Northwest Geological Society

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Society Field Trips in Pacific Northwest Geology

The Ice Age Floods Through the Western Channeled Scablands

June 21-22 2008

Bruce Bjornstad

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Dry Falls and the Lower Grand Coulee

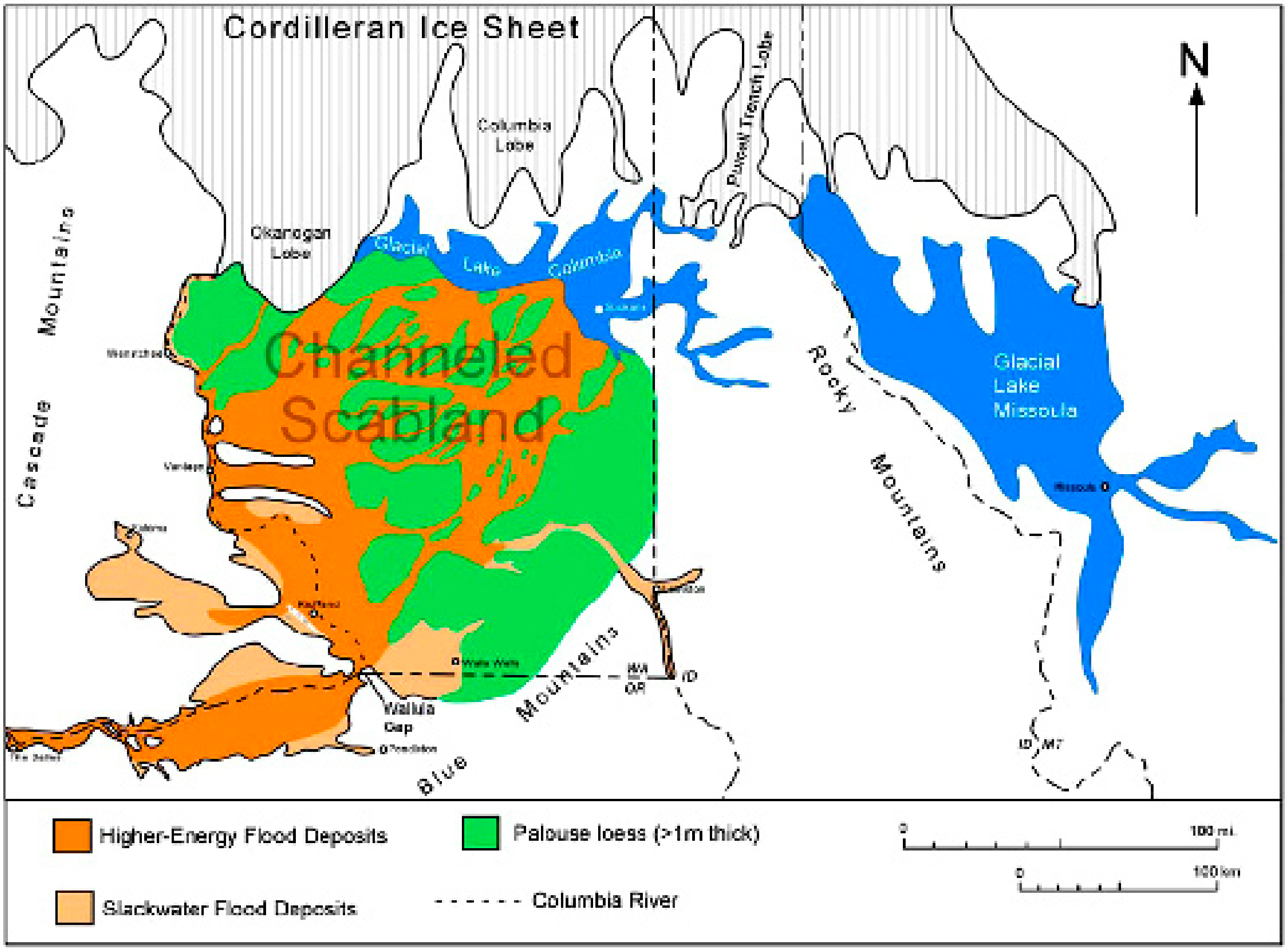


Figure 1*: Location of the Cordilleran Ice Sheet, Glacial Lake Missoula, and the Channeled Scabland during the last glacial maximum (~20,000 calendar years ago).*

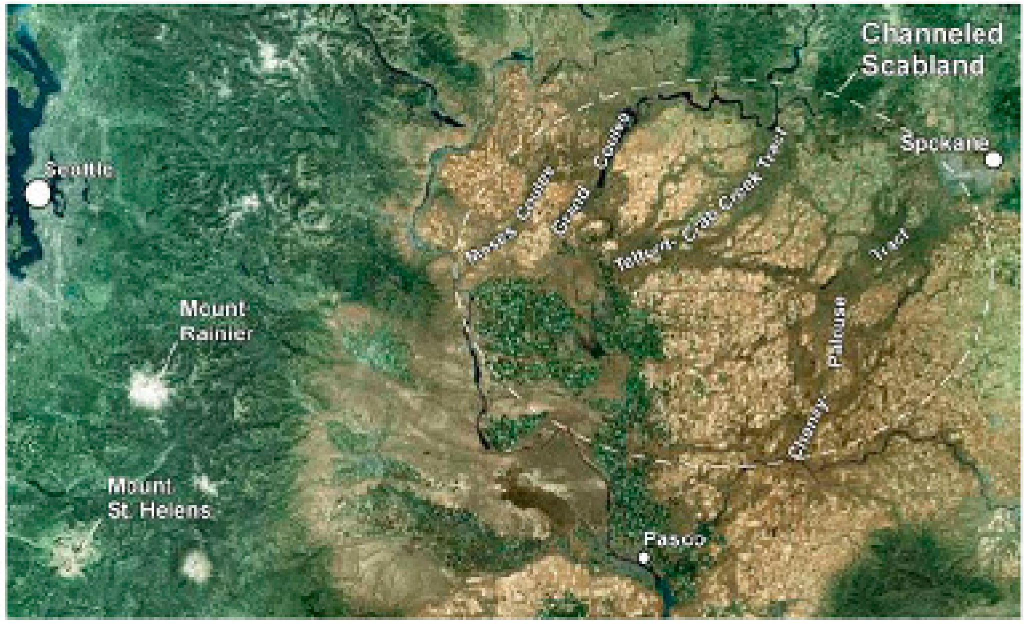
Introduction

Ice Age floods were first identified by J Harlen Bretz in 1923. Since that time the source for most of the floods has been linked to periodic outbursts from Glacial Lake Missoula (Figure 1), although floods came from other sources as well (e.g., Lake Columbia and perhaps subglacial outbursts). Glacial Lake Missoula, which contained up to 500 cubic miles of water, formed where the Cordilleran Ice Sheet blocked the Clark Fork River valley near the Idaho-Montana border (Figure 1). Floods from Lake Missoula may have occurred every few dozen years by the periodic floating and sudden failure of the ice dam. As many as 100 separate flood events have been proposed for the last glaciation, which lasted between 14,000 and 20,000 calendar years ago. Prior to this time, other major glaciations occurred at about 100,000 year intervals for at least the last million years, some of which produced similar cataclysmic outburst floods.

After escaping Lake Missoula Ice-Age floods raced through the Spokane area. As the floods encountered Glacial Lake Columbia, already in place behind the Okanogan ice lobe (Figure 1), floodwaters quickly overtopped the Columbia River valley spilling out to the south across the Channeled Scabland. The interconnected paths of the floodwaters are clearly visible from space where the windblown Palouse soil has been completely stripped away, exposing the bare basalt bedrock below (Figure 2).

Spreading out across the 100-mile-wide Channeled Scabland, floodwaters converged in the Pasco Basin before being forced through a single opening as little as 2 miles wide at Wallula Gap. More water entered this bottleneck than could pass through so the water backed up behind the gap to 1200 ft in elevation, creating Lake Lewis. In Richland, Lake Lewis approached depths of 900 ft! The lake was only temporary however since each flood, from start to finish, lasted only a week or less. Floodwaters were diverted around several east-west trending anticlinal ridges that protruded above flood level. Floods raced at up to 80 mph through constrictions along route

Figure 2: (Right) Satellite image highlighting Eastern Washington's Channeled Scabland



(e.g.,. Drumheller Channels, Wallula Gap, etc.), slowing down temporarily when the flow expanded into the Quincy (Figure 3) and other basins.

Much of the discussion on Ice Age flood features is reproduced from a previous field trips (Bjornstad 2004; Kiver and Bjornstad 2008), and a recently published book "*On the Trail of the Ice Age Floods: A Geological Field Guide to the Mid-Columbia Basin"* (Bjornstad 2006).

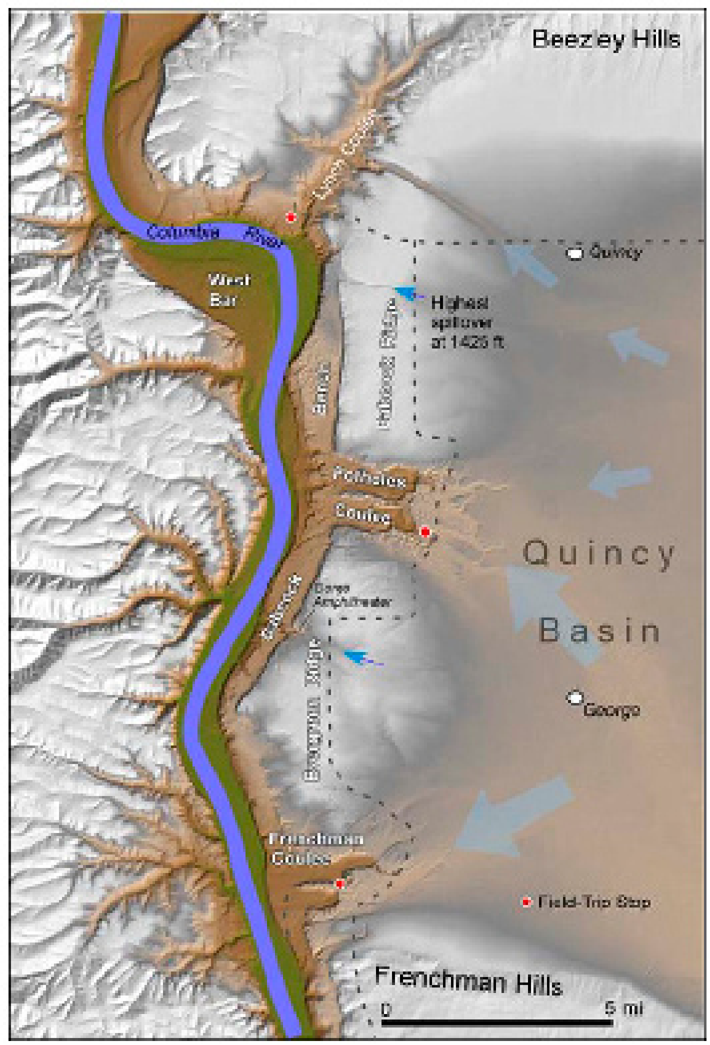


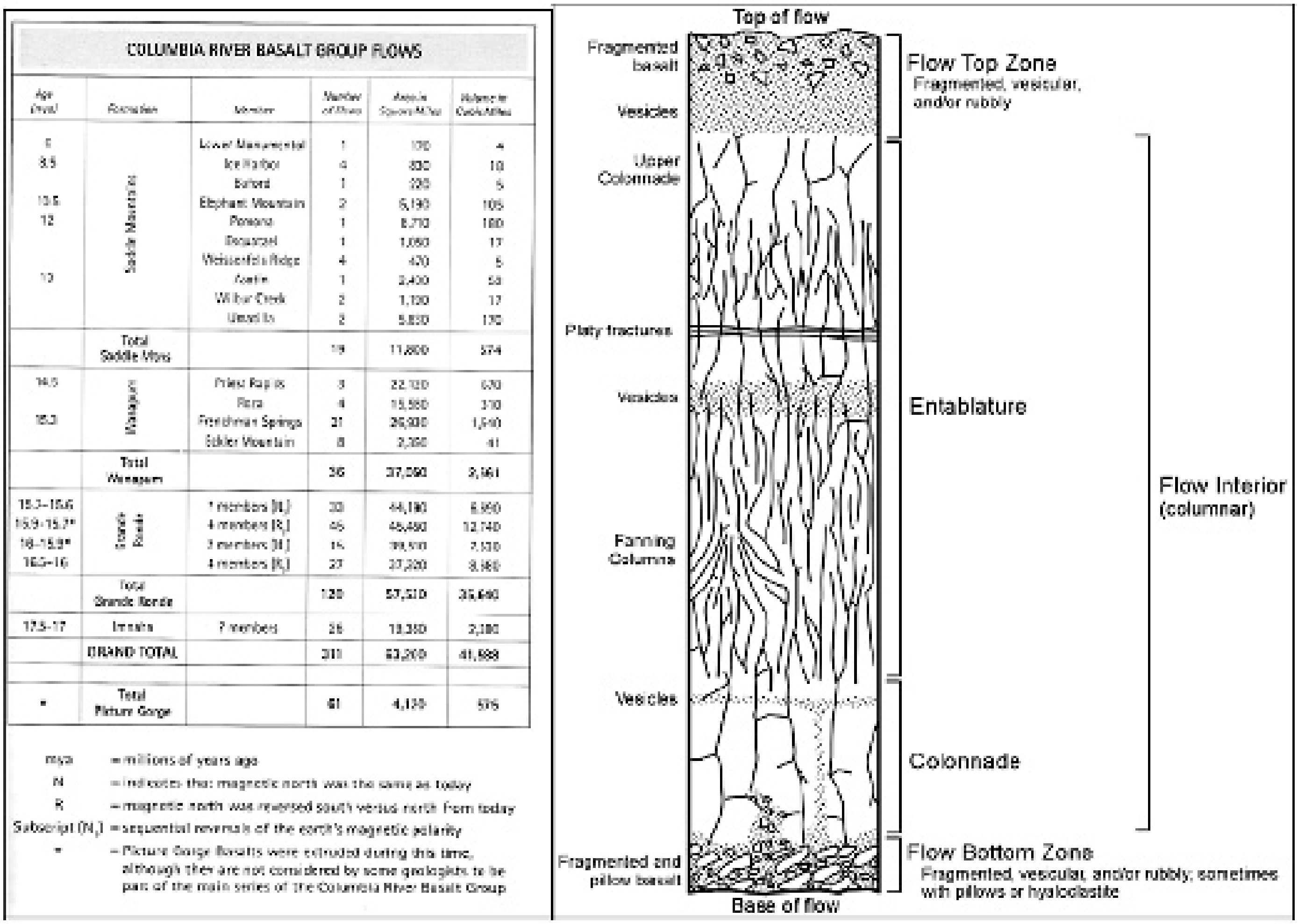
Figure 3: Flood features along the western Quincy Basin and Columbia River Valley. Areas in white are above maximum flood level.

DAY 1

The field trip begins and ends at Gingko Petrified Forest State Park in Vantage.

Stop 1-1. Ginkgo Petrified Forest State Park Interpretive Center.

Petrified wood was first discovered by construction crews building the Old Vantage Road (WSPRC, 1999). The significance of the find wasn't appreciated until George Beck, a professor at Washington State Normal School (now Central Washington University) learned about the petrified wood and organized an excavation program that ultimately identified dozens of fossil-tree species at the site. The park was opened to the public in 1938 after construction of the museum building and a caretaker's cottage by the Civilian Conservation Corps. The museum, reconstructed in 1953, is open seasonally and has many excellent examples of petrified wood on display as well as exhibits on the natural history of the region. Outside are numerous petrified logs hauled in from the surrounding area and some basalt columns salvaged from the Wanapum Dam reservoir that display pre-historic petroglyphs.



COLUMBIA RIVER BASALT GROUP FLOWS					
Age (mya)	Formation	Member	Number of Flows	Area in Square Miles	Volume in Cubic Miles
6	Saddle Mountains	Lower Monumental	1	170	4
8.5		Ice Harbor	4	830	10
		Buford	1	220	5
10.5		Elephant Mountain	2	6,190	105
12		Pomona	1	8,710	180
		Esquatzel	1	1,080	17
		Weissenfels Ridge	4	420	5
13		Asotin	1	2,400	58
		Wilbur Creek	2	1,100	17
		Umatilla	2	5,850	170
	Total Saddle Mtns		19	11,800	574
14.5	Wanapum	Priest Rapids	3	22,120	630
		Roza	4	15,380	310
15.3		Frenchman Springs	21	26,930	1,540
		Eckler Mountain	8	2,360	41
	Total Wanapum		36	37,090	2,561
15.7–15.6	Grande Ronde	? members (N_2)	33	44,180	6,950
15.9–15.7*		4 members (R_2)	45	46,480	12,740
16–15.9*		3 members (N_1)	15	39,510	7,330
16.5–16		4 members (R_1)	27	37,220	8,980
	Total Grande Ronde		120	57,510	35,640
17.5–17	Imnaha	7 members	26	10,350	2,180
	GRAND TOTAL		201	83,200	41,598
*	Total Picture Gorge		61	4,130	575

mya = millions of years ago
N = indicates that magnetic north was the same as today
R = magnetic north was reversed south versus north from today
Subscript (N_1) = sequential reversals of the earth's magnetic polarity
* = Picture Gorge Basalts were extruded during this time, although they are not considered by some geologists to be part of the main series of the Columbia River Basalt Group

Figure 4. *Stratigraphy of the Columbia River Basalt Group (left, from Mueller and Muller 1997) and illustrated internal structure of basalt flows (right).*

The cliffs rising out of the reservoir below belong to the uppermost flow (Museum flow) of the 15.6 Ma Grande Ronde Basalt (Figure 4) upon which the museum rests. The top of the Grande Ronde Basalt forms Babcock Bench, an elevated, flood-scoured rocky bench that can be traced northward along the Columbia River for over 30 km. Above the bench are Wanapum Basalts consisting of multiple flows of the Frenchman Springs Member all capped by a single thick flow of the Roza Member.

From Vantage drive east on I-90 to Silica Rd (Exit 143). Drive 0.6 mi on Silica Rd, turn left onto Old Vantage Highway and descend into Frenchman Coulee all the way to Columbia River.

Frenchman Coulee

Frenchman Coulee (Figure 5) is a dual coulee and cataract system that formed in the southwestern corner of the Quincy Basin (Figure 3). Like its neighbor to the north, Potholes Coulee, Frenchman Coulee developed as floodwaters overtopped a low divide across Evergreen Ridge, where it butted up against the Frenchman Hills. During the initial stages of flooding the difference in water levels between the flood-filled Quincy Basin and the Columbia River immediately west of Evergreen Ridge approached 700 ft over a distance of just a few miles! As with Potholes Coulee this incredible difference in water level caused floodwaters to rapidly and voraciously eat away at the underlying rock layers. Erosion continued for at least as long as it took for the water level in the Columbia valley to rise up to that in the Quincy Basin, or until the supply of floodwater was exhausted.

The uppermost basalt at Frenchman Coulee lies on the flood-scoured surface of the Roza Member. The white Quincy Diatomite, which at one time blanketed the Roza in this area, was eroded away within the coulee by the floods. Erosional remnants of the diatomite lie along the margins of the coulee to the north and south (Figure 5). The broad, level floor at the mouth of the Frenchman Coulee, now part of Babcock Bench, represents the eroded surface of the uppermost flow of Grand Ronde Basalt (i.e., Museum flow).

Like Potholes Coulee, Frenchman Coulee contains both an upper and lower cataract. In some places, such as the head of the south alcove, the two cataracts merge to form a single, very high

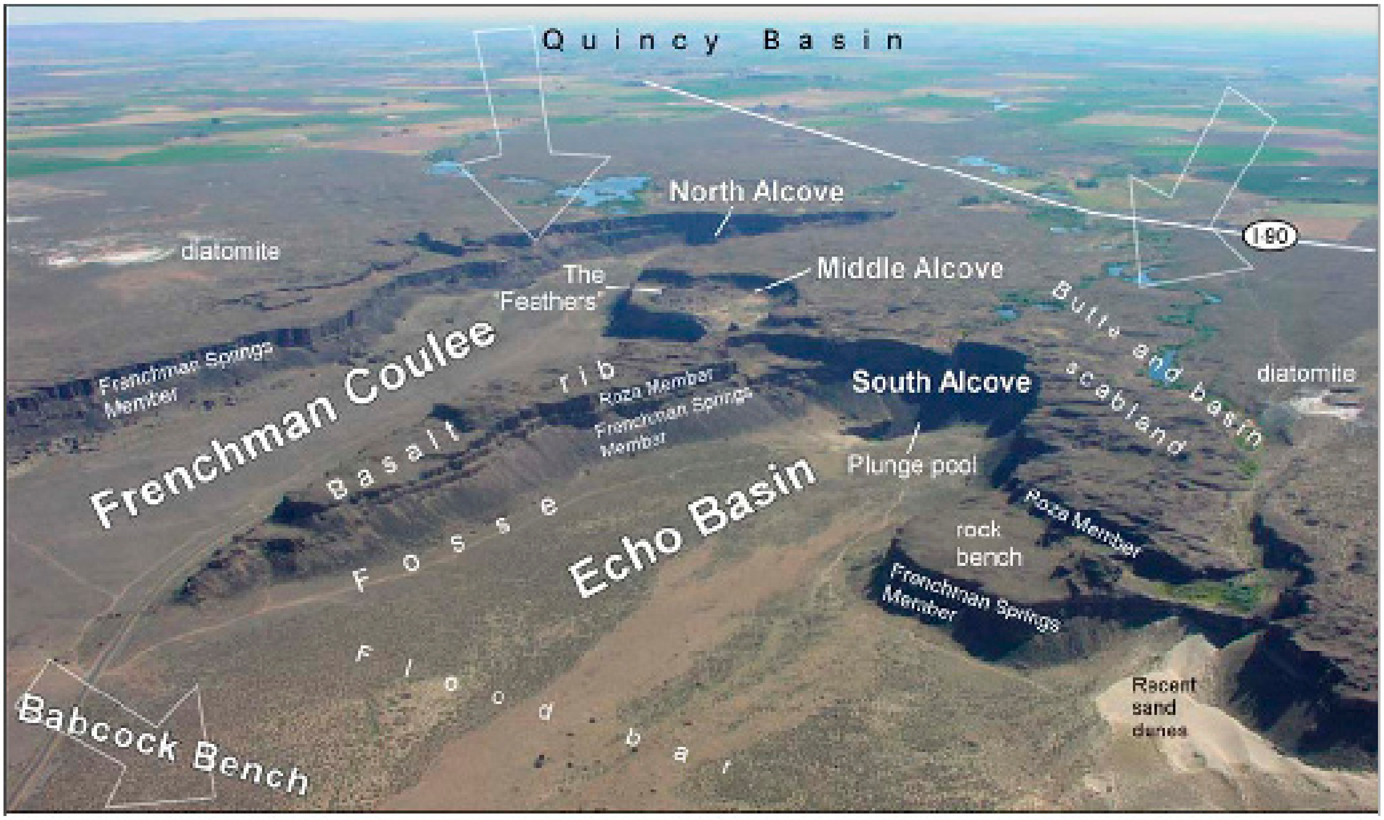


Figure 5: Frenchman Coulee from the air. Looking northeast

cataract (Figure 5). These cataracts originated at the mouth of the coulee and receded eastward up the coulee during repeated floods. Another common feature between Frenchman and Potholes Coulees is a flood-scoured blade of basalt that separates the two main, amphitheater-shaped alcoves. In addition a third, less-well-developed alcove (middle alcove) exists in between at Frenchman Coulee.

Below some of the cataracts lie plunge pools. Beyond the cataract complex coarse-grained flood deposits cover the bottom of the alcoves to Babcock Bench, similar to Potholes Coulee. The flood deposits were laid down as giant flood bars with deep troughs (i.e., fosses) developed between flood bars and the steep coulee walls.

Huge, house-sized boulders of basalt lie scattered along the bottom of Frenchman Coulee. Many of these may have been ripped away from the cataract walls and transported a short distance toward the close of scabland flooding. Some of the boulders however, especially those close the coulee walls, may represent material that simply tumbled off the steep coulee walls into the valley since the last Ice-Age flood.

Stop 1-2. Frenchman Coulee

Park near "the Feathers" (Figure 6) and take a short hike to a fantastic overlook into the Echo Basin.

Figure 6: *"The Feathers", a flood-coured, single row of huge basalt columns of the Rosa Member, and a popular rock-climbing area*

Drive to end of the road at Wanapum Lake (backwater behind Wanapum Dam) along the shore of the Columbia River. Road ends after descending across flood bar with huge boulders several feet in diameter. Return to Silica Rd, turn north to follow Evergreen Ridge.

Babcock and Evergreen Ridges

Babcock and Evergreen Ridges consist of low-relief uplands, blanketed by a thin sediment cover over basalt, which parallels the east side of the Columbia River valley (see Figure 3). The basalt in this region dips gently eastward, under the influence of uplift associated with the Cascade Mountains to the west. Prior to Ice-Age flooding a single continuous north-south ridge extended across this entire area, which distinctly divided the Columbia River valley on the west from Quincy Basin on the east. During Ice-Age flooding, however, the ridge was overtopped by the larger floods at several low points along the ridge, partially to totally removing the sediment cover. At three places along the ridge, Frenchman Coulee, Potholes Coulee and Crater Coulee, the floods were especially effective at scouring deep recessional cataract canyons across the ridge. Today the Potholes Coulee chasm separates the northern part of the ridge (Babcock Ridge) from the southern part (Evergreen Ridge).

Follow Silica Rd to the Gorge Amphitheater. Road bends right (east) to become Road 1 NW. Continue east for ~3 mi, turn left (north) onto Road U NW. Continue north toward Quincy Lakes Recreation Area and Potholes Coulee via Rd 2 NW. Unpaved road.

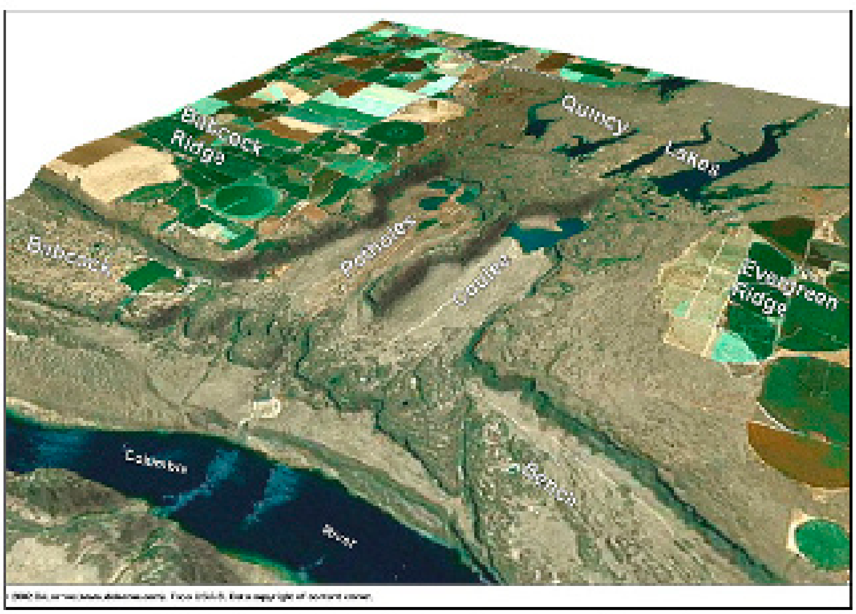


Figure 7. *Aerial view of Potholes Coulee. Potholes Coulee consists of two alcoves separated by a flood-scoured basalt ridge. The flood-scoured area is well defined by scabland where crop-supporting topsoil was completely removed.*

Potholes Coulee

The drainage divide into Potholes Coulee is the lowest of the three coulees that drop into the Columbia valley from the Quincy Basin. Potholes Coulee (Figure 7), and its neighbors, Crater Coulee and Frenchman Coulee, are a series of spectacular, horseshoe-shaped, tiered cataract canyons that developed as floodwaters rose up to 1,425 ft elevation and overtopped several low divides across Evergreen and Babcock Ridges. When this happened an amazing drop in elevation of over 850 ft existed over a distance of less than 3 miles between the Quincy Basin and the Columbia River valley (see Figure 3). With this incredible difference in water level over an extremely short distance, floodwaters madly ate away at the underlying basalt layers in their vain attempt to establish equilibrium. All the topsoil was effectively stripped off along this gash between Babcock and Evergreen Ridges.

Potholes

At least two sets of cataracts are preserved within the two-mile wide Potholes Coulee canyon; referred to here as the upper and lower cataracts. A third, incipient cataract complex appears to have just begun forming with the last Ice-Age flood(s) at mouth of Potholes Coulee along Babcock Bench (Figure 7). The upper cataract, probably developed with the earliest floods, near the mouth of the coulee where it joined the Columbia valley, receding east with each subsequent flood.

As the upper cataract receded, previously covered basalt layers were then exposed to attack by the floodwaters. Younger floods scoured down to the next deepest resistant layer in basalt at the mouth of Potholes Coulee, forming the lower cataract. Over time, the upper cataract receded up to 3 miles to near Quincy Lakes, while the lower cataract, which started later, only receded 2.5 miles. The upper cataract receded further up the southern alcove than the northern alcove, almost all the way to Evergreen Reservoir.

Potholes Coulee consists of two parallel amphitheater-shaped alcoves defined by the eastward extent of the lower cataract canyons. The two alcoves are separated by a flood-scoured rib of basalt running down the middle. The older upper cataract steps up from these alcoves, forming a wild and desolate butte-and-basin scabland complex all the way up to Quincy Lakes. At the bottoms of some of the cataracts lie deep plunge pools. Beyond the cataracts are giant, rounded bars of coarse-grained flood deposits, which cover the bottom of both alcoves westward to Babcock Bench.

Figure 8. *Dusty Lake basin, Potholes Coulee.*

Stop 1-3. Potholes Coulee

Short hike to edge of south alcove of Potholes Coulee and view into the upper cataract (Dusty Lake) basin (Figure 8). Continue north through the Quincy Lakes Recreation Area.

Quincy Lakes

Quincy Lakes (Figure 9) formed by scabland floods that overtopped Evergreen and Babcock Ridges from the east. They consist of three parallel natural lakes (Stan Coffin, Quincy, and Burke Lakes) and one reservoir (Evergreen Reservoir), which fill low-relief, flood-scoured grooves in the slightly east-dipping basalt plateau above Potholes Coulee. The lakes are exactly aligned with the direction of Ice-Age floods, the largest of which delivered floodwaters up to 200 feet deep where these lakes are now. Quincy Lakes mark the eastern extent of cataract recession within Potholes Coulee. During future Ice-Age floods the cataracts in Potholes Coulee will likely resume their eastward migration, gobbling up part or all of the present Quincy Lake system.

Scouring of Quincy Lakes occurred because of the venturi effect whereby floodwaters moved faster through flow constrictions such as Potholes Coulee - a narrow, several- mile wide opening across Evergreen and Babcock Ridges (see Figure 3). Erosional scouring was significantly reduced east of Quincy Lakes because flood flow moved through a much wider channel (i.e., 20-mile width of the Quincy Basin), and

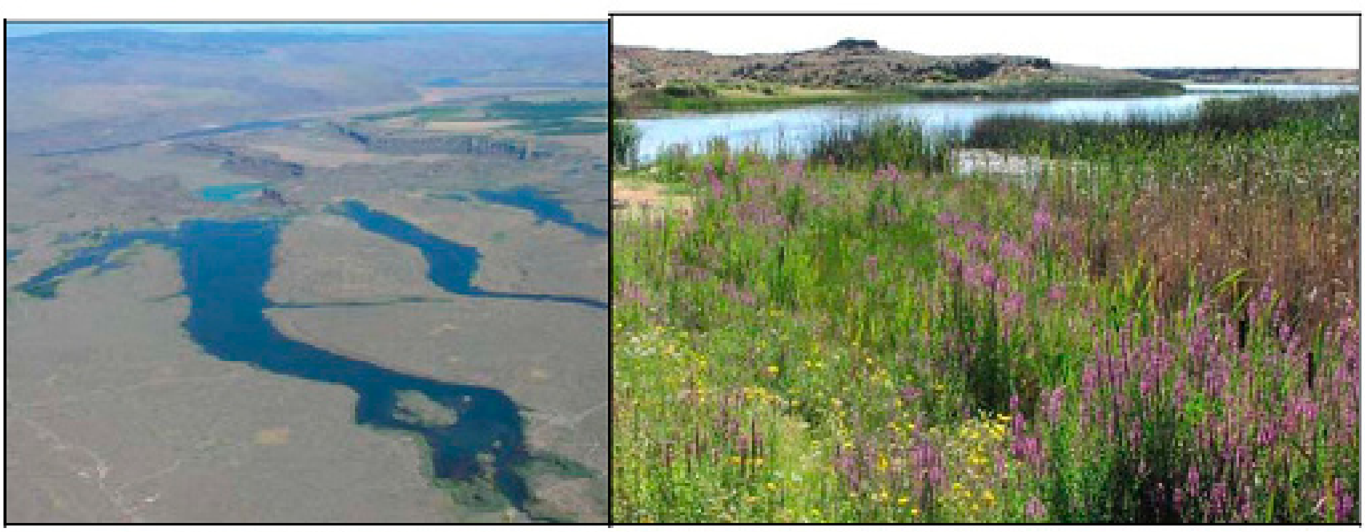


Figure 9. *Quincy Lakes from the air (left) and at ground level (right).*

thus moved at a much slower rate; this is why no channeling or other scabland features occur to the east toward the central Quincy Basin (Figure 3).

Turn left at end of unpaved road onto White Trail Rd (Rd U NW). Continue west and then north ~5 miles to SR 28, turn left (west). Pass rest area and descend towards Columbia River. At Trinidad turn left towards Crescent Bar.

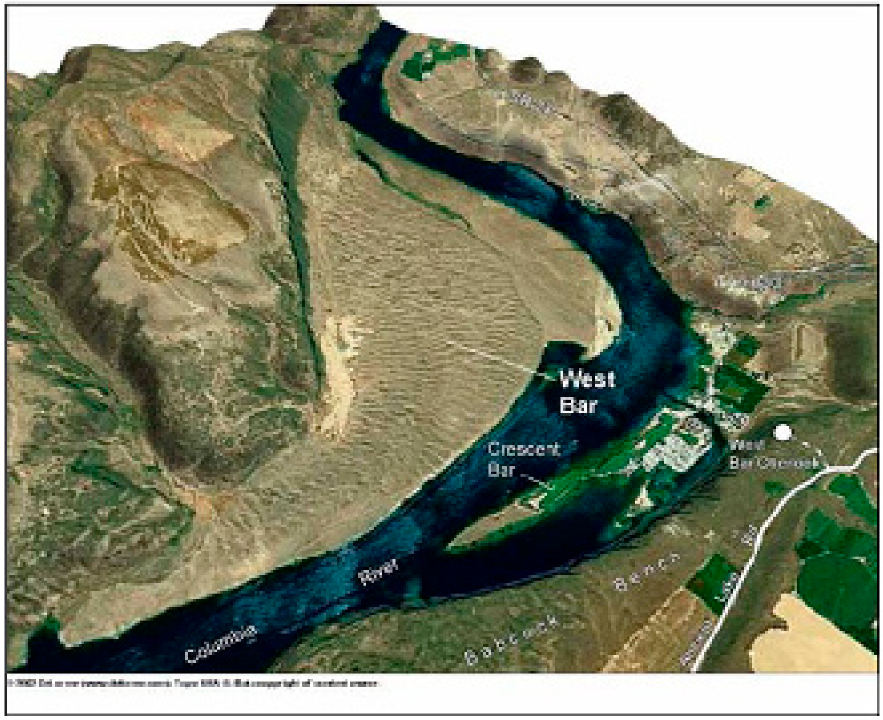


Figure 10. *Aerial view of West Bar (with giant current ripples) and vicinity.*

Stop 1-4. West Bar Overlook.

West Bar Giant Current Ripples

As early as 1930, when J Harlen Bretz looked down onto West Bar near our stopping point he noted:“Seen from viewpoints along the highway east of the river, the surface of West Bar seems to be marked by great current ripples.” The giant current ripples (Figure 10) average 24 ft in height and 360 ft in spacing, and are composed of coarse sand and gravel with boulders up to 4.5 ft in diameter. The ripples are presently 150-250 ft above river level. Based on the size of the ripples, the depth of water that generated these GCR’s has been calculated at ~650 ft deep.

The orientation of the GCR’s indicates they formed from a flood coming down the Columbia River from the north at the very end of the last glacial cycle, probably between 14-15,000 calendar years ago. This flood occurred after retreat of the Okanogan ice lobe, which allowed floods to flow directly down the Columbia valley instead of across the Channeled Scabland, as did most (or all) earlier floods from glacial Lake Missoula (see Figure 1).

The last floods from glacial Lake Missoula occurred prior to the retreat of the Okanogan lobe and it’s understood that glacial Lake Columbia outlasted Lake Missoula by several centuries. Therefore, the flood that generated the West Bar GCR’s must have come from a source other than Lake Missoula. The source of the flood that produced GCR’s at West Bar, and other giant bars along the Columbia is not well understood, but may be from Lake Columbia after the breakup of the Okanogan lobe, or perhaps from an, as yet unidentified, elusive ice-dammed lake or subglacial outburst from beneath the retreating Cordilleran Ice Sheet to the north.

Retrace route to SR 28, turn right towards Quincy. Pass over Crater Coulee on way to Quincy.

Crater Coulee

Crater Coulee is the smallest and least accessible of the three recessional cataracts at the west end of the Quincy Basin. Crater Coulee is a long (4 mi) and narrow (0.5 mi) flood coulee, that spilled out of the northwest corner of the Quincy Basin over Babcock Ridge (see Figure 3). Crater Coulee drops about 300 ft into Lynch Coulee before exiting into the Columbia valley. (The floods scoured out only the lower part of Lynch Coulee below its intersection with Crater Coulee.) Several water-filled rock basins occur along the route, and during flooding a 200 ft high cataract and plunge pool receded up the coulee about a mile above the confluence with Lynch Coulee (Figure 9). Because of its higher elevation, Crater Coulee was used only during the largest Scabland floods. Because two other nearby coulees, Potholes and Frenchman Coulees, were much lower (80 feet), a larger volume of floodwaters passed through them more frequently and thus, they are much larger and better developed.

Continue east on SR 28 to Ephrata. End of Day 1.

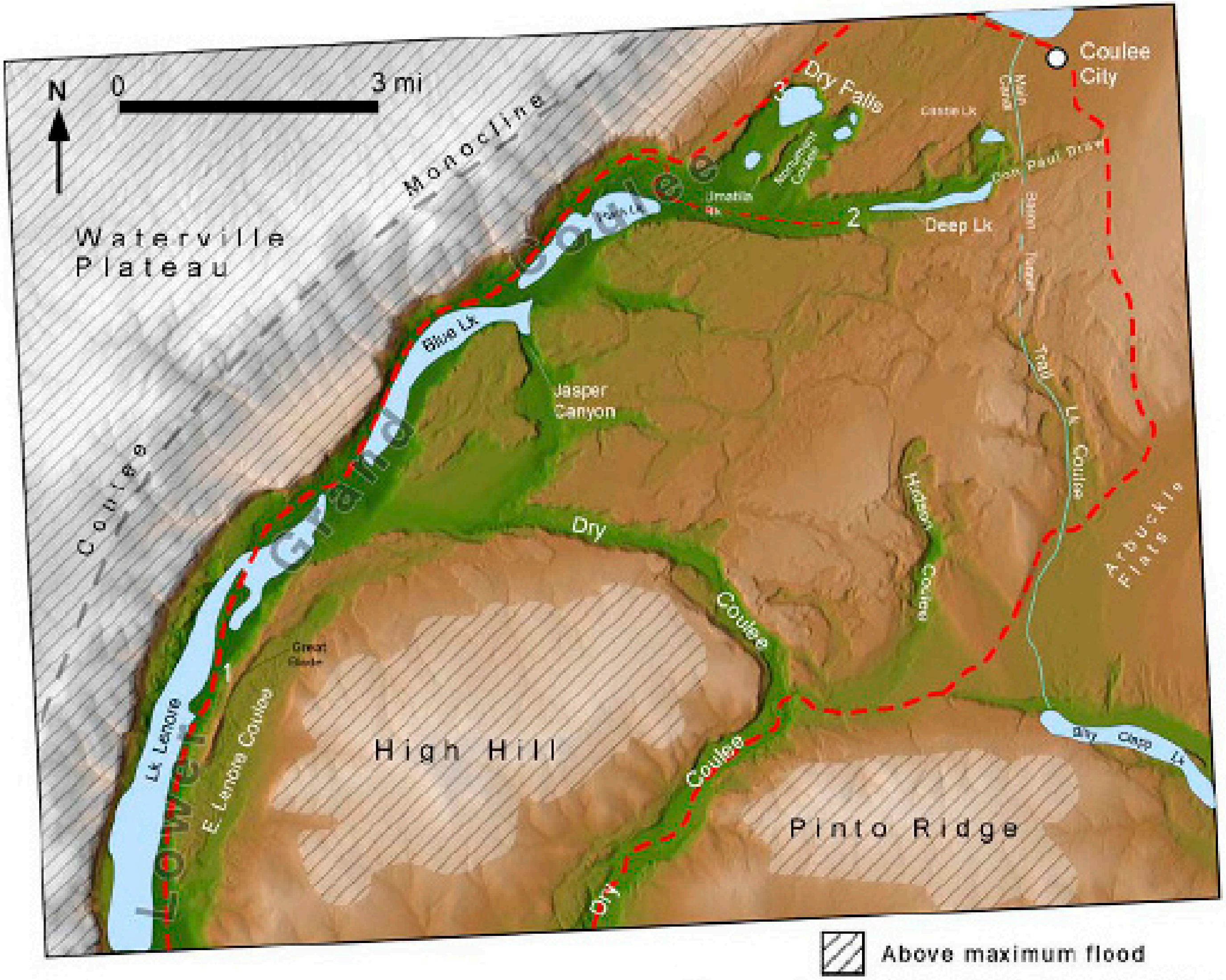


Figure 11. *Shaded-relief map showing a portion of Day 2 tour route (red dashed line). Stops include Lake Lenore Caves/Great Blade (1), Deep Lake pothole swarm (2) and Dry Falls (3).*

DAY 2

Leave Ephrata and drive NE on SR 28 to Soap Lake and the mouth of Lower Grand Coulee. Tour route through Lower Grand Coulee shown in Figure 11.

Soap Lake

Ice Age floods churned through the Grand Coulee when the Okanogan lobe blocked the Columbia River near the present site of Grand Coulee Dam. Upstream migration of the recessional cataract in the Lower Grand Coulee and deep scouring along the fractured edge of the Coulee Monocline enabled floodwater to gouge deeply into the basalt leaving a series of depressions now occupied by scenic lakes (Soap, Lenore, Blue, and Park Lakes) in the Lower Grand Coulee. The first lake, Soap Lake, is a two-mile-long, deep flood-scoured lake that contains a deep depression that is 95 feet deep just west of the center of the lake. Fine sediment (silt and clay) help seal the lake bottoms and exclude or minimize water loss through seepage.

With increasing aridity following the last Ice Age the lakes lowered in elevation from at least 1,160 feet to near their present levels within a few feet of Soap Lake (elev. 1,074 feet) as more water evaporated than was replaced by precipitation or influx of fresh groundwater. Dissolved chemicals from the surrounding basalt and sediment were carried into the lake and trapped. Over time with more evaporation, the salinity and alkalinity of the lake increased to its present high level (pH = 9+). The lakes furthest hydraulically down gradient (i.e., Soap Lake) are the most saline and mineral rich. The denser saltwater in Soap Lake sank and a deep layer of mineral-rich water has formed. This layer has remained intact for at least 2000 years and perhaps 8,000 years! Such a condition of non mixing creates a rare condition that produces a meromictic lake.

At Soap Lake we are standing at the muzzle of the "gun barrel" where water shot out of the Grand Coulee and sprayed debris into the Quincy Basin, forming Ephrata Fan to the south. Floodwater was at least 700 feet above the present lake elevation and moving at an estimated 60-70 mph during the larger floods Deposition initially increased away from the coulee mouth creating a reverse topographic slope that increases in elevation just south of the Lower Grand Coulee! Thus Soap Lake and other coulee lakes are located in a 20-mile-long enclosed depression with no surface outlet. Park Lake in the northern part of the Lower Grand Coulee is about 22 feet higher (elev. 1,096') than Soap Lake (elev. 1,074). Little Soap, Lenore, and Blue Lakes lie between these elevations.

Continue north ~8 miles to Lake Lenore and Lake Lenore Caves and the Great Blade.

Patches of lake silts exposed near Soap Lake and northward indicate the existence of a large late Pleistocene-post-glacial lake occupying the entire lower coulee up to at least the 1145-foot elevation. The debris dam at Soap Lake (elevation 1,500 feet) and wetter late glacial-post glacial climates account for these now-abandoned lake levels.

Lake Lenore Caves and the "Great Blade"

Crowning the top of the ridge is a fin of rock referred to by Bretz as the "Great Blade" (Figure 14), a narrow, 3-mile–long, eroded rib of Wanapum Basalt. On the west wall of the Great Blade lie a series of natural caves plucked out along a particular weak basalt lava flow belonging to the Frenchman Springs Member. The caves are carved out along the basal columnar basalt of a flow (Figure 13), which was more easily plucked out by the floods than the overlying entablature portion of the basalt flow (see Figure 4, right). The series of caves here are all developed in the same weak rock horizon and appear to be the result of differential erosion. Post-flood weathering created a talus slope that furnished easy access and temporary overnight camps and storage for hunters and gatherers for at least 5000 years. A well-marked trail leads from the parking area to some of the caves.

The flood-scoured coulee to the east (East Lenore Coulee) follows the trough of a syncline and was likely a stream valley prior to the Ice Age floods. Bretz believed that this was the original channel of the Lower Grand Coulee. However, the enormous volume of floodwater descending the coulee simultaneously covered both the synclinal valley and the edge of the Coulee Monocline to the west. The more fractured bedrock along the monoclinal edge was easier to erode and thus its channel was deepened faster than in the synclinal valley. Thus the dominant channel shifted into its present position by cutting deeper into the steeply dipping, fractured edges of the monocline.

Stop 2-1. Lake Lenore Caves and the "Great Blade"

Turn off to Lake Lenore Caves. Short hike up to the Lake Lenore Caves, an overhanging pothole, and to a saddle in the Great Blade with view into East Lenore Coulee.

Return to SR 17 and continue north to Blue and Park Lakes (Figure 15) along the axis of the Coulee Monocline. The high west wall of the coulee exposes the Grande Ronde Basalt flows overlain by the Frenchman Springs and Roza members of the Wanapum Basalt (see Figure 3, left).

Figure 12. *Airview northward showing the Lower Grand Coulee and Lake Lenore. The Great Blade separates Lake Lenore Coulee from another coulee, just as massive, to the east (East Lenore Coulee). Note the complex coulee system and the butte and basin (potholed plateau) topography east of Lake Lenore.*

Coulee Monocline

The Coulee Monocline, which parallels the Lower Grand Coulee (see Figure 11), played a big role in coulee development. The basalt flows on both sides of the coulee and monocline comprise some of the same stratigraphic units except that equivalent flows on the east side of the flexure are estimated to be as much as 1,000 ft lower than their western counterparts (Figure 16).

At several places tilted hogbacks of eroded basalt protrude above lake level along the coulee floor. The basalt rock along this tectonic flexure was weaker due to the increased fracturing along the fold. Ice Age floods were naturally funneled down the edge of the flexure and preferentially eroded away the weaker, more-fractured rock along the flexure.

Figure 13. *View of Lake Lenore Caves, all located along a particularly weak stratigraphic horizon in basalt. Notice the "Great Blade" in the background that separates Lower Grand Coulee from East Lenore Coulee. Hike will proceed up the ridge to the saddle in the upper right center.*

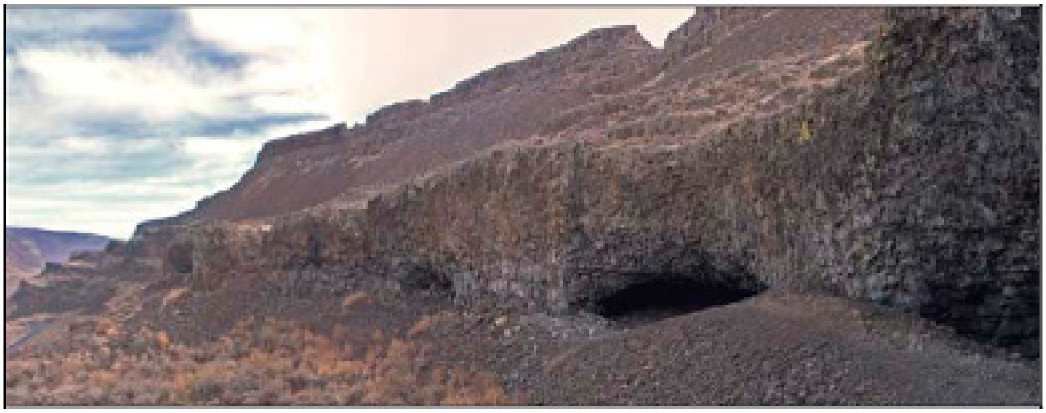


Figure 14. *View from top of Bretz's "Great Blade", a long, narrow eroded rib of basalt the resisted erosion by the Ice Age floods.. The Great Blade separated simultaneous flow down Lake Lenore (right) and East Lenore Coulee (left). During the largest Ice Age floods the blade summit would have been completely underwater.*

Figure 15. *View south down the Lower Grand Coulee. Note the complex of large coulees like Jasper and Dry Coulee that conducted some of the massive volumes of Ice Age floodwater southward. Broad, green area at the top is soil-covered High Hill, which lay above maximum flood level and escaped erosion.*

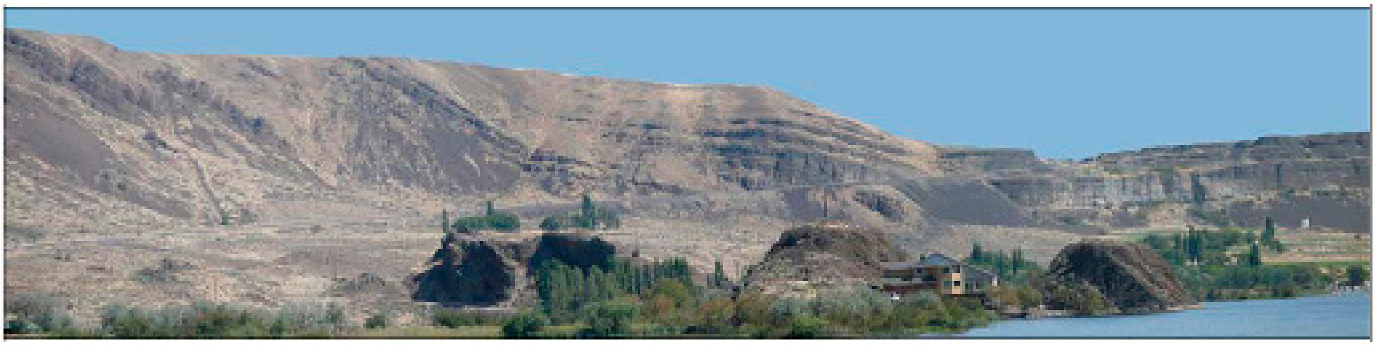


***Figure 16**. Structural cross section of the Coulee Monocline, well exposed near Sun Lakes State Park. Notice tilting basalt hogbacks in foreground*

Continue north on SR 17 toward Sun Lakes State Park

The Lower Grand Coulee follows the edge of the Coulee Monocline past Blue Lake and Park Lake. While driving along Blue Lake notice the 100+ ft tall flood bar blocking the mouth of Jasper Canyon (Figure 17).

***Figure 17**. A large flood bar is located at the mouth of Jasper Canyon. Part of Blue Lake is in the foreground. View to the east.*

***Figure 18.** Severely eroded scabland in upland areas east of Lower Grand Coulee (upper left). Jasper Canyon runs through lower left of this image. A deep, long recessional cataract canyon branches off to the right of Jasper Canyon.*

Floods were not confined to the valley walls of the Lower Grand Coulee. The largest floods easily overtopped the coulee walls deeply eroding the plateaus east of the coulee for miles (Figure 18). Scabland features are abundant on the top of the high mesas and several recessional cataracts branch off into Jasper Canyon.

Proceed north on SR 17 and turn east into Sun Lakes State Park. Drive through park into Deep Lake Canyon.

Deep Lake Canyon

The Deep Lake recessional cataract canyon (Figure 19) extends eastward for many miles and can be partly accessed by a side road near the campground. During the largest floods, water spilled over what Bretz called the "Great Cataract Group" , which was over 4 miles wide, and included Deep Lake and Dry Falls, as well as Castle Coulee Don Paul Draw (see Figure 11). Deep Lake is 120 feet deep, the deepest lake in the Grand Coulee region! Southwest of Deep Lake on a basalt bench above the lake is a pothole swarm where swirling flood waters (i.e., kolks) excavated dozens of potholes (Deep Lake Pothole Swarm).

Stop 2-2 Deep Lake Pothole Swarm

Short hike to several deep potholes on rock bench above Deep Lake (Figure 20).

Deep Lake Pothole Swarm

A dense clustering of about two dozen potholes occurs on an elevated, basaltic bench , located at the west end of Deep Lake (Figure 20). Most potholes are only 50-100 ft in diameter and extremely deep with steep side walls. Swirling floodwaters, hundreds of feet deep, moving down Deep Lake canyon created forceful whirlpools (kolks), which augered deep holes into the basalt.

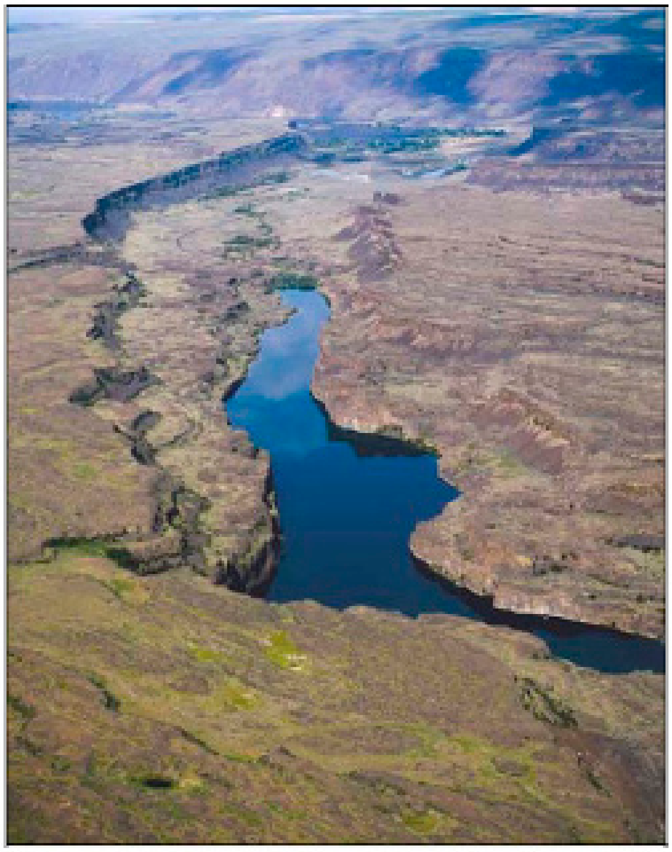


Figure 19.(Above) Deep Lake, canyon looking west. Lower Grand Coulee and Sun Lakes State Park are at top center.

Retrace route to SR 17. Continue north on SR 17 to Dry Falls Overlook.

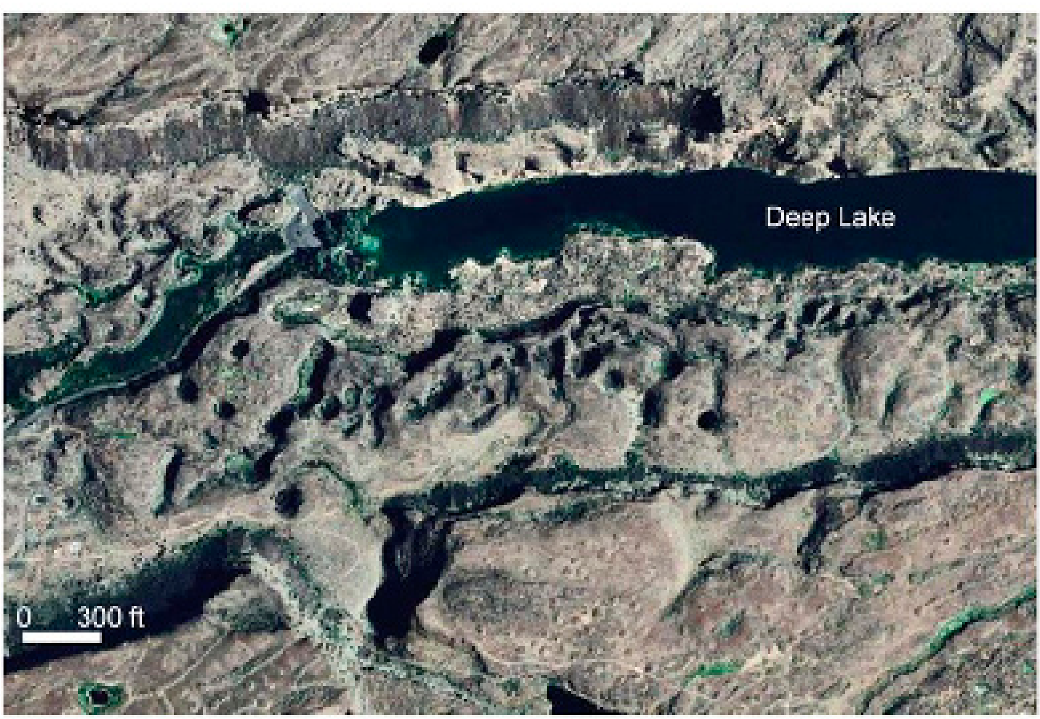
Stop 2-3. Dry Falls Cataract Overlook.

Dry Falls Cataract

The ”footsteps” here of the giant Pleistocene (Ice Age) floods are unmistakable. The area looks much like it did when Ice Age ended. The geologic recency of the last Scabland flood (about 15,000 years ago) and the semi-arid climate contribute to the lack of major weathering and erosional modifications of the flood features here and elsewhere in the Columbia Plateau. The 400-foot-tall abandoned cataract (Figure 21) lies at the head of the Lower Grand Coulee (see Figure 11). Two major and one minor alcove and two plunge pool lakes (Dry Falls and Green Lakes) are visible from the visitors center. The dual cataract coulees are separated by a tall blade of basalt (Umatilla Rock) that mostly obscures Monument Coulee on its east side. The farthest visible eastern rim is about 1.2 miles away. The cataract rim extends much farther to the east past Deep Lake, Castle Lake, and into Don Paul Draw for a total width of the Great Cataract Group of ~ 4 miles (see Figure 11).

The volume of water racing over Dry Falls is estimated to be 10 million m3/sec. Grand Coulee Dam contains 9.2 million m3 of concrete. Thus a volume of water approximately equivalent in size to one Grand Coulee Dam would pass here every second during a large Missoula flood!

Figure 20 *(Below)* **.** *Swarm of deep, round potholes on basalt bench near Deep Lake (upper right).*



Dry Falls are 2.4 times taller than Niagara Falls and considerably wider. With 400 feet of water below the rim and another 300 feet above, flood depth here was over 700 feet! Flow velocities are estimated to be close to 70 mph. The awesome power of such a cataclysmic event is difficult to imagine. At maximum flood flow the Dry Falls site was actually a subfluvial waterfal system with a bump in the water surface rather than a cascading drop in the water surface like a Niagara Falls system.

Large boulders plucked from the waterfall head and canyon walls are strewn about downstream of the falls. Some of the house-size boulders are large slump blocks moved from the oversteepened wall during or shortly after the flood peak.

Figure 21. *Dry Falls showing multiple cataract alcoves and plunge-pool basins. Umatilla Rock, a long, narrow blade of basalt, passes through the center foreground. Coulee City in upper right.*

Not visible from ground level near Dry Falls are hundreds of well-developed, parallel longitudinal grooves carved into the basalt bedrock during extreme flood erosion. Examples of these grooves are shown in Figure 22 as well as the cover of this field guide.

Continue 2 miles north on SR 17 to US 2 and turn right crossing Banks Lake Dam. In Coulee City turn right (south) onto Pinto Ridge Rd. Descend into Hartline Basin, across Arbuckle Flats and past mouth of Hudson Coulee (see Figure 11).

A series of dry fall alcoves in Hudson Coulee mark the position of the cataracts as they receded headward. A spectacular canyon and scabland remain in this remote canyon. An elongate closed depression (partially erosional and depositional in origin) over 120 feet deep occurs in the bottom of Hudson Coulee! Such depressions are common where high-energy currents reach gentler slopes. The process can be thought of as the "garden hose effect" where the nozzle pointed at the ground excavates and maintains the depression and soil and debris accumulate on the lateral and down current sides.

At entrance to Summer Falls State Park turn right into Dry Coulee.

Dry Coulee

Pinto Ridge was too high for floods to flow over so floodwaters were forced to go around this obstruction. Floodwaters split with part of the stream flowing eastward down the channel occupied by Billy Clapp Lake and the rest flowing west down Dry Coulee, a structural and topographic low between Pinto Ridge and High Hill (see Figure 11). The gravel road leads westward over flood deposits formed at the mouth of the large Hudson Coulee to the north.

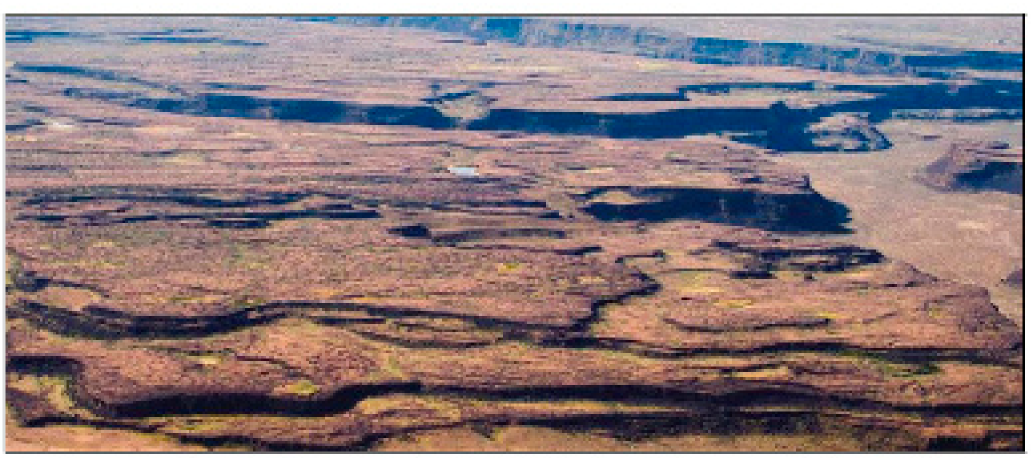


Figure 22. *Stripped-off, fluted, and grooved uplands on plateau south of Dry Falls. Jasper Canyon on the right.*

The road swings westward around the north end of Pinto Ridge and joins the eastward flowing segment of Dry Coulee . The road then follows southward along Dry Coulee. The head of Dry Coulee trends eastward from Lake Lenore in the Lower Grand Coulee, around the north edge of High Hill, and southwestward through the gap between High Hill and Pinto Ridge (see Figure 11) before it enters the broad Quincy Basin 11.5 miles to the south.

The walls of this little known canyon are nearly vertical and locally over 300 feet high. The sediment-covered floor of the coulee lacks surface streams and displays a number of pendant/shoulder bars and shallow depressions. Fewer than a half dozen ranches are located in the north part of the coulee. Farms pump groundwater from the productive aquifer within flood sediments that fill the coulee bottom to irrigate their alfalfa crops.

The coulee walls lower where they leave the confines of the gap between High Hill and Pinto Ridge and open up into the Quincy Basin. The expanding water surface resulted in reduced carrying capacity of the water column and a significant part of the sediment load was deposited as a huge expansion bar (Ephrata Fan) displaying a complex of flood bars on its surface (Figure 23). During Ice Age floods, floodwaters from Dry Coulee merged with floodwater emanating from the Lower Grand Coulee, the Billy Clapp spillway, and water pouring down the Wilson and Crab Creek floodways. This gathering of the waters overwhelmed the Quincy Basin forming a vast temporary inland lake, up to hundreds of feet deep, as far as the eye could see.

At the mouth of Dry Coulee cross SR 28 and continue straight towards Adrian. Turn west (right) onto Rd 20NE.

Ephrata Fan

Ephrata Fan is an immense expansion flood bar with many low-lying, interconnected channels and closed basins north and west of Moses Lake. The bar spreads out at the mouth of the Grand Coulee (Figure 23). Floodwaters formed the fan after breaking out of the confines of Grand Coulee and expanding into the Quincy Basin. Some floodwaters that formed the fan also came down Dry Coulee and Crab Creek.

Due to sudden expansion, the floodwaters decelerated and deposited about 130 feet of sediment onto the fan. Sediment sizes in the fan decrease with distance south from the mouth of the Grand Coulee. Large boulders that cover the fan were ripped out of Grand Coulee and other scabland channels just upstream. At the head of the bar, east of Ephrata, are house-size boulders up to 60 feet in diameter. Some of the extremely large basalt boulders have large depressions upstream of the boulders. These are called scour holes, which formed after the boulders stopped moving but floodwaters continued to flow and sculpt the loose sediment around them. They were created by irregularities in water flow as floodwaters passed over and around the giant monoliths. Anyone who has walked along the seashore has seen similar depressions (on a much smaller scale) where waves wash over isolated pebbles on a sandy beach. The giant boulders and scour holes attest to the great depth and velocity of the floodwaters across Ephrata Fan. The large boulders on Ephrata Fan were mostly or entirely carried as traction flow for at least part of their journey. Most of the boulders are composed of basalt but as much as 10% are composed of exotic granite, metamorphic, and sedimentary rocks from other upstream sources.

Floodwaters used higher channels that spread east and west of Ephrata Fan during larger discharges, either during earlier floods or early on during the last flood(s). As floods waned and the flows became smaller, only the main, central channels were used.

The route enters the debris-strewn area where extremely high-energy flood currents emerged from the mouth of the Lower Grand Coulee and spread out into the Quincy Basin. The size of the boulders is an excellent indicator of energy levels in the turbulent flow. Larger boulders indicate higher current veloci-

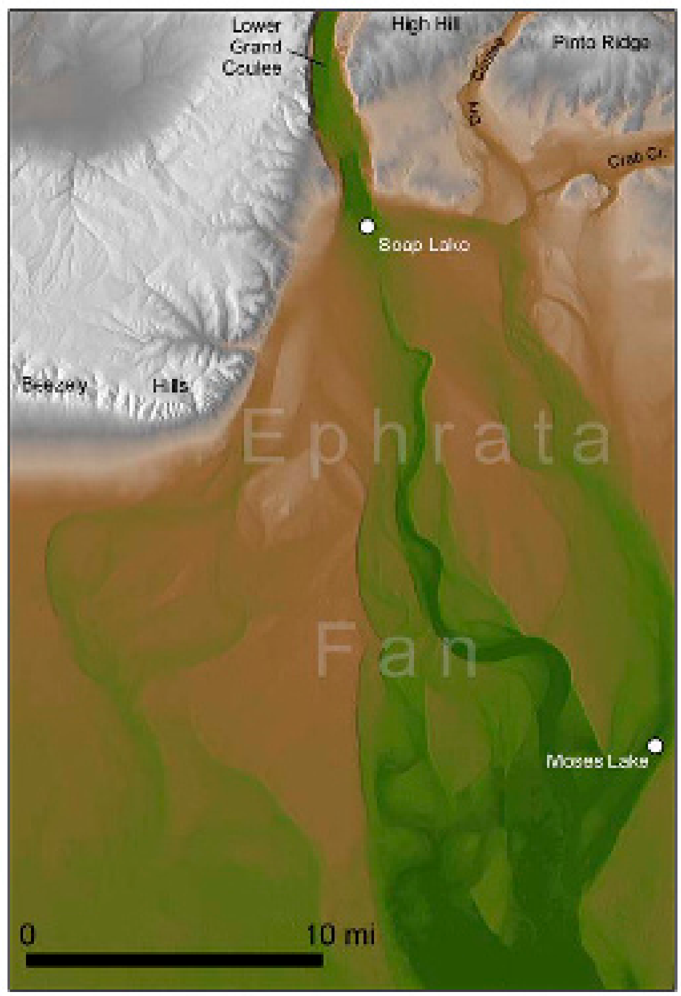


Figure 23. *Braided channel network across the broad Ephrata Fan.*

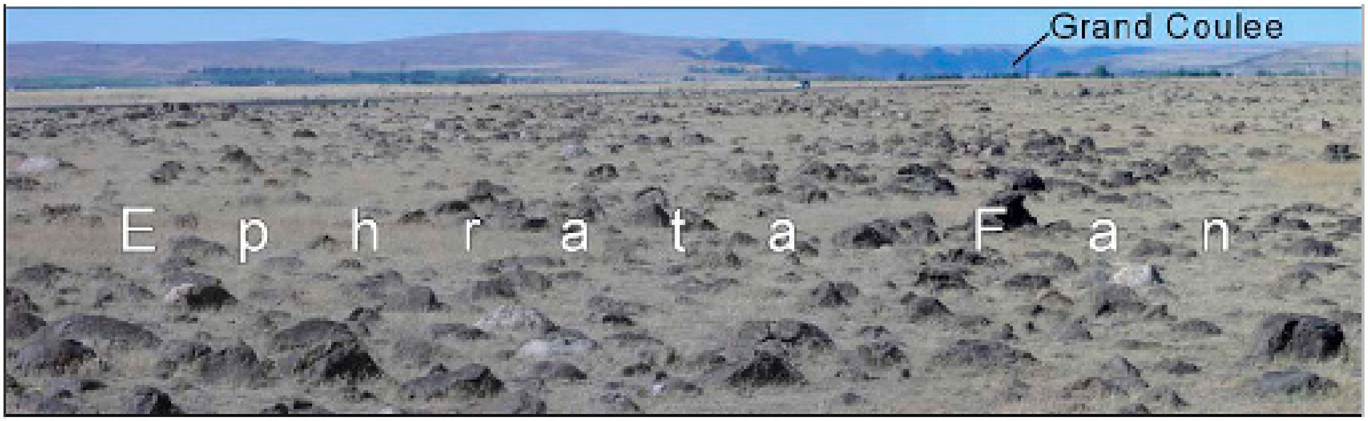


Figure 24. *Flood-transported boulders cover the surface of Ephrata Fan. Looking north.*

ties. However, the "garden hose" effect ("fire hose effect" here!) was important at the mouth of the Lower Grand Coulee where extremely large boulders and other sediment were carried some distance from the coulee mouth before current energy reduced sufficiently to allow deposition!

In rapid succession turn left onto Rd B7NE, left on Rd B, left onto Rd 19E and right onto Rd B5NE

Note the large boulders that were uncovered and pushed to the road margins during road construction. Most boulders are rounded indicating that they rubbed and ground against one another during tractive bedload along the sediment-water interface at the base of the flood flow.

Road descends into Rocky Ford Creek to the Trout Lodge Fish Hatchery becoming Trout Lodge Rd.

This location provides a sweeping view to the south of the Rocky Ford Valley cut into the Ephrata Fan and to the north the gaping mouth of the Lower Grand Coulee. The debris flushed out of the coulee complex is the source of most of the huge debris fan boulders surrounding this site. However, considerable sediment was also flushed into the northeast side of the Quincy Basin from the Crab Creek and other spillways.

During the last glaciation the Okanogan Ice Lobe filled the channel of the Columbia River and thereby diverted the Columbia River into Grand Coulee. The river emerged from the Lower Grand Coulee and flowed towards the present site of Moses Lake. The meandering channel near Moses Lake appears to be the remnant of the Ice Age Columbia River channel. The straight channel north of Moses Lake to the fish hatchery below this view does not appear to be cut by normal river processes and is at least partially the result of the Ice Age floods.

Geomorphic relations indicate that the last flow of water down Grand Coulee was an Ice Age flood that occurred at the end of the Ice Age after the Columbia River had shifted back to its present channel. Rocky Ford Creek lies about 170 feet below the fan surface and appears too high, narrow, and straight, especially in its upper section, to be cut by the Columbia River when it was diverted into Grand Coulee by the Okanogan Ice Lobe.

Farther north the channel has a two-mile long elongate depression over 20 feet deep. Since irrigation began, rising groundwater tables have filled the depression to form Ephrata Lake (Fig. 8). North of the depression towards Soap Lake the channel disappears and is obscured by flood debris at the mouth of the Upper Grand Coulee. The channel of the ice-diverted Columbia River here is completely buried or at least partly buried in flood sediment from a late ds down the Grand Coulee post-dates the occupation of the Columbia River in Grand Coulee.

Continue west along Trout Lodge Road.

Stop 2-4. Monster Rock.

Monster Rock

The boulder field here is one of several sites used by NASA scientists to anticipate conditions on Mars. Large volumes of water from the southern highlands on Mars emerged catastrophically from the confines of large channels onto the northern lowland plains. Fan-shaped deposits on Mars resemble the Ephrata Fan and have a similar origin. Thus areas such as this on Mars would also have samples of many of the upstream rocks. Thus landing in such areas could potentially help identify the bedrock base of the southern highlands. Information gathered from sites such as this on the Ephrata Fan led to the identification of potential landing sites on Mars and the successful 2003 landing of Mars Rovers, Spirit and Opportunity.

The northern surface of the Ephrata Fan is characterized by a series of longitudinal gravel bars oriented parallel to the flow direction (Figure 23). The surface also has low relief lobate forms perpendicular to the flow direction. The bars and lobate forms reflect the complex hydrologic conditions when sediment transfer and deposition across the surface of the expanding debris fan.

Water depth near the mouth of the Lower Grand Coulee was likely over 600 feet. Velocities initially exceeded 60 mph and

Figure 25. *Monster Rock on the Ephrata Fan is flood transported and estimated to weigh over 1,500 tons! Note scour-hole depression on up-stream (left) side.*

rapidly decreased southward before the floodwater speeded up again and roared down narrow escape routes in the Drumheller Channels area in the south end of the Quincy Basin and three major spillways that lead westward into the Columbia River valley.

Water and debris exploded from the mouth of the Lower Grand Coulee complex sending debris in a wide swath like pellets from the mouth of a shotgun. Velocity reduction at the coulee mouth and debris momentum carried large boulders a mile or more before they began to settle out of the slowing water stream.

The largest of these, "Monster Rock", is estimated to be about 8m (25 feet) in diameter and contains over 500 cubic yards of rock that weighs over 1,500 tons! It's difficult to imagine how such a huge boulder of basalt entablature, riddled with weak fractures, could survive transport rolling and bouncing along the base of a flood. Perhaps the boulder eroded off the Okanogan Lobe and partially floated in ice to this point before grounding. Or perhaps the floodwater consisted of a dense slurry, which supported and transported the boulder intact. Similar to what was observed in lahars and mudflows during the 1980 eruption of Mount St. Helens.

Continue west and turn south onto SR 17.

Usually, flood channels are straight or slightly curving, but west of Moses Lake (Figure 23) you can see sinuous, meandering channels. These channels are very unlike flood channels and appear to represent an old streambed of the Columbia River that flowed through this area between Ice Age floods when the Columbia was diverted down Grand Coulee by the Okanogan ice lobe. The sinuous channel disappears to the north beneath Ephrata Fan where it lies buried by deposits from the last Scabland flood(s) that raced down Grand Coulee. The Columbia River apparently reestablished itself into its present course prior to the last Scabland flood.

At the downstream end of Ephrata Fan flood deposits consist of mostly fine-grained sand and silt. Southward beyond the bouldery areas, however, a lot more fertile, fine-grained soil exists for farming. At the far end of the fan, south of Moses Lake, a large field of sand dunes developed soon after the end of the floods. The dune field has since been flooded by Potholes Reservoir and, as a result, most dunes are no longer active.

Pass through Moses Lake on SR 17. ~9 miles south of Moses Lake turn west onto SR 262 (Rd 7 SE) toward Potholes Reservior. Drive over O'Sullivan Dam; the upper Drumheller Channels are immediately below and to the left (south).

Drumheller Channels

Drumheller Channels is an awesome and chaotic plexus of scabland, carved out by floods that repeatedly chewed away at east end of the Frenchman Hills anticline. The stark beauty of Drumheller Channels was formally recognized by the National Park Service, who in 1986 designated Drumheller Channels a National Natural Landmark. In the words of J Harlen Bretz, the geologist who first envisioned the floods back in the early 1920's: "Drumheller is the most spectacular tract of butte-and basin scabland on the plateau. It is an almost unbelievable labyrinth of anastomosing channels, rock basins, and small abandoned cataracts".

The natural low point for the Quincy Basin is in the south-east corner where the east-plunging Frenchman Hills meet the southwest-dipping Palouse Slope . Ice-Age floods inundated the Quincy Basin from the north via Grand Coulee and from the east off the Channeled Scabland via the Telford

–Crab Creek Scabland Tract and Lind Coulee. Upon encountering the impassable Frenchman Hills the floods were forced to divide, some going west over divides along Evergreen and Babcock Ridges before cascading into the Columbia valley via Crater, Potholes and Frenchman Coulees. The bulk of the floodwaters though, took the path of least resistance, which was straight ahead through Drumheller Channels.

Floodwaters naturally funneled through the primary outlet for the Quincy Basin at Drumheller, carving out a well-defined swath across the east end of the Frenchman Hills (Figure 26). The east and west margins of the 8-mile-wide channel are well-defined by scarps, some more than 100 ft high, eroded into basin-fill sediments.

Drumheller Channels formed by being forced to go around the nose of an anticlinal ridge but constrained to the east by the gently west-dipping Palouse Slope. Not only were floods slightly constrained through the opening but the height of the floodwaters was up to 150 ft higher above the channels than below.

This significant difference in water level is responsible for the tremendous erosive power which went to work scouring out an interconnected network of eroded channels, buttes, and basins here (Figure 27). However, unlike most other areas in the Channeled Scabland,

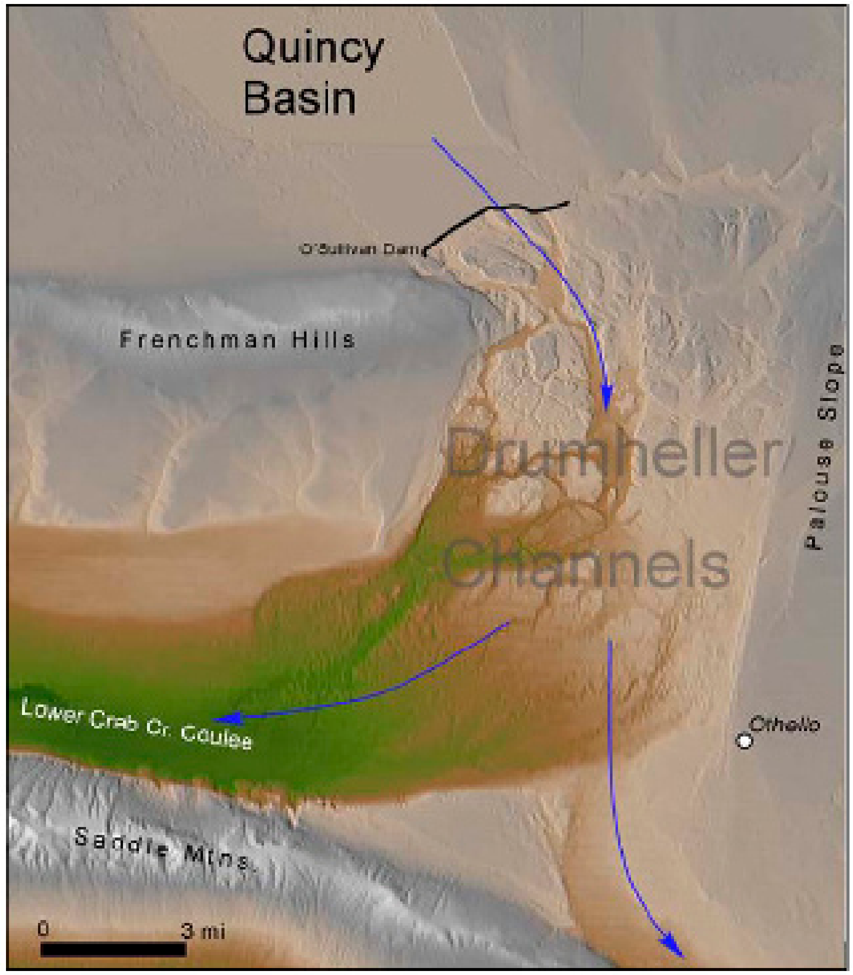


Figure 26*. Eight-mile wide Drumheller Channels, escape route for floodwaters out of the southeast corner of the Quincy Basin.*

Figure 27: *Chaotic butte and basin plexus of the Drumheller Channels.*

Figure 28. *Exotic, ice-rafted erratics along the Frenchman Hills.*

no central channel or dominant cataract developed; instead the floods through Drumheller Channels behaved more like a broad cascade – up to 8 miles wide!

Numerous seep lakes fill depressions scoured out by the floods within Drumheller Channels. These lakes are filled by water seeping out through cracks in the basalt connected with Potholes Reservior.

Continue west along SR 262.

Stop 2-5. Frenchman Hills Erratics.

A cluster of ice-rafted erratics lie on either side of the road here at 1,190 ft above sea level.

Frenchman Hills Erratics

High along the north slope of the Frenchman Hills lie a number of misplaced, light-colored boulders (ice-rafted erratics) – very different from dark basalt, which is the only indigenous rock in this area. One grouping of erratics is clustered at 1,190 feet elevation on either side of SR 262 just east of the intersection with Frenchman Hills Road. The cluster consists of a mixture of different igneous rock types, including granite and diorite. Some of the boulders consist of a granitic pegmatite. The origin of the pegmatite can be traced to the Lake Pend Oreille area, the site of the ice-dam that formed Glacial Lake Missoula. The largest erratic is 8 feet long and 4 feet wide. These erratics are about 200 feet below the maximum flood level (1,425 feet) in the Quincy Basin. Because the erratics are aligned parallel to the road, they probably were moved, some maybe even exhumed, during road construction.

Just past erratics turn right onto Frenchman Hills Rd (Rd 7SW). After ~4 mi turn right (north) onto Dodson Rd. After ~9 miles intersect with I-90. Go I-90 west back to Vantage.

End of field trip.

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