

Use of Wyoming Southern Bighorn Mountains Topographic Map Evidence to Test a Recently Proposed Regional Geomorphology Paradigm: USA

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Abstract

Detailed topographic maps covering a high elevation Bighorn-Powder River drainage divide segment in the southern Bighorn Mountains are used to test a recently proposed regional geomorphology paradigm. Fundamentally different from the commonly accepted paradigm the new paradigm predicts immense south-oriented continental ice sheet melt water floods once flowed across what is now the entire Missouri River drainage basin, in which the high Bighorn Mountains are located. Such a possibility is incompatible with commonly accepted paradigm expectations and previous investigators have interpreted Bighorn Mountains geomorphic history quite differently. The paradigm test began in the high glaciated Bighorn Mountains core area where numerous passes, or divide crossings, indicate multiple and sometimes closely spaced streams of water once flowed across what is now the Bighorn-Powder River drainage divide. To the south of the glaciated area, but still in a Precambrian bedrock region, the test found the roughly adjacent and parallel south-oriented North Fork Powder River and Canyon Creek headwaters located on opposite sides of the Bighorn-Powder River drainage divide with North Fork Powder River headwaters closely linked to a 300-meter deep pass through which south-oriented water had probably flowed. Shallower divide crossings located further to the south suggest diverging and converging streams of water once flowed not only across the Bighorn-Powder River drainage divide, but also across Powder River and Bighorn River tributary drainage divides. The paradigm test also found published geologic maps and reports showing the presence of possible flood transported and deposited alluvium. While unable to determine the water source, the new paradigm test did find evidence that large south-oriented floods had crossed what was probably a rising Bighorn Mountains mountain range.

Keywords: drainage divide crossings, landform origins, Missouri River drainage basin, mountain passes, North Fork Powder River, paradigm test, regional geomorphology paradigm

1. Introduction

1.1 Statement of the Problem

Thomas Kuhn (1970) describes scientific paradigms as frameworks of rules and ideas that define and govern a scientific discipline's research efforts. To become successful a scientific paradigm must enable that discipline's investigators to explain their observed evidence and also to develop productive new research opportunities. By themselves scientific paradigms are neither correct nor incorrect, but are judged based on their ability to explain observed evidence and to open up future research opportunities. Paradigm change is not easily accomplished, but from time to time anomalous evidence appears that a discipline's accepted paradigm cannot explain. Kuhn suggests such anomalous evidence is dealt with in one of three ways: first, the paradigm rules and assumptions eventually explain the evidence and the accepted paradigm continues without serious interruption; second, the anomalous evidence is labelled and shelved for future consideration; and third, a new and fundamentally different discipline paradigm emerges and a battle develops over which paradigm should be used. In other words, to be accepted a new paradigm must demonstrate an ability to explain previously unexplained evidence.

The study described here uses previously unexplained Wyoming southern Bighorn Mountains drainage system evidence (obtained from detailed topographic maps) to test a recently proposed regional geomorphology paradigm that requires immense south-oriented continental ice sheet melt water floods to have flowed across what is today the entire Missouri River drainage basin. The Bighorn Mountains are an excellent test region as the

Bighorn Mountains are located within the Missouri River drainage basin and rise more than 2500 meters above the Powder River Basin to the east, the Bighorn Basin to the west, and valleys and lowlands to the north and south meaning the new paradigm requirement forces the assumption that the Bighorn Mountains either rose as large melt water floods flowed across them or have since risen. In either case the massive melt water floods requirement is incompatible with a commonly accepted regional geomorphology paradigm expectation that late Cenozoic continental ice sheet melt water could not have flowed uphill to reach what is now Wyoming, much less to have flowed across what during the Quaternary were high Bighorn Mountains. If massive melt water floods did flow across the Bighorn Mountains, as the new paradigm requires, evidence of those floods should be observable on detailed topographic maps of the high elevation southern Bighorn Mountain test region and the purpose of the study reported here is to identify, describe, and analyze any such evidence.

1.2 Geographic Setting of the Southern Bighorn Mountains Region

The Bighorn Mountains (Figure 1) are a high Rocky Mountain range located in northcentral Wyoming between the Powder River Basin to the east and the Bighorn Basin to the west. The highest peaks are located in the uplift's northwest-to-southeast oriented northern half while in the north-to-south oriented southern half elevations are generally lower and decrease in a southward direction. The north-oriented Powder River drains large areas of the southern Bighorn Mountains and has significant barbed tributaries, some of which originate to the west of the Bighorn Mountains axial crest. Significant south-oriented tributaries originating to the west of the Bighorn Mountain axial crest flow from the southern Bighorn Mountains to the north- and northwest-oriented oriented Nowood River and then the north-oriented Bighorn River. To the north of figure 1 (in the state of Montana) the Bighorn and Powder Rivers join the northeast-oriented Yellowstone River, which near the Montana-North Dakota border joins the east-oriented Missouri River with the water eventually flowing in south and southeast directions before reaching the Gulf of Mexico. Important to this paper, but not now draining any Bighorn Mountains regions is the North Platte River, which originates in the high northcentral Colorado Rocky Mountains (south of figure 1) and flows in a northwest and north direction into the figure 1 map area where it cuts across the Laramie Range northwest end and turns in an east and southeast direction with its water eventually reaching the south-oriented Missouri River.

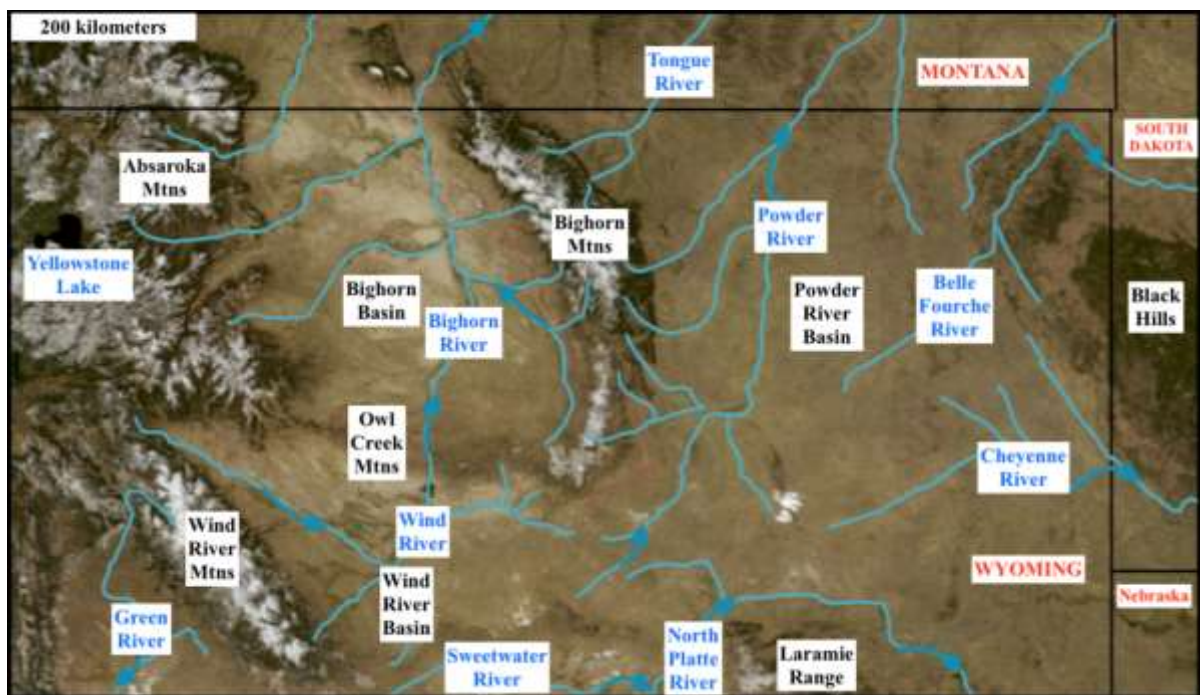


Figure 1. Modified imagery from the United States Geological Survey (USGS) National Map website showing the Bighorn Mountains location in northcentral Wyoming relative to regional rivers, intermontane basins, mountain ranges, and state boundaries. Arrows show river flow directions

Thornbury (1965) describes the Bighorn Mountains as follows: “They consist of a granite core flanked by steeply dipping Paleozoic and Mesozoic rocks. The crystalline core is largely covered by Paleozoic rocks in both the northern and southern thirds of the range, but in the middle part Precambrian crystalline rocks are extensively exposed... [and] extensive mountain glaciation has given to the crest of the range the distinctive biscuit board effect produced by cirque development on two sides of a mountain range.” The southern Bighorn Mountain region studied here begins near the southern margin of the glaciated crystalline core and to the south of the glaciated area Precambrian bedrock extends southward in the Bighorn-Powder River drainage divide area for approximately 20 kilometers before Paleozoic bedrock is encountered. Previous investigators have mapped alluvial sediments on top of study region Precambrian and Paleozoic bedrock. Bighorn Mountains crest elevations generally decrease in a southward direction from the glaciated core and south-oriented drainage is to be expected, although at lower elevations the south-oriented streams make U-turns to join either the north-oriented Powder River or the north-oriented Bighorn River. The commonly accepted regional geomorphology paradigm considers the Bighorn and Powder Rivers to be components of the pre-glacial north-oriented Bell River drainage system (described by Jackson, 2018 and Sears, 2013) with water prior to North American continental glaciation flowing northward across Canada.

1.3 Previous Work

Darton (1906) conducted the first extensive Bighorn Mountains geologic study and his report describes evidence suggesting extensive uplift occurred in early Tertiary time, but was then truncated with Oligocene deposits lying on an eroded surface. He suggests the “Oligocene and overlying deposits were laid down by streams and local lakes.... Erosion has removed them from most of the higher regions where they formerly existed.... Some deposits of supposed Tertiary age remain in the center of the Bighorn Mountains at altitudes of from 8000 to 9000 feet... [2438 to 2743 meters]. They are probably the remnants of much more extensive sheets.” He further comments “the Bighorn Mountains were occupied by glaciers during two widely separated glacial epochs, and there is a suggestion that there may have been glaciers at a still earlier time.” While mentioning Bighorn Mountains drainage routes Darton does not address the unusual drainage features such as the U-turns that south-oriented streams make before or when joining north-oriented Bighorn and Powder River Basin drainage routes.

In a classic paper Mackin (1937) suggests the deposition of eroded materials following early Tertiary Bighorn Mountains uplift filled the Bighorn Basin “to a high level relative to the surrounding ranges.” He notes, “All major streams cut across structural barriers in positions that indicate superposition from a higher level.... Extensive deposits of stream rounded gravel [are found] at elevations from 7,000 to 9,000 feet [2134 to 2743 meters] on the flanks of the Bighorn Range.... The gravel surfaces on the Bighorns slope smoothly outward from the high axial peaks of the range, but end abruptly in a steep descending scarp at the range front.” He comments the “subsummit peneplain” erosion surface found at 8000 to 10,000 feet [2438 to 3048 meters] is probably Pliocene in age and could have formed at a lower level with its present elevation and the deep trenching of present streams being due to uplift that occurred subsequent to its formation, but he prefers a different history because “the gravel that still mantles part of this erosion surface was formerly continuous with the aggraded floor of the [Bighorn] Basin and, in turn with the late Tertiary aggradational surface of the Great Plains,” suggesting the erosion surfaces formed at a high level and that most uplift occurred during or before mid-Tertiary time.

McKenna and Love (1972) used vertebrate fossils collected from 9000-meter high alluvial deposits found at Canyon Park along the Bighorn-Powder River drainage divide as “a reference datum for the reconstruction of regional sedimentation during early Miocene time and for determination of the maximum age of epeirogenic uplift. As a result of regional aggradation, the Bighorn Basin was filled with sediments. These buried the rugged peaks and canyons of the Bighorn Mountains up to a level corresponding to the present 9000-foot [2743-meter] altitude during early Miocene time. The lower Miocene and older rocks are beveled by the subsummit surface, a remarkably flat and even surface of Miocene or Pliocene age. Excavation of the Bighorn and Powder River basins and exhumation of the Bighorn Mountains must have been accomplished during a the relatively short interval of late Cenozoic time after the subsummit surface was cut.” McKenna (1980) correlates high elevation Bighorn Mountains alluvium with the lower part of the Arikaree Group of eastern Wyoming, Nebraska, and South Dakota and comments, “As late as the early Arikareean the Bighorn Basin continued to fill with sediments, until only a small area of Precambrian igneous rocks marked the site of the buried Bighorn Range.”

In a review of Wyoming’s high-level erosion surface research literature Mears (1993) observes Colorado geologists consider the sub-summit erosion surface to be late Eocene in age while Wyoming “dissenters” prefer a late Miocene age. The described Wyoming version begins with a latest Paleocene and earliest Eocene

Laramide orogeny climax when relief of the mountains was greater than today which was followed by a late Eocene erosion episode that lowered the mountains and filled mountain valleys and adjacent intermontane basins. Another erosion episode followed and “the rising level of Oligocene and then Miocene deposits eventually lapped across the lower segments of the crystalline-cored uplands that had been eroded down to broad sub-summit surfaces surmounted by residual hills and peaks. At some time during this aggradational episode, broad regional uplift began to raise the mountains to their present-day elevations. The exhumation of the present broad basin floors and adjacent mountain valleys began in mid-Miocene time, following the end of massive volcanic ash falls and accompanying the acceleration of regional uplift. This uplift may have contributed to the onset of late Cenozoic alpine glaciation in the mountains of Wyoming.” Mears also comments on how various investigators have proposed differing geomorphic processes, such as peneplanation, pedimentation, and altiplanation to explain how the high-level erosion surfaces formed.

More recently Pelletier (2009) proposed an increase in the intensity of snowmelt flooding to explain up to 1.5 km of erosion in southern Rocky Mountain intermontane basins since middle Miocene time. He argues, “In the middle Miocene, snowmelt runoff was limited to the highest elevations (>3 km) and hence impacted only a small fraction of the regional landscape. As the global climate system cooled during the late Miocene and Plio-Quaternary periods, the fraction of total river discharge derived from snowmelt increased significantly in areas between 1.5 and 3 km elevation, thereby increasing the magnitude of flooding during periods of snowmelt and the resulting bedload sediment flux and erosion of rivers in that elevation range.” Pelletier cites several references to support his 1.5 km depth of erosion claim including a McMillan et al. (2006) Rocky Mountain region study and a Heasler and Kharitonova (1996) Bighorn Basin study. While recognizing epeirogenic uplift is frequently cited to explain the deep Rocky Mountain intermontane basin excavation (e.g. Eaton, 2008) Pelletier considers it inconsistent with higher elevation Rocky Mountain peak area erosion rates. For that reason, he considers climatic change as a more probable intermontane basin excavation explanation and tries to explain how climatic change might lead to the reported 1.5 km basin erosion depths.

In addition to interpretations such as those described above that reflect and help define the commonly accepted regional geomorphology paradigm previous investigators have also prepared paradigm neutral geologic and topographic maps. For example, Darton’s (1906) Bighorn Mountain area geologic map and more recent geologic maps such as the Ver Ploeg and Boyd (2002), Ver Ploeg et al. (2003) and Ver Ploeg et al. (2004) maps identify in paradigm neutral ways observable bedrock units and geologic structures that may have helped shape landscape features, although modern-day drainage systems postdate many of those bedrock units and geologic structures. In addition to bedrock geologic maps Hallberg et al. (2000) and Hallberg et al. (2001) have prepared paradigm neutral digital surficial geologic maps showing Bighorn Mountain area locations of glacial and other surficial materials. Detailed topographic maps provide the most useful paradigm neutral landscape information, yet previous investigators rarely mention that information (perhaps because the commonly accepted regional geomorphology paradigm does not permit that information to be satisfactorily explained).

Detailed topographic map evidence has recently been used to propose a fundamentally different regional geomorphology paradigm (Clausen, 2018a) in which massive south- and southeast-oriented glacial melt water floods flowed across the entire Missouri River drainage basin (including much of the Rocky Mountain area). That paradigm requirement forces recognition of an ice sheet created deep “hole” in which a thick continental ice sheet was located and also forces recognition of ice sheet related crustal warping that occurred as meltwater floods flowed across rising mountain ranges and plateaus. As a bulge within the Missouri River drainage basin near, but not on the deep “hole’s” southwest rim, the new paradigm requires south- or southeast-oriented melt water floods to have flowed across what must have been a rising Bighorn Mountain range. Previously published new paradigm papers among other things demonstrate how detailed topographic map evidence suggests large south- and southeast-oriented floods flowed across a rising Wyoming-South Dakota Black Hills upland (Clausen, 2018b), a rising Wyoming Laramie Range (Clausen, 2018c), rising Montana Lewis and Clark and Sawtooth Ranges (Clausen, 2019), a rising Montana Boulder Batholith region (Clausen, 2017a), rising Montana Beaverhead, Centennial, Pioneer, and Anaconda Mountain ranges (Clausen 2017b) and the eastern Powder River Basin (Clausen, 2018d) and also demonstrate how the southeast Montana north-oriented Powder River valley eroded headward across massive southeast-oriented floods (Clausen, 2018e). The study reported here seeks to determine whether detailed topographic map evidence in the high elevation southern Bighorn Mountains region can be interpreted in similar ways.

2. Research Method

This paper represents a subcomponent of the author’s larger Missouri River drainage basin landform origins research project. Anomalous alluvium and erosional landform evidence first led to the exploration and rejection

of numerous possible explanations. Unable to develop a hypothesis that could explain the observed evidence a decision was made to systematically study hard copy detailed topographic maps covering the entire Missouri River drainage basin with the goal of determining how that drainage basin originated. That systematic study was first conducted over three years during the 1999-2001 time period and found evidence that all Missouri River drainage basin valleys had eroded headward across large southeast-oriented floods that had crossed all drainage divides within and surrounding the present-day Missouri River drainage basin. The first systematic study evidence was on hard copy detailed topographic map mosaics and could not be presented in a form that skeptical reviewers would accept. The systematic study was repeated during the 2011-2013 time period using National Geographic TOPO software and maps with more than 500 detailed research notes in blog format describing more than 4000 different Missouri River drainage basin drainage divide origins being posted at geomorphologyresearch.com. More recently larger project subcomponents, such as the study reported here, are being repeated for publication purposes.

The project subcomponent repeated here used topographic maps available at the United States Geological Survey (USGS) National Map, website and was supplemented by geologic maps. The study region follows the Bighorn-Powder River drainage divide in a southward direction from the high Bighorn Mountains glaciated region to a subsummit erosion surface area. Detailed topographic maps were used to identify water eroded drainage divide crossings, now found along the Bighorn-Powder River and other nearby high elevation drainage divides that could be interpreted as places where water had once crossed what are now significant drainage divides. Flow directions were interpreted, where possible, from drainage divide crossing orientations and drainage routes on either side of the drainage divides. Closely spaced drainage divide crossings and drainage routes were interpreted to be possible evidence of diverging and converging drainage routes such as might be found in flood formed anastomosing channel complexes and detailed topographic maps were checked to determine if further evidence of such anastomosing channels could be found. In addition, geologic maps were studied to note where in and near the study region previous investigators had identified what might be flood transported alluvial materials now lying on top of the study region's Precambrian and Paleozoic bedrock.

3. Results

3.1 Glaciated Area of the Bighorn Mountains High Precambrian Core Area

The Bighorn-Powder River drainage divide in the Bighorn Mountains glaciated Precambrian region follows a high crest ridge with numerous passes cut across that ridge. Figure 2 illustrates one such pass between southwest-oriented East Tensleep Creek headwaters and the Firehole Lakes valley draining to east- and northeast-oriented South Clear Creek. East Tensleep Creek joins southwest-oriented Tensleep Creek, which flows as a barbed tributary to the northwest-oriented Nowood River and then to the north-oriented Bighorn River while South Clear Creek joins east-oriented Middle Clear Creek, which joins east- and northeast-oriented Clear Creek with water reaching the north-oriented Powder River. The pass at point A in figure 2 has a floor elevation of about 3272 meters and is located between Bighorn Peak (3756 meters) to the northwest and Loaf Mountain (3573 meters) to the southeast. Water flowing across what is now the high Bighorn Mountains crest ridge, which is now the Bighorn-Powder River drainage divide, eroded the 300-meter deep valley remnant now preserved between Bighorn Peak and Loaf Mountain. That water either flowed in a southwest direction from what is today the Powder River Basin to what is now the Bighorn Basin or in the opposite direction from the Bighorn Basin to the Powder River Basin. In either case erosion of the pass occurred at a time when the Bighorn Mountains crest ridge did not stand more than 2 kilometers above the adjacent Powder River and Bighorn Basins as it does today.

Using the pass orientation to determine the water flow direction is difficult because other passes crossing the crest ridge have different orientations. The pass shown in figure 2 is near the glaciated region's southern end (Hallberg et al, 2000) and to the north of Bighorn Peak a 250-meter deep pass between Bighorn Peak and Darton Peak (3741 meters) has an east-southeast to west-northwest orientation while other closely spaced passes in the region have more of an east-to-west orientation. Still further to the north is Florence Pass (3331 meters) located between Mather Mountain (3784 meters) and Bomber Mountain, (3914 meters), which links a southwest-oriented valley draining to south-oriented West Tensleep Creek and the east-southeast-oriented North Clear Creek headwaters. Darton (1906) describes the Florence Pass sharp turn as an example of glacial piracy where glacial erosion enabled headward erosion of the North Clear Creek valley to capture the southwest-oriented West Tensleep Creek headwaters. Still further to the northwest are additional closely spaced and unnamed passes plus 350-meter deep and north-to-south oriented Geneva Pass and 250-meter deep and northeast-to-southwest oriented Edelman Pass. The closely spaced passes cutting across the high elevation glaciated crest ridge suggest large volumes of water did flow across what is today the Bighorn-Powder River

drainage divide prior to Bighorn Mountains glaciation, although determining flow directions and other details requires evidence not available from this paper's study region topographic maps.

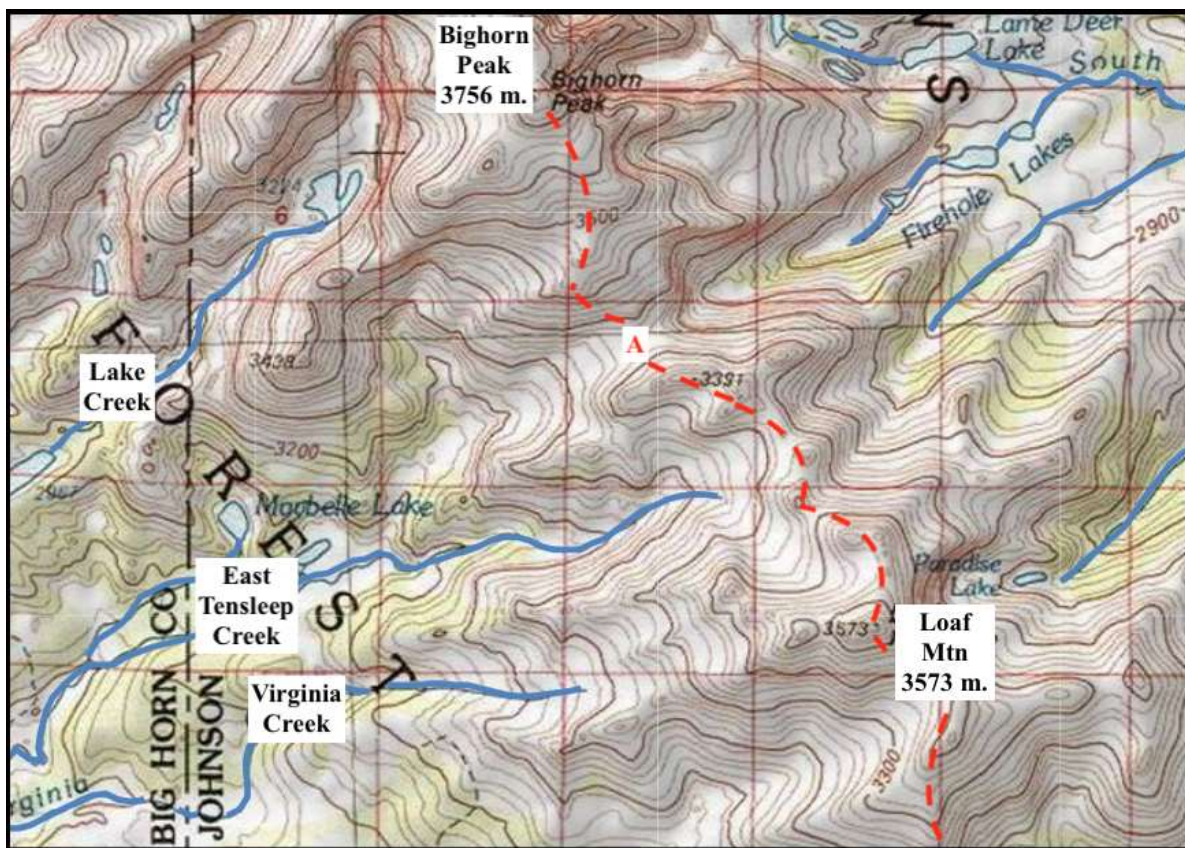


Figure 2. Modified topographic map from the USGS National Map website showing the pass between Bighorn Peak and Loaf Mountain at point "A" that links southwest-oriented East Tensleep Creek headwaters with northeast-oriented Clear Creek headwaters. Elevation at point "A" is 3272 meters. Red grid lines are 1 mile (1.6 km) apart. Red dashed line shows the Bighorn-Powder River drainage divide. Contour interval is 20 meters

3.2 North Fork Powder River and Canyon Creek Headwaters Area

Moving south to a non-glaciated region underlain by metamorphic granite gneiss dated to be 3,000 Ma or older (Love and Christiansen, 1985) figure 3 provides a modified topographic map showing where Leigh Creek, Canyon Creek, the North Fork Powder River, and North Fork Crazy Woman Creek begin. Leigh and Canyon Creeks flow in south and then northwest directions along different routes to reach southwest-oriented Tensleep Creek, which as a barbed tributary joins the northwest-oriented Nowood River (which flows to the north-oriented Bighorn River). The North Fork Powder River flows in a south-southwest and then southeast direction to reach the east- and north-oriented Powder River. North Fork Crazy Woman Creek flows in a southeast, northeast, and southeast direction to reach northeast-oriented Crazy Woman Creek, which flows to the north-oriented Powder River. Middle Fork Crazy Woman Creek originates in the figure 3 southeast corner as an unnamed northeast-oriented stream that to the east of figure 3 turns in a southeast direction. The dashed red line in figure 3 follows the Bighorn-Powder River drainage divide and to the south of figure 3 Webb Creek joins the North Fork Powder River. To the northeast of figure 3 is the northeast-oriented Sourdough Creek valley leading to the east- and northeast-oriented Clear Creek valley.

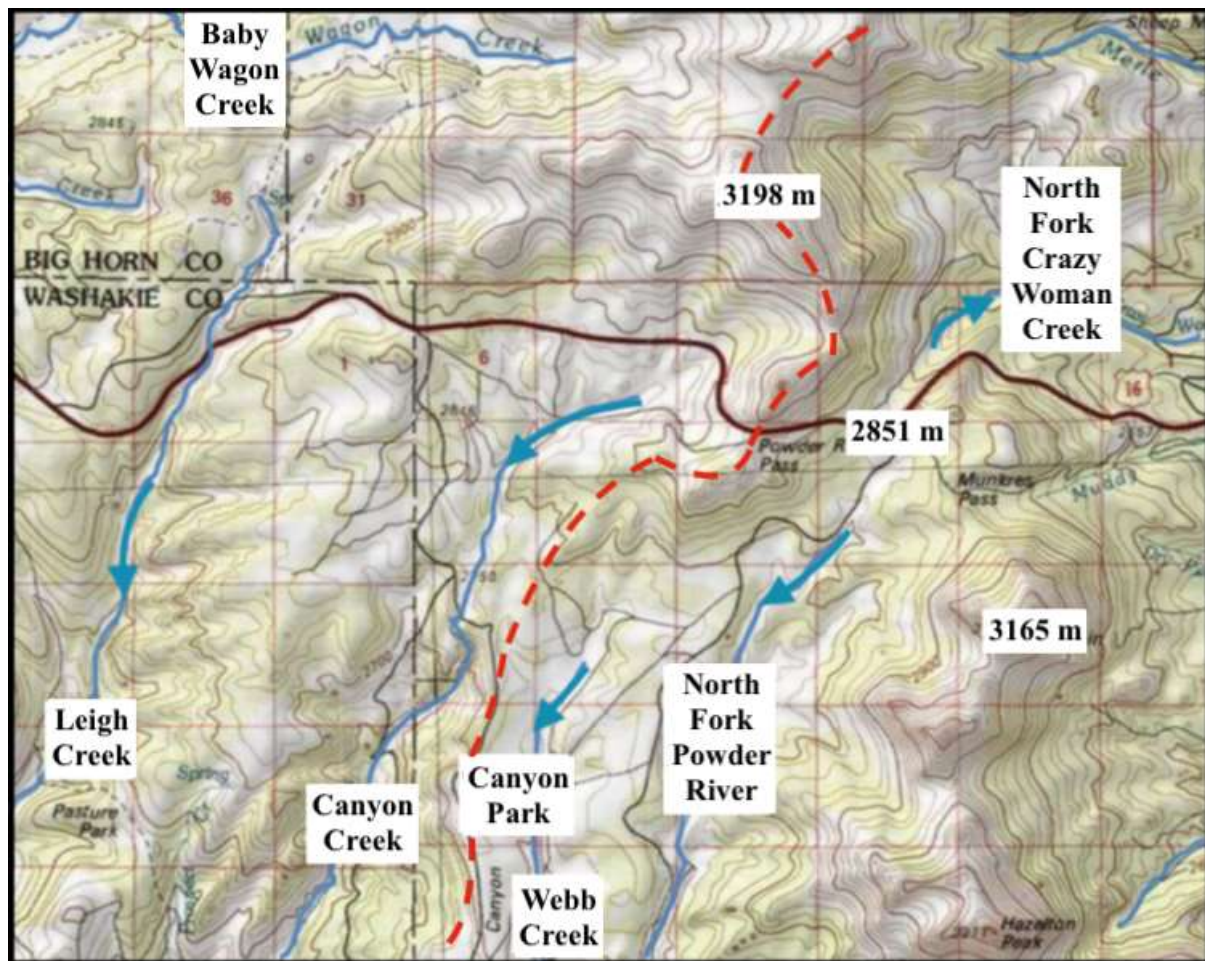


Figure 3. Modified topographic map from the USGS National Map website showing the Bighorn-Powder River drainage divide (dashed red line) and headwaters of North Fork Crazy Woman Creek, the North Fork Powder River, Canyon Creek, and Leigh Creek. Contour interval is 20 meters and red grid square sides are 1 mile (1.6 kilometers) in length. Figure 3 is directly to the south of figure 2

Powder River Pass is where the highway crosses the Bighorn-Powder River drainage divide, but more important to this paper is the 300-meter deep pass where the highway crosses from the North Fork Powder River drainage basin into the North Fork Crazy Woman Creek drainage basin. Projecting the North Fork Powder River headwaters orientation in a north-northeast direction (to the northeast of figure 3) leads to the northeast-oriented Sourdough Creek valley, which drains to east- and northeast-oriented Clear Creek (flowing to the north-oriented Powder River). Water flowing in one direction or the other eroded the 300-meter deep pass between the North Fork Powder River and North Fork Crazy Woman Creek. It is difficult to conceive how north-northeast oriented flow along what is today the south-southwest oriented North Fork Powder River headwaters alignment would be consistent with the south-southwest oriented Webb Creek, Canyon Creek, and Leigh Creek flow directions, especially when Canyon and Leigh Creeks are flowing in deeper valleys than Webb Creek and the North Fork Powder River. While today the North Fork Powder River and Webb Creek are on one side of the Bighorn-Powder River drainage divide and Canyon Creek and Leigh Creek on the other side, all four streams flow in south directions suggesting they originated when the Bighorn-Powder River drainage divide did not exist and south-oriented water flowed across the region.

The question can be asked, where did that south-oriented water come from? Looking at today's topography with difficulty a case might be made that some south-oriented melt water from Bighorn Mountains glaciers reached the Leigh Creek headwaters. However, a 3198-meter high mountain is located to the north of the Canyon Creek headwaters and a 130-meter deep mountain pass is located to the north of that high mountain. Water flowing from the Baby Wagon Creek drainage basin to the North Fork Crazy Woman Creek drainage basin or vice

versus eroded that 130-meter deep pass. Baby Wagon Creek today joins southwest-oriented Tensleep Creek and to the east of figure 3 the southeast-oriented North Fork Crazy Woman Creek headwaters turn in a northeast direction before resuming a southeast flow direction. That 130-meter deep pass now has a floor elevation of about 3065 meters and water that eroded that pass came from (or across) either the Bighorn or the Powder River Basin. In either case that 130-meter deep pass is today more than 1500 meters higher than either of those basin floors and either the Bighorn Mountains have since been uplifted by at least 1500 meters or more than 1500 meters of sedimentary rock that once filled the Bighorn and Powder River Basins has since been removed.

While maps of this paper's study region do not permit determination of the direction of flow through the 130-meter deep pass melt water from Bighorn Mountains alpine glaciers could not have reached the North Fork Powder River headwaters. In other words, south-southwest oriented water from the Powder River Basin area must have eroded the 300-meter deep pass between the North Fork Crazy Woman Creek and the North Fork Powder River as that water flowed into the North Fork Powder River drainage basin. If so, the south-southwest oriented water probably flowed along the alignment of what is now the northeast-oriented Sourdough Creek valley (to the northeast of figure 3). If correctly interpreted headward erosion of the deeper southeast-oriented North Fork Crazy Woman Creek valley eventually captured the south-southwest oriented flow and subsequent Bighorn Mountains uplift caused a reversal of flow to create what is today northeast-oriented Sourdough Creek (and possibly what is today the northeast-oriented North Fork Crazy Woman Creek segment to the east of figure 3). Such a scenario requires Bighorn Mountains uplift and not Powder River and Bighorn Basin excavation to explain the Bighorn Mountains elevation seen today.

3.3 North Fork Powder River Direction Change Area

Figure 4 provides a modified topographic map of the Bighorn-Powder River drainage divide area located approximately 8 kilometers to the south of figure 3. The north-to-south oriented black dashed line is the Washakie-Johnson County line and can also be seen in figure 3. Note how the North Fork Powder River near the figure 4 north center edge is just beginning to turn away from that county line and flow in a southeast direction. The Denson et al map (1992) shows a southeast-oriented North Fork Powder River segment roughly following the contact (which in places is a fault line) between Precambrian bedrock (north) and Paleozoic bedrock (south), although other regional drainage routes do not appear to follow bedrock contacts or faults. Johnson Creek, which originates almost adjacent to the North Fork Powder River valley joins the North Fork Powder River to the east of figure 4. Between southeast-oriented Johnson Creek and the figure 4 east edge is a south-southeast oriented valley (near the two numbers "36") that also appears to diverge from the North Fork Powder River valley and then joins the Johnson Creek valley. In the Washington Channel Scabland Region Baker (1981) considered similar diverging and converging bedrock valleys to have been carved when large floods overwhelmed an existing drainage system and spilled across drainage divides.

A further suggestion that large south-oriented floods flowed across the region can be obtained by noting how the Bighorn-Powder River drainage divide, which in the figure 3 south half had a north-to-south orientation is almost adjacent to the southeast-oriented North Fork Powder River southwest valley wall for approximately 7 kilometers before circling around the Billy Creek headwaters. To the south of that 7-kilometer drainage divide segment are the Bader Gulch, Cabin Draw, and Billy Creek headwaters, which drain in southwest and west directions to reach south- and northwest-oriented Canyon Creek. Immediately to the north of Bader Gulch is Bear Gulch and immediately to the north of figure 4 is southwest-oriented Onion Gulch, which originates to the south of where south-oriented Webb Creek (seen in figure 3) turns to join the North Fork Powder River. More detailed topographic maps (than shown in figure 4) show drainage divide crossings that were probably eroded as multiple streams of south-oriented floodwaters spilled from the North Fork Powder River valley to reach the heads of Onion Gulch, Bader Gulch, Cabin Draw, and Billy Creek. Additional shallow drainage divide crossings suggest those closely spaced southwest- and west-oriented Canyon Creek tributary valleys most likely eroded headward from the Canyon Creek valley across massive south-oriented floods and diverted the floodwaters into Canyon Creek with headward erosion of the Billy Creek valley occurring first, Cabin Draw second, Bader Gulch third, Bear Gulch fourth, and Onion Gulch fifth.

The south-oriented Spring Creek valley and the north-to-south oriented through valley in which the north-oriented Billy Creek and Pass Creek headwaters are located provide additional clues that headward erosion of those valleys captured south-oriented flood flow. South-oriented flow in the through valley was first captured by headward erosion of the east-oriented Pass Creek valley (with a reversal of flow creating the north-oriented Pass Creek headwaters) and next by headward erosion of the west-oriented Billy Creek valley (and another reversal of flow creating the north-oriented Billy Creek headwaters). Today Spring Creek flows in a southwest- and northwest-oriented canyon to join the north-oriented Nowood River. The abrupt Spring Creek direction

change, like the Canyon Creek direction change suggests the northwest-oriented Spring Creek segment originated as a southeast-oriented stream that joined the southwest-oriented Spring Creek segment to form a south-oriented stream. The same argument can be applied to other Bighorn Mountain drainage routes, including Canyon Creek, Tensleep Creek and Otter Creek, which flow in southwest directions before turning in northwest directions, and also to the North Fork Powder River, several Crazy Woman Creek tributaries, and several Middle Fork Powder River tributaries, which flow in southeast-directions before making turns to the northeast as they enter the Powder River Basin. Each direction change, or elbow of capture, suggests a reversal of flow on what had formerly been a south-oriented Bighorn and Powder River Basin drainage route and captured a south-oriented drainage route originating in the higher Bighorn Mountains axial crest area.

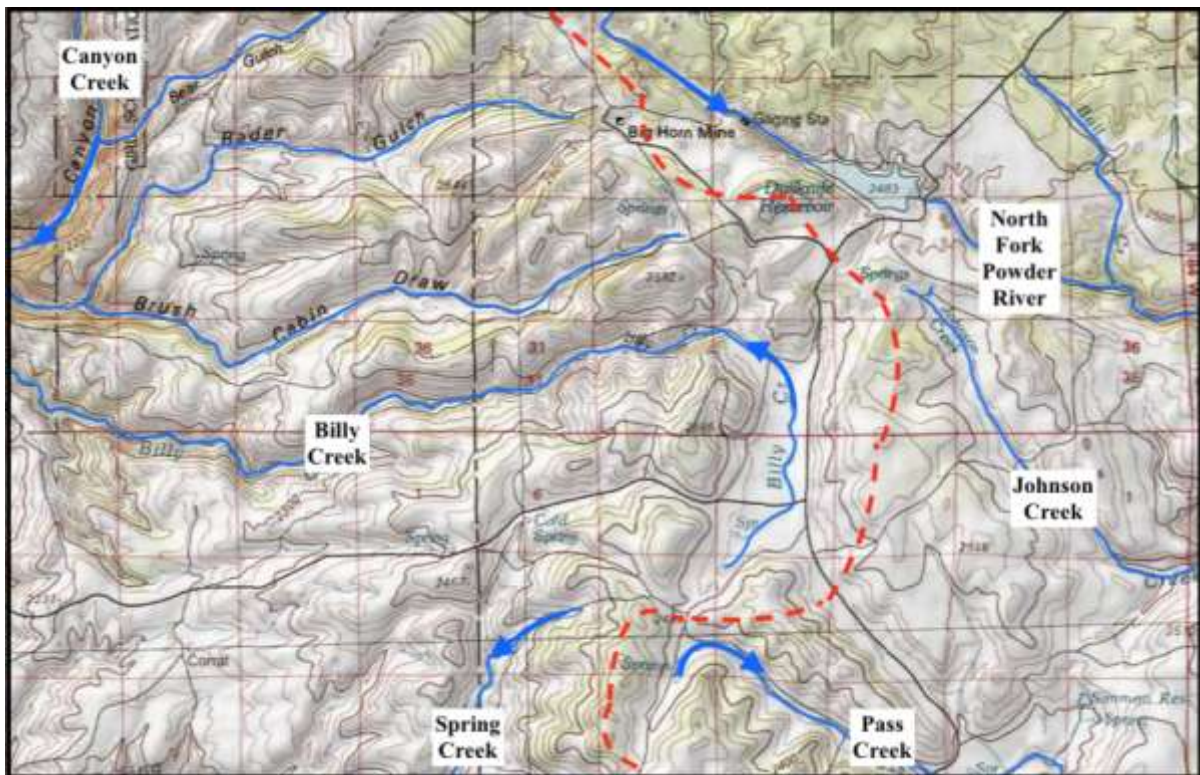


Figure 4. Modified topographic map from the USGS National Map website showing the Bighorn-Powder River drainage divide area to the south of figure 3. There is a gap of approximately 8 kilometers between figures 3 and 4. The dashed red line shows the Bighorn-Powder River drainage divide and arrows show drainage directions. Contour interval is 20 meters

3.4 Pass Creek, Beartrap Creek, Otter Creek Headwaters Area

Figure 5 provides a detailed topographic map showing water-eroded drainage divide crossings linking the North Fork Powder River, Middle Fork Powder River, and Bighorn River drainage basins and includes Pass Creek headwaters seen in figure 4. Pass Creek to the east of figure 4 turns in a southeast direction and joins the North Fork Powder River. Beartrap Creek to the south of figure 5 flows in a south-southeast direction to join the south-southeast oriented Red Fork Powder River, which joins the northeast- and east-oriented Middle Fork Powder River. Spring Creek is a south-, southwest-, and northwest-oriented Nowood River tributary. Otter Creek to the southwest of figure 5 flows in a south-southwest, west, and northwest direction to join the Nowood River. The dry valley or drainage divide crossing at the red letter “A” links the north-oriented Pass Creek headwaters with a west-oriented Spring Creek tributary, with North Fork Otter Creek headwaters, and to the south of point “A” with an unnamed south- and west-oriented Otter Creek tributary. The red letter “B” identifies another dry valley now crossing the Bighorn-Powder River drainage divide and the red letter “C” identifies a dry valley crossing the North Fork-Middle Fork Powder River drainage divide. Similar dry valleys cross drainage divides throughout the study region and were most likely eroded by diverging and converging flood flow channels (such as are found in flood formed anastomosing channel complexes).

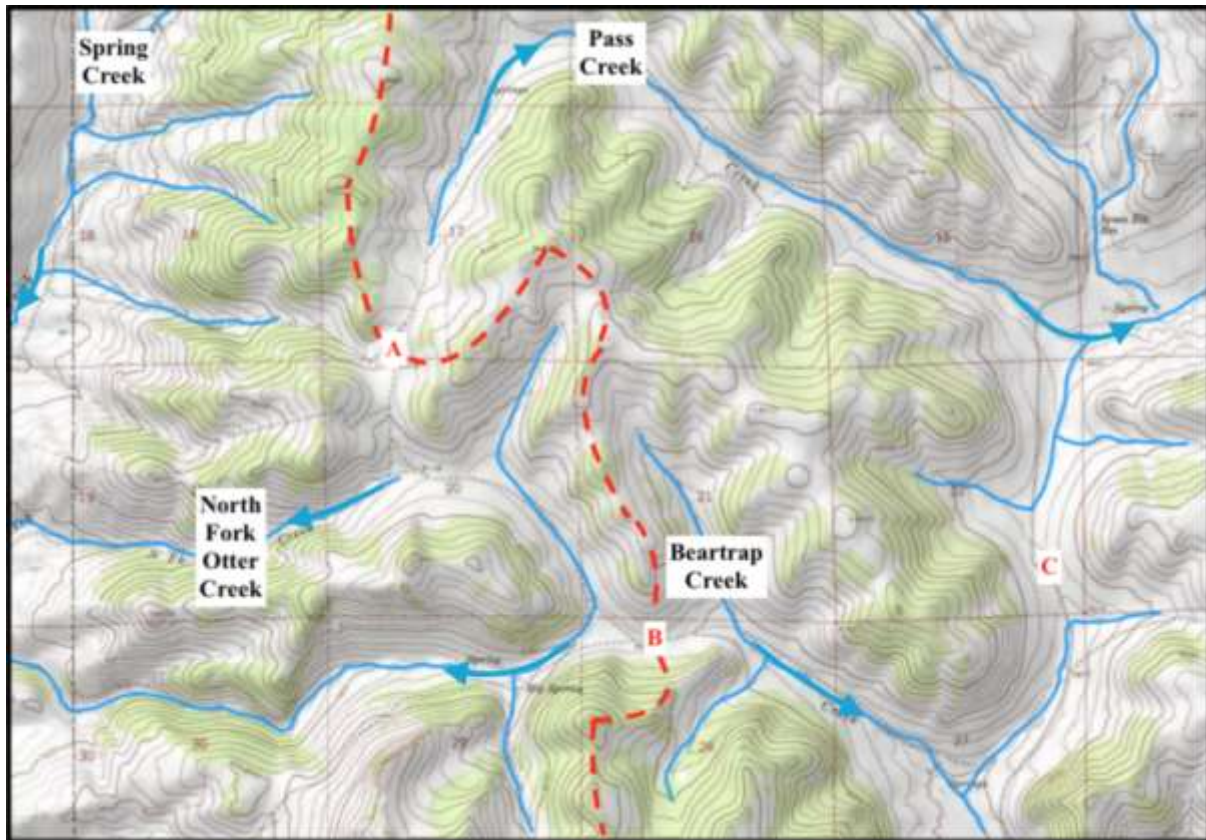


Figure 5. Modified detailed topographic map from the USGS National Map website showing the Pass Creek headwaters area. The red dashed line shows the Bighorn-Powder River drainage divide location. The red letters A, B, and C identify dry valleys discussed in the text. Sides of the red grid squares are 1 mile (1.6 km) in length. The contour interval is 40 feet (12 meters)

3.5 Evidence of Possible Flood Transported and Deposited Alluvium

Other evidence of large floods was found on geologic maps and in literature descriptions. Darton (1906) was the first to map and describe pockets of alluvium and he commented that at several “localities along the middle slopes of the Bighorn Mountains there are deposits of sands, volcanic ash, gravel, and [boulders] which are older than the glacial drift of the early Quaternary and therefore provisionally classed in the Tertiary system. Some of the deposits are older than others, but it has not been possible to classify them satisfactorily. One of the most remarkable areas caps a portion of the main divide between the heads of [the] North Fork of Powder River and Canyon Creek, at an altitude from 8700 to 9100 feet” [2652 to 2743 meters and located in the Canyon Park region, which is seen in figure 3]. A measured section made a short distance to the southwest of the figure 3 southwest corner and described by Darton measured 60 feet [18 meters] of crystalline rock gravel with volcanic ash lenses near the base and occasional boulders up to 2 feet [60 cm] in diameter on top of 73 feet [22 meters] of indistinctly stratified volcanic ash and rock fragments, which was on top of 22 feet [7 meters] of a lime carbonate cemented conglomerate containing well rounded boulders up to 4 feet [122 cm] in diameter.” At a nearby location another “deposit similar to those at the head of Powder River is exposed on the North Fork of Crazy Woman Creek... It consists partly of light-colored sandy loam with hard concretions and partly of a conglomerate of boulders with carbonate of lime cement. It is similar to some of the Oligocene deposits in the Black Hills, so it is provisionally correlated with them, the deposit appears to occupy a depression in granite and to be of limited extent, but possibly it extends southeastward under the cap of high-terrace gravels extending to the head of Billy Creek.”

Geologic maps show similar high-level alluvial deposits throughout the Bighorn Mountains in the 2- to 3-kilometer elevation range. Subsequent investigators have collected Oligocene and Miocene vertebrate fossils at several of those locations (e.g., McKenna and Love, 1972). Based on McKenna and Love interpretations Denson et al. (1992) mapped the Canyon Park alluvium as the lower Miocene Arikaree Formation and some other

alluvial deposits to be Oligocene White River Formation, although Love and Christiansen (1985) mapped the Canyon Park deposit as White River Formation. Probably because some of the deposits contain both Oligocene and early Miocene fossils the Ver Ploeg et al maps show such deposits as possible White River Formation. The correlation of high-level Bighorn Mountains alluvial deposits with Tertiary units elsewhere raises two interesting questions. First, if the Bighorn and Powder River Basins were filled with 1.5 kilometers of sediments, as previous investigators have suggested and as the commonly accepted paradigm implies, then how is it possible for high-level Bighorn Mountains alluvial deposits to correlate with sedimentary units now exposed at much lower elevations? The geologic literature does not provide answers.

The second interesting question is, if the correlations of high-level Bighorn Mountains alluvium with the Oligocene White River Formation and lower Miocene Arikaree Formation are correct, and if as the new paradigm predicts and (and this paper suggests), south-oriented floods moved across a rising Bighorn Mountains range and deposited that alluvium, then did south-oriented floods also deposit Oligocene White River Formation and early Miocene Arikaree Formation sediments now found at much lower elevation locations? An answer is beyond the scope of the study reported here, but literature descriptions and personal field observations indicate rounded boulders and other coarse-grained alluvium are present at lower elevation Oligocene White River Formation locations. In fact, it was anomalous alluvium found at mapped and much lower elevation southwest North Dakota and northwest South Dakota White River Formation deposits (described in Clausen, 1989) that eventually led to the new regional geomorphology paradigm and the study reported here.

4. Discussion

Mountain passes and other divide crossings along a Bighorn-Powder River drainage divide segment extending from the high elevation Bighorn Mountains glaciated area southward to a subsummit erosion surface area document where multiple and sometimes closely spaced streams of water once flowed across the high Bighorn Mountains crest that now stands 1.5 to almost 3.0 kilometers above the surrounding region. The mountain passes and other divide crossings, shallow diverging and converging valleys now carved into the subsummit erosion surface, and the presence of previous investigator mapped alluvial deposits strongly supports a recently proposed regional geomorphology paradigm prediction that large south-oriented floods once crossed what are now the high Bighorn Mountains, although the flood source could not be determined from the study region map evidence. The question of where the floodwater came from provides an opportunity to illustrate how two fundamentally different regional geomorphology paradigms lead to fundamentally different flood source interpretations.

Previous investigator interpretations based on commonly accepted paradigm rules suggest up to 1.5 kilometers of now absent middle Tertiary sediments once filled the Bighorn and Powder River Basins to the subsummit erosion surface level (about 2750 meters) with higher elevation Bighorn Mountains areas rising hundreds of meters above that surface. Today the highest peaks rise to elevations greater than 3750 meters and within the higher elevation areas most divide crossings are significantly higher than 2750 meters. Floods from late Cenozoic snowmelt and heavy rains could have reached and flowed across the subsummit erosion surface, however those floodwaters could not have reached and eroded the mountain passes and other divide crossings now notched into the higher elevation Bighorn-Powder River drainage divide segments. While previous investigators have never said so most if not all of those high elevation mountain passes and other divide crossings must have been eroded much earlier in geologic history. Also, if 1.5 kilometers of middle Tertiary sediments did once fill the Bighorn and Powder River Basins, as previous investigators have suggested, there are the unanswered questions of how were those vast quantities of sediment removed and where are those sediments today?

In contrast the recently proposed paradigm does not require the Bighorn and Powder River Basins to have been filled above the level of existing erosional remnants (e.g. Tatman Mountain in the Bighorn Basin and Pumpkin Buttes in the Powder River Basin) and instead requires regional and Bighorn Mountains uplift to have occurred as massive melt water floods flowed across a rising deep "hole" rim. The deep "hole" rim developed when a thick North American continental ice sheet caused crustal warping that raised mountain ranges and plateaus. The deep "hole's" southwest rim followed what today is the North American east-west continental divide from northern Colorado across Wyoming and Montana and into Canada. Initially melt water floods flowed in south directions across that rising rim, although as uplift progressed floodwaters were diverted in southeast directions. For example, the North Platte River abrupt direction change seen in figure 1 occurred because Colorado mountain range uplift blocked and reversed a southeast-oriented flood flow route to create what is today the northwest-oriented North Platte River headwaters (to the south of figure 1). In time as uplift progressed and ice sheet melting opened up deep "hole" space deep north-oriented valleys (including the Yellowstone valley and its tributary Powder River and Bighorn River valleys) eroded headward from deep "hole" space to divert massive

southeast-oriented meltwater floods into and across the deep “hole” floor. The resulting reversal of Powder River and Bighorn Basin flood flow explains barbed tributaries and elbows of capture now seen on many Bighorn Mountains area drainage routes.

The question can validly be asked, when during geologic time did the thick North American ice sheet that created and occupied a deep “hole” exist? Previous investigators have correlated what is probably high elevation Bighorn Mountains flood deposited alluvium with lower elevation Oligocene and lower Miocene sediments. From the new paradigm perspective that correlation suggests a similar melt water flood origin for those comparable Oligocene and lower Miocene deposits. If so, the new paradigm and the commonly accepted regional paradigm require fundamentally different absolute time intervals to have occurred between the Oligocene and lower Miocene sediment deposition and the present. In addition, while the commonly accepted paradigm sees several late Cenozoic North American glacial and interglacial episodes the recently proposed regional geomorphology paradigm only sees two linked North American continental ice sheets with the thick continental ice sheet that created and occupied a deep “hole” being the first. Late in that thick ice sheet’s melt history the immense south-oriented melt water floods were diverted to flow in north directions into and across the deep “hole” floor and around decaying first ice sheet remnants to reach northern oceans. Diversion of the massive south-oriented melt water floods and other drainage to the north changed climatic conditions with the result that floodwaters and other drainage froze between the first ice sheet remnants, which created a second and much thinner continental ice sheet composed of first ice sheet remnants embedded in frozen north-oriented floodwaters and other drainage.

5. Conclusion

Kuhn (1970) describes paradigms as fundamentally different frameworks of rules and ideas governing how scientific disciplines conduct their research. Any newly proposed paradigm to be accepted must demonstrate an ability to explain previously unexplained evidence. The study reported here tested a recently proposed regional geomorphology paradigm prediction that large continental ice sheet melt water floods once flowed in south directions across a rising Bighorn Mountains range and investigated evidence on detailed topographic maps showing a Bighorn-Powder River drainage divide segment stretching southward from high glaciated Bighorn Mountains areas to the subsummit erosion surface area. The test found numerous divide crossings indicating multiple and sometimes closely spaced streams of water had once crossed the highest Bighorn-Powder River drainage divide segments. In addition, the maps show the subsummit erosion surface to be crossed by diverging and converging bedrock channels, typical of flood formed anastomosing channel complexes, and also identified previous investigator mapped and described alluvial deposits characteristic of flood deposited materials. While a water source and many other flood details could not be determined from the study region map evidence, the new paradigm test determined large south-oriented floods did once flow across the high Bighorn Mountains.

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