RECONSTRUCTION OF A PALEO DEBRIS FLOW EVENT IN A LIMESTONE CAVE USING FIELD WORK, TERRESTRIAL LIDAR, AND CFD SIMULATION

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Million Year Old Mega Flood in Kentucky

A Mammoth Myth or a Tremendous Truth?

In the New Discovery section of the Mammoth Cave System in Kentucky, USA, there is a deposit consisting predominantly of Big Clifty sandstone with a total volume of about 1300 m^3 that cavers have named Mt. Ararat. This is a chaotic, angular, roughly inversely graded deposit with grain sizes ranging from clay through boulders larger than 1 m on an edge. The angularity of the material in this deposit indicates it has not experienced significant abrasion and therefore is believed to have been transported only a relatively short distance over a short time period. We thus interpret this as a cave diamicton deposit (Bosch and White, 2018) resulting from a debris flow event. Determination of the mechanism and timing for this event has implications for the geomorphic history of the Mammoth Cave system; behavior of debris flows in caves, narrow canyons, or other confined spaces; and evaluation of the relative contributions to cave development from mechanical and chemical erosion.

Figure 1. The clastic material deposit that cavers have named, Mt. Ararat. This is believed to be the downstream side of the deposit. The large angular rocks are predominantly sandstone. Walls and ceiling of the cave passage are limestone.

The background . . .

In 1971, John Wilcox observed sandstone boulders in the New Discovery section of Mammoth Cave deep under the Central Kentucky Karst landscape. He noted these boulders on his map as, "SANDSTONE BREAKDOWN" (Figure 2). This was one year before he and other Cave Research Foundation explorers made the connection between Flint Ridge and Mammoth caves, which then became, and still remains, the longest cave in the world.

There are many piles of sandstone throughout Mammoth Cave. Most don't get more than a cursory look. This one in New Discovery prompted further scrutiny when Art and Peggy Palmer noticed the pile and in 2016 began to investigate why this much sandstone was located so far into the cave (Palmer et al., 2019).

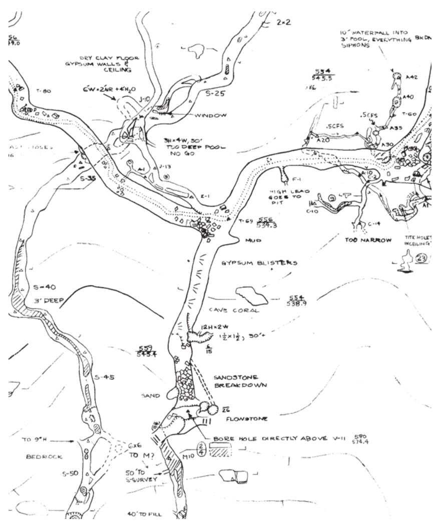

Figure 2. John Wilcox map based on 1970s mapping and exploration in the New Discovery section of Mammoth Cave.

Figure 3. Mt. Ararat viewed from Big Avenue. Flow is believed to have gone from left to right.

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The question . . .

What physical events could have led to the deposit known as Mt. Ararat in the New Discovery section of Mammoth Cave?

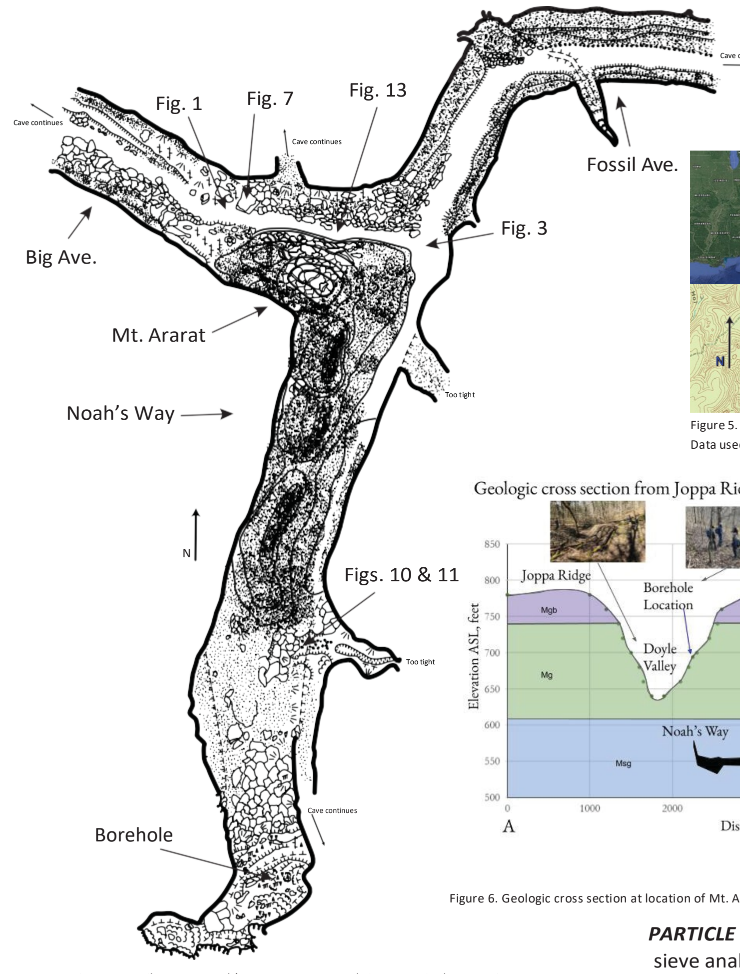

Figure 4. Fossil Avenue, Noah's Way, Mt. Ararat, and Big Avenue in the New Discovery section of Mammoth Cave.

LOCATION GPS, USGS topo and geologic maps, GIS, cave surveying

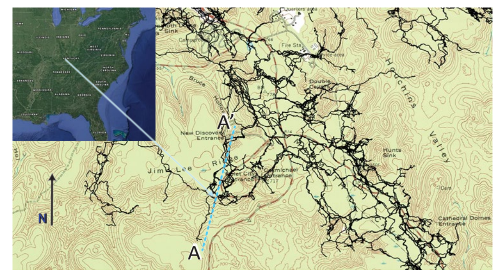

Figure 5. Location of Mt. Ararat in the New Discovery section of Mammoth Cave. Data used with permission of Cave Research Foundation and National Park Service.

Geologic cross section from Joppa Ridge to New Discovery, compass bearing from A to A′ = 25°

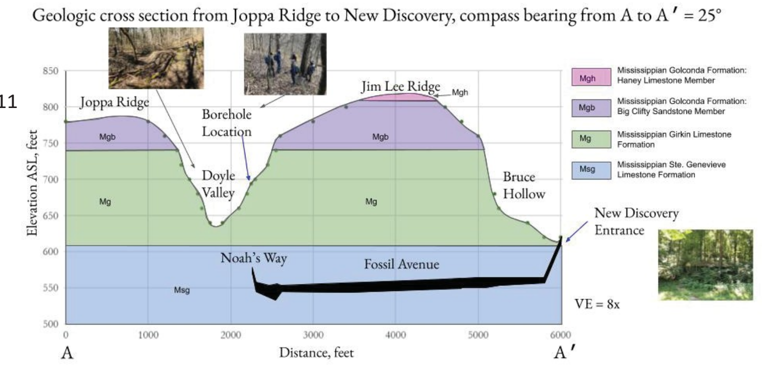

Figure 6. Geologic cross section at location of Mt. Ararat (Noah's Way) in Mammoth Cave.

VOLUME OF DEPOSIT AND COMPUTATIONAL MESH terrestrial lidar

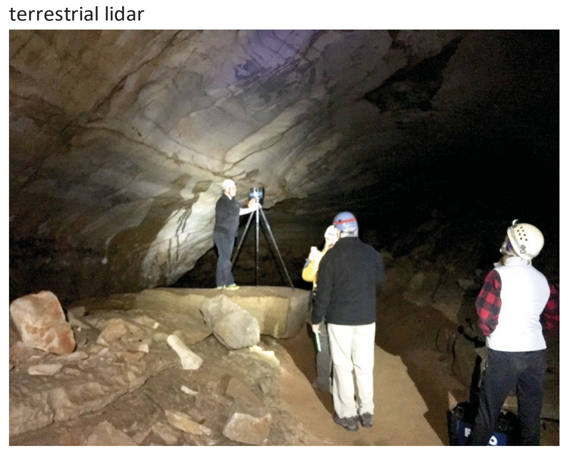

Figure 7. LIDAR scanning in Big Avenue near Mt. Ararat.

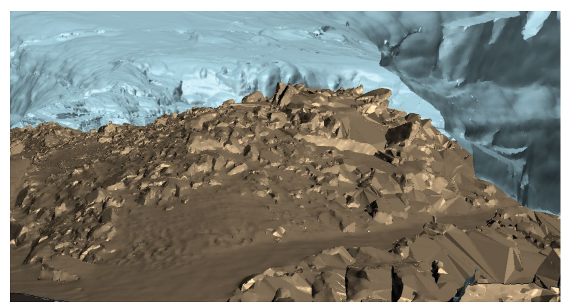

Figure 8. LIDAR scan of Mt. Ararat. This is the same view as the photograph in Figure 3.

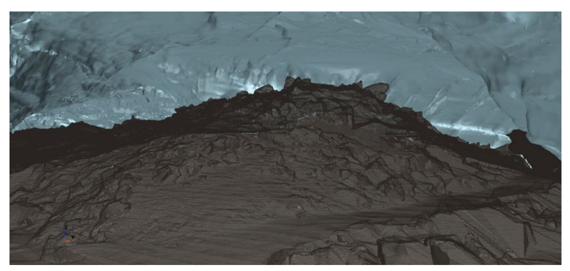

Figure 9. Computational mesh on Mt Ararat used as a basis for the CFD simulations.

PARTICLE GRAIN-SIZE DISTRIBUTION sieve analysis, grid counting

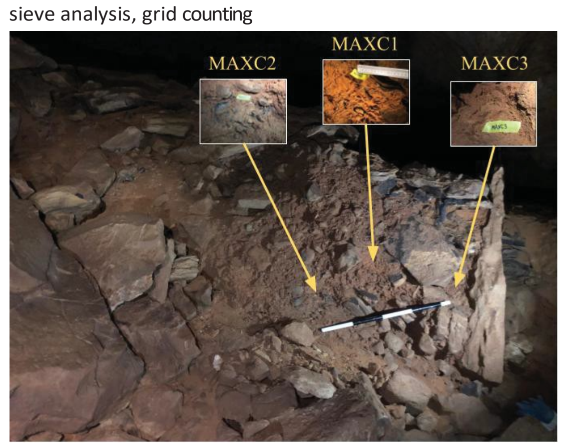

Figure 10. Cross section of debris flow at Mt. Ararat exposed by subsequent erosion.

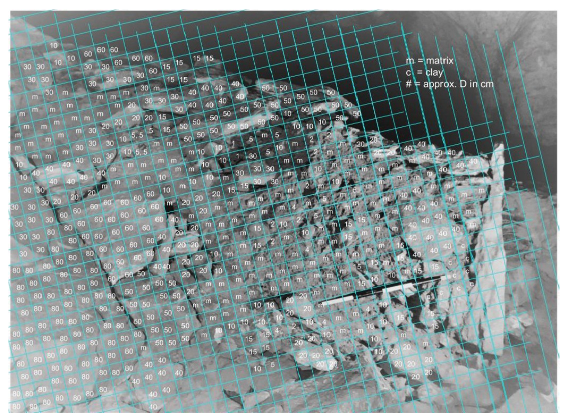

Figure 11. Sizing by grid counting.

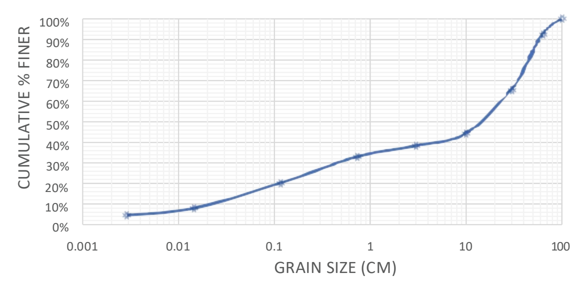

Figure 12. Grain-size distribution of observed particles at Mt. Ararat.

VOLUME OF DEPOSIT AND NEAR-SUBSURFACE STRATIGRAPHY Wenner vertical electrical resistivity survey (VES)

Figure 13. Electrical resistivity on trail at Mt. Ararat.

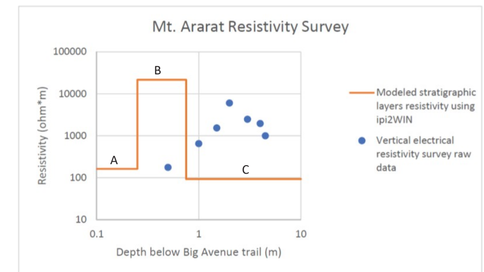

Figure 14. Electrical resistivity signal responses. Data modeling indicates the trail depth below the center of the resistivity array at 0.25 m (A), debris flow deposits from 0.25 m to 0.75 m in depth (B), and below 0.75 m as bedrock with vugs and fractures (C).

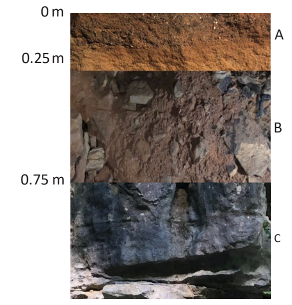

Figure 15. Stratigraphic interpretation of VES results using photos of trail material, Mt. Ararat material, and Mammoth Cave limestone bedrock.

MECHANISM OF DEPOSITION computational fluid dynamics (CFD)

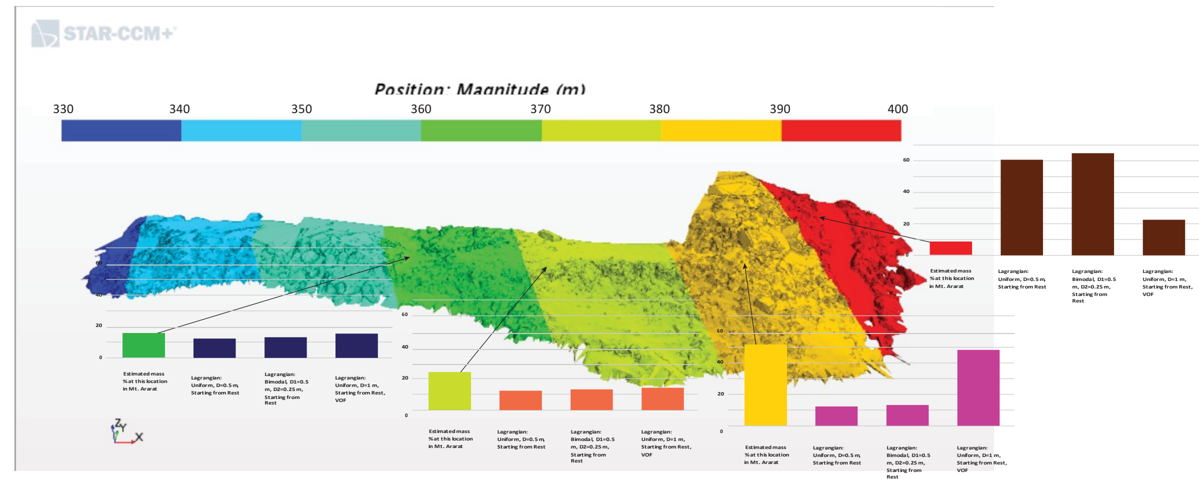

Figure 16. Predicted mass percentages at key locations on Mt. Ararat in comparison with estimated actual mass percentages.

What we think we know now . . .

- The combination of sedimentological analysis and numerical simulation supports the interpretation of the Mt. Ararat deposit as resulting from a debris flow event.
- The law of superposition combined with cosmogenic radionuclide burial dating analysis implies an age less than 1.2 Ma with material possibly sourced from a collapse or blockfall (Granger et al., 2001; Granger, personal communication, 2019).
- Electrical resistivity and lidar data enable the calculations of the volume of this deposit at approximately 1300 m^3.
- Current CFD results indicate that a supply of that volume of material would have been sufficient to result in a Mt. Ararat-sized deposit in a similar location.
- **The evidence presented in this work supports the conclusion of a sinkhole collapse releasing material into the cave system. These clasts were either previously at rest in the base of the sinkhole or entered the sinkhole at the time of collapse via a mass flow event upslope from the sinkhole.**

Questions remaining . . .

- Did the material for Mt. Ararat begin at rest or as a landslide? Additional numerical simulations are underway to answer this.
- Does surface evidence exist to support our hypothesized location of a sinkhole in Doyle Valley at about 1 Ma?
- Could a different location and size of sinkhole have resulted in the same depositional event?
- Did Mt. Ararat's deposition and the erosion of nearby scallops occur at the same time? How can this inform paleoflow interpretations?
- Did other morphologic heterogeneities such as wall roughness or obstructions in the cave floor play a part in determining the distribution of the deposited materials?
- How important were physical conditions such as flow dilatancy, block rafting, diversely shaped clasts, or non-Newtonian flow characteristics in determining the distribution of the deposited materials?
- Were the fine sediments at the terminus of Big Avenue deposited by the same flow event(s)?
- Do the findings from this work allow us to better describe and understand other deposits that appear to have resulted from debris flows?

Sources of info . . .

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Thank you!

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