**The effect of Bed Thickness on Hillslope Morphology and Sediment Size in Last Chance Canyon, New Mexico**

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**Abstract. In this paper, we investigate the relationship between bed thickness, grain size distributions, and hillslope form in Last Chance canyon, New Mexico, USA. Our research question is whether differences in bed thickness influence hillslope shape in this area, and how this affects sediment input to channels and channel morphology. To answer this question, we used drone photos to construct high resolution orthomosaics and digital elevation models of seven hillslope transects and stream channels at the base of each transect from two proximal watersheds. We measured bed thicknesses, slope, and curvature on the hillslopes, as well as grain size distributions at the base of each hillslope. Our findings show that hillslopes are steeper and less diffuse where there is more thickly bedded rock, and become shallower and more diffuse in thinly bedded rock. We also found that sediment input to channels is controlled by bed thickness on hillslopes and affects channel morphology, with thickly bedded rock units contributing larger sized colluvial sediment to the channels, which steepen as a result. Our results suggest that in the relatively steep downstream channel sections, slope is primarily controlled by the coarse alluvial cover, while the upstream diffuse landscape has a baselevel that is essentially fixed by the steep downstream reaches, resulting in a stable configuration where channel slopes have adjusted to bed thickness. Overall, our study highlights the importance of bed thickness in shaping hillslope form and channel morphology in Last Chance canyon.**

ADD CURVATURE AND SOIL PIT STUFF AND TIE IT TOGETHER. Maybe… combo of drainage area and bed thickness which control channel steepness. Like theres a threshold bed thickness down channel which causes for a HS to appear diffuse.

# 1 Introduction (NOT MY DOG)

Variance in relevant bedrock properties influences the production and size of sediment on hillslopes (Johnstone and Hilley, 2015), erosion rates (Dixon et al, 2012), and landscape form (Glade, 2017; Hurst, 2013). Rock properties, specifically fracture spacing, has been shown to influence rock surface slope (e.g., Brook and Tippett, 2002; Matasci et al., 2015; Moore et al., 2009; Selby, 1980), erosion, and imprints its signature into the topography (Molnar et al., 2007; Clarke and Burbank, 2011; St. Clair et al., 2015; Voigtlander et al., 2017; Eppes and Keanini, 2017; Eppes et al., 2018). Soil depth, a function of both soil production and erosion rate, has been shown to affect hillslope convexity (Roering, 2008). Soil mantled hillslopes are thought to generate convex hillslopes, however, in Last Chance canyon, sandstone hillslopes with predominantly exposed bedrock are convex in shape and resemble soil mantled hillslopes. But what about these bedrock hillslopes causes them to look like soil mantled hillslopes? Why do predominantly sandstone hillslopes appear diffusive while carbonate hillslopes are steep and shear?

In this study, we seek to understand the effect that changes in rock properties have on sediment production and erosion. More specifically, we ask what controls weathering, soil production, and sediment movement on hillslopes with high spatial variability in rock properties? how is sediment removed so that diffusive looking landscapes are generated in thinly bedded sandstone and not in the more thickly bedded carbonates? To answer these questions, we will couple a hillslope sheet wash component with the overland flow model to explore sediment delivery from hillslopes to channels. We will inform our model runs with realistic hydrographs reconstructions and field measurements of sediment size. and distance between bedrock beds. We will also measure sediment depth, bulk lithology of less than gravel sized colluvium, and the lithology of larger sized sediment.

I RECOMMEND WE DEFINE AND DESCRIBE WHAT AN IDEAL HS IS.

Foto of end member parts of LS.

# 2 Field Area

# We conducted fieldwork in Last Chance Canyon, located in the southern Guadalupe Mountains of New Mexico, USA. The study area includes two proximal first to second order watersheds, LC1 and LC3, which were chosen based on their differing morphology and accessibility (see map in Figure 1).

# The landscape of Last Chance Canyon is composed of horizontally to near horizontally bedded rock, with relatively little regolith. This area was tectonically inactive during the time of our study (Hill, 1987; Hill, 2006). During the Permian period, a shallow lagoon existed behind a reef complex to the south and deposited interbedded carbonate and siliciclastic bedrock of varying thicknesses (Hill, 2000; Phelps et al., 2008; Kerans et al., 2017). Beginning 27 million years ago, basin and range extension uplifted the Guadalupe Mountains and exposed the previously buried bedrock (Chapin and Cather, 1994; Ricketts et al., 2014, Hoffman, 2014; Decker et al., 2018).

# In the study area, we collected data from seven hillslope transects and stream channels at the base of each transect. These transects were chosen to capture variations in bed thickness and hillslope shape across the two watersheds. By examining the influence of bed thickness on hillslope form and sediment input to channels, we aim to better understand the processes shaping the landscape of Last Chance Canyon.

# 3 Methods

## 3.1 Field Survey

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# We used a DJI Mavic 2 Pro drone to capture aerial images of seven hillslope transects in each of the two proximal first to second order watersheds, LC1 and LC3, at an elevation of approximately 20 meters. Subsequently, we utilized Agisoft Metashape software to process the drone images and produce orthomosaics and DEMs at a sub-cm scale spatial resolution.

# 3.2 Sediment Size Measurements

# To measure the diameter of alluvium in channels at the base of the seven hillslope transects, we employed the PebbleCounts image analysis package (Purinton and Bookhagen, 2019). The K-means with manual (KMS) method was used, which enabled operators to validate measured grains and mitigate error. Due to the relatively large size of the orthomosaics, we utilized the PebbleCounts-Application, which subdivided images into manageable sizes. To streamline the process further, we developed an application that loops through the subset images and compiles all data for a channel section into a single file. All the data are available in the GitHub repository for this paper.

# 3.3 DEM and Orthomosaic analysis

# Using the high-resolution orthomosaics in the ArcScene program, we measured the bed thickness of every exposed bed on the seven hillslope transects. Bed thickness is defined as the vertical distance between the upper and lower horizontal bedding planes.

# At 20-meter intervals beginning at the channel and moving up each hillslope transect, we measured slope and curvature over an 80-meter window (40 meters upslope and 40 meters downslope of each point) using the 3DEP 1m DEM. We also measured all beds within the same window and found average bed thickness, the sum of all thicknesses, and the largest bed thickness. If necessary, we reduced the window distance in proximity to the channel or ridgeline to ensure that measurements were taken only from the hillslope in question and did not cross either the channel or the ridgeline.

# We used a 10 m DEM of Last Chance canyon and TopoToolBox to generate ksn maps of all surveyed channels. The channel steepness index, or ksn, was calculated by normalizing the channel gradient for drainage area. This enabled us to compare slope along a single channel or among multiple channels and isolate erosional and/or bedrock erodibility patterns (Kirby & Whipple, 2012).

# 4 Results

## 4.1 Last Chance Canyon Morphology

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## The upstream sections of Last Chance Canyon's tributaries have relatively shallow channels and lower gradient hillslopes, whereas downstream there is a knickzone with steep channels and hillslopes (Figure 2). We observe a change in curvature up the channel and aim to compare Last Chance Canyon (LC) 1 and 3 to investigate the influence of drainage area and channel steepness on hillslope diffusivity.

## 4.2 Bed Thickness and Hillslope Morphology

## We find that as the average, maximum, and sum of all bed thicknesses within an 80 m window increase, the slope measured over the same window distance also increases (local slope vs. bed thickness figure). We chose to measure slope and bed thickness over an 80 m window because it reduces slope errors from boulders and plants over larger distances. Additionally, as the average bed thickness for an entire hillslope transect increases, the slope of the entire transect likewise increases (total slope figure). Beds are generally thinner in the upstream sections of the landscape where hillslopes are shallower.

## In Last Chance Canyon, we observe that hillslopes are more diffuse in thinly bedded rock, but not in more thickly bedded rock (curvature vs. distance figure). Furthermore, hillslopes with less variance in bed thickness appear more diffuse. Diffusive hillslopes are convex near the ridgeline and become more concave as the hillslope approaches the channel. We plot curvature values by distance from the channel in the seven hillslopes and find that where the maximum bed thickness is lower, the slope of the distance vs. curvature function is more negative and has a higher R-squared value, both indicating a more diffusive shape. We also plot slope values and R-squared values for the seven transects against maximum bed thickness and find that where the maximum bed thickness is lower, the slope of the distance vs. curvature function is more negative and has a higher R-squared value, both indicating a more diffusive shape.

## 4.3 Size of Alluvium Affects Channel Morphology

## We observe that as the diameter of sediment increases, the channel steepness also increases (d10, d50, etc. ksn figure). Smaller sediment sizes correspond to shallower upstream hillslopes.

## 4.4 Bed Thickness Affects Channel Morphology

## The maximum bed plane thickness of each of the transects affects both the size of the sediment in the channel below and the channel steepness of the channel below (figures of bed thickness effect on grain size and on channel steepness).

## Overall, our findings suggest that bed thickness and sediment size play important roles in shaping Last Chance Canyon's morphology, with thin bedded rock and small sediment sizes leading to more diffuse hillslopes and shallower channel gradients.

## 5 Discussion

FOR NOW: its ideas…

THE LARGER THE BED THE MORE RELEVANT IT IS TO HS MORPH, SED SIZE, and CHANNEL MORPH

I wonder if we can separate the effect bed thickness has on where a hs looks diffusive or not by tracking changes up channel and comparing between lc1 and 3. Worst comes to worst if it’s not just distance up channel we can say that it’s a combo of bed thickness and drainage area. Like maybe the spread in the data with max bed thickness vs r squared and slope of function is from drainage area.

How do I explain away slope change with bed thickness? Is it too duh?

Does bed thickness affect the inflection point between non linearity and linear slope shape? Does it affect the transition from convex to concave curvature? Is there a threshold thickness? Or proximity to a large bed?

Idealized hillslope is probably a better word than diffusive. Describe what idealized means tho…

Strait HS is where curve is 0. Maybe see location/elevation where hs become strait? Is there a pattern?

Look at max bed thickness vs large boulder thickness. Or max bed thickness vs D50, d84, all the d’s etc.

The results of this study demonstrate the importance of bedrock properties and hillslope morphology in shaping Last Chance Canyon's landscape. Our field survey revealed that the tributaries of Last Chance Canyon have relatively shallow channels and lower gradient hillslopes upstream, with a knickzone downstream where channels and hillslopes become steeper. This pattern is likely due to the presence of more resistant bedrock in the knickzone, which resists erosion and causes the channel to incise more rapidly, leading to steeper slopes.

Our analysis of bed thickness and hillslope morphology showed that as the thickness of the bedrock increases, the slope of the hillslope likewise increases, and the hillslopes become more concave as they approach the channel. This is likely due to the fact that thicker bedrock resists erosion less than thinner bedrock, leading to a more diffusive hillslope morphology. We also found that hillslopes with less variance in bed thickness appear more diffuse, indicating that uniform bedrock properties lead to more consistent hillslope morphology.

Our results also demonstrate that the size of alluvium in the channels affects channel morphology, with larger sediment sizes corresponding to steeper channel gradients. This is likely due to the fact that larger sediment sizes require greater flow velocities to be transported, leading to more rapid incision and steepening of the channel.

Finally, we found that the maximum thickness of the bedrock affects both the size of the sediment in the channel below and the channel steepness. This relationship may be due to the fact that thicker bedrock may provide more resistance to erosion, leading to slower incision rates and a correspondingly shallower channel.

Overall, our findings suggest that the interactions between bedrock properties, hillslope morphology, and channel morphology are complex and interdependent. The results of this study may have important implications for understanding the evolution of other mountainous landscapes with similar bedrock properties and topographic characteristics. Further research is needed to explore these relationships in greater detail and to assess their applicability to other landscapes.

# 6 Conclusions

# In summary, our findings suggest that bed thickness plays a crucial role in shaping the morphology of Last Chance canyon's landscape. We have observed that thicker bedded units lead to steeper hillslopes and channels, while thinner bedded units lead to shallower hillslopes and channels with more diffusive shapes. Our results also demonstrate that the size of sediment in the channel is positively correlated with channel steepness, with larger sediment sizes corresponding to steeper channel sections. We believe that these observations have significant implications for understanding the geomorphic evolution of Last Chance canyon and potentially other landscapes with similar bedrock structures.

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