CEDARVILLE UNIVERSITY

GLACIAL OUTFLOW ORIGIN OF MASSIE CREEK GORGE, GREENE COUNTY OHIO

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ABSTRACT

Massie Creek Gorge is one of several small but impressive canyons in Greene County, Ohio that cut through a typically low-relief landscape. Massie Creek Gorge displays spectacular dolomite cliffs (up to 20 m high), large rockfalls (averaging 100 m in the lower gorge and 1800 m^3 in the upper gorge), numerous large potholes (up to >5 m wide and >7 m high), a dry valley branching off the main channel with a resultant bedrock island (≈ 30,000 m^2 in area) and two boulder bars on its lee side (the largest ≈13.5 m thick). Short side canyons are cut to the same depth as the main drainage, but are dry; sometimes they also contain potholes on their walls. Massie Creek Gorge's geomorphological features, its location in relation to end moraines from the last glaciation episode, and regional surficial deposits and stratigraphy indicate the terminus of the glacial ice was directly above the proximal end of Massie Creek Gorge. With the exception of some late-occurring rockfalls, sediment deposition, aggrading spring deposits, and the undersized river show Massie Creek Gorge is a relict landscape. Joint orientations correlate locally with gorge direction and perpendicular side-streams/crevices, and regionally with morphologically similar Clifton Gorge and Glen Helen Gorges. Previous studies concerning these two nearby gorges were analyzed, along with work dealing with glacial history, processes, and features in southwestern Ohio.

Studies dealing with pothole types and formation were reviewed and applied to Massie Creek Gorge. These along with the dry river channel, the bedrock island, boulder bars and short but deep side canyons testify to very significant past flow conditions. Evidence suggests the gorge was cut by high-volume, sediment-laden outwash from ice that was in close proximity to the gorge, probably during a glacial outburst flood or rapid glacial melting and retreat. This is consistent with the scale of potholes and boulder bars found within the canyon. The origin of this gorge may provide clues concerning the origin of other gorges around southwestern Ohio and deep canyons near significant end moraines.

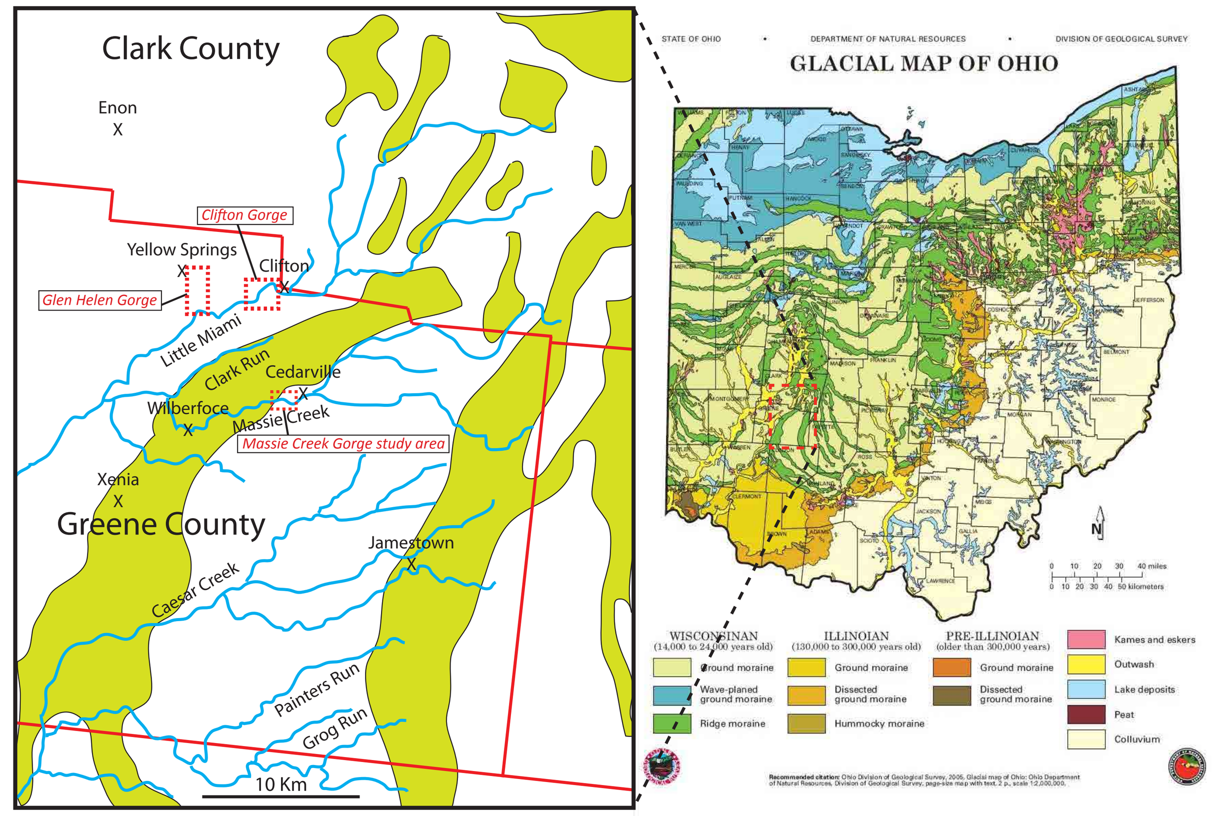


Figure 1. The Ohio DNR's Glacial Map displays regional extent and deposits of the most recent glaciations. The expanded area map shows our Massie Creek Gorge study near Cedarville, along with other gorges to the north. Note the regional drainage pattern and ridge moraines (green) delineating glacial sub-lobe movement and extent. From *Ohio Division of Geological Survey, 2005, Glacial Map of Ohio: Ohio Department of Natural Resources, Division of Geological Survey, page-size map with text, 2 p., scale 1:2,000,000.*

Regional Setting

Several bedrock gorges lie along the Little Miami River drainage system in the Green County Ohio area (Fig. 1). All display similar geomorphologies, steep dolomite cliffs, and a southwesterly orientation. Clifton Gorge is 4.8 km long and 34 m deep. Glen Helen Gorge is 15 m deep and 1.25 km long. Multiple previous studies on Clifton and Glen Helen Gorges have interpreted glacial and fluvial processes, erosion influenced by joint patterns, and karsting as the main formative agents (Schumacher et al., 2012; Waren, 1988).

To the south of these, Massie Creek Gorge in Cedarville (this study) is ≈1.8 km long, averages 15-18 m deep and gradually widens from 9-12 m upstream to ≈100 m in the lower region. Massie Creek Gorge cuts through two resistant dolomite formations overlying a softer shale layer (Fig. 2). The upper Cedarville Dolomite is the major cliff-former; Springfield Dolomite weathers to a less-resistant brick-like pattern; Massie Creek Shale lies at the gorge's bottom in its lower reaches.

A variety of glacial deposits blanket southwest Ohio, and a thin layer of glacial till from the Pleistocene Epoch's multiple glaciations overlies most of the study area. Gorge heads lie near low end moraines (Fig. 1). Notably, a thick deposit of till/outwash covers a region down-drainage of Massie Creek Gorge stretching from about 3.2 km to over 16 km west of Cedarville (Fig. 3).

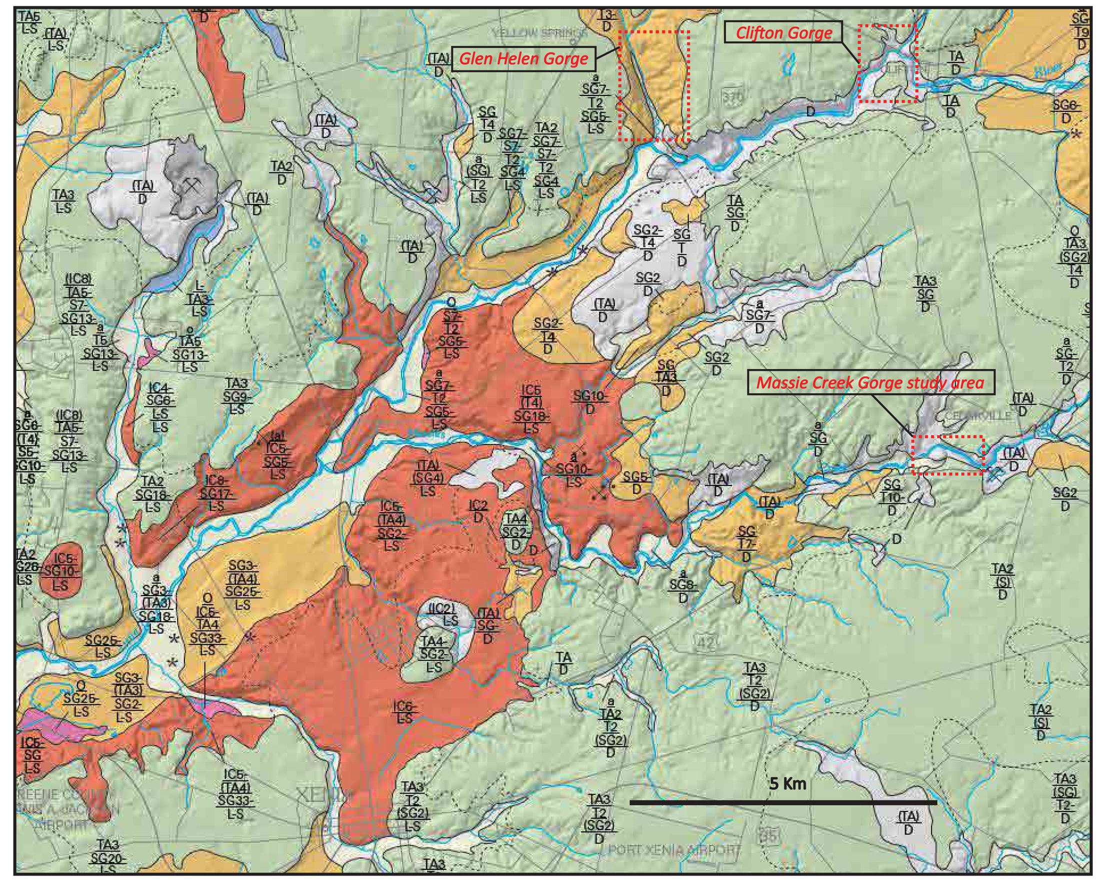


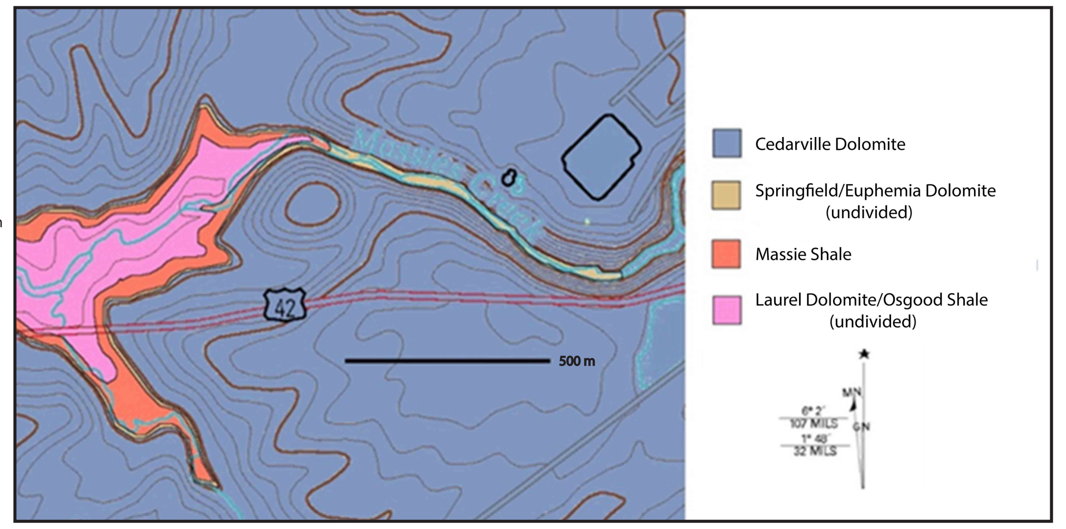
Figure 3. Surficial deposits of region surrounding Massie Creek Gorge study area. Stacks of letters/numbers represent a generalized cross section for each area. Note thickness of deposits downstream from our study area.
Surficial units include: "**O**" for organic deposits of muck, peat, clay; "**IC**" for highly variable, "ice-contact" deposits of poorly sorted gravel and sand, and common silt, clay, and till lenses; "**S**" for well-moderately sorted and moderately-well rounded sand, finely stratified to massive, with minor silt/gravel lenses; "**SG**" for well-moderately sorted and moderately-well rounded intermixed/interbedded sand and gravel, finely stratified to massive; "**TA**" for high carbonate content loam till possibly containing silt, sand and gravel lenses; "**T**" for undifferentiated surface till; "**a**" for alluvium containg silt to boulder size material.
Bedrock units include: "**Ls**" for Devonian-age limestone and dolomite; "**D**" for Silurian- and/or Devonian-age dolomite; "**L-S**" for interbedded Ordovician-age limestone and shale.
Lithologic colors represent: alluvium; organic deposits, Holocene-age; till, ice contact deposits, and sand and gravel, all Wisconsinan-age.
Numbers following the lithology designator represent average thickness of each unit in tens of feet; if no number is present, the average thickness is 1 (10 feet).
From *Brockman, C.S., Schumacher, G.A., Shrake, D.L., Swinford, E.M., and Larsen, G.E., 2005, Surficial geology of the Springfield 30 X 60-minute quadrangle: Ohio Division of Geological Survey Map SG-2 Springfield, scale 1:100,000.*

Results

Width of Gorge Compared to Lithology (Fig. 4)

Where the bed of Massie Creek rests on Cedarville Dolomite, the gorge remains relatively narrow. Large rockfalls and slides occur downstream upon entering the Springfield / Euphemia Dolomites. Further downstream, where Massie Shale underlies the stream, it widens dramatically from ≈30 m to ≈100 m.

Figure 4. Geologic map of Massie Creek Gorge, showing the correlation between gorge width and bedrock type. Contacts are approximate.



Rockfalls (Fig. 5, LOC 3)

Large, isolated blocky rockfalls upstream average 5.55 m high, 31.1 m long, and 10.7 m wide (n=4). More abundant, smaller rockfalls lie downstream, averaging 3.0 m high, 8.3 m long, and 4.0 m wide (n=11).

Dry Valley and Bedrock Island (Fig. 5)

In the downstream reaches of Massie Creek Gorge, at the point where the river drops into Massie Shale and widens drastically, it flows along the northern side of a circular bedrock island approximately 30,000 m^2 in area. A steep-sided dry valley whose floor lies just above the current river level curves along the island's southern side. Smaller but more numerous rockfalls surround the island (25 on northern side, less numerous along western and southern sides, and a dozen along the dry valley's southern cliff).

Boulder Bar (Fig. 5)

A boulder bar measuring 64.5 m long, 13.5 m high and ≈30 m wide lies along the bedrock island's western side. It is composed of bedrock float and well-rounded glacial erratics. Boulder measurements (n=33) averaged 29-37 cm along the long axis.

Another smaller bar lies ≈75 m to the south and displays ≈40 m^2 of exposed cobble similar to the first.

Potholes (Fig. 5, LOC 1-9)

Numerous large but well-weathered and incomplete potholes line the gorge, averaging a minimum width of 2.5 m and at least 3.2 m tall. They occur along the gorge's cliff face, on a rockfall, on bedrock beside and within current flow, and along the dry channel cliff face.

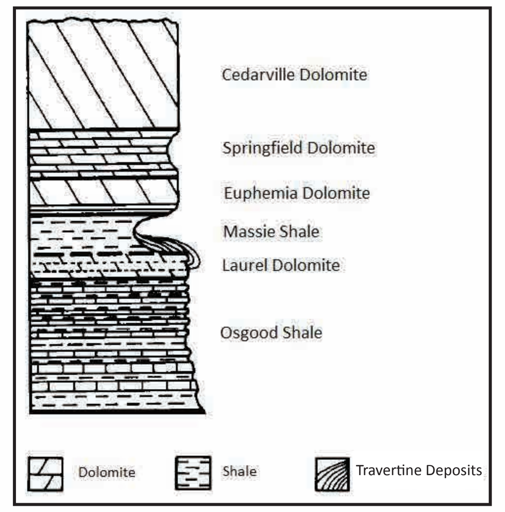
Joints (Fig. 5)

Near-vertical joints are clearly visible in the cliff face along the gorge's entire length, as well as in the dry channel. Orientations of 47 joints were plotted, and compared to orientations of the gorge and numerous minor streams and crevices perpendicularly intersecting the near-linear gorge walls.

Spring Deposits (Fig. 5, LOC 8)

Multiple travertine and tufa spring deposits up to 5 m^3 in volume occur at the contact between Massie Creek Shale and the Euphemia Dolomite, accumulating as groundwater flows out of the cliff face above the less permeable Massie Shale.

Figure 2. Generalized lithostratigraphic section of Massie Creek Gorge study area. Note resistant cliff-face formers, and location of travertine/tufa spring deposits. Modified from Ausich, W.I., 1987. John Bryan State Park, Ohio: Silurian Stratigraphy. In: *Biggs, D.L. (Ed.), Centennial Field Guide, Volume 3. Geological society of America, Boulder, CO, 419-430.*



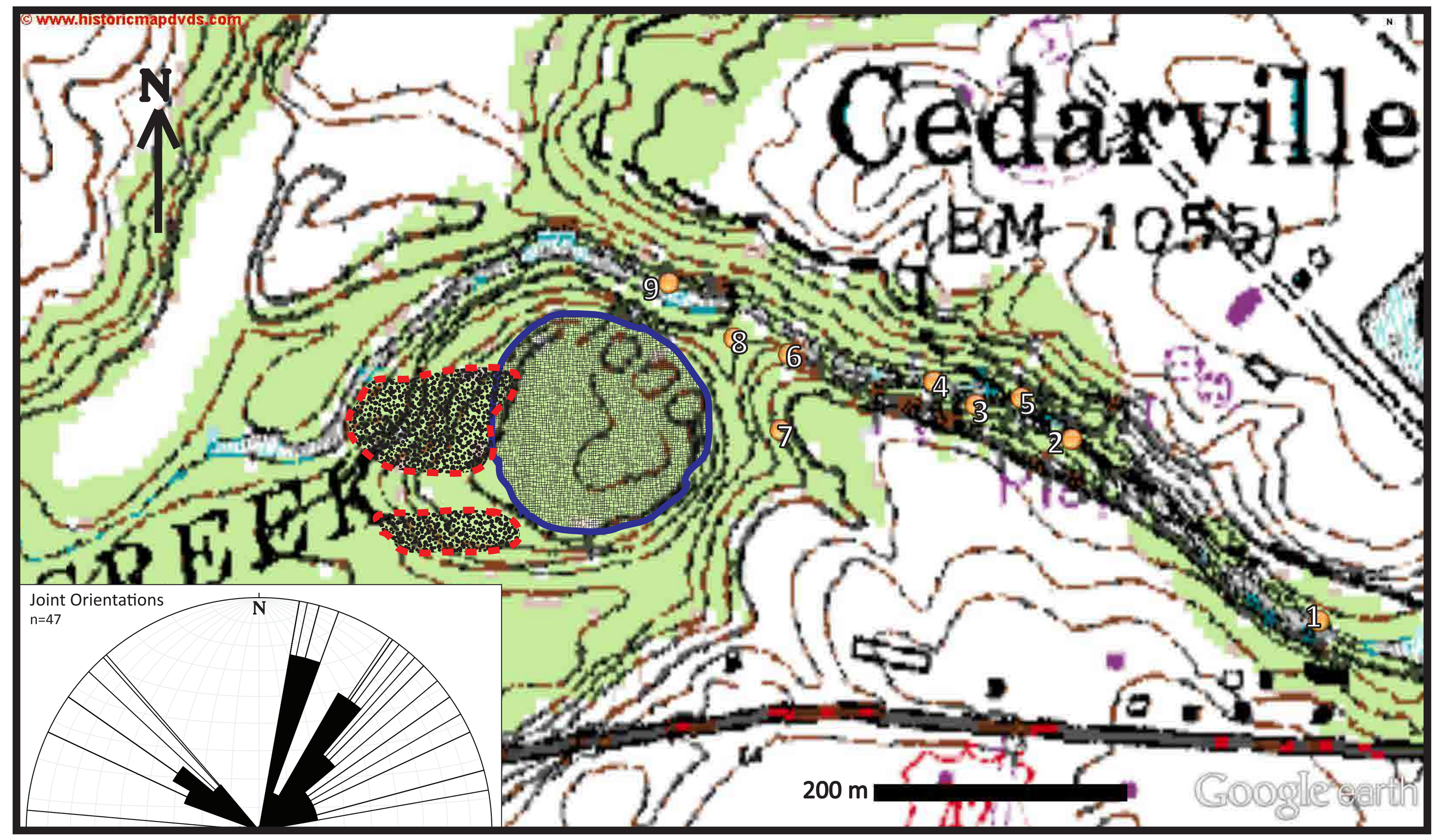


Figure 5. Map of Massie Creek Gorge study area. Locations 1-9 are noted. Circular bedrock island is outlined in blue; large and small gravel bars on west side of island are outlined by red dashes. Inset rose diagram shows joint orientations along the gorge. The dry canyon/channel curves around the bedrock island's southern side. Note the correlation of joint patterns with stream and dry channel orientations.
Map from *Google earth* and *www.glib.com/usgs-topographic-maps-2.htm.* Rose diagram drafted in *Rick Allmendinger's Stereonet 8* program, *www.geo.cornell.edu/geology/faculty/RWA.*

Discussion

The thick deposits downstream of Massie Creek Gorge may be the result of glacial outwash that helped shape the upstream Clifton, Glen Helen, and Massie Creek Gorges. The rock-layer controlled, sudden drainage widening led to decreased competence. The extent of these deposits suggests previously significant water flow. Lack of silt or organic-rich layers between deposits suggests rapid deposition. The deposits' variations in composition, thickness, grain size, rounding, and sorting are indicative of rapid and massive glacial outwash. (Stewart, 2007; Waren, 1988)

The eroded nature and location of potholes suggest formation contemporaneous with that of the gorge and evidence previous flow elevations. They represent either suspended sediment leading to vortex abrasion or toolless cavitation. The differing pothole types (vertical, plunge, trough) observed suggest changes in joint-controlled drainage resulting in "rip-up" clasts and rapid headward erosion and gorge cutting. For most potholes located higher up, plunging water likely from an overlying and retreating glacier may have initiated formation. Large pothole sizes and similar morphologies suggest common formation in a single or multiple rapid, massive-flow events. (Wang et al., 2009; Zen and Prestegaard, 1994)

The high gravel bar, its large boulders, and its location on the lee side of the bedrock island suggests a depositional environment of deep, fast-moving floodwaters. The dry channel bordering the island's southern side supports this idea. (Bretz, 1969)

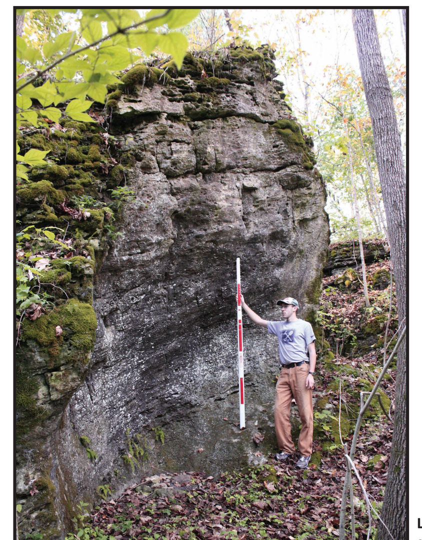
Present-day accumulation of spring deposits testify to decreased erosion rates compared to the past, showing Massie Creek Gorge is a relic landscape, and thus past gorge-forming processes are not presently observed.

Numerous and large rockfalls resulted from relief jointing due to mass gorge erosion and rapid undercutting by stream erosion. Overall joint orientations correlate with the orientations of Massie Creek Gorge and its side channels, along with regional southwesterly drainage. Joint-controlled glacial outflow may have formed the present drainage network. (Waren, 1988)

Multiple mechanisms may have contributed to Massie Creek Gorge's formation. A jökulhlaup, or glacial outburst flood, occurs when a subglacial or proglacial lake catastrophically drains following the breaching of a dam consisting of glacial ice or a terminal moraine (Rushmer, 2006). These events can be episodic. Also, rapid melting and receding of the glacial lobe produced large volumes of meltwater, which may have been dammed by proglacial moraines, whose subsequent breach resulted in catastrophic outwash. Lastly, subglacial flow may have eroded into bedrock, similar to current formation of karst caves.

Due to the location of Massie Creek Gorge between two end moraines, our proposed hypothesis employs subglacial processes as the initial causative agent for canyon formation. A lack of significant glacial till between end moraines points to later rapid glacial retreat. First, subglacial bedrock erosion and episodic outwash from jökulhlaups resulted in significant flow following joint-controlled drainage, and massive pothole formation and rapid bedrock removal. Sediment-laden outflow following glacial retreat continued these processes, and explains the downstream deposits, large bedrock island, abandoned channel, and boulder bar. Rockfalls formed and were left along canyon walls as flow subsided.

LOC 1. **A)** Large vertical/plunge pothole, south side of river (scale = 2 m). **B)** Same large pothole, with smaller one closer to water (can circled at bottom of large hole is about 15 cm long). **C)** Part of large vertical/plunge pothole along north cliff face.



LOC 2. Partial vertical/plunge pothole on side of rockfall, south side of river (scale = 2 m).

LOC 3. **A)** Pair of stacked lateral/trough potholes on south side, angled downstream about 30° below horizontal (scale = 2 m). **B,C)** Large rockfalls along south side of river.

LOC 4. **A,B)** Large vertical/plunge pothole split between two close rockfall blocks on river's south side. Lower pothole section in A, top in B. Scale = 2 m.

LOC 5. **A)** Vertical/plunge pothole on river's north side, along water (scale = 2 m). **B)** Vertical/plunge pothole in bedrock, center of river (scale = 2 m).

LOC 6. **A)** Vertical/plunge pothole along south cliff face (scale = 2 m). **B)** "Hourglass-shaped" vertical/plunge compound pothole located just west of A on same cliff face (scale = 2 m).

LOC 7. Vertical/plunge pothole located near base of dry channel's cliff face (scale = 2 m).

LOC 8. Large travertine/tufa spring deposits along base of north cliff face, extending downwards from Springfield Dolomite to Massie Creek Shale (scale = 2 m). Some blocks have broken off.

LOC 9. Vertical/plunge pothole well above water level along north cliff face (scale = 2 m).

Conclusions

Massie Creek Gorge was formed by episodic, catastrophic subglacial lake drainage (jökulhlaups) and significant sediment-laden glacial outwash. These eroded the canyon along previously existing joint-controlled drainage patterns. Evidence includes an abandoned channel and bedrock island, boulder bars, and numerous large potholes. As the glacier rapidly retreated, the large volume of meltwater further deepened and widened the gorge, undercut resistant layers, caused rockfalls associated with relief jointing, and deposited sediment downstream. This model may prove useful in interpreting the formational processes of gorges in southwestern Ohio and other deep canyons near significant end moraines.

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