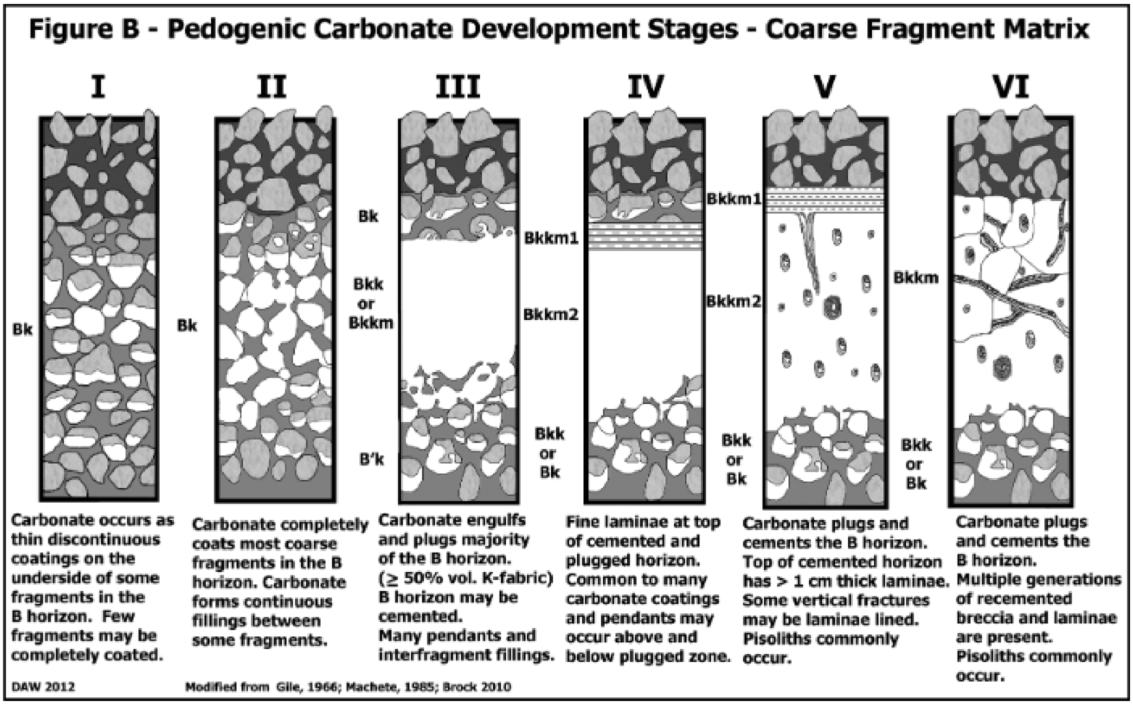


Figure B - Pedogenic Carbonate Development Stages - Coarse Fragment Matrix

I: Carbonate occurs as thin discontinuous coatings on the underside of some fragments in the B horizon. Few fragments may be completely coated.

II: Carbonate completely coats most coarse fragments in the B horizon. Carbonate forms continuous fillings between some fragments.

III: Carbonate engulfs and plugs majority of the B horizon. (≥ 50% vol. K-fabric) B horizon may be cemented. Many pendants and interfragment fillings.

IV: Fine laminae at top of cemented and plugged horizon. Common to many carbonate coatings and pendants may occur above and below plugged zone.

V: Carbonate plugs and cements the B horizon. Top of cemented horizon has > 1 cm thick laminae. Some vertical fractures may be laminae lined. Pisoliths commonly occur.

VI: Carbonate plugs and cements the B horizon. Multiple generations of recemented breccia and laminae are present. Pisoliths commonly occur.

DAW 2012

Modified from Gile, 1966; Machete, 1985; Brock 2010

Figure 21. Time-dependent, soil carbonate stages in gravelly *parent material*. Source: Schoeneberger and others (2012).

Old Floods from the Columbia River Valley (continued)**.** …(1976). Given a flood source moving from east to west across the Quincy Basin, we would expect the dip to be down to the west. Instead, flood sediments here dip down toward the east, southeast, and south suggesting flood flows came from the Columbia River Valley via the Potholes Coulee cataract. Further supporting this source is the presence of *tuffaceous silt* and sand boulders of the Vantage Sandstone Member, an interbed within the Columbia River Basalts (Figure 5). According to Webster and others (1976) and Nummedal (1978), these boulders could have only come from outcrops along Babcock Ridge about 6 miles to the west.

George Gravel Pit to Potholes Coulee

Route and Directions. Proceed southeast on Road 1 NW for ~0.5 miles to road R NW. Turn left onto R NW and proceed ~0.5 miles to WA 281. Turn left and head north on WA 281 for ~4 miles. Near the Quincy Valley Golf Course, turn left and proceed west on White Trail Road. At ~3 miles, the road makes a sharp turn north. At this sharp corner, turn left onto the gravel road marked "Public Fishing". Follow this gravel road south ~2 miles to Burke Lake. Park along the road or in one of the parking areas near the Dusty Lake Trailhead. We will take the trail out of the large parking/camping area just north of the formal Dusty Lake trailhead.

Stop 3—Potholes Coulee

Location. We are located just north of the Dusty Lake Trailhead above Potholes Coulee (Figure 22). We will hike on faint trails to viewpoints above Dusty Lake and Ancient Lakes.

Scablands. Our hike to the viewpoints crosses butte and basin topography of the channeled scablands. Buttes and basins abound on this flood-scoured landscape. Very little soil remains atop the basalts. The large lakes east of us--Stan Coffin Lake, Quincy Lake, Burke Lake, and Evergreen Reservoir (Figure 20)—occupy scabland channels leading into Potholes Coulee. While the scablands are Ice Age features, the lakes are a product of irrigation leakage and irrigation return flow from the irrigation lands of the Columbia Basin Irrigation Project.

Potholes Coulee as a Giant Cataract. Potholes Coulee (or "The Potholes as referred to on the 1910 USGS Quincy quadrangle—Figure 23) is a double cataract over 1.5 miles wide. In fact, it was the Quincy quadrangle that set J Harlen Bretz on the path of Ice Age flooding as an origin for this feature. Bretz first saw this map soon after it was published while he was a teacher in the Seattle School District (Soennichsen, 2008). In Bretz (1923b) he said "The Potholes is the best example mapped of a receding waterfall over lava flows which is known to the writer". While Bretz' may have subsequently seen better examples of receding waterfalls, "The Potholes" nonetheless are very prominent features. Note the absence of water in Potholes Coulee in 1910 (Figure 23). Runoff from the Columbia Basin Irrigation Project has since formed Dusty Lake in the southern arm of the coulee and Ancient Lakes in the northern alcove. These lakes occupy plunge pools formed by giant waterfalls. The downstream ends of the lakes are impounded by large bars. A prominent, >2 mile long bedrock blade separates the two alcoves of the coulee. This blade ranges up to nearly 1000 feet wide and 375 feet tall. Potholes Coulee has the lowest drainage divide elevation of the three western Quincy Basin outlets (Bjornstad, 2006; Baker and others, 2016) therefore should been the last to transmit water to the Columbia River Valley. With a drop of >850 ft over a distance of <3 miles, Potholes Coulee was rapidly eroded in the Columbia River Basalts (Bjornstad, 2006; Baker and others, 2016).

Cataract Levels. Potholes Coulee consists of three cataract levels eroded in the basalts—upper, middle, and lower (Figure 22). The Upper Cataract is eroded into the Roza flow and extends nearly 3 miles to the western edge of the Quincy Lakes. The Middle Cataract is in the Frenchman Springs flow and forms much of the rims of the two alcoves of Potholes Coulee. The Lower Cataract is in the Sentinel Bluffs flow The position and small sizes of the lowest alcoves indicate that they had just started to form in the final floods to pass through the area (Bjornstad, 2007).

Bars and Giant Current Ripples. Large gravel bars are present in each of the arms of the coulee. Bretz (1923b) estimated that the bar in the southern arm was 200 feet thick. Bretz (1928, p. 677) described the bar in the northern arm as follows: *The northern alcove has a bar along its north side for a mile. The bar crest is distinct; it is elongate like a great beach ridge and throughout it is separated from the basalt wall by a fosse whose depth is 50 feet maximum. Talus in one place has nearly filled the fosse. Boulders of basalt 2 to 3 feet in diameter lie on the bar, clearly not debris from the crumbling wall adjacent. The channel in the middle of the alcove floor is at least 125 feet lower than the bar top. The water at the time the bar was built was at least that deep, for the lower 75 feet of this channel depth is a rock basin. The channel is more than half a mile wide. The size and vigor of the stream here is thus indicated".*

Stop 3—Potholes Coulee

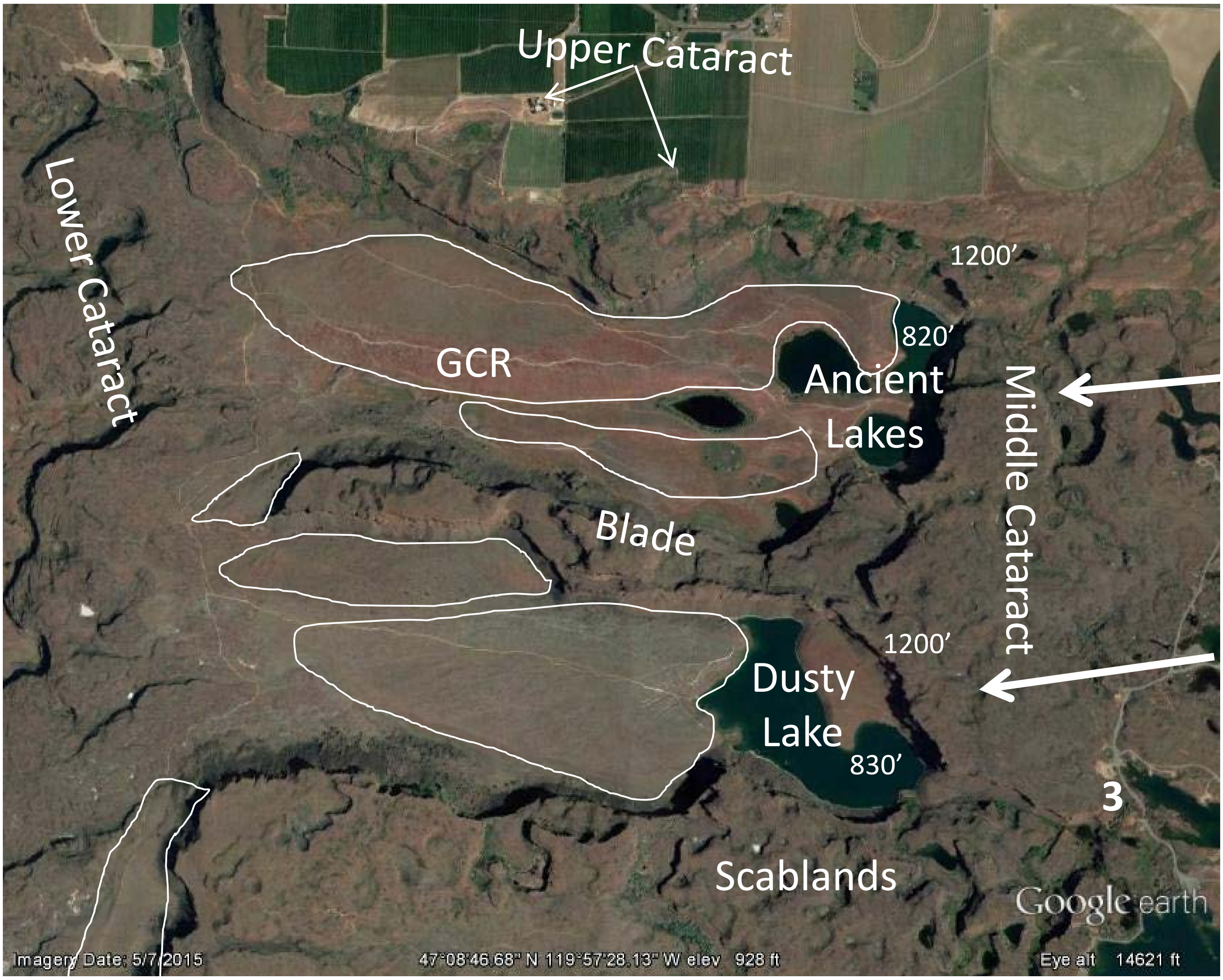


Figure 22. Potholes Coulee. Approximate boundaries of bars outlined in white (Fairbanks, 2003). Giant current ripples (GCR) from Fairbanks (2003). Examples of locations of different cataract levels from Bjornstad (2006). Approximate elevations shown in small numerals. Bold 3 indicates approximate location of Stop 3. Source: Google Maps.

Bars and Giant Current Ripples (continued). … Fairbanks (2003) mapped the bars as crescent-point bars at the mouths of each of the alcoves, pendant bars in the Ancient Lakes alcove, and pendant and expansion bars in the Dusty Lakes alcove (Figure 22). Giant current ripples are present on the large pendant bar in the Ancient Lakes alcove (Figure 22). The average wavelength of these giant current ripples is 23 m (Fairbanks, 2003) suggesting they were formed by very high velocity flows.

Columbia Basin Irrigation Project and a Not-So-Ancient Lake. The Columbia Basin Irrigation Project brought tremendous changes to the Potholes Coulee area (Figure 24). With the delivery of irrigation water to Western Quincy Basin beginning in 1952, wastewater flowed into the northern arm of Potholes Coulee via the West Canal, Columbia River Wasteway and Stan Coffin Lake. This resulted in a large lake that filled the northern arm of the coulee. By 1954, the U.S. Bureau of Reclamation had stopped delivery of the surface water and the lake level dropped 130 feet. Faint shorelines reflect this high level   Four smaller lakes remain in the northern alcove fed by limited surface and groundwater flow.

Stop 3– Potholes Coulee

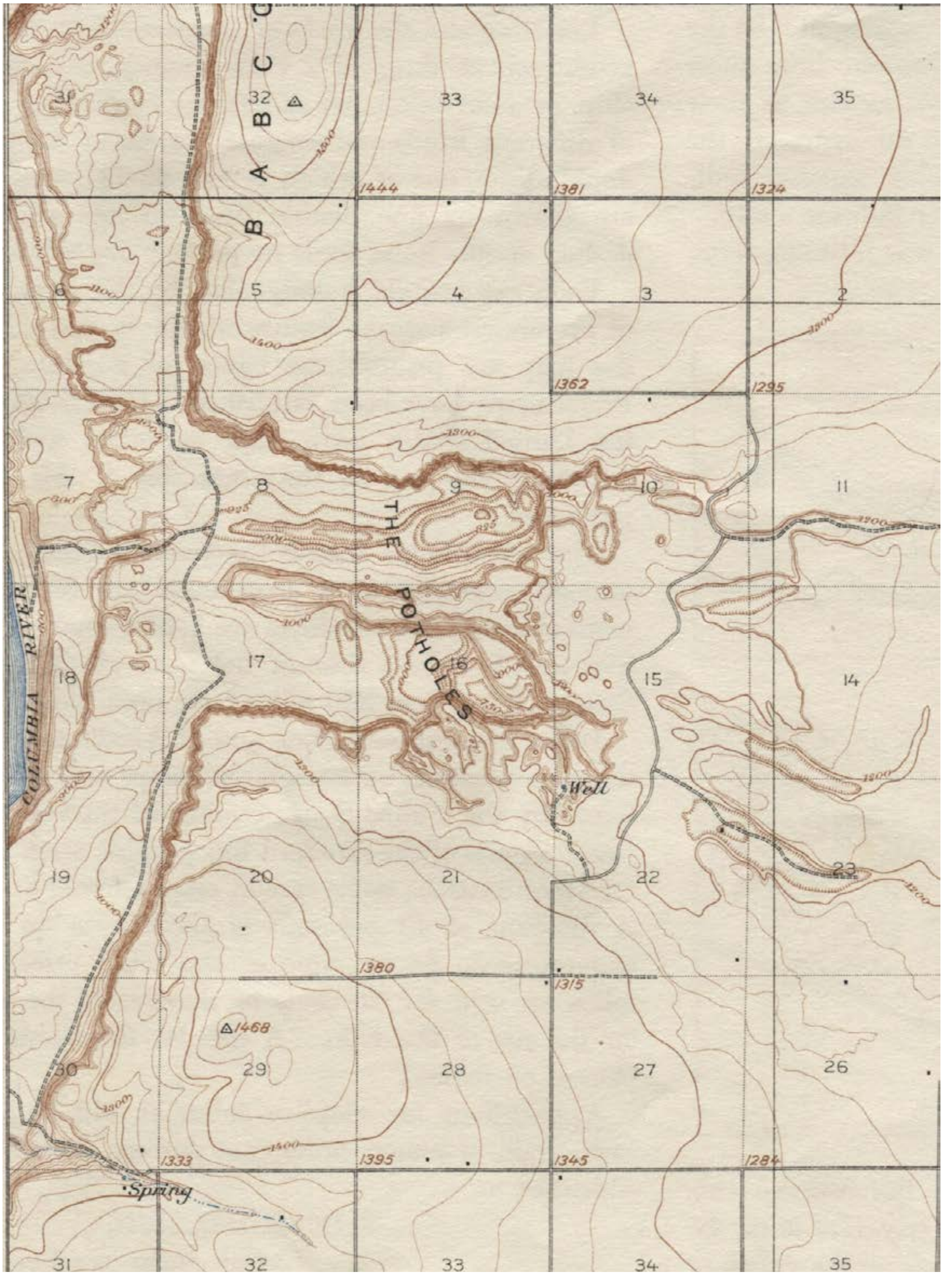


Figure 23. The Potholes (i.e., Potholes Coulee) on the eastern portion of the Quincy, Washington 1:125,000 quadrangle. This is the map that initially caught J Harlen Bretz' eye. Source: US Geological Survey.

Stop 3—Potholes Coulee

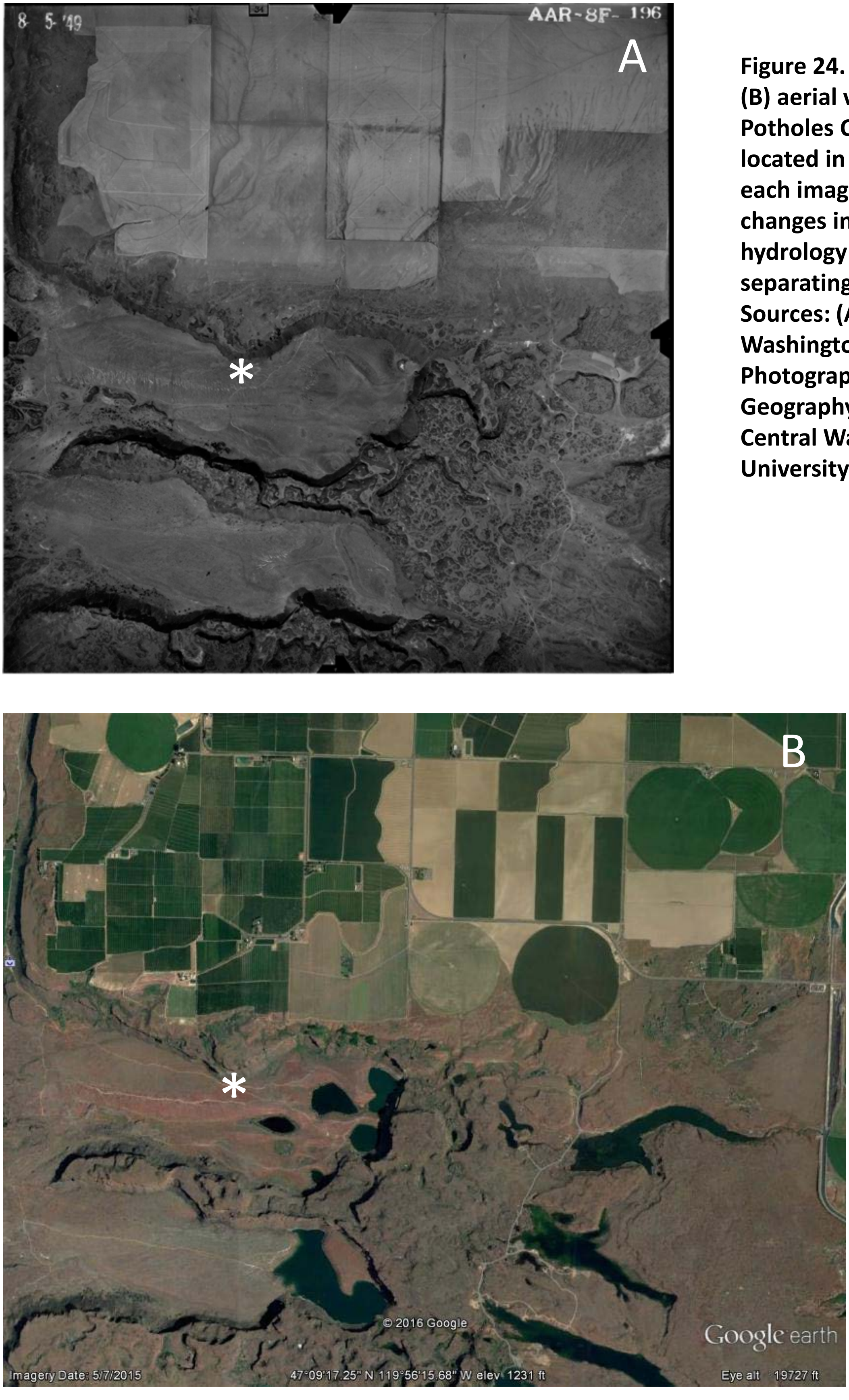


Figure 24. 1949 (A) and 2015 (B) aerial views of the Potholes Coulee area. The * is located in the same place on each image. Note the distinct changes in agriculture and hydrology over the 66 years separating the two images. Sources: (A) Central Washington Historical Aerial Photograph Project, Geography Department, Central Washington University; (B) Google Earth.

Stop 3—Potholes Coulee

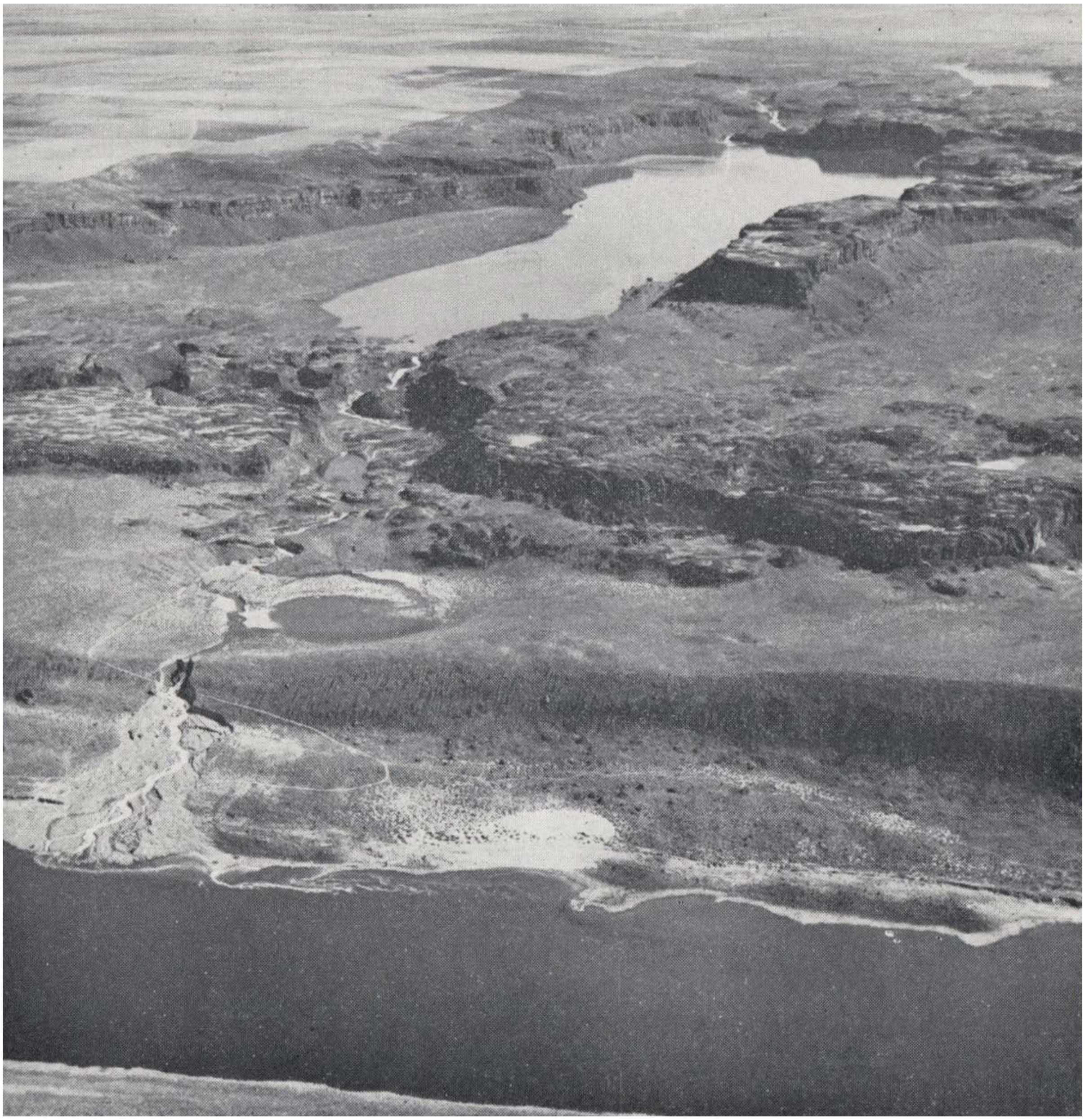


Figure 25. Irrigation wastewater lake in the north alcove of Potholes Coulee in 1954. U.S. Bureau of Reclamation photograph P-222-177-35237 in Bretz (1959, p. 28)

Potholes Coulee to Crater Coulee

Route. From near the Burke Lake and the Dusty Lake Trailhead, return to White Trail Road. Turn left onto White Trail Road and follow it west, then north ~6 miles to its junction with WA 28. Turn left onto WA 28 and follow it ~3 miles west to Baird Springs Road. Turn right onto Baird Springs Road and follow it ~2 miles to road W NW. Turn left onto this road and follow it up the hill to a good viewpoint above the Burlington Northern Santa Fe railroad line. This is Stop 4.

Optional Stop 4—Crater Coulee (Lower Lynch Coulee)

Location. We are located on road W NW across lower Lynch Coulee from the mouth of Crater Coulee (Figure 26).

Crater Coulee and its Formation. J Harlen Bretz (1928a) first recognized Crater Coulee ("Crater Cateract") as the northernmost and the smallest of three catastrophic flood-created cataracts in the western Quincy Basin (Figure 26). He discussed these cateracts (including Crater Cataract) in subsequent papers (1928b, 1928c, 1930, 1956, 1959, and 1969). The following summarizes Bretz' thoughts on Crater Coulee's formation. Crater Coulee formed as floodwaters overtopped a low divide created by the Lynch Coulee anticline (Figures 8 & 26), exploiting a pre-existing, non-scabland "gulch" eroded in the western limb of the anticline to the Lynch Coulee floor below. Headward erosion of the resistant, folded basalts of the anticline's western limb must have

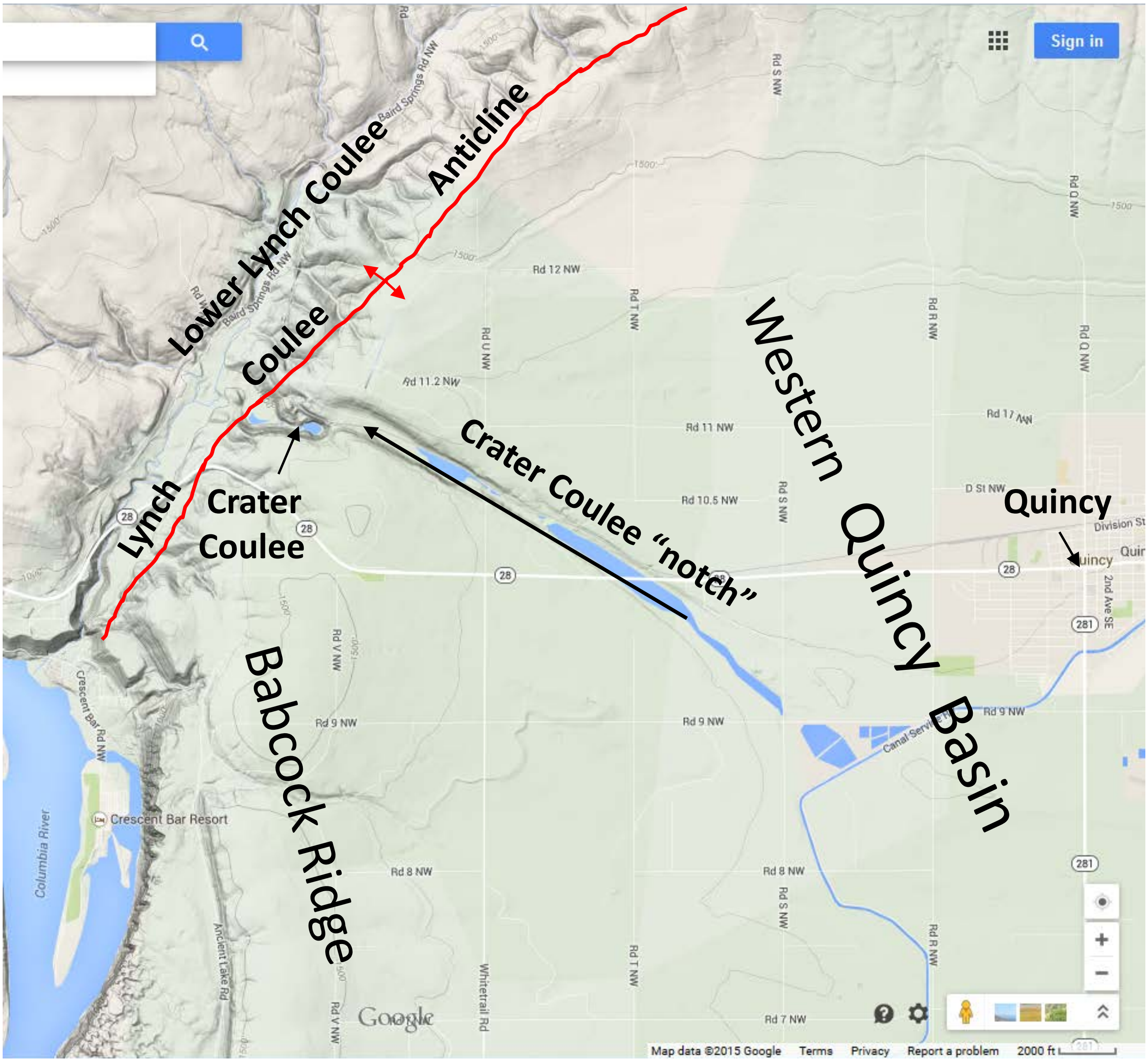


Figure 26. Crater Coulee and Crater Coulee "notch", western Quincy Basin. Large arrow indicates flood flow direction. Source: Google Maps.

Optional Stop 4—Crater Coulee

Crater Coulee and its Formation (continued). …rapidly resulted in a ~200 foot tall waterfall and a smaller, ~70 foot tall waterfall (Figure 27). With time, the Crater Cataract receded headwardly approximately 1mile. Most of Crater Coulee's "notch" (or channel eroded into the eastern limb of the anticline) is intact because the waterfall receded so little.

Crater Coulee and Bretz' Catastrophic Flood Hypothesis. Bretz (1956) attributed Crater Coulee's slightly (~70 feet) higher elevation to lower flood discharge and shorter use as a floodway on the northern margins of the basin compared to Potholes and Frenchman Springs coulees to the south. He also noted that the bedrock and sediment-filled plunge pool basin of Crater Coulee suggested discharge through Crater Coulee decreased rapidly because Frenchman Springs and Potholes coulees deepened faster. My observations indicate that the rim of Waterfall B (Figure 25) is ~70 feet higher than that of Waterfall A (~1320 feet vs. 1250 feet). This may suggest that larger flow through the area created both waterfalls but as water levels dropped, flow concentrated at Waterfall A.

Lower Lynch Coulee. Bretz (1930) refers to this as Willow Creek Draw. Upstream of Crater Coulee, the valley floor averages about 400 feet in width (Figure 28). Conversely, the valley floor downstream of the coulee mouth is closer to 800 feet wide, and has a lower gradient. This increased width and lower gradient is the result of floodwaters descending Crater Coulee into Lynch Coulee. The slopes of Lower Lynch Coulee are also truncated as a result of flood erosion (Figure 28). Bretz (1930) first recognized the low gradient, gravel fill of the floor of Lower Lynch Coulee that stretches from the mouth of Crater Coulee to Trinidad. Waitt (1977) identified two distinct, but similar-aged flood deposits in the Lower Lynch Coulee fill. The lower sediments indicate flow upvalley (into Lynch Coulee) and the upper sediments show downvalley flow (likely from Crater Coulee).

Columbia Valley Floods in Crater Coulee. "Slightly bruised" columnar [basalt] fragments in mostly unsorted gravels containing caliche, other basalts, siltstones, and loess at the head of Crater Coulee suggest eastward flow of cataclysmic floodwaters from the mainstem Columbia River through Crater Coulee (Bretz, 1969). Based on this and evidence from the George Gravel Pit (Stop 2), it appears huge Columbia Valley floods preceded the humongous outpourings from north and east.

Optional Stop 4—Crater Coulee

Figure 27. Crater Coulee cataract. Arrows indicate floodwater movement directions. Letters indicate plunge pools. View toward east. Source: Google Earth.

Wrap-up

You have had an opportunity to see the key characteristics of an Ice Age flood-shaped landscape in Western Quincy Basin. All three outlets (Figures 3 & 22): 1) formed in Columbia River Basalts; 2) have similar upper elevations indicating that they operated simultaneously (hence are evidence for a flood origin for the scablands); 3) eroded headwardly through Evergreen-Babcock ridge; 4) resulted in prominent cataracts consisting of two or more coulees or alcoves; 5) have prominent plunge pools at their heads; 6) are surrounded by Channeled Scablands that include butte and basin topography; 7) have bars on their floors; 8) shaped the land use of Quincy Basin; and 9) are currently influenced by irrigation runoff. They differ in their degrees of development, their impoundment of irrigation water in lakes, and in the development of sand dunes within.

Optional Stop 4—Crater Coulee

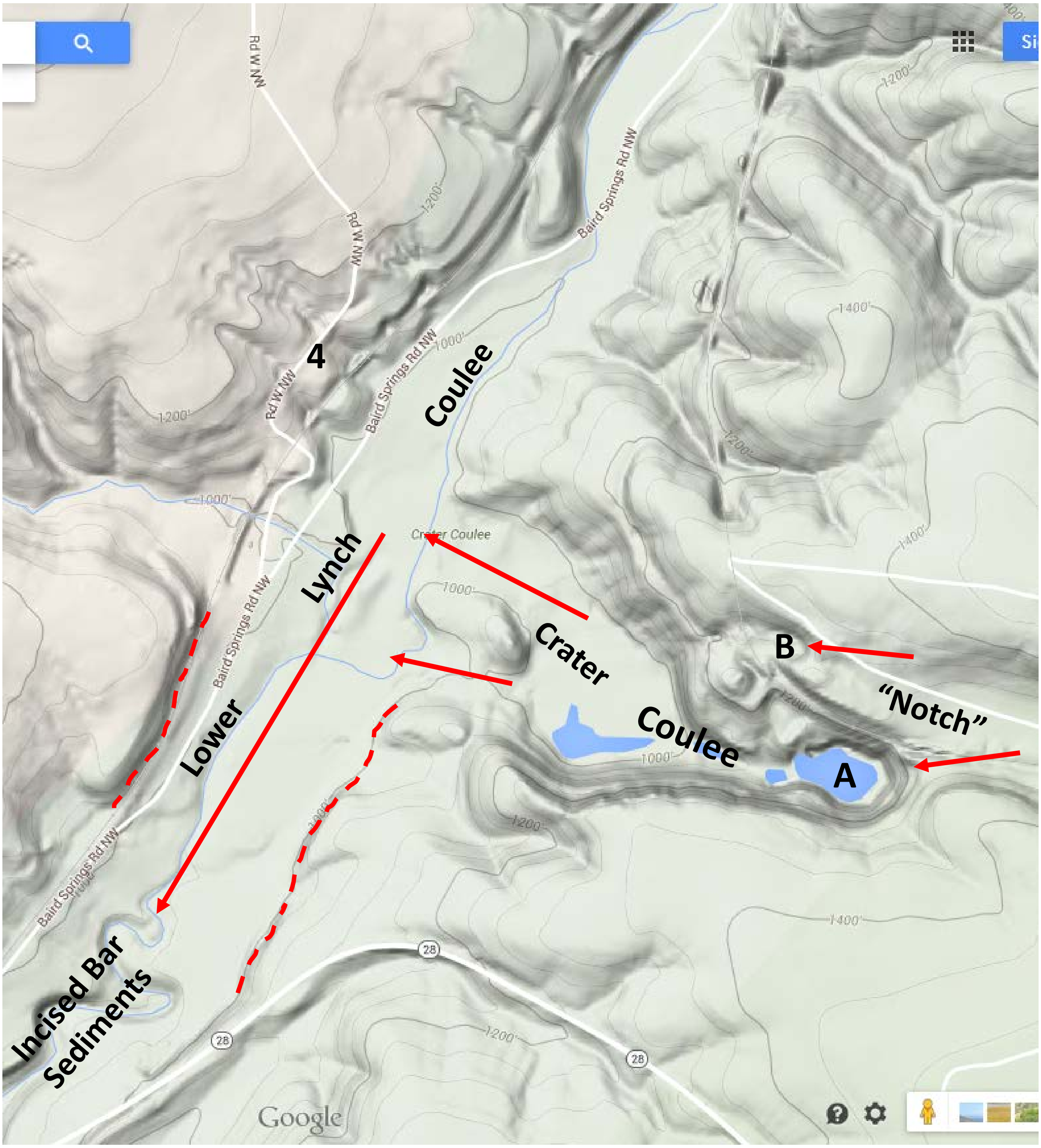


Figure 28. Crater Coulee and Lynch Coulee. Note the double, albeit unequal sized, plunge pools in the Crater Coulee cataract. Also, note the width difference between Lynch Coulee above and below Crater Coulee. Finally, note the abrupt east and west walls of Lower Lynch Coulee below Crater Coulee (dashed) that resulting from floodwater erosion. Letters indicate plunge pools. Source: Google Maps.

Wrap-up

(Continued)…Bretz (1928b, 1928c, 1930, 1956, 1959, and 1969) recognized the importance of Frenchman, Potholes, and Crater coulees in the catastrophic flood story. The fact that each of the outlets cuts across a topographic divide suggests that huge amounts of water were present in Quincy Basin. Further, common elevations for the upper levels of entrenchment (~1300 feet) suggest all three outlets operated contemporaneously to drain floodwaters from the Quincy Basin. Such contemporaneous operation was a key piece to arguing that floods, not long-term diversion of a "normal" Columbia River, resulted in the erosion of each of the outlets at different times.

I hope this has been an educational and enjoyable field trip for you. Don't hesitate to contact me with questions or comments about this field trip or associated Ice Age floods issues.

Thanks for participating! Karl Karl.Lillquist@cwu.edu & (509) 963-1184

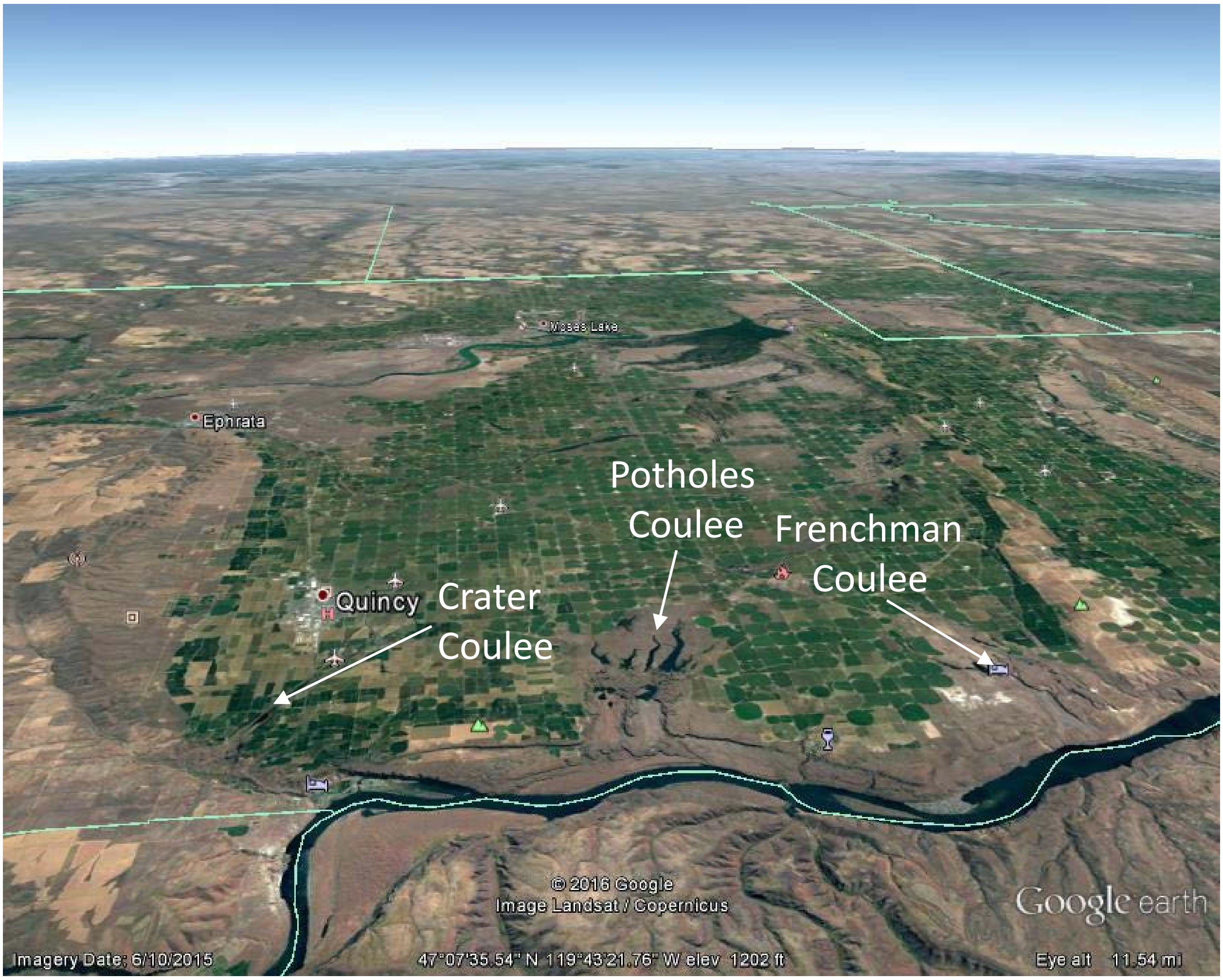


Figure 29. Oblique view of Quincy Basin, looking east. Note the locations of Crater Coulee, Potholes Coulee, and Frenchman Coulee. Source: Google Earth.

References

- Anglin, R. 1995. *Forgotten Trails: Historical Sources of the Columbia's Big Bend Country*. Washington State University Press. Pullman.
- Baker, V.R. 2009. The Channeled Scabland: A retrospective. *Annual Reviews of Earth and Planetary Sciences* 37: 6.1-6.19.
- Bandfield, J.L., K.S. Edgett and P.R. Christensen. 2002. Spectroscopic study of the Moses Lake dune field, Washington: Determination of compositional distributions and source lithologies. *Journal of Geophysical Research* 107 (E11, 5092): 2-1 to 2-15.
- Bjornstad, B.N. 2006. *On the Trail of the Ice Age Floods: A Geological Field Guide to the Mid-Columbia Basin*. Keokee Company Publishing, Inc. Sandpoint, ID.
- Bjornstad, B.N., K.R. Fecht and C.J. Pluhar. 2001. Long history of Pre-Wisconsin, ice age cataclysmic floods: Evidence from southeastern Washington state. *Journal of Geology* 109: 695-713.
- Bjornstad, B. and E. Kiver. 2012. *On the Trail of the Ice Age Floods: The Northern Reaches*. Keokee Company Publishing, Inc. Sandpoint, ID.
- Bretz, J H. 1923a. The Channeled Scablands of the Columbia Plateau. *Journal of Geology* 31 (8): 617-649.
- Bretz, J H. 1923b. Glacial drainage on the Columbia Plateau. *Bulletin of the Geological Society of America* 34: 573-608.
- Bretz, J H. 1927. Channeld Scabland and the Spokane Flood. Journal of Washington Academy of Sciences 18: 200-211.
- Bretz, J H. 1928a. The Channeled Scabland of Eastern Washington. *Geographical Review* 18 (3): 446-477.
- Bretz, J H. 1928b. Bars of Channeled Scabland. *Geological Society of America Bulletin* 39: 643-702.
- Bretz, J H. 1928c. Alternate hypotheses for Channeled Scabland. *Journal of Geology* 36: 193-223, 312-341.
- Bretz, J H. 1959. Washington's Channeled Scabland. *Washington Division of Mines and Geology Bulletin 45*.
- Bretz, J H. 1969. The Lake Missoula Floods and the Channeled Scabland. *Journal of Geology* 77: 505-543.
- Bretz, J H., H.T.U. Smith and G.E. Neff. 1956. Channeled Scabland of Washington: New data and interpretations. *Bulletin of the Geological Society of America* 67: 957-1049.
- Campbell, N.P. 1975. A Geologic Road Log Over Chinook, White Pass, and Ellensburg to Yakima Highways. *Washington Division of Geology and Earth Resources Information Circular 54*.
- Carson, R.J., T.L. Tolan and S.P. Reidel. 1987. Geology of the Vantage area, south-central Wahsington: An introduction to the Miocene flood basalts, Yakima Fold Belt, and the Channeled Scabland. Pp. 357-362 in M.L. Hills, ed., *Geological Society of America Centennial Field Guide—Cordilleran Section.* Boulder, CO.

References (continued)

- Donaldson, W.R. 1979. Washington Climate for these counties: Grant, Kittitas, Klickitat, and Yakima. *Washington State University Cooperative Extension Service EM 4422.*
- Fairbanks, M. 2003. The Geomorphology of Potholes Coulee, Quincy Basin, Washington. Undergraduate Research Project, Geography Department, Central Washington University. https://www.cwu.edu/geography/karl-lillquist-previous-research-students.
- Fairbridge, R.W. 1968. Coulee, Coulee Cliff, Coulee Lake, Couloir. Pp. 205-206 in R.W. Fairbridge, ed., *The Encyclopedia of Geomorphology*. Reinhold Book Corporation. New York.
- Gentry, H.R. 1984. Soil Survey of Grant County, Washington. U.S. Department of Agriculture, Soil Conservation Service.
- Grolier, M.J. and J.W. Bingham. 1978. Geology of parts of Grant, Adams, and Franklin counties, east-central Washington. *Washington Division of Geology and Earth Resources Bulletin 71.*
- House, P.K., B.J. Buck and A.R. Ramelli. 2010. Geologic Assessment of Piedmont and Playa Flood Hazards in the Ivanpah Valley Area, Clark County, Nevada. *Nevada Bureau of Geology and Mines Report 53*.
- Huckleberry, G., B. Lenz, J. Galm, and S. Gough. 2003. Recent geoarchaeological discoveries in central Washington. Pp 237-249 in T.W. Swanson, ed., *Western Cordillera and Adjacent Areas*. Geological Society of America Field Guide 4. Boulder, CO.
- Landes, H., A.W. Mangum, H.K. Benson, E.J. Saunders and J. Jacobs. 1912. A Preliminary Report on the Quincy Valley Irrigation Project. *Washington Geological Survey Bulletin 14*.
- Lewis, W.S. 1926. *Early Days in the Big Bend Country*. W. D. Allen, Publisher. Spokane.
- Mangum, A.W., C. Van Duyne and H.L. Westover. 1913. Soil Survey of the Quincy Area, Washington. U.S. Department of Agriculture Bureau of Soils.
- McIntyre, A.A. 1906. *The Last Grand Roundup*. The Chief Research Company. Sacramento, CA.
- Meinig, D.W. 1968. *The Great Columbia Plain: A Historical Geography, 1805-1910*. University of Washington Press. Seattle.
- Menicucci, A.J., P.J. Noble and M. Houseman. 2016. Paleolimnology and diatom flora of the Miocene Quincy diatomite, Washington, USA. *Revue et micropaleontology* 59: 381-395.
- Morris, F. 1976. *They Claimed a Desert*. Ye Galleon Press. Fairfield, WA.
- Newcomb, R.C. 1958. Ringold Formation of Plestocene Age in type locality, the White Bluffs, Washington. *American Journal of Science* 256 (5): 328-340.
- Nummedal, D. 1978. Field trip stop descriptions. Pp. 131-168 in V.R. Baker and D. Nummedal, eds., *The Channeled Scabland*. NASA. Washington, D.C.
- Petrone, A. 1970. The Moses Lake Sand Dunes. M.S. Thesis. Washington State University. Pullman, WA
- Reidel, S.P. and N.P. Campbell . 1989. Structure of the Yakima Fold Belt, central Washington. Pp. 275-306 in N.L. Joseph, ed., Geologic Handbook for Washington and Adjacent Areas. *Washington Division of Geology and Earth Resources Information Circular 86*.

References (continued)

- Schoeneberger, P.J., D.A. Wysocki, E.C. Benham and Soil Survey Staff. 2012. Field Book for Describing and Sampling Soils (version 3.0). Natural Resources Conservation Service, National Soil Survey Center. Lincoln, NB.
- Schuster, J.E., C.W. Gulick, S. P. Reidel, K.R. Fecht, and S. Zurenko. 1997. Geologic Map of Washington—Southeast Quadrant. *Washington Division of Geology and Earth Resources Geologic Map GM-45*.
- Schwennesen, A.T. and O.E. Meinzer. 1918. Ground Water in Quincy Valley, Washington. *U.S. Geological Survey Water Supply Paper 425*.
- Soennichesen, J. 2008. *Bretz's Flood: The Remarkable Story of a Rebel Geologist and the World's Greatest Flood*. Sasquatch Books. Seattle.
- Stoffel, K.L., N.L. Joseph, S. Zurenko Waggoner, C.W. Gulick, M.A. Korosec and B.B. Bunning. 1991. Geologic Map of Washington—Northeast Quadrant. *Washington Division of Geology and Earth Resources Geologic Map GM-39*.
- Symons, T.W. 1882. The Upper Columbia River and the Great Plain of the Columbia. U.S. 47th Congress, 1st Session, Senate Executive Document 186.
- Tolan, T.L., B.S. Martin, S.P. Reidel, J.L. Anderson, K.A. Lindsey and W. Burt. 2009. An introduction to the stratigraphy, structural geology, and hydrogeology of the Columbia River Flood-Basalt Province: A primer for the GSA Columbia River Basalt Group field trips. Pp. 599-643 in J.E. O'Conner, R.J. Dorsey and I.P. Madin, eds. *Volcanoes to Vineyards: Geologic Field Trips through the Dynamic Landscape of the Pacific Northwest*. Geological Society of America Field Guide 15. Boulder, CO.
- U.S. Weather Bureau. 1962. Evapotranspiration maps for the state of Washington.
- Waitt, R.B. 2016. Megafloods and Clovis cache at Wenatchee, Washington. *Quaternary Research* 85: 430-444.
- Washington, N.W. 1956. The nomadic life of the Tsin-Cayuse as related by Billy Curlew (Kul Kuloo) in the fall of 1956 to Nat Washington, Jr. Unpublished manuscript. Ephrata, Washington. 4 p.
- Webster, G.D., V.R. Baker, and C. Gustafson. 1976. Channeled Scablands of Southeastern Washington: A Roadlog via Spokane-Coulee City-Vantage-Washtucna-Lewiston-Pullman. Geological Society of America Cordilleran Section Meeting Field Guide 2.
- Western Regional Climate Center. n.d. Quincy 1 S Washington (456880). http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa6880
- Works Projects Administration. 1941. *Washington: A Guide to the Evergreen State*. Binfords and Mort. Portland, OR.