Analysis of anthropogenic and runoff erosion into sandstone canyon walls using repeat structure-from-motion

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November 24, 2022

Abstract

Modern bedrock streams and rivers emerged in the Midwestern United States in response to glacial outwash floods ˜19,000 years ago and continued to adjust to new drainage patterns over the landscape formed by Wisconsin glaciation events. The Illinois River and corresponding tributaries form a fascinating landscape with canyons carved 50-200 m deep into the St. Peter Sandstone. These geomorphic features are preserved and open to visitors as Starved Rock State Park in Central Illinois. Free access to the state parks and close proximity to the large Chicago metropolitan area result in frequent visitation to this natural attraction. Recently, the rates of natural stream incision appear to be overprinted by direct human influences on the landscape. The St. Peter Sandstone is a weakly cemented, extremely friable quartz arenite, making it susceptible to human disturbance and rapid natural erosion. This study explores how quickly present day changes occur along bedrock surfaces using photogrammetric Structure-from-Motion (SfM). Repeat photographic data were collected once per month from two sites within the park where canyon walls contained human carvings that served as reference features to align photos and monitor change. Photos were merged in Agisoft PhotoScan Pro to construct 3D point clouds and imported into CloudCompare to measure changes to rock surfaces between monthly visits. The photogrammetric SfM analysis detected measurable change on a centimeter to millimeter scale. Changes along footpaths were observed when visitor traffic was high. During winter months when visitor traffic decreased, rainfall and snowmelt runoff primarily caused mobilization and removal of loose sediments covering bedrock surfaces. Bedrock thin sections from each site were studied to assess the influence of cement on erosion rates. Lower cement concentrations were observed at the outcrop site with the greatest measured surface change. Changes detected with SfM analyses demonstrate that human interactions can influence erosion processes in a short time. While both natural and human caused changes occurred on bedrock surfaces, precipitation created greater measurable differences.

G51C-0741

AGU 100 FALL MEETING Washington, D.C. | 10–14 Dec 2018

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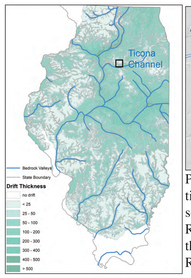
Introduction

Modern bedrock streams and rivers emerged in the Midwestern United States in response to glacial outwash floods ~19,000 years ago and continued to adjust to new drainage patterns over the landscape formed by Wisconsin glaciation events. The Illinois River and corresponding tributaries form a fascinating landscape with canyons carved 50-200 m deep into the St. Peter Sandstone. These geomorphic features are preserved and open to visitors as Starved Rock State Park in Central Illinois.

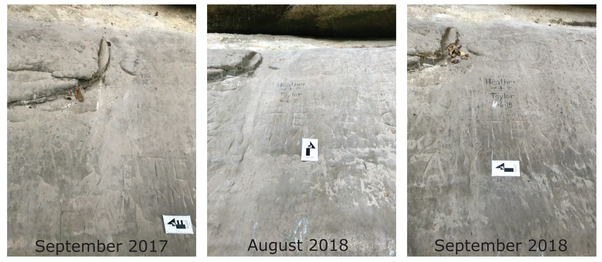


Prior to Wisconsin glaciation, the Ticona channel south of the modern Illinois River served as a tributary to the ancestral Mississippi River.

The study site is located in north-central Illinois. The Illinois map demonstrates the thickness of glacial sediments and pre-glacial river networks. This work focused on two bedrock outcrops in LaSalle Canyon and Illinois Canyon. These canyons were carved by two tributaries to the Illinois River.

In 2017 and 2018, rockfalls occurred demonstrating the natural potential for changes to bedrock surfaces an hazards in this environment. Visitor traffic to the area aided in transportation of loose sediments and breakdown of larger fallen blocks. Monitoring all surface changes helps communicate hazards, safety, and preservation.

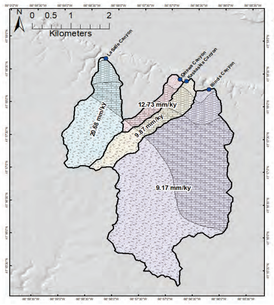
Free access to the state parks and close proximity to the large Chicago metropolitan area result in frequent visitation to this natural attraction. Recently, the rates of natural stream incision appear to be overprinted by direct human influences on the landscape.



This bedrock surface demonstrates the impact of visitor traffic to Starved Rock State Park. The first image from 2017 shows evidence of sand scraped over the surface from foot traffic along our study outcrop in LaSalle Canyon. The 2018 images show modifications to the surface after 1 year and 1 additional month.

The St. Peter Sandstone is a weakly cemented, extremely friable quartz arenite, making it susceptible to human disturbance and rapid natural erosion. This study explores how quickly present day changes occur along bedrock surfaces using photogrammetric Structure-from-Motion (SfM).

St. Peter Sandstone Erosion Rates



Cosmogenic radionuclides were used to determine post-glacial erosion rates since exposure after the Wisconsin glacial episode.

Bedrock erosion rates in the sandstone along a canyon wall are ~132 mm/kyr measured from bedrock surfaces. Catchment averaged erosion rates are ~13 mm/kyr.

Structure from Motion

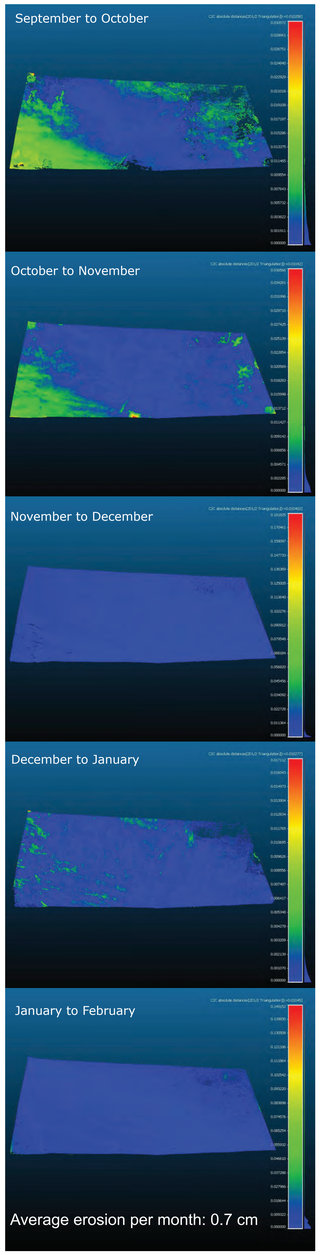
Photoscan Pro:

Repeat photographic data were collected once per month from two sites within the park where canyon walls contained human carvings that served as reference features to align photos and monitor change. Photos were merged in Agisoft PhotoScan Pro to construct 3D point clouds.

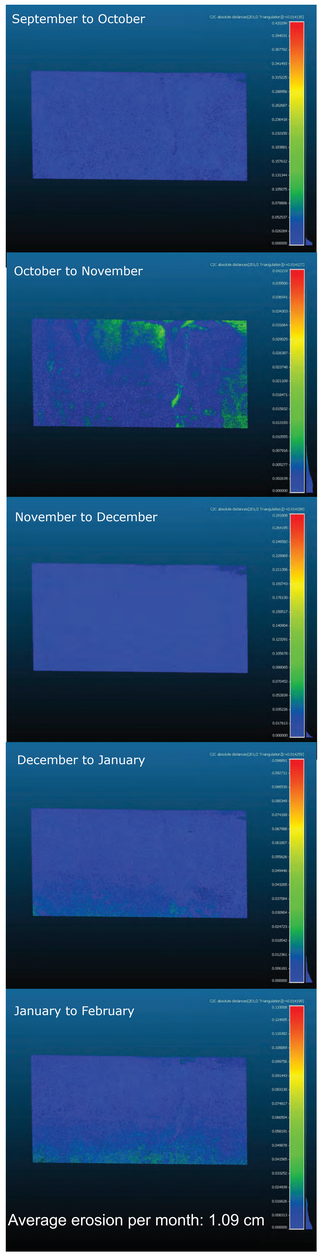
CloudCompare:

3D point clouds were imported into CloudCompare to measure changes to rock surfaces between monthly visits.

LaSalle Canyon Surface



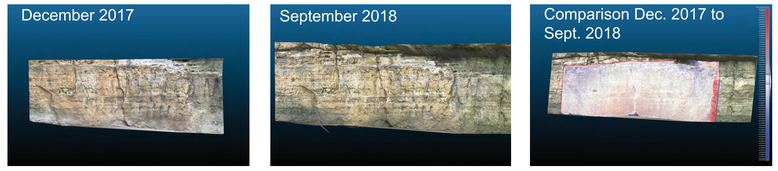
Illinois Canyon Surface



Results and Summary

The photogrammetric SfM analysis detected measurable change on a centimeter to millimeter scale. Changes along footpaths were observed when visitor traffic was high. During winter months when visitor traffic decreased, rainfall and snowmelt primarily caused mobilization and removal of loose sediments covering bedrock surfaces.

The Illinois Canyon outcrops was located away from the primary foot traffic, so disturbances to the surface were expected to occur less frequently. These images indicate the difference in spiderweb accumulation when surfaces were compared.

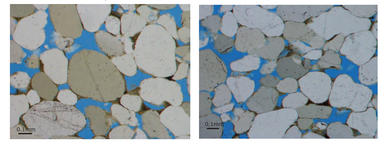


Months	Type of Precipitation	Mean Temperature (degree C)	Total Precipitation (cm)
Sept.-Oct.	Rain	18.14	1.04
Oct.-Nov.	Rain	8.24	18.67
Nov.-Dec.	Rain	1.87	2.67
Dec.-Jan.	Rain/Snow	-5.94	30.23
Jan.-Feb.	Rain/Snow	-3.01	50.55

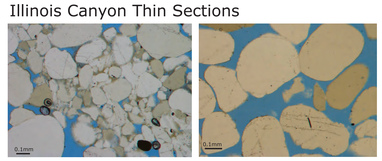
Greatest precipitation during the period of monthly observations occurred between visits during December, January, and February. These observations of high precipitation matched with the greatest change detection in surfaces. Water running over the bedrock surfaces transported sediments that accumulated in carved letters or surface cracks.

Bedrock thin sections from each site were studied to assess the influence of cement on erosion rates. Lower cement concentrations were observed at the outcrop site with the greatest measured surface change.

LaSalle Canyon Thin Sections



Illinois Canyon Thin Sections



Thin sections of rock from Illinois Canyon displayed greater porosity and less cement than rock from LaSalle Canyon. Measurements of rock strength taken with a Schmidt hammer indicated slightly weaker rocks in Illinois Canyon. Erosion estimates from SfM indicated that the Illinois Canyon surface eroded more than the LaSalle Canyon surface.

Changes detected with SfM analyses demonstrate that human interactions can influence erosion processes in a short time. The contrast between strong and weak surfaces highlights the sensitivity of this environment.

Examples of surfaces with with various weathering surfaces, vegetation growth, or mineral accumulation. Thin crusts maintaining the canyon wall surfaces degrade easily when broken or disturbed. Fresh surfaces crumble away easily to when weakly cemented surfaces are exposed.

Acknowledgements and References

We thank Starved Rock State Park and the Illinois Department of Natural Resources for allowing us to complete this research within the state park. We also thank David Olchoa and Becky Andrews from Covia (Wedron Silica) for assistance collecting samples and observations near Wedron, IL. Cosmogenic radionuclide analyses were completed at Purdue University PRIME Lab.

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