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Knickpoint formation and retreat: stairway to heaven or pathway to declivity

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The importance of knickpoints in shaping fluvial systems has been observed in laboratory settings, small experimental plots, and at the landscape scale. By creating a step in a river's longitudinal profile, knickpoints can shield upstream tributaries from a much lower base level, and therefore represent a buffer in the energy transfer of a stream system. Knickpoints are located at a transition point between the potential energy of material stored upstream and the kinetic energy of erosion processes and sediment transport below the knickpoint. We hypothesize that the long-term persistence of a discrete, retreating knickpoint requires a balance between the fluvial erosion of the feature, and sedimentation rates downstream. Here we present the results of a short-term (four year) study of knickpoint morphology in a natural gully system to better constrain the conditions necessary to preserve distinct knickpoints over time. We monitored knickpoint erosion using time-lapse photography, repeat terrestrial lidar, soil moisture monitoring, and rainfall-runoff measurements. Our results indicate that shallow subsurface hydrology leads to knickpoint erosion via mass failure, and produces a stable and predictable morphological signature of knickpoint erosion (amphitheater shaped heads). We generalized these observations into a numerical model of erosion/sedimentation to understand the geomorphic legacy of knickpoints in deeply incised gullies. Modeling showed that knickpoints can maintain an incisional step for hundreds to thousands of years when knickpoints retreat via mass failure and sediment is removed from the knickpoint base by fluvial scour. To test simulations of long-term stability generated by the numerical model, we used Optically Stimulated Luminesence to date alluvial deposits at existing gully knickpoints. This geochronological dating confirmed that gully knickpoints have been active in our study area for hundreds to thousands of years, particularly during drought periods. Therefore, numerical modeling and field data support our hypothesis that knickpoint preservation during upstream retreat represents a delicate balance between erosion and sediment transport, and given ideal conditions, a steep knickpoint may persist in long-term dynamic equilibrium.