Ice Age Floods Institute—Ellensburg Chapter

Upper Crab Creek Field Trip

<u>Field Trip Leaders</u>:

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Jack Powell, Washington DNR

Sunday 14 April 2013

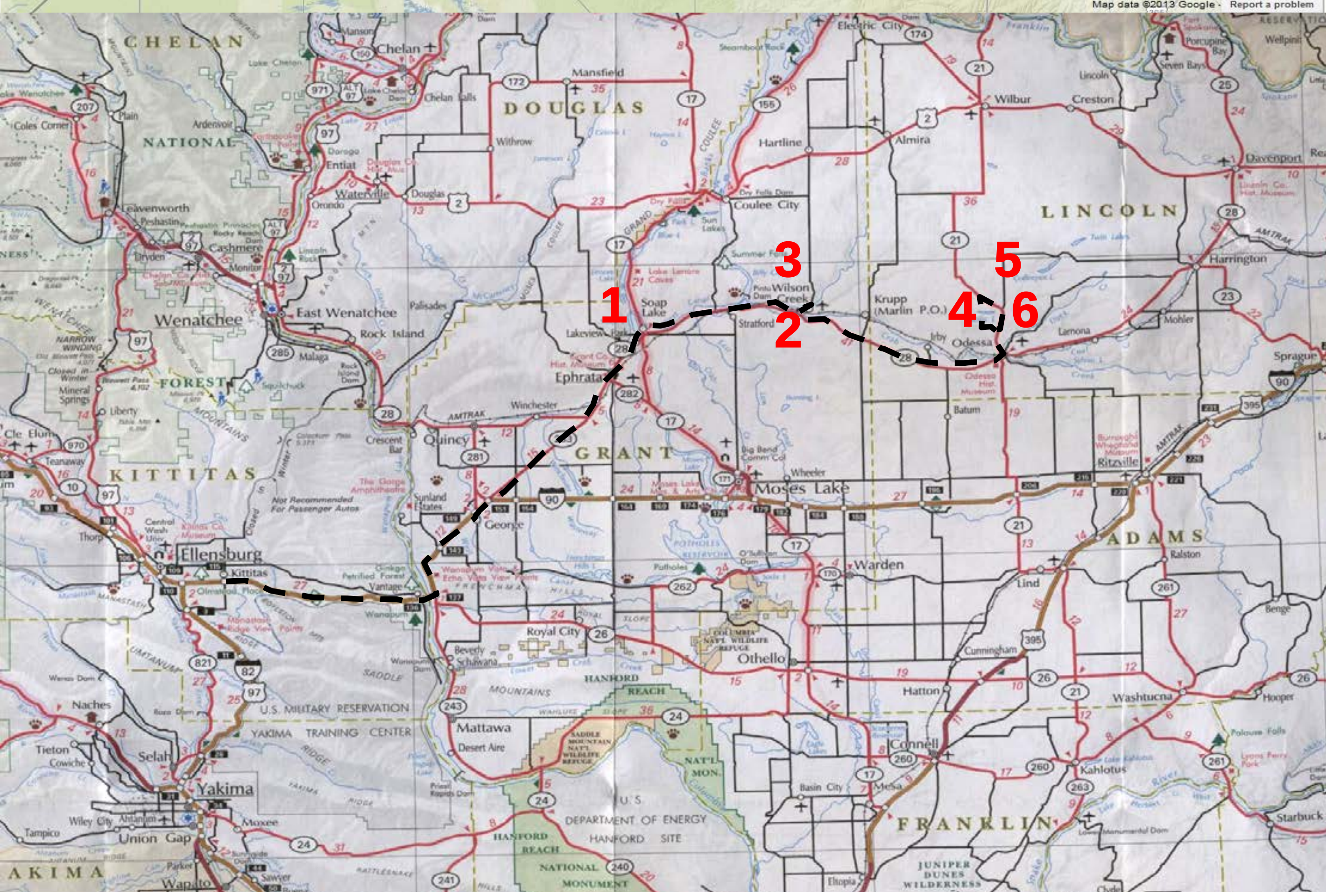


Figure 1. Our route across Central Washington. Numbers above refer to stops. Image source: Washington state highway map.

Itinerary & Trip Overview

8:30	Depart from CWU	
9:45	**Stop 1—Soap Lake Park**	
	- Restrooms	
	- Closed-Basin Soap Lake	
10:25	Depart	
10:45	**Stop 2—Wilson Creek Flood Bar**	
	- Columbia River Basalts	
	- Giant Flood Bars	
11:10	Depart	
11:15	**Stop 3--Wilson Creek School**	
	- Giant flood bars	
	- Giant current ripples	
11:45	Depart	
12:30	**Stop 4—Pacific Lake**	
	- Restrooms & lunch	
	- Demise of Pacific Lake	
	- Intro to basalt ring structures	
1:15	Depart	
1:30	**Stop 5—Odessa Craters Loop**	
	- Ring structures	
3:15	Depart	
3:30	**Stop 6—Cinammon Roll**	
	- More ring structures	
4:00	Depart	
6:00	Arrive in Ellensburg	

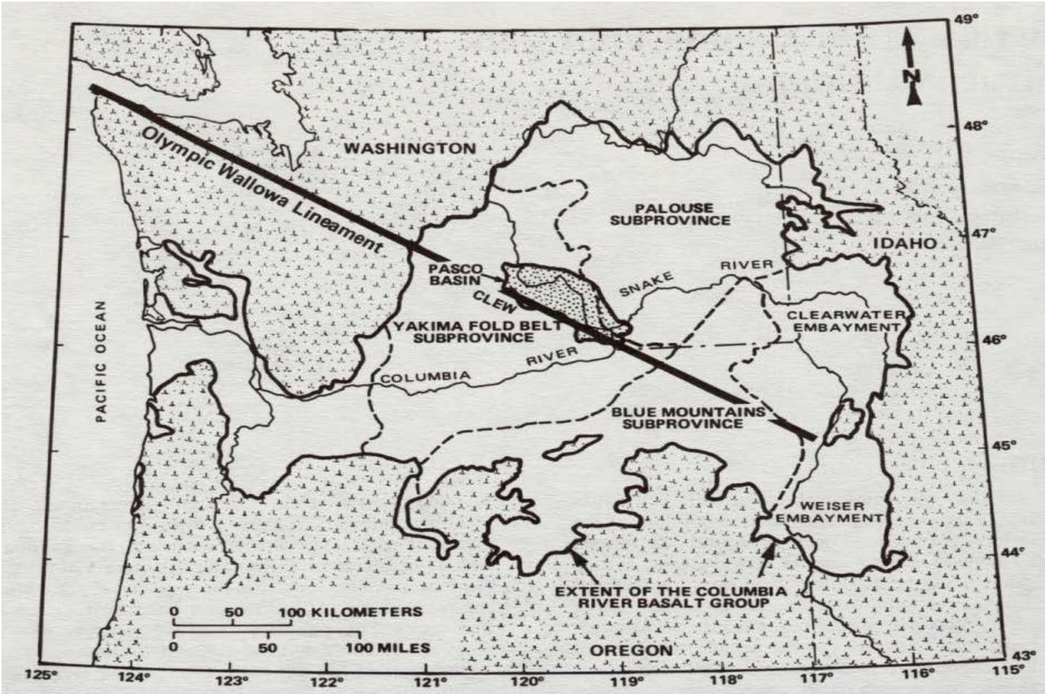
Join us to explore the geology and physical geography of the Upper Crab Creek drainage of eastern Washington. We will carpool from Hebeler Hall on the Central Washington University campus at 8:30 am and head non-stop to Soap Lake's City Park. There, we will discuss the origins and significance of Soap Lake. From Soap Lake, its up the Crab Creek Valley to near Wilson Creek where we examine giant flood bars and current ripples. Our next stop will focus on Pacific Lake and its demise on the Bureau of Land Management's Lakeview Ranch property north of Odessa This will also serve as our lunch stop. Following Pacific Lake, we will explore the character and origins of the "Odessa Craters" (also known as "ring dikes". "basaltic ring structures", "ringed craters" or "sag flowouts"), circular structures in the basalts that are so common in the area yet so poorly understood. One of the stops focused on the circular structures will involve a ~2 mile hike over rough terrain.

En route to Stop 1

Figure 2. Topography of our route to Stop 1. Source of image: Google Maps.

- Our route takes us from Ellensburg to Vantage via I-90 (Figures 1 & 2).
- Ellensburg lies near the western margins of the Columbia River Basalts. Our drive from Ellensburg begins on the floor of the Kittitas Basin syncline with downfolded Columbia River Basalts ~4000 feet below us (Figures 3 & 4). Mantling the Columbia River Basalts are alluvial fan sediments from the surrounding mountains, Yakima River sediments, and loess.
- East of Kittitas we begin to ascend the Ryegrass anticline (Figure 5) where we see the wind towers of the Wildhorse and Vantage Wind Farm. Wind farms remind us of the regularity and strength of winds on the eastern margins of the basin. The thick deposits of loess that blanket the Badger Pocket area in the southeastern part of the Kittitas Basin are a reminder of the importance of wind over time as well.
- Descending the Ryegrass anticline, we reach the upper limit of Missoula Flood slackwater at ~1260 feet (Figure 6) 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 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.
- In Vantage, we are in a very different climate from that of Ellensburg. Because we are ~900 feet lower than Ellensburg, temperatures are likely 4-5^{o}F higher. With distance from Cascade Range, it is also slightly drier here than in Ellensburg. Dunes here indicate that winds are more southwesterly than the northwesterlies of Ellensburg.
- The Columbia River "Gorge" here is a result of pre-Missoula Flood, Missoula Flood, and post-Missoula Flood erosion.

En route to Stop 1



Stop 3. The Columbia Plateau and the areal extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament, and the CLEW, which is the central portion of the OWL that passes through the western part of the Columbia Plateau (Reidel & Campbell, 1989, p. 281).

Stratigraphic Subdivision of Columbia River Basalt Group (CRBG)

SERIES		GROUP	SUB-GROUP	FORMATION (Age, Volume, % of CRBG)	MEMBER	MAG*
Miocene	Upper	Columbia River Basalt Group	Yakima Basalt SubGroup	Saddle Mountain Basalt (14–6 Ma, 2,400 km3 volume, 1.5% of CRBG)	Lower Monumental Member	N
					Ice Harbor Member	N,R
					Buford Member	R
					Elephant Mountain Member	R,T
	Middle				Pomona Member	R
					Esquatzel Member	N
					Weissenfels Ridge Member	N
					Asotin Member	N
					Wilbur Creek Member	N
					Umatilla Member	N
				Wanapum Basalt (15.5–14.5 Ma, 10,800 km3 volume, 6.0& of CRBG)	Priest Rapids Member	R3
					Roza Member	T,R
					Frenchman Springs Member	N2
					Eckler Mountain Member	N2
	Lower			Grande Ronde Basalt (17–15.5 Ma, 151,700 km3, 87%)		N2
						R2
				Picture Gorge Basalt		N1
						R1
				Imnaha Basalt (17.5–17 Ma, 9,500 km3 volume, 5.5% of CRBG)		R1
						T
						N0
						R0

* Magnetic Polarity:
N, normal; R, reversed; T, transitional; subscripts denote magnetostratigraphic units

USGS *Topinka, USGS/CVO, 1997, Modified from: Swanson, et.al., 1989, AGU Field Trip Guidebook T106*

Figure 4. Stratigraphy of the Columbia River Basalt Group. Image from Cascade Volcano Observatory website.

En route to Stop 1

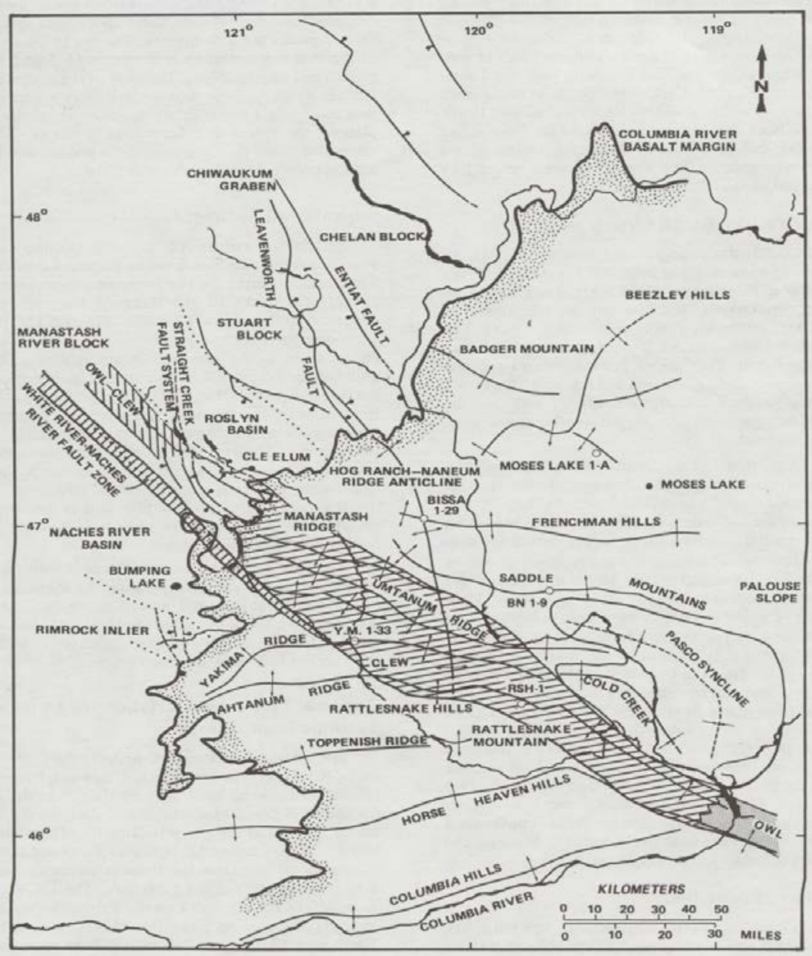


Figure 5. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt (from Reidel & Campbell, 1989, p. 281).

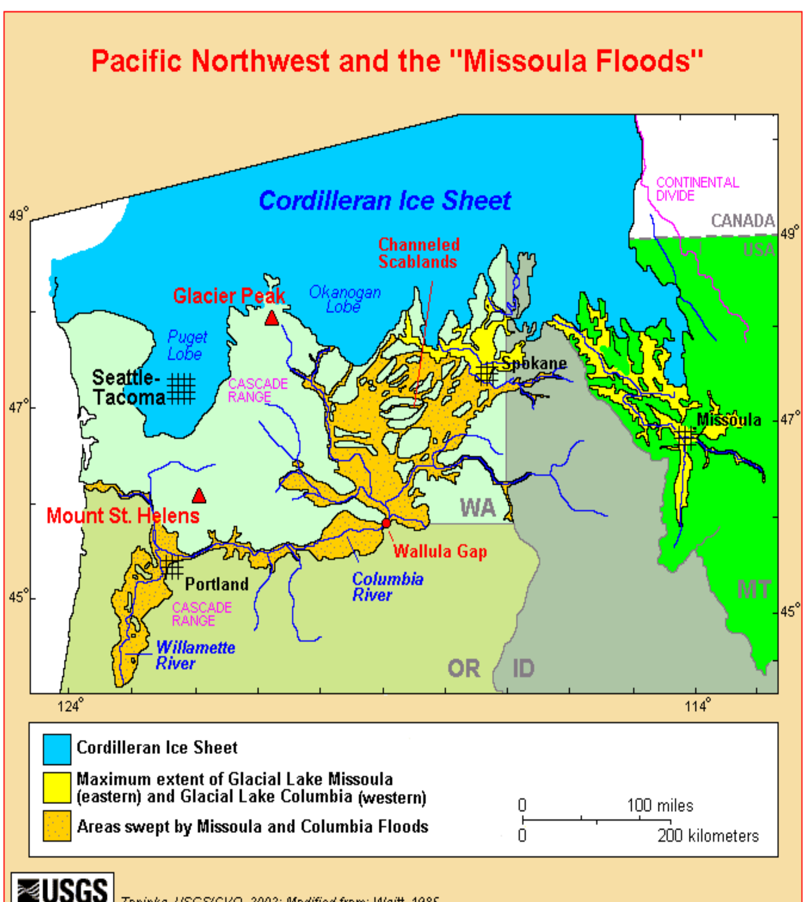


Figure 6. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. From the Cascade Volcano Observatory website.

En route to Stop 1--Vantage to Soap Lake

- From Vantage, we cross the Columbia River on I-90 and ascend to the Quincy Basin. The ~horizontal bench we follow until nearly entering the Columbia Basin Irrigation Project is the Babcock Bench. This is a stripped structural surface created by selective erosion of Columbia River Basalts. From here, we have fine views of channeled scablands (to your west) that are so indicative of Missoula Flood-ravaged surfaces.
- We enter the Quincy Basin essentially where I-90 reaches its high point before descending to the Silica Road exit. The Frenchman Hills and Beezley Hills (Figure 2) are anticlines on the northwestern part of the Yakima Fold and Thrust Belt (Figure 5). These anticlines guided floodwaters entering the basin from the northeast and east (Figures 6 & 7).
- White is a common landscape color in the Quincy Basin. White sediments in large piles are diatomaceous earth remaining from mining operations. White seen in roadcuts may be a soil carbonate known as caliche or it may be Mount St. Helens ash from 1980. Caliche is usually present several feet below the soil surface while Mount St. Helens ash should be just below the surface.
- The Quincy Basin is a vastly different place now than in 1952 when Columbia River water was first delivered to the area via the Columbia Basin Irrigation Project. Prior to that time, it was a dry, sand-covered basin characterized by ranching and meager attempts at dryland farming. Now it boasts over 60 different crops. Water for these crops reach the Quincy Basin from Lake Roosevelt via Banks Lake Reservoir and a series of canals and siphons.
- Just east of George, we exit I-90 and take WA 283 to Ephrata. Our route takes us across flood bars, cover sand, and patterned ground. A giant flood bar formed at the mouth of the Lower Grand Coulee Upper Crab Creek Valley as the waters left their confines (Figures 8 & 9). The largest sediments were deposited near the mouth of the lower Grand Coulee as the "Ephrata Fan" (or more accurately, "Ephrata Expansion Bar"). Keep your eyes open for evidence of large, flood-transported boulders between George and Ephrata (near milepost 10), and again between Ephrata and Soap Lake, some of which have been piled into huge stone fences. These floodwaters also left distributary channels throughout the basin. Ephrata lies in once such channel, aptly named the Ephrata channel.
- Windblown sand originating from the Columbia River and from wind reworking distal Missoula Flood deposits covers much of this bar. Unlike the deposits near Moses Lake, these deposits take on the flatter form of "cover sand" rather than dunes.
- "Patterned ground" appears as pimple-like features on the gravelly to bouldery Missoula Flood deposits as we near Ephrata. If you look closely, you can also see patterned ground on the Beezely Hills. Given the position of these features, they must have formed following the floods in the latest Pleistocene or Holocene. Are they cold climate phenomena, the result of water or wind erosion, seismic activity, burrowing rodents, or something else?
- From Ephrata, we climb to the top of the expansion bar on WA 17, then descend to Soap Lake. At the junction south of Soap Lake, we take WA 17 into Soap Lake to the City Park and Stop 1. The City Park lies on the north end of town on the west side of WA 17.

Stop 1—Soap Lake

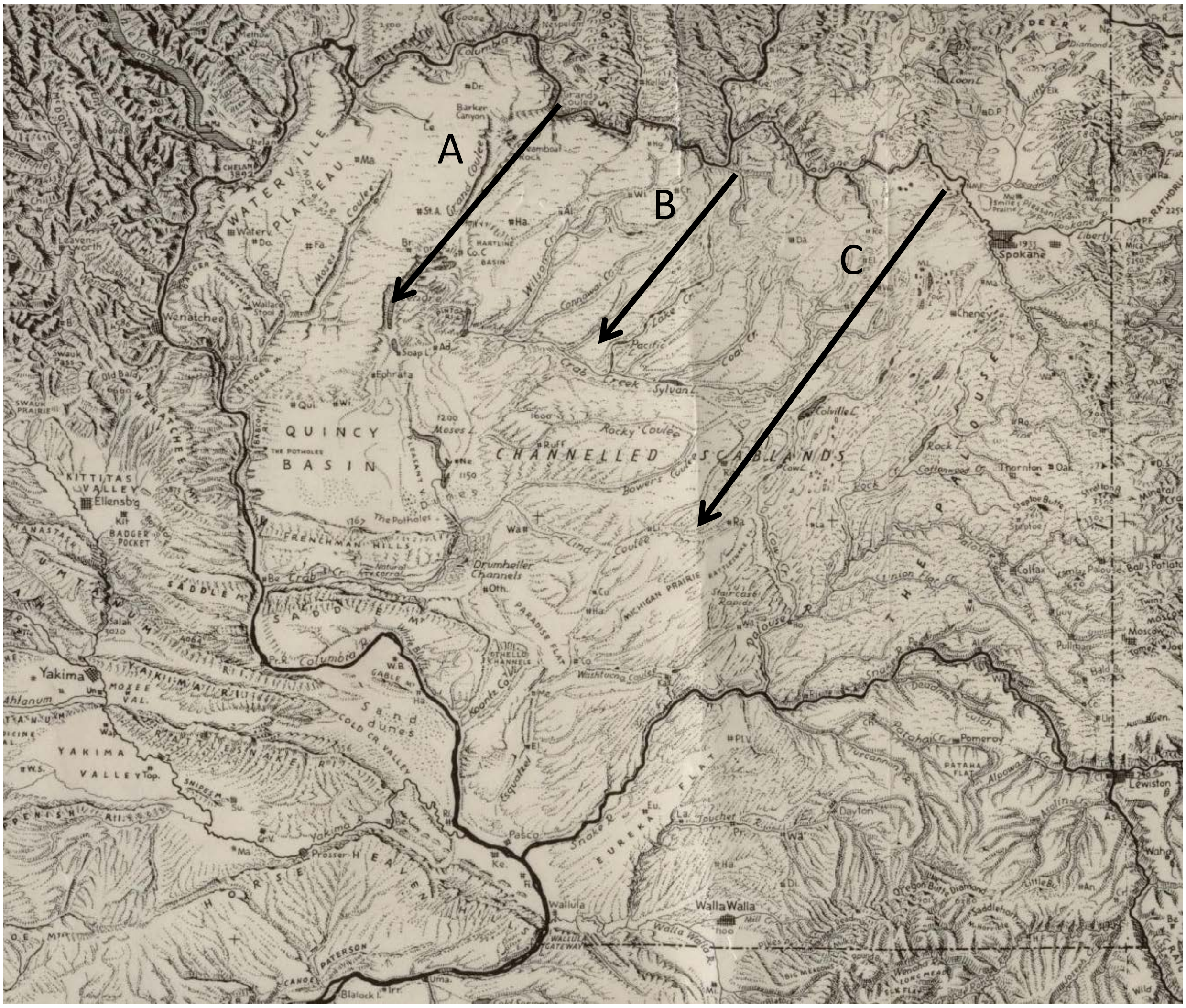


Figure 7. Channeled scablands of central Washington state. A is the Grand Coulee scabland tract, B is the Telford-Crab Creek tract, and C is the Cheney-Paluse tract. From Raisz (1941).

- Soap Lake is located at the distal end of the Lower Grand Coulee. The Lower Grand Coulee formed from recession of a cataract in Columbia River Basalts as water spilled along the inclined limb of the Coulee Monocline. This cataract receded ~15 miles to its present location at Dry Falls. Its difficult to imagine erosion of this magnitude in hard basalt. Much of the erosion was accomplished by kolks (i.e., near-vertical vortices) formed in the deep, fast, flood flows that exploited the columnar joints of the basalts (Figure 10).
- The high velocity of floodwaters through the Lower Grand Coulee (30 m/sec or 67 mph—Baker, 1978) led to erosion 214 feet below the present lake surface (Bretz and others, 1956). Evidence for the rapid erosion of the Lower Grand Coulee can be seen in the "hanging valleys", especially evident on the west side of the Upper Grand Coulee. Uniform river processes result in valleys that join at essentially the same level.
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Stop 1—Soap Lake (continued)

Figure 8. Quincy Basin distributary channels. Note three main dis-tributaries from west to east—Ephrata, Rocky Ford, and Willow Springs. Note origins of dis-tributaries at apex of Ephrata Fan (i.e., expansion bar). From Bretz (1959, p. 33).

Figure 9. Soap Lake at the terminus of the Lower Grand Coulee. Solid arrow shows flood flows. Dashed arrows show development of explansion bar. Source: Google Earth.

Stop 1—Soap Lake (continued)

- As floodwaters exited the Lower Grand Coulee, they rapidly lost velocity depositing their “load”. This deposition from the Lower Grand Coulee resulted in the formation of the huge Ephrata fan or expansion bar, a good chunk of which we drove over between the western Quincy Basin and Soap Lake. This bar impounds Soap Lake. Approximately 110 feet of flood gravels overlie the flood scoured basalt floor of Soap Lake (Bretz and others, 1956).
- Grand Coulee operated early and often as a major path for Missoula Floods (Figure 11). In fact, it was the geomorphic evidence found in the Quincy Basin that led Bretz and others (1956) to identify the relations between the Grand Coulee and other coulees and ultimately the evidence for multiple floods through the area (Bretz, 1969).
- Soap Lake’s current high water surface (~1075 feet) is about 80 feet below the lowest point on the expansion bar (~1155 feet) south of the intersection of WA 28 and 17. Flood gravel-capping lake silts south and north of present-day Soap Lake suggest that a once-deeper lake existed here to an elevation of ~1150 feet (Waitt, 1994). Roald Fryxell’s student Jerry Landye (1973) named this Lake Bretz, and suggested it was a Late Pleistocene lake formed following the passage of the last Missoula Floods through the coulee.
- Soap Lake gets its name from its soapy appearance, especially when the wind whips up the surface of the lake. This soapy appearance comes about because it is a closed-basin lake. Closed-basin lakes are characteristic of arid and semi-arid environments where insufficient water is available to erode outlets in the impounding dams. Closed-basin lakes are mineral-rich because water loss occurs only with groundwater seepage and evaporation. As such, Soap Lake is the 3rd largest saline lake in Washington (behind Omak Lake and Lake Lenore (Bennett, 1962).

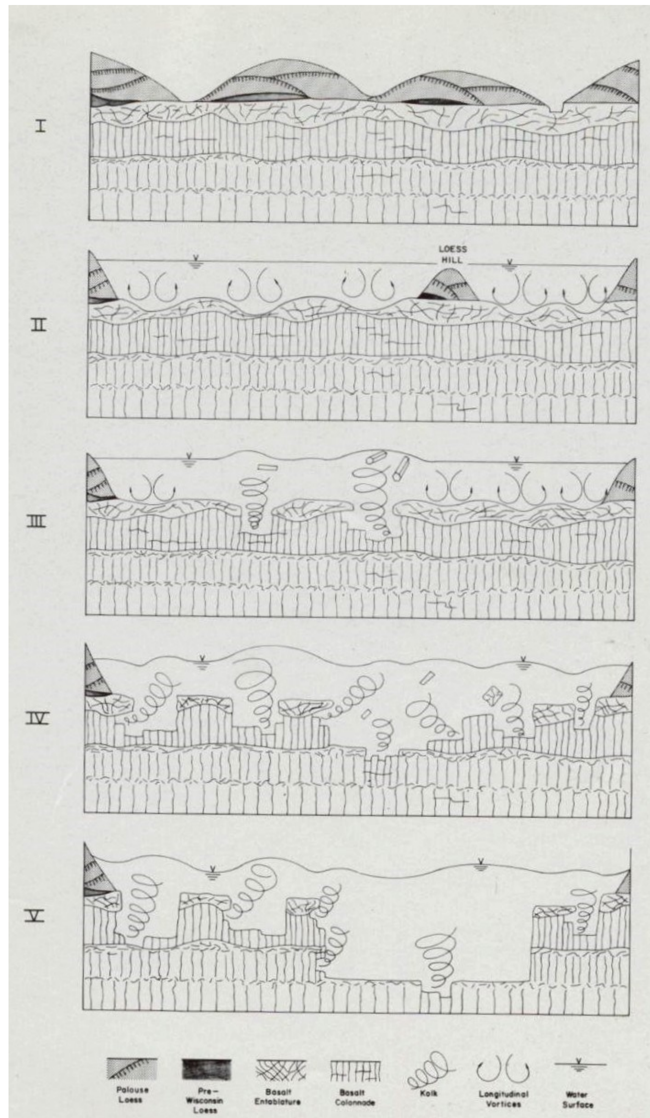


Figure 10. Illustration of kolk-based erosion in columnarly jointed basalts. From Baker (1978, p. 105).

Stop 1—Soap Lake (continued)

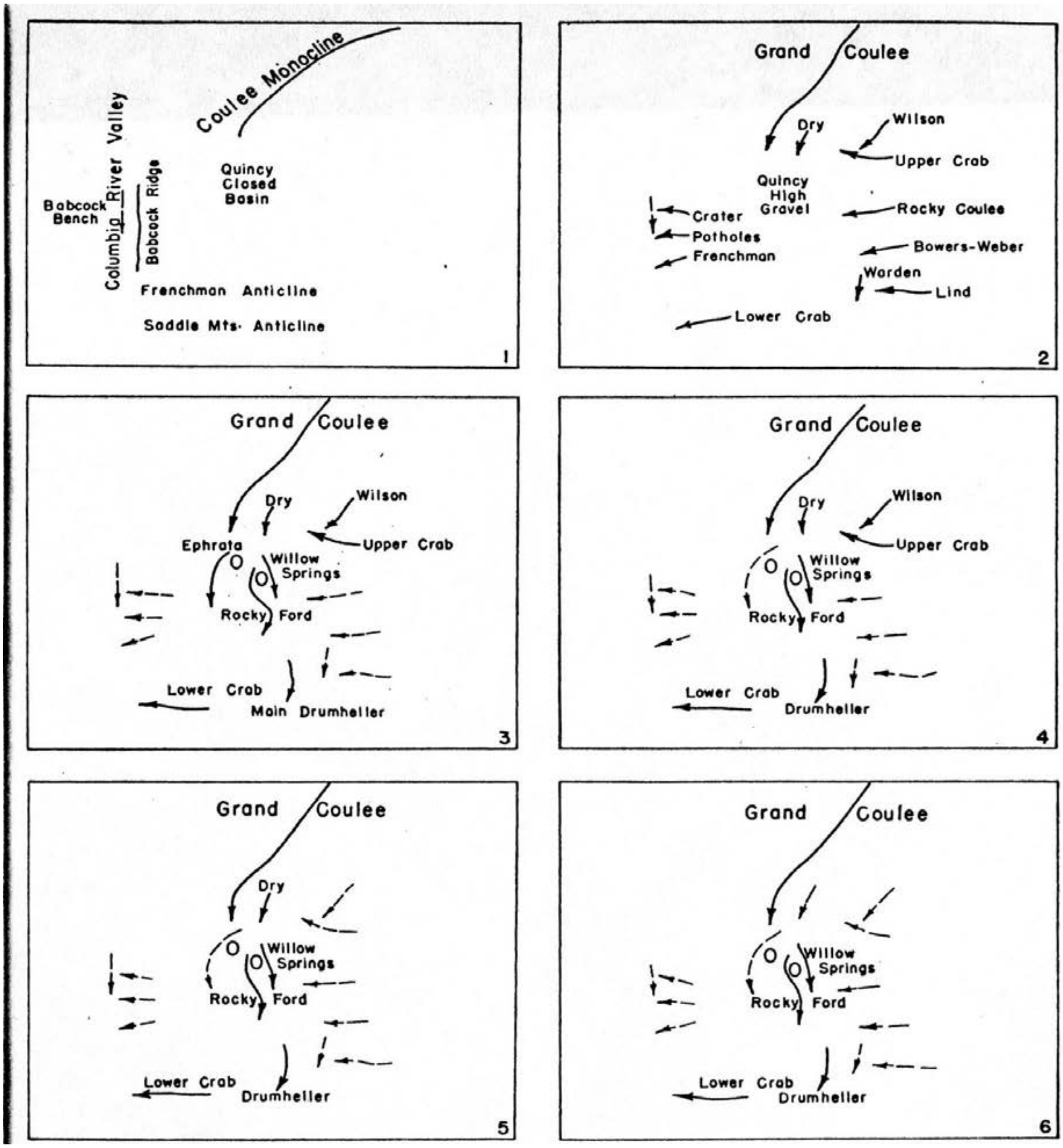


Figure 11. Sequence of floods into the Quincy Basin according to Bretz and others (1956).

- Because of evaporation, Soap Lake is also an alkaline lake with a pH of 9. The main salt is Sal Soda (Na_2CO_3). In the 1940's, the lake had total dissolved solids of about 37 g/L and was 20% more saline than seawater (Bennett, 1962; Edmondson, 1992).

Stop 2—Soap Lake (continued)

- Humans have long exploited the mineral waters of Soap Lake beginning with Native Americans and continuing with Euroamericans. The lake was called Sanitarium Lake because of purported therapeutic value of lake waters at around turn of century. The small settlement that began in 1904 was incorporated as Soap Lake in 1919. People came from all over to soak in and ingest the Soap Lake waters for their healing effects. The town of Soap Lake was built (physically and economically) around these mineral waters (Fiege, n.d.).
- Inflow of Columbia Basin Irrigation Project water in the early 1950's diluted lake waters causing concern for City of Soap Lake residents and business owners. To solve this problem, the Bureau of Reclamation installed pumps in wells adjacent to the lake to intercept the incoming fresh Columbia River water. Since 1959, the salinity of the lake has generally been stable at about 15 g/L total dissolved solids. However, this concentration is well less than when the lake was first measured in the 1940's (Edmondson, 1992).

En route to Stop 2

- From the City Park in Soap Lake, we return south to WA 28 and head east. We ascend and then descend the edge of the Ephrata expansion bar.
- The highway soon climbs to the top of a large expansion bar that formed at the mouth of flows from Dry Coulee (Figures 12 & 13). Dry Coulee received flood flows from the Grand Coulee as did the coulee just upstream from Dry Coulee (Figure 12). The position and condition of this bar suggests that it formed following the main flows down Crab Creek.
- As we head further east, it becomes apparent that Crab Creek Valley is a coulee shaped by floodwaters from the Telford-Crab Creek scabland tract (Figure 11). Were we travelling in the Late Pleistocene, we would be heading upcurrent against the flow of the floods. However, the meandering nature of Crab Creek Valley suggests that this was a channel that pre-dated the Missoula Floods and was "only" shaped by these floods.
- What evidence would J Harlen Bretz (1959) have used to identify an area as being impacted by the Missoula Floods?
  - Anastomosing channels
  - Loess scarps
  - Closed rock basins (potholes)
  - Butte & basin topography
  - Accordant channel head elevations
  - Cataracts
  - Broad gravel deposits
  - Gravel bars
  - Giant current ripples
  - Backwater (Slackwater) deposits
- Can you see any of these features as we drive upvalley?
- The town of Wilson Creek is located at the junction of Crab Creek and Wilson Creek. Canniwai Creek enters Crab Creek just upstream of the town of Wilson Creek. Wilson Creek and Canniwai both delivered floodwaters from the upper Telford-Crab Creek drainage to the area.
- Pass the westernmost road into Wilson Creek. We will take the second road. Stop 2 is on this road and south of Crab Creek (dry this year). Park on the wide right shoulder.

En route to Stop 2

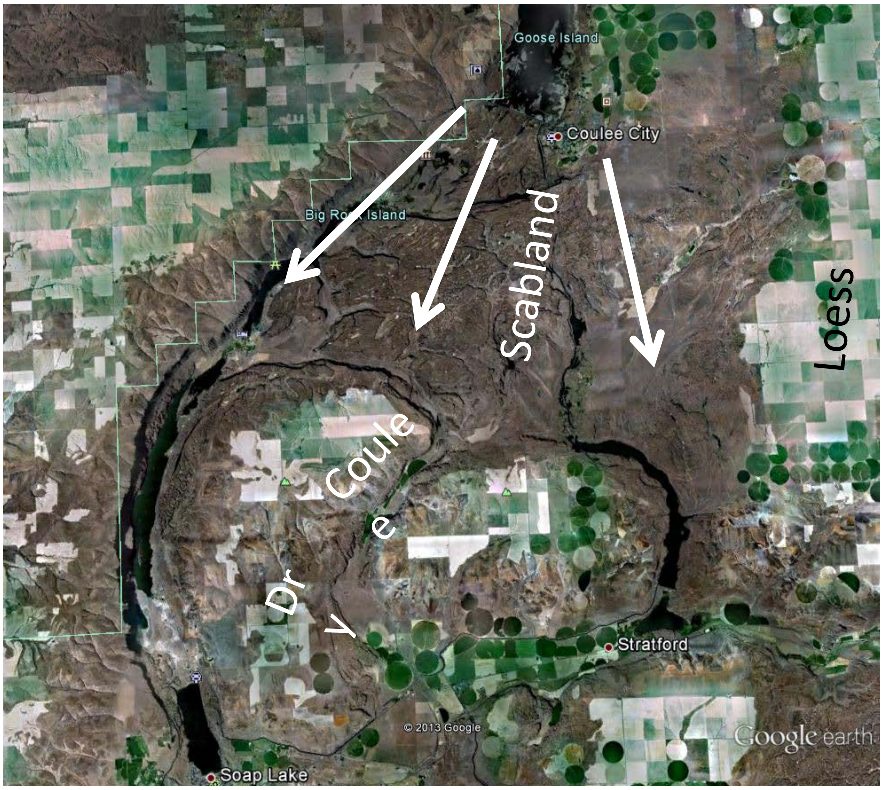


Figure 12. Flood flows from Grand Coulee southward. Source: Google Earth.

Figure 13. Expansion bar at mouth of Dry Coulee. Source: Google Maps.

Stop 2—Wilson Creek Flood Bar

- At this stop, we see a fine example of a giant flood bar (Figure 15), one of the pieces of evidence J Harlen Bretz used to argue for a catastrophic flood origin for the channeled scablands. This is one of many flood bars in the Wilson Creek area (Figure 16). Bars form sub-fluvially as velocity decreases. They typically have blunt upvalley "heads" and long, tapering downvalley "tails". Their surfaces slope downvalley. Some have described their forms as "whalebacks", a shape very different from a dissected terrace, a form the non-catastrophists 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):
  - *Crescent Bars* —form on the inside bend of channels
  - *Longitudinal Bar* —form in mid-channel or along a channel wall
  - *Expansion Bar* —form where channels widens abruptly
  - *Pendant Bar* —form downcurrent of mid-valley obstacle or valley-wall spur on bend
  - *Eddy Bar* —form in a valley at the mouth of a tributary
  - *Delta Bar* —form where floodwater on a high surface adjacent and parallel to a main channel encounters a transverse tributary valley where it deposits
- What type of bar is this?

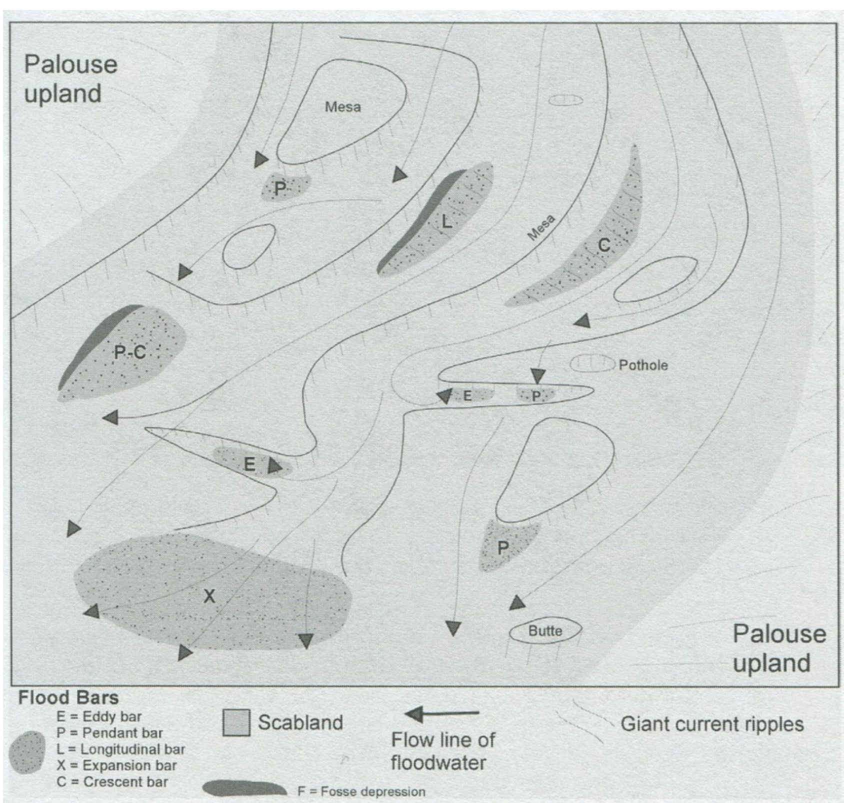


Figure 14. Types of flood bars. From Bjornstad and Kiver (2012, p. 51).

- From here, we will drive across Crab Creek, and turn left onto 1st Street, and soon take a right onto Navar Street. This will take us to the top of the hill and Wilson Creek School. Follow the signs to the Gym Commons and park in the highest lot. This is stop 3.

Stop 2—Wilson Creek Flood Bar (continued)

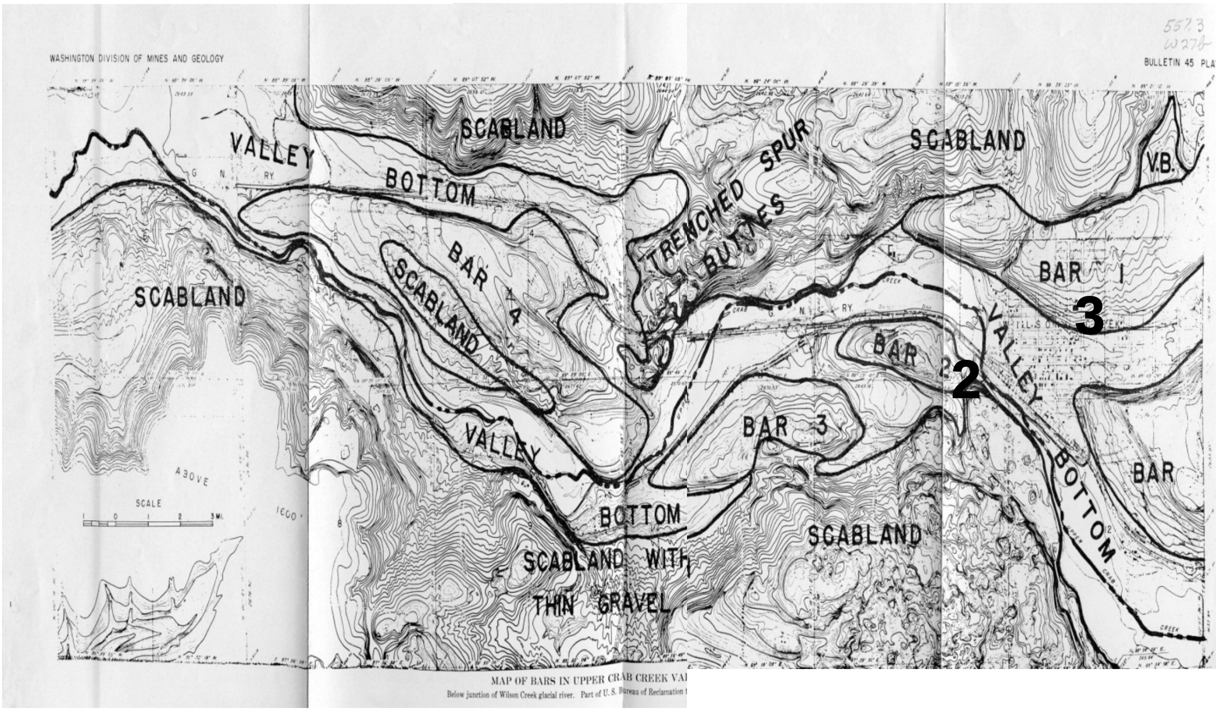


Figure 15. Bars & scablands in the vicinity of Wilson Creek (far east portion of map). Number indicates location of Stops 2 & 3 From Bretz (1959).

Figure 16. Bretz (1959) flood bar 2 and our Stop 2. Source: Google Earth.

Stop 3—Wilson Creek School

Figure 17. Giant Flood Bar and current ripples at Wilson Creek. Number indicates location of stop. Heavy arrow indicates direction of flood flow. Source: Google Earth.

- From the Wilson Creek School parking lot, we will hike north onto the flood surface behind the school buildings.
- What type of bar are we standing on here?
- Notice on Figure 17 that there appear to be "ripples" atop the bar surface. These are giant current ripples (or dunes) formed at the base of the raging floodwaters. These are just one of over 100 sets of these features in Missoula Flood channels (Baker, 1978). Using Google Earth, we count at least five sets of these features in the immediate vicinity of Wilson Creek, and we will see more as we head to Odessa. What made this area prone to development of giant current ripples?
- Giant current ripples form transverse to flow and are asymmetrical in cross section with gentle upcurrent (stoss) slopes and steeper downcurrent (lee) slopes. Sediment is transported up the stoss slopes and deposited as foreset beds on the lee slopes.

Stop 3—Wilson Creek School (continued)

- How to really see these features? Examine flood paths from the air. In fact, Bretz didn't really see these features until he examined airphotos (Bretz and others, 1956). They are highlighted by shadows. Fly over them at low light. An oblique view like that from a small aircraft or Google Earth turned on its side is also helpful. Loess has accumulated in the swales over time resulting in different vegetation from bar crest to swale. A thin snow cover can also help one discern these features.
- Examine Figures 18-21 below to see the relationships between ripple chord (i.e., wavelength), ripple height, water depth, water velocity, and stream power.

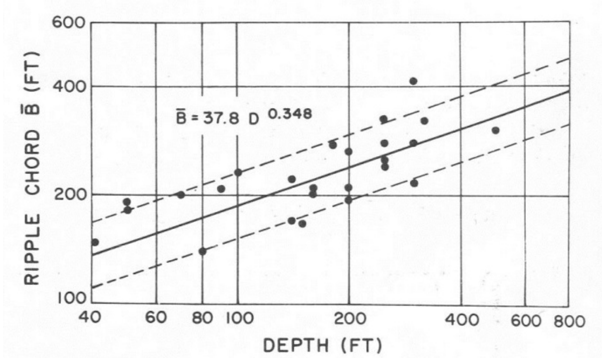


Figure 18. Logarithmic regression of ripple chord as a function of depth. The dashed line represent one standard error. From Baker (1978b, p. 113).

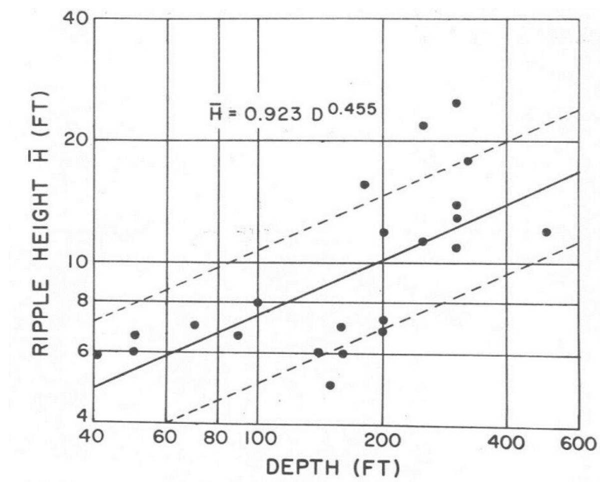


Figure 19. Logarthmic regression of ripple height as a function of depth. The dashed lines represent one standard error. From Baker (1978b, p. 113).

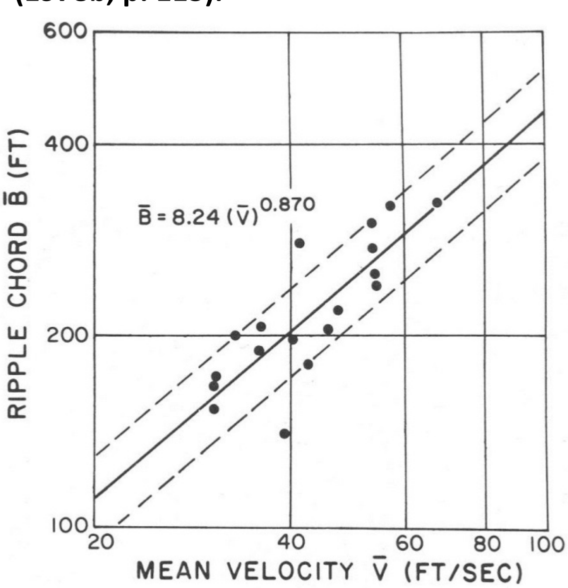


Figure 20. Ripple chord as a function of mean flow velocity (discharge velocity) as calculated by the slope-area methods. The dashed lines represent one standard error. From Baker (1978b, p. 113).

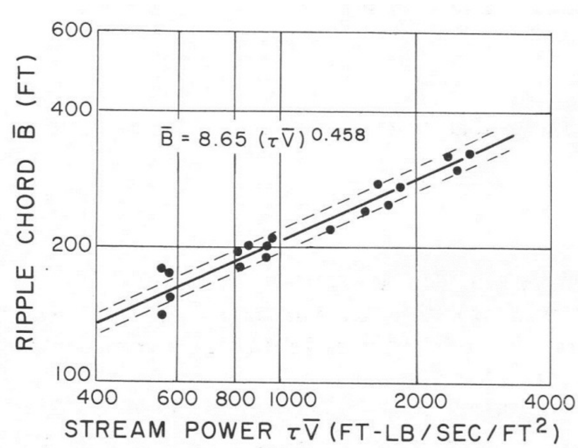


Figure 21. Mean ripple chord as a function of stream power. The dashed lines represent one standard error. From Baker (1978b, p. 115)

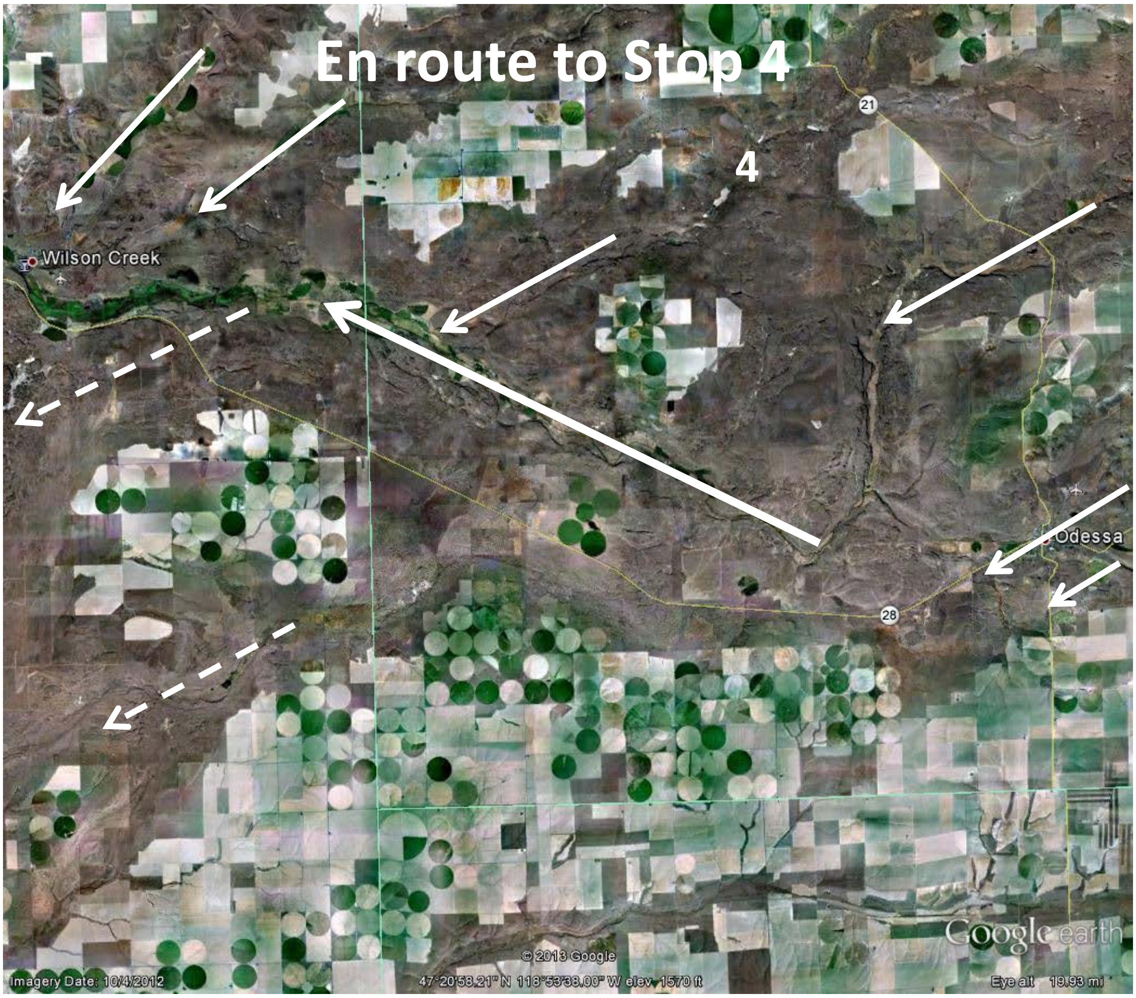


Figure 22. WA 28 route from Wilson Creek to Odessa. Main flood flow in Crab Creek Valley shown with wide, solid arrow. Flood flows into Crab Creek Valley shown with narrower solid arrows. Overflows to the south shown with dashed arrow. Source: Google Earth.

- From Wilson Creek School, we return to WA 28 and continue east. The first few miles of our route follow the flood-scoured Crab Creek Valley. We then rise to near the upper limit of flooding at about ~1750 feet. Maximum flood depths in the Upper Crab Creek Valley were about 300 feet (Waitt, 1994). Evidence for being near the upper flood limit includes decreasing scabland relief and thicker soils with elevation.
- Four main flood inflows entered Crab Creek between Wilson Creek and Odessa—these were (from west to east) Canniwai Creek, Marlin Hollow, Lake Creek, and Duck Creek (Figure 22).
- Two main flood outflows created scablands to the south from Upper Crab Creek Valley along our route (Figure 22). Both delivered flood flows to the vicinity of present day Moses Lake thus back into the Lower Crab Creek drainage. These waters would have then flowed south through the Drumheller Channels and either north or west of the Saddle Mountains.
- As we near Odessa, we again pass through giant flood bars covered with giant current ripples. These features are hard to see on the ground. Look for gravel deposits (and associated quarries), and gentle undulations on these gravel deposits.
- In Odessa, will take WA 21 north toward Wilbur. About 3 miles north of Odessa, we will turn west onto a good gravel road (Lakeview Ranch Loop Road) that we will follow west and north to the Bureau of Land Management's Pacific Lake Management Area. At Lakeview Ranch, we will turn east into the management area, drive less than a mile, and park. This will be our Stop 3 for lunch, restroom, and a discussion on Pacific Lake.

Stop 4—Pacific Lake

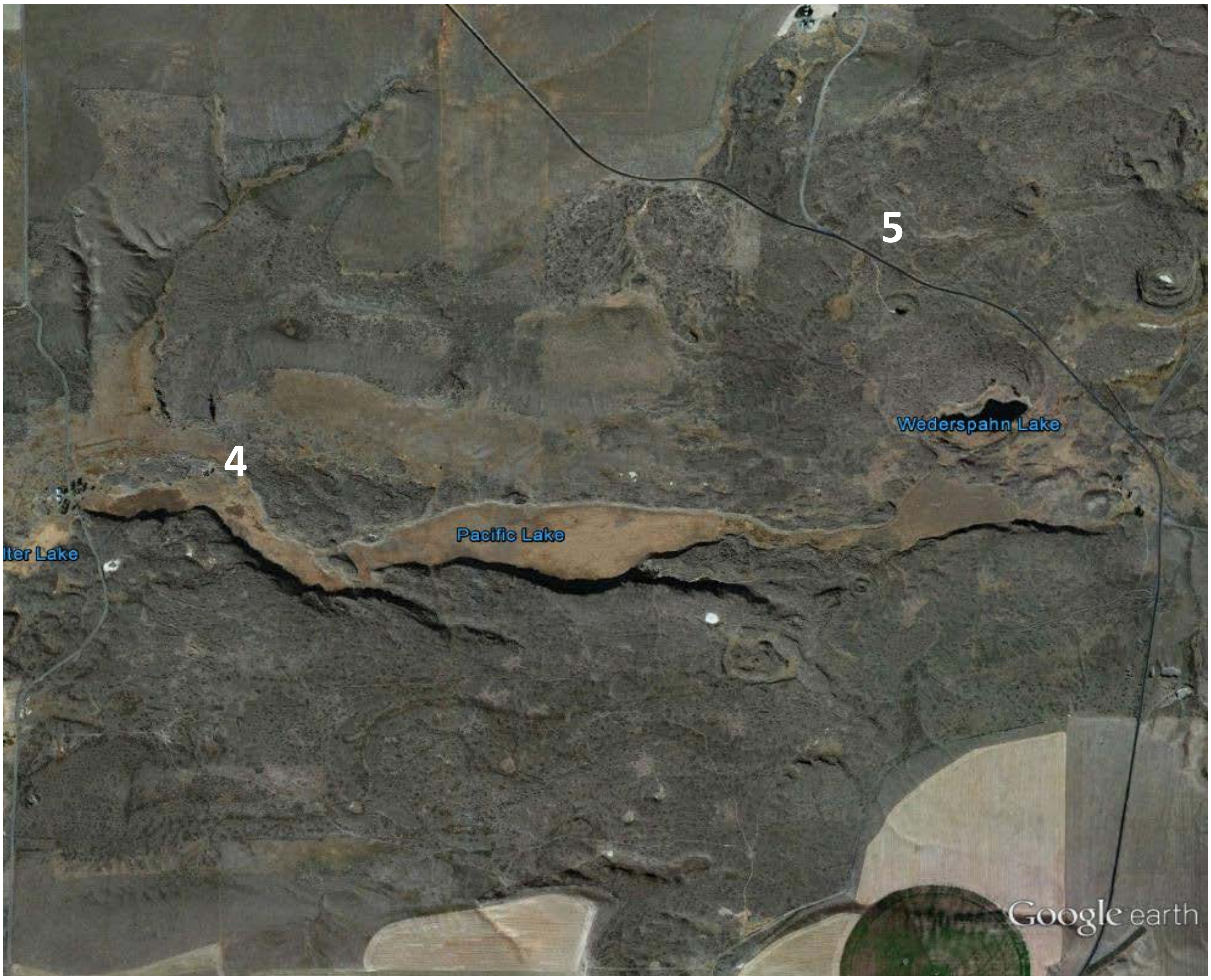


Figure 23. Stop 4 on Pacific Lake, Lakeview Ranch, north of Odessa. Numbers indicate locations of stops. Source: Google Earth.

- As you can see from the October 2012 image above (Figure 23) and as you can see on the ground, Pacific Lake is no longer a lake. According to images on Google Earth Pro, it was a lake in 1996 (although small), as well as in 2003 and 2005. In July 2006, it was more of a marsh. In 2009 and 2011 it was dry. Why these changes?
- One might argue that the Pacific Lake (and other lakes & ponds) fluctuate based on weather and climate patterns (Figure 24). This is especially true for closed-based lakes. Note the overall decline in precipitation since the mid- to late 1990's. Also, note this drier period fits in the overall scheme of wet and dry periods (shown with arrows) over the past century.
- One might also argue that these fluctuations are a result of the removal of groundwater by deep wells used to irrigate crops in the area (Figure 25) Pacific Lake lies within the area underlain by the Odessa Aquifer and is east of the Columbia Basin Irrigation Project. Farmers here are irrigating with fossil groundwater rather than Columbia River water, and the climate is not sufficiently wet to recharge the aquifer. In addition to precipitation and surface water inputs, the lakes of the area may receive significant inflow from groundwater. If groundwater levels are dropping that can reduce or potentially eliminate, inputs to lakes.

Stop 4—Pacific Lake (continued)

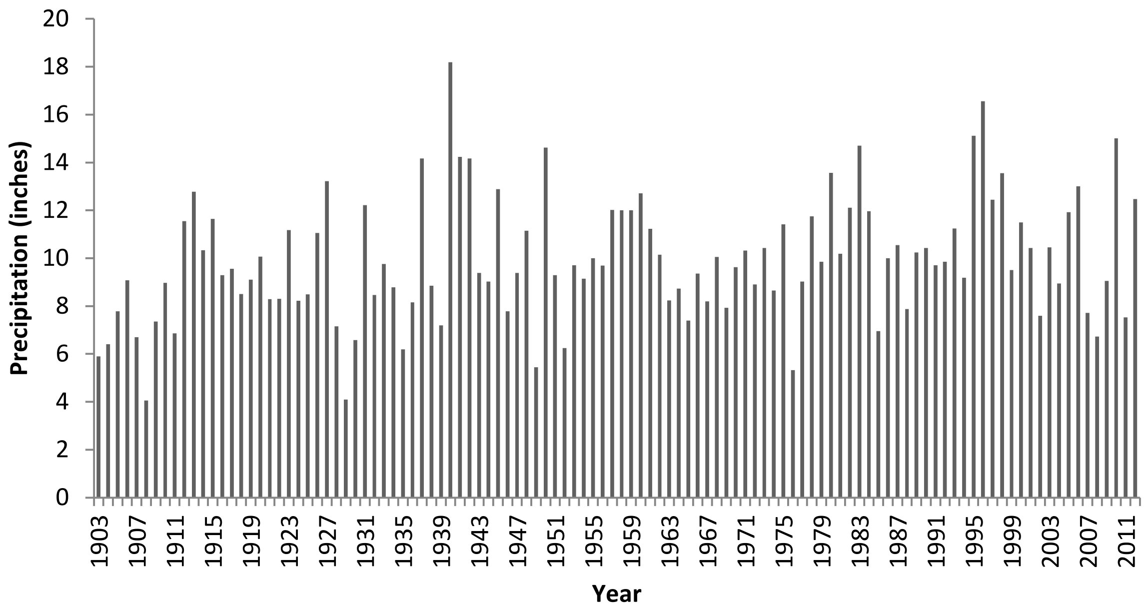


Figure 24. Odessa, WA total annual precipitation, 1903-2012. Source: Western Regional Climate Center.

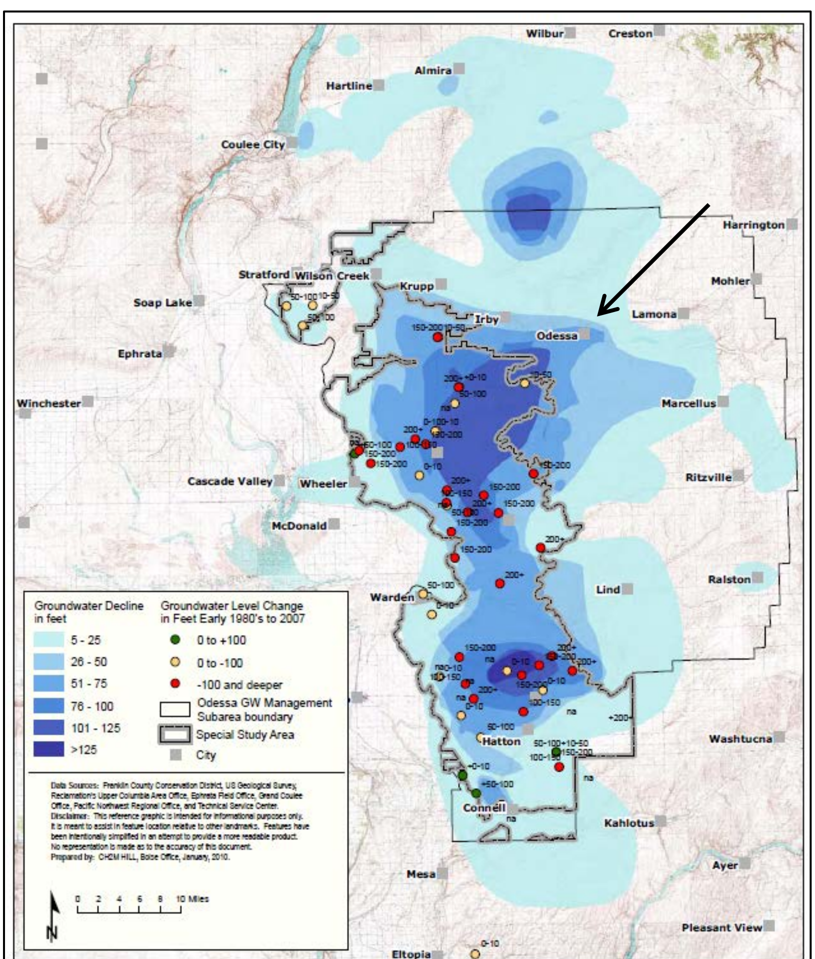
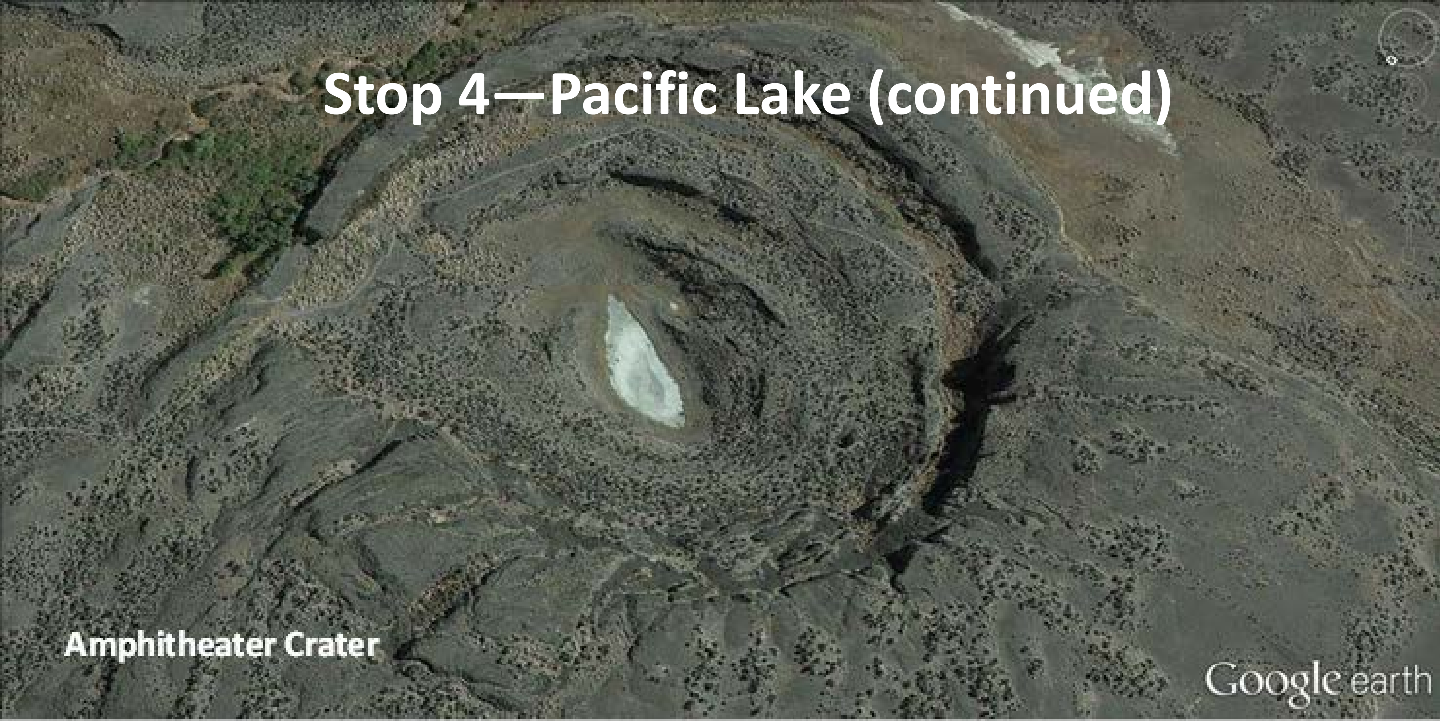
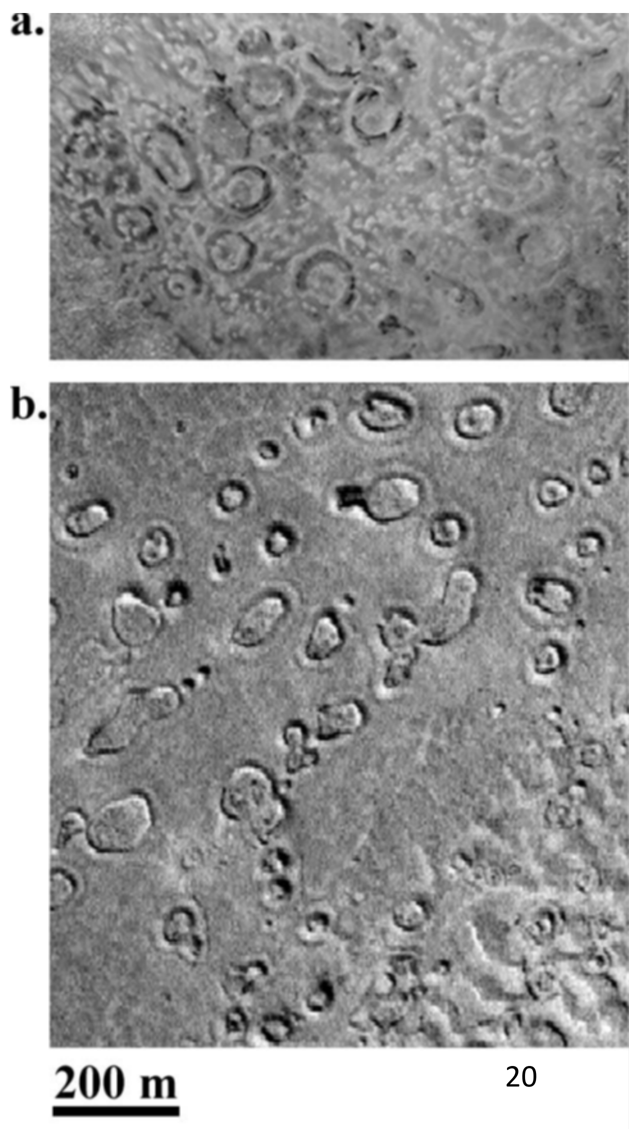


Figure 25. Groundwater change in feet, 1981-2007. From U.S. Bureau of Reclamation (2012).

Stop 4—Pacific Lake (continued)

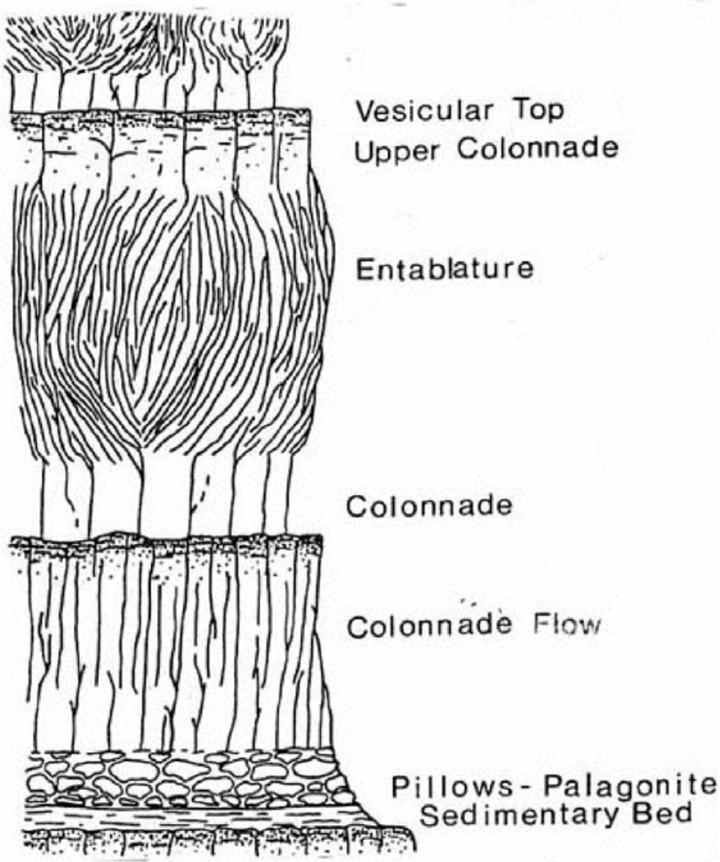


In the Odessa area, erosion by Ice Age Floods has exposed unusual basaltic ring structures. The unusual features were described by Hodges (1978) as "circular structures, defined by arcuate, concentric ridges and scarps that surround hills, mesas, or crater-like depressions". Most of these basalt ring structures are located within the Roza Member of the Yakima Basalt, although they have also been identified at the several locations in Grande Ronde Basalt and one location in Priest Rapid Basalt. These quasi-circular structures sometime referred to as ring dike structures or sag flowout features range in size from 200 to 1500 feet in diameter. They vary from circular to elliptical concentric rings of low ridges separated by shallow swales. They are only known to exist in a limited area of the Columbia Basin Scablands, however, similar structures were carved out of similar lava flows by comparable massive flood(s) on Mars.



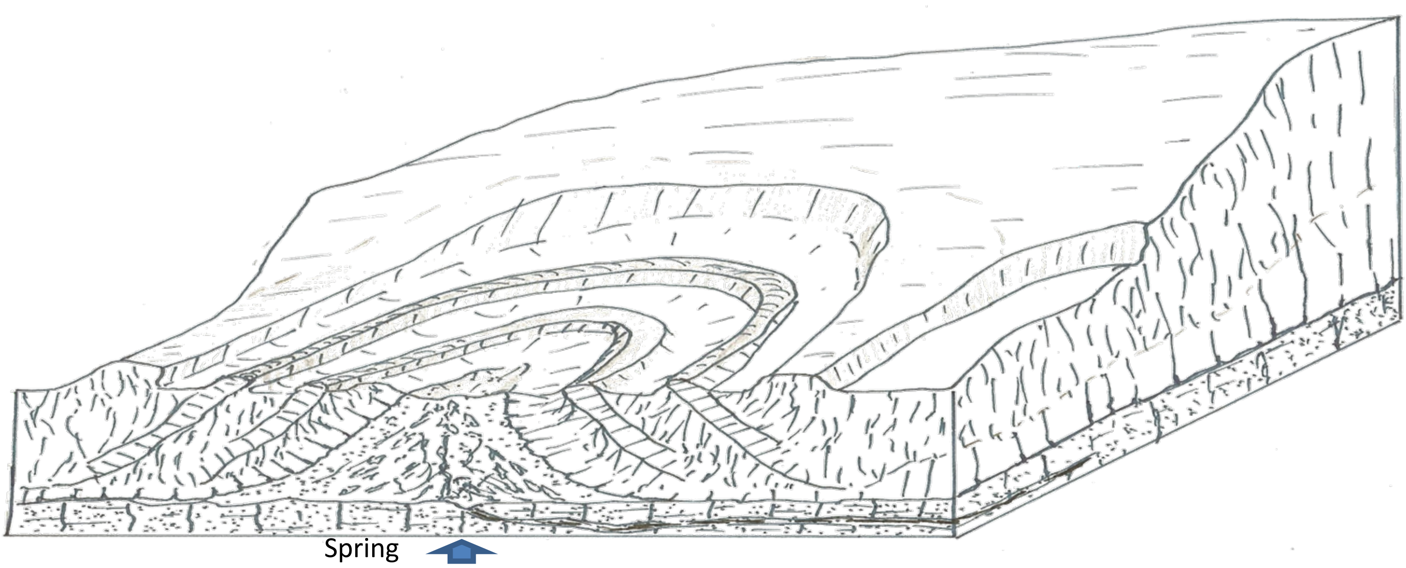
Aerial photograph (a.) is from an area near Sprague Lake along I-90. Aerial photograph (b.) shows similar features of comparable size on the planet Mars.

Stop 4—Pacific Lake (continued)



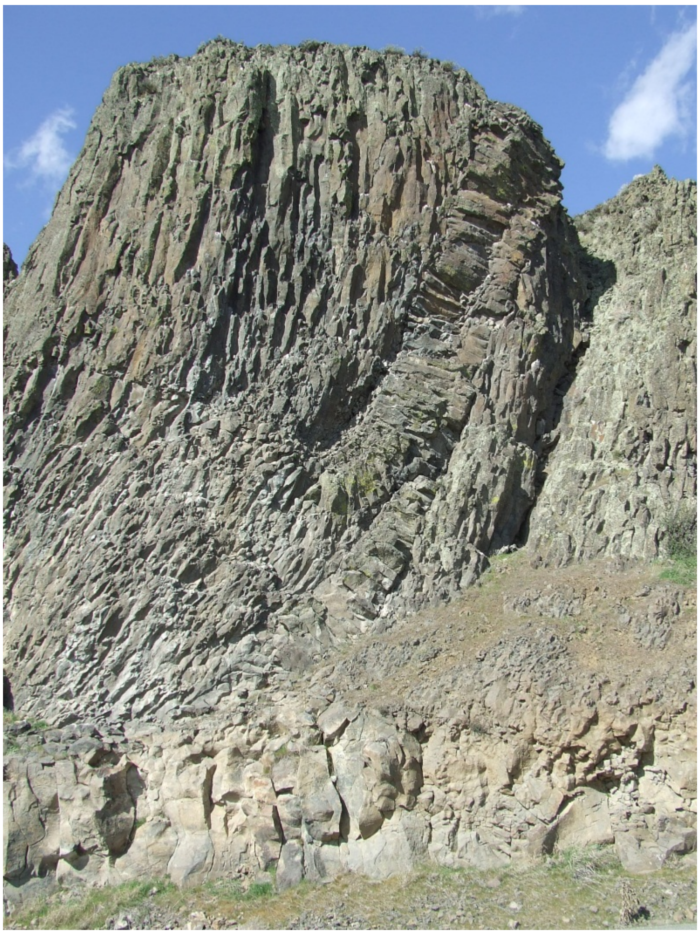
Typical Columbia River Basalt flows form jointing (cracks) perpendicular to cooling surfaces (the surface of the ground and the top of the lava flow). The colonnade forms slowly and more uniformly from the bottom of the lava flow upward. The entablature forms more rapidly with a more disorganized nature to the columns from the top down. This cooling pattern creates the characteristic vertical jointing (cracking) exposed in the walls of coulees throughout central Washington. The tops and bottoms of lava flows and flow units form the horizontal lines exposed in cliff faces.

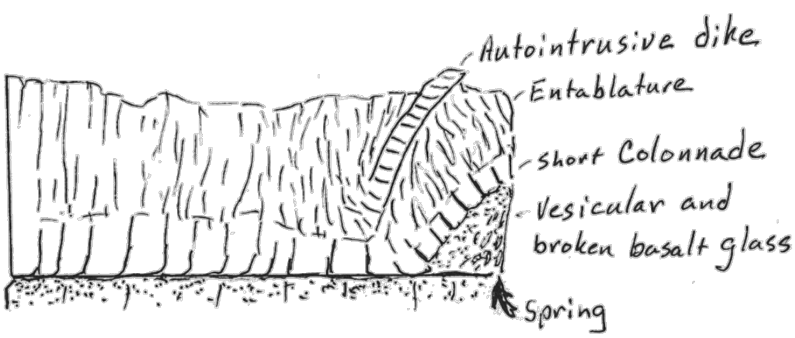
The basalt ring structures form more like a dome or the rings in half an onion. Instead of cooling away from cooling surfaces above and below the lava flow, it cooled from a point at the base of the basalt flow (probably over a spring). As the basalt cooled and crystalized it shrank forming the colonnade and entablature. If cooling formed shrinkage cracks in the flow above a spring it would form a dome like structure when stripped (eroded) by the Ice age floods would produce ring structures.



Stop 4—Pacific Lake (continued)

Some of the resistant ring features in these structures appear to be basaltic dikes. Dikes usually occur where magma is being injected into preexisting older rock layers, however, in these structures it appears that these are autointrusive dikes that form when lava from the molten interior of the flow moved upward through cracks in the solidified upper portion of the flow. This type of dike is shown on the photographs below taken from an exposure along upper Crab Creek.





Solidified basalt is less voluminous than magma resulting shrinking and cracking of the lava flow. As the basalt cooling rapidly above a spring it would shrink toward the cooling point causing it to concentrically pull away from the still molten portion of the flow. Lava would then push in to these concentric cracks forming the concentric ring dikes which tend to dome up over the spring. In some areas pillows, vesicular basalt and broken basaltic glass are found in the center of these basalt ring structures which would be expected if they formed above a spring buried by the base of a molten lava flow.

Stop 4—Pacific Lake (continued)

The most complete description of this basaltic ring structures can be found in a GSA paper by Carroll Ann Hodges of the USGS (1978). Why the basaltic ring structures are so rarely found may be related to the rarity of having a cooling point source under the lava flow (like a spring on earth or a pocket of permafrost on Mars). As Hodges suggest, the springs in this area may have been the result of the advancing Roza lava disrupting the flow of ancient rivers (like the Columbia).

Two concentric autointrusive ring dikes surround the pillow vesicular core of the Cinnamon Roll Crater.

En route to Stop 5

- From Pacific Lake, we return to the Lakeview Ranch Loop Road and continue north and east. At the junction with WA 21, turn right and head south. Within a mile, we will pass a small ring structure—Cache Crater—on the west side of the road. In another mile, we will arrive at Stop 4—Odessa Craters Trail. Park in the small lot on the east side of the road or along the road shoulders. We will hike approximately two miles here.

Stop 5—Odessa Craters Trail

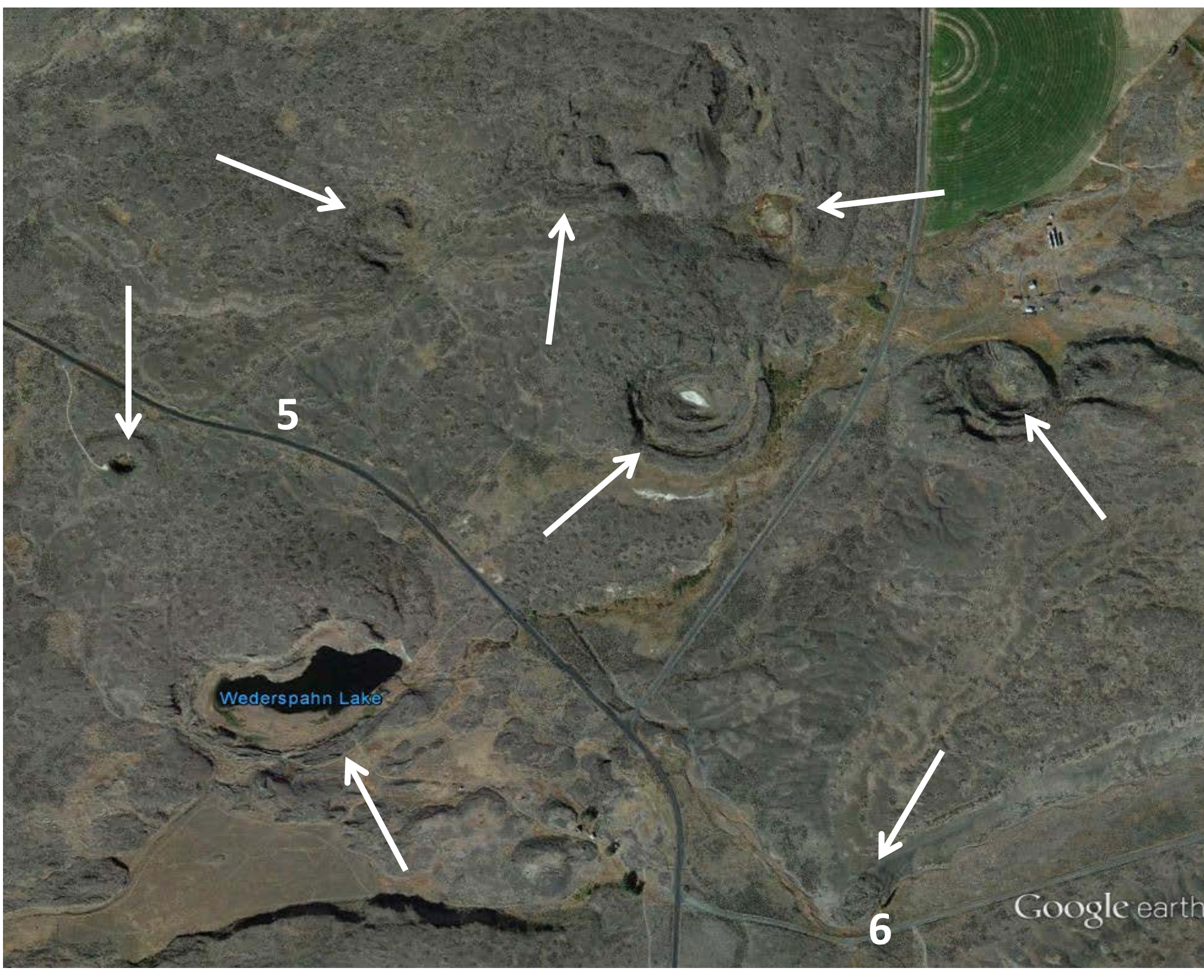


Figure 26. Site of Stops 5 Odessa Craters Trail and Stop 6—Cinnamon Roll. Stop 4 lies about 2 miles east of Stop 3. Arrows indicate ring structures in the area. Source: Google Earth.

Stop 5—Odessa Craters Trail (continued)

- The foci of this stop are the odd, circular features known as "craters", "ring-like depressions", "ring dike-like structures", "sag flowout structures", "basaltic ring structures", "ring dike structures", "Odessa-type craters", and "ringed craters". We will call them "basaltic ring structures".
- What do we know about the basaltic ring structures?
  - Best seen from the air
  - Circular to ellipical in shape, often with 2-5 concentric ridges
  - Centers may be depressions or may be buttes
  - When depressions, may contain a pond or lake
  - Range from 150-1500 feet in diameter
  - Seen only on scabland surfaces
  - Typically form in an over-thickened Roza member of the Wanapum Basalt
  - Original vesicular flow top dips toward the center of the structure
  - Cut by dikes of the same composition as the country rock and that dip toward the outside of the structure
  - Palagonite may be present in centers of features
  - Centered on Odessa area (Figure 27) but found nearly as far east as Sprague and as far north as the Upper Grand Coulee (Baker, 1978, p. 71; McKee and Stradling, 1970, p. 2040).
- Why are these features not more common on the Columbia Plateau?
- J Harlen Bretz must have seen these features but didn't have the benefit of airphotos until very late in this research (1950's) to fully appreciate them. Further, his focus was on catastrophic flooding, not structures within the basalts. George Neff, a geologist for the U.S. Bureau of Reclamation, appears to have been the first to identify these features (see Grolier, 1965, p. 71). Grolier identified them in the Priest Rapids member in the western portion of the Drumheller Channels. Dale Stradling, an Eastern Washington State College Geographer, and University of Washington geologist Bates McKee were the first to fully describe the features, discuss their spatial distribution, and their genesis (McKee and Stradling, 1970). They proposed the Sag Flowout model (see below). Fred Dayharsh (1970) a student of Stradling's at EWSC, mapped these features. His map shows up in Mueller and Mueller (1997, p. 114) (Figure 27). Carroll Ann Hodges of the US Geological Survey found palagonite in the centers of several basaltic ring structures and proposed a second model of formation (1978) (see below). These features have also been addressed briefly in Baker (1978, p. 70-72) and Keszthelyi et al (2009, p. 862-863). Over time, researchers have tried to link the basaltic ring structures seen in the channeled scablands with similar appearing features on Mars (e.g. Hodges, 1977; Jaeger and others, 2003; and Keszthelyi and others, 2009).

Stop 5—Odessa Craters Trail (continued)

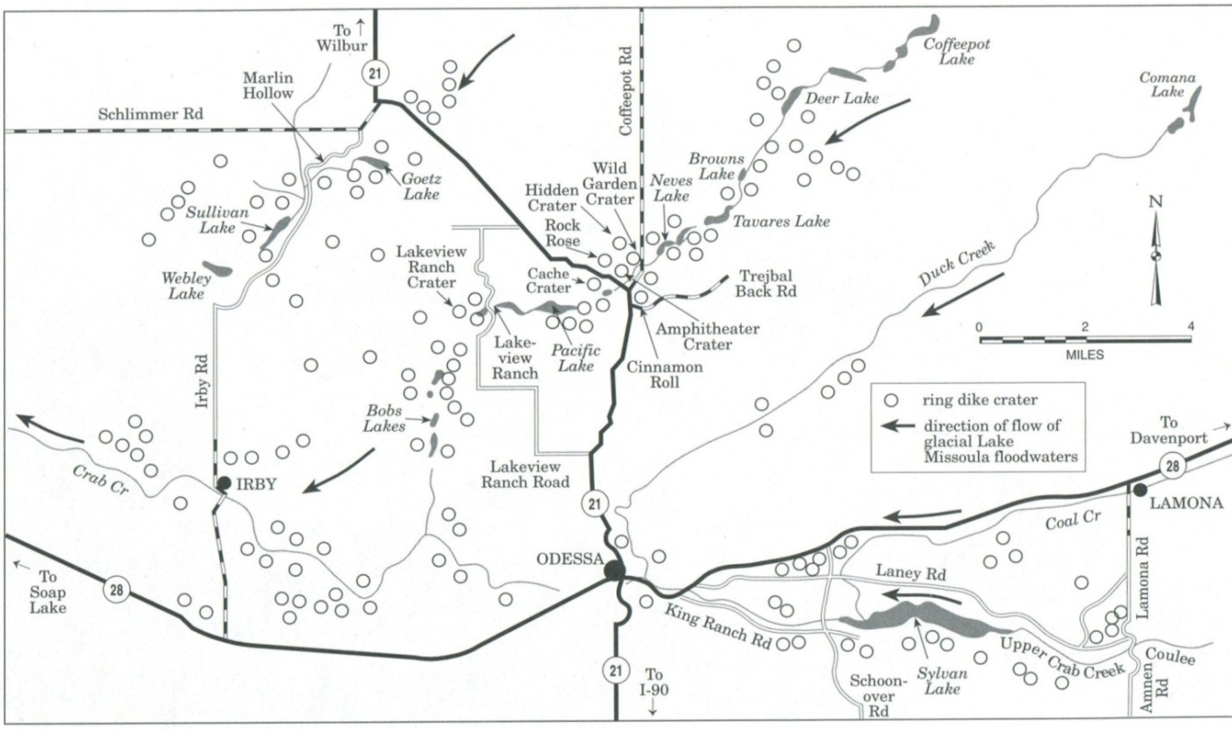


Figure 27. Map of basaltic ring structures in the vicinity of Odessa, Washington. From Mueller and Mueller (1997, p. 114)

- *Sag Flowout Model of Formation* (McKee and Stradling, 1970). This theory involved: flowout of lava (I in Figure 28); subsequent sag or collapse of partly cooled lava flow because of the flowout (II); development of tension cracks that served as conduits for the upward flowout of lava due to the sagging (II & III); and plucking erosion by Missoula floodwaters (III).

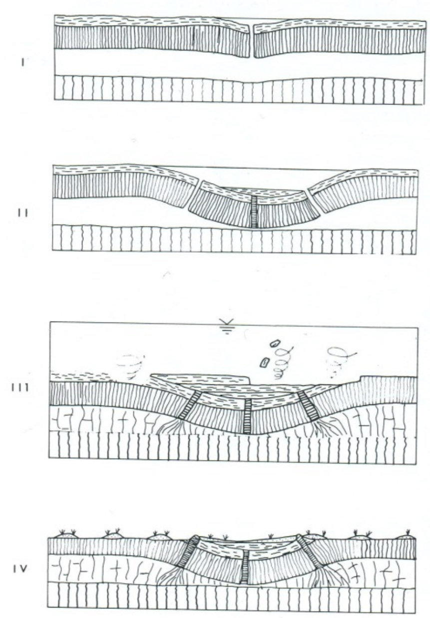


Figure 28. McKee and Stradling (1970) model modified by Baker (1978a).

Stop 5—Odessa Craters Trail

- *Lava-Water Interaction Model of Formation* (Hodges, 1978) (Figure 29). Huge outpourings of basalt disrupted drainages causing local groundwater table to rise and intersect the confined, cooling lava. The presence of palagonite supports theory that water and lava interacted. Among the results of this interaction was the development of doming and cracking of the overlying cooler basalts. Subsidence following the initial venting could allow still-molten lava to intrude fractures in the cooled crust leading to dike formation.

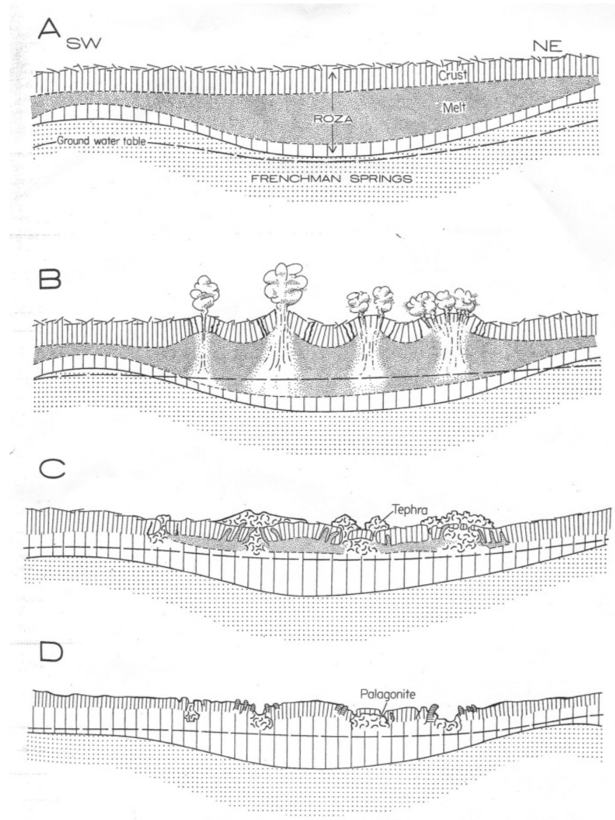


Figure 29. Lava-water interaction model proposed by Hodges (1978).

En route to Stop 6—Cinnamon Roll

From the Odessa Craters Trail, we will head south several miles to Trejbal Back Road. We will turn left on this road, travel for a short distance then turn around so we are facing west. We will park along this road for our final stop. This stop is a chance to explore the interior of a small basaltic ring structure with a very short walk.

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