Interpretation of Ice-Marginal Hydrologic Conditions Based on Sediment Preservation in Clarksville Cave: East-Central New York State

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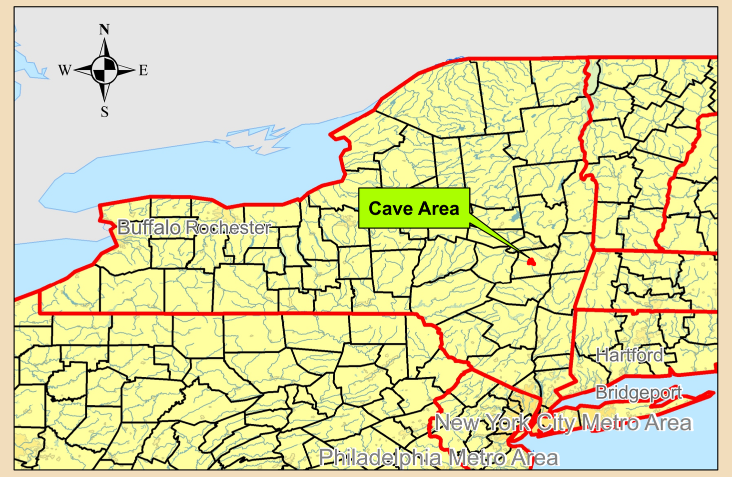
WORK IN PROGRESS

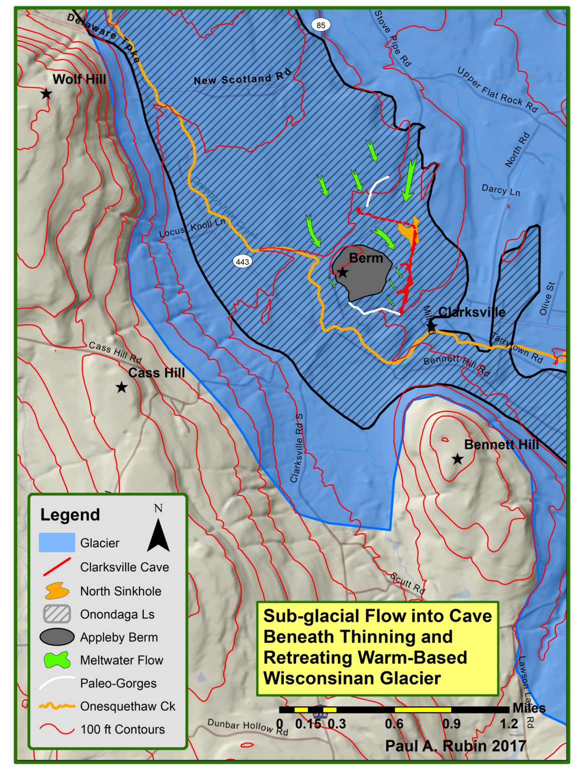
Abstract

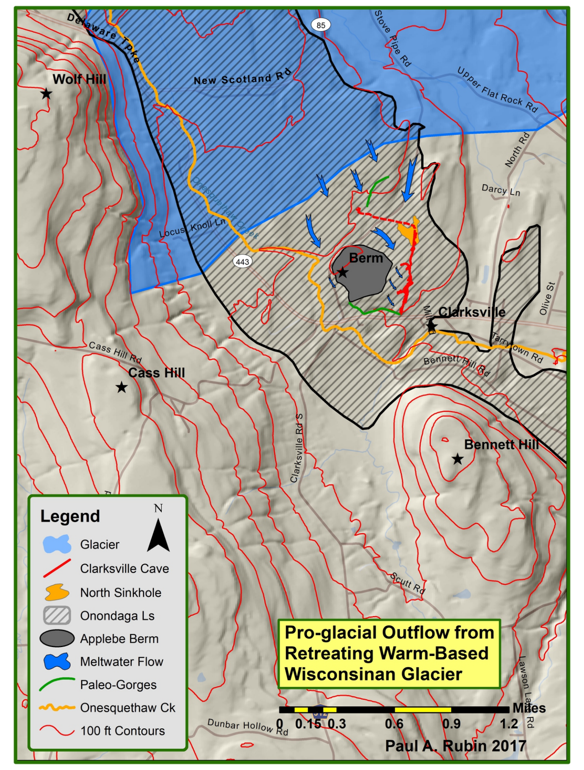
Quaternary sediments in Clarksville Cave, in Albany County, NY (228m to 203m msl), permit interpretation of ice marginal mechanisms of flow transport and deposition. Sediments faithfully record Wisconsinan subglacial, proglacial and climatic conditions. Major cave development occurred beneath warm-based ice, an analogue to alpine Castleguard Cave in Canada. Subglacial meltwaters dissolutionally-enlarged joints and steeply-dipping fault planes (~14°SE to 32°SE) within Devonian Onondaga limestone. Within 60m of water inlet points and shafts, vadose flow was forced southward along a strike-oriented $14m^2$ master conduit largely situated within a thrust zone, down thrown against impermeable Schoharie sandstone. During glacial retreat, sediment and erratic cobble influx occurred through now relict conduits (at least 17) either under subglacial or, more likely, proglacial conditions. The short distance between sediment influx points and the master conduit allow interpretation of hydrologic conditions during deposition because little sediment redistribution occurred. Sediment "*marker beds*" are traceable throughout the cave, indicating contemporaneous sediment and cobble inputs via braided streams, alternating between glacier ice-proximal and distal zones. Initial deposition of finely laminated lake clays and silts occurred in a clean, nearly sediment-free, cave situated near and back-flooded behind a proglacial lake (within 60m; 218m msl). Above basal glaciolacustrine sediments, a sequence of subaqueous, pebble-cobble, debris flow diamictons are punctuated by stratified and graded gravels, sands, silts, and clays (11 cycle minimum with quiescent periods) that once filled the cave to the ceiling. An upper subaqueous turbulent underflow deposit (yellow silts and clays) with climbing ripples provides an important marker throughout the cave. Above this, a calcite-coated, pebble-rich, debris flow that truncates a glacier-fed delta deposit in McNab Hall and massive ceiling collapses atop stratified sediments, provide evidence of a short-lived glacial re-advance before retreat and later sediment excavation by a cave stream. Clarksville Cave provides a unique and exceptional setting for examination of episodic and seasonal glacial outflows close to the source.

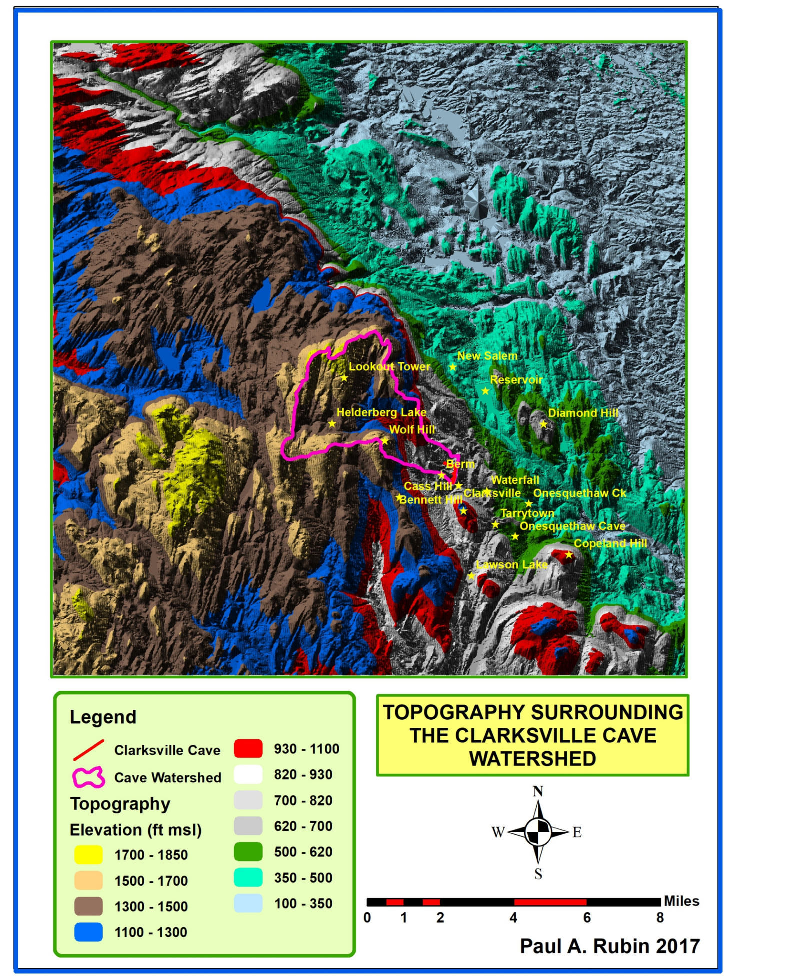


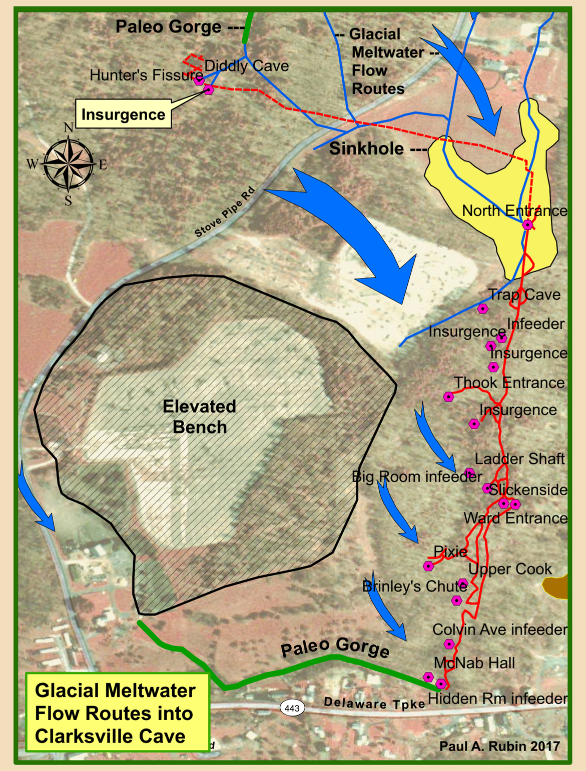
Some Key Points:

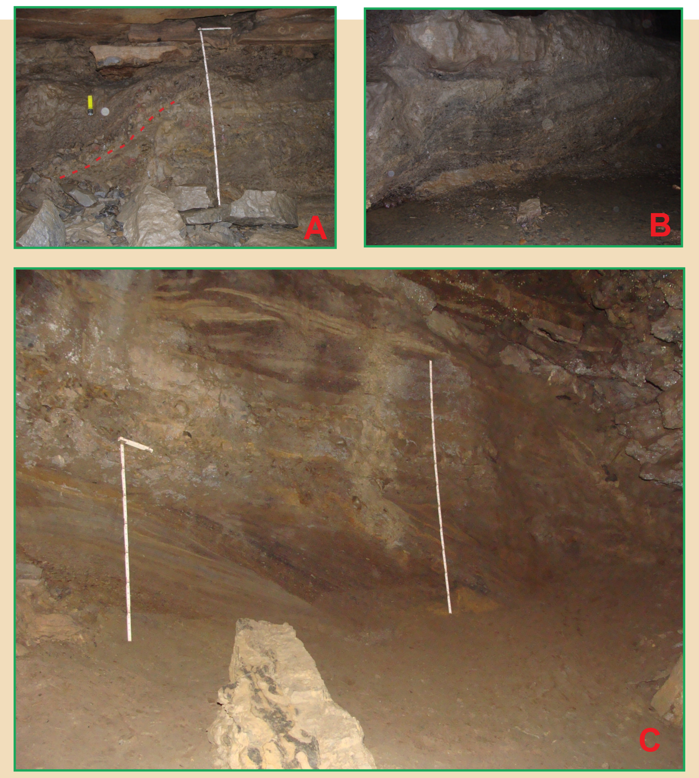
- Cave development, including some infeeders, occurred along a thrust fault zone - following an increasing fault angle to the south;
- Significant cave development occurred beneath glacial ice, much like Castleguard Cave (perhaps largely during the Wisconsinan glacial period);
- Meltwater carves paleo-gorges, Hunter's Fissure & Diddly Cave that drain into Clarksville Cave;
- Sediment influx occurred through multiple shafts and sink points (at least 17) on exposed Onondaga limestone under subglacial or proglacial conditions (as retreat progressed);
- Sediments in infeeder conduits are elevated and removed from any major existing surface drainage (e.g., McNab Hall ceiling joint, Pixie Passages to ~ 3 m bgs, Thook, Ladder shaft, Hunter's Fissure, Diddly Cave);
- Sediment-laden meltwater roared in through the Pixie Passages and Corkscrew, Thook, North & Ward entrances;
- Almandine garnet, schist, and gneiss cobbles document glacial transport from the ADKs;
- Sediment "*marker beds*" are traceable throughout the cave;
- Cave sediment proximity to input point sources allows differentiation of seasonal climate conditions;
- Multiple subaqueous fans developed in the cave outward from input conduits;
- Finely laminated lake clays were deposited in a clean, nearly sediment-free, cave;
- Massive pebble/cobble/boulder debris flows followed as subaqueous underflow deposits (turbidites);
- Debris flows were punctuated by stratified sands, silts, and clays (11 cycle minimum with quiescent periods) filling much of the cave to the ceiling;
- Sediment continuity suggests a short-lived deposition period, mostly during glacial retreat;
- A final pebble-rich debris flow invaded cave and massive ceiling collapses occurred atop stratified sediments, providing evidence of a short-lived glacial readvance (e.g., Ward entrance, Slickenside Block area, Upper Cook Ave.); and
- Clarksville Cave provides a unique setting for examination of episodic and seasonal glacial outflows close to the source vs. far down-gradient after sediment redistribution.











Inclined sediment beds proximal to input locations. A) Near former north shaft entrance to the cave, B) Near one of many Perry Ave infeeder locations, C) Exposed McNab Hall cross-section through subaqueous fan. Note yellow clay beds exposed at top of right 6-foot ruler top descending at 50 degrees east on right (north) side of photo.

Alaskan pro-glacial lakes perhaps similar to that formerly in Clarksville. Sediment, pebble and cobble input to Clarksville Cave occurred via braided streams, alternating between glacier ice-proximal and distal zones. Multiple inputs occurred through dissolutionally enlarged joints and bedding planes, and along a thrust fault. Basal lacustrine clay deposition probably occurred under subglacial conditions.

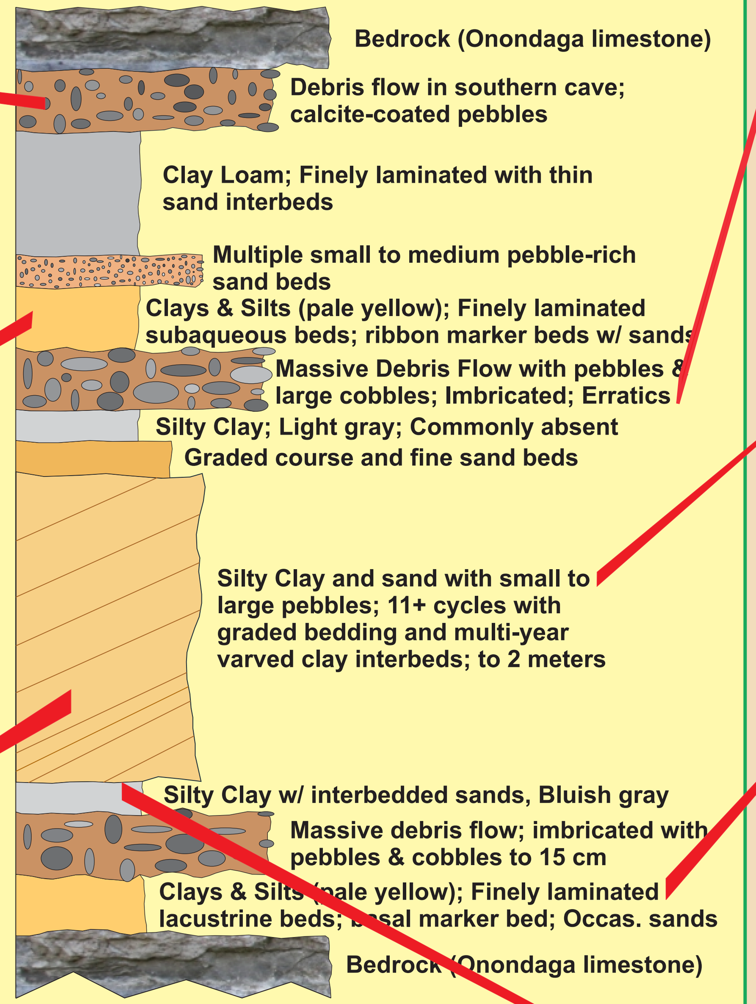
Rounded cobbles and erratics document glacial transport from as far away as the ADKs. Note almandine garnets in upper left of photo.

Uppermost debris flow in cave truncating yellow ribbon beds.

McNab Hall. Partial sediment column showing cyclic and graded deposition. Laminated gray and white clay interbeds reflect quiescent conditions. The yellow clay-rich ribbon beds at the top of the photo are a marker bed visible throughout much of the cave.

Imbricated debris flow that entered the cave through its northern Perry Avenue sinkhole entrance. Note cobbles forcefully jammed against the bedrock ceiling. Clay and silt-rich yellow ribbon beds overlie the debris flow on photo right.

Generalized Composite Stratigraphic Column



Gray lacustrine beds in side passage off Perry Avenue.

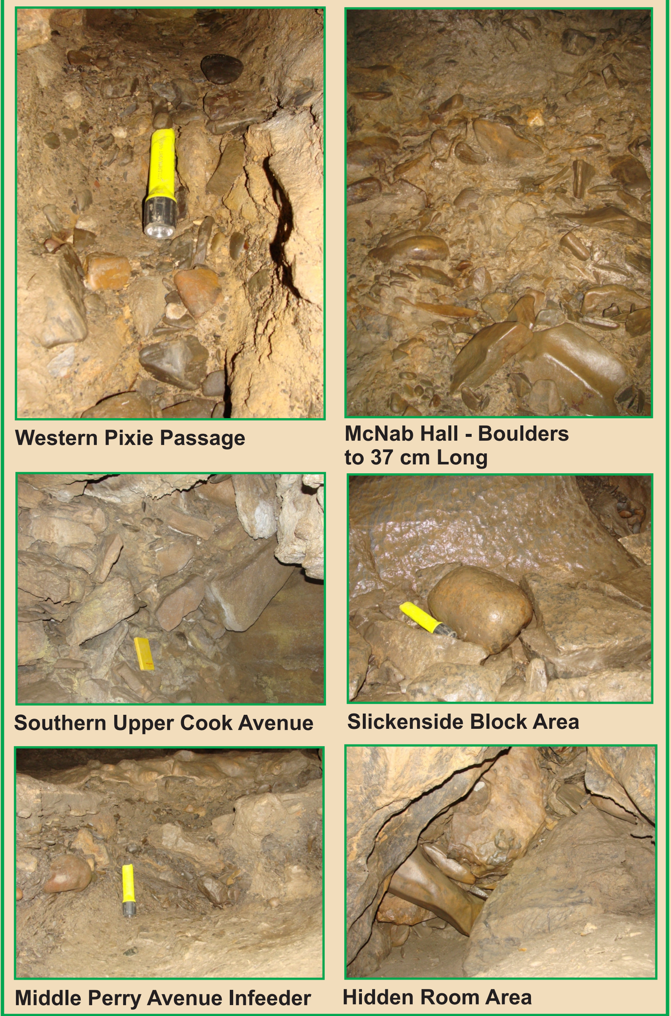
Subaqueous flow conditions. Finely laminated clay and silt units forming rhythmic "marker" beds with interspersed fine sand lenses. Note flow direction from right to left with lower sheared clay beds below ripple cross laminations. Massive pebble-cobble debris flow present at photo base from turbulent inflow. Lake Room in Clarksville Cave.

McNab Hall. Core of subaqueous fan. Sediment Pedestal in Perry Avenue

Northern Perry Avenue East of Slickenside Block Middle Perry Avenue Just North of the Big Room

Finely laminated basal clays indicate deposition under flooded conditions.

Silty Clay with interbedded sands preserved low in the sediment column, directly above the basal debris flow. (Gley 2 7/1; light bluish gray)



Western Pixie Passage McNab Hall - Boulders to 37 cm Long

Southern Upper Cook Avenue Slickenside Block Area

Middle Perry Avenue Infeeder Hidden Room Area

Cobbles and boulders in Clarksville Cave provide evidence of powerful debris flows through multiple nearby shaft and conduit locations. Large boulders atop the mapped sediment column mark a short-term glacial readvance that resulted in collapse in a number of cave areas (e.g., Ward entrance, Slickenside Block area; Upper Cook Ave.) and sediment and boulder occlusion of others (e.g., Pixie Passages).

Collapse features and final debris flow atop stratified sediments provide evidence of glacier readvance. Location: At top of inclined chute leading steeply downward to Brinley's Sump.

Questions:

Was the bulk of Clarksville Cave carved by largely sediment-free subglacial meltwaters far removed from the retreating glacial terminus (much like Castleguard Cave in Alberta, Canada that extends beneath the Columbia Icefield)?

Did the bulk of cave development occur during the Wisconsin glaciation?

Are seemingly different cave levels indicative of variable cave levels adjusting to a lowering regional base level **OR** are they time synchronous and actually reflective of preferential phreatic dissolution along thrust slices ramping or splaying upward from a sole thrust (Rubin, 1991) that were subjected to variable meltwater influx volumes and water pressures within and below glacier ice?

Did all or most of the cave sediment fill occur during the most recent glacial period as likely indicated by a consistent sediment profile throughout the cave? OSL, U/Th and/or Be dating methods may resolve this.

Did debris flows into the cave occur in a pro-glacial or sub-glacial setting?

Geologic Characterization and Preliminary Interpretation

Caves provide important windows into the past, with sediments often faithfully preserving events and surface conditions naturally removed by glacial bulldozing and erosion. Geologic mapping of sediments in Clarksville Cave provides a means of unravelling these events. While much of the cave sediment record has been removed by stream erosion, much of it has been exposed and remains preserved in-situ. In Clarksville Cave, this is especially true where relict stream infeeders (tributary conduits) meet the master cave conduit, on bedrock ledges, in bedrock protected alcoves, and in the master conduit itself.

Numerous in-cave sediment columns and exposures were examined and compared. Sediments were characterized using USDA soil texture classification methods. Particles larger than sand were sized according to a modified Wentworth scale (pebbles to boulders). Erratic cobbles were documented, as they provide information on sediment transport and source area. Erratics present in debris flows include almandine garnet and assorted metamorphic rocks, denoting long-distance transport from a far larger "watershed" area than is present today.

The volume of water required to develop large and multi-level conduits in the cave is not available from the relatively small upgradient watershed area present today under ice-free conditions (see watershed map). Water pirated into fractures in the bed of the Onesquethaw Creek (upgradient of the cave) is not of sufficient volume, sediment load and stream power to account for sediments in high level cave conduits. And, importantly, the current hydrologic setting does not have viable water and sediment sources capable of developing existing cave infeeders or the sloping sediment profiles in them that grade into former subaqueous fans within the master cave conduit. Rubin (1991) proposed a glacial meltwater invasion scenario to explain conduit size, elevation, and sediment distribution found in the cave. This ongoing geologic work provides additional supportive evidence. It also provides new sediment detail that enables interpretation of the timing of new conduit development and ceiling collapse features within the cave.

Characterization of multiple sediment exposures present throughout the cave documents a consistent stratigraphic profile. A number of geologic beds are readily discernable and, thus, serve as excellent marker beds. Two of the most distinctive marker beds are pale yellow rhythmic clay and silt beds deposited under subaqueous lacustrine conditions. It is likely that these beds were initially gray, having now turned yellow under oxidizing conditions. Interestingly, thick basal lacustrine clays (to ~ 55 cm) are found in contact with bedrock conduit floors in locations that might, in their absence, be interpreted as being late-forming diversion passages around sediment occlusions. Instead, their presence confirms that some, not all, conduit diversions formed prior to the cave filling with sediment. Furthermore, the lack of sediments beneath these basal clays, or of sediments elsewhere in the cave that are not consistent with the sediment profile developed, provides indirect evidence that all cave sediments correspond with a single glaciation. The basal clay beds are interpreted as being deposited beneath glacier ice, followed by a number of major debris flows originating in the ice-proximal zone coincident with glacial retreat. Subsequent sediment deposition also provides evidence of variable ice margin positions and climatic conditions.

Ongoing Interpretive Work

Sediment location in conduits may provide insight into the conditions under which the cave and its different levels formed before sediment influx. Sediment exposures in close contact with cave walls reveal consistent stratigraphic beds atop clean bedrock walls, supporting sediment influx associated with Wisconsinan glacial positions. In places, massive quantities of sediment fills large portions of the cross-sectional area of major conduits (e.g., northern Perry Avenue, Upper Cook Avenue). Logically, these conduits formed prior to sediment inundation atop clean conduit walls. Importantly, the large quantity of water required to bring the sediments into the cave via some 17 discrete inputs (see map) was also needed to form and fill large-diameter phreatic conduits. Again, it is unlikely that there was ever sufficient water influx into the bed of the Onesquethaw Creek to supply enough water to fill large Clarksville Cave conduits. The only reasonably large water supply source area would have been from subglacial meltwater inputs via dissolutionally-enlarged joint, bedding, and fault plane controlled infeeders. The lack of sediments other than those consistent with the identified column may provide evidence that cave development and enlargement occurred sub-glacially over time when little sediment transport occurred. Then, much like the variable flow conditions documented in Castleguard Cave (British Columbia), sub-glacial hydrostatic pressures may have resulted in rises and falls in cave water levels - varying between vadose conditions graded to an Onesquethaw Creek base level and phreatic conditions controlled by conduit outlet size and glacial overburden (vs. an alternate pre-glacial development scenario). Under this scenario, water influx and level of in-cave water flow would have varied depending on climatic conditions and, at times, diurnal temperature fluctuations. Thus, phreatic conduits in the cave may reflect periodic short-term fluctuations in subglacial hydraulic conditions vs. sequential lowering of the regional base level elevation. Geologic and interpretive work is ongoing.

Lake Room in Clarksville Cave