



PROBABLE DEEP EROSION BY CONTINENTAL ICE SHEET MELT WATER FLOODS: CHALK BUTTES AREA OF CARTER COUNTY, MONTANA, USA

 Eric Clausen¹

¹Independent Researcher, 100 West Ave D-17, Jenkintown, PA, USA
Email: eric2clausen@gmail.com



ABSTRACT

Article History

Received: 5 March 2018
Revised: 26 March 2018
Accepted: 28 March 2018
Published: 30 March 2018

Keywords

Asymmetric drainage divide
Barbed tributary
Boxelder Creek
Drainage divide
Ekalaka Hills
Little Missouri River
Powder River.

Topographic maps are used to determine erosional landform origins along the Little Missouri River-Powder River drainage divide in the Chalk Buttes areas of Carter County, Montana. Asymmetric drainage divides, drainage divide gaps, and isolated erosional remnants are used to determine a sequence of erosion events beginning with headward erosion of northeast-oriented Little Missouri River tributary valleys and ending with headward erosion of the deeper north-northeast and north-northwest oriented Powder River valley. Gaps notched into present day drainage divides and orientations of valley heads on either side of those gaps suggest many closely spaced southeast-oriented streams flowed across the region immediately prior to being captured by headward erosion of deeper north-oriented valleys. Buttes capped by horizontal Miocene Arikaree sandstones stand 500 feet (152 meters) or more above surrounding Little Missouri River tributary drainage basin elevations while the Powder River valley floor elevation is as much as 800 feet (244 meters) below those surrounding elevations. A water source could not be determined from the map evidence, however the study area is located to the south and west of a known continental ice sheet margin and large southeast-oriented ice-marginal melt water floods should have logically crossed the region.

Contribution/Originality: This study documents how large volumes of southeast-oriented water of probable continental ice sheet melt water origin deeply eroded the Chalk Buttes area of Carter County in southeast Montana and suggests that at least one continental ice sheet deeply eroded the North American continent.

1. INTRODUCTION

How a specific erosional landform originated is a question the current geomorphology literature seldom addresses, yet an answer may be essential if a region's landscape evolution is to be properly understood. Bishop (2007) reports research in long-term "landscape evolution...slowed considerably in the mid-20th century, when Davisian and other approaches to geomorphology were replaced by functional, morphometric and ultimately process-based approaches." Bishop goes to say dissatisfaction with the previous approaches "was embodied in [the] Strahler (1952) call for radical change and the embracing of a new approach and underpinning concepts...[which] is now being heard in long-term landscape evolution as geomorphology embraces quantitative and geochemical analytical approaches to the sorts of questions that Davis sought to address." Yet, search the recent geomorphology literature for papers describing how most specific erosional landforms originated and you will probably end up

empty handed. For some reason geomorphologists are not publishing papers in which quantitative and geochemical approaches to landscape evolution are explaining in detail how specific erosional landform features originated.

Many questions geomorphologists using the previous research approaches could not answer are still not answered. For example, water in several north-oriented Missouri River tributaries makes a U-turn to flow in a south direction to eventually reach the Gulf of Mexico (see figure 1). Early investigators (e.g. (Warren, 1869; Todd, 1914; Alden, 1932)) interpreted these north-oriented Missouri River tributaries and abandoned northern extensions of their valleys to be components of a pre-glacial drainage system that once flowed to the Hudson Bay area and then to the Labrador Sea. Such workers interpreted the Missouri River (M in figure 1) to have formed when a continental ice sheet blocked north-oriented drainage routes and forced water to flow along the ice sheet's margin. But, various investigators who tried to determine when these north-oriented Missouri River tributaries developed never reached any consensus. Bauer (1915) suggested north-oriented drainage routes extended their routes headward from the Hudson Bay area to and across the Great Plains when the late Cretaceous sea withdrew and he attributed deposition of early Tertiary sediments to these rivers. Howard (1958) considered Bauer's early Tertiary drainage history speculative, but noted Alden (1932) had described fluvial gravel of possible Oligocene or Miocene age on the divide west of the Yellowstone River (Y) and now 1200-1300 feet (366-396 meters) above the Yellowstone valley floor. (Mackin (1937) suggested this alluvium might be younger). Howard (1958) named the alluvium as the Rimroad Gravel and observed, "There is no factual evidence bearing on the drainage prior to Oligocene or Miocene time. In Oligocene or Miocene (?) time, however, a river presumably flowed northeastward across the area in a path immediately to the west of, and 1200-1300 feet (366/-396 meters) higher than the present floor of the Yellowstone Valley.... Rejuvenation, resulting from uplift, climatic change or both, resulted in a reversal of topography in Miocene-Pliocene time."

More recently the north-oriented Missouri River tributary valleys have been described as components of the pre-glacial Bell River system that drained much of central Canada to the Hudson Bay area and then through the Hudson Straits to the Labrador Sea ((McMillan, 1973; Duk-Rodkin and Hughes, 1994)). Even more recently Sears (2013) suggested a possible late Oligocene-Miocene "super-river" flowed from the Grand Canyon area in the southwestern United States to southwest Montana and then to the Labrador Sea.

The Bell River valley system pre-glacial age has been determined by the presence of glacial sediments in abandoned valley segments located to the north and east of the present day Missouri River and also by the presence of Tertiary sediments found in or near some of the north-oriented Missouri River tributary and headwaters valleys and has been rarely challenged. One of the few challenges came from White (1972;1988) who when proposing his deep erosion by continental ice sheets hypothesis observed the reported failure of continental ice sheets to completely destroy the pre-glacial valleys, especially in easily eroded bedrock, defied common sense logic. White's deep erosion by continental ice sheets hypothesis received strong criticism from Gravenor (1975); Sugden (1976) and others who used various lines of evidence, including the pre-glacial Bell River valley system age, to overwhelmingly reject Whites's hypothesis.

Overwhelming rejection of White's hypothesis killed future research efforts related to the deep erosion by continental ice sheets hypothesis, although none of White's critics ever explained why or how continental ice sheets and melt water from those ice sheets did not completely destroy all evidence of the pre-glacial Bell River system valleys, especially in the easily eroded northern Great Plains bedrock. Puzzled by this apparent contradiction and other anomalous evidence including the presence of large glacial erratic boulders that can be found in North and South Dakota and eastern Montana as much as 100 kilometers (62 miles) to the south and west of the present day Missouri River the author of this paper began what ultimately became his Missouri River drainage basin landform origins research project, which consisted of systematically studying detailed United States Geologic Survey (USGS) topographic maps of the entire Missouri River drainage basin and adjacent drainage basins to determine how major drainage divides within and surrounding the large and complex Missouri River drainage basin originated. Drainage

divide origins were determined by using divide crossings (through valleys, wind gaps, etc.) as evidence of previous drainage routes and then using barbed tributaries, elbows of capture, asymmetric drainage divides, abandoned headcuts, and similar evidence to determine how thousands of capture events altered earlier drainage routes so as to produce present day Missouri River drainage basin drainage routes.

The multi-year Missouri River drainage basin landform origins research project results strongly suggested north- and northeast-oriented Missouri River tributary and headwaters valleys eroded headward from space being opened up at the south end of a melting continental ice sheet, an ice sheet which had created and occupied a deep “hole”. The deep “hole” had been created not only by deep continental ice sheet erosion, as White suggested, but also by ice sheet related crustal warping that occurred as large melt water floods flowed across the developing deep “hole’s” rim. Project results further suggested supra-glacial melt water rivers sliced ice-walled and bedrock-floored canyons into the thick ice sheet surface and systematically captured southeast-oriented melt water floods that were flowing at much higher elevations along the ice sheet’s southwest margin so as to divert those floodwaters in north and northeast directions onto and then across the deep “hole’s” floor and eventually to the North Atlantic Ocean. This diversion of southeast-oriented melt water floods, by the systematic headward erosion of north- and northeast-oriented valleys from space being opened up as the ice sheet melted, probably triggered a major climatic change that ended ice sheet melting and formed a much thinner continental ice sheet consisting of frozen melt water flood water surrounding thick ice sheet remnants. Unpublished Missouri River drainage basin landform origins research project essays (or research notes) are found in blog format at the geomorphologyresearch.com website and papers such as this one (e.g. Clausen (2017a;2017b)) are being submitted for publication.

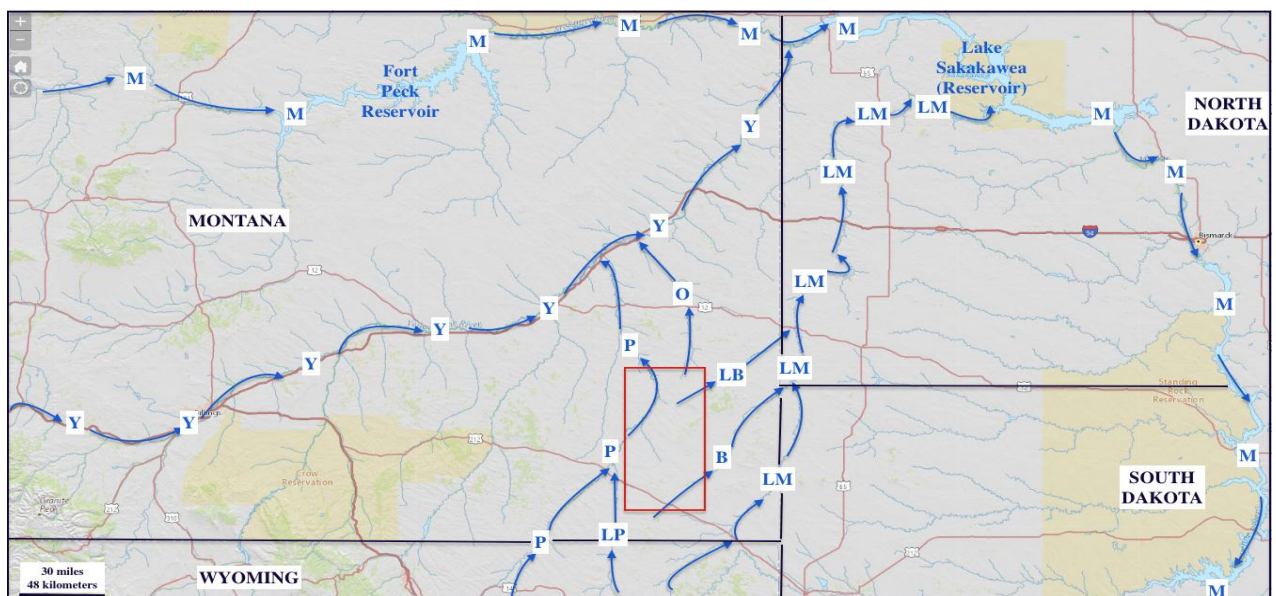


Figure-1. Map showing the study region (red rectangle) location near the Montana southeast corner. Blue arrows emphasize drainage routes discussed in the text and flow directions. Blue letters identify those drainage routes as follows: “B” Boxelder Creek, “LB” Little Beaver Creek, “LM” Little Missouri River, “LP” Little Powder River, “M” Missouri River, “O” O’Fallon Creek, “P” Powder River, and “Y” Yellowstone River. **Source:** Base map from United States Geological Survey (USGS) National Map website with author modifications.

As seen in figure 1 the Powder River (P) is a major north-oriented Yellowstone River tributary originating to the south of figure 1 in central Wyoming and flows northward through the Powder River Basin to southeast Montana while the Little Missouri River (LM) originates in northeast Wyoming and flows in a northeast and north direction across the Montana southeast corner and South Dakota northwest corner and then enters North Dakota where it joins the Missouri River. Considerable literature dating back to the early 1900s suggests by Oligocene time north-oriented rivers flowed roughly along what are now the Powder and Little Missouri River alignments. For example, Douglas (1909) used alluvium found in isolated Oligocene deposits on the east side the present day north-oriented Little Missouri River valley to suggest a river formerly flowed from the Black Hills (located along

the Wyoming-South Dakota border just to the south of figure 1) to southwest North Dakota. More recently Seeland (1985) put the Oligocene Arctic Ocean-Gulf of Mexico continental divide across the southern Powder River Basin (approximately 100 miles or 160 kilometers south of the figure 1). While the vast majority of the literature supports a north-oriented Oligocene river from the Black Hills area to southwest North Dakota Denson and Gill (1965) and Clausen (1989) challenged the interpretation that alluvium in southwest North Dakota Oligocene sediments came from the Black Hills. Instead they demonstrated at least some of the coarse-grained alluvium (including cobbles and small boulders) came from the Beartooth Mountains (near the figure 1 southwest corner).

If the Bell River system valleys are not pre-glacial, as most geological literature claims, but was eroded late during a thick continental ice sheet's melt history, as the Missouri River drainage basin landform origins research project results suggest, deep erosion of drainage divide areas between north-oriented Missouri River tributaries by melt water from at least one North American continental ice sheet must have occurred. If so the drainage divide area now separating the Little Missouri River and the Powder River drainage basins in the Chalk Buttes area of Carter County, Montana, should have been deeply eroded by large southeast-oriented ice-marginal melt water floods moving across what is today the deep and north-oriented Powder River valley and then into the modern day north-oriented Little Missouri River drainage basin. The question asked here is does detailed topographic map evidence support such a prediction and if so does such an interpretation provide a logical explanation for the origins of regional erosional landforms such as the Powder River-Little Missouri River drainage divide and today's drainage route orientations?

2. RESEARCH MATERIALS AND METHOD

Primary research materials and references used when preparing this paper were detailed topographic maps found at the United States Geological Survey (USGS) National Map website. This website offers the ability to view areas of interest using a variety of different map and imagery types and at different scales. Various cartographic layers can be added as desired and several GIS tools can be used when analyzing the map data. For purposes of determining erosional landform origins simple topographic map interpretation methods used with detailed topographic maps showing the same detail as is available on hard copy USGS 1:24,000-scale topographic maps was determined to be most useful. Dates of when the original hard copy topographic maps were first published can be obtained from the USGS Topoview website. This paper's study area is included on the USGS 1:250,000-scale Ekalaka topographic map with a 100-foot (30 meter) contour interval that was first published in 1954. Some features needed to do this study can be observed on that map, although other features are only seen on the more detailed 1:24,000-scale topographic maps with contour intervals of 20 feet (6 meters) that were first published at various dates ranging from the late 1970s to the early 1990s. The 1:24,000-scale maps show enough detail and provide enough drainage route and other landform names that a skilled topographic map interpreter can easily visualize landform shapes and provide written descriptions of the features seen.

Regional geology literature and maps were also investigated and Gill (1959) describes the Ekalaka Hills along the Little Beaver Creek-Boxelder Creek drainage divide as being "along the western margin of a broad shallow syncline between the northwest-trending extension of the Black Hills uplift on the southwest and the Cedar Creek anticline on the northeast. The Cretaceous Hell Creek formation and the Tertiary Fort Union (Paleocene) and Arikaree (Miocene) formations form the bedrock.... The Hell Creek and Fort Union formations...dip from 1 to 3 degrees northeast. The flat-lying rocks of the Arikaree formation lie on the beveled edges of these formations." Vuke *et al.* (2001a) show bedrock under Beaver Flats area alluvial terrace deposits of Pleistocene or Pliocene age to be the Ludlow Member of the Fort Union Formation, which overlies the Cretaceous Hell Creek Formation into which the Powder River valley has been eroded. The Hell Creek Formation is a 350 to 500 feet (107 to 152 meters) thick mudstone, which contains channel sandstones and the 82-245 foot (25-75 meter) thick Ludlow Member is similar to the Hell Creek Formation. Gill (1959) describes the Arikaree as 250 feet (76 meters) of fine-grained

tuffaceous sandstone. Further to the south bedrock units dip gently in a westward direction and Cretaceous Pierre Shale with an overlying band of Cretaceous Fox Hills Formation outcrop near the Little Missouri-Powder River drainage divide with the Hell Creek Formation exposed along the Powder River valley's east wall (Vuke *et al.*, 2001c). Bedrock along Powder River valley walls near the Little Powder River is the Tullock Member of the Fort Union Formation with younger units found to the west (Vuke *et al.*, 2001b; Vuke *et al.*, 2001d). The Pierre Shale is a bentonitic claystone and shale ranging from 500 to 700 feet (152 to 213 meters) thick and the Fox Hills Formation is ~~an~~ 80 to 100-foot thick fine- to medium-grained sandstone with some shale near the base. The Tullock Member of the Fort Union Formation is a 150-foot (46 meter) thick fine- to medium-grained sandstone interbedded with less dominant shale, mudstone, and argillaceous limestone beds.

Erosional landforms investigated during this study included asymmetric drainage divides, gaps notched into the drainage divides, buttes and other high points located along the divides, valley orientations, and barbed tributaries. The principle of cross cutting relationships was applied when determining erosion event sequences. For example, a deep valley truncating another drainage basin was interpreted to be younger than the drainage basin it cuts and a barbed tributary was interpreted to have formed when a valley eroded headward across a previous drainage route. The Little Missouri River-Powder River drainage divide was systematically studied starting in the Beaver Flats area at the Ekalaka Hills southwest end and continuing in a south and southwest direction to beyond the Chalk Buttes area. Erosional remnants such as Chalk Buttes were used to determine the regional erosion depth prior to headward erosion of the north-oriented Powder River valley. Streams of water were interpreted to have eroded gaps notched into the Little Missouri-Powder River drainage divide and the flow direction was determined by studying orientations and gradients of opposing valleys on either side of those gaps. The large number and close spacing of the drainage divide gaps was interpreted to mean large volumes of water had crossed the drainage divide and probably supplied the massive volumes of water required to erode the deep north-oriented Powder River valley headward across the water flow. The study area is located south and west of a well recognized continental ice sheet margin and the only source of the immense volumes of water required to erode the region as documented by present day erosional remnants and deep valleys and consistent with the known regional geological history are large southeast-oriented ice marginal melt water floods.

3. RESULTS

3a. Little Missouri-Powder-Yellowstone River Triple Drainage Divide At Beaver Flats

The Little Missouri, Powder, and Yellowstone River drainage basins meet at a triple drainage divide found at the Beaver Flats western end (see figure 2). O'Fallon Creek is a north- and northwest-oriented Yellowstone River tributary and Little Beaver Creek flows in a northeast direction from Beaver Flats to join the Little Missouri River. To the west of this triple divide the Powder River valley turns from a north-northeast to a north-northwest direction. Further downstream the Powder River again flows in a north direction before joining the northeast-oriented Yellowstone River. Before reaching Beaver Flats Little Beaver Creek flows in a southwest direction from the Ekalaka Hills southwest end (not seen, but immediately to the east of the figure 2 southeast corner) before turning in a north direction and then in a northeast direction to reach the Little Missouri River as seen in figure 1. To the northeast of Beaver Flats Little Beaver Creek enters a well defined northeast-oriented oriented valley and is joined by multiple and closely spaced southeast-oriented or barbed tributaries from the northwest and multiple and closely spaced northwest-oriented tributaries from the Ekalaka Hills to the southeast. The Ekalaka Hills form the Little Beaver Creek-Boxelder Creek drainage divide. High points along the Yellowstone River-Little Beaver Creek drainage divide are as much as 300 feet (91 meters) above the Little Beaver Creek valley floor and in the Ekalaka Hills (capped by Miocene Arikaree Formation) along the Little Beaver-Boxelder Creek divide are as much as 500 feet (152 meters) above the Little Beaver Creek valley floor. Little Beaver Creek tributary valley orientations and

the numerous barbed tributaries suggest the Little Beaver Creek valley eroded headward across multiple and closely spaced streams of southeast-oriented water.

Relative dates of the three drainage basins can be determined if the principle of cross cutting relations is applied. Highest points seen in figure 2 are on Beaver Flats, which is at the southwest end of the present day northeast-oriented Little Beaver Creek valley. How far to the southwest the Little Beaver Creek valley extended cannot be determined, but it probably once extended in a southwest direction across what is now the deep Powder River valley. Likewise the Little Beaver Creek northwest valley wall may have once extended in a southwest direction across what is now the north-oriented O'Fallon Creek valley head. If so the Little Beaver Creek valley was truncated by O'Fallon Creek and Powder River valley erosion. Slopes on the Powder River valley side of the O'Fallon Creek-Powder River drainage are steeper than slopes on the O'Fallon Creek valley side suggesting the Powder River valley also truncated the O'Fallon Creek drainage basin. A case can be made that erosion of each of the three drainage basins seen in figure 2 developed during the same erosion cycle or event, although the valleys eroded headward into the figure 2 map area in an identifiable sequence. Headward erosion of the northeast-oriented Little Beaver Creek valley was first and was across multiple and closely spaced southeast-oriented streams of water. Headward erosion of the north- and northwest-oriented O'Fallon Creek valley next removed a section of the Little Beaver Creek northwest valley wall. Finally headward erosion of the north-northwest oriented Powder River valley truncated a segment of the O'Fallon Creek valley, beheaded the northeast-oriented Little Beaver Creek drainage basin, and then turned to erode headward in a south-southwest direction. The age relationship determined here is consistent with a previously established drainage basin age relationship demonstrated for western South and North Dakota Missouri River tributaries (Clausen, 2017a;2017b).

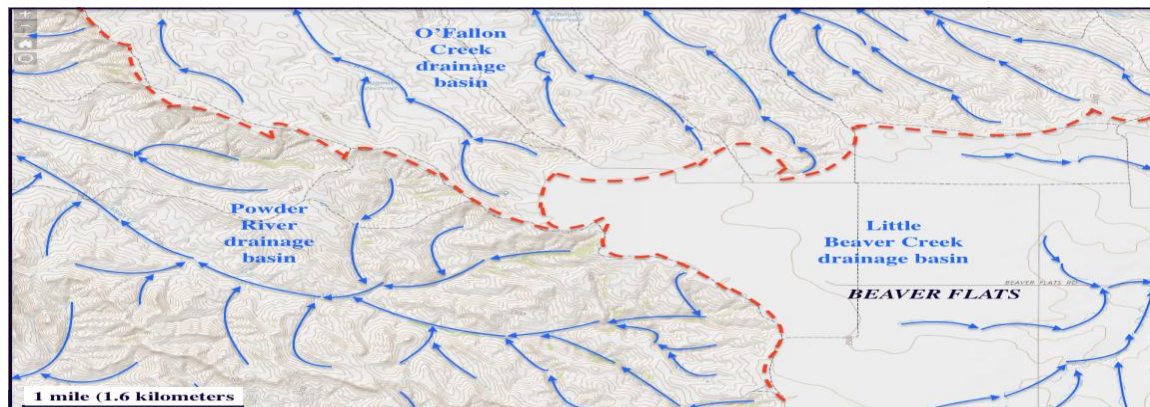


Figure-2. Map showing the triple drainage divide where the Powder River, Yellowstone River (O'Fallon Creek), and Little Missouri River (Little Beaver Creek) drainage basins meet. Blue arrows emphasize drainage routes and directions and dashed red lines show major drainage divide locations. The contour interval is 20 feet (6 meters).

Source: Topographic map from the USGS National Map website with author modifications.

3b. Nature of the Powder River Valley

To the west of the Powder River-Little Missouri River drainage divide the Powder River flows on the floor of a 800-foot (244-meter) deep valley as seen in figure 3, which shows the north-northeast oriented Powder River valley at the point where the valley turns in a north-northwest direction. Note how the Little Missouri River (Little Beaver Creek and Boxelder Creek)-Powder River drainage divide changes direction reflecting the Powder River change from flowing in a north-northeast direction to flow in a north-northwest direction. To the west of the north-oriented Powder River valley seen in figure 3 is north-oriented Mizpah Creek (not seen in figure 3), which joins the north-northwest oriented Powder River segment to the northwest of figures 2 and 3. Elevations along the Mizpah Creek-Powder River drainage divide seen in figure 3 are approximately 400 feet (122 meters) lower than elevations along the Powder River drainage divides with Little Beaver and Boxelder Creeks. Note how Powder River tributaries from the east generally flow in northwest directions and how tributaries from the west generally

flow in southeast directions and join the north-northeast oriented Powder River as barbed tributaries. This southeast and northwest tributary orientation is true for most north-oriented southeast Montana rivers including the Little Missouri River and its Boxelder and Little Beaver Creek tributaries and is also true for Mizpah Creek to the west of figure 3. These tributary orientations were probably established when deep north-oriented valleys, such as the Powder River valley, eroded headward across multiple and closely spaced southeast-oriented streams, such as might be found in a large southeast-oriented anastomosing channel complex.

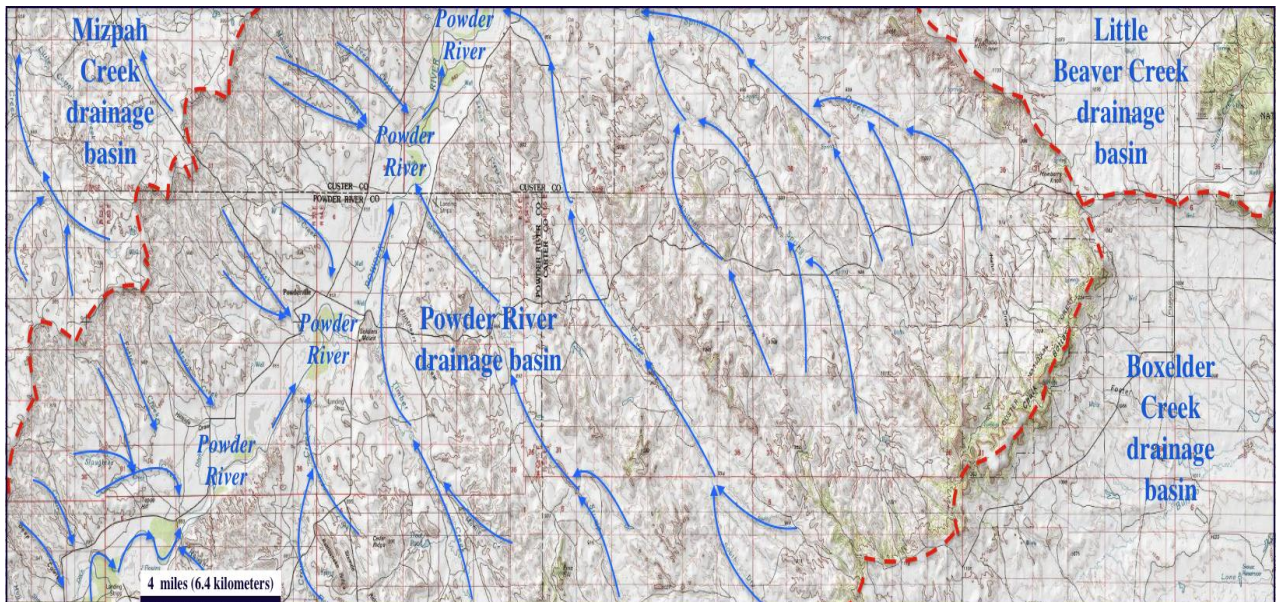


Figure-3. Topographic map showing the Powder River valley and includes areas seen in figures 2 and 4. Blue arrows emphasize drainage routes and directions and dashed red lines show major drainage divides. Mizpah Creek is a north-oriented tributary joining the north-northwest oriented Powder River to the northwest of figure 3. The contour interval is 20 meters (66 feet).

Source: Topographic map from the USGS National Map website modified by the author.

3c. Little Beaver Creek-Boxelder Creek-Powder River Triple Drainage Divide

Figure 4 is immediately to the south of figure 2 and shows the divides between the Powder River and the Little Beaver Creek and Boxelder Creek drainage basins. Little Beaver Creek originates near the Ekalaka Hills southwest end as a southwest-oriented stream with multiple northwest-oriented headwaters and flows almost to the Boxelder Creek drainage divide where it enters figure 4 and then flows in a north direction around the Ekalaka Hills southwest end before turning on Beaver Flats to flow in a northeast direction to reach the Little Missouri River (the green areas in the figure 4 northeast corner and in the figure 3 northeast corner are the Ekalaka Hills southwest end). The divide between the Little Beaver and Boxelder Creek drainage basins in figure 4 is a low ridge and south-facing escarpment standing about 100 feet (30 meters) above the Boxelder Creek drainage basin to the south and is the contact between the Fort Union Ludlow Member (north) and the Cretaceous Hell Creek Formation (Vuke *et al.*, 2001a). Red numbers identify gaps in the ridge and red letters identify high points. The letter A identifies a high point on the Little Beaver Creek-Powder River divide known as Newberry Knob, which rises to more than 3700 feet (1128 meters). Floors of gaps numbered 1, 2, and 3 are between 3600 and 3620 feet (1097 and 1103 meters) and the high point at letter B rises to more than 3680 feet. The gap at number 4 has the same floor elevation as gaps numbered 1, 2, and 3 and the large gap at number 5 has a floor elevation of between 3580 and 3600 feet (1091 and 1097 meters). The high point at letter C rises to more than 3750 feet (1143 meters). Additional gaps exist to the east of letter C, but are higher in elevation than the previously described gaps. Southeast-oriented streams of water flowing from the present-day northeast-oriented Little Beaver Creek drainage basin into the northeast-oriented Boxelder Creek drainage basin eroded the gaps. Today the south-oriented Boxelder Creek

tributaries seen in figure 4 converge to form southeast-oriented Buffalo Creek, which to the south and east of figure 4 reaches northeast-oriented Boxelder Creek as a barbed tributary.

Gaps numbered 1-5 in figure 4 have similar floor elevations suggesting erosion by diverging and converging streams of water rather than by independent streams of water and the question immediately arises, “where did the water come from?” The water flowed in a southeast direction, yet a look at figures 1 and 2 shows the water must have traveled along what is now an 800-foot (244 meter) deep north-northwest oriented Powder River valley. In other words at the time the south-facing escarpment now forming the Little Beaver Creek-Boxelder Creek drainage divide seen in figure 4 eroded headward the 800-foot (244-meter) deep Powder River valley to the west did not exist, although late during the escarpment’s headward erosion a reversal of flow along the present day north-northwest oriented Powder River valley alignment was probably beginning to take place. South and southwest orientations of headwaters of some Powder River tributaries seen in figure 4 provide a hint that headward erosion of the deep north-northwest oriented Powder River valley captured at least some of the southeast-oriented water that was flowing to the Boxelder Creek drainage basin. If correctly interpreted those south and southwest oriented headwaters of Powder River tributary valleys support the hypothesis that a single large erosion event eroded the Boxelder Creek, Little Beaver Creek, and Powder River drainage basins in that order.

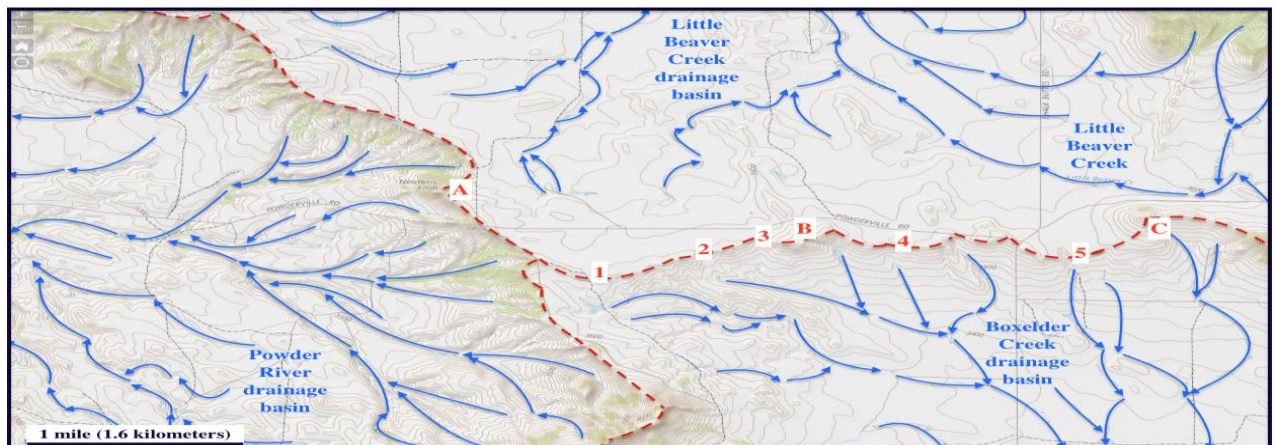


Figure-4. Topographic map showing the Little Beaver Creek-Boxelder Creek-Powder River divides located to the south of figure 2. Blue arrows emphasize drainage routes and directions and dashed red lines show drainage divides. The contour interval is 20 feet (6 meters).
Source: Topographic map from USGS National Map website modified by the author.

3d. Powder River-Boxelder Creek Divide in the Chalk Buttes Area

Chalk Buttes seen in figure 5 are an isolated and relatively flat-topped chain of southwest-to-northeast oriented erosional remnants standing on today’s Powder River-Boxelder Creek drainage divide and are capped by the Miocene Arikaree Formation (Vuke *et al.*, 2001a). The highest point on Chalk Buttes is 4191 feet (1277 meters) with much of the flat-topped butte surface having an approximate elevation of 4140 feet (1262 meters). The Powder River to the west of Chalk Buttes is flowing at an elevation of approximately 2800 feet (853 meters) and Boxelder Creek to the east of Chalk Buttes is flowing at an elevation of slightly less than 3200 feet (975 meters). The top of Chalk Buttes is slightly higher than the tops of similar buttes in the Ekalaka Hills along the Little Beaver Creek-Boxelder Creek drainage divide (to the northeast of figure 2) and the tops of similar buttes in the Long Pine Hills along the Boxelder Creek-Little Missouri River drainage divide to the southeast of figures 5. Flat lying Miocene Arikaree Formation bedrock caps all of these buttes. Before deep regional erosion began the Arikaree Formation almost certainly extended across the entire region and these buttes provide markers documenting the regional erosion depth.

The question can be asked, “did the deep regional erosion take place gradually over extremely long periods of time as commonly accepted regional geologic histories imply or did the deep regional erosion take place rapidly during massive southeast-oriented ice-marginal continental ice sheet melt water flood events as the (Clausen,

2017a;2017b) interpretation implies?” Elevations along the Powder River-Boxelder Creek drainage divide are higher in the Chalk Buttes region than to the northeast or to the southwest and gaps eroded into this drainage divide segment provide clues as to how water eroded Chalk Buttes and the larger region. The red number 1 in figure 5 identifies a deep west-to-east oriented gap in the Chalk Buttes ridge. A northwest-oriented Powder River tributary valley and a southeast-oriented Boxelder Creek tributary valley drain in opposing directions from that gap location. The gap has a floor elevation of between 3820 and 3840 feet (1164 and 1170 meters). The Chalk Buttes ridge immediately to the north of the gap rises to more than 4120 feet (1256 meters) and the larger Chalk Buttes area to the south rises to more than 4140 feet (1262 meters). In other words the gap is approximately 300 feet (91 meters) deep. Southeast-oriented water flowing from what is now the deep Powder River valley area almost certainly eroded the gap as the water flowed from what is today the 800-foot (244-meter) deep Powder River valley area into what is now the northeast-oriented Boxelder Creek drainage basin.

Additional gaps notched into the Powder River-Boxelder Creek drainage divide are found at the locations of the red numbers 2 and 3 in figure 5. The gap at number 2 has a floor elevation of between 3840 and 3860 feet (1170 and 1177 meters). To the north of gap 2 the drainage divide rises to more than 4120 feet (1256 meters) and to the south the divide rises to more than 3960 feet (1207 meters). The gap at number 3 has a floor elevation of between 3740 and 3760 feet (1140 and 1146 meters) and drainage divide elevations to the south rise to more than 3860 feet (1177 meters). When using the lower of the adjacent drainage divide elevations the gap at number 2 is at least 120 (37 meters) deep and the gap at number 3 only appears to be 100 feet (30 meters) deep, however if the nearby Chalk Buttes elevations are used the gaps at numbers 2 and 3 are approximately 300 feet (91 meters) deep. These three gaps (especially gaps 1 and 2) suggest southeast oriented water once flowed across the Chalk Buttes upper surface, which means the southeast-oriented water lowered the Powder River-Boxelder Creek drainage divide elevation to the north and to the south of figure 5 by as much as 500 feet (152 meters) or more. Just as impressive since southeast-oriented water lowered the present day Powder River-Boxelder Creek drainage divide area by approximately 500 feet (152 meters) something subsequently eroded the 800-foot (244-meter) deep north-northeast and north-northwest oriented Powder River valley just to the northwest of the modern day Chalk Buttes erosional remnants. Large volumes of southeast-oriented water provide an explanation for that deep erosion.

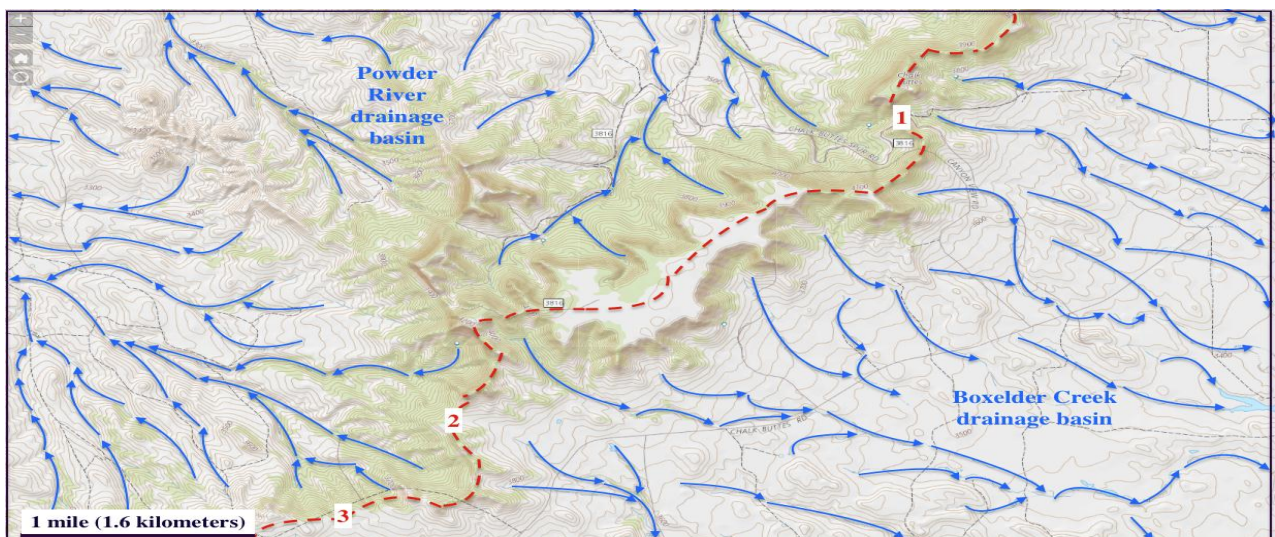


Figure-5. Topographic map showing the Chalk Buttes area to the southwest of figure 4. Blue arrows emphasize drainage routes and directions and the dashed red line shows the Powder River-Boxelder Creek drainage divide location. Red numbers identify locations discussed in the text. The contour interval is 20 feet (6 meters).

Source: Topographic map from the USGS National Map website modified by the author.

3e. Davis Creek-Cabin Creek Drainage Divide Area

To the southwest of Chalk Buttes most gaps notched into the Powder River-Little Missouri River drainage divide link northwest-oriented Powder River tributary valleys with southeast-oriented Boxelder Creek tributary valleys. As already described streams of southeast-oriented water moving from what is now the deep Powder River valley into the present day northeast-oriented Boxelder Creek drainage basin eroded these gaps and opposing valley orientations (at least near the gaps) reflect that earlier flow direction. Figure 6 illustrates two such gaps linking the northwest-oriented Davis Creek drainage basin with the southeast-oriented Cabin Creek drainage basin. The gap at the red number 1 has a floor elevation of between 3520 and 3540 feet (1073 and 1079 meters) and is about 100 feet (30 meters) deep. The gap at red number 2 has a floor elevation of between 3580 and 3600 feet (1091 and 1097 meters) and in figure 6 appears to be only about 40 feet (12 meters) deep. However just to the north of figure 6 the drainage divide elevation rises to more than 3700 feet (1228 meters) and to the south of figure 6 the drainage divide elevation also rises to more than 3700 feet (1228 meters). In other words the gaps at numbers 1 and 2 record deeper channels eroded into the floor of a much broader gap crossing the present day Powder River-Little Missouri River drainage divide. The gaps noted here and the Chalk Buttes and Ekalaka Hills erosional remnants suggest deep regional erosion must have occurred during a continuous series of erosion events.

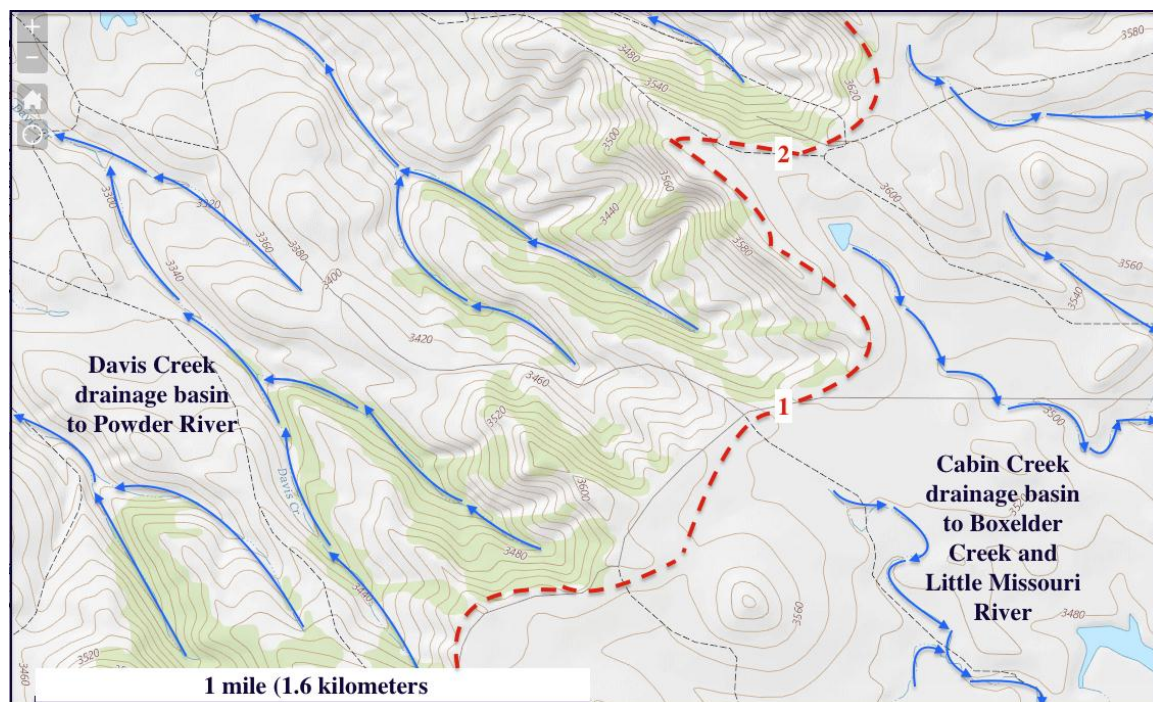


Figure-6. Topographic map showing the Davis Creek-Cabin Creek drainage divide area to the southwest of figure 4. Blue arrows emphasize drainage routes and directions. The dashed red line shows the Powder River-Little Missouri River (Davis-Cabin Creek) drainage divide and the red numbers refer to locations discussed in the text. The contour interval is 20 feet (6 meters).

Source: Topographic map from USGS National Map website modified by the author.

4. DISCUSSION

A sequence of deep regional erosion events can be put together for the Ekalata Hills and Chalk Buttes areas of Carter County, Montana. It seems reasonable to assume the horizontal Miocene Arikaree Formation once covered much or all of the region and large volumes of southeast-oriented water first flowed across that surface. The deep north-oriented Little Missouri River valley then eroded headward across the southeast-oriented floods of water and subsequently its northeast-oriented Boxelder Creek tributary valley captured the southeast-oriented water as it subsequently eroded headward from the actively eroding Little Missouri River valley, probably during the same deep erosion event. Next headward erosion of the deep northeast-oriented Little Beaver Creek valley beheaded and reversed the southeast-oriented streams of water to create what is today the Little Beaver Creek-Boxelder Creek

drainage divide now located along the Ekalaka Hills crest. After Little Beaver Creek valley headward erosion the northeast-oriented Yellowstone River valley and its north- and northwest-oriented O'Fallon Creek tributary valley eroded headward into the study region and removed a Little Beaver Creek northwest valley wall segment, but did not capture Little Beaver Creek. Following O'Fallon Creek headward erosion, and ending the O'Fallon Creek valley headward erosion, the even deeper north-northeast and north-northwest oriented Powder River valley eroded headward from what must have been an actively eroding northeast-oriented Yellowstone River valley and truncated the newly eroded O'Fallon Creek valley head and the Little Beaver Creek valley's southwest end and beheaded and reversed the multiple southeast-oriented streams of water flowing into the northeast-oriented Boxelder Creek drainage basin. Finally, at least in terms of features seen and discussed here, the north-oriented Mizpah Creek valley eroded headward from the north-northwest oriented Powder River valley segment and beheaded and reversed southwest-oriented streams of water that had previously been flowing into the newly eroded and deep north-northeast oriented Powder River valley.

Chalk Buttes and the Ekalaka Hills now stand more than 500 feet (152 meters) above the Beaver Flats surface and suggest headward erosion of the north-oriented Little Missouri River drainage basin (including its tributary northeast-oriented Boxelder Creek and Little Beaver Creek drainage basins) removed significant depths of bedrock from much of the region. The Powder River valley floor is today from 600 to 800 feet (183 to 244 meters) lower than corresponding elevations along much of the Little Missouri River-Powder River drainage divide and approximately 1300 feet (396 meters) lower than the top of the Miocene Arikaree Formation capping Chalk Buttes. All erosion events described here were initiated as numerous and closely spaced streams of southeast-oriented water crossed the region. Volumes of water needed to remove 500 feet (152 meters) of bedrock from much of the region and then to erode a 600 to 800 foot (183 to 244 meter) deep valley into the newly formed surface must have been immense. The only geologic event known to this author capable of generating such water volumes is the melting of a large continental ice sheet. The Chalk Buttes area is located south and west of a known continental ice sheet margin and large southeast-oriented ice marginal melt water floods logically should have flowed across the study region. Assuming the continental ice sheet created and occupied a deep "hole" as described in the introduction to this paper deep north- and northeast-oriented valleys logically should have eroded headward across that southeast-oriented ice marginal melt water flow and erosion events described here can all be explained.

5. CONCLUSIONS

Determination of how the Little Missouri River-Powder River drainage divide originated in the Ekalaka Hills and Chalk Buttes area of Carter County, Montana demonstrates the north-oriented Powder River and Little Missouri River valleys and at least some of their north-oriented tributary valleys eroded headward in an identifiable sequence from east to west across immense southeast-oriented floods of probable ice-marginal continental ice sheet melt water origin. If correctly interpreted the north-oriented valleys eroded headward late during a continental ice sheet's melt history from the southern end of a deep "hole" that had been created by deep continental ice sheet erosion and ice sheet related crustal warping. Such an interpretation requires north- and northeast-oriented Missouri River tributary valleys to have been eroded late during the melting of a large North American continental ice sheet and not during pre-glacial time as is frequently claimed. The interpretation also has significant implications for commonly accepted North American late Cenozoic and glacial histories and future work is needed to better describe ice-marginal melt water flood flow routes and how deep north-oriented valleys eroded headward across those ice-marginal melt water flood flow routes so as to divert the southeast-oriented melt water floods into space the melting ice sheet was opening up in what had been a large and deep ice sheet created and occupied "hole".

Funding: This study received no specific financial support.

Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

Contributors/Acknowledgement: Arthur Strahler during the 1964-5 academic year taught Columbia University courses where the author became aware of the geomorphology research community's inability to answer many erosional landform origin questions. Brainerd Mears and other University of Wyoming faculty members during the late 1960s made the author aware of unsolved Rocky Mountain and Great Plains erosional landform origin problems. Early work that led to the Missouri River drainage basin landform origins research project and to this paper was done while employed at Minot State University (North Dakota) where other faculty members and library staff members greatly assisted in developing and providing access to topographic map collections.

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