Did Bonneville Flood Inundate the Pine Valley Region of Northeastern Oregon? [1)]

Introduction

Recent geologic mapping of Late Quaternary (about 18,000 to 11,400 years ago) erosional and depositional landforms in Hells Canyon and adjacent areas of eastern Oregon and western Idaho, suggests that the Bonneville Flood, which swept through the region about 14,500 (O'Connor, 1993) to 16,000 years ago (O'Connor, oral communication, 2013), was deeper than previously recognized.

I conjecture that Bonneville Flood water overtopped Snake River Canyon's western rim in several places east and southeast of Pine Valley, flowing across spillways (sills) such as those above Road Canyon and Cave Creek, and across other low areas in the canyon's western rim, subsequently eroding coulees, fosses, plunge basins, water conduits (now wind gaps), and cataracts, while depositing boulder and cobble megaripples, channel and eddy bars, terraces, and alluvial fans. At the same time flood waters flowed up Snake River tributaries, including Wildhorse and Powder rivers, in addition to Pine, Brownlee, and other creeks. Coalescing and competing spillover currents may have drowned Pine and Eagle valleys with water of unknown (possibly several hundred feet) depths.

Constrictions in the Snake River Canyon (including Hells Canyon) downriver from Huntington, Oregon caused the floodwater, estimated by O'Connor (1993) to have flowed at an average of at least 540,000 cubic meters per second (about 19 million cubic feet per second) with velocities as great as 35 miles per hour, to be impounded behind those constrictions like behind a series of dams, and subsequently to flow backwards up the canyon making it possible to spill over the canyon's rim in relatively low areas.

I don't know if the Lake Idaho flood(s) was also a culprit, but I deduce that the age of that flood(s) (about two million years) was too long ago to account for most present-day erosional and depositional flood-related landscape features in the region. Today's landscape is very different from the landscape during and after the Lake Idaho flood(s). Regional uplift, local faulting, and several glaciations greatly affected the landscape during the past two million years, thereby making Lake Idaho features difficult to recognize.

1) A preliminary manuscript by Tracy Vallier (09/2013)

Data and observations that strengthen Bonneville Flood consequences in the Hells Canyon and Pine Valley-Eagle Valley regions are presented below, but additional mapping and measurements are necessary before my colleagues and I will be confident to publish interpretations and conclusions in a science journal. This manuscript is a first step in the process, which is written to introduce this hypothesis to other scientists and to residents in the Hells Canyon and Pine-Eagle regions. I invite comments from both.

Four assumptions and estimations are important for a suitable analysis (based in part on conclusions of O'Connor, 1993): 1) Bonneville Flood had a sustainable flow of at least one million cubic meters per second (about 35 million cubic feet per second) at the outlet where Lake Bonneville (now occupied in part by the Great Salt Lake in Utah) floodwater cut through Red Rock Pass, spilled over, and flowed into the Snake River and onto the Snake River Plain near Pocatello. From there the floodwater flowed through Snake River Canyon below Huntington, Oregon, into the Columbia River, and then into the Pacific Ocean, passing over and through the Astoria Fan and flowing farther west onto the deep ocean floor; 2) Flow and velocity decreased to between 0.57 and 0.62 million cubic meters per second (19 to 20 million cubic feet per second) at Lewiston (compare this to an average of about 15 thousand cubic feet per second for present-day flow); 3) The minimum duration of these estimated flows was at least one month (the flood probably lasted longer, perhaps several months, but at different depths, velocities, and discharges); and: 4) Channel current velocity in Hells Canyon was as high as 35 miles per hour (about 50 feet per second) and reverse currents, caused by boundary shear, along slopes of Hells Canyon carried suspended sediment upstream.

First major backup of Bonneville Flood water in Snake River Canyon would have occurred near Huntington where the canyon narrows significantly, and the next most likely at the Oxbow, but major constrictions downriver from Oxbow made temporary dams throughout Hells Canyon, beginning where the canyon narrows and steepens near Copper Creek (Oregon) and Lime Point Creek (Idaho) and continuing from there as a long and irregular series of constrictions to at least Sheep Creek, nearly 30 river miles below Copper and Lime Point creeks. Constrictions downstream from Sheep Creek at Suicide Point, at West and Pleasant Valley creeks on the north edge of Pittsburg Landing, and at the canyon's very narrow segment between the mouths of Imnaha River and Salmon River greatly affected the depth and backup of floodwaters from those areas. The abrupt turn from north to northwest below Getta Creek also provided a major constriction. I conjecture that floodwater may have overtopped the ridge between the Snake River and Salmon River at Divide Creek, but have not yet climbed over that ridge to investigate the possibility.

Dynamics of Bonneville Flood are well modeled by O'Connor (1993), particularly for flow through the Snake River Plain. Dynamics, however, are complicated, and I presume even more so in the Snake River Canyon below Huntington. I quote O'Connor's assessment of the flood's dynamics as written in his abstract on page 1: "Diverse geologic and geomorphic environments along the flood route resulted in large spatial variations in the channel geometry as the flood moved downstream. Consequently, the local hydraulic conditions (flow depth, velocity, boundary shear stress) of the Bonneville Flood varied substantially within and between the study reaches."

In this manuscript I first describe several Bonneville Flood erosional and depositional landforms in the Snake River Canyon from Lewiston to about 100 miles upstream. Second, I briefly discuss the role of Mima mounds on geomorphology and landscape evolution in the Pine-Eagle region. Third, I focus on specific features in the Pine Valley region, including both Pine and Posy valleys. And, in a fourth section I describe features of a sill, plunge basin, and fosse (wide canyon) that are probable consequences of a spillover at headwaters of Cave Creek. These data and preliminary interpretations suggest that water of Bonneville Flood flowed over the Snake River Canyon's western rim in several places between Brownlee Dam and mouth of Powder River, thereby inundating the Pine–Eagle region.

A "Glossary" section near the end of this article can be referred to while reading and studying the included figures and captions. A few references are given at the very end for additional reading.

Bonneville Flood Landforms along Snake River Canyon from Lewiston to McGraw Creek

Evidence for Bonneville Flood erosional and depositional effects in the Snake River Canyon, particularly in Hells Canyon below the Oxbow is abundant. Erosional features are cataracts, plunge basins, water-planed terraces and plateaus, wind gaps, stream diversions and piracy, and holes up to 100 feet deep in the present-day Snake River channel. Depositional features are alluvial fans, channel and eddy bars, landslide deposits, high sediment-covered canyon slopes, sediment waves (also referred to as megaripples and giant current ripples), and both erosional and depositional terraces.

Photographs (Figures 1 through 10) in this section show features in and along the Snake River Canyon. Additional photographs and maps in the next three sections show erosional and depositional features within the Pine Valley/Brownlee Dam and upper Hells Canyon regions of Oregon and Idaho.

Figure 1. Exposure of Bonneville Flood boulders, cobbles, gravels, and sands (lower gray-colored unit) and Missoula Flood sands and silts (upper unit of brown colors) in the Atlas Company borrow pit in south Lewiston, Idaho. Note channel fills (dark-brown v-shaped deposits) in the Missoula Flood unit. (Photographed in late 1990s). Dipping beds of similar Bonneville Flood materials can be seen along the terrace bank in Lewiston just east of the "Blue" bridge that spans the reservoir/river between Clarkston and Lewiston.

Figure 2. Big Bar Idaho, between Eckels and Kinney creeks in Idaho (left) and near Leep and Kirby creeks in Oregon (right) during construction of Hells Canyon Dam. Photographed from the north in 1965. Notice borrow pit in upper center (see details in Figure 3) and smoothed surface of landslide toe along river northwest of mobile home park and ranch buildings (lower center). Bonneville Flood waters captured lower part of Kirby Creek (sediment-smoothed former creek bed in right center, with two pine trees near shadow marking pre-existing channel) in Oregon that previously had flowed into Leep Creek. Powerful floodwaters “captured” (or “pirated”) the lower reaches of Kirby Creek and diverted the channel, thereby causing it to flow directly into Snake River (Hells Canyon Dam Reservoir) at a point across from southern tip of the smoothed landslide deposit. Landslide scar is marked by nearly bare rock face north of Kirby Creek, part of which can be seen just north (downstream) from the bush-covered protuberance that lies directly across the river from the landslide toe in right center of photograph.

Figure 3. Bonneville Flood channel cobbles and gravels (lower strata) and back eddy (?) sands (upper strata) in borrow pit near southern end of Big Bar, Idaho (see Figure 2 for location). The cobbles, gravels, and sands were crushed, sorted, and subsequently used in constructions of Hells Canyon Dam and Idaho Power Company road that parallels the reservoir in Idaho between Oxbow, Oregon and Hells Canyon Dam. Maximum height of cliff face is about thirty feet (1965 photograph).

Figure 4. Water carried by Bonneville Flood backed up behind Suicide Point (peak and ridge near top center of photograph), slowed, and deposited a boulder/cobble/gravel terrace south of Temperance Creek (ranch buildings in center right are near the north end of that terrace), plus gravel and sand on high slopes above the terrace (for example the gray-colored sediments in left foreground of photograph), more than 300 feet above river level. Flood water apparently reached a depth here of more than 1,000 feet, flowed over the v-shaped wind gap in background east of Suicide Point, and deposited gravel and sand on Kirkwood Creek canyon slopes south of the Carter mansion. The alluvial fan of Kirkwood Creek hosts the USFS visitor center with buildings at one time owned by the Jordan family. Grace Jordan wrote the book, *My Home Below Hells Canyon*—an enjoyable read.

Figure 5. Bonneville Flood gravels (gray-colored deposit) mantle the north slope of Jones Creek with apex of the deposit about 300 feet above river level. Deeper flood channel carried boulders, cobbles, and gravels as bed load; shallower and slower currents carried gravels and sands like those in the photograph and were deposited as water slowed over the slopes' impediment. Similar gray-colored flood sediments occur along slopes of many tributary canyons in Hells Canyon, for example in Smooth Creek, Klopton Creek, Wolf Creek, and several small-unnamed creek canyons in Idaho between Wolf Creek and Dug Bar.

Figure 6. McGraw Creek, Oregon. Platform on north side of the creek (near center of photograph illuminated by sun) and grass-mantled platform north of Spring Creek (sun-lit platform in background) were possibly smoothed by water from Bonneville Flood. Abundant potholes, deep scours and flutes, and accumulations of water-rounded quartzite boulders on the upper platform north of McGraw Creek indicate powerful currents. The lower platform along north side of McGraw Creek is the top of a pre-Bonneville-Flood slump deposit consisting of displaced Columbia River Basalt lava flows (center of photograph). (George Hauptman, pilot)

Figure 7. The sloped terrace of Marks Creek landslide, in Oregon between river miles 234 and 235, may have been smoothed (and rippled?) by Bonneville Flood water. Photographed from north with Snake River to the left. Partly rounded boulders along south edge of the landslide deposit, about 300 feet above the river, indicate high current velocity and coarse sediment transport. The terrace is between 800 and 900 feet above river level, which suggests a water depth of at least 900 feet in this part of the canyon. A terrace above this one, however, also has traces of water dynamics, but specific features have not been mapped.

Figure 8. Bonneville Flood gravels (grayish-tan color) along the north side of Klopton Creek near upper (southern) campground at Pittsburg Landing in Idaho. Notice the sloping flood-smoothed terrace in upper center of photograph. View north from a “notch” or nick point cut by Bonneville Flood.

Figure 9. Bonneville Flood sediment waves (megaripples in center right of photograph) north of Klopton Creek in southern part of Pittsburg Landing. Ripple-like landforms below terrace slope and above tree and between fence and edge of flat terrace, are also a consequence of floodwater processes. These sediment waves are composed of coarse sand and fine gravel and formed along the eastern edge of the main flood channel. Photograph was taken looking southeast with Klopton Creek canyon in background. Tom Chase, my colleague at the U.S. Geological Survey, used a large helium-filled balloon to carry a camera to an appropriate altitude for the photograph.

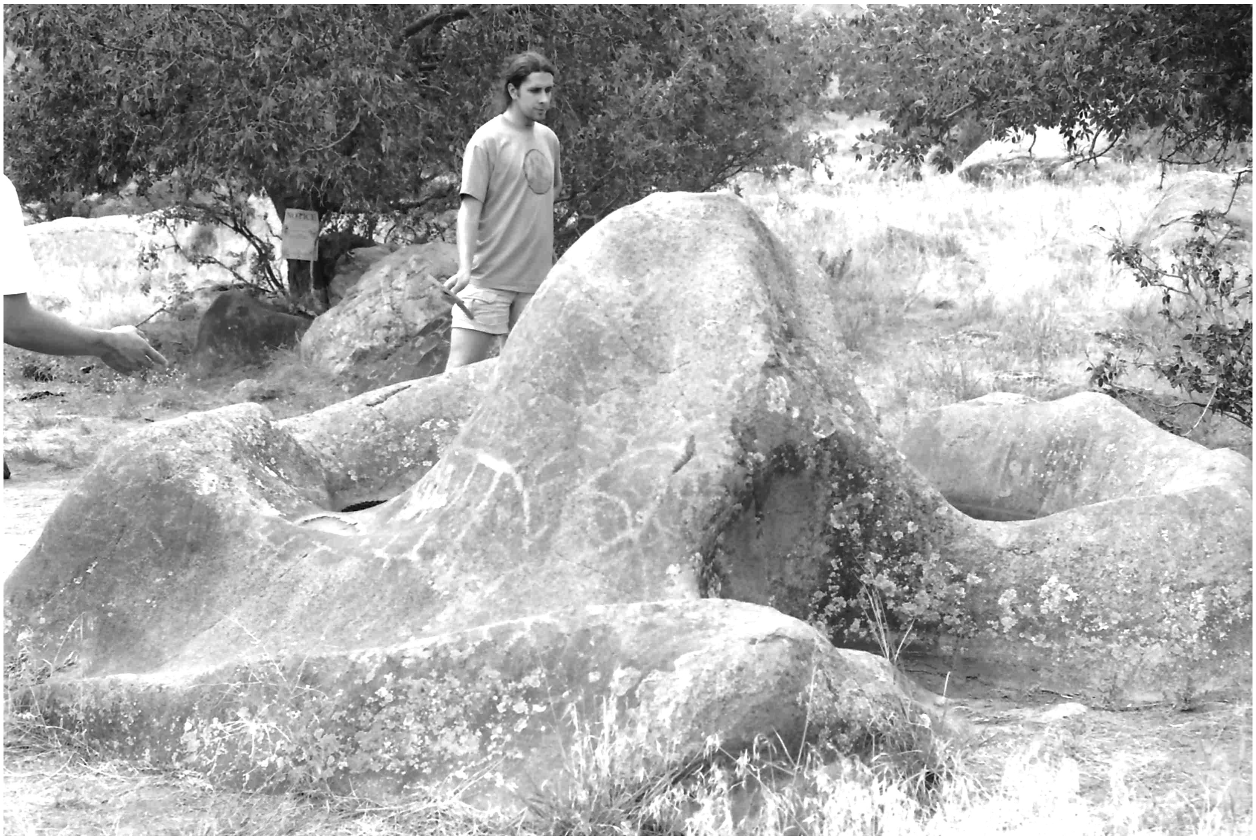

Figure 10. Sombrero Rock is etched with petroglyphs and lies on the Bonneville Flood terrace southwest of Circle-C (now U.S. Forest Service) ranch buildings at Pittsburg Landing. This enormous boulder is only one of nearly 100 boulders transported by a pre-flood landslide that cascaded from a rugged rock face east of Klopton Creek Fault. Sombrero Rock was subsequently pot-holed and rounded by high-velocity sediment-laden currents in the main channel of Bonneville Flood.

Mima Mounds

Mima and Mima-type mounds are new to me. I've not mapped them previously, but have learned that arguments over their origin(s) still cloud interpretations. I first looked at the elongate and (or) lens-shaped Mima Mounds as loess-covered megaripples, but colleagues Jay VanTassel and Jim O'Connor pointed out that they are Mima mounds. This, of course, opened for me a new field of interest, but many unanswered questions concern me, such as: 1) Why did they form only in the Pine Valley environs (as far as I know) and not elsewhere in the region? 2) What physical, chemical, and biological processes built and maintained them? 3) What is (or are) their age(s)? 4) What are the foundations (such as vegetation, eroded lava flow tops, eroded and transported cobbles and boulders) that initiated Mima-mound formation? And 5) Do they mostly form on flood-affected (Missoula and Bonneville floods and glacial-outwash) landscapes here and throughout the Pacific Northwest?

Mima mounds have multiple (and often controversial) origins (read articles in Horwath Burnham and Johnson, 2013, particularly that written by Johnson and Johnson, pages 135-159). In Pine Valley region they occur predominantly where inferred floodwaters flowed, leaving the water-eroded and adjacent areas with a biscuit-like landscape.

The mounds have heights as great as six feet and variable circular and oval diameters (estimated at 15 to 30 feet) with lengths as many as 100 feet. Mima mounds in the area have multiple sediment contributors, including boulders and cobbles, finer-grained flood-water (?) sediment, loess (transported and deposited by wind processes), and probably rare volcanic ash, all of which have been modified by burrowing mammals such as pocket gophers (not yet observed but some burrows are of appropriate size), voles and (or) field mice (two voles were seen on one Mima mound), and badgers (wide deep burrows). Various grasses, bushes, and flowers, along with insects, snakes, predators like fox, wolf, coyote, and bobcat, in addition to cattle, horses, deer, sheep, and antelope continually modify the Mima mounds. Humans with off-road vehicles also affect some Mima mounds.

I consider most Mima mounds I've observed to be hybrid Mima mounds, defined by Johnson and Horwath Burnham (2013, p. 3) as referring "to a pre-existing microhigh formed by any physical (freeze-thaw, dune) or biological (tree-uprooting) process or combination (coppice), which becomes inhabited by soil animals (pocket gophers, ground squirrels, badgers and other predators, moles, ants, termites, other insects, etc.) and modified in form and shape to become Mima mound-like." I noticed that many of the microhighs are eroded tops of lava flows and transported boulders, some arranged in ripple-like sequences.

Spillways, Fosses, Coulees, Dissected Plateaus, Sills, Sediment Wave (Megaripple) Fields and Mima Mounds in Pine Valley/Brownlee Reservoir Region

Below is a Google Earth satellite image (Figure 11) of Brownlee Dam and Reservoir, including Pine and Eagle valleys. Find the Brownlee Dam and Powder River for orientation.

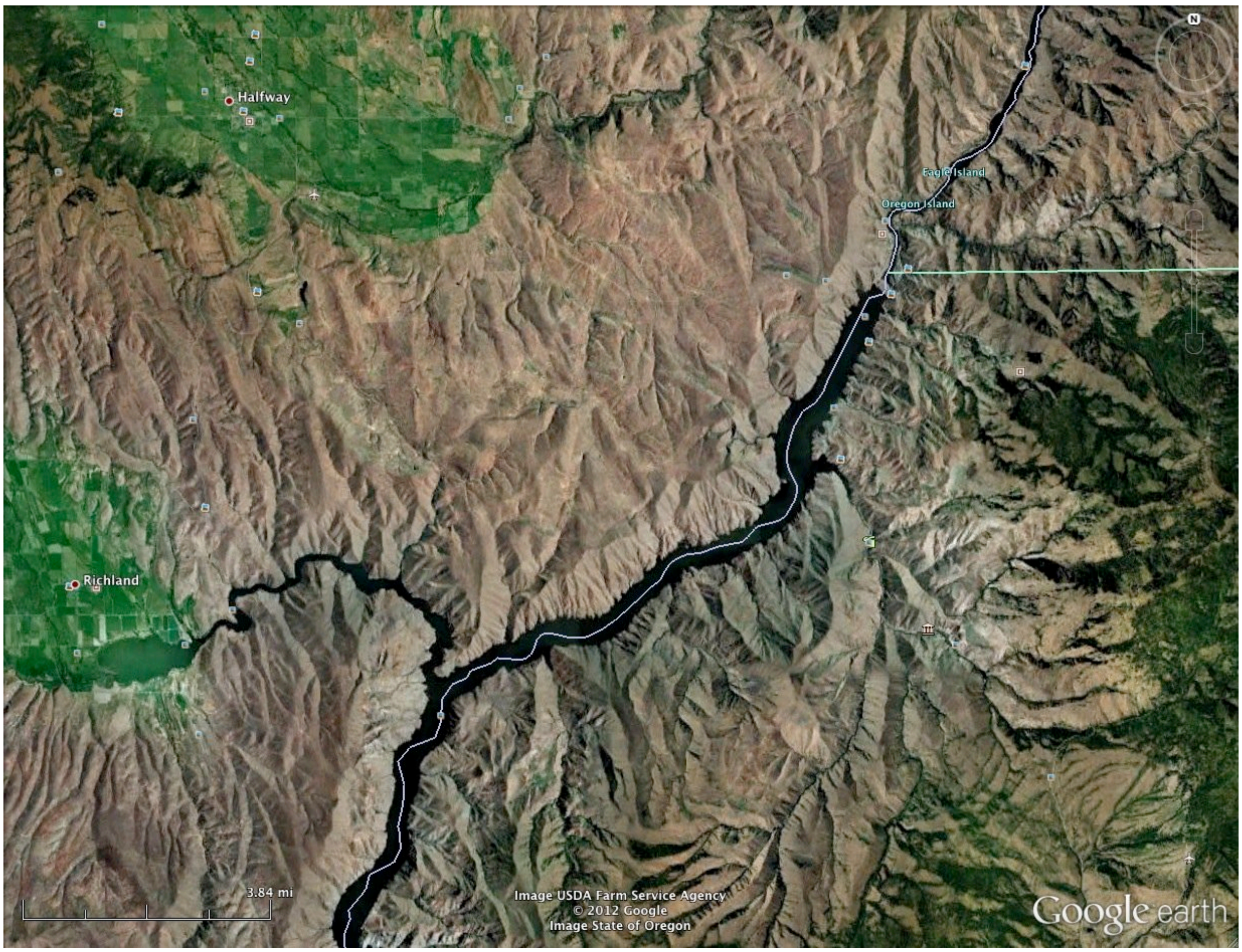

Figure 11. Google Earth image shows the Brownlee Dam and Pine/Eagle valley areas. Enlarge photo for better viewing. Scale is given in lower left corner. After reading the following text and viewing the maps and photos in figures, return to this photo to pick out Road Canyon Spillway, Deer Creek Coulee, Cave Creek Spillway, and Posy Valley. Look closely at the drainage pattern south of Powder River. Did a spillover also occur along the western rim of Snake River Canyon just south of the photograph and flow north to inundate Eagle Valley at the same time that floodwater was flowing into Pine Valley from the east?

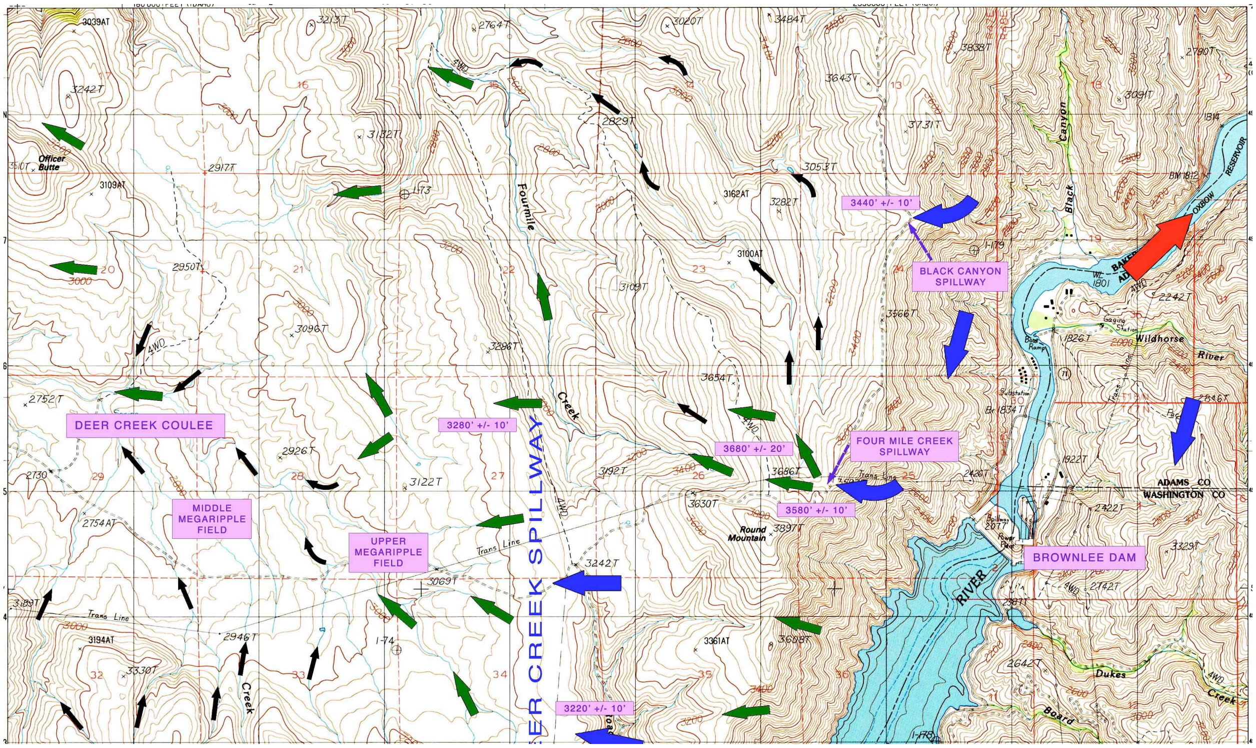

Figure 12. Northeast part of the USGS Brownlee Dam Quadrangle map. Arrows indicate suspected channel flow (red), overflow points and current directions (blue) and suspected secondary current directions green). The arrow sizes show relative volume estimates for water flow. Notice the reverse flow along edges of canyon. After initial spillovers, competing and interfering currents would have changed some current directions and volumes. Other major features on the map (in purple boxes) are spillways, coulees, Mima mound and megaripple fields, and elevations. The name of Deer Creek Spillway on this map has been changed in text and other figure captions to Road Canyon Spillway. Elevation of Cave Creek Spillway, or Sill, should be changed on map to 3220 +/-10 feet, which is about the same elevation as the lowest point on Road Canyon Sill or Spillway. Enlarge to see features more clearly and compare with Figure 11.

Preliminary mapping suggests that water flowed into Four Mile Creek drainage not only through Road Canyon but also through what are now two wind gaps, or passes, at much higher elevations (Figure 12); from north to south they are informally named Black Canyon Spillway (lowest elevation in pass, or wind gap, is 3440+/-10 feet) and Four Mile Creek Spillway (elevation 3580 +/-10 feet). Drainage patterns and a smoothed Round Mountain suggest flow over that feature at an elevation of at least 3897 feet, but I doubt that water reached those elevations; I leave open the possibility.

The major spillway, nearly three miles long, is informally named the Road Canyon Spillway, or Sill, (changed from map name of Deer creek Spillway). It has a low point at 3220 +/- 10 feet near its south end and a high point of about 3300 +/- 10 feet on its northwest projection.

Figure 13. Photograph of grass-covered Road Canyon Spillway (center), above Road Canyon, where I think Bonneville Flood waters spilled over the canyon's west rim and flowed into Pine Valley, thereby cutting Deer Creek Coulee. Photograph taken from ridge above Idaho Power Company's Woodhead Park in Idaho. Abrupt south edge of Deer Creek Coulee can be traced toward Pine Valley in middle distance, with Pine Valley in upper right. (It may be an eroded fault scarp but that structure has not been mapped.) A possible second spillway occurs over the small ridge south of Roadway Canyon Spillway (or Sill). Figures 15 and 17 show that spillway.

Maximum water depths in Pine and Eagle valleys are unknown, but may have been at least 600 feet, depending on depth of floodwater during spillovers, length of residence time, velocity of water flow, and volume of the flood at this location. Is it possible that floodwater also flowed up Powder River, maintaining a water-level elevation of about 3300 feet to inundate Baker Valley?

Figure 14. Flattened-U-shaped spillover feature (Road Canyon Sill) and resultant Deer Creek Coulee, clothed in smoky haze near center of photograph directly below highest (and nearly flat) peak of Cuddy Mountains, viewed from west side of Pine Valley.

Figure 15. The water-smoothed western rim of Road Canyon (creek along right side of photograph) marks Road Canyon Spillway (Sill) with upper part of Deer Creek Coulee on left. Photograph taken from south. The spillway first trends north and then turns to trend NNW for a total length of about three miles. Notice a secondary and unnamed higher spillway in lower left corner that was mentioned in Figure 13 caption. Mima-type mounds occur all along the main spillway and on top the elongated and bisected ridge north of the secondary higher and unnamed spillway. A suspected, and as yet unmapped, normal fault(s) follows Road Canyon and also the upper part of Four Mile Creek north to where the creek drains into Pine Creek. Columbia River Basalt lava flows east of the suspected fault(s) dip west between three and five degrees whereas lava flows west of the fault lie approximately horizontal. Notice the second canyon west (partly in shadow) nearly perpendicular to the unnamed spillway. An alluvial fan at the base of that small canyon suggests large water flow sometime in the past. (George Hauptman, pilot)

Figure 16. Deeply eroded creek canyons (that I refer to as either “under fit” stream valleys or fosses) may have been widened by floodwaters as they cut into flows of Columbia River Basalt south of Deer Creek Coulee (Upper right side of photograph with Pine Valley and Wallowa Mountains in distance). (George Hauptman, pilot)

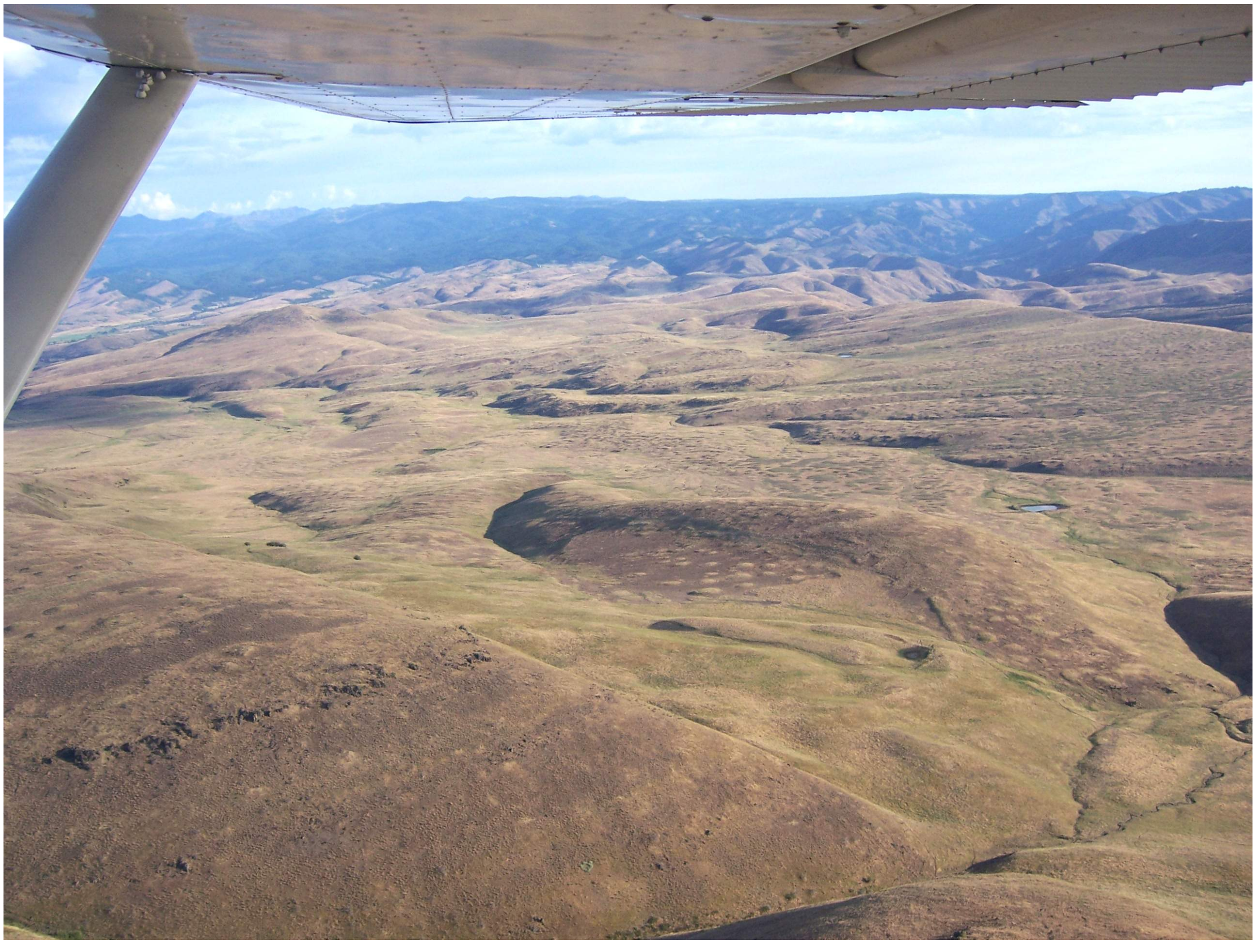

Figure 17. Primary Roadway Canyon Spillway (in upper right corner), and a secondary unnamed spillway's fosse, or small coulee, is shown in bottom center of photograph (also see figures 13 and 15). Deer Creek Coulee extends from right center across the entire photograph to the west (left). Notice a possible current scar along south side of the ridge in lower center and channels (indentations) cut into the small coulee's floor. Wallowa Mountains peaks show in upper left under plane's wing. (George Hauptman, pilot)

Figure 18. Megaripples (grass-covered undulations near center of photograph) and erosional scarps (center left, and center right near reservoir) lie southeast of Road Canyon Spillway (and south of Brownlee Creek) in Idaho. (Garry Vallier, pilot)

Mima Mound Fields in Deer Creek Coulee

Mima mound fields in Deer Creek Coulee, initially mapped as megaripple fields (so named on map in Figure 12), may provide additional evidence for large-volume and powerful currents' erosional and depositional processes (Figures 19 through 25) if it can be established that the mounds are built on current-eroded and -deposited foundations. For example, many crests of elongate Mima mounds trend approximately perpendicular to suspected current directions, and up-current sides or slopes of these ripple-like features are generally flatter (less slope degrees) than down-current slopes, thereby suggesting current directions. Wind-carried silt (loess), however, may be the major factor in mound shape.

Preliminary examinations of Mima mounds (and Mima-type mounds) on Road Canyon Sill, and in fields of Deer Creek Coulee, indicate a large variation in sediment sizes. Several studied Mima Mounds in the spillway, and higher parts of the coulee, have boulder, cobble, and gravel bases with relatively finer-grained sediments toward their crests. Some near the spillway are capped by wind-blown loess. Sediment of Mima mounds in Middle and Lower fields are noticeably finer grained; in places the entire elongate mound consists of poorly sorted gravel, sand, silt, and clay. Clay and rare flat-shaped pebbles are dominant materials in one Mima mound I examined near the Deer Creek Road. The clay-like sediment probably is highly compacted (semi-lithified) brown and rusty-red montmorillinite, a clay closely associated with volcanic ash and weathering of volcanic flow rocks.

Figure 19. This photograph of Deer Creek Coulee from Deer Creek Road shows parts of the Upper, Middle, and Lower (to the right of road) Mima mound fields. Cuddy Mountains are in center of the east horizon. Round Mountain protrudes above the landscape in upper left. Road Canyon Sill (Spillway) lies in center.

Figure 20. Elongate and nearly parallel-trending crests of Mima-type mounds along east side of Road Canyon Sill looking north toward Pine Creek. Road Canyon and Round Mountain are to the right.

Figure 21. This photograph shows the west side of Road Canyon Spillway (Sill) looking south at loess-capped Mima-type mounds (modified megaripples?) in eastern (uppermost) part of the Deer Creek Coulee. Notice the nearly parallel crests of elongate mounds in center right of photo.

Figure 22. Boulder deposit photographed along the south side of Deer Creek Road in upper Mima mound field. Rocks from three different lava flows were identified by texture and composition. Some boulders are partly rounded, suggesting either deep weathering or water transport. Aluminum map case near center, about 12 inches long, is included for scale.

Figure 23. Photograph of irregular (wavelengths, heights, and trends), and somewhat elongate, Mima-type mounds near Deer Creek Road in upper Mima Mound field looking east with Round Mountain in upper left. Possible current direction, no matter if supplied by wind or water, is from the right (southeast).

Figure 24. This photograph shows parts of both Upper and Middle Mima mound fields in Deer Creek Coulee with Round Mountain (highest point is 3897 feet) in left background and Road Canyon Spillway (Sill) across center of photograph. Cuddy Mountains, Idaho make up horizon in center right.

Figure 25. Middle Mima Mound field of Deer Creek Coulee with Round Mountain in upper left, Road Canyon Spillway (Sill) in upper center, and Cuddy Mountains in distance. Notice elongated crests and nearly parallel configuration. During initial mapping I interpreted these as megaripples, but soon learned that I was wrong. They are Mima (or Mima-type) mounds. Are they built on pre-existing megaripples?

Posy Valley and The Sag

Mima mound fields, smoothed plunge basins, plus a cascade and its associated alluvial fan suggest erosional and depositional effects from Bonneville Flood (Figures 26 through 30). If floodwater inundated Pine and Eagle Valley, it did so by surging across spillways above Road Canyon and Cave Creek along the canyon's western rim, rushing up Pine Creek from the Oxbow, and flowing up Powder River to Eagle Valley. I infer that Posy Valley filled at about the same time as Pine Valley, possibly with help from water that passed through Cave Creek Spillway and (or) up Timber Canyon from Powder River.

Figure 26. This air photo includes the northern part of The Sag in Posy Valley looking north toward Pine Valley. Scoured plunge basins (?) lie near center of photo suggesting flow from the north. Note channel-like feature (fosse?) on right that produced most erosional power and discharge for the Mima Mound field crossed by the power-line road (Figure 27). Irregular elongate Mima-type mounds can be seen in lower right corner of photograph. (George Hauptman, pilot)

Figure 27. Power Line Mima Mound Field slopes to the south. This view of Posy Valley is toward the power line road and Timber Canyon. The wide and elongate feature is similar to a coulee, with an abrupt eastern edge that can be seen in left center of photograph. Power poles in right center can be used for scale.

Figure 28. This photograph shows a possible Bonneville Flood-eroded cataract (sloped dry waterfall in center of photograph) and its resultant alluvial fan (in lower center), with megaripple-like elongate Mima-type mounds that occur north of the power line road in Posy Valley.

Figure 29. Elongated hybrid Mima-type mounds, that on preliminary investigation seemed similar to megaripples, consist of boulder–to silt–sized sediments, and lie north of power line road. Note nearly parallel crests in center and the aligned (transported?) boulders and cobbles in foreground and lower center that may have formed substrate (foundations) to many Mima mounds. View to northeast. Plunge basins (Figure 26) lie to the west (left).

Figure 30. These Mima-type mounds, during preliminary observations, were also thought to be megaripples. (This is a small Mima mound field east of The Sag road and southern plunge basin shown in Figure 26.) A cobble "stone pavement," possibly made by freeze-thaw conditions, whereby fine-grained sediment is carried away by melt water as it flowed over the cobbles, is in lower right corner (for explanations of sorted stone borders and rubbly stone pavements read pages 147-149 in Horwath Burnham and Johnson, 2013, referenced below).

Suspected Cave Creek Spillover with Sill, Wide Under-fit Canyons (Fosses?), and Plunge Basin

Cave Creek cuts through a short and deep canyon and drains the Snake River Canyon's west rim just north of Powder River in Oregon (Figures 31 and 32). A sill (Figures 33 and 34) abruptly terminates the creek's drainage at its headwaters and may mark a spillover of Bonneville Flood at around 3220 +/- 10 feet. A plunge basin, modified by a small dam to contain run-off and spring water (Figures 35 and 36), is upstream from an area of intense bedrock erosion. The inferred floodwater eroded a wide canyon (fosse), the upper reaches of which are shown in top left corner (with wide blue arrow) of Figure 31.

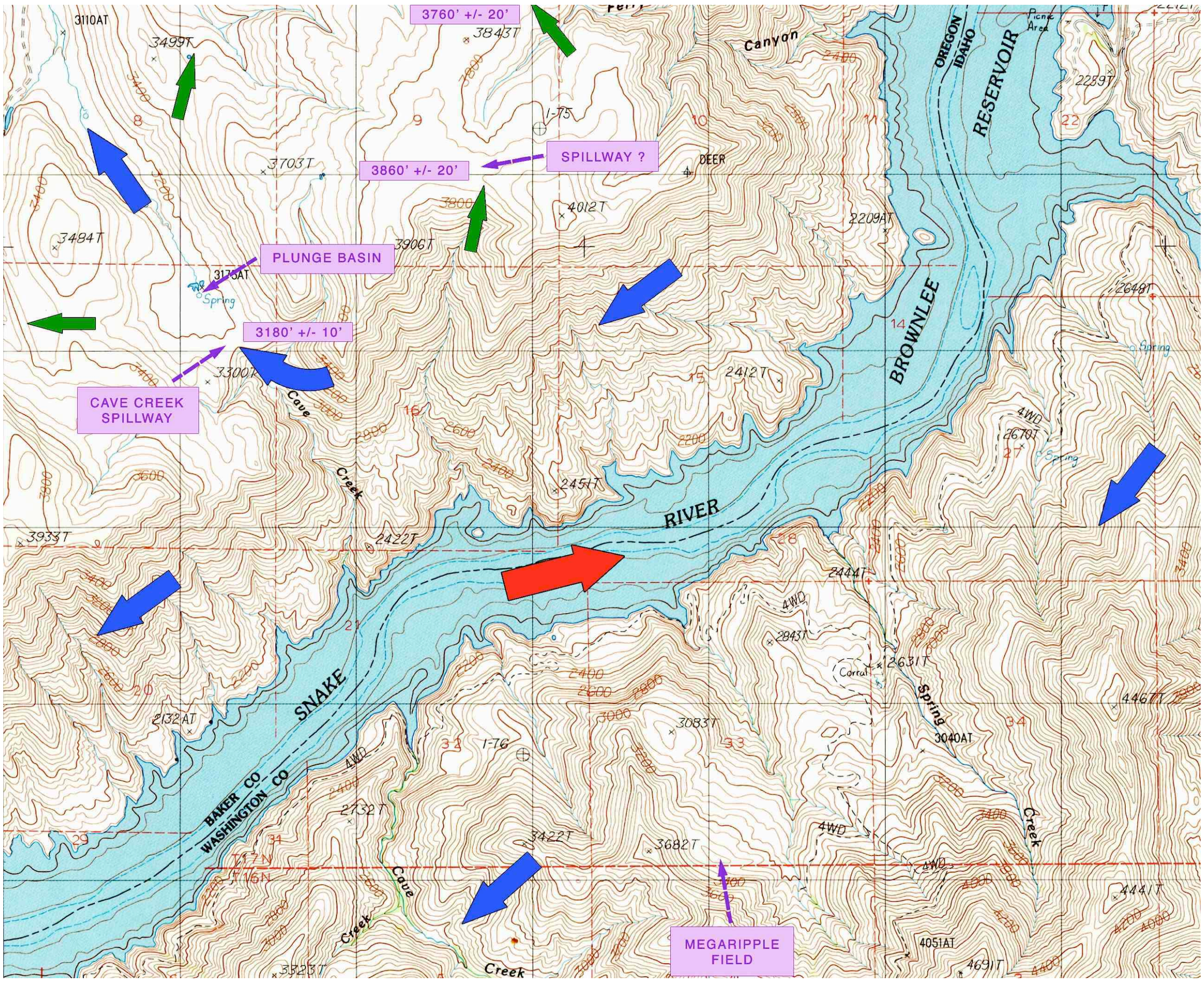

Figure 31. Lower left corner of Brownlee Dam quadrangle map showing Cave Creek and inferred spillway (sill) near curved blue arrow in center left of map. Lowest elevation of the sill lies at about 3220 +/- 10 feet (rather than the 3180 +/- 10 feet on map), which is about the same as the sill above Road Canyon (Figure 12).

Figure 32. Cave Creek looking east from sill or spillover site in Oregon and toward Brownlee Reservoir. Notice the slump or landslide scar along the right (south) side of Cave Creek canyon in lower right, an indentation (scour) in Idaho below prominent lava flows in left center, and a sloping platform (caused by flood erosion?) a few hundred feet above reservoir in center of photograph.

Figure 33. Cave Creek Sill (or Spillover) looking south, with Charles Ray and backpack for scale. Notice the possible erosion scar (?) near top left of photograph. Loose boulders and cobbles on top the sill are partly rounded by water transport (or weathering), possibly by Bonneville Flood which here would have been more than 1300 feet deep (above bottom of flood channel).

Figure 34. Cave Creek Sill looking south with Charles Ray for scale.

Figure 35. This inferred plunge basin was dammed by ranchers to contain run-off and spring water for cattle. Charles Ray on dam crest in center right for scale. Steep bank below horizon is south edge of a wide canyon (fosse?) that is indicated by upper blue arrow in Figure 31.

Figure 36. Another photograph of plunge basin(s) with Charles Ray in center right for scale. Notice the Mima mounds in upper right that are built on loose boulders of the water-eroded bedrock (lava flows) surface.

Water that surged over the sill flowed into both Posy and Pine valleys (see cataract in Figure 28). High valley walls of the fosse may be affected by faults, but they have not yet been mapped. Charles Ray mapped landslide or slump materials along the fosse's south edge that may have been triggered by earthquakes along faults.

The oldest age of the inferred sill, plunge basin, and fosse is constrained by the presence of Mazama Ash (Figure 37) mapped within a small creek's debris flows that penetrate the fosse's south edge, about a half mile from the plunge basin shown in Figures 35 and 36. The landscape features are older than Mazama Ash, which was deposited about 7,000 years ago.

Figure 37. Mazama Ash, transported initially by wind when Mount Mazama erupted about 7,000 years ago (Crater Lake fills the caldera), lies within a series of debris flows in upper part of an alluvial fan that protrudes into the fosse from the south, about a half mile southwest of the inferred plunge basin(s) shown in Figures 35 and 36. Aluminum map case and leather notebook case are on right for scale.

Conclusions

Data are convincing, but not irrefutable, that water from Bonneville Flood overtopped the Snake River Canyon's western rim, between Brownlee Dam and Powder River, and flowed into Pine, Posy, and Eagle valleys (basins) through several spillways to meet floodwater that surged up Pine Creek and Powder River. Many questions remain that will be answered by additional work (mapping and measurements).

Mima mounds are fascinating, in part because of the controversy over origins. I conclude that Mima mounds and Mima-type mounds in the region have hybrid origins. They are composed of boulder-to clay-sized sediments and many are built upon eroded bedrock and (or) boulder/cobble foundations. Parallel alignment of crests in several fields suggests water-rippled foundations. I don't doubt that most have been modified, and some even built, by burrowing animals such as pocket gophers, moles, badgers, voles, and field mice. The presence of Mima mounds in the Pine Valley region should prick our curiosity and encourage additional research. And, they might even be of interest to tourists if the story of flood, inundation, and burrowing creatures is convincing.

Like most scientific studies, first investigators generally dig shallow holes; I'll appreciate any and all input from others who will help deepen them. I invite both local residents and scientists to pick up a shovel to join us.

In the meantime, imagine rushing chocolate-brown floodwater as it carved spillways, raced down stream valleys while cutting coulees and fosses, and surged up Powder River, Pine Creek, and other creeks. Even though this inferred environmental catastrophe took place 14,500 (and maybe as long as 16,000) years ago, the relict landforms thus far mapped should prod our curiosity.

Glossary

Definitions of erosional and depositional geomorphic features (below) are based mostly on those of Bates, Robert L. and Jackson, Julia A., 1987, *Glossary of Geology* (*Third Edition*), American Geological Institute, 4220 King St., Alexandria, Virginia. The definition of Mima mound is from Johnson and Horwath Burnham, 2013, p. 2, and of Mima-type and Mima-like mounds from Johnson and Johnson, 2013, table 2, p. 138. I've added comments to further clarify definitions as they relate to specific landscape features.

Erosional Geomorphic Features (Landforms)

Abandoned Spillway: An overflow channel (can erode a coulee if flow discharge down slope is large).

Cascade*:* A waterfall. (In the Pine Valley region, cascades caused by Bonneville floodwaters, are now dry.) Cascade features include:

Cataract: (Dry waterfall that may leave a vertical, or nearly vertical precipice.) See Figure 28.

Plunge Basin: Small basin form beneath a waterfall (now dry in the Brownlee, Oxbow, and Pine Valley areas). If filled with water it is called a *plunge pool*. (Best example of a plunge basin is just west of Cave Creek Spillway, shown in Figures 35 and 36.)

Coulee: A dry or intermittent stream valley, gulch, or wash of considerable extent; especially a long, steep-walled, trench-like gorge or valley representing an abandoned overflow channel that temporarily carried melt water from an ice sheet (like the Missoula floods). (In my discussion above, this would be water caused by the spillover, at Red Rock Pass south of Pocatello, Idaho, of ancient Lake Bonneville onto Snake River Plain about 14,500 years ago.) An example is Deer Creek Coulee.

Eddy Scar: Basins, pools, and scarps caused by strong currents along edges of the main channel.

Fosse (Latin is fossa, meaning ditch): A long, narrow waterway such as a ditch, canal, or trench. (Fosses mentioned here are probable results from erosion of narrow pre-existing creek canyons by Bonneville Flood water. Best example is the wide canyon near headwaters of Cave Creek spillway and several wide canyons (stream valleys) between that spillway and Pine and Posy Valleys.

Rock-Paved Channels: Small and dry rock-paved channels that probably formed by freezing and melting of accumulated boulder and cobble deposits with subsequent removal of finer sediment, thereby leaving a rock pavement. They are apparent within Mima mound fields, particularly in the Mima mound fields near power-line road in Posy Valley.

Stream Diversion: Suspected water of the Bonneville Flood diverted lower reaches of Kirby Creek, which discharges into Hells Canyon Reservoir near Big Bar, from its former channel that flowed south into Leep Creek and now forms a waterfall entrance into Hells Canyon Reservoir.

Rock Terrace: A flat area paralleling a stream that was formed by erosion of bedrock on the edges of a pre-existing wider and more powerful stream channel, like that associated with large floods. A rock terrace can be observed on the Oregon side of Snake river in Hells Canyon between Rush and Sheep creeks that may be the result of high Bonneville Flood waters and (or) the smaller flood which occurred after the Rush Creek landslide dammed Snake River within the time interval between Bonneville Flood and eruption of Mt. Mazama.

Wind Gap: a) A shallow notch in the crest or upper part of a mountain ridge (or canyon slope). b) A former water gap (a v-shaped channel and associated gulley or canyon now abandoned by the stream that formed it). In Snake River Canyon near Oxbow several wind gaps occur which are thought to be abandoned erosional channels of Bonneville Flood. A prominent wind gap is the small pass where Idaho Highway 70 is nearest the

Oxbow Dam. The long terrace-like feature above the IPCO buildings, turbines, and Highway 70 near Oxbow is a wide wind gap through which the main channel of Bonneville Flood once flowed.)

Depositional Geomorphic Features (Landforms)

Alluvial Fan**:** A low, widespread, relatively flat to gently sloping mass (of unconsolidated sediments) shaped like an open fan, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley. (Bonneville Flood alluvial fans occur at the base of Deer Creek Coulee and where a steep cascade, or cataract, concentrated floodwater that subsequently decreased in velocity as it flowed into The Sag of Posy Valley.)

Channel (gravel, cobble, and boulder) Bar**:** An accumulation of coarse-grained gravels, cobbles, and (or) boulders that is located in the course of a stream. At Pittsburg Landing the accumulations are preserved in present-day river terraces and at Big Bar these channel deposits, at one time, must have covered the entire Bonneville Flood channel.

Eddy Bar**:** Sediment bar (generally but not necessarily built by back-flowing water).

Landslide: A general term covering a wide variety of mass-movement landforms and processes involving the down-slope transport, under gravitational influence, of soil and rock material en masse. (There are many landslide and landslide remnants along the Snake River Canyon. Good examples are at Big Bar, between Marks and Waterspout creeks, at the mouth of Rush Creek, and near the southern end of Pittsburg Landing.)

Megaripple **(Sediment Wave or Giant Current Ripple):** Defined as a current ripple mark with a wavelength greater than 30 meters (100 feet) in length. Best example is in Idaho south of Brownlee Creek (Figure 19). Volume of discharge, variability in the amount of sediment available, and interfering currents influence the size and shape of megaripples.

Mima Mound (Mi'-ma [my'-ma]): A term originally and historically used in the NW U.S., but now also elsewhere, for one of hundreds of thousands, possibly millions of low, roughly circular or elliptical domes, sometimes with flat tops, or low shield-like mounds composed of loose, unstratified often gravelly silt of loamy soil material, formed on a wide array of soil and landform types, geologic substrates, and ecological environments, from sea level to alpine tree line; basal diameters vary from 1 m to > 30 m, and heights from about 10 cm to more than 2 m. Named after Mima Prairie in western Washington state. Cf: *pimple mound. SP. Monticulo de Mima.*

Mima-Type Mound: Mounded biomantles with fixed (relatively permanent activity centers) in contrast with Mima-like Mounds that are defined as "Mounded biomantles with unfixed (impermanent) activity centers."

Ripple Mark: An undulatory surface or surface sculpture consisting of alternating subparallel ridge and hollows formed at the interface between a fluid and incoherent sedimentary material.

Sediment Wave: This feature is a current ripple of several types and can be applied to both wind-deposited features (e.g., dunes) and water-deposited features (e.g., wave forms) deposited 1) by Missoula, Bonneville and other floods (e.g., megaripple), 2) in an estuary such as at the mouth of San Francisco Bay where they are formed by tidal currents, 3) along continental and island margins, 4) within submarine canyons, 5) on deep-sea fans, and 6) even on deep sea floors where currents are strong enough to transport sediment.

Sediment Terrace: A valley-contained depositional landform, composed of unconsolidated material, which is long, narrow, relatively flat, and generally less broad than a plain. It occurs along the margin, and above, a body of water, marking a former water level.

Suggestions For Additional Reading

Malde, H.E., 1968, The Catastrophic Late Pleistocene Bonneville Flood in the Snake River Plain, Idaho: U.S. Geological Survey Professional paper 596, 62 pages.

Burnham Horwath, Jennifer L. and Johnson, Donald L., (compilers and editors), 2013, Mima Mounds: The Case for Polygenesis and Bioturbation, Special Paper 490, The Geological Society of America, Boulder Colorado, 205 pages (thoroughly reviewed in seven chapters and six appendices).

Johnson, Donald L. and Burnham Horwath, Jennifer L., 2013, Introduction: Overview of Concepts, Definitions, and Principles of Soil Mound Studies, *in* Burnham Horwath, Jennifer L. and Johnson, Donald L., (compilers and editors), 2013, Mima Mounds: The Case for Polygenesis and Bioturbation, Special Paper 490, The Geological Society of America, Boulder, CO, pages 1-20.

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and Johnson, Donald L., (compilers and editors), Mima Mounds: The Case for Polygenesis and Bioturbation, Special Paper 490, The geological society of America, Boulder, CO, pages 135-160.

O’Connor, Jim E., 1993, Hydrology, Hydraulics, and Geomorphology of the Bonneville Flood: Geological Society of America Special paper 274, Boulder, CO, 84 pages (and references therein).

Vallier, Tracy, 1998, Islands and Rapids: A Geologic Story of Hells Canyon: Confluence Press, Lewiston, ID, 151 pages (and references therein).

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