Influence of rock strength properties on bedrock channels and hillslope erosion in Illinois

Lisa M. Tranel[1^*], Savannah Thielbar[1], Anthony Gaeti[1]

[1] Geography, Geology and the Environment Department, Illinois State University, Normal, IL, USA.

* Corresponding author information: ltranel@ilstu.edu, 1-309-438-7966
^ Presenting author

1. Introduction

Topographic relief across large areas of the Midwest is subtle compared to mountain regions, however, glacial outwash floods and river reorganization during Quaternary glaciations created and maintained some steep bedrock valleys, including impressive bluffs along the Mississippi River and its tributaries (Reams, 2021; Curry et al., 2014; Wickert et al., 2019). The height of some bedrock channel walls in an area with low relief is a fascinating feature to study to understand the relationship between weathering, erosion, and rock strength. In particular, it is interesting to assess what processes and bedrock properties lead to the maintenance of steep bedrock channel walls. Factors that control bedrock valley wall evolution over time include response to a number of driving forces, including channel erosion, base level change, regional glacial processes including outburst floods and glacial isostatic adjustments, bedrock properties, and groundwater flow (Lamb et al., 2006; Curry et al., 2014; Wickert et al. 2019; Reams, 2021; Marcotte et al., 2021, Naylor, 2021).

This study evaluated features in bedrock canyons in two Illinois landscapes to assess conditions in regions with differing Quaternary histories and rock types. One location is in northwest Illinois known as the Driftless Area due to the lack of glacial evidence across the region. The second location is in central Illinois where glaciers covered the area during the Wisconsin Glacial Episode. Both study sites contain vertical bedrock walls at least 30 meters in height and are adjacent to active bedrock river or stream channels. In central Illinois, the canyon walls consist of weakly cemented coarse grained quartz sandstone. In northwest Illinois, the bedrock is primarily dolomite.

We investigated the evolution of these landscape with a specific interest to understand the controls of bedrock properties on erosion of the valley walls. Through repeated visits to the field sites, we observed what processes lead to erosion of steep bedrock channel walls across Illinois and how those processes may be related to rock strength and properties.

2. Study Sites

Observations and data were collected from two different field sites. One field site includes bedrock walls along the Menominee River, a tributary to the Mississippi River in northwest Illinois. This field site is located in the Driftless Area where the landscape lacks evidence of Quaternary glaciations. The timing of bedrock exposure is difficult to constrain. Evidence indicates the extent of the river valley width probably existed prior to the last glacial maximum because slackwater sediments accumulated during the last glacial maximum (Knox, 2019). Bedrock exposed in this area is primarily dolomite from the Ordovician Platteville and Galena formations (Panno et al., 2015). Bedrock outcrops display thin to thickly bedded dolomite with occasional layers of chert, limestone, and shale.

The second field site is in north central Illinois where the glaciers from the Wisconsin Episode created moraines and glacial lake deposits. Outburst floods from glacial lake Wauponsee carved the Illinois River channel (Curry et al., 2014). Now tributaries to the Illinois River incise though Ordovician St. Peter sandstone. The canyons and waterfalls created by these tributaries are within the area of Starved Rock State Park. This sandstone is thickly bedded, weakly cemented quartz arenite with cross beds (Nelson et al., 1996).

3. Methods

Observations from both sites were collected on several return visits to the field. The Menominee River site was assessed in 2017 with a group of undergraduate students to collect observations of rock strength. The site was revisited in 2019 while a graduate student investigated sediment transport along segments of the Menominee River channel (Konop, 2020). A visit to the site again in Fall 2021 noted a rockfall had occurred in the river channel upstream from the thesis study site.

The state park study also began in 2017 with a graduate student thesis project observing changes to graffiti accumulation and erosion into bedrock faces (Rutte, 2018). Monitoring those faces over the past five years across seasonal changes has allowed for additional observations of features and change along the bedrock wall surfaces.

Quantitative measurements of rock strength were collected with a Schmidt hammer on bedrock from both field sites. At the Menominee River site, Schmidt hammer measurements are an average of 20 hits on the bedrock wall completed by three groups of students. At the Starved Rock sites, we collected 10 observations across each outcrop and also tested for the change between two hits at the exact same spot on the bedrock surface (Rutte, 2018). At the Menominee River site, the Selby (1980) rock strength classification was also used to assess the rock strength of the bedrock wall including observations of bedding or fracture spacing, fracture width, weathering, groundwater flow, and orientation of the fracture or bedding surfaces into or out of the bedrock wall. Rock samples collected from boulders or blocks of rock that fell from the canyon walls were also collected from the Starved Rock sites to look for variations in cement and porosity in the sandstone.

4. Results

Over the course of the study period, rockfalls occurred along both the sandstone and dolomite canyon walls. The most frequent rockfalls were observed in late winter or early spring, however the exact timing of the rockfalls was not recorded. One rockfall in the sandstone and one rockfall in the dolomite each appeared to include a tree with roots that extended into fractures in the rock. The hilltop surface of both study sites was wooded with a variety of trees. Bedrock alcoves and overhanging bedrock features were observed in several sandstone canyon walls. The bedrock walls within overhangs displayed peeling layers of sand and the release of small blocks of rock ~2 cm thick (Figure 1). Layers observed to peel off the surface were often covered with moss. Ice crystals were also observed to form between grains, causing an outer layer of quartz grains to extend from the rock surface.

Figure 1. Images of St. Peter Sandstone from Starved Rock State Park canyon walls. The photograph on the left was from La Salle Canyon. Rocks covered in moss break off the bedrock wall below overhangs where water actively seeps from the rock. The photograph on the right was taken in Kaskaskia Canyon. Exfoliation of outer sandstone surface occurs where lichen and moss covered the rock. Ice crystals form between grains and push surface vegetation and grains away from rock. (Photograph by L.M. Tranel).

The average Schmidt hammer values were 37 ± 2 MPa for the sandstone sites and 44 ± 13 MPa for the dolomite sites. At the sandstone sites we also observed changes in rock strength ranging from 1.1 to 7.5 MPa between the first and second hit on the same point on the rock surface. A comparison between the percent cement observed in the rocks in thin section and the change in rock strength value showed a positive relationship where the change was greater when there was more cement in the rock (Rutte, 2018). Observations of rock strength and analyses of thin section cements and porosities will be continued through summer 2022.

The Selby rock strength analysis of the dolomite resulted in a site classification of moderately strong rock. The spacing between fractures and beds ranged from 0.3-3 m. The width of joints in the rock were 5-20mm. Additional measurements will be collected to evaluate these metrics again in April 2022.

5. Summary

Field observations indicate a combination of forces at the base and tops of these vertical walls maintain the steep bedrock exposures. Root wedging contributes by creating weaknesses along the top surfaces of the bedrock walls while seepage erosion, including freeze-thaw and ice needle growth, create weaknesses along the base (Lamb et al., 2006). The timing of rockfalls in late winter to early spring suggests a potential freeze-thaw influence on these events.

Fracture properties, including spacing and width, also influence the rock strength and erosion potential. Although the sandstone had a weaker rock strength, beds are massive, creating fewer weaknesses relative to the spacing of bedding and joints in the dolomite outcrops.

6. Acknowledgments

Funding provided by the USGS EDMAP Program Grant, Illinois State University Graduate Program and University Research Grants.

7. References

Curry, B. B., Hajic, E. R., Clark, J. A., Befus, K. M., Carrell, J. E., and Brown, S. E., 2014, The Kankakee Torrent and other large meltwater flooding events during the last deglaciation, Illinois, USA: Quaternary Science Reviews, v. 90, p. 22-36.

Knox, J. C., 2019, Geology of the Driftless Area, *in* Carson, E. C., Rawling, J. E., Daniels, J. M., and Attig, J. W., eds., Physical Geography and Geology of the Driftless Area: the Career and Contributions of James C. Knox, Volume 543: Boulder, Geological Soc Amer Inc, p. 1-35.

Konop, P. J., 2020, Impacts Of Land-Use Change On The Menominee River In Jo Daviess County, Illinois [M.S.: Illinois State University, 56 p.

Lamb, M. P., Howard, A. D., Johnson, J., Whipple, K. X., Dietrich, W. E., and Perron, J. T., 2006, Can springs cut canyons into rock?: Journal of Geophysical Research-Planets, v. 111, no. E7, p. 18.

Naylor, S., Wickert, A. D., Edmonds, D. A., and Yanites, B. J., 2021, Landscape evolution under the southern Laurentide Ice Sheet: Science Advances, v. 7, no. 48, p. 8.

Nelson, R. S., Malone, D. H., Jacobson, R. J., and Frankie, W. T., 1996, Guide to the Geology of Buffalo Rock and Matthiessen State Parks Area, La Salle County, Illinois: Champaign, IL, Illinois State Geological Survey, p. 94.

Panno, S. V., Luman, D. E., and Kolata, D. R., 2015, Characterization of karst terrain and regional tectonics using remotely sensed data in Jo Daviess County, Illinois, *in* Survey, I. S. G., ed., Volume 589.

Reams, M. W., An Overview of the Formation Processes of Illinois Waterfalls, *in* Proceedings Geological Society of America North-Central/South-Central Annual Meeting2021.

Rutte, M. M., 2018, Analysis of Short-Term Erosion of The St. Peter Sandstone In Lasalle County, Illinois [M.S.: Illinois State University, 69 p.

Selby, M. J., 1980, A rock mass strength classification for geomorphic purposes: with tests from Antarctica and New Zealand: Zeitschrift fuer Geomorphologie, v. 24, no. 1, p. 31-51.

Wickert, A. D., Anderson, R. S., Mitrovica, J. X., Naylor, S., and Carson, E. C., 2019, The Mississippi River records glacial-isostatic deformation of North America: Science Advances, v. 5, no. 1, p. 7.