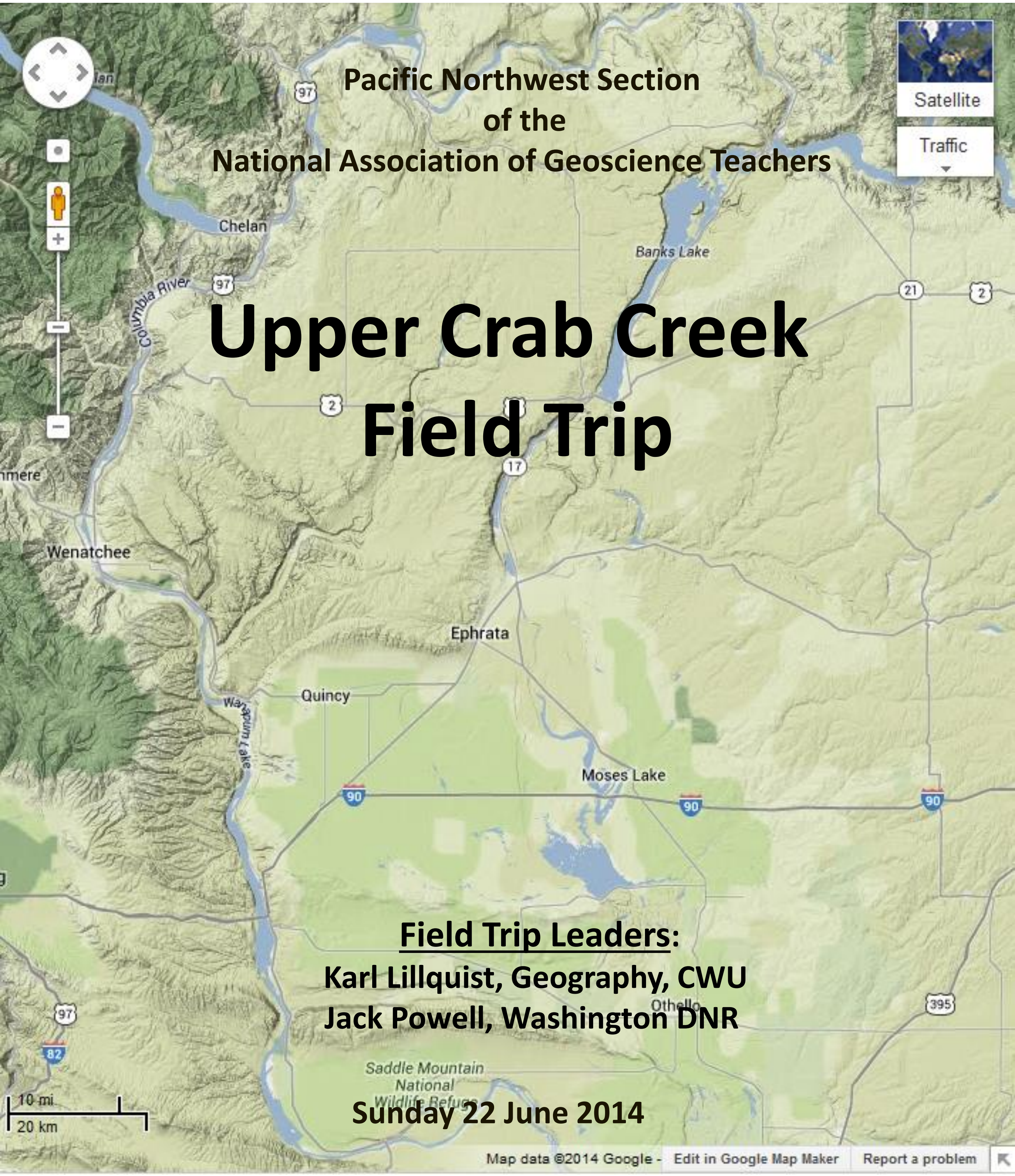


Pacific Northwest Section
of the
National Association of Geoscience Teachers

# Upper Crab Creek
# Field Trip

**Field Trip Leaders**:

**Karl Lillquist, Geography, CWU**
**Jack Powell, Washington DNR**

**Sunday 22 June 2014**

# Itinerary & Trip Overview

| | |
|---|---|
| 8:00 | Depart from WVC |
| 9:15 | **Stop 1—Soap Lake Park** |
| | - Restrooms |
| | - Closed-Basin Soap Lake |
| 10:00 | Depart |
| 10:30 | **Stop 2—Kappel Road** |
| | - Columbia River Basalts |
| | - Giant Flood Bars |
| 11:00 | 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 |
| 1:30 | Depart |
| 1:45 | **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 Wenatchee |

This trip will focus on the geology and physical geography of the Upper Crab Creek drainage of eastern Washington. Our first at Soap Lake's City Park will center on the origins and significance of Soap Lake. From Soap Lake, its up the Crab Creek Valley to near Wilson Creek where we will 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.

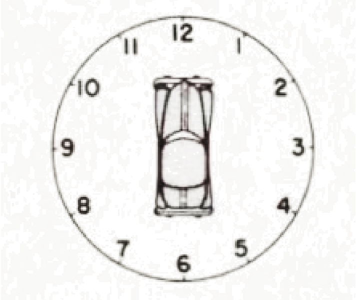


**Figure 1. Relative bearings using a clock. Assume that the bus is always pointed to 12 o'clock. Source: Campbell (1975, p. 1).**

# Our Route & Stops

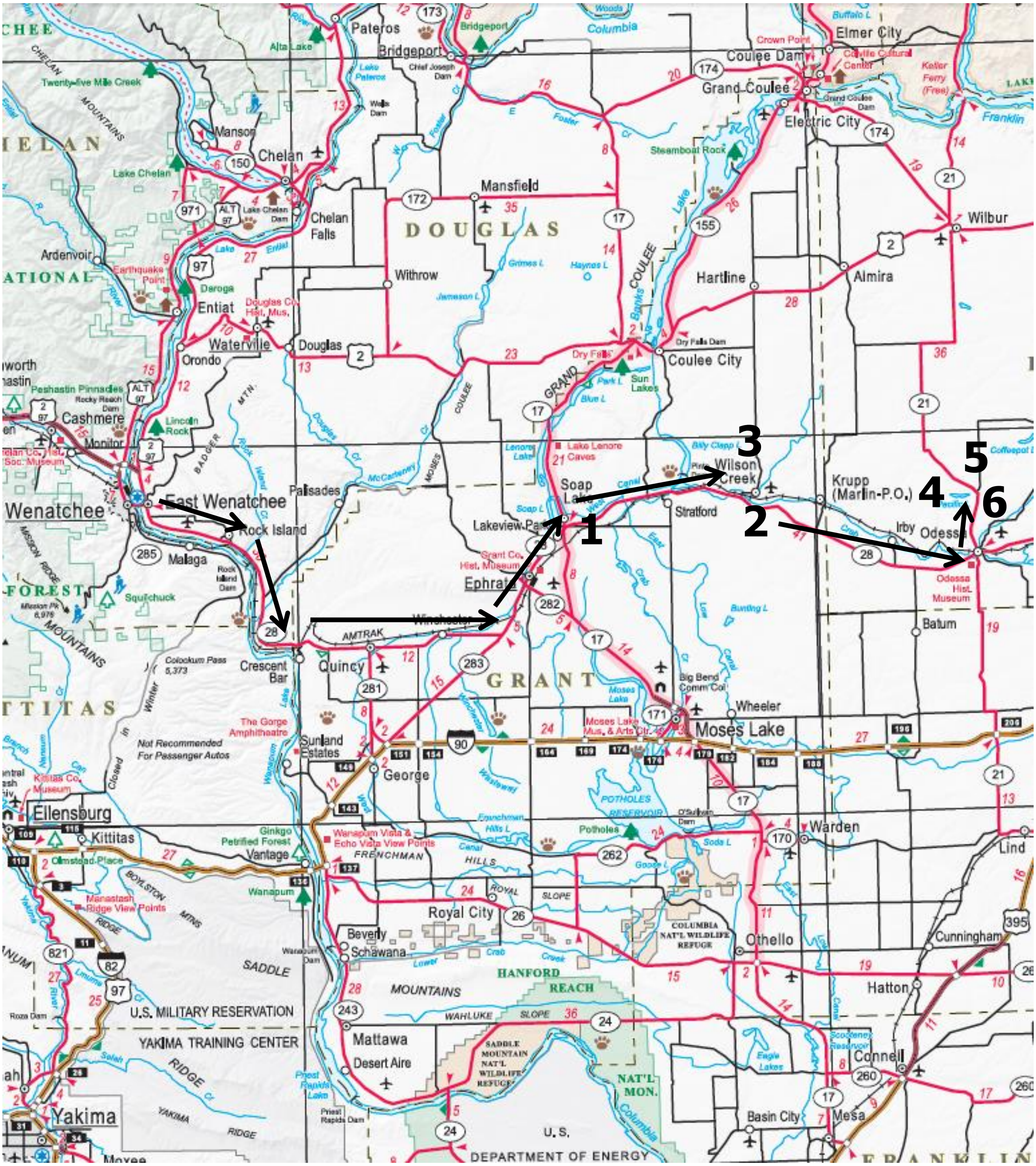


Figure 2. Our route shown with arrows and stops noted with numbers. Source: Washington State Department of Transportation http://www.wsdot.wa.gov/NR/rdonlyres/14A6187A-B266-4340-A351-D668F89AC231/0/TouristMapFront_withHillshade.pdf

# Wenatchee to Quincy Basin

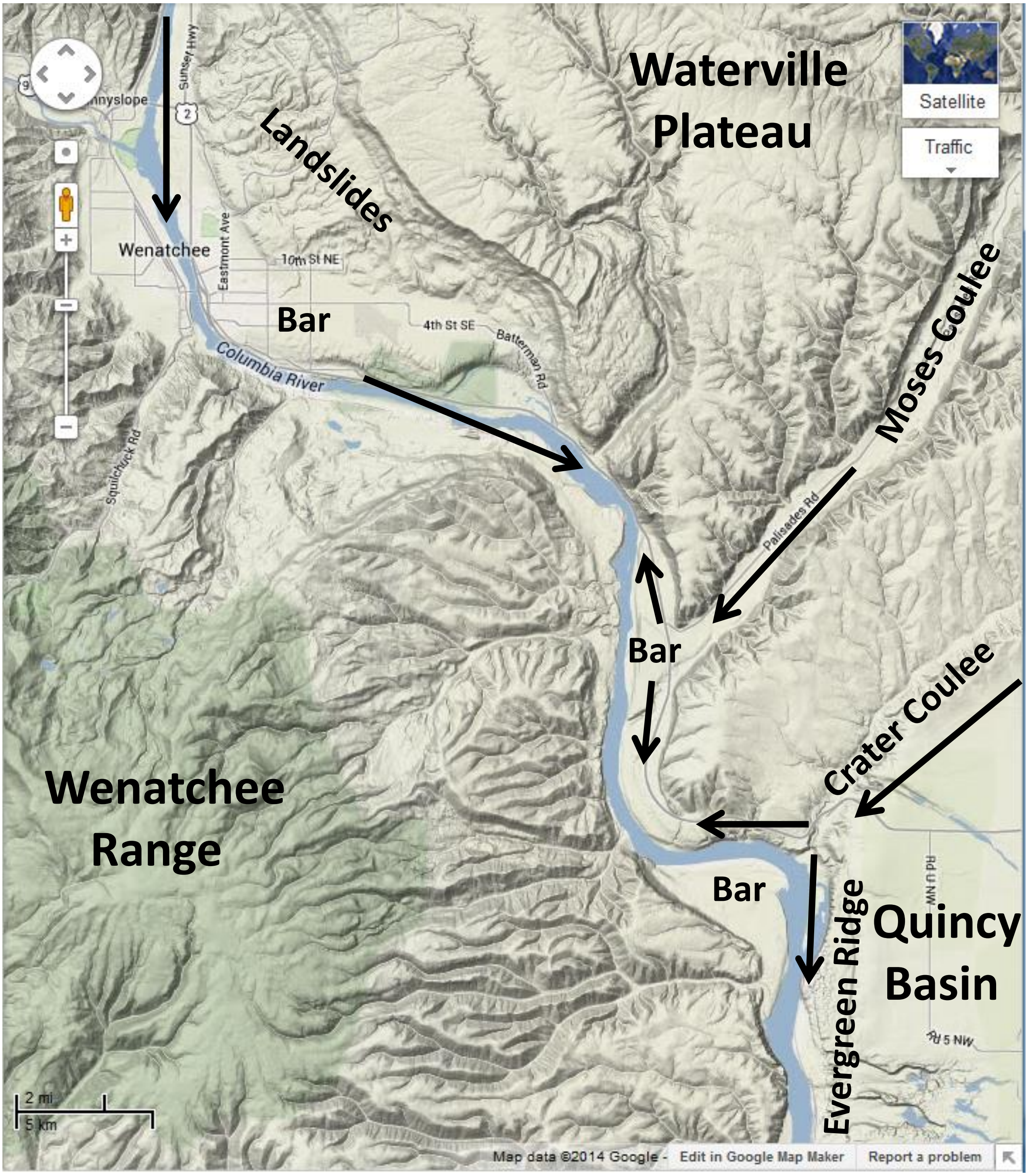
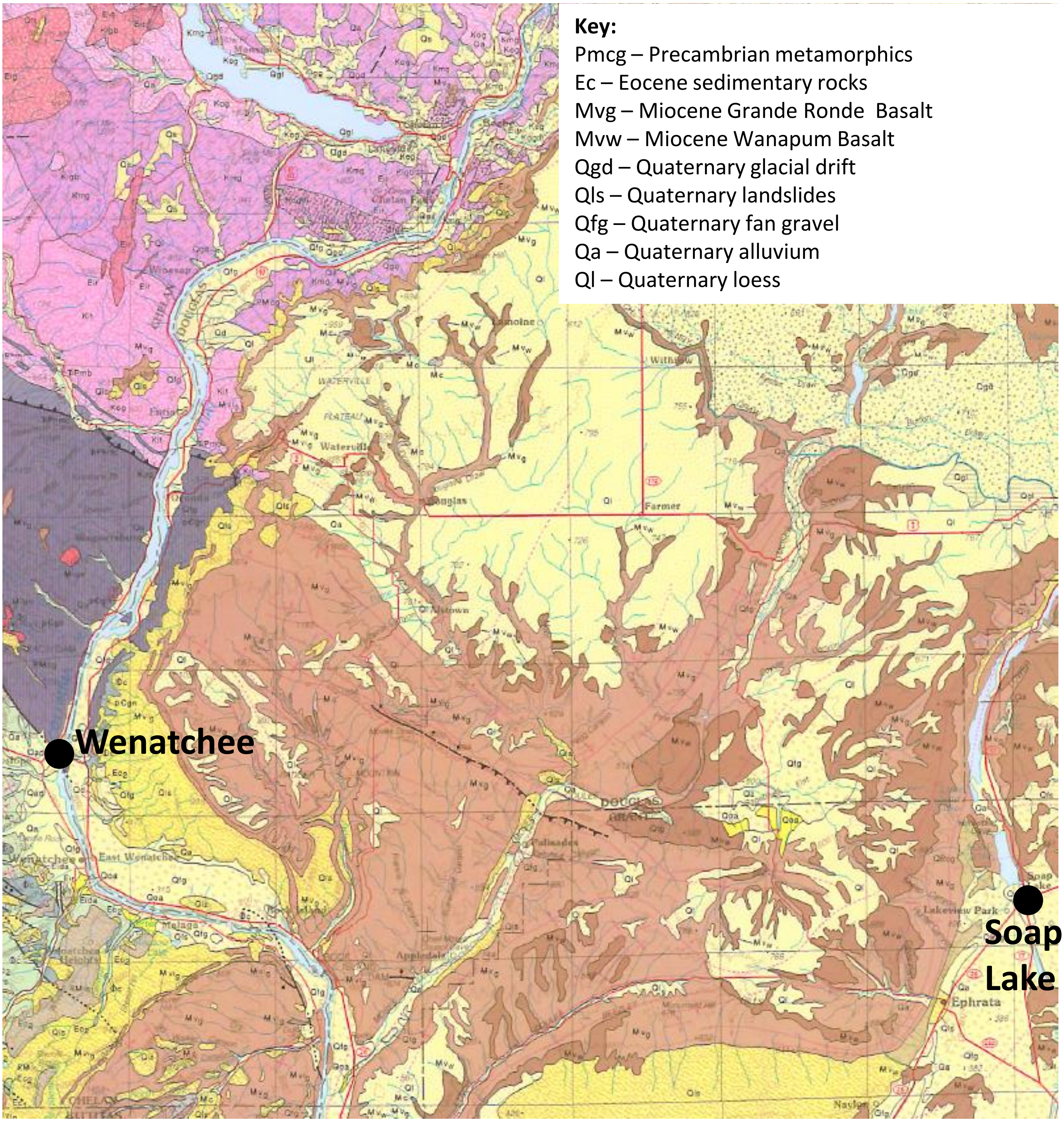


**Figure 3. Topography of route from Wenatchee to Quincy Basin. Arrows indicate direction of Missoula Flood flows. Source of image: Google Maps.**

# Wenatchee to Quincy Basin

- **Route:** Part of our route to Stop 1 takes us from Wenatchee to the Quincy Basin via WA 28 (Figures 2 & 3).
- **Lithology & Structure:** Wenatchee lies at the eastern margin of Precambrian metamorphics and Eocene sedimentary rocks, and the western margin of the Columbia River Basalts (Figure 4).
- **Topography and past environments:** As we head downriver toward Trinidad, the Wenatchee Mountains lie to our west (Figure 3). Summits of these folded basalts extend above 6,000 feet on Mission Ridge. It is unlikely that they were sufficiently high to have been impacted by alpine glaciers during the Late Pleistocene. The absence of glaciers was likely due to a relative lack of precipitation compared to the main Cascade Range further west. However, temperatures were sufficiently low that rock glaciers formed in the Wenatchee Range under periglacial conditions. The upland to our east is the Waterville Plateau. This feature is elevated above the surroundings because of folding as well as incision of the Columbia River Valley. The Waterville Plateau was covered by the Late Pleistocene Okanogan Lobe of the Cordilleran Icesheet south nearly as far as US 2 (Figure 4).
- **Missoula Floods**: Latest Pleistocene floods from Glacial Lake Missoula descended the Columbia River Valley before the Okanogan Lobe had advanced to, and after it had retreated from, the Waterville Plateau (Figure 5). A huge pre-Okanogan Lobe flood reached levels 1100 feet above the surface of the present day Columbia River. While the Okanogan Lobe blocked the upper Columbia River Valley, floodwaters were diverted down Moses Coulee and the Upper Grand Coulee. Some of the Moses Coulee and Upper Grand Coulee floodwaters (via the Quincy Basin) actually flowed *up* the Columbia River Valley. The huge bar at the mouth of Moses Coulee blocked the flow of the Columbia River sufficiently long that deltas were constructed at the mouths of tributaries (Figure 3). Graded silt-clay couplets exposed on this bar suggest that nearly 40 years separated two of the Moses Coulee floods. In total, five floods appear to have come down Moses Coulee. Following the recession of the Okanogan Lobe, at least three significant floods passed through the Columbia River Valley. The largest occurred prior to the deposition of 11,250 yr BP Glacier Peak tephra. The giant current ripples of West Bar likely formed during the passage of the last large ice age flood down the Columbia River Valley. Nineteen rhythmic gravel to silt beds (i.e., rhythmites) in a quarry in the Trinidad bar suggest that 19 large floods occurred in the area, the later of which were successively smaller (Waitt, 1994).
- **Landslides:** Landslides are common in the Columbia River Basalts along the Columbia River Valley (Figures 3 & 4). Some of these are pre-flood features, perhaps related to incompetent interbeds between the basalt flows. Others may have formed during floods from undercutting. Others still formed following large floods.
- **Structure:** Above Trinidad, we drive over Babcock-Evergreen Ridge, a low anticline that forms the western edge of the Quincy Basin (Figure 4). The top of this anticline was not covered by floodwaters; however, it was cut by floodwaters in three places—Crater Coulee, Potholes Coulee, and Frenchman Coulee (Figure 9).

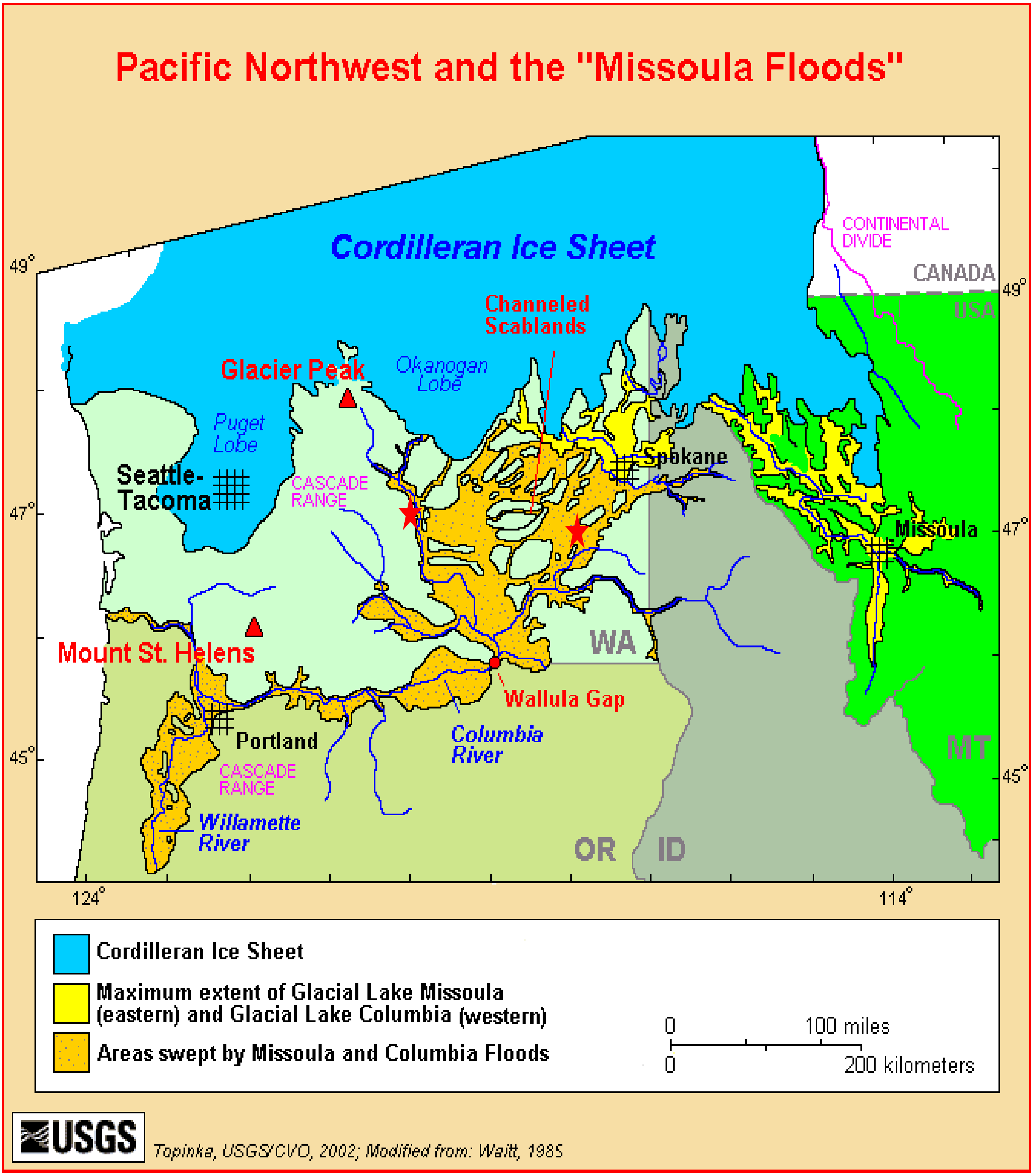
# Wenatchee to Soap Lake



**Key:**
Pmcg – Precambrian metamorphics
Ec – Eocene sedimentary rocks
Mvg – Miocene Grande Ronde Basalt
Mvw – Miocene Wanapum Basalt
Qgd – Quaternary glacial drift
Qls – Quaternary landslides
Qfg – Quaternary fan gravel
Qa – Quaternary alluvium
Ql – Quaternary loess

**Figure 4. Geologic map of the Wenatchee to Soap Lake leg of the field trip. Source: http://www.dnr.wa.gov/Publications/ger_gm39_geol_map_ne_wa_250k.pdf.**

# Wenatchee to Quincy Basin



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

**Figure 5. Map of the late Pleistocene Cordilleran Icesheet and Missoula Floods in the Pacific Northwest. Stars indicate approximate locations of Wenatchee and Odessa. Source: Cascade Volcano Observatory website.**

# Quincy Basin to Soap Lake

- **Route:** This leg of the route takes us across the Quincy Basin to the mouth of the Lower Grand Coulee. (Figures 2 & 6). We enter the Quincy Basin essentially where WA 28 reaches its high point above Trinidad. We then follow WA 28 along the base of the Beezley Hills through Quincy to Ephrata and Soap Lake.
- **Substrate:** The Quincy Basin is underlain by *Miocene* Grande Ronde and Wanapum basalts of the Columbia River Basalt group (Figures 4, 6, 7 & 8). The individual flows are interbedded with sedimentary units including *diatomaceous earth*, which is mined in the basin. The Ringold Formation, a mix of *Tertiary* and *Quaternary alluvial* and *lacustrine* sediments, is found in scattered exposures in the basin. Gravels, sands, and silts associated with late Quaternary Missoula Floods cover much of the basin. Loess mantles much of the slopes of the basin. The tan soils of the basin are low in organic matter and indicate aridity.
- **Structure and Flooding:** The Frenchman Hills and Beezley Hills (Figure 6) are anticlines on the northwestern part of the Yakima Fold and Thrust Belt (Figure 9). These anticlines guided floodwaters entering the basin from the northeast and east. Flood outlets from the basin were (clockwise from the northwest) at Crater Coulee, Potholes Coulee, Frenchman Coulee, and Drumheller Channels (Figure 6).
- **Columbia Basin Irrigation Project:** The Quincy Basin is a vastly different place now than in 1952 when Columbia River water was first delivered to the area via the Columbia Basin Irrigation Project. Prior to that time, it was a dry, sand-covered basin characterized by ranching and meager attempts at dryland farming. Now it boasts over 60 different crops. Water for these crops reach the Quincy Basin from Lake Roosevelt via Banks Lake Reservoir and a series of canals and siphons.
- **Flood Bars:** A giant flood bar formed at the mouths of the Lower Grand Coulee and Upper Crab Creek Valley as the waters left their confines (Figures 10 & 11). The largest sediments were deposited near the mouth of the lower Grand Coulee as the Ephrata Fan (or Ephrata Expansion Bar). This bar impounds Soap Lake. Keep your eyes open for evidence of large, flood-transported boulders between Quincy and Ephrata , and again between Ephrata and Soap Lake, some of which have been piled into huge stone fences. These floodwaters also left *distributary channels* throughout the basin. Ephrata lies in once such channel, aptly named the Ephrata Channel. From Ephrata, we climb to the top of the expansion bar on WA 17, then descend to Soap Lake. Note the impacts of these bar sediments on land use.
- **Cover Sand:** Windblown sand originating from the Columbia River and from wind reworking distal Missoula Flood deposits covers much of this bar. Unlike the deposits near Moses Lake, these deposits take on the flatter form of cover sand rather than dunes, perhaps reflecting the lower amount of sand available. These sands are a main parent material for the basin's soils.
- **Patterned Ground:** Patterned ground appears as pimple-like features on the gravelly to bouldery Missoula Flood deposits as we near Ephrata. If you look closely, you can also see patterned ground on the Beezley Hills. Given the position of these features, they must have formed following the floods in the latest *Pleistocene* or *Holocene*. Are they cold climate phenomena, the result of water or wind erosion, seismic activity, burrowing rodents, or something else?

# Quincy Basin to Soap Lake

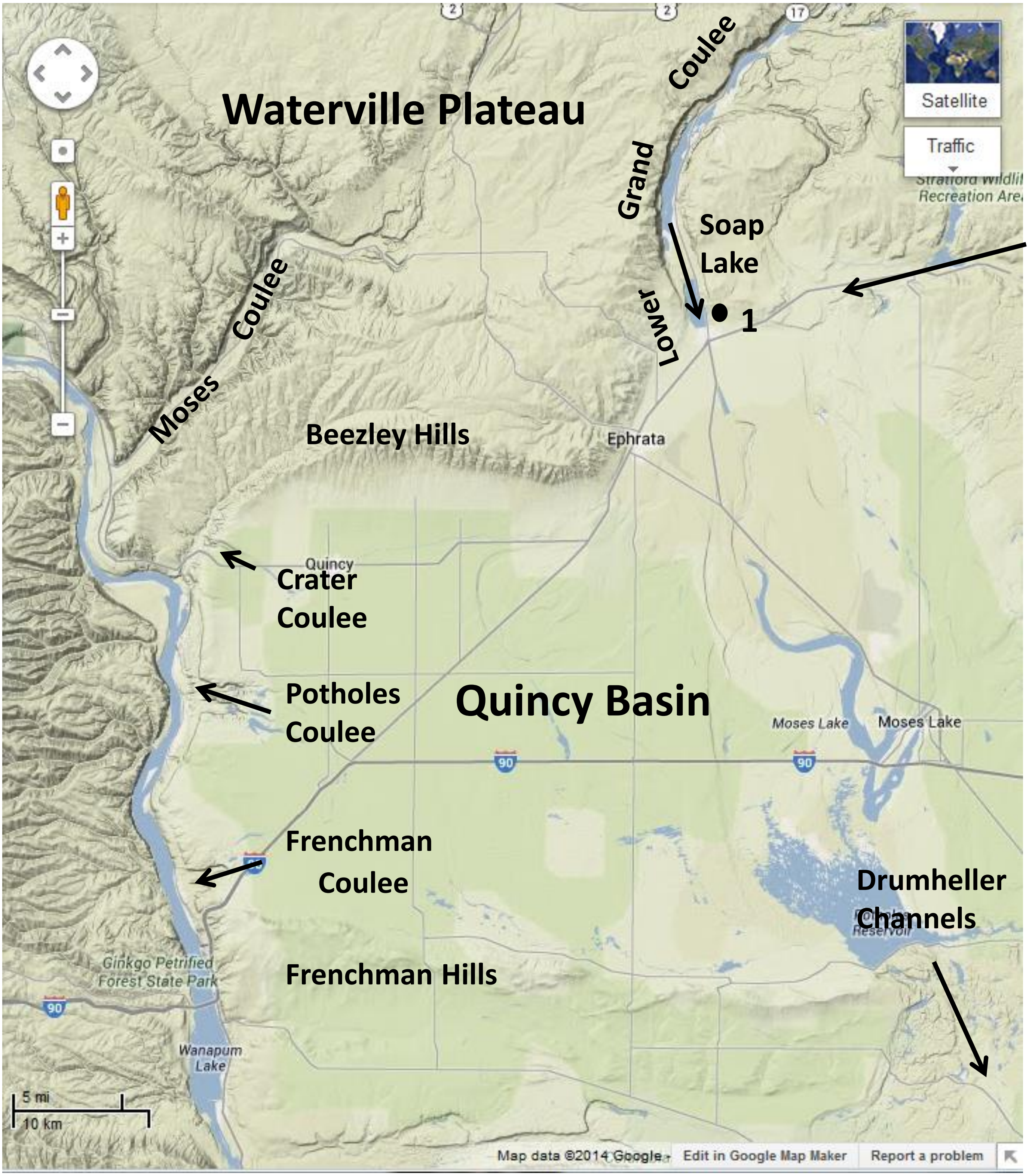


Figure 6. Topography of the Quincy Basin to Lower Grand Coulee part of our route. Arrows show direction of flood flows into, and out of, the Quincy Basin. Source of image: Google Maps.

# Wenatchee to Quincy Basin

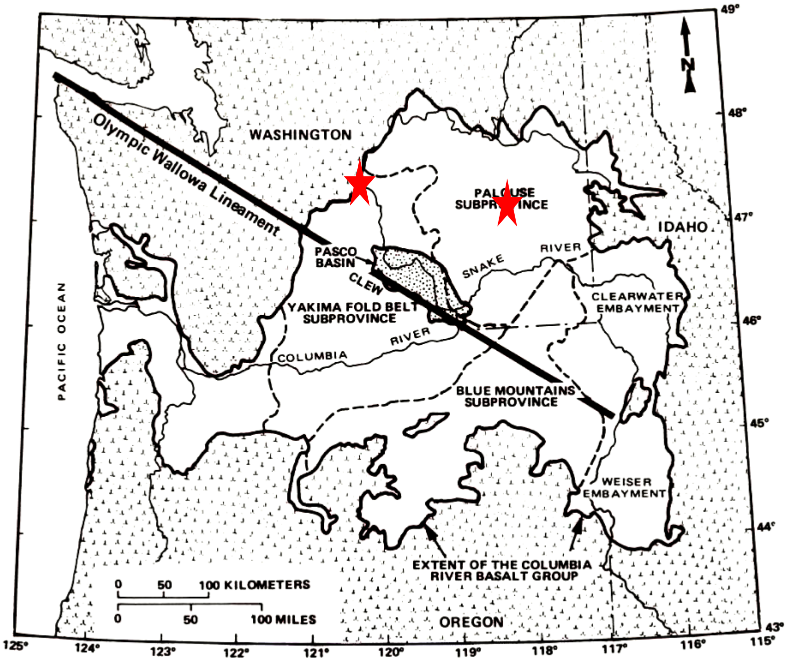
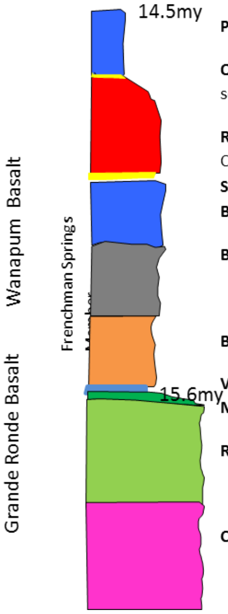


**Figure 7. The Columbia Plateau and the areal extent of the Columbia River Basalt Group, the four major structural-tectonic subprovinces (the Yakima Fold Belt, Palouse, Blue Mountains, and Clearwater-Weiser embayments), the Pasco Basin, the Olympic-Wallowa lineament. Stars indicate approximate locations of Wenatchee and Odessa. Source: (Reidel & Campbell, 1989, p. 281).**



**Priest Rapids Member**

**Quincy Member** – Sedimentary layer some times diatomaous, can be uplifted Squaw Creek sediment

**Roza Member** – Small plagioclase crystals in this flow makes the most easily recognized of the CRB

**Squaw Creek Member** – Sedimentary bed; often diatomaous;

**Basalt of Sentinel Gap** – foreset bedding in basal pillows

**Basalt of Sand Hollow** – Double barrow flow

**Basalt of Ginkgo** – Petrified Forest in basal pillows

**Vantage Sediment Member** – Major topographic bench and regional aquifer

**Museum Flow** – Short colonnade flow

**Rocky Coulee Flow** – massive entablature Flow

**Cohasette Flow** - massive entablature Flow

**Figure 8. Stratigraphy of the Columbia River Basalt Group.**

# Wenatchee to Quincy Basin

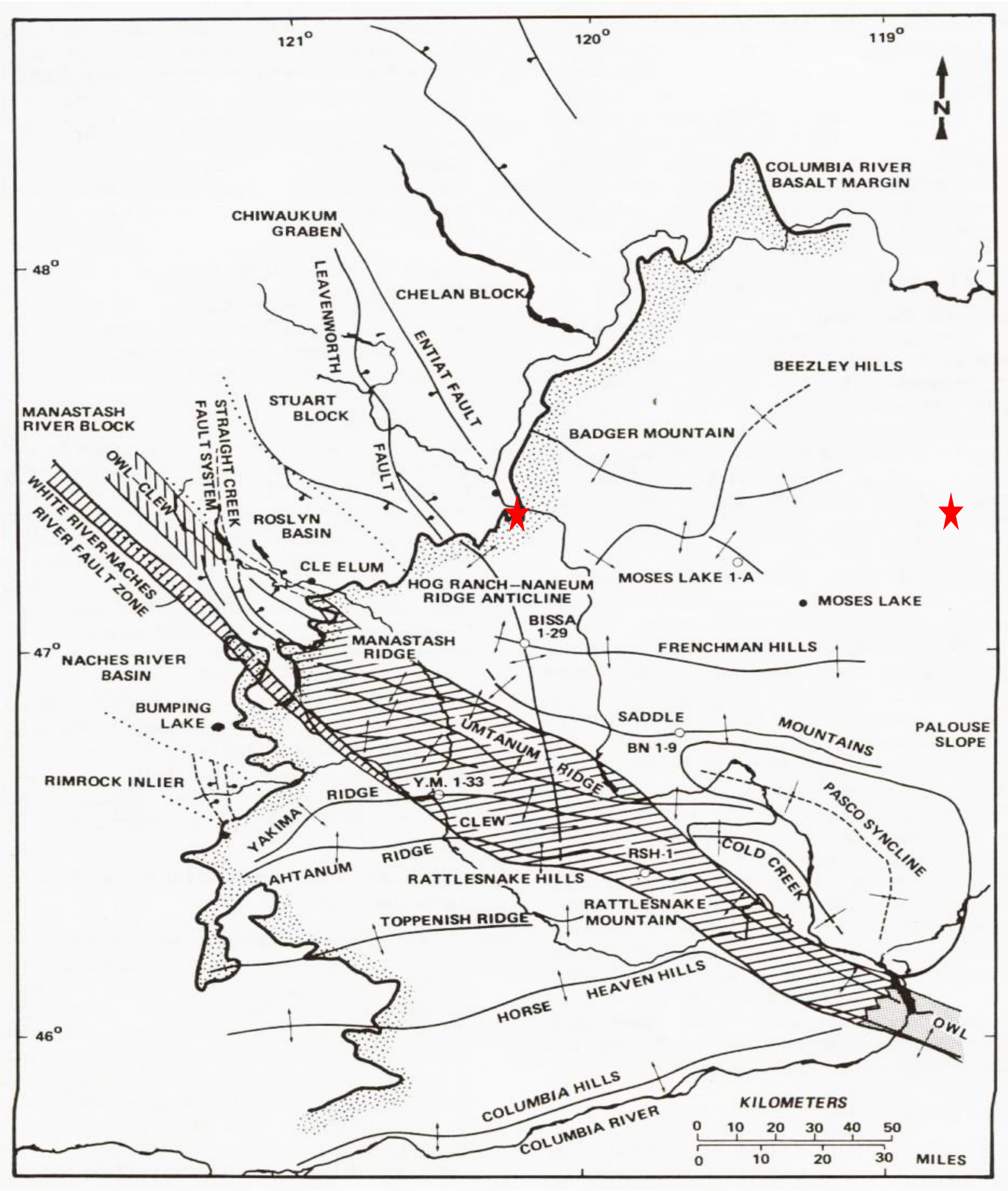


Figure 9. Generalized map of major faults and folds along the western margin of the Columbia Plateau and Yakima Fold Belt. Stars indicate approximate locations of Wenatchee and Odessa. Source: Reidel & Campbell (1989, p. 281).

# Quincy Basin to Soap Lake

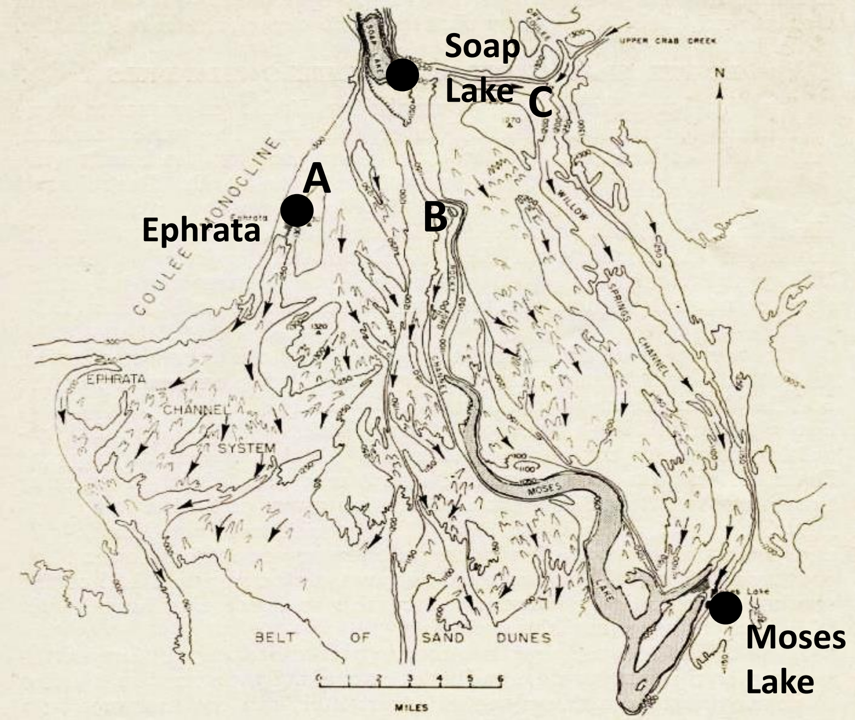


**Figure 10. Quincy Basin distributary channels. Note three main distributaries from west to east—Ephrata (A), Rocky Ford (B), and Willow Springs (C). Note origins of distributaries at apex of Ephrata Fan (i.e., expansion bar). Source: Bretz (1959, p. 33).**

**Figure 11. Oblique view of Soap Lake at the terminus of the Lower Grand Coulee. Solid arrow shows flood flows. Dashed arrows show development of explansion bar. Source: Google Earth.**

# Stop 1—Soap Lake

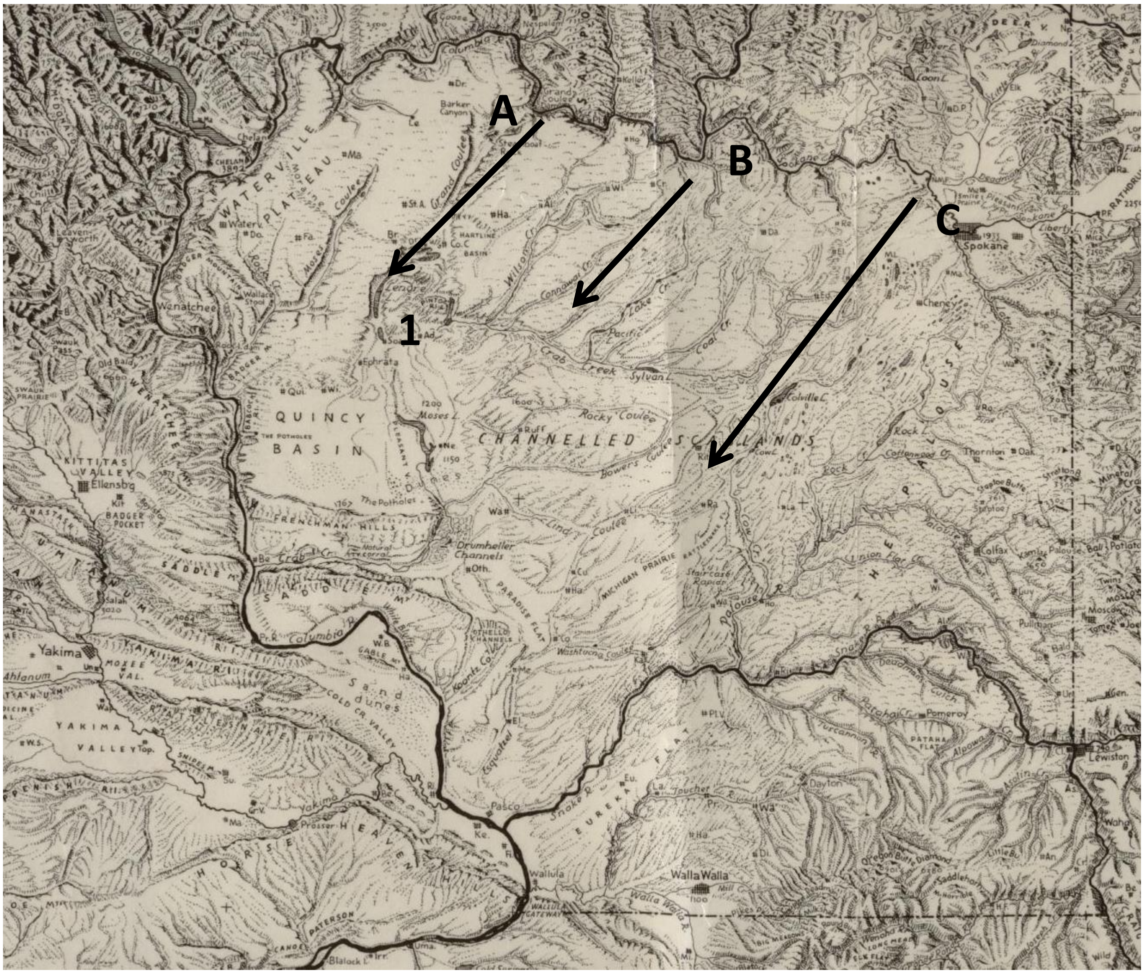


**Figure 12. Channeled scablands of central Washington state. A is the Grand Coulee scabland tract, B is the Telford-Crab Creek tract, and C is the Cheney-Palouse tract. Number 1 represents Soap Lake field stop. From Raisz (1941).**

- **Soap Lake & the Lower Grand Coulee**: 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. Grand Coulee operated early and often as a major path for Missoula Floods (Figure 12). 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).
- **Lower Grand Coulee Formation**: It is 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 13). 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 Lower Grand Coulee.

# Stop 1—Soap Lake (continued)

- **Soap Lake & the Ephrata Expansion Bar:** 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).
- **Glacial Lake Bretz:** 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 as a Closed Basin Lake:** 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 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). Closed-basin lakes are characteristic of arid and semi-arid environments where insufficient water is available to erode outlets in the impounding dams.
- 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).

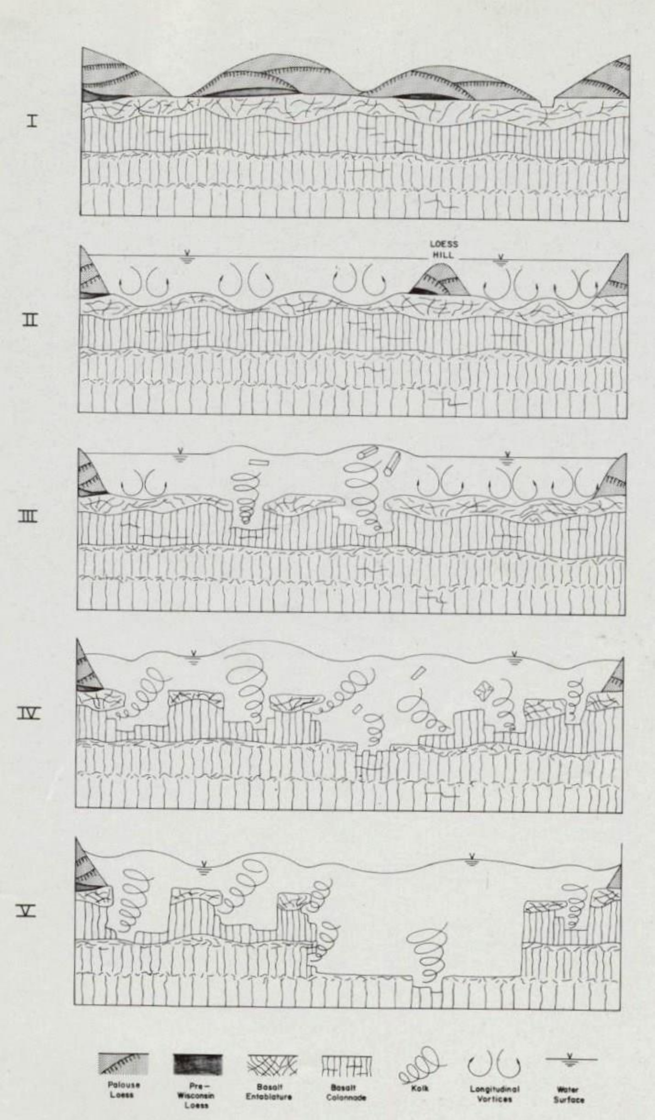


**Figure 13. Illustration of kolk-based erosion in columnar jointed basalts. From Baker (1978, p. 105).**

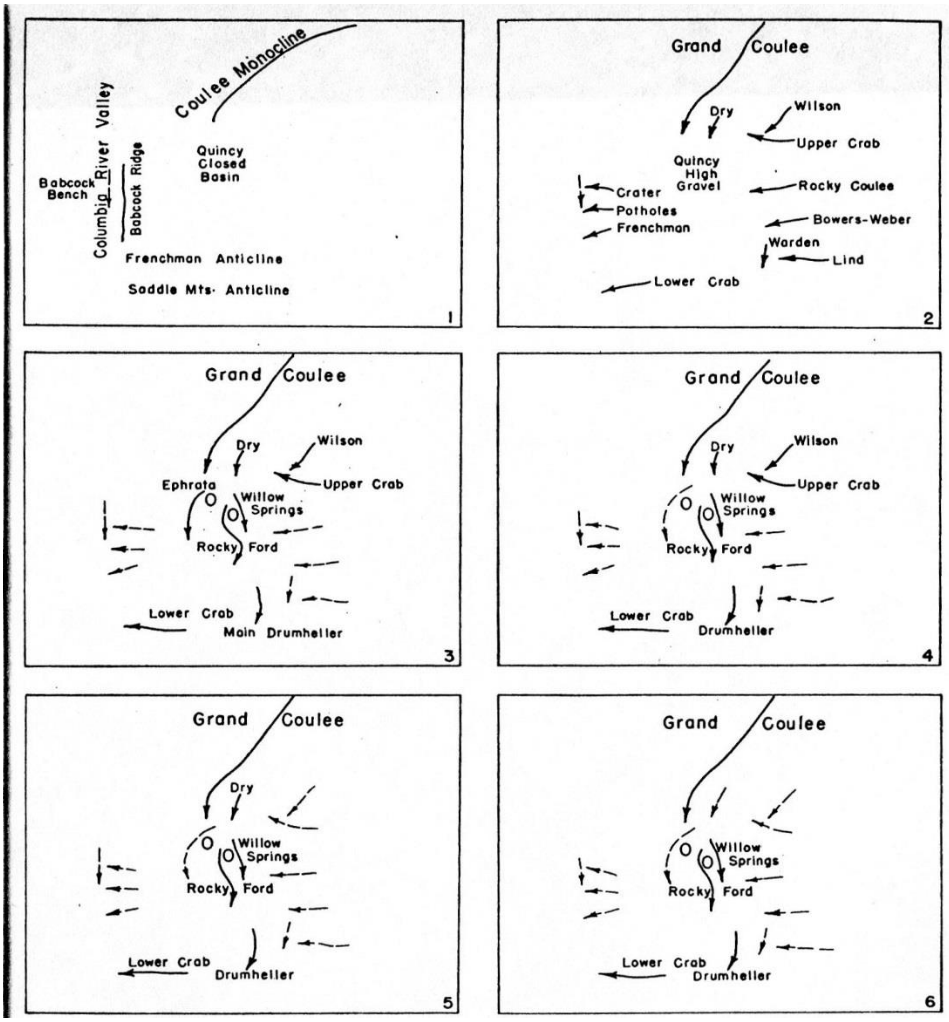


**Figure 14. Sequence of floods into the Quincy Basin according to Bretz and others (1956).**

- **Soap Lake & Human Activity**: 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

- **Route:** From the City Park in Soap Lake, we return south to WA 28 and head east up the Upper Crab Creek Valley (Figures 2 & 15). We ascend and then descend the edge of the Ephrata expansion bar to the Crab Creek Valley floodplain. We mostly follow the valley floor to Wilson Creek. We will take the second road (Kappel Road) into Wilson Creek. Stop 2 is on this road and south of Crab Creek (dry this year). Park on the wide right shoulder.
- **Substrate:** We are surrounded by Columbia River Basalts (Figure 16). The valley floor is Quaternary alluvium and Quaternary fan gravel from the Missoula Floods.
- **Dry Coulee Expansion Bar:** The highway soon climbs to the top of a large expansion bar that formed at the mouth of flows from Dry Coulee (Figure 15). Dry Coulee received flood flows from the Grand Coulee as did the coulee just upstream from Dry Coulee. The position and condition of this bar suggests that it formed following the main flows down Crab Creek.
- **Crab Creek Valley & Missoula Floods**: 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 12). 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.
- **Evidence for Missoula 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?
- **Crab Creek**: Contemporary Crab Creek originates near Reardan, about 60 miles northeast of Wilson Creek (Figure 17). Downstream of us, Crab Creek flows south to Moses Lake, then south and west to the Columbia River near Schawana. The Crab Creek Watershed is very large in relation to its discharge. This relationship is characteristic of semi-arid watersheds that are also impacted by irrigation.
- **Wilson Creek:** The town of Wilson Creek is located at the junction of Crab Creek and Wilson Creek (Figure 18). 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.

# Soap Lake to Wilson Creek

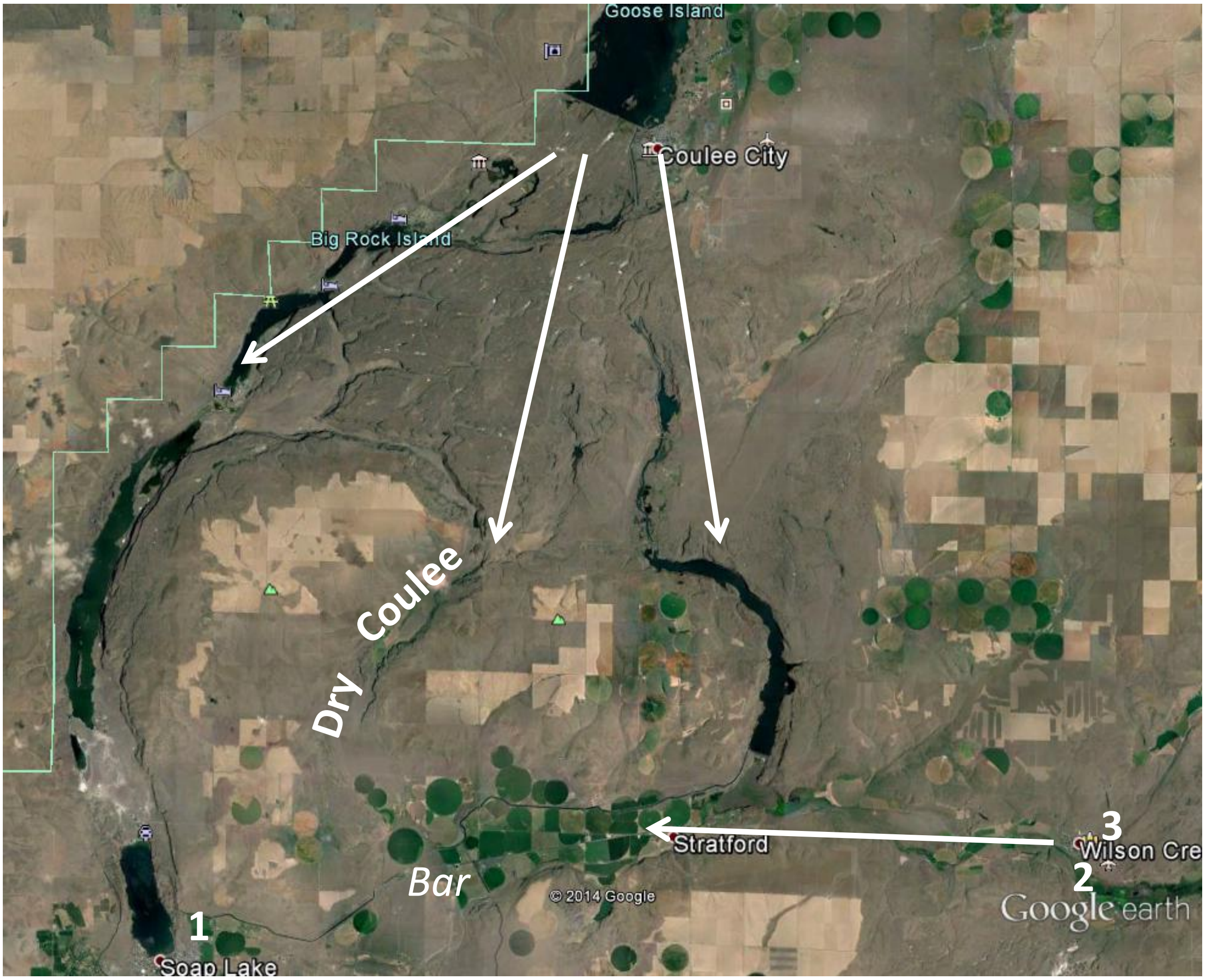


**Figure 15. Landscape between Soap Lake and Wilson Creek. Note the brown “scablands” extending south from Coulee City. The tan and green areas were not impacted by flooding. Arrows indicate flood flow directions. Numbers represent field trip stops. Source of image: Google Earth.**

# Soap Lake to Odessa

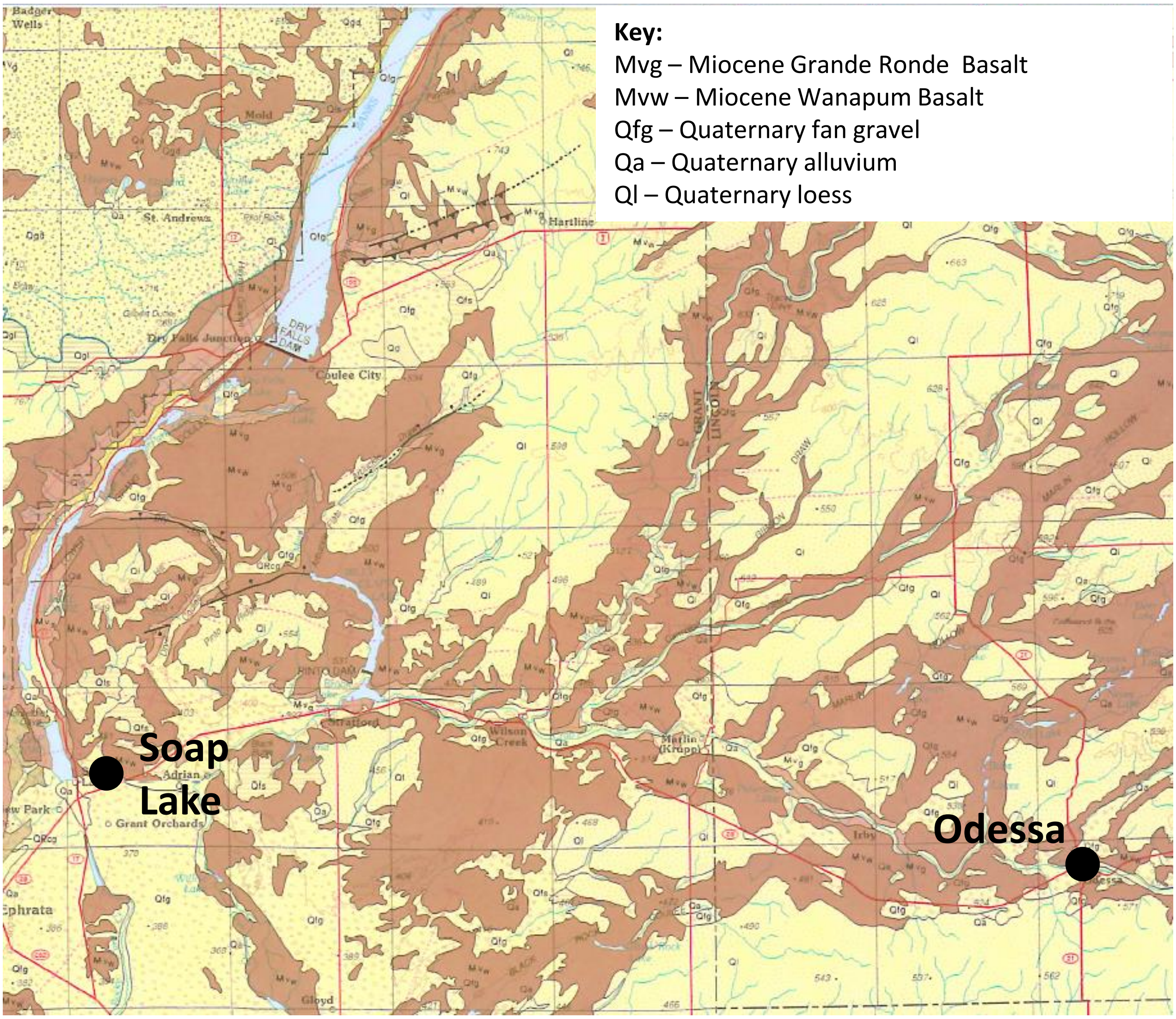


**Figure 16. Geologic map for the part of the field trip between Soap Lake and Odessa. Source: http://www.dnr.wa.gov/Publications/ger_gm39_geol_map_ne_wa_250k.pdf**

# Soap Lake to Odessa

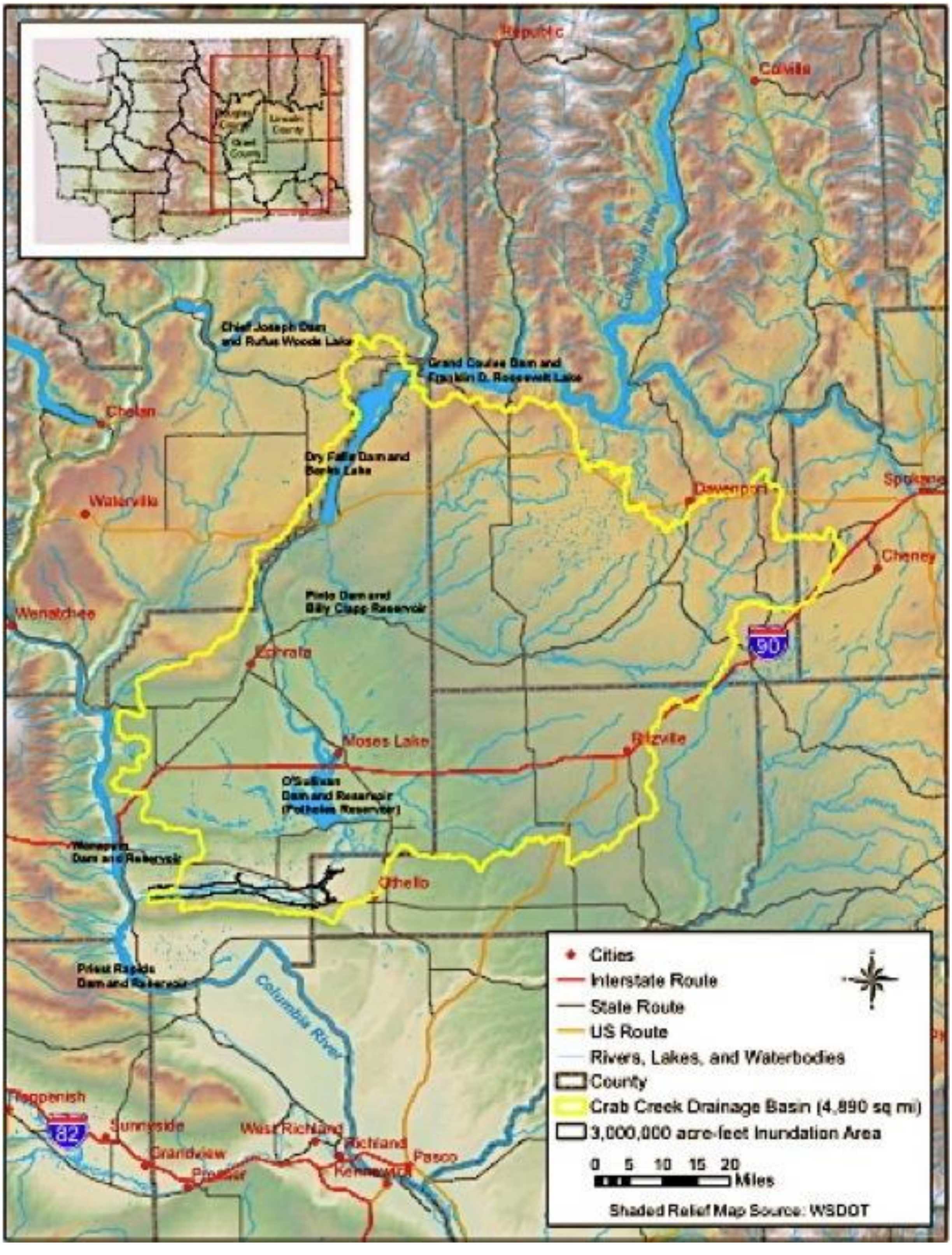


**Figure 17. Crab Creek Watershed. Source: http://www.waterplanet.ws/crabcreek/ccrhome/Home.html**

# Stops 2 & 3—Wilson Creek

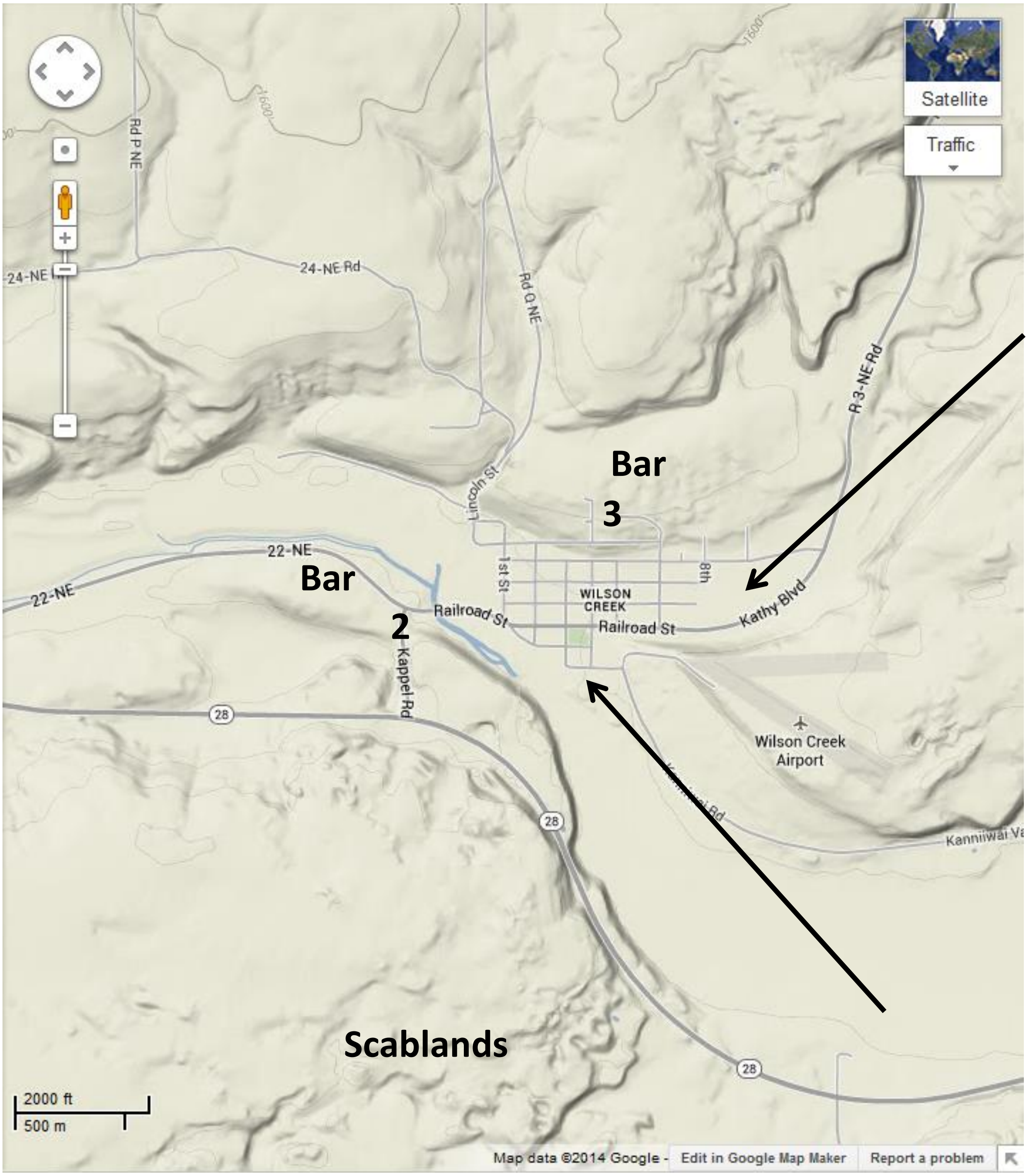


Figure 18. Topography of the Wilson Creek area. Arrows indicate flood flow directions here. Numbers indicate field trip stops. Source: Google Maps.

# Stop 2—Kappel Road

- **Location:** We are parked at a wide spot near the junction of Kappel Road and 22-NE just south of Wilson Creek.
- **Substrate:** Priest Rapids basalt flows are present in the roadcut here, separated by a baked zone. This baked zone is a flow top as indicated by the abundant vesicles.
- **Flood bars**: At this stop, we see a fine example of a giant flood bar (Figure 19), 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 (Figures 20 & 21). 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 19): 1) c*rescent bars* —form on the inside bend of channels; 2) l*ongitudinal bars* —form in mid-channel or along a channel wall; 3) e*xpansion bars* —form where channels widens abruptly; 4) *pendant bars* —form downcurrent of mid-valley obstacle or valley-wall spur on bend; 5) e*ddy bars* —form in a valley at the mouth of a tributary; and 6) *delta bars* —form where floodwater on a high surface adjacent and parallel to a main channel encounters a transverse tributary valley where it deposits. What type of bar is this?

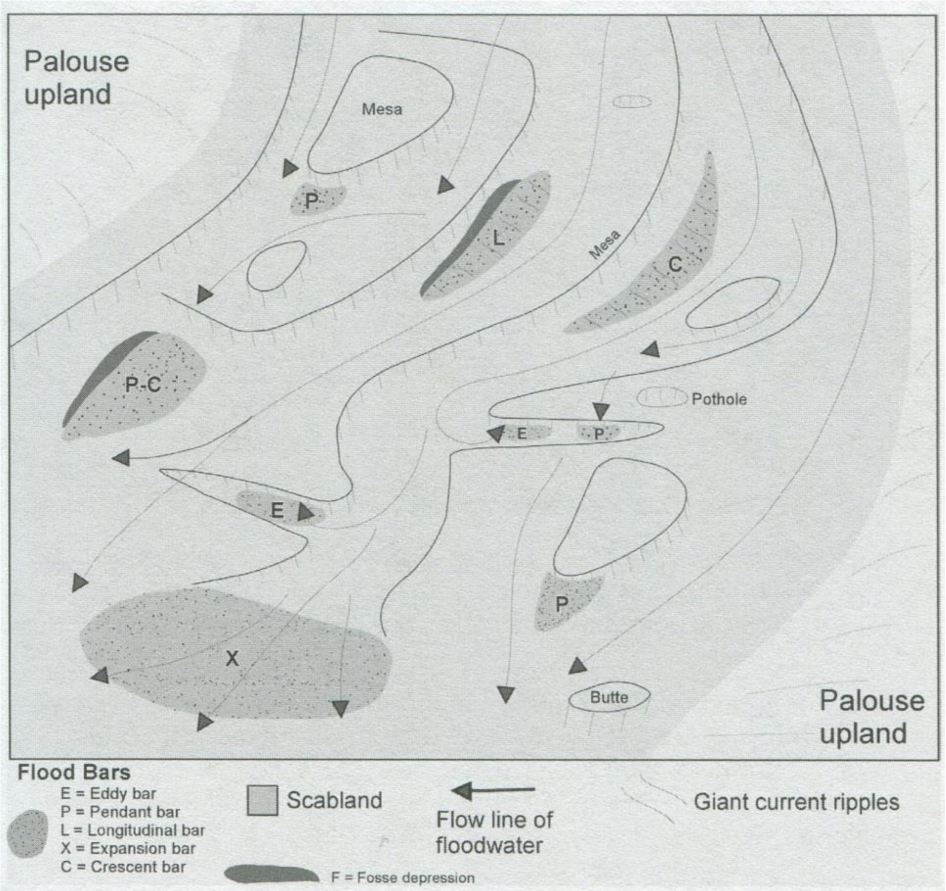


**Figure 19. Types of flood bars. From Bjornstad and Kiver (2012, p. 51).**

# Stop 2—Wilson Creek Flood Bar (continued)

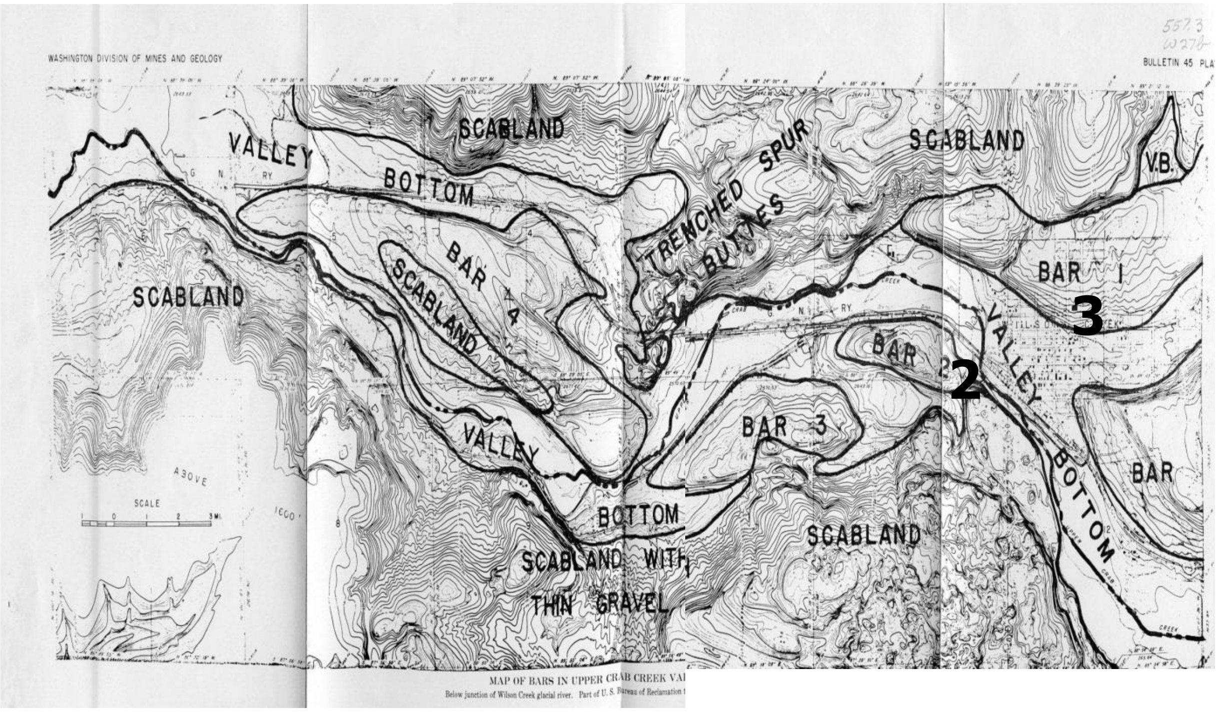


**Figure 20. Bars and scablands near Wilson Creek (far east portion of map). Numbers indicate locations of Stops 2 & 3. Arrow indicates flood flow direction. From Bretz (1959).**

**Figure 21. Bretz (1959) flood bar 2 and our Stop 2. Source: Google Earth.**

# Stop 3—Wilson Creek School

**Figure 22. Giant flood bar and current ripples at Wilson Creek. Number indicates location of stop. Arrow indicates direction of flood flow. Source: Google Earth.**

- **Location:** Stop 3 is located at the Wilson Creek School. We get there from Stop 2 by driving across Crab Creek and turn left onto 1st Street, and soon taking 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. From the Wilson Creek School parking lot, we will hike north onto the flood surface behind the school buildings.
- **Flood bars:** What type of bar are we standing on here?
- **Giant Current ripples:** Notice on Figure 22 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)

- Examine Figures 23-26 below to see the relationships between ripple chord (i.e., wavelength), ripple height, water depth, water velocity, and stream power.

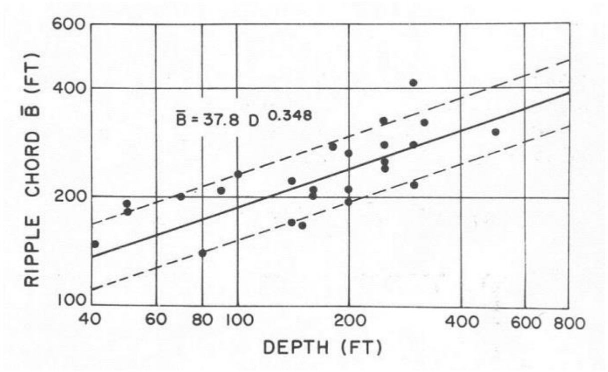


**Figure 23. Logarithmic regression of ripple chord as a function of depth. The dashed line represent one standard error. From Baker (1978b, p. 113).**

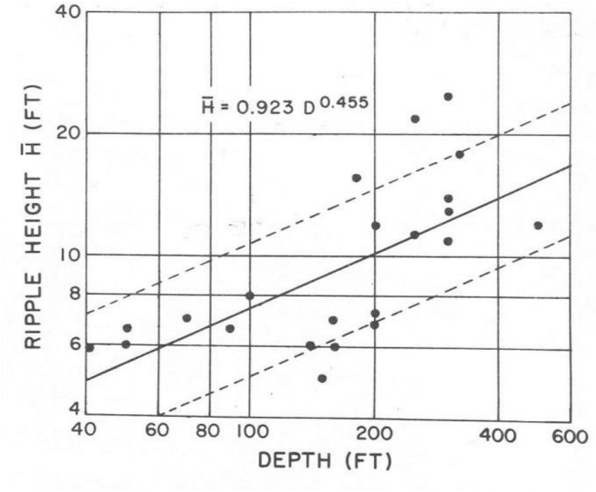


**Figure 24. Logarthmic regression of ripple height as a function of depth. The dashed lines represent one standard error. From Baker (1978b, p. 113).**

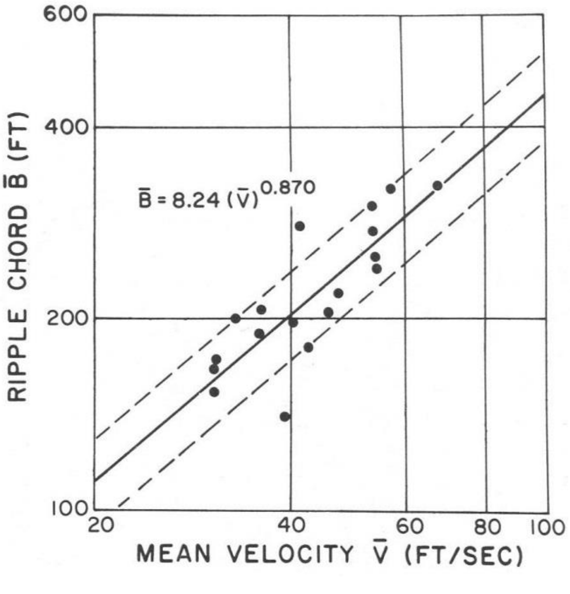


**Figure 25. Ripple chord as a function of mean flow velocity (discharge velocity) as calculated by the slope-area methods. The dashed lines represent one standard error. From Baker (1978b, p. 113).**

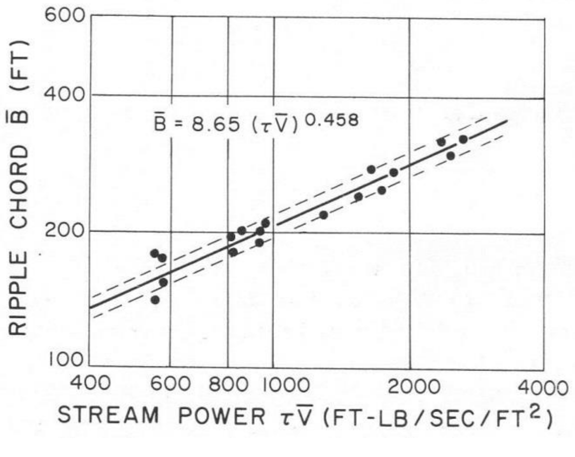


**Figure 26. Mean ripple chord as a function of stream power. The dashed lines represent one standard error. From Baker (1978b, p. 115)**

**Importance of a birds-eye perspective:** 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.

# Wilson Creek to Odessa

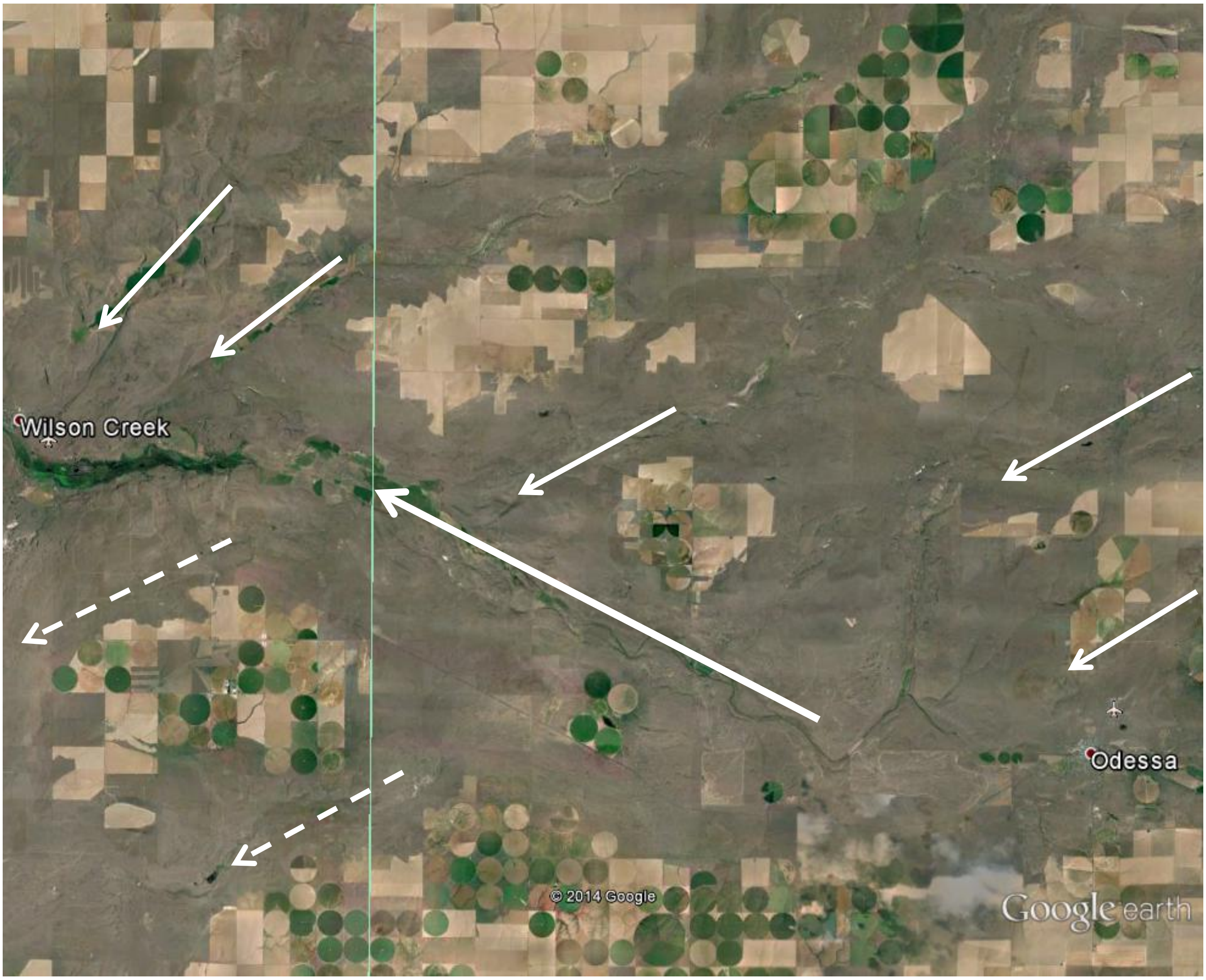


**Figure 27. Landscape between Wilson Creek and Odessa. Dark brown is scabland created by 8huge floods. Tan to green is land that was not impacted by flooding. Main flood flow in Crab Creek Valley shown with wide, solid arrow. Flood flows into Crab Creek Valley shown with narrower solid arrows. Overflows to the south shown with dashed arrow. Source: Google Earth.**

# Wilson Creek to Odessa

- **Route:** From Wilson Creek School, we return to WA 28 and continue east to Odessa (Figures 2 & 27). In Odessa, will take WA 21 north toward Wilbur. About 3 miles north of Odessa, we will turn west onto 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.
- **Flood flows:** The first few miles of our route follow the flood-scoured Crab Creek Valley. The main floodwaters of Crab Creek Valley came from the northeast where they spilled over a low divide just south of the Columbia River Valley. This main Crab Creek Valley flow was augmented by four large inflows that entered the valley between Wilson Creek and Odessa—these were (from west to east) Canniwai Creek, Marlin Hollow, Lake Creek, and Duck Creek (Figure 27). Two main flood outflows from the Upper Crab Creek Valley created scablands to the south of our route (Figure 27). 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.
- **Flood limits:** As WA 28 leaves the Crab Creek Valley east of Wilson Creek, it passes through scablands to 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 deeper soils (Figure 27). Land use in the scablands is primarily rangeland. Above ~1750 feet, "islands" of loess remain that are the foci of dryland and irrigated agriculture.
- **Flood bars & giant current ripples:** 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.
- **Loess-covered uplands:** North of Odessa, we travel through loess covered uplands before again descending into a flood channel. The source of the loess was primarily slackwater deposits in the Pasco Basin to the southwest of here. Prevailing southwest winds entrained the dry sediments and blew them to the northeast. As a result, soils closer to the Pasco Basin source are deeper and coarser than those more distant. Depth and texture affect farmland quality and associated farm practices. Proximal, coarse-textured soils are droughty therefore require irrigation while the fine-textured, more distal soils are more conducive to dryland (i.e., non-irrigated) agriculture. This is significant in an area of ~11 inches of precipitation annually and declining groundwater tables.

# Stop 4—Pacific Lake

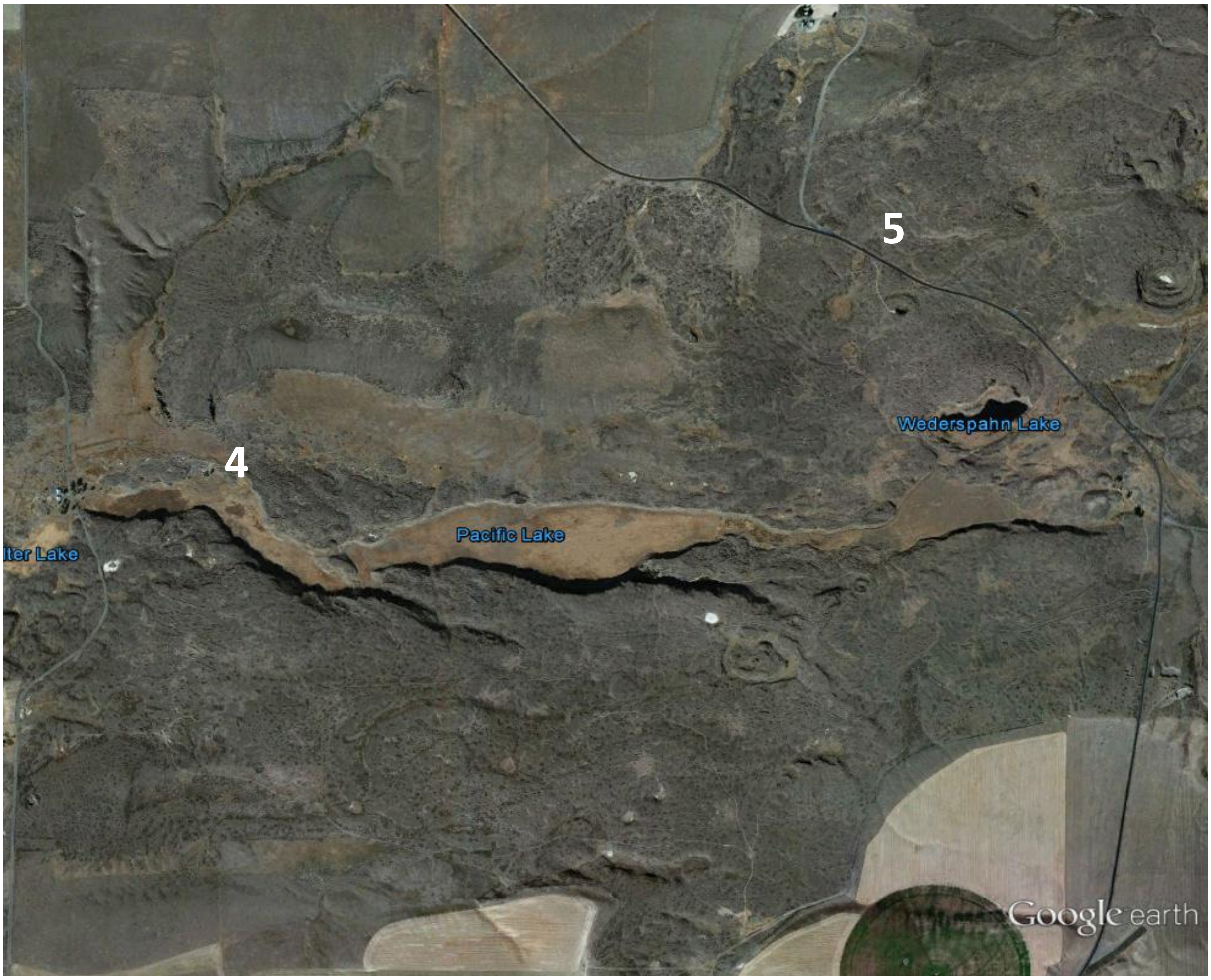


**Figure 28. Stop 4 on Pacific Lake, Lakeview Ranch, north of Odessa. Numbers indicate locations of stops. Source: Google Earth.**

- **Location:** We are located at the Pacific Lake Recreation Site, a recreation area managed by the U.S. Bureau of Land Management.
- **Pacific Lake:** As you can see from the October 2012 image above (Figure 28) and on the ground, Pacific Lake is no longer a lake. According to images on Google Earth, 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?
- **Weather, climate & Pacific Lake**: Pacific Lake (and other lakes & ponds) may fluctuate based on weather and climate patterns (Figure 29). 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.
- **Groundwater removal & Pacific Lake**: Pacific Lake levels may also fluctuate as a result of the removal of groundwater by deep wells used to irrigate crops in the area (Figure 30) 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)

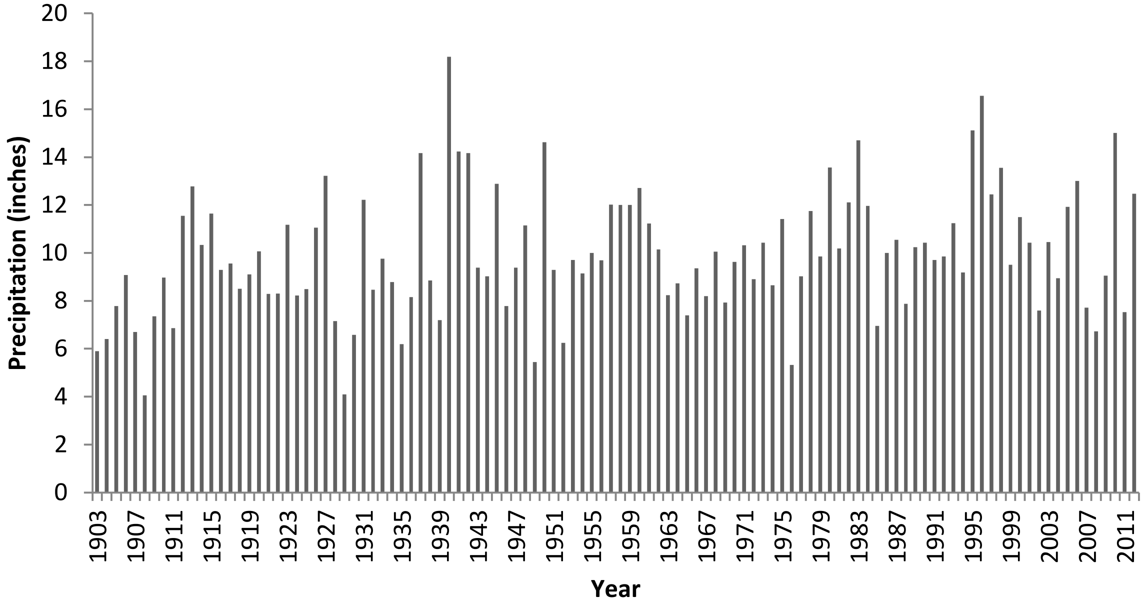
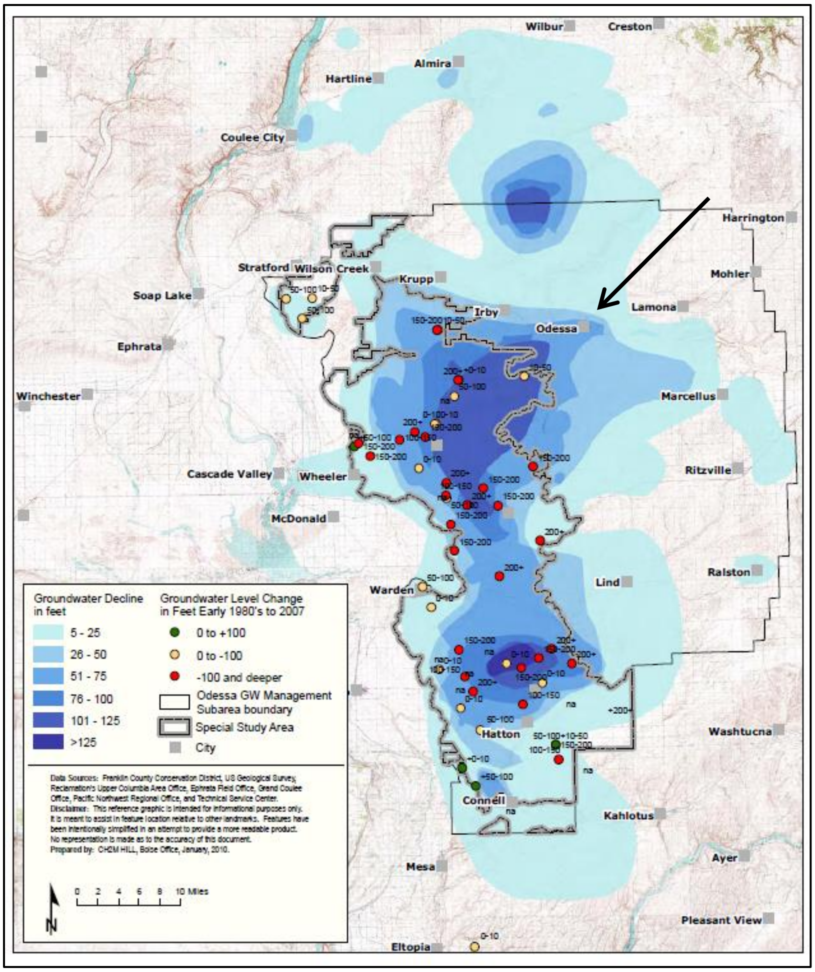


**Figure 29. Odessa, WA total annual precipitation, 1903-2012. Source: Western Regional Climate Center.**



Data Sources: Franklin County Conservation District, US Geological Survey, Reclamation's Upper Columbia Area Office, Ephrata Field Office, Grand Coulee Office, Pacific Northwest Regional Office, and Technical Service Center.
Disclaimer: This reference graphic is intended for informational purposes only. It is meant to assist in feature location relative to other landmarks. Features have been intentionally simplified in an attempt to provide a more readable product. No representation is made as to the accuracy of this document.
Prepared by: CH2M HILL, Boise Office, January, 2010.

**Figure 30. Groundwater change in feet, 1981-2007. From U.S. Bureau of Reclamation (2012).**

# Stop 4—Pacific Lake

- **Columbia River Basalt flows:** Typical Columbia River Basalt flows form jointing (cracks) perpendicular to cooling surfaces (the surface of the ground and the top of the lava flow) (Figure 31). 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.

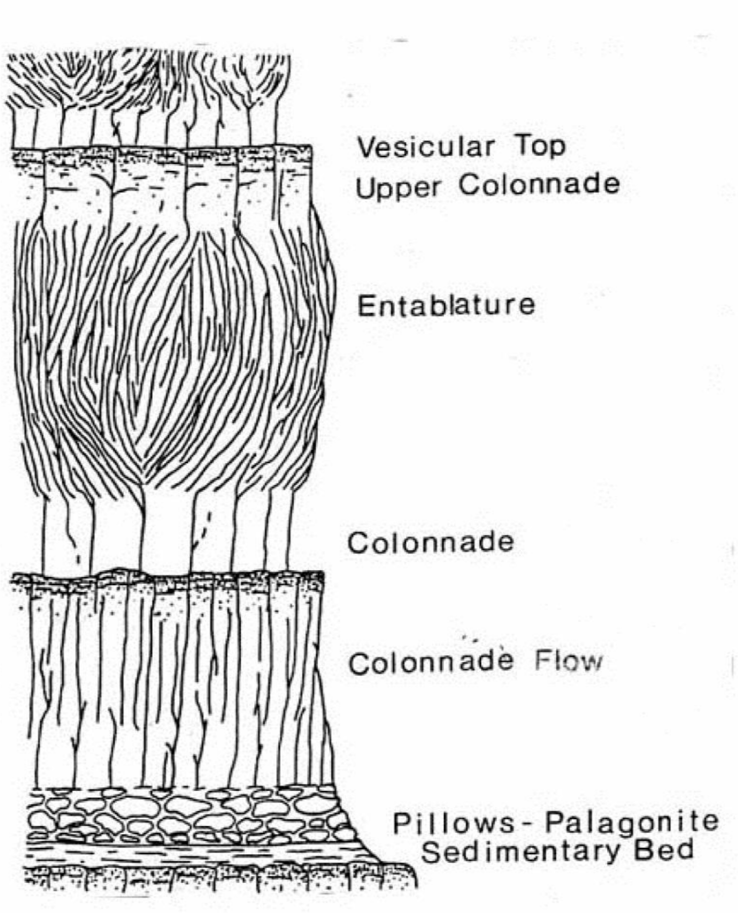


**Figure 31. Typical Columbia River Basalt flow cross-section. Source: Jack Powell.**

# En route to Stop 5

- **Route:** 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 (Figure 32). 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

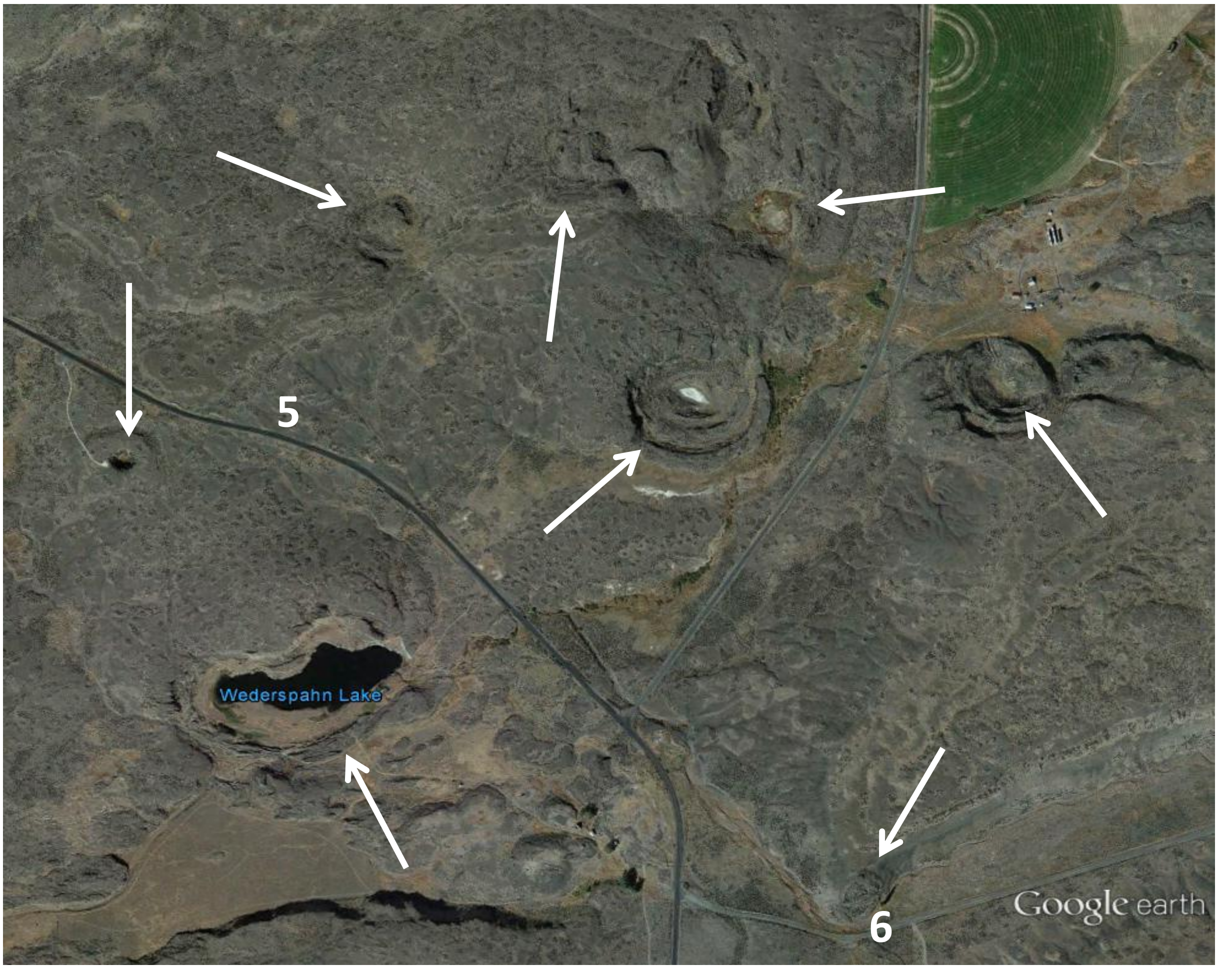


**Figure 32. Site of Stops 5 -- Odessa Craters Trail and Stop 6—Cinnamon Roll. Stop 4 lies about 2 miles west of Stop 5. Arrows indicate ring structures in the area. Source: Google Earth.**

# Stop 5—Odessa Craters Trail (continued)

- **Basaltic ring structures:** 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". In the Odessa area, erosion by Ice Age Floods has exposed these unusual features. Hodges (1978) described them as "circular structures, defined by arcuate, concentric ridges and scarps that surround hills, mesas, or crater-like depressions" (Figures 33, 34, 35 & 36). They are only known to exist in a limited area of the Columbia Basin Scablands, however, similar structures were exposed in similar lava flows by comparable massive flooding on Mars (Figure 35).
- **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).
- **Previous researchers & basaltic ring structures:** 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

**Figure 33. Basaltic ring structures. Source of image: Google Earth.**

- **Basalt ring structure formation:** The basalt ring structures form more like a dome or the rings in half an onion (Figure 34). 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 shrunk 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 Ice Age floods would produce ring structures.

# Stop 5—Odessa Craters Trail

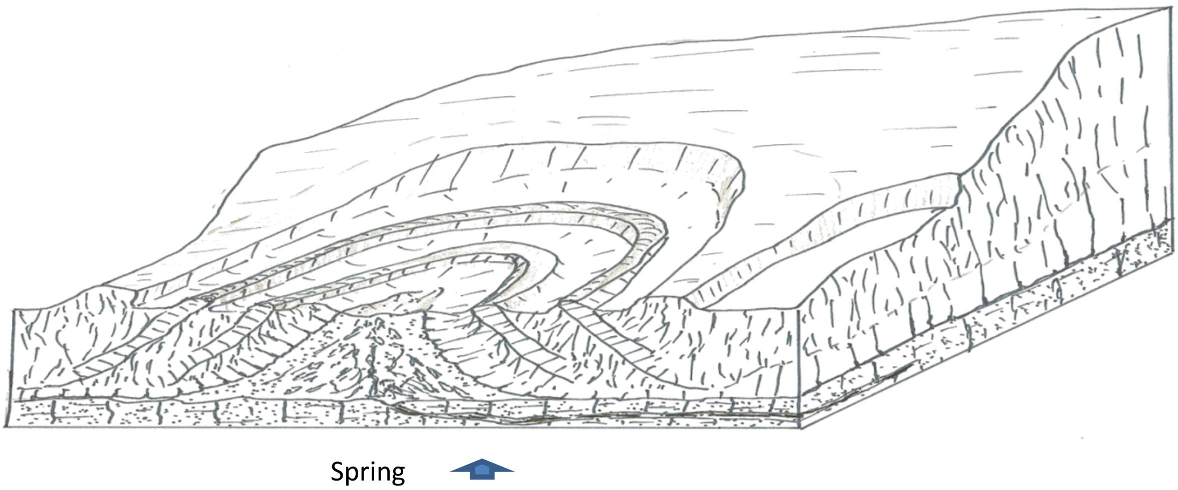


Figure 34. Cross-section sketch of basaltic ring structure. Source: Jack Powell.

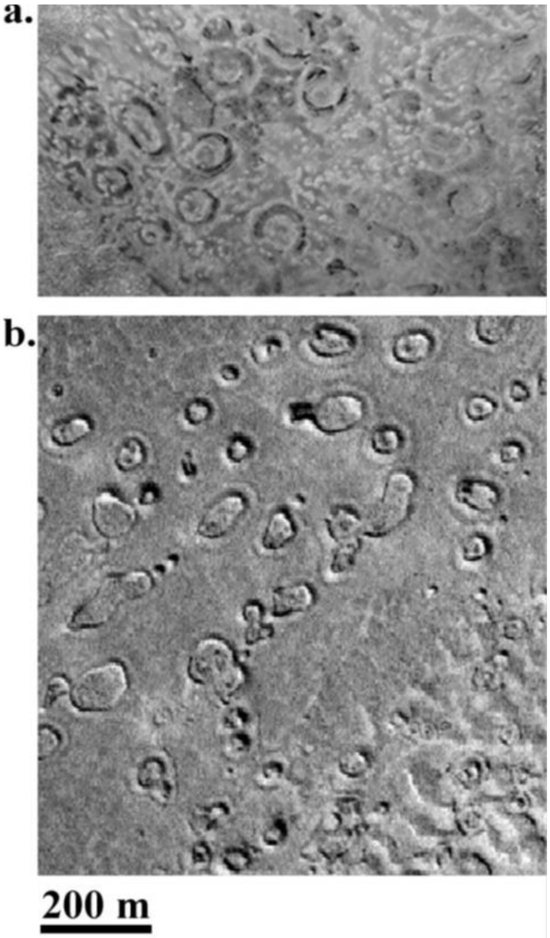


Figure 35. Image a. is from an area near Sprague Lake along I-90. Image b. shows similar features of comparable size on the planet Mars. Source:

# Stop 5—Odessa Craters Trail (continued)

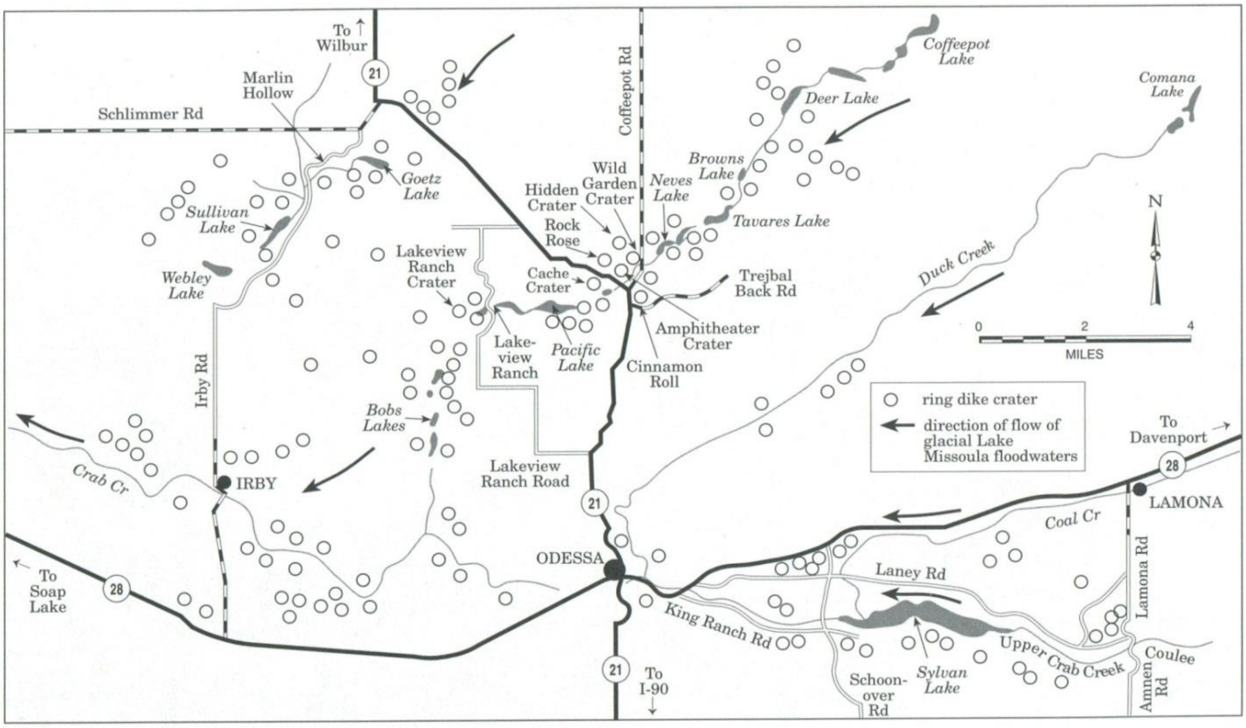


**Figure 36. Map of basaltic ring structures in the vicinity of Odessa, Washington. From Mueller and Mueller (1997, p. 114)**

- **Sag Flowout Model of Formation:** (McKee and Stradling, 1970). This theory involved: flowout of lava (I in Figure 37); 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).

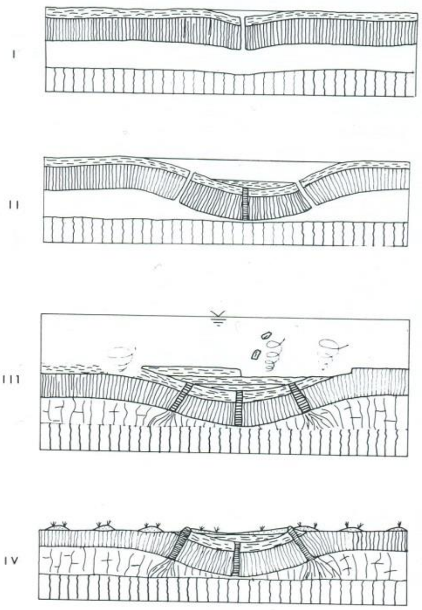


**Figure 37. McKee and Stradling (1970) model modified by Baker (1978a).**

# Stop 5—Odessa Craters Trail

- **Lava-Water Interaction Model of Formation:** (Hodges, 1978) (Figure 38). 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.

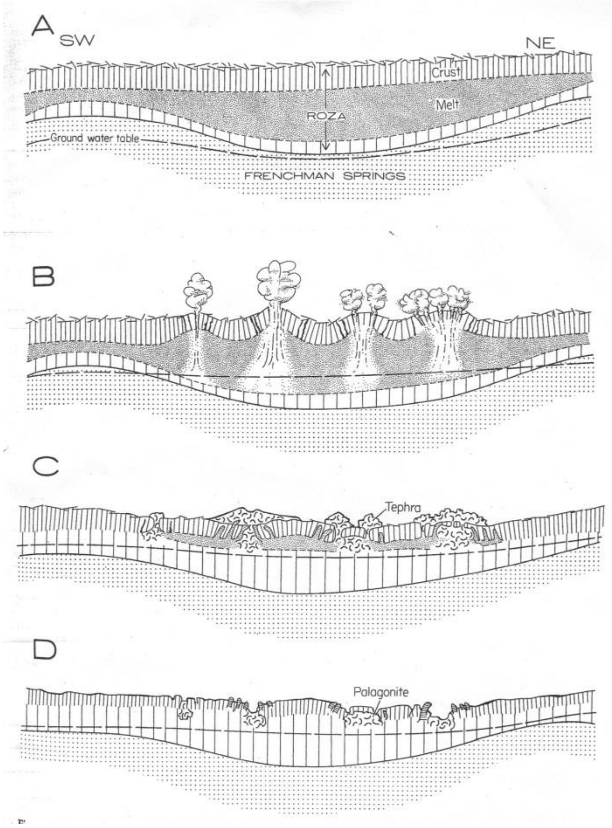


**Figure 38. Lava-water interaction model proposed by Hodges (1978).**

# Stop 5—Odessa Craters Trail (continued)

**Autointrusive dikes:** Some of the resistant ring features in these structures appear to be basaltic dikes. Dikes usually occur where magma is injected into older rock layers. However, 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 Figure x below taken from an exposure along Upper Crab Creek.

**A model for ring structure development:** Solidified basalt is less voluminous than magma resulting in shrinking and cracking of the lava flow. As the basalt cools rapidly above a spring, it shrinks 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 autointrusive ring dikes which tend to dome up over the spring (Figures 39 & 40). 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.

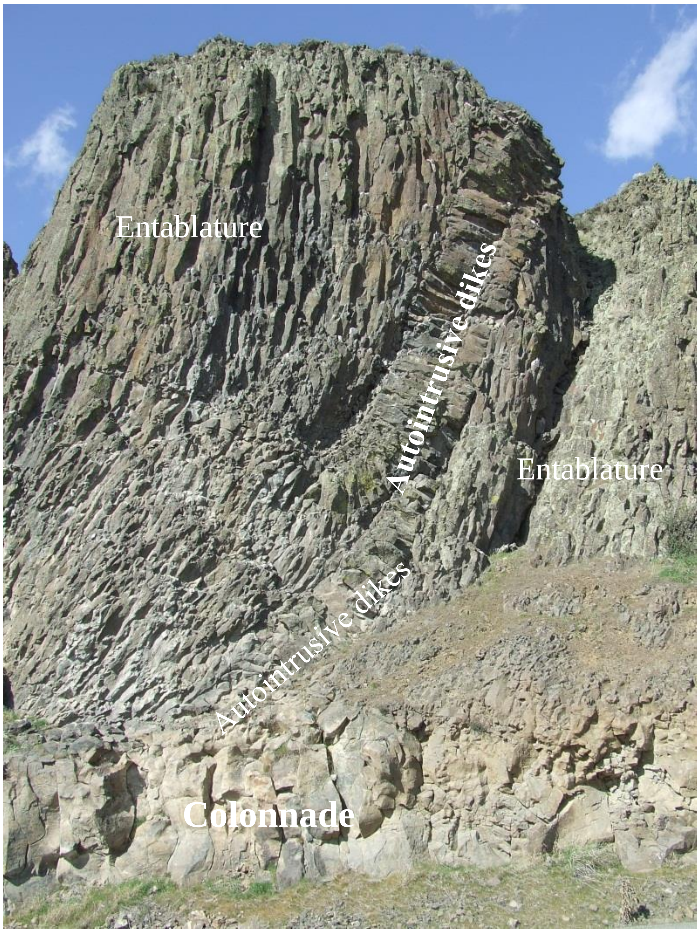


**Figure 39. Autointrusive dikes in basalt flow, Upper Crab Creek Valley. Source: Jack Powell photo.**

**Uncommon basalt ring structures:** Why the basaltic ring structures are so rare 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 (1978) suggests, springs in this area may have been the result of the advancing Roza lava disrupting the flow of ancient rivers (like the Columbia).

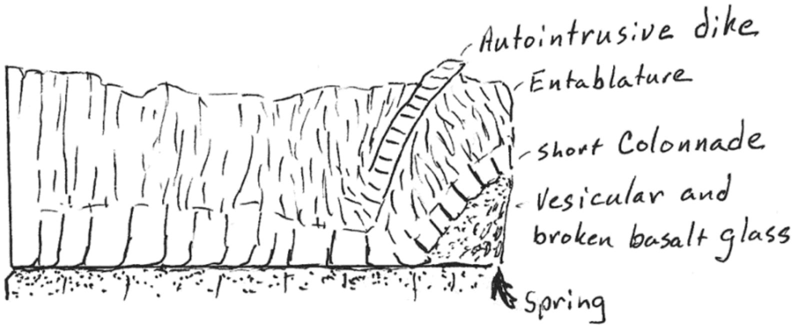


**Figure 40. Sketch of relationship of autointrusive dikes to basalt flow features. Source: Jack Powell.**

# En route to Stop 6—Cinnamon Roll

**Route:** 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—Cinnamon Roll—(Figure 41) with a very short walk.

# Stop 6—Cinnamon Roll

**Figure 41. Two concentric autointrusive ring dikes surround the pillow vesicular core of the Cinnamon Roll Crater. Source: Jack Powell photo.**

# Select References

- Baker, V.R. 1978a. Paleohydraulics and hydrodynamics of scabland floods. p. 59-79 in V.R. Baker and D. Nummedal, eds.,*The Channeled Scabland: A Guide to the Geomorphology of the Columbia Basin, Washington*. NASA. Washington, D.C.
- Baker, V.R. 1978b. Large-scale erosional and depositional features of the Channeled Scabland. p. 81-115 in V.R. Baker and D. Nummedal, eds., *The Channeled Scabland: A Guide to the Geomorphology of the Columbia Basin, Washington*. NASA. Washington, D.C.
- Bennett, W.A.G. 1962. Saline Lake Deposits in Washington. *Washington Division of Mines and Geology Bulletin* 49.
- Bjornstad, B. and E. Kiver. 2012. *On the Trail of the Ice Age Floods: The Northern Reaches: A Geological Field Guide to Northern Idaho and the Channeled Scabland*. Keokee Books. Sandpoint, ID.
- 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 he 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.
- Dayharsh, F.L. 1970. Distribution of ring dike-like structures near Odessa, Washington. In E.H. Gilmour and D. Stradling, eds., *Proceedings of the Second Columbia River Basalt Symposium*. Eastern Washington State College, Cheney, WA. March 21-23, 1969. EWSC Press.
- Edmondson, W.T. 1992. Saline lakes in the lower Grand Coulee, Washington, USA. *International Journal of Salt Lake Research* 1(2): 9-20.
- Fiege. B. n.d. *The Story of Soap Lake*. Soap Lake Chamber of Commerce. Soap Lake, WA.
- Grolier, M.J. 1965. Geology of part of the Big Bend area, in the Columbia Plateau, Washington. PhD Dissertation, Johns Hopkins University.
- Hodges, C.A. 1977. Basaltic ring structures of the Columbia Plateau and possible extraterrestrial analogs. *Abstracts of the Lunar and Planetary Science Conference* 8, p. 449.
- Hodges, C.A. 1978. Basaltic ring structures of the Columbia Plateau. *Geological Society of America Bulletin* 89: 1281-1289.
- Jaeger, W.L., L. P. Keszthelyi, D.M. Burr, A.S. McEwen, V.R. Baker, H. Miyamoto and R.A. Beyer. 2003. Ring dike structures in the Channeled Scabland as analogs for circular features in Athabasca Valles, Mars. *Lunar and Planetary Science* XXXIV.
- Keszthelyi, L.P., V.R. Baker, W.L. Jaeger, D.R. Gaylord, B.N. Bjornstad, N. Greenbaum, S. Self, T. Thordarson, N. Porat, and M. Zreda. 2009. Floods of water and lava in the Columbia River Basin: Analogs for Mars. P. 845-874 in J.E. O'Conner, R. J. Dorsey and I.P. Madin, *Volcanoes to Vineyards: Geologic Field Trips Through the Dynamic Landscape of the Pacific Northwest*. Geological Society of America Field Guide 15. Boulder, CO.
- Landye, J.J. 1973. Environmental Significance of Late Quaternary Nonmarine Mollusks from Former Lake Bretz, Lower Grand Coulee, Washington. MA Thesis, Washington State University.
- McKee, B. and D. Stradling. 1970. The sag flowout: A newly described volcanic structure. *Geological Society of America Bulletin* 81: 2035-2044.
- Mueller, M. and T. Mueller. 1997. *Fire, Faults & Floods: A Road & Trail Guide Exploring the Origins of the Columbia River Basin*. University of Idaho Press. Moscow, ID.
- Raisz, 1941. Landforms of the Northwestern States. Self-published.
- 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.
- U.S. Bureau of Reclamation. 2012. Final Feasibility-Level Special Study Report, Odessa Subarea, Columbia Basin Project, Washington. Yakima, Washington.