

**TITLE: The Origin of Convex Downstream Waterfall Morphology Along the Niobrara River Near Valentine, NE**

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**Purpose:** The morphology of waterfalls along the Niobrara River cannot be explained using the current theories and models for waterfall erosion. In fact, these waterfalls contradict many of the conceptual models for waterfall migration. The purpose of this study is to identify the processes that control this unique form of waterfall morphology. All forms of waterfalls along the tributaries feeding the Niobrara River within the study area were mapped, photographed, described, and classified. The study quantified the rate of weathering processes at the site of the waterfalls and proposes a new conceptual model for waterfall erosion and knickpoint migration.

**Abstract:** Over 200 waterfalls exist along the southern spring branch tributaries feeding an approximately thirty mile section of the Niobrara River east of Valentine, Nebraska. Many of these waterfalls are convex in the horizontal plane and buttressed. Season specific weathering along the waterfall sidewalls and lack of stream erosion of the waterfall face controls this morphology. The waterfall faces are comprised of the Rosebud Formation, a friable siltstone that should easily be eroded by running surface water. The streams are ineffective at eroding the falls due to low discharge and sediment load. Talus slopes at the base of vertical cliffs extend into cutbanks of the Niobrara River and are found at the bases of waterfalls along the tributaries. This shows that rock weathering due to groundwater sapping processes operates at a faster rate than surface water erosion.

Groundwater seepage and waterfall spray exposes the sidewalls to alternating, season specific weathering processes. During the summer, the sidewalls undergo daily and seasonal moisture level changes. During the winter seeping groundwater and waterfall spray freeze into the rock. The differential expansion and contraction of the rock due to moisture change and freeze-thaw causes shingle like flakes to develop. These flakes are then further exploited by salt crusts and ice crystals which form on the backside of the flakes. These weathering processes are observable only on surfaces lacking stream flow. The stream protects the waterfall from these weathering processes by preventing cyclic moisture level changes during the summer and freeze thaw cycles during the winter. With increasing convexity, stream flow is diverted to either side of the waterfall face. The waterfall face is then exposed to alternating season specific weathering processes due to lack of stream protection. Weathering causes the waterfall face to experience failure and erode upstream, whereby the face is once again protected by stream flow and begins to regain a convex shape.

**Conclusion:**

This study illustrates that groundwater and surface weather interactions and specifically groundwater sapping processes can play a very important role in waterfall erosion. The processes acting on the waterfalls of the southern spring tributaries of the Niobrara as

well as the proposed conceptual model for waterfall retreat are not site specific. Groundwater sapping processes likely play an important role in many waterfall settings, even where surface waterfalls are met with mixed success. In many cases where stream power law does not accurately predict waterfall location, groundwater is not credited for the discrepancy. It is the belief of the author that groundwater processes may play a role in the discrepancies of stream power law relationships and should not be ignored. The role of groundwater processes are easy to miss as they can often times be very subtle and difficult to measure, as was shown in this study. A rigorous field effort that identifies all possible processes is a necessity for accurate explanation of waterfall processes. There is still room for future work concerning the waterfalls along the Niobrara River. It may be interesting to attempt to quantify the different rates of weathering for sidewalls that are covered by ice versus sidewalls where ice crystals only form behind the loose flakes. The next direction of research concerning waterfalls along the Niobrara River should be to derive a numerical modeling approach to predict the location of waterfalls along tributaries. This model would possibly need to be both empirical and physical. It would need to account for groundwater sapping processes, groundwater surface water interaction, the role of surface water protection, surface water erosion, and the weathering cycles found along the waterfall sidewalls. Some of the southern spring tributaries appear to be “clustered” together. This “clustering” of springs may be a result of a groundwater table disturbance that initiated the springheads. These springs are now competing for groundwater and some may capture the groundwater discharge at the expense of other springs. It may be interesting to look at spacing and based on aquifer properties determine if the spacing follows physical principals for stream spacing. With this it may be interesting to study the history of Niobrara River incision and the activation of spring creeks. High resolution digital elevation maps may help constrain the elevations of waterfalls. With this information, it may be possible to correlate waterfalls to certain stages of Niobrara River incision.