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Numerical Evaluation of Post-Flood Formation of Transverse Drainages (Water Gaps)

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Abstract

Transverse drainages (water & wind gaps) have been proposed as a criterion for determining the Flood/post-Flood boundary, but what are the limits of the conventional formation mechanisms? In this study I establish an index for comparing transverse drainages of differing depth scales. An index value near zero implies that the stream passes through the lowest divide, and is associated with plausible lake spillover or tectonic and erosional changes to the hydraulic system. An index value near one implies that the transverse drainage is hydraulically close to the same configuration as when it was carved. This index is used to select the Shoshone-Rattlesnake and Wheeler Ridge transverse drainages for modeling their formation by antecedence. Linear and logarithmic uplift models are used. The maximal depth of an antecedent or superimposed transverse drainage is determined to be around 200 ft. without enhanced erosion. Enhanced uplift rate at the end of the Flood is found to necessitate higher erosion rates, and sets a minimum catastrophe size required to generate a gap. For the Shoshone-Rattlesnake transverse drainage, the necessary erosion strongly implies a late-Flood origin, whereas for Wheeler Ridge, the required erosion is of the same order of magnitude as modeled, and could plausibly be generated in post-Flood time by antecedence.

Key Words: antecedence, Shoshone, transverse drainages, water gaps, Wheeler Ridge

Introduction

Transverse drainages (also known as water and wind gaps) are landforms that are as enigmatic as they are ubiquitous (Lee, 2019). The primary characteristic of transverse drainages is that the axis of a valley (in the case of wind gaps) or stream (in the case of water gaps) crosses the trend of a structural barrier. It was this feature of crossing pre-existing barriers which thwarted alternative uniformitarian models of the Missoula Flood at the beginning of the last century, and this same feature

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ensures research on the origin of the Grand Canyon is perpetually vigorous. There has been a resurgence in recent decades in research relating to the formation of transverse drainages by overspill of a bedrock ridge (Meek, 2019). In the past, transverse drainages were primarily explained by *antecedence*, whereby a preexisting river cuts through rising terrain, and very occasionally *superimposition*, when the river eroding through soft sediment sets its course and drapes itself across buried resistant topography (also referred to as superposition), and piracy by drainage-head erosion, regardless of the presence or absence of any applicable evidence. The cause for this was largely paradigmatic (i.e., overspill mechanisms were considered philosophically unacceptable). However, this has been changing partly due to the abundant evidence for spillover (Hilgendorf et al., 2020).

Figure 1. View of Shoshone Canyon looking West. Photo courtesy of Michael Oard.

Douglass et al. (2009) summarize the four conventionally invoked mechanisms for transverse drainage formation as well as many variants and in-between cases. They then develop a suite of criteria that can be used to help distinguish the various types. The distinguishing criterion of first importance is the relative timing between ridge uplift and stream establishment. Antecedence and superimposition require that the stream predates the uplift of the bedrock high that will eventually become the crossed range. Overspill and piracy, on the other hand, have the ridge forming before being breached. It is also noted that because superimposition implies erosion of not only the transverse drainage gorge but also a large volume of covermass over the whole area, it is expected to take significantly longer to develop a transverse drainage by this mechanism than antecedence. The authors also note that drainage-head erosion will also take a significant amount of time and that it is only applicable in special circumstances. Instead, the authors point to other variants of piracy that are more likely to occur.

Beyond the mechanisms discussed in the conventional literature, Oard (2013) has laid out numerous lines of evidence that most large-scale transverse drainages were carved during the latter half of the Genesis Flood. While obviously sharing many characteristics in common with the overspill mechanism, there are enough differences that make Flood runoff its own unique formation mechanism. Lake overspill is expected to develop at the topographic low point of the bounding basin. Flood runoff is not limited to pre-existing low points, and in some cases can be expected to form transverse drainages near the top of the ridge. Flood runoff can also produce multiple gaps simultaneously in the same range. Both of these distinguishing characteristics of Flood runoff are features shared with antecedence and superimposition in the criteria of Douglass et al. (2009).

Though the Flood is a sufficient mechanism for carving any transverse drainage, the other mechanisms remain as potential explanations, and should be considered as alternatives when interpreting the origin of any particular transverse drainage, particularly overspill and antecedence. Transverse drainages need to be analyzed individually for applicable evidences for all of the available mechanisms. Additional theoretical work to evaluate the full spectrum of formation mechanisms within the framework of Flood Geology needs to be produced. This study aims to constrain the maximal scale of transverse drainage that is possible by antecedence (and by extension, superimposition) to constrain its applicability in the post-Flood era. The applicability of post-Flood lake spillover is also briefly addressed through measurements of water gap configurations.

Transverse Drainages Examined in This Study

The Shoshone-Rattlesnake transverse drainage, commonly called Shoshone Canyon near Cody, Wyoming, cuts over 3000 ft. across the trend of Rattlesnake Mountain, which is an uplift block of Laramide age (Figure 1). The uplift is comprised of numerous well-indurated formations from the Cambrian Flathead Sandstone to the upper Cretaceous Frontier Sandstone with a granitic core. The interven-

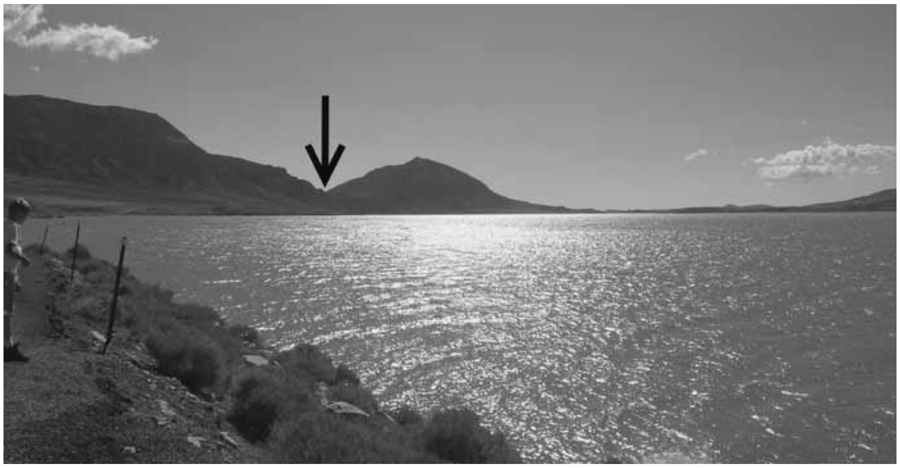

Figure 2. View of the Rattlesnake Mountains with Shoshone Canyon looking southeast. The alternate divide between the upstream and downstream basins is at lake level in the center-right. Photo courtesy of Michael Oard.

ing formations run the gamut from mudstone, shale, and sandstone to limestone and dolomite. The canyon has been cut without regard to the inherent strength of the underlying rocks (Johnson, 1934). Despite the great depth of the gorge through which the Shoshone River runs, there is essentially no divide separating the reaches above and below the canyon because the mountain range ends only three miles to the south. When the dam for Buffalo Bill Reservoir was built inside the gorge, a secondary dam also had to be built along the southern end of the reservoir (Figure 2) to prevent it from spilling around the edge of the range (Oard, 2018).

The Wheeler Ridge transverse drainage addressed in this study is a recently defeated wind gap through Wheeler Ridge through which the California Aqueduct flows south of Bakersfield, California (Figure 3). A water gap with a stream flowing through it is defeated when tectonic uplift forces the stream to abandon the water gap and flow through a lower-elevation alternate route, leaving a wind gap behind. Wheeler Ridge also has a smaller, presently active water gap, and a creek flowing around the

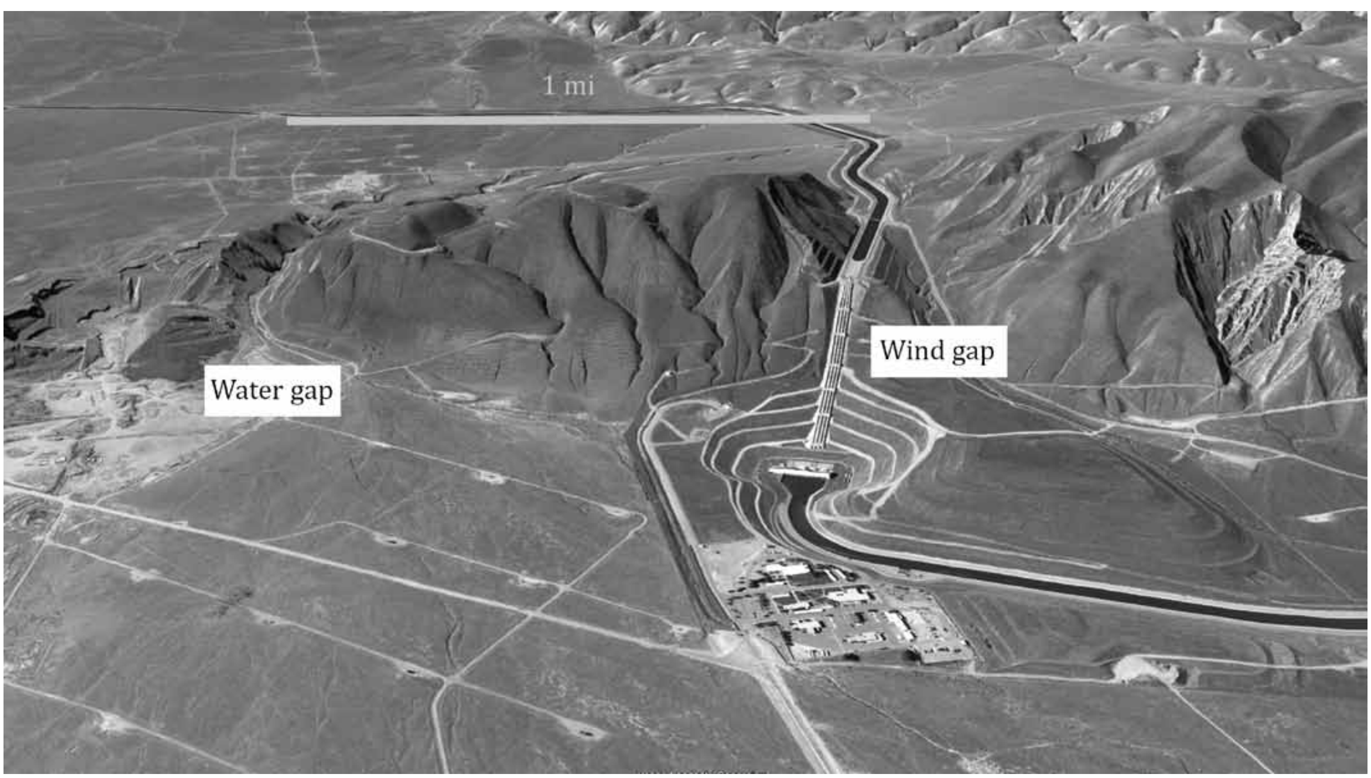

Figure 3. Oblique view of Wheeler Ridge looking south. Image credit: Google, Landsat/Copernicus.

eastern nose of the ridge which may cause the abandonment of the current water gap. Wheeler Ridge is an actively deforming fault-bend fold developed from a series of blind thrusts that are migrating laterally eastward (Mueller and Talling, 1997). Wheeler Ridge is located on the "Big Bend" segment of the San Andreas fault where it trends more east-west, whereas the large-scale trend of the overall fault is southeast-northwest. Shortening associated with Pacific plate movement is accommodated on minor thrust fault systems like the Pleito-Wheeler Ridge thrust fault system, while the main San Andreas fault remains largely strike-slip. Wheeler Ridge is composed of Pliocene to Pleistocene gravel, sand, and clay of the Tulare Formation which is locally up to 1960 ft. thick. The Tulare Formation is unconsolidated, and is sourced from the San Emigdio Mountains to the south. Distinct terrace levels with eastward decreasing dissection by gullies indicate that the fold is progressively migrating eastwards (Keller et al., 1998).

Both of the examined transverse drainages are conventionally considered to have been carved by antecedence.

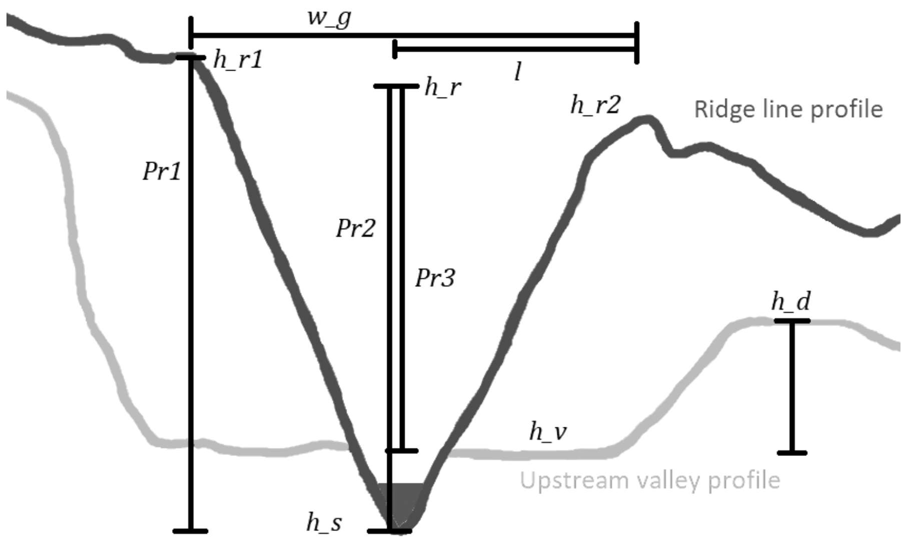

Figure 4. Schematic transverse drainage showing features and points of measurement.

Erosion Rate Model

Given the central role of erosion rate in the formation of transverse drainages, it is important to establish an erosional model that will apply to the post-Flood conditions evaluated in this study. Several authors have made models of erosion rate based on the stream power equation (Rosenbloom and Anderson, 1994; Stock and Montgomery, 1999; Snyder et al., 2000), with calibration points selected based on the age dating of events in the distant past. The model implemented as part of this study, however, was that of Whipple et al. (2000) which provides an empirically derived erosion model based on measurements of the Upper Ukak River in the Valley of Ten Thousand Smokes, Alaska. The 1912 eruption of Novarupta buried the old Upper Ukak river pathway in ash, forcing the establishment of a new channel where there had previously been none. The new channel eroded into bedrock with some loose ash covering. Vegetation was largely disrupted by ash covering in the area as well. These conditions are well analogous to those expected in the aftermath of the Flood. Whipple et al. (2000) measured thalweg depth (i.e., the deepest portion of the stream crossing the ridge) from this known starting condition in 1997 covering 85 years of erosion, and their erosion rates were derived by fitting a model directly to the observations without any timing or old-age boundary assumptions.

Methods

Transverse drainage index and measurements

To facilitate direct comparison of transverse drainages in different geological contexts, I define a standard set of measurements and metrics that are broadly applicable to all transverse drainage scales. The typical features of a transverse drainage are shown in Figure 4. Transverse drainages comprise at minimum a ridge line with an eroded gorge transverse to the trend of the ridge. On the upstream side, there is typically a broad valley with a generally defined base level. The stream may be incised below the elevation of the valley in an inner gorge.

First, we define the ridge line path to be composed of line segments which connect adjacent local high points along the ridge line while being generally aligned with the overall ridge line trend. Then, let h_{r1}, h_{r2} be the elevation of the high points immediately adjacent to the transverse drainage on either side of the stream with $h_{r1} \geq h_{r2}$. Additionally, let h_s be the elevation of the stream as it crosses the ridge line path, and l be the map projected distance from h_{r2} to the stream along the ridge line path. Finally, let the gap width, w_g, be the map projected distance between h_{r1} and h_{r2}. The elevation of the upstream valley above the inner gorge shall be denoted h_v, and the elevation of the alternate divide between the upstream and downstream valleys shall be denoted h_d.

Given the above measurements, we may determine the interpolated height of the ridge line at the location of the transverse drainage as

$$h_r = h_{r2} + \frac{l}{w_g}(h_{r1} - h_{r2}).$$

We may also define three prominence measures for transverse drainages, $\mathrm{Pr}_1 \geq \mathrm{Pr}_2 \geq \mathrm{Pr}_3$. The first prominence metric is the difference in elevation between the highest adjacent ridge point and the stream elevation. The second is the difference between the interpolated ridge line height and the stream elevation. The third is the difference between the interpolated ridge line height and the upstream valley elevation. According to the terminology established above, these can be written as:

$$\begin{aligned} \mathrm{Pr}_1 &= h_{r1} - h_{s,} \\ \mathrm{Pr}_2 &= h_r - h_{s,} \\ \mathrm{Pr}_3 &= h_r - h_v. \end{aligned}$$

The above measurements allow direct comparison between different transverse drainages based on their overall size—very useful in its own right. We can also use these measurements to categorize and compare transverse drainages independently of absolute size by comparing the height of the transverse drainage achieved compared to the height of the alternate divide. This dimensionless index is defined as

$$k = 1 - \frac{\max\{h_d - h_v, 0\}}{\mathrm{Pr}_3}.$$

The transverse drainage k index provides a measure of the significance of the transverse drainage in its overall hydraulic system context. When the transverse drainage cuts through the ridge line at the lowest overall upstream basin outlet elevation (meaning there are no other likely lower elevation passes for a stream to pass through), the index is 0. However, when the alternate divide is at the same elevation or lower than the bottom of the upstream valley, the index is 1. Examples of both of these extremes are shown in Figure 5. The index is a measure of the incongruence of the transverse drainage to the "natural" or pre-existing drainage pathways, and can be used to gain insight into the most probable geological history and formation mechanisms (described below).

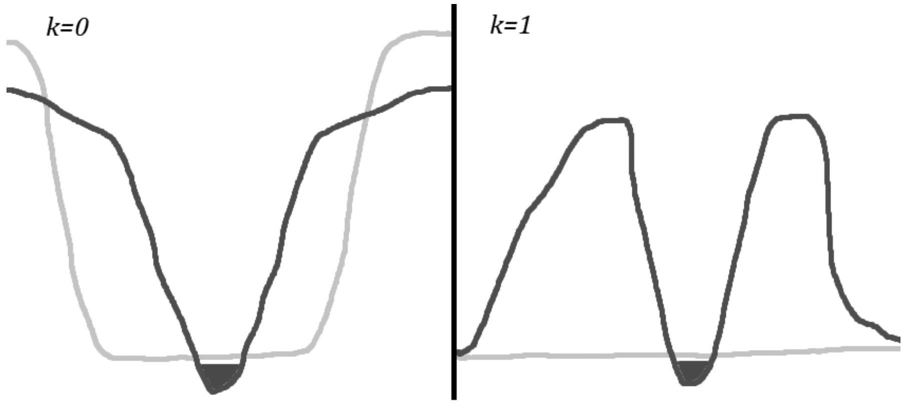

Figure 5. Schematic examples of an index 0 transverse drainage (left) and an index 1 transverse drainage (right).

Logarithmic uplift model

I will use two simplified models of mountain uplift to compare with erosion for the formation of transverse drainages. The first is a linear model where all of the uplift occurs at a constant rate from the time of the end of the Flood to reach the current modern height at present. In both models, the ridge is at the same height as the river with the river crossing the incipient ridge immediately at the end of the Flood, then reaching its modern height at the present. The linear uplift model, of course, implies continuing rapid uplift, which generally is not the case for most mountain ridges at the rates implied. The modern uplift rate does not impact the model results. Tectonic events are well-known to occur in discontinuous jumps followed by periods of quiescence. If these jumps occur, then the behavior of the real system may diverge from these models. Generally, a system with discontinuous jumps will decrease its ability to form transverse drainages by antecedence. For the sake of these models, we will assume tectonic events are frequent and do not deviate far from the long-term trend.

The second model is logarithmic, which shifts the majority of uplift into the past, and most closely adheres to the intent behind the descriptive phrase, "exponentially decreasing tectonic activity" in the post-Flood era (Austin et al., 1996). With $t = 0$ being the end of the Flood with time progressing forward to the present day, the ridge uplift is given by:

$$y(t) = a\ln(bt + 1).$$

The parameter b is free, and controls both the slope of the uplift at present (which likewise must be greater than 0) and the amount of uplift accomplished near the beginning of the time interval. For this paper, b is arbitrarily set so that 50% of the total uplift is accomplished by 500 years. The parameter a is solved by specifying the initial value conditions $y(0) = 0$, and $y(T) = h_r$ with T being the present day. The result is:

$$a = \frac{h_r}{\ln(bT + 1)}.$$

The "working time," t', represents the amount of time before the incipient transverse drainage thalweg rises to the height of the alternate divide, taking into account both the uplift rate and erosion rate over time as well as the total time available from the beginning of the time interval. As soon as water begins to flow through the alternate divide, then the transverse drainage will be abandoned and form a wind gap. If the ridge elevation rises, but does not cause the stream to divert through the alternate divide, then the stream would be expected to pond on the upstream side. For the transverse drainage carving to be successful, the stream must erode the entire elevation of the ridge in less time than the working time. The governing equation is

$$h_d = y(t') - ct',$$

where c is the modeled erosion (cutting) rate. For the logarithmic uplift model, the working time solution is:

$$t' = \frac{-ab\mathrm{W}_0\left(\frac{-ce^{(h_d - c/b)}}{abe^a}\right) - c}{bc},$$

where W_0 is Lambert's W function, principal branch (also known as the product log function).

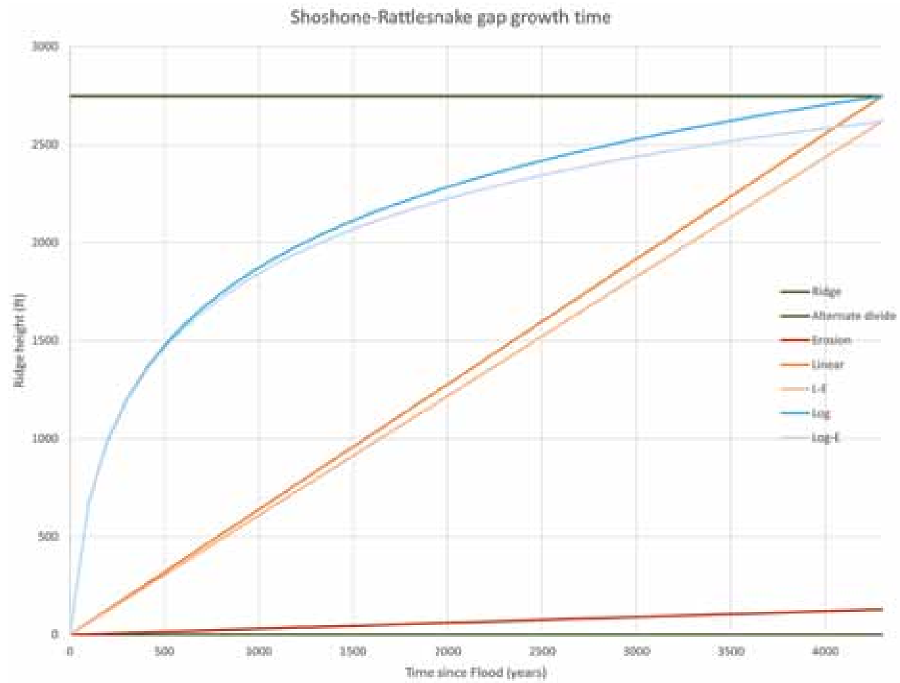

Figure 6. Uplift and erosion model of the Shoshone-Rattlesnake transverse drainage with baseline erosion rate.

Description of system model

For this study, measurements of the Shoshone-Rattlesnake water gap and Wheeler Ridge wind gap were taken using Google Earth Pro to determine the k index, and prominence measures Pr_2 and Pr_3. The overall time at the end of the Flood was taken to be 4300 years before present. Both transverse drainages were chosen because their k indexes were 1. For each transverse drainage, three erosion rates were determined according to the strong, weak, and totals models of Whipple et al. (2000). The first examination was to compare the expected incision from the available total time and modeled erosion rates in comparison to the overall transverse drainage height (Pr_2 from ridge to stream). Then the time required to erode the inner gorge is calculated and subtracted from T to provide a maximal constraint to working time. The working time is then calculated for both tectonic models to provide a maximal transverse drainage depth that is achievable. Finally, erosion rates are adjusted until the transverse drainage can be eroded within the given constraints. For each transverse drainage, the erosion and uplift rates are analyzed graphically.

Discussion

Transverse drainages are amongst the youngest landforms since they cut mountains, which themselves are universally geologically young (Ollier and Pain, 2000). Nevertheless, the hydraulic system of any transverse drainage can have been altered since the time that it was first eroded. Two possibilities for this include uplift/subsidence or erosion of the region of the alternate divide. Because it depends on the ratios of the transverse drainage depth and the height of the alternate divide, the index also provides a measure of how likely it was in the past for the transverse drainage ridge and the alternate divide to have traded roles.

Table I. Measured parameters and calculated erosion rates for the two transverse drainages.

Parameter	Shoshone-Rattlesnake	Wheeler Ridge
Pr_2 (ft)	2949	481
Pr_3 (ft)	2747	463
Index	1	1
Alternate divide (ft)	0	0
Gorge depth (ft)	202	18
Slope (ft/mi)	73.4	244
Width (ft)	114	490
Erosion rate – resistant (ft/yr)	$3.00 \cdot 10^{-2}$	$2.71 \cdot 10^{-2}$
Erosion rate – weak (ft/yr)	$3.53 \cdot 10^{-2}$	$3.02 \cdot 10^{-2}$
Erosion rate – total (ft/yr)	$5.09 \cdot 10^{-2}$	$4.59 \cdot 10^{-2}$

When the index is near zero, the ridge and alternate divide are close to the same elevation and either could have been the lowest point depending on the tectonic and erosive history of the system. Conversely, when the index is high, then the elevation of the ridge and alternate divide are significantly different, and it is unlikely that the ridge was ever lower than the alternate divide absent a compelling geological case. For this reason, transverse drainages with indexes near 1 (as the two selected ones do) justify applying this particular formation model.

It is also worth noting the relationship between the index and transverse drainages formed by lake overspill. A lake will always overtop its lowest barrier, so in this case, the ridge and alternate divide are the same point and the same elevation. This will cause its index to be 0. Further modification of the overall system may occur, changing the index value, but any transverse drainage plausibly carved by lake overspill should have a low index value. This constraint does not apply to Flood overspill formation. Neither of the transverse drainages considered here has evidence of impounded lakes on their upstream sides, and neither has a geometry that is favorable for impounding a lake or deep sediment. The index of the Grand Canyon is also 1, as the upstream valley elevation (represented by Cape Solitude) is higher than multiple alternate divides.

Table I shows the measured values and modeled erosion rates for both the Shoshone-Rattlesnake water gap and Wheeler Ridge wind gap. A value for each of the modeled erosion trends given in Whipple et al. (2000) is calculated for both transverse drainages, though in the case of the Shoshone-Rattlesnake the rock is resistant, and in the case of Wheeler Ridge, the rock is weak. In all three cases, the modeled erosion rates are remarkably similar between the two transverse drainages. The erosion rates according to the total erosion model are among the highest seen in an informal survey of around a dozen North American transverse drainages (not otherwise here reported on) and so provide a case for the maximal scale of transverse drainages formed by antecedence in the post-Flood period at around 220 ft. This was calculated by assuming continuous erosion at the rate of the fit Shoshone-Rattlesnake total erosion rate over 4300 years. In neither case can erosion successfully cut the observed depth, though in the case of the Wheeler Ridge wind gap, the maximal depth is the same order of magnitude as the total gap depth. So, for any transverse drainage greater than 220 ft. deep from ridge line to gorge to form in the post-Flood period by antecedence (or superimposition), significantly enhanced erosion is required.

Figure 6 shows the modeled uplift and erosion history of the Shoshone-Rattlesnake gap with the resistant rock erosion rate from the Whipple et al. (2000) model. The height of the ridge line and the height of the alternate divide are shown as horizontal green lines with the alternate divide below at zero height. Since both of these gaps have indexes of 1, the alternate divide line is sitting on top of the horizontal (time) axis. The red erosion trend shows the total amount of downcutting that has occurred since the beginning of the simulation. The saturated blue curve shows the logarithmic uplift model for the ridge line height. The saturated orange line is the linear uplift model. The less saturated curves of both colors are the uplift with the erosion subtracted, representing the height of the stream thalweg at any given time. The point at which the less saturated curves cross the alternate divide height defines the working time for that uplift model. In this case, the working time is zero for both. For the carving of the transverse drainage by antecedence to be successful, the erosion line must reach the ridge line height before the uplift minus erosion line reaches the alternate divide height. With the modeled erosion rate, the stream would make very little progress overall in the erosion of the gorge. In both the linear and logarithmic uplift cases, it would not even get the chance, as any uplift at all would send the stream around the ridge through the alternate divide. Because the alternate divide is at 0 ft., the only possible scenario for successful transverse drainage generation is for the erosion to completely out-pace the uplift.

Figure 7 shows the same system but with the erosion rate enhanced sufficiently to carve the gap with the linear uplift model. This requires boosting the erosion rate by a factor of 22.9. The red erosion line now comfortably reaches the ridge line height. This intersection occurs slightly before the present time. The difference represents the time required to erode the inner gorge at the modeled erosion rate. Any lower erosion rate would have insufficient time to erode both the gap and the inner gorge by the present day. As the erosion line is rotated upwards (counter-clockwise from the origin), the uplift minus erosion lines are rotated downwards. Now that the erosion rate outstrips the linear uplift rate, the linear uplift minus erosion line is entirely negative and does not cross the alternate divide height at any time. This negative height is slightly unphysical, as the base level of the system is at zero height, and the stream would tend to maintain that level as long as it could sufficiently erode any uplift that was occurring. That aspect of the system is out of the scope of the model. All that is required is to show that the uplift rate never overwhelms the gorge erosion rate. In this case, the logarithmic minus erosion line curves downwards, but it still crosses the alternate divide height.

Figure 8 shows the same system with the erosion rate boosted from the baseline sufficiently to cause a successful transverse drainage cutting with the logarithmic uplift model. The erosion required for this is 410 times that which the slope and channel width would otherwise indicate. At this rate, the entire height of the gap would be carved

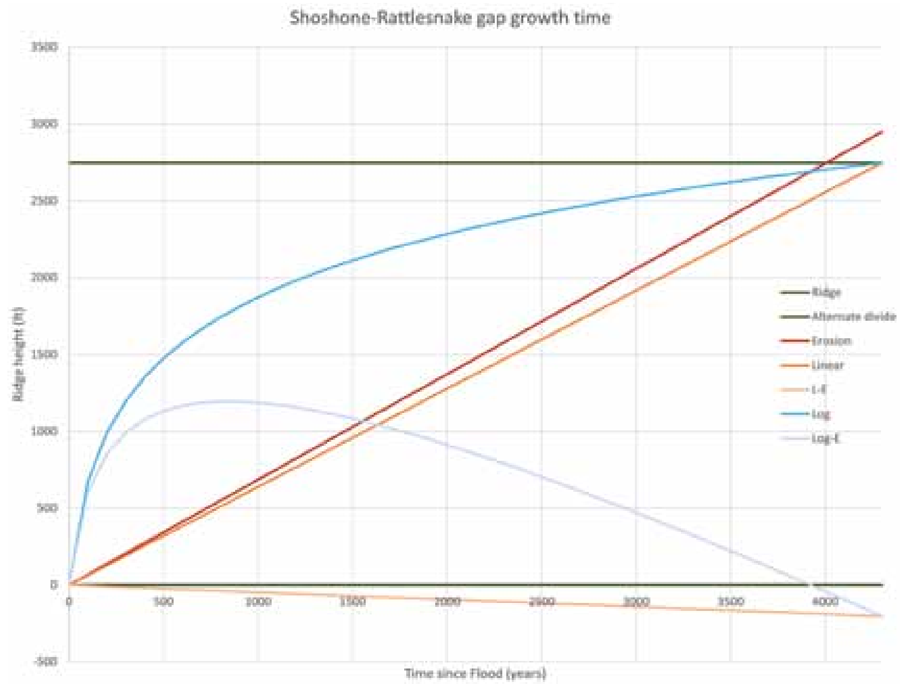

Figure 7. Uplift and erosion model of the Shoshone-Rattlesnake transverse drainage with erosion rate enhanced by a factor of 22.9.

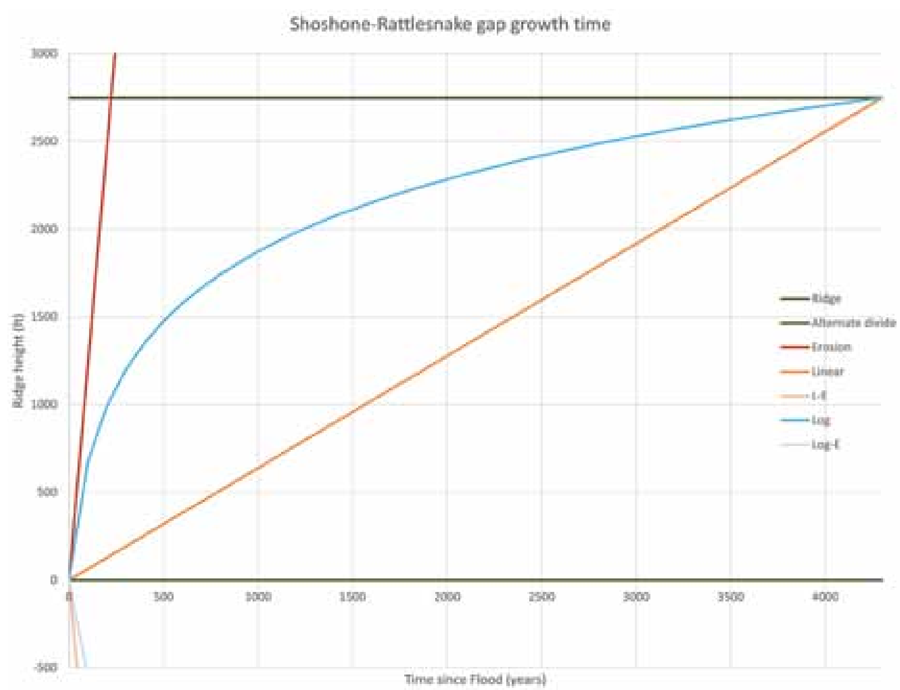

Figure 8. Uplift and erosion model of the Shoshone-Rattlesnake transverse drainage with erosion rate enhanced by a factor of 410.

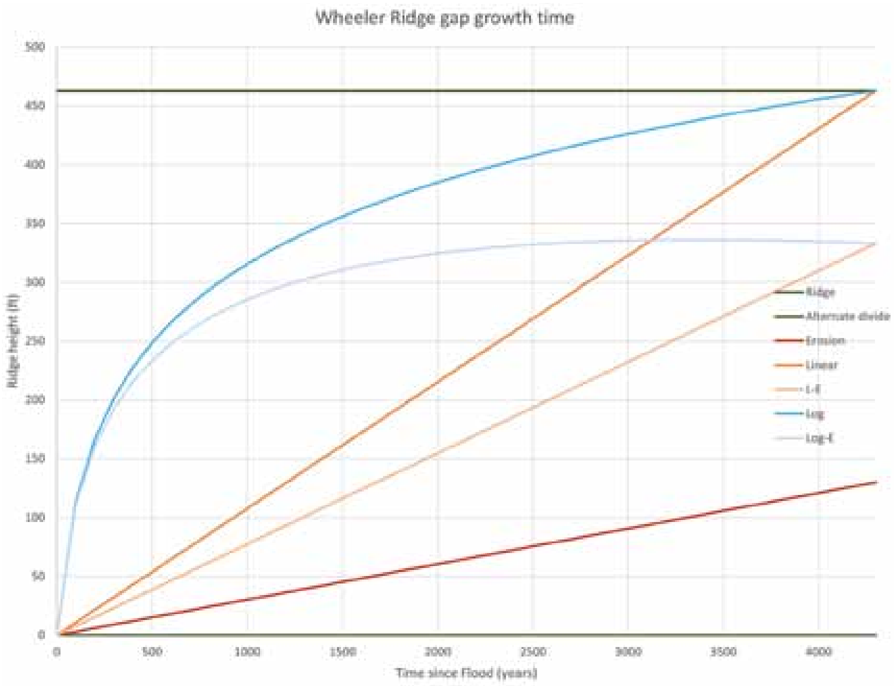

Figure 9. Uplift and erosion model of the Wheeler Ridge wind gap with baseline erosion rate.

Figure 10. Uplift and erosion model of the Wheeler Ridge wind gap with erosion rate boosted 3.6 times.

in just over 200 years. Even with this remarkably high average erosion rate, discontinuous jumps of uplift, which are concentrated during the same early time frame would be likely to disrupt gap carving, since there is no barrier of any height preventing the stream from reorganizing around the ridge line.

It is also exceedingly difficult to devise a cause for the extreme erosion rate of over 12 ft. per year on average. The erosion rates from Whipple et al. (2000) are already measured on a denuded terrain with unconsolidated ash cover. This rate would necessitate repeated large-magnitude catastrophes. These would manifest as discontinuous outbursts over time. In the intervening time, uplift along the ridge is likely to have occurred, which would divert future outbursts smaller than a certain scale around the ridge. A more plausible scenario is for a single catastrophe large enough to carve the entirety of the water gap in a single episode. The minimum magnitude of such a catastrophe (water surface elevation of at least 7800 ft. ASL) is large enough to imply flooding on a continental scale. It should be clear then that the required catastrophe is identical to the Global Flood. Even the relatively more modest erosion rate associated with the linear uplift model would be difficult to justify given the geological context of the Shoshone-Rattlesnake transverse drainage.

The Wheeler Ridge wind gap, given its smaller magnitude, weaker rock composition, and formation dynamics offers another situation for an otherwise similar transverse drainage. Figure 9 shows the dynamics of the Wheeler Ridge wind gap with the baseline weak rock erosion rate from Whipple et al. (2000). Similarly, to the Shoshone-Rattlesnake gap above, this rate is insufficient to successfully carve the gap by antecedence in the time since the Genesis Flood. Figure 10 is the same system with sufficient erosion rate to carve the transverse drainage with the linear uplift model. In this case, the boost to the average erosion rate is a modest 3.6 times the modeled rate. Unlike the Shoshone-Rattlesnake case, this erosion rate is potentially justifiable by enhanced erosion in the post-Flood period, though I don't identify any specific mechanisms based on local evidence to arrive at a concrete expected erosion rate in this study.

Figure 11 shows the Wheeler Ridge wind gap system with sufficient erosion rate to overcome uplift associated with the logarithmic model. The boost, at 68.6 times is greater than that required for the linear uplift at the Shoshone-Rattlesnake transverse drainage, but not at the astronomically high erosion rate required by the equivalent logarithmic model. Nevertheless, it is likely outside the realm of easy justification. However, given Wheeler Ridge's relationship to the actively deforming San Andreas fault system, the linear uplift model for Wheeler Ridge is likely defensible, and so the lower required erosion rate can be justified.

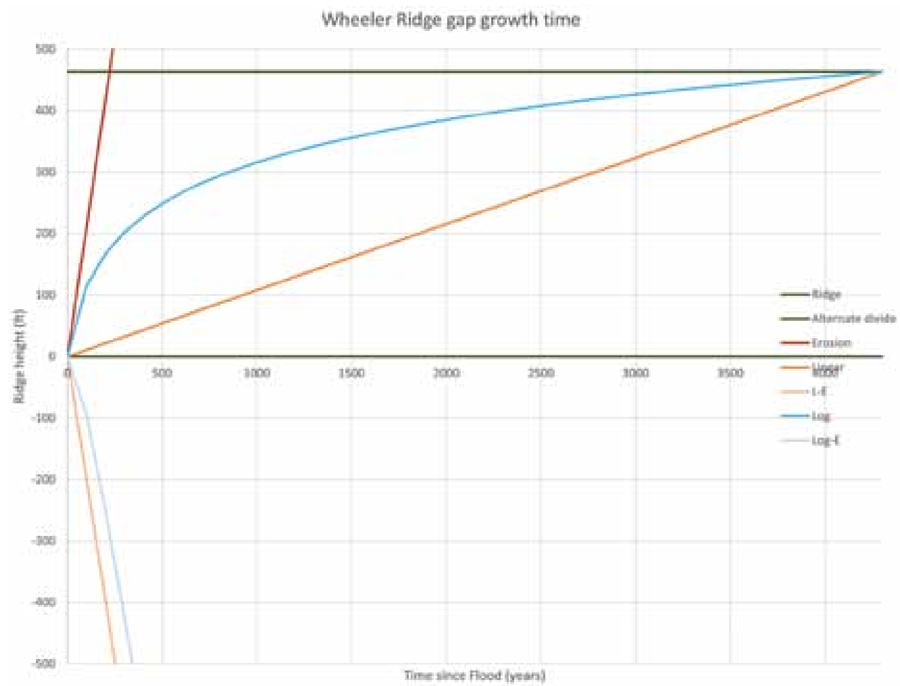

Figure 11. Uplift and erosion model of the Wheeler Ridge wind gap with erosion rate boosted 68.6 times.

The methodologies demonstrated above in addition to the criteria laid out in Douglass et al. (2009) are useful for distinguishing among the various formation mechanisms for transverse drainages and have been proved useful for distinguishing Flood-carved vs. post-Flood water gaps. In general, if the required erosion rate is more than an order of magnitude larger than the maximal measured erosion rates, then the generation of such transverse drainages can confidently be placed during the waning stage of the Flood. This applies to any transverse drainages 2200 ft. or deeper. For transverse drainages less than 220 ft. deep, a post-Flood origin is eminently reasonable. The in-between cases are potentially ambiguous, and the tools laid out in this paper can aid in deciding or identifying the necessary pathways for achieving transverse drainage generation. For these in-between cases, an elevated long-term erosion rate should be supported by local evidence and modeling of the conditions. Possible mechanisms for enhanced erosion can include mass wasting from unconsolidated or denuded ridges, or frequent upstream flooding events. The specific mechanisms invoked in each case should be shown to produce the required scale of erosion.

Declining catastrophic tectonism and erosion in the early post-Flood period, while generally accepted as a means of generating mesoscale and smaller landforms and features, tends to work against transverse drainage formation by catastrophes smaller than a minimum threshold.

Conclusion

Modeling uplift and erosion can aid in the identification of formation mechanisms for individual transverse drainages in addition to the other criteria that have been developed. Post-Flood erosion can only account for relatively small transverse drainages in post-Flood time by antecedence or superimposition. Erosion rates within an order of magnitude of those that have been observed are potentially justifiable given the conditions in the immediate post-Flood period with possible post-Flood catastrophism. However, hypothetical erosion rates more than an order of magnitude higher should be justified by particular evidence of a more energetic catastrophic process. In the case of the Shoshone-Rattlesnake transverse drainage, neither repeated large catastrophes nor lake overspill can be supported by the evidence, and antecedence is implausible as a mechanism. The only remaining plausible mechanism is runoff from the Genesis Flood. This is true of many large-scale transverse drainages, justifying its applicability as a Receding Stage of the Flood criterion. Rapid tectonic change following the Flood increases the required catastrophism of the erosive mechanism, and so decreases the likelihood that a particular gap can be carved by antecedence. The Wheeler Ridge wind gap and other small-scale transverse drainages cut through unconsolidated sediment and presently active tectonics may be generated in the post-Flood era by antecedence if the required enhanced erosion rates can be supported by the local evidence. The transverse drainage index is useful to compare gaps of multiple scales and can help inform whether or not a gap has been created by overspill. The index should be measured and used in future transverse drainage studies.

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