Fluvial System Response to Abrupt Base-Level Fall: Mapping Tributary Stream Terraces in the Lower Chippewa River Watershed

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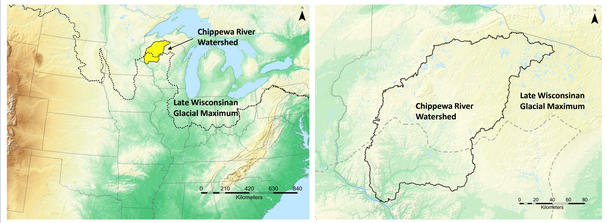
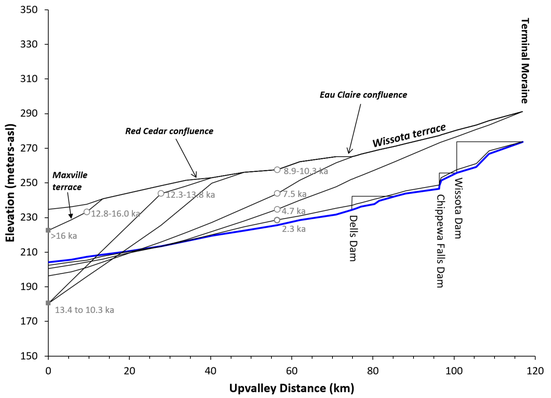
Introduction and Background

During the Late Wisconsinan, the Laurentide Ice Sheet (LIS) advanced from Canada towards the Chippewa River Watershed. Approximately 30,000 years ago (30 ka), the Chippewa Lobe of the LIS entered the watershed and reached its maximum extent by around 25 ka. Approximately 20 ka, the ice began to retreat and had pulled out of the watershed by 13 ka. During this time, the LCR and its two largest tributaries, the Red Cedar River and the Eau Claire River, were glacial meltwater streams, overloaded with glacial outwash that filled their valleys. It has been estimated that the glacial ice was completely retreated from the LCR around 13 ka.

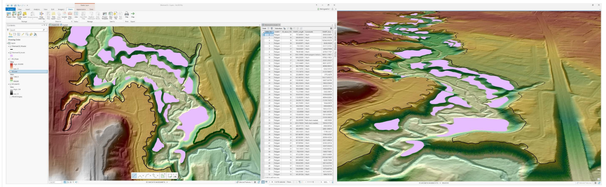


Past research by Faulkner and others aimed at reconstructing how the Chippewa River responded to base-level fall, which occurred when the Upper Mississippi River (UMR) incised during deglaciation of the Upper Midwest. The UMR is the base level for the Chippewa River and acts as the control for how far it can incise. When base level drops, it can trigger incision, or active downcutting, of the river. Faulkner et al. (2016) proposed a model of episodic knickpoint migration and incision up the LCR in response to UMR incision (see figure below). The objective of our study is to test the model by focusing on the incision of tributaries to the LCR, building on the research of Hilgendorf and Faulkner (2015). Our hypothesis is that tributaries that join the LCR farther upstream from the UMR would have more terraces than those downstream.



The longitudinal profile above is the model proposed by Faulkner et al. (2016) of episodic knickpoint migration and incision in response to UMR incision at 16-18 ka and at 13.4 ka. This model is based upon mapping of terrace remnants and dating of terrace fill with optically stimulated luminescence. The highest terrace in the LCR valley is the Wissota terrace, which marks the maximum level of outwash aggradation. This terrace can be traced from the UMR to the LIS terminal moraine. Remnants of several lower fill-cut terraces reside below the Wissota terrace. Note that the longitudinal profile flattens as the knickpoint migrates upstream, as is characteristic of knickpoint migration up transport-limited streams.

Methods

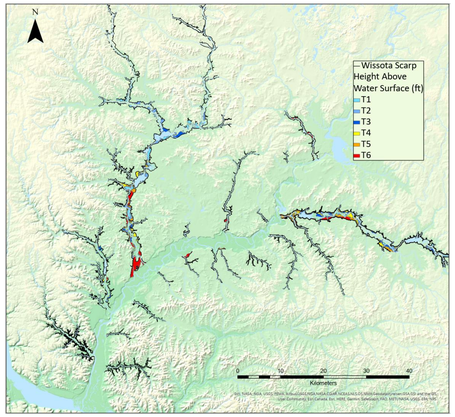


ArcGIS Pro was utilized to digitize the Wissota scarp and lower terraces along 18 tributary streams. The Wissota and lower terrace treads were identified with the use of visualization and elevation tools by from a Digital Elevation Model (DEM) and slope raster created from LiDAR derived data. We classified terraces by requiring a minimum 10-foot difference between them. The identification and digitizing primarily occurred in ArcGIS Pro as shown by the image above on the left. It also provided key visualization capabilities by allowing for a 3D perspective for viewing the fluvial features (see image above on the right).

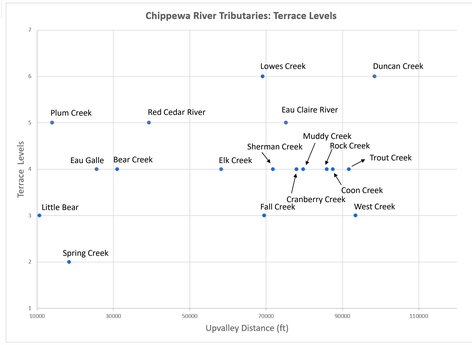
Field checks were utilized to verify difficult to discern features. Both images above are of Sherman Creek. The figure above on the left shows where the incised gorge is widening, with terrace scarps outlined in a yellow line. The dashed yellow line marks the floodplain and the highest yellow line marks the Wissota terrace. The above image on the right is upstream of the image on the left. This reach of Sherman Creek is not incised below the Wissota terrace.

Results

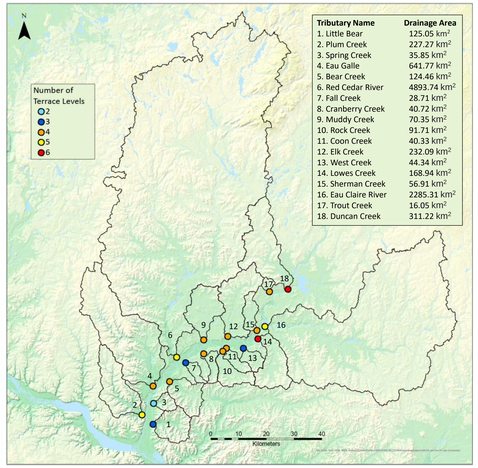
This map shows the digitized terraces along the 18 tributaries of the study. The Wissota terrace scarp is shown in black for each tributary. Lower terraces are also shown, classified as previously described. The highest identifiable terrace below the Wissota is in red and the lowest terrace is colored in the lightest blue.



Results (cont'd.)



The chart above shows the number of terrace levels below the Wissota terrace found near the mouth of each tributary stream. The tributary streams are plotted relative to their distance upstream from the UMR.



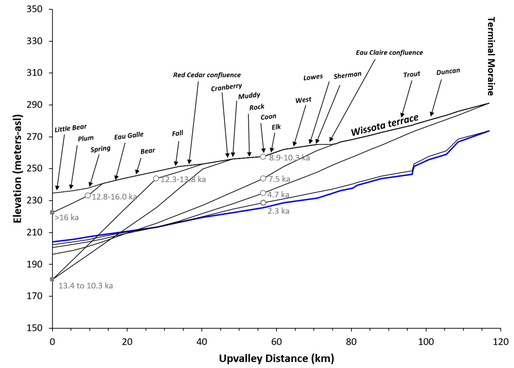
Tributary Name	Drainage Area
1. Little Bear	125.05 km²
2. Plum Creek	227.27 km²
3. Spring Creek	35.85 km²
4. Eau Galle	641.77 km²
5. Bear Creek	124.46 km²
6. Red Cedar River	4893.74 km²
7. Fall Creek	28.71 km²
8. Cranberry Creek	40.72 km²
9. Muddy Creek	70.35 km²
10. Rock Creek	91.71 km²
11. Coon Creek	40.33 km²
12. Elk Creek	232.09 km²
13. West Creek	44.34 km²
14. Lowes Creek	168.94 km²
15. Sherman Creek	56.91 km²
16. Eau Claire River	2285.31 km²
17. Trout Creek	16.05 km²
18. Duncan Creek	311.22 km²

The map above shows the watersheds of the 18 tributaries to the LCR with the drainage area for each listed in km².

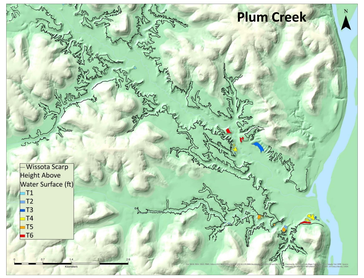
Discussion

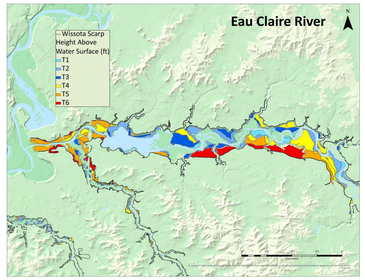
Based on the model of Faulkner et al. (2016), we expected to find more terraces along tributaries that join the LCR farther upstream. The reason we expected this is that the tributaries farther upstream experienced more episodes of base-level fall.

Discussion (cont'd.)



Generally, incision of the LCR's tributaries is consistent with our hypothesis. This is demonstrated by the terrace levels present on Plum Creek, which joins the LCR 4 km upstream from the UMR, and the Eau Claire River, which is situated 23 km upstream. However, there are some notable differences that indicate that this model is far from a perfect explanation. Our results show that there are more terrace levels for tributaries upstream ***and*** for those with larger watersheds. Tributaries with larger watersheds have more of an ability to build floodplains in between each episode of incision, resulting in the formation of more terraces. However, there are additional factors that have likely influenced knickpoint migration and terrace formation, such as complex response and bedrock controls.





For example, the tributaries nearest the confluence of the Mississippi River have terrace remnants that are consistent with complex response. If the terrace levels for the downstream tributaries fit within the original model, we would expect to find very few, if any, terraces for the tributaries nearest the confluence of the Chippewa River to the Mississippi River. If this were the case, Plum Creek, which stands out as an outlier with 5 terrace levels, would have very few terraces. This is consistent with complex response, meaning that as a knickpoint migrated up Plum Creek, it began to incise, creating steep unstable banks. These banks would often collapse, adding more sediment into the river and depositing it downstream. When the banks would then stabilize and sediment would be cut off, it could trigger incision again and form terraces that are clustered near the mouth. Bedrock also plays a significant role in controlling fluvial incision rates, which is evident for streams such as Rock Creek, that have a knickpoint hung up on bedrock that has slowed the rate of incision and prevented it from progressing further upstream.

Acknowledgements

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References

Faulkner, D. J., P. H. Larson, H. M. Jol, G. L. Running, H. M. Loope & R. J. Goble (2016)
Autogenic incision and terrace formation resulting from abrupt late-glacial base-level fall, lower Chippewa River, Wisconsin, USA. Geomorphology, 266, 75-95.

Hilgendorf, Z.T., and Faulkner, D.J. 2015. The extent of tributary incision in response to knickpoint migration on the lower Chippewa River in west-central Wisconsin (poster): Abstracts, Annual Meeting - Association of American Geographers, Chicago, IL.