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Yellowstone Region Drainage History as Determined from the 1955 Ashton, Idaho, Montana, and Wyoming 1:250,000 Scale Topographic Map, USA

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Abstract

The United States Geological Survey (USGS) 1955 (revised in 1972) Ashton topographic map (Ashton map) with a 1:250,000 scale and a 200-foot (about 60-meter) contour interval covers almost all of Yellowstone National Park and some adjacent regions to the south and west. In spite of numerous publications discussing Yellowstone region geologic history the drainage system and erosional landform evidence on the Ashton map appears to have been ignored. Drainage divides identifiable on the Ashton map separate the north-oriented Yellowstone, Gallatin, Madison, and Jefferson River drainage basins (which are located to the north and east of the continental divide with their water flowing to the Missouri River and ultimately the Gulf of Mexico) from the south-oriented Snake River drainage basin (with its water eventually reaching the Pacific Ocean). The Ashton map shows water-eroded passes and through valleys which link diverging and converging valleys which drain in opposite directions from the continental divide. These diverging and converging valleys suggest large volumes of south-oriented water once flowed across the Yellowstone region continental divide and some other Ashton map drainage divides. The accepted geology and glacial history paradigm (accepted paradigm) cannot satisfactorily explain the Ashton map drainage system and erosional landform evidence, which may be why geomorphologists have never addressed the map evidence. A new and fundamentally different geology and glacial history paradigm requiring the Yellowstone region to be located on the rim of a continental ice sheet created and occupied deep “hole” (which was uplifted as immense meltwater floods flowed across it) explains Ashton map drainage system and erosional landform evidence, but raises questions about previously published Yellowstone region geologic histories.

Keywords

Continental Divide, Firehole River, Gallatin River, Geomorphology, Madison River, Snake River

1. Introduction

1.1. Statement of the Research Problem

The United States Geological Survey (USGS) Ashton, Idaho, Montana, and Wyoming 1:250,000 scale topographic map [1] with a contour interval of 200 feet (about 60 meters) was published in 1955 and revised in 1972. The map (referred to here as the Ashton map) covers almost all of Yellowstone National Park and includes adjacent regions to the west and south. Topographic mapping of Yellowstone National Park began in the late 19th-century and resulted in the 1:125,000 scale and 100-foot (about 30-meter) contour interval Canyon [2], Gallatin [3], Lake [4], and Shoshone [5] topographic map sheets which were included in the 1896 USGS Yellowstone National Park Folio of the Geologic Atlas of the United States [6]. However, topographic map coverage for areas west of Yellowstone National Park did not become available until publication of the 1955 Ashton map. Today, newer and more detailed topographic maps cover the entire Ashton map region.

For mid 20th-century geomorphologists the 1955 Ashton map offered an important new source of drainage system and related landform information. The Ashton map showed drainage system and erosional landform evidence over a much larger region than any single previously published Yellowstone National Park topographic map. Further, the Ashton map provided a more accurate and complete representation of Yellowstone region drainage systems and landform features than what previously published topographic maps had showed. Yet, surprisingly in spite of extensive Yellowstone region geological studies, geomorphologists do not appear to have used drainage system and related evidence on the Ashton map (or on older or more recent topographic maps of the same region) to interpret and then publish a detailed Yellowstone region drainage history.

The failure of mid 20th-century geomorphologists to use available topographic map evidence to publish a Yellowstone region drainage history is not unique to the Yellowstone region. According to Clausen [7] in spite of excellent topographic maps covering the entire United States geomorphologists almost never address topographic map drainage system and erosional landform evidence (anywhere). Clausen attributes this failure to an inability of the accepted Cenozoic geology and glacial history paradigm (accepted paradigm) to satisfactorily explain most of the well-mapped topographic map drainage system and erosional landform evidence. While usually not stated, the ignored topographic map drainage system and erosional landform evidence is what Thomas Kuhn [8] refers to as anomalous evidence, or evidence a scientific discipline's accepted paradigm cannot satisfactorily explain. According to Kuhn, anomalous evidence can lead to the development of a new paradigm which is able to explain what the discipline's accepted paradigm cannot satisfactorily explain.

Clausen's book [7] describes a new Cenozoic geology and glacial history paradigm (new paradigm) which was developed by using Missouri River drainage basin topographic map evidence and which after extensive testing appears to explain most if not all of the topographic map drainage system and erosional landform evidence, but which is fundamentally different from the accepted paradigm. The goal of the study reported here is to determine if from the new paradigm's perspective, there is a consistent set of explanations for the Ashton map drainage system and erosional landform evidence and if so to use those explanations to construct a Yellowstone region drainage history.

1.2. Geographic Setting

The Ashton map as seen in **Figure 1** covers Wyoming's northwest corner and Montana and Idaho areas immediately to the west. The map area includes most, but not all of Yellowstone National Park. Almost all map areas exceed 2000 meters in elevation (with many areas being several hundred meters higher) and includes mountains exceeding 3000 meters in elevation. To the west of the Wyoming

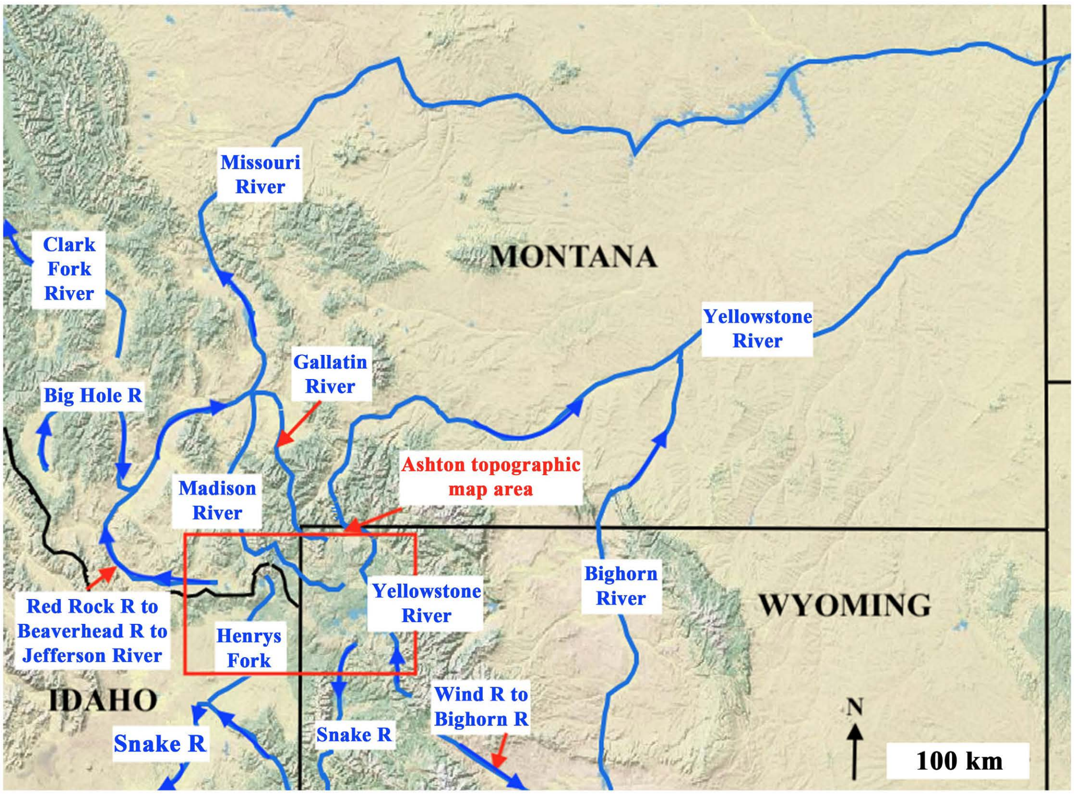

Figure 1. Modified map from the United States Geological Survey (USGS) National Map website showing the Ashton map area (red rectangle) location in relation to Idaho, Montana, and Wyoming boundaries and major regional drainage routes discussed in the text.

border, but still on the Ashton map, the Idaho-Montana border is located along the east-west continental divide which separates north-oriented Madison and Jefferson River drainage from south-oriented Snake River drainage. In Wyoming the continental divide extends in what could be considered to be a southeast direction across the Ashton map area and separates north-oriented Madison and Yellowstone River drainage from south-oriented Snake River drainage.

The Madison, Gallatin, and Red Rock-Beaverhead-Jefferson Rivers and the Snake River begin in the Ashton map area while the Yellowstone River begins further to the south and then flows in a north direction across the Ashton map area. Outside of the Ashton map area the Madison, Gallatin, and Red Rock-Beaverhead-Jefferson Rivers flow along separate north-oriented routes (separated by high mountains) to converge (at Three Forks) and form the north-oriented Missouri River. While beginning on the Ashton map as a west-oriented drainage route the Red Rock River flows in west direction and leaves the Ashton map area before turning in a northwest direction to join the northeast Beaverhead River which after being joined by the Big Hole River becomes the northeast-oriented Jefferson River. To the north of the south-oriented Big Hole River segment is Deer Lodge Pass (unlabeled in **Figure 1**) which crosses the continental divide and which separates north- and northwest-oriented Clark Fork River drainage (flowing to the Pacific Ocean) from south-oriented Big Hole River drainage (flowing to the Gulf of Mexico). To the south of the Red Rock River's turn to the northwest is unlabeled Monida Pass which also crosses the continental divide and which separates north-oriented drainage to the Gulf of Mexico from south-oriented drainage to the Snake River (water in which eventually reaches the Pacific Ocean).

The Yellowstone River begins in high mountains to the south of the Ashton map area and flows in north and northwest directions across the Ashton map's easternmost section, although its route is interrupted by Yellowstone Lake. To the south of Yellowstone Lake, the continental divide is located between south-oriented Snake River headwaters (flowing to the Pacific Ocean) and north-oriented Yellowstone River headwaters (flowing to the Gulf of Mexico). To the south of the Yellowstone River headwaters are southeast-oriented Wind River headwaters which to the south of **Figure 1** make a U-turn to flow in a deep canyon cut across the Owl Creek Mountains (Wind River Canyon) and to become the Bighorn River. Likewise, to the south of **Figure 1** the Snake River turns in a north direction to join south-oriented Henrys Fork before turning in a south direction and then in an east direction to flow across southern Idaho before turning in a north direction to eventually reach the Columbia River which flows to the Pacific Ocean.

2. Previous Literature

The 1896 USGS Yellowstone National Park Folio [6] discussion section (written by Hague) briefly addresses the then known Yellowstone region glacial evidence.

In a subsequent publication Hague [9] described evidence that lava flows and glacial ice dammed the Yellowstone River to create Yellowstone Lake which then overflowed to the south. More recently Pierce *et al.* [10] who based their publication on previous work by Pierce [11], Sturchio *et al.* [12] and others noted that "the glaciation of Yellowstone had two modes; 1) a mode during both the early and late part of a glacial cycle when glaciers formed and flowed down valleys from the mountains surrounding the Yellowstone Plateau, and 2) a climax mode when a large ice cap built up on the Yellowstone Plateau to a thickness of more than 1000 m (3000 ft) and dominated the glacial flow from the surrounding mountains." Richmond [13] commented that "the Quaternary glaciers in Yellowstone Park originated in sources on high plateaus northeast and southeast of the park and in the Gallatin Range." A Pierce *et al.* [10] map suggests that glaciers 17,000 years ago covered much of what is today's Yellowstone River drainage basin within Yellowstone National Park and spilled over into the Firehole River drainage basin to the west and into the Snake River drainage basin to the south.

Among early drainage history interpretations Goode [14] identified several possible Yellowstone Lake southern outlets and noted the upper Yellowstone and Lamar River valleys are old and were developed before rhyolite lavas covered much of the Yellowstone Plateau. Goode also proposed that headward erosion of a north-oriented Lamar River tributary into what was a south-draining Yellowstone Lake basin (following the end of glaciation) shifted the continental divide from north of the lake to south of the lake. Howard [15] argued the southern lake outlets were only used when ice blocked the northern drainage route. In either case Fenneman [16] noted the now north-oriented upper Yellowstone valley (located to the south of Yellowstone Lake) was "not reached by the rhyolite flows, [and] is several miles [kilometers] wide and has a swampy flood plain".

Most Yellowstone region topographic map drainage system evidence has never been addressed, although publications imply the Yellowstone region drainage system origin is well known. For example, Hamilton [17] states "During early Tertiary time, varied volcanic rocks were deposited upon the eroded Laramide uplifts of the Yellowstone region. During the middle Tertiary, these uplifts and the volcanic rocks, were segmented obliquely by block faults, and the present mountain ranges were inaugurated... During the Pliocene, an ancestral Yellowstone Plateau, [was] at about the same elevation as the present one." According to Shapiro and Koulakov [18] "The Yellowstone complex is made of large calderas generated by several explosive eruptions. The three largest eruptions occurred 2.1 million years ago (Ma), 1.3 Ma, and 640,000 years ago, forming the Island Park caldera, the Henry's Fork caldera, and the Yellowstone caldera, respectively." Pierce and Morgan [19] link Yellowstone region uplift with the Yellowstone hot spot arrival and suggest "The track of the Yellowstone hot spot is represented by a systematic northeast-trending linear belt of silicic, caldera-forming volcanism that arrived at Yellowstone 2 Ma".

Pierce *et al.* [10] claim that "Before arrival of the hotspot, an older landscape existed, particularly mountains created during the Laramide orogeny about 70 - 50 Ma and volcanic terrain formed by Absaroka andesitic volcanism mostly between 50 - 45 Ma. These landscapes were more muted than the present hotspot modified landscape because the Laramide-age mountains had worn down and an erosion surface of low relief had developed on the Absaroka volcanic terrain." And Christiansen [20] claims that once the hot spot had arrived "The Yellowstone Plateau volcanic field…evolved through three cycles during the past 2 m. y. Each cycle began and ended with protracted periods of episodic eruptions of rhyolitic lava but climaxed with an explosive caldera-forming pyroclastic eruption of…rhyolitic magma, mainly as ash flows. These climactic eruptions occurred about 2.0, 1.3, and 0.6 m. y. B.P.".

Pierce and Morgan [19] without mentioning any of the Yellowstone region topographic map drainage system and erosional landform evidence claim in a review paper that uplift associated with the arrival of the Yellowstone hot spot altered drainage routes to the north and east of the Yellowstone region. Their literature summary states "Abandoned terraces of many drainages east and north of Yellowstone record a history of stream displacement, either by capture or slip off, that tends to be away from the Yellowstone crescent… Three main processes have been evoked to explain unidirectional stream migration: 1) greater supply of sediment, particularly coarse gravel, by tributaries on one side of a stream, 2) migration down-dip, particularly with interbedded erodible and resistant strata, and 3) tectonic tilting with lateral stream migration driven either by sideways tilt of the stream or…by increased or decreased sediment supply to the trunk stream depending on whether tributary streams flow in or opposed to the direction of tilt."

Some more recent regional drainage system interpretations include proposals by Sears [21] and Sears and Beranek [22] based on detrital zircon and other evidence (but not a study of topographic map evidence) that the Colorado River in Oligocene-Miocene time turned in the Arizona Grand Canyon region to flow in a north direction across an area to the west of Yellowstone National Park and then through what is today Montana's north-oriented Missouri River valley before flowing across Canada to reach the Labrador Straits. Detrital zircon evidence led Staisch [23] to propose that the Snake River might have once flowed in a north direction in the region to the west of Yellowstone National Park to reach what is today the north- and northwest-oriented Clark Fork River. These proposals do not address any of the regional topographic map drainage system and erosional landform evidence and do not directly relate to drainage systems in the Ashton map area (except possibly in its westernmost section) but they do illustrate how accepted paradigm researchers are ignoring topographic map drainage system and erosional landform evidence and looking for evidence of preglacial north-oriented drainage systems.

Clausen's book [7] points out how the accepted geology and glacial history paradigm has not permitted geomorphologists to explain most topographic map drainage system and erosional landform evidence. The book also introduces a fundamentally different Cenozoic geology and glacial history paradigm which has been remarkably successful in explaining previously unexplained Missouri River drainage basin topographic map drainage system and erosional landform evidence. Unlike the accepted paradigm the new paradigm requires a thick North American continental ice sheet (located approximately where ice sheets are usually interpreted to have been) which created and occupied a deep "hole". Immense meltwater floods first flowed across and then along a rising deep "hole" rim before being diverted to flow on the deep "hole" floor toward what eventually became the deep "hole's" only southern exit (the Mississippi River valley). The deep "hole" rim is today the east-west continental divide from the Canadian border southward to the Arkansas River drainage basin southern boundary and then eastward to the Mississippi River valley. To the east of the Mississippi River valley the deep "hole" rim follows what is today the Atlantic Ocean-Gulf of Mexico drainage divide in an east and then northeast direction.

The new paradigm predicts immense south-oriented meltwater floods flowed across the Ashton map area until deep "hole" rim uplift combined with ice sheet melting (which opened-up deep "hole" space) reversed the south-oriented flow and diverted the water toward southern deep "hole" exits. Clausen's book [7] lists published papers which demonstrate the new paradigm's ability to explain detailed topographic map drainage system and erosional landform evidence at more than 40 modest sized continental United States geographic locations. One such paper [24] interprets topographic map evidence to show that immense south-oriented floods carved the mountain passes now crossing continental divide segments surrounding the Beaverhead and Big Hole River drainage basins (see **Figure 1**). Another paper [25] interprets topographic map evidence to show that immense south-oriented floods eroded mountain passes now crossing continental divide segments surrounding the Boulder River drainage basin (located to the east of the Clark Fork River headwaters seen in **Figure 1**). And a third paper [26] interprets topographic map evidence to show that immense south-oriented floods eroded mountain passes crossing continental divide segments surrounding the upper Sun River drainage basin (located in **Figure 1** to the west of where the Missouri River turns from flowing in a northwest direction to flow in a northeast direction).

3. Research Method

This study addresses drainage system and erosional landform features as recorded on the 1972 revised version of the 1:250,000 scale Ashton, Idaho, Montana, and Wyoming topographic map which has a 200-foot (about 60-meter) contour interval. The map was obtained from the USGS topoView website. A spot elevation tool and newer and more detailed topographic maps available at the USGS National Map website were used when obtaining elevation data. The

Ashton map drainage system and erosional landform features were assumed to be accurately shown (at least to the level of resolution possible with a 1:250,000 scale and a 200-foot or 60-meter contour interval). For purposes of illustrating the drainage system and erosional landform evidence in this paper the Ashton map was subdivided into a western region partially seen in Figure 2, a central region partially seen in Figure 3 and Figure 4, and an eastern region partially seen in Figure 5 and Figure 6.

Most topographic map interpretation methods used were first developed by different geomorphologists during the early 20th-century. The study of each Ashton map section began by identifying major drainage divides and obvious passes or through valleys that now cross those drainage divides. The east-west continental divide location is shown on the Ashton map, although map drainage system and contour lines had to be used to determine other drainage divide locations. Passes and through valleys crossing the identified drainage divides were assumed (unless there was reason to believe otherwise) to have been eroded by

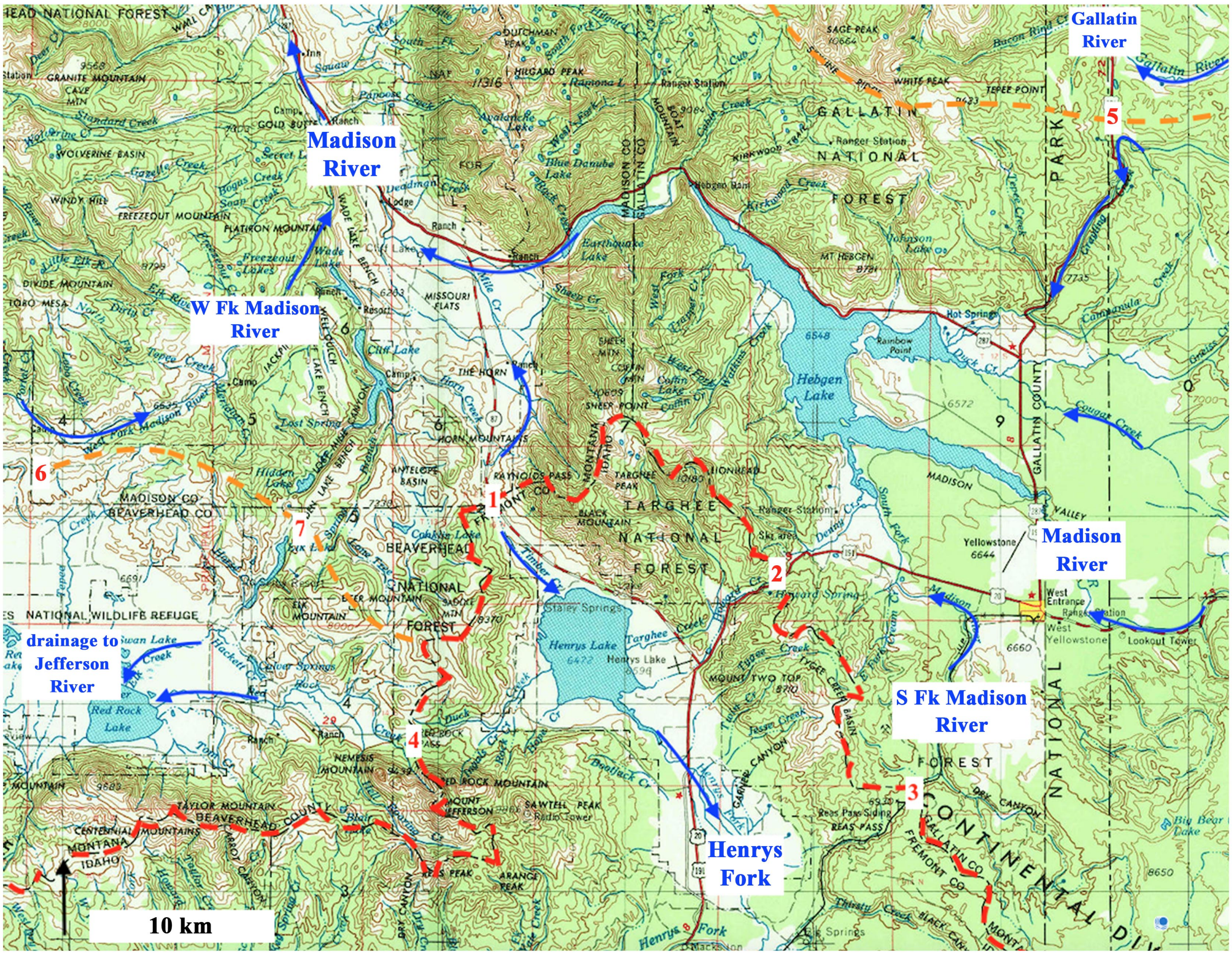

Figure 2. Modified section of the USGS Ashton map [1]. The red dashed line emphasizes the east-west continental divide and orange dashed lines show other major drainage divides. Red numbers identify passes and through valleys discussed in the text. Blue arrows emphasize present-day flow directions. The contour interval is 200 ft (about 60 m).

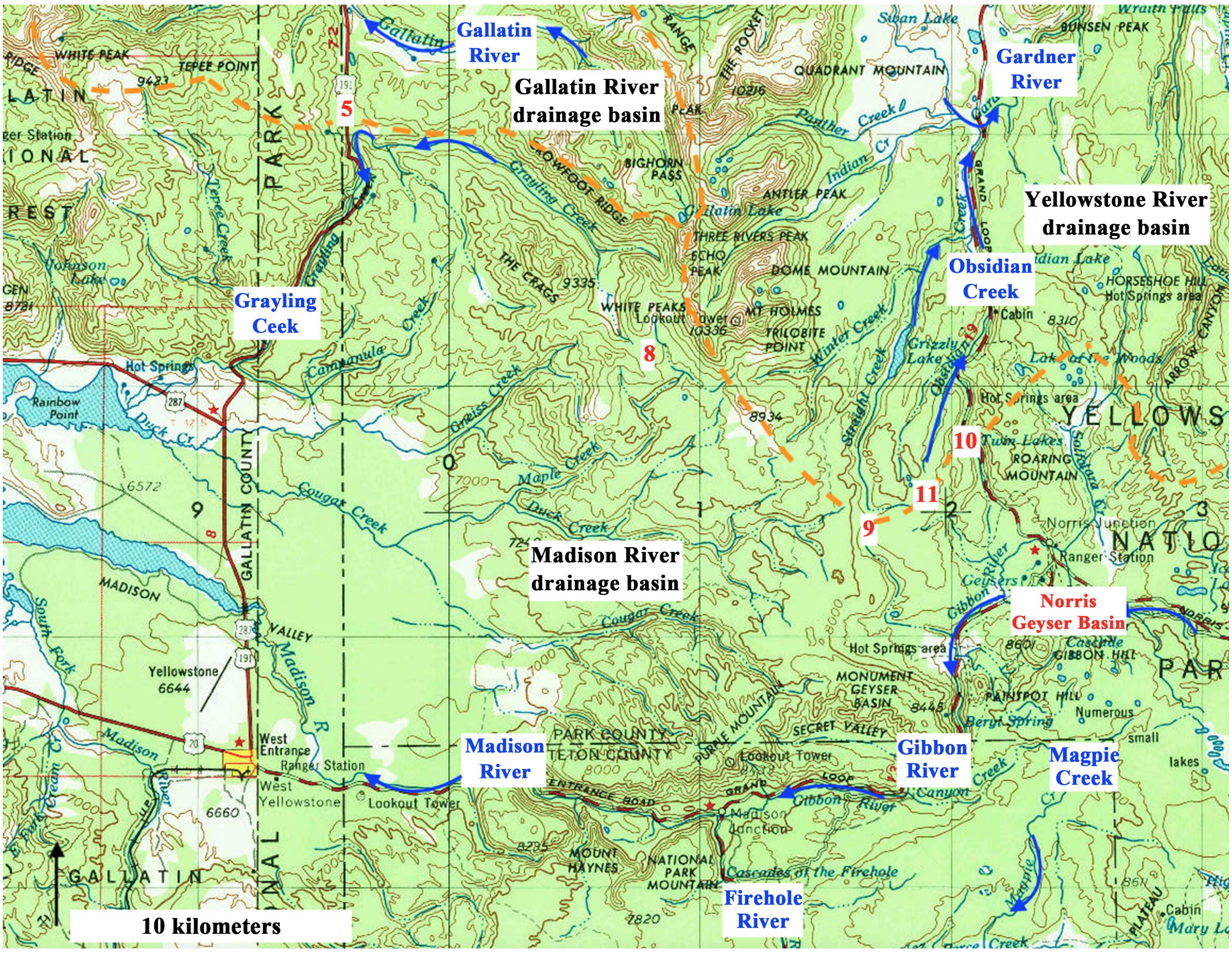

Figure 3. Modified section of the USGS Ashton map [1] located east of overlapping Figure 2. Blue arrows emphasize present-day flow directions. The dashed orange lines show major drainage divides. Red numbers identify through valleys and passes discussed in the text. The contour interval is 200 ft (about 60 m).

streams of water flowing in one direction or the other. Passes and through valleys crossing major drainage divides were noted to almost always link drainage routes now flowing in opposite directions. The assumption was made that unless map evidence suggested otherwise the drainage divides developed when regional uplift forced a flow reversal in one of the opposing stream valleys (which then created the drainage divide).

Tributaries to drainage routes on either side of the passes and through valleys (which today cross the major drainage divides) were studied to determine probable former flow directions. Barbed tributaries were considered to be evidence of a possible trunk stream drainage reversal. Combinations of barbed and normal tributaries were used to determine if prior to a drainage reversal water had once flowed in a complex of diverging and converging channels. This determination could be made if the valley of what is today a normal tributary was linked by a through valley (now crossing a secondary drainage divide) with the valley of what is today a barbed tributary. Pass and through valley depths were used to

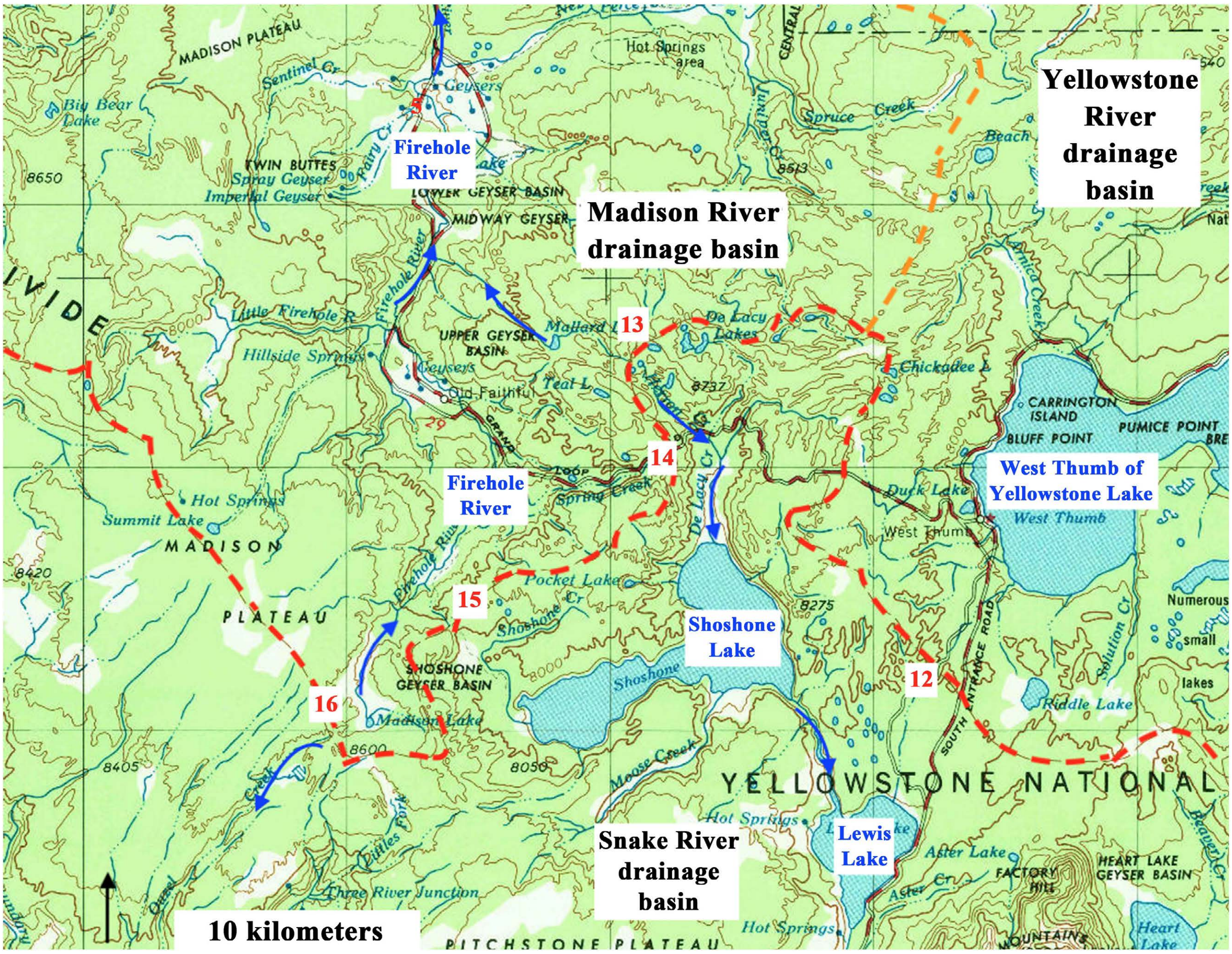

Figure 4. Modified section of the USGS Ashton topographic map [1] located to the south of Figure 3. Blue arrows emphasize present-day drainage route flow directions. The red dashed line emphasizes the continental divide and the orange dashed line shows the Madison River-Yellowstone River drainage divide. The contour interval is 200 ft (about 60 m).

determine today's elevation of the surface on which the drainage routes responsible for eroding the passes and through valleys had initially flowed. The present-day elevation of that former regional surface was then used to estimate the amount of uplift that occurred prior to the interpreted flow reversals that created today's drainage system.

4. Results

4.1. Western Ashton Map Evidence

Figure 2 shows a modified section of the Ashton map western area with a labeled north-to-south oriented line on the map (located near the figure easternmost margin and slightly to the west of the Wyoming state line) showing the Yellowstone National Park western border. Blue arrows have been added to emphasize some present-day drainage route flow directions. An added red dashed line emphasizes the continental divide and added orange dashed lines show drainage divides between the north-oriented Gallatin, Madison, and Jefferson

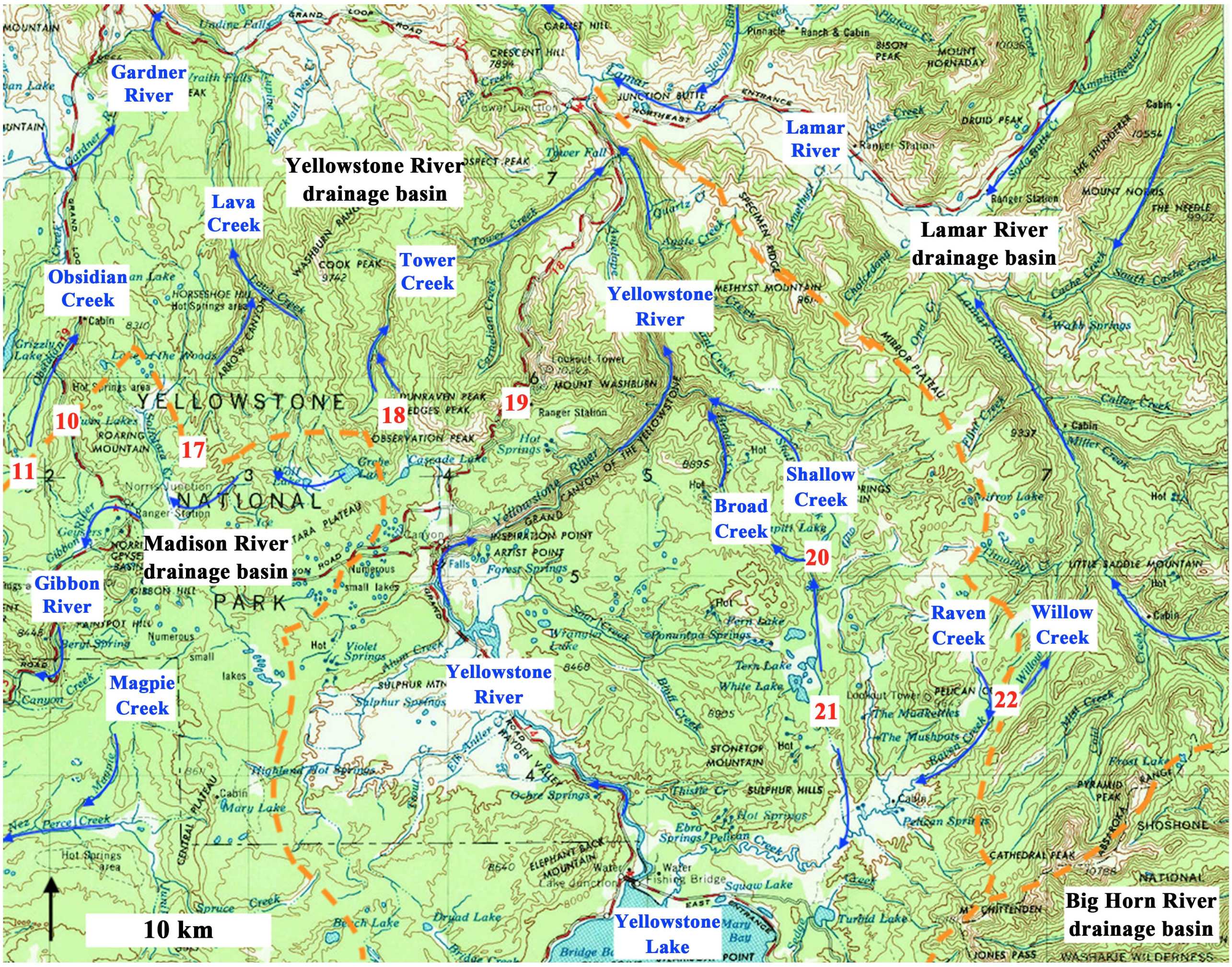

Figure 5. Modified section of the USGS Ashton map [1] which is located to the east of overlapping Figure 3. Blue arrows emphasize present-day flow directions. Dashed orange lines show major drainage divide locations and red numbers identify passes and through valleys discussed in the text. The contour interval is 200 feet (or about 60 meters).

River drainage basins. The Gallatin, Madison, and Jefferson Rivers meet to the north of the figure (at Three Forks) to form the Missouri River which as seen in Figure 1 flows in a north direction before turning to roughly follow the southwest margin of continental ice sheet deposited materials. The continental divide in this figure separates north-oriented drainage to the Missouri River (where water now flows to the Mississippi River and then the Gulf of Mexico) from south-oriented drainage to Henrys Fork of the Snake River (where water now flows to the Columbia River and then to the Pacific Ocean).

Added red numbers identify passes and through valleys crossing major drainage divides as follows: 1) Raynolds Pass with a floor elevation of about 2086 m, 2) Targhee Pass with a floor elevation of about 2156 m and which is not named on the map, 3) Rheas Pass with a floor elevation of about 2110 m, 4) Red Rock Pass with a floor elevation of about 2180 m, 5) an unnamed through valley (along the Wyoming-Montana state line) with a floor elevation of about 2213 m and linking the north-oriented Gallatin River with south-oriented Grayling

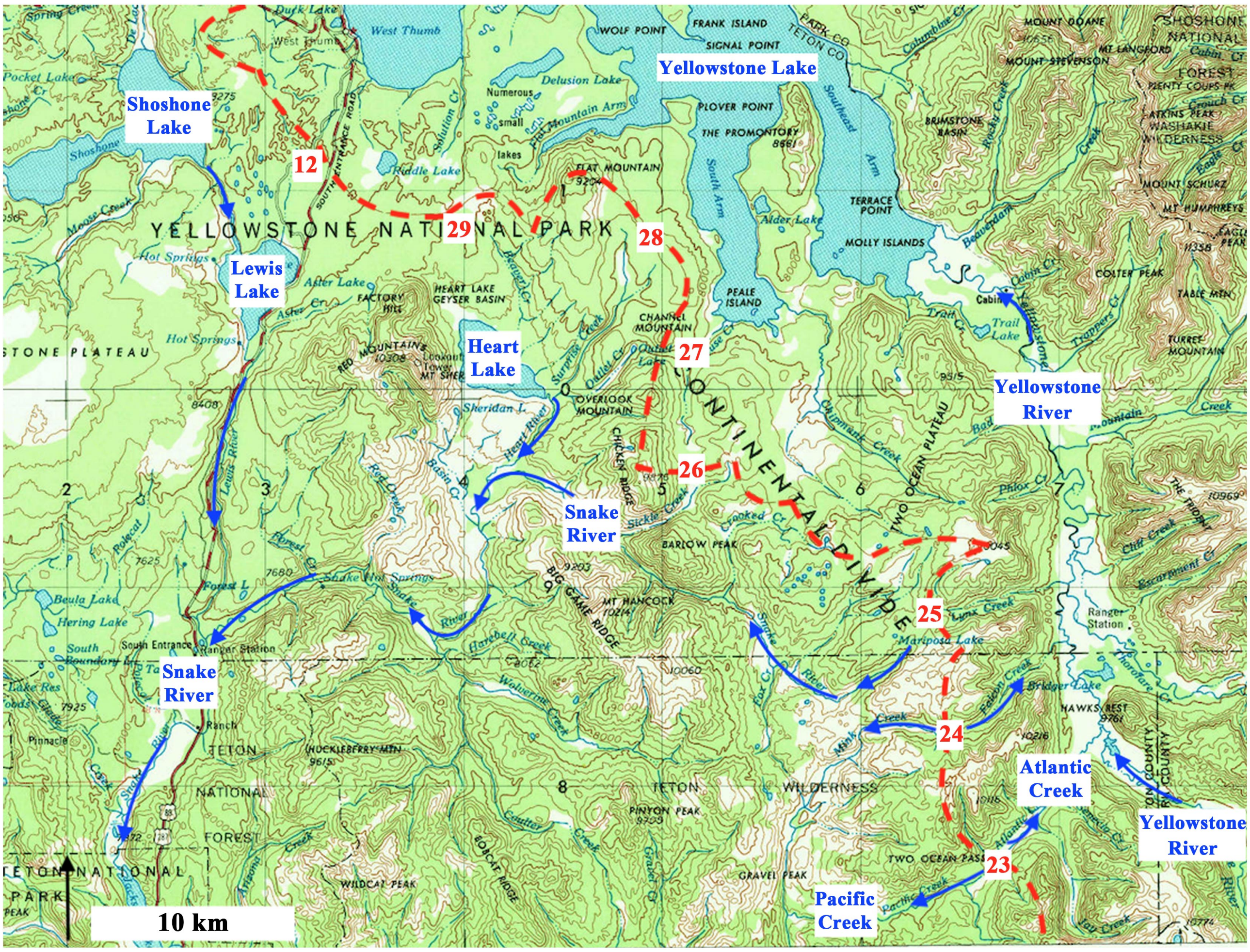

Figure 6. Modified section of the Ashton map [1] east of overlapping Figure 4 and to the south of non-overlapping Figure 5. The red dashed line emphasizes the continental divide and the red numbers identify passes and through valleys discussed in the text. The contour interval is 200 feet (about 60 meters).

Creek, 6) an unnamed gap with a floor elevation of about 2228 m which links the northeast-oriented West Fork Madison River with the west-oriented Red Rock River (in the Jefferson River drainage basin) and 7) an unnamed through valley with a floor elevation of about 2085 meters which links the north-oriented Madison River with the west-oriented Red Rock River. Ridges surrounding the passes and through valleys can rise as much as 500 m or more above the pass or the through valley floors and some of the mountain elevations exceed 3000 m.

Using the Ashton map evidence to construct a regional drainage history can begin by interpreting the Raynolds Pass origin. Raynolds Pass is at least 300 m deep and was eroded by water flowing across what is now the continental divide. To the north of Raynolds Pass the north-oriented Madison and Missouri River valleys extend in a north direction to elevations of less than 1000 meters and to where a continental ice sheet margin once existed. To the south of Raynolds Pass is south-oriented Henrys Fork which further to the south joins a south-oriented Snake River segment which still further to the south has an elevation of about

1300 meters where the river turns in an east direction. To understand the Raynolds Pass origin, it is important to look at the Madison River route and at Targhee and Rheas Passes. The Madison River flows in a west and northwest direction to Hebgen Lake Dam (at the Hebgen Lake northwest end) where the river makes an abrupt turn in a southwest direction before turning in a north direction in the north-to-south oriented valley in which Raynolds Pass is located. Also note how Targhee and Rheas Passes link the northwest-oriented Madison River valley segment with the south-oriented Henrys Fork valley.

Diverging and converging streams of south-oriented water flowing on a surface now preserved (if it is preserved at all) by the regional ridge tops (which now exceed 2700 m in elevation) between what is today the north-oriented Madison River valley and today's south-oriented Henrys Fork valley must have also eroded Targhee and Rheas Passes both of which are also at least 300 m deep and which have floor elevations only slightly higher than the Raynolds Pass floor elevation. The through valley at number 5 can be interpreted to add to the diverging and converging valley complex because it links the north-oriented Gallatin River valley with the northwest-oriented Madison River valley and via Rheas Pass and possibly Targhee Pass with the south-oriented Henrys Fork valley. To the north of **Figure 2** the Gallatin and Madison Rivers meet (with the Jefferson River) at Three Forks to form the north-oriented Missouri River and the passes and through valleys at numbers 4, 6, and 7 link the Jefferson and Madison River valleys.

The diverging and converging through valley complex origin can be explained if prior to and during Yellowstone Plateau area uplift massive volumes of water flowed in a south direction probably from a melting continental ice sheet to where Three Forks is today and then split into two or more diverging south-oriented channels. Water in the easternmost south-oriented channel flowed along the now north-oriented Gallatin River alignment while water in another south-oriented channel flowed along the now north-oriented Madison River alignment with water in both channels spilling over drainage divides to erode additional southeast- and southwest-oriented flood flow channels. Flow in these diverging south-oriented channels converged again in **Figure 2** map area with the combined flow then continuing in a south direction in what is now the south-oriented Henrys Fork valley. Eventually Yellowstone Plateau area uplift forced reversals of flow that created today's north-oriented Madison and Gallatin River drainage routes. This interpretation requires Yellowstone region uplift to have occurred while (or after) a large North American continental ice sheet existed and the erosion of 300 - 500 m deep Ashton map area valleys to have occurred before the south-oriented flow was reversed.

Not seen on the Ashton map is most of the Red Rock River drainage route in the Jefferson River drainage basin. Clausen [24] used topographic map evidence to show how the diverging and converging through valley complex continues westward from the Ashton topographic map area as the west- and northwest-oriented Red Rock River flows to the northeast-oriented Beaverhead River, which after being joined by the south-oriented Big Hole River becomes the northeast- and east-oriented Jefferson River (which at Three Forks joins with the north-oriented Madison and Gallatin Rivers to form the north-oriented Missouri River). To the southeast of the northwest-oriented Red Rock River segment (and to the west of the Ashton map) is Monida Pass which crosses the continental divide with a floor elevation of about 2079 m (similar to floor elevations at Raynolds Pass and the through valley at number 6). Combining evidence from the Ashton map with evidence presented in Clausen's paper [24] it appears as though massive volumes of south-oriented water flowed in a large south-oriented diverging and converging channel complex along and across today's continental divide until mountain uplift forced flood flow reversals that ultimately resulted in the present-day drainage systems.

4.2. Central Ashton Map Evidence

To the east of **Figure 2** is the overlapping **Figure 3** where a Gallatin River-Madison River drainage divide segment is seen along with segments of the Gallatin River-Yellowstone River and Yellowstone River-Madison River drainage divides. The previously mentioned through valley at number 5 was eroded by south-oriented water moving from the now north-oriented Gallatin River valley along the now south-southwest oriented Grayling Creek alignment and then in a southwest direction across today's northwest-oriented Madison River valley to erode Rheas Pass before reaching the south-oriented Henrys Fork valley. The Grayling Creek abrupt direction change from a northwest orientation to a south orientation suggests the south-oriented water split into two diverging streams just to the south of number 5 with one stream flowing in a south-southwest direction and the other stream flowing in a southeast direction along the now northwest-oriented Grayling Creek alignment to the through valley at number 8 and then continued further to the southeast. Regional uplift reversed the south-oriented flow to create today's north-oriented Gallatin River and northwest-oriented Grayling Creek headwaters.

Red numbers 9, 10, and 11 identify through valleys (crossing the Yellowstone River-Madison River drainage divide) which link north-oriented drainage to Obsidian Creek which flows to the southeast- and northeast-oriented Gardner River which in turn flows to a northwest-oriented Yellowstone River segment (located to the north and east of the figure). The Gardner River has northeast-oriented headwaters before flowing in a south-southeast direction into **Figure 3** northeast corner where it makes a U-turn to flow in a north-northeast direction to join the Yellowstone River (to the north of the Ashton map). The Gardner River U-turn, the through valleys at numbers 9, 10, and 11, and the south-oriented Gibbon River segment (seen in the figure) all suggest diverging and converging south-oriented flood flow channels once crossed the region, which implies a drainage reversal has occurred in what is now the north-oriented

Yellowstone River valley to the north of the Ashton topographic map area (see **Figure 1**).

Figure 4 shows an Ashton map section located to the south of **Figure 3** map area (with a gap between the two figures) and shows most of the north-oriented Firehole River drainage basin. The figure is located to the south of where the Firehole River joins the Gibbon River (seen in **Figure 3**) to form the west-oriented Madison River headwaters. Note how the Firehole River begins almost along the continental divide. Through valleys now crossing the continental divide, while not as obvious on the Ashton map as on more recent and more detailed topographic maps provide evidence that south-oriented water once flowed from the present-day north-oriented Firehole River drainage basin to what are now south-oriented Snake River tributaries. Red numbers 13, 14, and 15 in **Figure 4** identify three such through valleys that can be seen with careful study of the Ashton map. Red number 12 identifies a deeper through valley that links West Thumb of Yellowstone Lake (in the north-oriented Yellowstone River drainage basin) with Lewis Lake (in the south-oriented Snake River drainage basin) and which previous researchers [9] [14] have suggested was once a Yellowstone Lake southern outlet.

Floor elevations of some of the numbered through valleys where they cross the continental divide suggest they may be channels which were eroded on the floor of a much broader and deeper through valley. For example, the floor elevation of the through valley at the number 12 is about 2435 m. Number 13 identifies a through valley with a floor elevation of about 2580 meters, the through valley floor elevation at number 14 is about 2510 m, and the through valley floor elevation at number 15 is about 2444 m. To the east of the through valley at number 12 (and just to the east of the figure) the continental divide elevation increases to 2805 m at Flat Mountain. To the west of number 15 the continental divide elevation rises to about 2621 m before reaching the through valley at number 16 which has a floor elevation of about 2560 m. Continuing in a northwest direction across the Madison Plateau the continental divide elevation gradually rises to almost 2700 m which suggests a broad north-to-south oriented valley once extended across the region. It is doubtful that an ice-dammed Yellowstone Lake south-oriented outlet would have carved what must have been a 150 - 250-meter-deep and a 20 - 40-kilometer-wide valley.

The Ashton map evidence suggests diverging and converging south-oriented flood flow channels developed on the floor of that north-to-south oriented 150 - 250-meter-deep and 20 - 40-kilometer-wide valley, although the map evidence is less clear in terms of whether the larger valley is entirely a flood eroded feature. The possibility exists that lava flows and/or localized uplifts in the Madison Plateau area and perhaps in the region to the east of **Figure 4** contributed to at least some of the present-day north-to-south oriented larger valley's depth. Regional uplift almost certainly caused a reversal of the south-oriented floodwaters to create what are today the north-oriented Firehole River drainage basin and the continental divide. What the Ashton map does convincingly show is that south-oriented water at multiple locations once flowed across the continental divide.

4.3. Eastern Ashton Map Evidence

Figure 5 shows an area on the Ashton map east of (and overlapping with) **Figure 3** which illustrates how west-oriented Gibbon River headwaters in the Madison River drainage basin extend eastward almost to the north-oriented Yellowstone River. Note how the Gibbon River turns in a south direction before turning in a west direction to join the north-oriented Firehole River and to form the west-, northwest-, and north-oriented Madison River. Red number 17 identifies another through valley crossing the Yellowstone River-Gibbon River drainage divide (in addition to through valleys at numbers 10 and 11). These three through valleys, the Gardner River U-turn (seen in **Figure 3** northeast corner), the Gibbon River south-oriented segment, and southwest-oriented Magpie Creek (in the north-oriented Firehole River drainage basin) suggest that headward erosion of the west-oriented Madison-Gibbon River valley captured diverging and converging south-oriented flood flow channels which before being captured had been supplying the water that crossed the continental divide segment seen in **Figure 4**.

The through valley (or pass) at number 18 is located to the east of Observation Peak and the through valley at number 19 (which a highway uses to cross the drainage divide at Dunraven Pass) are shown on the Ashton map as linking north-oriented tributaries to northeast-oriented Tower Creek (which flows to the north-oriented Yellowstone River as a normal tributary) with south-oriented streams (which flow to a northeast-oriented Yellowstone River segment as barbed tributaries. While these are subtle features on the Ashton map (and better seen on newer and more detailed topographic maps) those through valleys strongly support the hypothesis that prior to a regional drainage reversal a south-oriented complex of diverging and converging flood flow channels crossed the region.

Further evidence of diverging and converging through valleys linking north- and south-oriented Yellowstone River tributaries is seen on the Ashton map at the numbers 20, 21, and 22. Number 21 identifies a north-to-south oriented through valley which links north-oriented Broad Creek (which flows to the north-oriented Yellowstone River) with a south-oriented Yellowstone River barbed tributary. Number 20 identifies a through valley which links the north-oriented Shallow Creek headwaters with the north-oriented Broad Creek valley (with Shallow and Broad Creeks converging before reaching the Yellowstone River}. Much easier to see on the Ashton map is the through valley at the red number 22 which links the northeast-oriented Willow Creek valley (which drains to the northwest-oriented Lamar River) with the southwest-oriented Raven Creek valley (which drains to Yellowstone Lake and then to the north-oriented Yellowstone River as a barbed tributary). These through valleys are difficult to explain unless prior to the Yellowstone Plateau region uplift a network of south-oriented diverging and converging flood flow channels crossed the region with the present-day north-oriented Yellowstone River drainage system being formed as regional uplift forced a reversal of the south-oriented flood flow.

In the area to the south of Yellowstone Lake the Ashton map section seen in **Figure 6** (located east of overlapping **Figure 4**) shows the Yellowstone River flowing in a large north-oriented valley (in the Atlantic Ocean drainage basin) and less than 40 kilometers to the west the Snake River flowing in a south direction (in the Pacific Ocean drainage basin). South-oriented barbed tributaries flowing to the north-oriented Yellowstone River which can be seen along the figure's eastern margin suggest south-oriented drainage preceded the present-day north-oriented Yellowstone River drainage. Numbered passes and through valleys now crossing the continental divide are difficult to explain unless large volumes of south-oriented water once flowed across the region (it is very unlikely that they are all Yellowstone Lake southern outlets).

Number 23 locates the 500-meter deep Two Ocean Pass (floor elevation approximately 2480 m which is drained to the east by northeast-oriented Atlantic Creek and to the west by southwest-oriented Pacific Creek. To the north of Two Ocean Pass numbers 24 and 25 identify other passes also crossing the continental divide with floor elevations of about 2715 and 2835 m respectively. These three passes are difficult to explain unless they were eroded by powerful streams of southwest-oriented water which diverged from a larger stream of south-oriented water flowing in what is today the north-oriented Yellowstone River valley. Such an interpretation requires the south- and southwest-oriented water to have flowed on a surface now preserved (if it is preserved at all) by the highest regional ridges some of which today have elevations in excess of 3000 m. If so, as the regional topography emerged the southwest-oriented flood flow would have gradually been concentrated in what is today the deeper Two Ocean Pass valley until regional uplift reversed that flow to create present-day northeast-oriented Atlantic Creek.

Number 26 identifies a north-to-south oriented through valley (floor elevation of about 2552 m) crossing the continental divide and linking north-oriented drainage to Yellowstone Lake with southwest-oriented drainage to the Snake River. Just to the south of Channel Mountain (elevation 2665 m) at number 27 a deeper through valley (floor elevation of about 2440 m) links drainage to Yellowstone Lake with drainage to the Heart Lake outlet (Heart River) which flows to the Snake River and which was identified by Hague [9] and Goode [14] as being a Yellowstone Lake southern outlet. Number 28 between Flat Mountain (elevation 2805 m) and Channel Mountain identifies a broad through valley (floor elevation about 2470 m at its deepest point) linking north-oriented drainage to Yellowstone Lake with south-oriented drainage to Heart Lake and the Snake River. Number 29 identifies the eastern half of the previously mentioned broad 150 - 250-meter-deep north-to-south oriented through valley between Flat Mountain and the Madison Plateau (the broad valley's western half was seen in **Figure 4**). Significant stretches of the continental divide in the number 29 region have elevations of less 2450 m. The previously discussed through valley at number 12 has a floor elevation of about 2435 m.

Diverging and converging streams of south-oriented water must have eroded the numbered mountain passes and through valleys crossing the continental divide seen in **Figure 6**. Pass and through valley elevations which range from 2435 m to 2835 m suggest the present-day topography emerged as south-oriented water deeply eroded the region and as the flow became concentrated along fewer and fewer routes. This region is located along the southern margin of a hypothesized glacier that Pierce *et al.* [10] suggested once covered much of the eastern Yellowstone Park region. Meltwater from such a glacier (or south-oriented water draining from a glacially dammed Yellowstone Lake) could possibly explain some of the numbered passes and through valleys although is unlikely to have been of great enough volume to erode all of the numbered passes and through valleys and/or to deeply erode the region as the Ashton map evidence strongly suggests.

5. Discussion

Passes and through valleys seen on the Ashton map are difficult to explain unless diverging and converging streams of south-oriented water once flowed across today's continental divide. The depth and size of some passes and through valleys suggests large and prolonged volumes of water must have been involved. While overflow from a glacially dammed Yellowstone Lake or other glacially dammed lakes can explain a few of the passes and through valleys that explanation does not address the passes and through valleys as a group or even many of the individual passes and through valleys. The large volumes of water that must have eroded most if not all of the passes and through valleys is also difficult to explain unless the water came from a continental ice sheet. The flow of continental ice sheet meltwater across the Yellowstone region is equally difficult to explain unless at that time the Yellowstone region had a much lower elevation than it has today. Likewise, the depth of the passes and through valleys is difficult to explain unless the Yellowstone region was being uplifted as large volumes of water were flowing across it and the drainage divides formed when uplift outpaced the ability of the water to erode deeper valleys.

The Ashton map 1:250,000 scale and 200-foot (about 60-meter) contour interval makes the identification of lava flows and glacial moraines from map evidence difficult. Indirectly the Madison Plateau (seen in **Figure 4**) and the Pitchstone Plateau (seen along **Figure 4** south center margin and in **Figure 6** northeast quadrant) appear on the Ashton map to have been formed when lava flows may have buried many (but not all) of the south-oriented diverging and converging flood flow channels. The through valley at number 16 (shown in **Figure**

4) which crosses a Madison Plateau area is identifiable on the Ashton map by a single contour line and may or may not be evidence that floodwaters flowed across an actively erupting Yellowstone region. Flood-eroded valleys cross many other Ashton map areas including the usually mapped Yellowstone caldera areas. If this study has correctly interpreted the Ashton map evidence, most if not all Yellowstone region uplift must have occurred after the eruption(s) that created the Yellowstone caldera (which is usually dated to have been formed about 640,000 years ago).

That 640,000 years ago age date poses problems from both the accepted and the new paradigm perspectives. Accepted paradigm literature implies (but rarely actually says) that by 640,000 years ago considerable Yellowstone region uplift had already occurred. If the Yellowstone caldera formed after much of the Yellowstone region uplift had occurred continental ice sheet meltwater would have been unable to cross what is now the Yellowstone region which the Ashton map evidence suggests must have happened. From the accepted paradigm perspective either the Yellowstone region uplift occurred much more recently than is usually implied or Yellowstone caldera evidence was formed much earlier than the commonly claimed 640,000 years ago age date. The same problem occurs with the 1.3 Ma and 2.1 Ma ages of the two earlier Yellowstone region calderas, although those earlier ages allow more time for Yellowstone region uplift to occur.

The same age date problem exists from the new paradigm perspective which sees deep "hole" rim uplift (which is how the new paradigm explains Yellowstone region uplift) to be associated with the south-oriented continental ice sheet meltwater floods that eroded through valleys now crossing Wyoming's Laramie Mountains and that contain what previous investigators have mapped as Oligocene and Miocene sediments [27]. It does not matter which paradigm perspective is used, the Ashton map drainage system and erosional landform evidence is not consistent with commonly published Yellowstone region uplift timing interpretations, which probably explains why geomorphologists have never used the well mapped Ashton map (or other topographic map) drainage system and erosional landform evidence to construct a detailed Yellowstone region drainage history.

Possible age date problem explanations might include: 1) the calderas may be older than the age dates indicate, 2) the calderas were formed by less destructive volcanic events than the accepted paradigm literature usually implies, or 3) there is an explanation for the Ashton map drainage system and erosional landform features that does not require large floods of continental ice sheet meltwater to have flowed across a gradually rising Yellowstone region. In the first case it is possible the age dates may be incorrect or the age dates are correct but relate to events other than when the calderas actually formed. In the second case, it is possible preexisting valleys might have survived less destructive volcanic events than what the accepted paradigm literature usually implies. And, in the third case, there may be an explanation for Ashton map drainage system and erosional landform evidence that does not require continental ice sheet meltwater floods to have flowed across the Yellowstone region, although in the more than 50 years since the revised Ashton map was published no such alternate explanation is known to have emerged.

6. Conclusion

The Ashton map was first published in 1955 and revised in 1972 and subject to its 1:250,000 scale and 200-foot (about 60-meter) contour interval shows evidence that large volumes of south-oriented water moving in large complexes of diverging and converging channels once crossed the region. This evidence is not known to have been described or addressed in previously published Yellowstone region geologic reports. A new and fundamentally different paradigm (which interprets the Yellowstone region to be on the rim of a continental ice sheet created and occupied deep "hole" which was being raised as immense meltwater floods flowed across it) does explain most of the Ashton map diverging and converging valley evidence, but is not consistent with previously published Yellowstone region geologic histories. Further work is needed to better understand inconsistencies between what the Ashton map (and newer and more detailed topographic map) drainage system and erosional landform evidence shows and what previously published accepted paradigm Yellowstone region geologic histories claim.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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