A Geomorphological Perspective of Antelope Canyon

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**Definition of Terms:**

Abrasion: The mechanical scraping of a rock surface via friction, caused by another rock surface or moving particles.

Cementation: The process by which loose particulate matter comes together to form sedimentary rock.

Colorado Plateau: a physiographic province of the Intermontane Plateaus region. This region of arid highlands is located around the Four Corners Region of the United States (the border between Colorado, New Mexico, Utah and Arizona).

Dissolution: The process of a substance dissolving and dispersing into a liquid.

Fluvial: processes that are caused by, or involve running water.

Quarrying: Erosion process where particles are removed by moving glacial ice.

Streamload: Refers to the material, or sediments carried by a stream. It consists of three components: the bedload (pebbles and sand that is moved along the stream bed without being permanently suspended in the flowing water), suspended load (silts and clays in suspension), and dissolved load (the materials in solution).

Uplift: A change in the vertical elevation of the Earth’s surface in response to natural causes.

Abstract

Antelope Canyon is a slot canyon formed by the weathering and erosion of Navajo sandstone. It is divided in two sections: Upper and Lower Antelope Canyon (Crossley, 2011). This paper will explore the location in relation to North American as well as the history of the landform’s geology. A detailed description will provide essential facts about the slot canyons’ depth, length and elevation. The origins will be explored along with the processes that continue to carve it out of the rock. The characteristic narrow, undulating walls and down-cut bed plain will be discussed in further detail to better grasp the processes that cause these features, as well as their influence on the slot canyons’ continued morphology. The societal importance will also be explored in terms of being culturally significant to the Navajo Nation, but also due to the need to learn more in prevention of the potential lurking disasters that can occur in these narrow passage ways.

Landform and Location

Antelope Canyon is located east of Page, Nevada in the United States (Crossley, 2011) (Figure 1 and Figure 2). Antelope Creek, a seasonal stream that flows into nearby Lake Powell, runs through both sections of the canyon (Crossley, 2011) and is also a small tributary to the Colorado River (Hayes, 2008). This canyon is also located with the Navajo Nation and holds cultural significance to the Navajo people (Navajo Parks).

Geology

The type of rock from which Antelope Canyon formed is Navajo sandstone (Crossley, 2011) which represents a significant part of the Colorado Plateau. Approximately 200 million years ago an extensive desert covered what are now the American states of Colorado, Arizona,
Utah, Nevada and part of Wyoming (Hayes, 2008). This desert was comprised of extremely large sand dunes that traveled across the topography (Hayes, 2008) and eventually cemented into sandstone (Pratt, 2003). Geologists can tell that the sand came from winds from the north-north west by the incline of the stratified (layered) sediment, or the cross bedding (Pratt, 2003). According to sophisticated uranium-lead dating techniques, the only area in present day North American with the same make-up of the Navajo sediments grains are the Appalachians. The method through which the sediment arrived in the west is not currently fully understood (Pratt, 2003). This sandstone is not only unique for its cross-bedding, but also the range of colours in the stratified layers (Hayes, 2008). The differences in colour can be attributed to bleaching by hydrocarbons that emerged due to uplift and erosion of the Colorado Plateau (Beitler, 2003). Minerals such as iron oxide cause the bright colours (Hayes, 2008) pictured in Figure 3.

*General Description*

Upper and Lower Antelope Canyon are divided by several miles of flat desert ground (Crossley, 2011). Both sections have the north flowing seasonal stream of Antelope Creek cutting through them (eclectic). The Upper Canyon is approximately 180 metres in length (Crossley, 2011) and near 120 feet in depth (Lake Powell Navajo Tribal Park, 2010), while the Lower Canyon is measured at 800 metres in length (Crossley, 2011) and is 20 to 50 in depth (Stocking, 2000). Both sections of the canyon have a similar elevation of approximately 4, 100 feet; however the Lower Canyon portion is in fact slightly less elevated than the upper portion (Schulhauser, 2006). Generally, slot canyons are less than 5 meters in width, which varies with the undulations of the canyon walls (Carter & Anderson, 2006).
Slot canyons are a type of bedrock channel which normally form by erosion through a mix of abrasion, quarrying and dissolution (Carter & Anderson, 2006). Abrasion erosion dominates the formation of slot canyon bed channels (Carter & Anderson, 2006). These canyons begin as minute fissures in the sandstone rock; however over geologic time those small fissures are enlarged by flash floods (Milligan, 2010). These canyons generally only experience channel flow during periods of floods, and it is these infrequent high-flow events that are responsible for the erosion of the canyons (Carter & Anderson, 2006). The fluvial erosion during these events is abrasion-dominated due to both the bedload and suspended load of the stream water (Whipple et al., 2009). Erosional driving forces such as flow hydraulics, and channel geometry work against the resisting forces such as the shear-strength, permeability, jointedness and homogeneity of the bedrock (Wohl & Ikeda, 1997).

While the overall direction of a slot canyon may be straight, the steep walls of the canyon “will undulate in and out of phase with each other” in two different fashions: “pinch and swell” and meanders (Carter & Anderson, 2006). These wallforms may be defined as recurrent and cyclic discrepancies in the channel width, and can be quantitatively described by measures of amplitude, wavelength and concavity (Wohl et al, 1999); for a visual description see Figure 4 for a diagram. The exact formation of these undulations is still somewhat unclear; however they are generally found downstream of knickzones, areas of incline discontinuity (Carter & Anderson, 2006), that are made up of grooves and potholes (Wohl et al., 1999). The wall undulations are thought to be the remnants of these potholes and grooves that were broken through during the down cutting, or incision, of the knickzone (Wohl et al., 1999). Experiments have indicated that the presence and scale of wallform undulations are not dictated directly by the character of the
channel’s substrate for this general type of sandstone (Wohl et al., 1999). It is more probable that flow processes present in the channel play a more significant role in the formation of the wallform undulations (Wohl et al., 1999).

In addition to potentially forming from the remnants of potholes, undulating canyon walls may form from the turbulence created in the channel flow from the incessant erosion fixed on single points on the wallforms (Carter & Anderson, 2006). In experiments, both the pinch-swell and meandering styles of undulation showed the most erosion on the lee side of wall bumps due to vortices occurring in the flow (Figure 5). This is the potential cause of the pointed edges of wallforms (pinches) often seen in slot canyons (Figure 6). Experiments suggest these vortices may also form erosional bedforms (Carter & Anderson, 2006), lending more insight into the driving and resisting forces acting on the bed plains of slot canyons.

From the field study of slot canyons it is observed that infrequent mass flooding events that enter the canyon facilitate deep incision into the bed plain as opposed to widening of the channels (Carter & Anderson 2006). This has to do with the abrasive power of the sediment load of the water along with the form of the channel walls. The narrow pinch sections are often not widened by erosion due to the fact they increase stream velocity which, in turn, streamlines the sediment load to be parallel to the walls, reducing the abrasion (Carter & Anderson 2006). Any widening of the walls occurs, as previously stated, on the lee side of wall bumps (Carter & Anderson 2006). Additionally, sediment load places more shear stress on the channel bed during the high flow events, prompting the significant downward incision (Carter & Anderson 2006).
Why care? Societal Relevance

Not only are Upper and Lower Antelope Canyons loaded with cultural significance from being located within the Navajo Native American Nation (Lake Powell Navajo Tribal Park, 2010), these locations are high traffic tourist destinations that are especially popular with photographers. Photographers flock to the area for the unique shape of the canyon interior, the stratified colours and the way light enters at strange angles (Sprince, 2011). However beautiful these landforms may be, there exists potential life threatening dangers (Hayes, 2008).

The same flash flood events responsible for the carving the slot canyons are very likely deadly if caught inside the slot at the wrong moment. On August 12, 1997, a storm that took place approximately 15 miles southeast of Lower Antelope Canyon. This storm was preceded by others which saturated the ground. With the rainfall infiltration reduced, the water headed in large amounts to the area of Lower Antelope Canyon with little warning (Lamar, 1998). Enough water was provided during the storm to cause a flash flood so devastating that it tragically took the lives of 11 people that were hiking inside the slot at the time (Lamar, 1998).

People should celebrate these slot canyons for their unique beauty, but also be wary of the potential dangers so they may visit respectfully without loss or injury. Through education and furthering our scientific understanding of the geologic and geomorphologic processes that created and continue to shape these landforms, we may practice safer planning and infrastructure when it comes to touring these canyons.

Conclusion

For as popular as these landforms are, there is comparably very little scientific literature and certainty about the processes that create and shape Antelope Canyon and others like it.
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Current research indicates the formation is due to rapid high-flow events, which through the sediment load of the water, produce down cutting over sandstone. The characteristic undulating channel walls of these landforms are believed to be formed when the walls of grooves and potholes are breached from knickzone incision. Over time and flood events, these channels cut deeper into the ground.

Research on the topic is leading to more complicated formation and shaping that take into the account all the erosional driving and bedrock resisting forces acting to create slot canyons. These include the undulation of the walls effect on the velocity of the flow as well as the sediment load’s key role in down cutting the canyon bed plain to name a few.

Researching and learning about these canyons is important to not only further the scientific understanding of slot canyons, but to anticipate and prevent any future disasters at these canyons such as the August 1997 tragedy at Lower Antelope Canyon.
References


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