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# UNRAVELING THE GEOMORPHIC HISTORY OF BLACKTAIL DEER CREEK

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# **INTRODUCTION**

Yellowstone National Park has been at the center of scientific inquiry since it first received federal protection in 1872. It has served as a research hotspot for both biologists and geologists alike. The surrounding region is known as the Greater Yellowstone Ecosystem and includes flora and fauna that interact in an ecosystem that is highly protected from the majority of outside anthropogenic effects. The absence of major anthropogenic impacts in greater Yellowstone has resulted in one of the largest intact temperate ecosystems in the world (Knight & Landres, 1998). From within the boundaries of Yellowstone, one of the most divisive ecological debates on the planet began: the effects that wolves have had on the greater Yellowstone ecosystem (National Research Council, 2002). Wolves were removed from the park in the 1920's and subsequently reintroduced from 1995 to 1997 (National Research Council, 2002). This loss and reintroduction of wolves provides a unique opportunity to observe the effects that top predators have on other organisms and fluvial systems. From this extirpation and reintroduction, the debate about how apex predators can influence an entire ecosystem began.

Trophic cascade theory states that changes to organisms in higher trophic levels have trickle-down effects on each lower trophic level. Yellowstone's wolves have become an example of the trophic cascade theory. The removal of wolves from the park in the 1920's, caused elk populations to increase due to the lack of apex predators. The increase in the total elk numbers or change in elk foraging behavior ("culture of fear") then increased herbivory on deciduous tree species, especially on elk winter grounds(Chadde & Kay, 1991). During winter, snow severely limits where elk can live, and they become confined into smaller areas: winter ranges. Some research suggests that within these elk winter ranges, there is increases in herbivores which leads to severe overgrazing of willows and aspens along riparian corridors (Ripple & Beschta, 2004). Overgrazing leads to less woody debris in streams and fewer plants anchoring the banks in place. The lack of wolves caused an increase in herbivory from elk, a loss of woody plants species, and therefore a lower hydraulic roughness. This change in hydraulic roughness thereby caused incision and widening of streams (Beschta & Ripple, 2006, 2018; Beschta & Ripple, 2018).

The goal of our research is to understand the geomorphic causes for changes in stream behavior and morphology of Blacktail Deer Creek. Our research seeks to discover and understand the possible changes to stream morphology stemming from both trophic cascades and other fluvial factors. We use the stratigraphic and geomorphic record to document the late Pleistocene and Holocene history of stream behavior and assess how modern channel form and processes are related to the longer-term record of stream behavior. Other environmental factors that influence stream behavior include changes to wildfire regimes (Legleiter et al., 2003), changes to beaver damming frequency (Persico & Meyer, 2013) or climate-induced changes to flood frequency (Meyer et al., 1995). Research has indicated that fluctuations in beaver behavior, stream capture and fire related flood events could have triggered incision in the region (Persico & Meyer, 2009). A working map of the region provides the localities of critical stratigraphic

relationships, and morphological features that better provide insight into the dynamic conditions along Blacktail Deer Creek. We hope to better understand when and where incision, aggradation, and channel shifts occurred along Blacktail Deer Creek by taking a holistic view and considering a large variety of potential fluvial altering factors.

## **STUDY AREA**

Blacktail Deer Creek is located on the Blacktail Deer Plateau in the northern Yellowstone National Park. The Northern Yellowstone boundary is low in elevation (1604m) and dry (25-38cm of rain per year) compared to the rest of the park (Yellowstone National Park, 1997). The sage and grassland is covered with an intermittent series of forests. The East and West fork of Blacktail Deer Creek flows out of the Washburn range and across the Blacktail Deer Plateau to the Yellowstone River. West Fork Blacktail Deer Creek drains 35km2 and East Fork Blacktail Deer Creek drains 27km2. Blacktail Deer Creek flows on through glacial meltwater channels, remnants from the Pinedale glaciation that dominated Yellowstone during the Pleistocene. (Pierce, 1979; Meagher & Houston, 1998). The plateau is predominately covered in kame terraces that creates a hummocky topography (Pierce, 1979). On the kame surfaces, sagebrush dominates with interspersed islands of aspen and pine trees. The riparian areas of East and West Blacktail Deer Creek are covered with willow and sedge species (Beschta & Ripple, 2018). Additionally, the plateau is serves as elk winter range habitat as well as other ungulates and predators. The plateau also hosts a beaver population which have potential to greatly alter the fluvial characteristics of the stream (Smith, 2003).

### **METHODS**

#### Field

We performed field work in July and August of 2019. This work was characterized by field mapping of geomorphic surfaces and valley floor topographic surveys along East and West Blacktail Creek. We mapped surfaces by hand-drawing contacts on a printed orthographic and DEM maps. We used a handheld GPS and printed maps to demarcate different surfaces. The accuracy of these contacts was aided via surveying through the use of RTK (1-cm accuracy) and D-GPS (20-cm accuracy) surveys. We mapped the kame boundaries, paleo-channels, river terraces, floodplain, and active channel. We completed this by walking contacts and analyzing relative elevational differences between each surface. We mapped the terrace highest above the modern channel (oldest terrace in the valley) as T1. Inset terraces, or younger fluvial terraces were marked as T2, T3, and so on depending on the height above the active channel. In addition to this mapping, detailed cross sections and longitudinal profiles of the drainages were made using RTK and D GPS. These cross sections were surveyed along each fork of the creek at intervals of approximately 30 meters. Cross sections were surveyed perpendicular to the stream and went from the edge of the kame, across the valley floor, to the opposite confining boundary of kame deposits. These were used to quantify terrace elevations relative to active and paleo channels. All the mapping and notes created during this phase of research served as guiding material for the later production of a digital map.

Stratigraphic sections were used to characterize the terrace deposits including sampling of organic material for 14C analyses. These locations were primarily focused around terraces near both active and paleo-channels. In order to locate datable material, active or old cut banks in the terrace were located and debris was cleared away to provide a clear look at the stratigraphy. We then searched the column for charcoal and other organic woody debris that would be suitable for radio carbon dating. Samples were then carefully collected, photographed, and recorded in detail about their location in the column. We also looked for volcanic ashes incorporated into terrace sediments. A volcanic ash collected was identified by the Pete Hooper GeoAnalytical Laboratory of Washington State University.

#### Laboratory

Using ArcGIS, we digitized the field maps. In ArcMap, the orthographic photos and identification of vegetation differences were readily identified. Kame surfaces are covered in sage and other fluvial surfaces are dominated by a variety of grass and bush species. This stark contrast in vegetation aided in the differentiation of kame terraces from fluvial terraces. Polygons were drawn over the top of kame deposits to show their locations on the map. Active channels were easily identified due the visibility of water. Using LiDAR derived DEM from NEON, other geomorphic surfaces could be noted. This DEM made for clear identification of paleo-channels and alluvial fans along the stream reaches. Lastly, the demarcation of distinct terrace surfaces was performed. The objective for terrace identification was to match up terrace deposits that had the same relief above the active channel. Additionally, the map separated out terraces that had lower relief within the valley. Profile lines as well the cross sections were used to create topographic profiles that were perpendicular to the active stream channel. These cross sections revealed the valley floor topography and the different terraces heights. Using multiple elevational profiles and the shading in the DEM, a terrace surface could be identified based upon its height above the active channel. Using this identified height above the active channel, terraces of different relative ages were demarcated with a polygon. In addition to the surficial map of geomorphic surfaces, raster slope maps, DEM's and hill shades were all produced as supplemental material to further interpret the landscape.

# **RESULTS**

Based upon the field mapping, the use of a highresolution DEM, and aerial photos a map showing the geomorphic surfaces of the valley floor was produced (Fig. 1). The mapping reveals that along East Fork of Blacktail Deer Creek, the majority of the valley bottom is the T1 terrace. The T1 terrace is the terrace with the highest relief (1.0-1.5 meters)above the active channel and therefore represents the oldest terrace. The cross sections show the relief for identifying the terrace surfaces (Fig. 2). This T1 terrace is incised where the T2 terrace and paleochannels are preserved. The paleo-channels, incised primarily in T1 terraces, can be traced back to the location of the active channel. Additionally, this map shows that most of the inset terraces lie on active and abandoned point bars. The paleo-channels and T2 terraces are inset in the T1 terrace (Fig 1). Many of the T2 terrace surfaces are preserved along point bars along active channels or old paleo-channels that had



Figure 1. Surficial Geomorphic Map- East Blacktail Deer Creek. This image shows geomorphic surfaces overlaying the orthographic photo of the reach. A-A' shows the location of the cross section in Figure 2. Inset shows mapped area within the Yellowstone National Park Boundary.





Figure 2. A) East Blacktail Deer Creek Cross Section from Figure 1. Labels on cross section indicate the identified feature on surficial geomorphic map. Kame is located on either side of the valley floor. Note paleo channels are at a lower elevation than the active channel on this reach. AC=active channel, PC= paleochannel, T1= Uppermost Terrace, T2=inset terrace. B) East Fork of Blacktail Deer Creek. This image shows the surfaces that were identified during mapping. Notice person for scale.

incised into the T1 terrace. The cross section in Figure 2 shows the complexity in certain stream reaches because the active channel has not significantly incised. Along some reaches, the active channel is at a higher elevation relative to the proximal paleo-channel (Fig. 2).

It is important to constrain the geochronology for



Figure 3. A) Image of stratigraphic column containing volcanic ash. Arrow indicates ash deposit. Image courtesy of Lyman Persico. B) Analysis of glass composition of ash from T1 terrace on East Blacktail Deer Creek (normalized weight % oxides).

when each surface was formed was to interpret the geomorphic history of Blacktail Deer Creek. Terrace ages were constrained on the east fork with a series of radiocarbon dates and a volcanic ash. The ash layer is located 1m below the surface of the highest terrace, T1 (Fig. 2). Analysis of the glass contained in the ash indicates that it is from the eruption of Glacier Peak ca. 11.2 ka (Fig. 3). A radiocarbon date higher in the stratigraphy of the T1 Terrace produced a date of ~3.3 ka. The T1 terrace was aggraded between 11-3.3ka. Additionally, the T1 terrace contains a well-developed soil containing a thick A- horizon, which indicates long term stability. A slip terrace on the T2 surface is dated at 1.4ka (Persico & Meyer, 2009). Fluvial deposits inset within the high terrace on the east fork date to the late Holocene, 1.0-1.4 ka. Thus, incision of the highest terrace and subsequent deposition of the inset material occurred between 1.4-3.3ka.

The paleochannels, active channels, and terrace surfaces have different slopes along both east and west forks (Fig. 4). The direction and slope of the raster tiles reveals the slope trend in terraces, kame, active and paleo-channels. There are 15 paleo-channels at the area near the confluence. This projection also shows alluvial fan along the East Fork Blacktail Deer Creek. East Fork is suspended on top of kame east of the confluence thus allowing aggradation of the alluvial fan. The broad flat valley decreased stream power in the east fork, which deposited sediment and created an alluvial fan. The shallow slope of the fan ends with a distinct drop into the confluence (Fig. 4). West Fork Blacktail Deer Creek maintains a slope around 0.0174. East fork maintains a slope of 0.118.



Figure 4. A) Slope Raster Map of confluence of West and Blacktail Deer Creek. East fork flows in from the right side of image and the west fork enters from the south. Black shaded region is the active channels and red shading shows the paleo-channels. White outlines Kame. B) Longitudinal profile showing the slops of West and East Fork Blacktail Deer Creek.

# DISCUSSION

The morphology of the West and East forks of Blacktail Deer Creeks are influenced by both Holocene and late Pleistocene geomorphic events. The Pinedale and Bull Lake glaciation events produced large amounts of ice and meltwater that influence much of the modern topography. The glacial meltwater channels and kame deposits control the drainage network pattern and net ability for channel incision. Glaciation during the Pleistocene deposited voluminous kame deposits and created a complex series of meltwater channels (Pierce, 1979). Much of this kame surface contains large cobbles and boulders that anchor the features into place and prevent incision in modern creeks. These meltwater channels and kame surfaces have dictated where Blacktail Deer Creek can currently flow. Given the size of stream and size of the sediment in the outwash deposits, the stream cannot move or meander beyond the confines of the meltwater channels. This has effectively confined drainage network of Blacktail Deer Creek. On East

Fork Black Tail Deer Creek, the slope of the channel is controlled by the kame terrace located just above the confluence (Fig. 4b).

The significance of the T1 terrace is that it records a long-term record of valley floor aggradation and then surface stability. The T1 terrace comprises most of the valley floor and formed between 11-3.3ka. The T1 terrace represents a system-wide aggradation of the valley floor. This widespread aggradation is likely a result of changes to sediment supply to valley floors related to deglaciation of the Yellowstone Plateau. Voluminous aggradation occurs after glaciation because sediments are being flushed out of oversteepened glacial deposits (Church & Ryder, 1972). These paraglacial processes may have resulted in widespread valley floor aggradation and the creation of the T1 terrace along relatively small streams like Blacktail Deer Creek that were able to effectively transport all sediment moved from hillslopes to the valley floor. The inset terraces (T2) date to the late Holocene at 1.0-1.4 ka. The T2 surfaces, often located on meander bends, are evidence of a transition of the fluvial system to channel both lateral migration and incision. The T2 dates and locations in the stream system indicate a fundamental change occurred along Blacktail Deer Creek between 1.4-3.3ka. During this time-period the incision of the T1 terrace began and the deposition of the inset terraces began. This boundary marks a critical period in which the stream is no longer carrying paraglacial sediments but has transitioned to the start of the neoglacial (Whitlock, 1993). This change to cooler conditions could increase stream discharge at the same time that sediment loads are decreased due to more vegetation on hillslopes. This incision significantly predates the removal and reintroduction of wolves in Yellowstone National Park. Additionally, the paleochannel mapping demonstrates that channel avulsion and incision has occurred well before the streams moved to their current location. The widespread occurrence of the T1 terrace over majority of the valley floor, indicates that much of the valley floor is not influenced by recent channel modifications. Therefore, trophic-cascade factors are not the only variable causing geomorphological changes along Blacktail Deer Creek. While wolves and trophic cascades have the potential to affect streams, the changes along Blacktail Deer Creek other

factors in the Holocene such as climatic variability and hillslope sediment supply are also important controls on the channel. Changes in fire regimes, or stream captures stimulated the morphological shifts along East and West Blacktail Deer Creek. The complexity of the environment requires analysis of all the factors involved in the creek morphology, and not exclusive analysis of ecological elements.

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