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Multi-method analysis of a historic wooden trough from Kentucky, USA: a case study in corroborating artifact oral histories with heritage science

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Abstract

Oral history indicates that a large wooden trough held in storage at the University of Kentucky's William S. Webb Museum of Anthropology was a component of the saltpeter mining operation in Mammoth Cave in the late 18th and early 19th centuries, worked largely by enslaved persons. We used multiple heritage science methods, including radiocarbon wiggle-match dating, tree-ring dating, scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDS), and optical scanning, combined with historical research, to examine the trough. Our analysis supports the oral history of the trough as an artifact of the mining system in Mammoth Cave. This case study illustrates how heritage science methods can provide corroboration for the origins and biographies of poorly documented historical artifacts.

Keywords Mammoth Cave, Saltpeter mining, Historic artifacts, Oral histories, 3D scanning, Radiocarbon wiggle-match dating, Dendrochronology, SEM-EDS

Introduction

The wooden trough held at the William S. Webb Museum of Anthropology at the University of Kentucky in Lexington, Kentucky, USA, that is the subject of this study is constructed from half of a large hollowed-out tulip popular (*Liriodendron tulipifera*) tree trunk. It is 3.40 m long by 0.85 m wide by 0.42 m high. The trough, which was transported to the Webb Museum from Louisville, has a vague oral history that indicates an origin in the late 18th/early 19th century saltpeter mining operation in Mammoth Cave, Kentucky (Fig. 1). The trough presents a case study for the application of heritage science methods to corroborate artifact oral histories.

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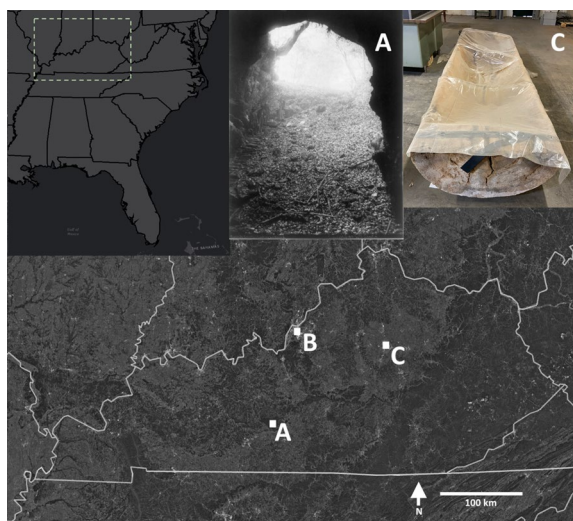


Fig. 1 Locations mentioned in the text: **A** Mammoth Cave National Park and (inset) the Historic Entrance to the cave [1]; **B** Louisville, Kentucky; **C** Lexington, Kentucky, where the trough was stored at the William S. Webb Museum of Anthropology at the University of Kentucky (inset)

The research potential of orphaned artifacts in archaeological collections

Many museums and university departments hold in their collections large numbers of artifacts that lack complete provenance. Such material often finds its way into collections as donations, sometimes having been passed through multiple hands over generations. These types of artifacts, which do not meet modern curation standards, are sometimes referred to as “orphaned” [2, 3]. Studies aiming to learn more about such objects have a dual benefit: by a focus on extant collections rather than new excavation, they preserve intact, not-at-risk sites for future archaeological research and slow the ongoing accumulation of archaeological collections in space-limited collections facilities (the “Curation Crisis” [4, 5]). By revealing or rehabilitating provenience and provenance, they also expand and restore the research potential of appropriately documented collections [e.g., 3, 6, 7, p. 87]. In some cases, studies on orphaned artifacts have the additional benefit of supporting restitution and repatriation efforts by verifying origin and ownership [e.g., 8, 9].

Various scientific methods can provide valuable, multi-line support for the origins and histories of artifacts. Alternatively, such methods may be able to disprove authenticity. Dating methods—including radiocarbon dating and dendrochronology—are commonly used to determine if the material used to create an artifact dates to the appropriate period [e.g., 10, 11]. The use of heritage science methods is particularly advantageous for the study of historic objects with incomplete or questionable

provenance. As more contextual information is usually available through written sources, more opportunities may exist to tie object data to recorded history. Here, we employ an array of heritage science methods to re-establish the context of the wooden trough, an artifact of unverified provenience.

Saltpetr mining and enslavement in Mammoth Cave in the late 18th/early 19th century

Mammoth Cave National Park (MCNP), in west-central Kentucky, USA, encompasses portions of the world’s longest known cave system. It was designated a UNESCO World Heritage Site in 1981 for its geological history and biodiversity [12] and listed on the National Register of Historic Places in 1991 for its historical significance [13]. Archaeological evidence indicates that Native Americans explored the caves as early as 5000 years ago and began to mine gypsum and other minerals by 3000 years ago. However, frequent Native American visitation to and use of the cave appears to have ceased by 2000 years ago [14, 15]. Soon after its rediscovery by Euro-Americans in the late 18th century, large reserves of calcium nitrate, or nitre—a major component of gunpowder—were located in Mammoth Cave; these reserves are noted on the earliest land claim for the cave, dated 1798 [16, 17, p. 248].

Although it is unclear when calcium nitrate mining first began at Mammoth Cave, it may have been as early as the late 1790s [18, p. 105]. The original, relatively small mining operation was located at the cave’s entrance (today called the Historic Entrance), with convenient access to water from a spring at the cave mouth. During the War of 1812, Mammoth Cave became a vital source of saltpeter when foreign sources of gunpowder were restricted by the Embargo Act of 1807 and then completely halted by British blockades of American seaports. In 1812, the processing operation was expanded to the Rotunda, one of the largest rooms within the cave system, and then further developed back to another large chamber now known as Booth’s Amphitheatre, half a mile into the cave from the Historic Entrance [17, p. 250].

The mining and processing of saltpeter that took place at Mammoth Cave during its peak production years was a complex operation. First, cave sediment rich in calcium nitrate (specifically, here, $\text{Ca}[\text{NO}_3]_2$) was excavated by hand from up to two to three miles deep into the cave [17, p. 252–253, 18, p. 104] and transported by wheelbarrow or ox cart to a central processing area. The sediment was placed in large (approximately $3 \times 3 \times 1.5$ m), rectangular wooden vats and saturated with water piped in from the spring at the cave entrance. Over several days, nitrates within the cave sediment would leach into the solution. The nitrate-rich solution was then drained into troughs located at the base of each vat that then drained

into a central reservoir. This solution was pumped out of the cave through wooden pipes. On the surface, the calcium nitrate was converted to potassium nitrate by adding potash and boiling the mixture to evaporate the water and leave behind the crystalline saltpeter. Finally, the saltpeter was transported to the E.I. du Pont factory on the Brandywine Creek near Wilmington, Delaware, where it was combined with sulfur and charcoal to produce gunpowder [19, 20].

Up to 70 enslaved men were forced to labor in Mammoth Cave's saltpeter mining operation during the peak production years between 1810 and 1814 [17 p. 251, 18, 21 p. 10]. These men were leased to the mining operation; who their enslavers were is unknown. The enslaved miners lived in one-room log cabins constructed for their housing. These cabins were later repurposed into part of the first Mammoth Cave Hotel. Basic supplies and tools would have been brought in for the miners' use from one or more of the closest population centers: Glasgow, Bowling Green and Louisville. It is likely that in addition to being provided with agricultural products, the enslaved men would have obtained fish (and perhaps shellfish) from the Green River and hunted and trapped game in the forest to supplement their diets [21 p. 10–11]. The conditions that the miners experienced in the cold, dark cave mining operation were poor. Breathing and visibility would have been affected by smoke from the oil lanterns and fires providing light. Miners labored long hours, sometimes entering the cave before sunrise and leaving after sundown [22].

The end of the mining operation and tourism development

The New Madrid earthquakes of 1811–1812 damaged Mammoth Cave's saltpeter mining system; repairing and rebuilding the operation took over a year. Quality control and managerial issues, however, continued to plague the operation. When the War of 1812 ended in 1815, the price of saltpeter plummeted, and the already-struggling processing operation in Mammoth Cave, no longer financially viable, came to an end [23].

Even as saltpeter production ceased, the focus of the cave was shifting from industrial production to (at the beginning, low levels of) tourism. Regular guided trips through the cave were occurring by 1816. Travel accounts emphasized Mammoth Cave's size and grandeur, and by the 1830s, the cave had become an icon of America's scenic natural beauty [16]. Today, over two million people visit MCNP every year, and over half a million take a tour of the cave [24].

Portions of the saltpeter mining system remain in situ within the cave, most prominently the large leaching vats (Fig. 2). Many pieces, however, such as the wooden pipeline and pump stations, have been moved from their

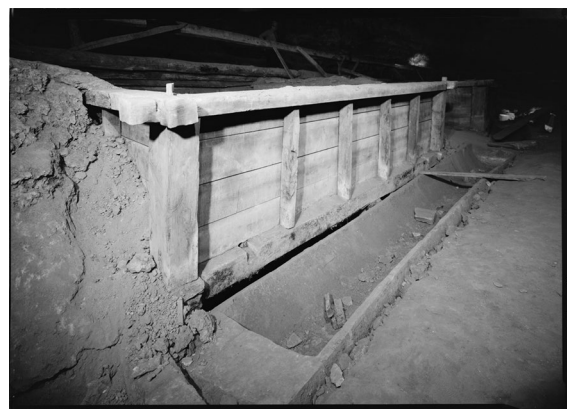


Fig. 2 An in situ leaching vat and trough (Vat #2) in the Booth's Amphitheatre section of Mammoth Cave, photographed prior to 1968 [25]

original location, are buried under cave sediment, or were destroyed. During the 1830s, for instance, wood from the mining system was burned in bonfires to light up the large passageways for visitors [18, p. 103; 23, p. 19]. The wooden objects that remain in their original positions are threatened by disintegration due to fungal action, condensation, and natural processes like roof fall events; the latter include a large slab that fell from the roof in the 1990s, damaging the last remaining wooden pump in the cave [18].

Oral history and provenance of the trough

What we know about the history of the trough is as follows. In January 2004, Jefferson Memorial Forest (JMF) (Louisville Parks and Recreation's Natural Areas Division headquarters) in southwest Louisville, Kentucky, contacted MCNP to ask if the park wanted a wooden trough in JMF's possession that was allegedly from Mammoth Cave. The trough had been stored in an open pole-barn behind the Ranger Station for many years. The trough, along with some dismantled log cabins, had been donated to the park by an older gentleman from Louisville. No one at JMF could remember the gentleman's name, but they believed that he had acquired some property with the cabins and trough from a deceased neighbor. There are therefore at least two degrees of separation—and probably more—between whoever may have originally obtained the trough and how it came into possession of JMF. While the chain of custody is lost, the oral history that the trough was originally from Mammoth Cave survived. Because of the significance of Mammoth Cave in Kentucky history, any association with the cave enhances the inherent value of and interest in an object.

The Cultural Resource Specialist at MCNP in 2004 contacted George Crothers of the University of Kentucky

and another archaeologist at the University of Louisville, both of whom had considerable experience in Mammoth Cave archaeology, for their opinions on the probability that the trough was authentically from Mammoth Cave. Based on direct visual examination and photos, the archaeologists agreed that its manufacture was consistent with what would be expected for a trough used in the saltpeter operation. After some discussion, it was agreed that Crothers would retrieve the trough from JMF for temporary storage at the Webb Museum until MCNP could retrieve it. The trough was moved to the museum on July 7, 2004. For various reasons, the trough remained at the Webb Museum, where it was stored in collections under plastic sheeting. In the meantime, the National Park Service administrative staff turned over, and the new managers were not as eager to accept the trough into the park's collection if there was not better corroborating evidence that it indeed came from Mammoth Cave. The trough became orphaned in the sense that it was in limbo between the Webb Museum, which was in possession of the trough but had not accessioned it into its collection, and MCNP, which had originally agreed to accept it. The trough remained in the museum's collections until this study began in late 2021.

Methods

Optical scanning and visual analysis

We scanned the trough with a wireless, AI-driven high-resolution Artec Leo optical scanner at a 3D resolution of up to 0.2 mm. 3D scanning creates an interactive visual record of an object at a specific point in time and is therefore valuable as a conservation monitoring tool and for developing an artifact's preservation strategy, such as in the case of wooden objects that are subject to curving, warping, and cracking over time [26–28]. 3D renderings can also support the identification and interpretation of geometric elements that can be difficult to discern solely with visual observation or to quantify using standard approaches [29]. Scanning of this trough, for example, allows for the entirety of the large object to be viewed in single frame, heightening the understanding of the spatial relationship between alterations and other marks on the artifact (see Additional file 1).

Radiocarbon wiggle-match dating: technique and sampling

Radiocarbon wiggle-match dating utilizes multiple radiocarbon dates separated by known time intervals to overcome the limitations of radiocarbon dating in the historic period of the Americas. The radiocarbon calibration curve is characterized by numerous reversals, plateaus, and “wiggles” ca. AD 1500–1950, meaning

that any single radiocarbon date from this period will have multiple intercepts with the calibration curve and ambiguous calendar ages. The result is that calibrated radiocarbon dates for the historic period typically span multiple centuries, offering little interpretive value [30]. Wiggle-match dating, however, can greatly narrow calibrated date ranges. Wood with visible rings and from tree species in regions where annual growth has been verified is ideal for wiggle-match dating, as the rings are separated by known time intervals [31, 32]. Dates on multiple individual tree rings and the known gaps in between them are statistically “matched” to the “wiggles” in the calibration curve to arrive at a precise calibrated calendar age, in effect reproducing a short portion of the calibration curve itself.

Wiggle-match dating has been widely used to date historic structures and dwelling sites around the world. These studies typically focus on structural timbers and posts [e.g., 33, 34] or wood charcoal [30]. The “approximate” wiggle-matching conducted on this trough is part of a larger study of ^{14}C wiggle-match dating on historic wooden museum artifacts in Eastern North America to showcase the benefits of this technique for a new region and artifact class [35]. In these cases, we aimed to alter the study objects as little as possible during analysis. A measure of uncertainty was incorporated into models to account for the possibility of miscounts, missing rings, and/or false rings due to lower levels of sample surface preparation than are typically employed in wiggle-match dating. Technical details regarding sampling, analysis, and wiggle-match model parameters are presented in Hadden et al. [35] and summarized here.

One full radius (~4 cm in width) and one overlapping partial radius (~6 cm in width) were gently sanded using a manual hand sander with increasingly fine grit levels to 600 grit (30 μm) on the best-preserved portion of a trough end to discern the annual rings for dating (Fig. 3). Sanding of the second partial radius was necessary because of numerous degraded areas of wood in the full radius where rings could not be confidently distinguished. 227 annual rings were counted across these overlapping radii (220 in the radius, and 7 more rings visible as layers in the tangential view), with some uncertainty in ring count in the middle portion of the trough, again due to degradation. As the waney edge (i.e., the outermost growth) is present on the trough, we were able to directly determine when the tree was felled to construct the trough.

We used a stainless steel blade and forceps to obtain small (~5 mg) samples from every tenth ring. After exploratory modeling to determine which samples should be analyzed to obtain the most precise date possible, we



Fig. 3 Overlapping radii sanded to distinguish annual rings for radiocarbon wiggle-match and dendrochronological dating

prepared and ran seven of these samples: Ring 0 (the innermost distinguishable annual ring), Ring 180, Ring 190, Ring 200, Ring 210, Ring 220, and Ring 227 (the outermost ring, taken directly from the waney edge).

Sample pretreatment, preparation, and dating was conducted at the Center for Applied Isotope Studies at the University of Georgia in Athens, Georgia, USA. Wood samples were pretreated following a standard acid/alkali/acid (AAA) protocol. Radiocarbon sample data is presented in Tables 1 and 2. The quoted uncalibrated dates are given in radiocarbon years before 1950 (years BP), calculated using the ¹⁴C half-life of 5568 years. The error is quoted as one standard deviation and reflects both statistical and experimental errors. The dates have been corrected for isotope fractionation using the δ¹³C value measured by IRMS.

The resulting radiocarbon ages were calibrated and modeled in OxCal version 4.4 [36] using the IntCal2020 curve [37]. To account for the uncertainty in ring counts due to the wood degradation in some areas of the sanded

radii (from approximately rings numbers 100 to 130), we used the Sequence and Interval functions in OxCal, rather than the D_Sequence and Gap functions that are more commonly used in wiggle-match dating [31].

Dendrochronological dating

Using dendrochronology, or tree-ring dating, the ring width pattern of a sample (in this case, the trough) can be compared against an existing reference chronology—a series of the average tree ring width over many years, developed by sampling many trees in a specific area. The width of the annual tree ring in many areas is largely based on environmental factors like precipitation or temperature. Since such factors are generally similar over a limited geographic area, the ring width patterns of trees within the area will often crossdate, or match. Because of the limited geographic regions over which chronologies are valid, tree-ring analysis can also aid in narrowing down the area in which a tree grew [e.g., 38, 39].

Ring width patterns should ideally be dated against a chronology developed from the same species, but interspecies dating is sometimes possible [e.g., 40, 41]. The International Tree-Ring Data Bank (ITRDB), available via the Paleo Data Search of the National Oceanic and Atmospheric Administration (NOAA), is a major repository of publicly available tree-ring chronologies and ring width-based paleoenvironmental reconstructions. While the ITRDB does not include any tulip poplar chronologies from the Mammoth Cave area, a Mammoth Cave-area chronology based on white oak (*Quercus alba*) that covers the years A.D. 1649–1985 is available [42]. Annual ring width for the Mammoth Cave white oak chronology correlates with high rainfall in June and cool summer temperatures [43]. Tulip poplars have previously been successfully crossdated against oak chronologies in Eastern North America [44].

High-resolution photos were obtained of the overlapping prepared trough radii, and ring widths were

Table 1 Sample information, raw radiocarbon measurements (uncalibrated, corrected for isotope fractionation; years BP) and errors (quoted as one standard deviation, reflecting statistical and experimental errors), and summarized calibrated and modelled results for the seven single-year radiocarbon samples obtained from the trough

| Approximate ring # | UGAMS | δ ¹³ C ‰ | ¹⁴ C age years BP | Modelled age, cal AD | % probability | Agreement index |
|--------------------|-------|---------------------|------------------------------|------------------------|---------------|-----------------|
| 0 | 57336 | -26.6 | 296 ± 22 | 1525–1598 1615–1655 | 46.4 49.4 | 90 |
| 180 | 57337 | -28.6 | 201 ± 24 | 1733–1757 | 95.4 | 96.3 |
| 190 | 57338 | -26.7 | 137 ± 23 | 1742–1765 | 95.4 | 72.7 |
| 200 | 57339 | -24.3 | 191 ± 22 | 1749–1775 | 95.4 | 119.7 |
| 210 | 57340 | -25.0 | 151 ± 21 | 1759–1785 | 95.4 | 68.5 |
| 220 | 57341 | -23.9 | 225 ± 23 | 1769–1795 | 95.4 | 124.4 |
| 227 | 57342 | -24.8 | 215 ± 42 | 1778–1804 | 95.4 | 151.3 |

Table 2 Unmodelled and modelled calibrated results for the seven single-year radiocarbon samples obtained from the trough

| Name | Unmodelled (BC/AD) | | | Modelled (BC/AD) | | | |
|--------------------|--------------------|------|------|------------------|------|------|-------|
| | From | To | % | From | To | % | A |
| Sequence | | | | | | | |
| Boundary | | | | 1443 | 1651 | 95.4 | |
| R_Date Ring0 | 1509 | 1594 | 68.6 | 1525 | 1598 | 46.1 | 90 |
| | 1618 | 1654 | 26.9 | 1615 | 1655 | 49.4 | |
| Interval N(180,36) | 108 | 252 | 95.4 | 90 | 133 | 49.6 | 72.5 |
| | | | | 148 | 220 | 45.9 | |
| R_Date Ring180 | 1650 | 1688 | 26.1 | 1733 | 1757 | 95.4 | 96.3 |
| | 1731 | 1807 | 57.4 | | | | |
| | 1925 | ... | 12 | | | | |
| Interval N(10,2) | 6 | 14 | 95.4 | 6 | 14 | 95.4 | 101 |
| R_Date Ring190 | 1675 | 1766 | 31.9 | 1742 | 1765 | 95.4 | 72.7 |
| | 1798 | 1943 | 63.5 | | | | |
| Interval N(10,2) | 6 | 14 | 95.4 | 6 | 14 | 95.4 | 101.8 |
| R_Date Ring200 | 1658 | 1688 | 21.8 | 1749 | 1775 | 95.4 | 119.7 |
| | 1730 | 1808 | 58.4 | | | | |
| | 1924 | ... | 15.3 | | | | |
| Interval N(10,2) | 6 | 14 | 95.4 | 6 | 14 | 95.4 | 101.5 |
| R_Date Ring210 | 1668 | 1703 | 15.4 | 1759 | 1785 | 95.4 | 68.5 |
| | 1721 | 1782 | 28.6 | | | | |
| | 1796 | 1817 | 9.9 | | | | |
| | 1832 | 1891 | 20.9 | | | | |
| | 1907 | ... | 20.7 | | | | |
| Interval N(10,2) | 6 | 14 | 95.4 | 6 | 14 | 95.4 | 101.9 |
| R_Date Ring220 | 1641 | 1682 | 45.9 | 1769 | 1795 | 95.4 | 124.4 |
| | 1738 | 1754 | 5.1 | | | | |
| | 1761 | 1802 | 42 | | | | |
| | 1938 | ... | 2.5 | | | | |
| Interval N(7,2) | 3 | 11 | 95.4 | 3 | 11 | 95.4 | 100.3 |
| R_Date Ring227 | 1527 | 1554 | 2.5 | 1778 | 1804 | 95.4 | 151.3 |
| | 1632 | 1699 | 30.1 | | | | |
| | 1722 | 1814 | 45.8 | | | | |
| | 1835 | 1885 | 4.6 | | | | |
| | 1910 | ... | 12.5 | | | | |
| Boundary | | | | 1776 | 1926 | 95.4 | |

The modelled date for Ring 227 (the waney edge) of 1778–1804 represents the best estimate of the felling date of the tree (95% HPD). Amodel = 94.5; Aoverall = 92.4

measured from these photos to the nearest 0.001 mm with the ObjectJ extension [45] of ImageJ [46, 47]. Since approximately ring numbers 100 to 130 were difficult to distinguish when examining the wood directly with a jeweler’s loupe and USB microscope—and not possible to measure from photos—due to wood degradation, we obtained two series spanning, respectively, rings 1–99 (n = 99 rings) and rings 131–220 (n = 90 rings). The two trough ring width series (inner and outer) were cross-dated against the Mammoth Cave chronology with visual (skeleton plotting) and statistical (COFECHA [48],

CDendro [49]) methods. We tested 40-year segments in COFECHA (with 20 year overlaps) against the reference chronology [48]. We also compared the outer series (as the inner series had little temporal overlap) against five other reference chronologies from the region developed from white oak [50–53] and tulip poplar [54] that were also available on the ITRDB.

While multiple radii should ideally be obtained from a tree or a wooden artifact for dendrochronological analysis, with the correlations of the series checked and a mean chronology developed, we examined only a single

radius on the trough because of two factors: (1) as stated previously, we aimed to alter the trough as little as possible, and hand sanding was necessary for distinguishing annual rings; and, (2) all other portions of both ends of the trough were far more degraded than the portion we selected for surface preparation, and the wood had split in multiple areas. Preparation of any other region of the trough would have required much harder sanding and may not have been ultimately successful at enhancing visibility enough for the measurement of annual rings. This dendrochronological analysis thus functions as a supporting measure for the radiocarbon wiggle-match dating and helps to narrow down the general area where the tree used to construct the trough grew.

Analysis of crystals on inner and outer surfaces of trough

White crystals were present on both the interior and exterior ends of the trough (Fig. 4). Since the oral history of the trough suggested its role as a saltpeter mining component, we hypothesized that these crystals would be calcium nitrate ($\text{Ca}(\text{NO}_3)_2$), the compound mined in Mammoth Cave in the early 19th century.

Scanning electron microscopy (SEM) uses the interactions between an electron beam and a sample of interest to produce high resolution images of a sample. Interactions with a high-voltage electron beam cause the sample to release X-rays with wavelengths characteristic to individual elements. Energy dispersive spectroscopy (EDS) detects the released X-rays and creates high resolution maps of the elemental composition of the sample [55, 56].

Using SEM–EDS, we imaged and analyzed samples from three locations on the trough: two areas of heavy crystallization on the interior of one end of the trough (Samples 1 and 2) and one piece from an exterior end of the trough (Sample 3)). We obtained samples using a stainless steel blade. For samples 1 and 3, we cut out small pieces of wood coated with crystals, while Sample

2 consisted solely of crystals scraped from the wood. The three samples were sputtercoated with gold–palladium to increase their conductivity. Imaging and analysis were performed using an FEI Quanta 250 SEM and Oxford EDS at the University of Kentucky’s Electron Microscopy Center. For this study, EDS was performed with an accelerating voltage of 20.0 kV.

Results

Scanning and visual analysis

The Artec Leo scan allowed for excellent visualization of the entirety of the Webb Museum trough (Fig. 5). The trough is generally well-preserved for an artifact that was at least partially exposed to the elements while in storage at JMF. The interior wood, however, particularly on the concave bottom of the trough is defibrated [57], suggesting decay possibly from exposure but also perhaps from heavy use if the trough was repeatedly saturated by leach water. In several places along the top of the trough, there are dark eroded patches that appear to be marks from dripping water, which is consistent with prolonged use in a cave system environment like that of Mammoth Cave. Numerous tool marks are visible on the trough’s interior and on the ends (see 3D rendering in Additional file 2); these marks appear to originate from the felling and hollowing of the trough using metal axes and/or adzes. On one end of the trough, a roughly rectangular section of wood has been removed from the upper portion. Multiple rusted nails are still lodged within the trough, and rust from these nails has stained portions of the wood. The locations of nails near the removed rectangular section suggest that a segment of sheet metal would have been attached to the trough to serve as a spout, probably moving liquids from this trough to another. Light marks left from the placement and rubbing of the nylon straps used to help lift the trough in its move to the Webb Museum are also visible.

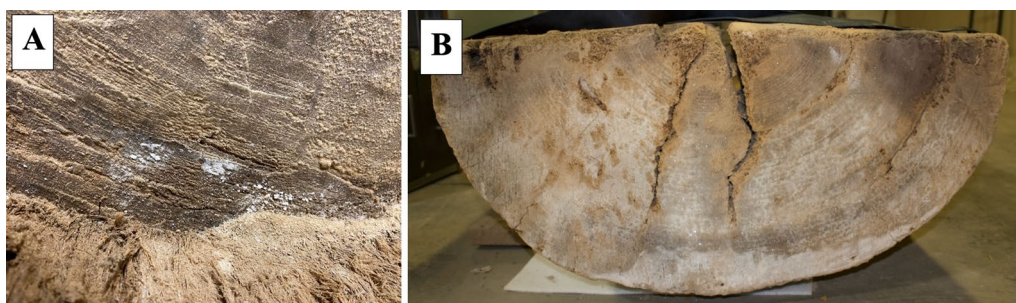


Fig. 4 White crystals on the lower interior end of the trough (A), the sampling location for SEM–EDS Sample #1. The “fuzzy” appearance of some of the delignified interior bottom wood is also evident in the lower portion of (A). A thin crust of white crystals is also apparent on both exterior ends of the trough (B)



Fig. 5 Images from trough optical scan: top: side view, middle: top view, bottom: end views; drip marks (e.g. *) are visible in numerous locations. See also 3D rendering in Additional file 2

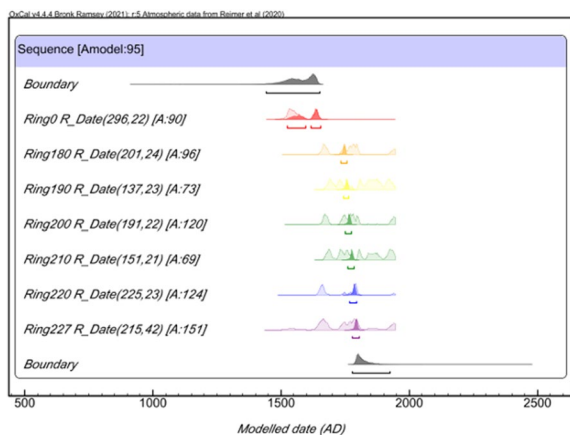


Fig. 6 Unmodelled (lighter-colored distributions) and modelled (darker-colored distributions) calibrated dates for the trough. Brackets indicate 95% HPD ranges. Ring 227 is the outermost ring

Radiocarbon wiggle-match and dendrochronological dating

Our modelling of the 7 AMS dates obtained from the trough indicates a felling date range for the tree of 1778–1804 cal AD (95% highest posterior density range) (Table 2; Fig. 6). Tree-ring dating supports the radiocarbon results. The trough ring width sequences cross-date against the Mammoth Cave chronology [42] with a higher *t*-value (*t*=5.0; overlap of 90 years) for the outer portion of the sequence than any of the other five

Table 3 *T*-values obtained from CDendro [47] between the outer trough ring width sequence and various tree-ring chronologies from the region (Midwest/Southeast U.S.)

| Chronology name | Species | Reference | <i>t</i> -value |
|-------------------------------|----------------------|-----------|-----------------|
| Mammoth Cave Recollect | <i>Q. alba</i> | [42] | 5.0 |
| Babler State Park | <i>Q. alba</i> | [52] | 4.0 |
| Lilley Cornett Tract | <i>Q. alba</i> | [50] | 3.1 |
| Chattahoochee National Forest | <i>L. tulipifera</i> | [54] | 2.8 |
| Piney Creek Pocket Wilderness | <i>Q. alba</i> | [53] | 2.7 |
| Andrew Johnson Woods Ohio | <i>Q. alba</i> | [51] | 2.4 |

There were 90 years of overlap between this portion of the trough sequence and all chronologies

reference chronologies from the Midwest/Southeast U.S. that we tested the sequence against (Table 3).

The last ring on the trough which can be crossdated against the Mammoth Cave chronology is 1797. Seven more annual rings whose widths are not measurable in the cross section, due to degradation of or impact to the corners of the trough, but which are countable as layers in the tangential section, are present after the 1797 ring. The intersection of both dating methods thus points to a felling date of A.D. 1804.

SEM-EDS analysis of crystals

Scanning electron microscopy revealed cubic crystals in all three samples (Fig. 7). EDS analysis identified all

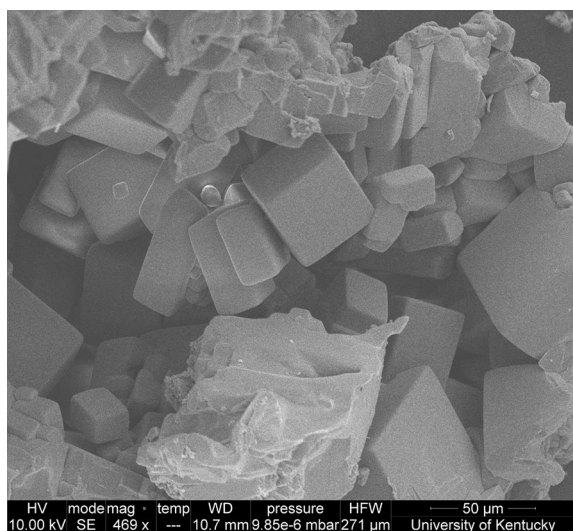


Fig. 7 SEM image (469x magnification) of cubic crystals from Sample #2, from the interior end of the trough; EDS indicated that the crystals from all three samples are sodium chloride

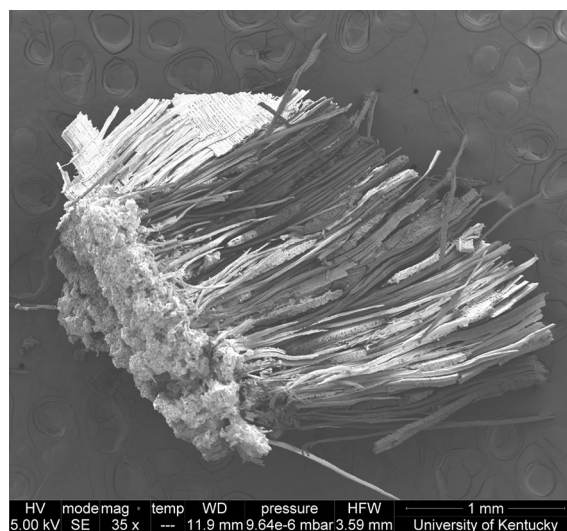


Fig. 8 SEM image of Sample #3 from an outside end of the trough; a coating of sodium chloride crystals is present on the surface of the wood (left side of image)

of these crystals as sodium chloride (NaCl)—salt. A range of other elements were also present in very small quantities (see EDS maps of identifiable elements in Additional file 3). Our analysis did not find evidence of calcium nitrate on the trough.

Discussion

Dating corresponds with Mammoth Cave saltpeter mining timeframe

The radiocarbon wiggle-match dating and dendrochronological dating point to A.D. 1804 as the year the tree used to make the trough was felled. This date falls during the earlier portion of the Mammoth Cave mining operation, before the processing expansion that occurred at the commencement of the War of 1812.

The successful crossdating of the trough against the Mammoth Cave white oak chronology [42] and the fact that the highest *t*-value found was between the trough and this reference chronology also suggest that the tulip poplar tree used to construct the trough grew geographically near the National Park, further supporting its existing oral history. The trough is also constructed from the same tree species (*Liriodendron tulipifera*) as the saltpeter troughs that are still in their original locations within Mammoth Cave [58].

Origin and impact of sodium chloride on the trough

The identification of the crystals on the trough as regular table salt was at first perplexing, and we considered possible reasons for the presence of NaCl. Was the trough not

a component of a mining system, as believed, but instead, perhaps, a meat-salting trough? Or was a saltpeter trough repurposed after its removal from the cave for this use? Some 19th century meat-salting troughs from the Southern U.S. are similar in appearance to the Webb Museum trough. They are often constructed out of large hollowed-out trees with blunt ends, although many are squared-off (e.g., two meat-salting troughs at Ashland, the Lexington, Kentucky estate of politician Henry Clay viewed and photographed by the first author during a research visit, as well as one originating from the Historic Hope Plantation in Windsor, North Carolina [59]).

We originally believed that the crystals on the exterior of the trough were an indication that a solution had leached through the trough, penetrating fully through the wood. However, our SEM–EDS analysis did not find crystals present within the wood itself, only on the inner and outer surfaces (Fig. 8). This suggests that the salt crystals did not permeate the wood; rather, the salt came into contact with only the inner and outer surfaces of the trough.

MCNP staff subsequently informed us that, in the past, maintenance staff had periodically applied a calcium chloride solution to the cave's dirt trails to suppress dust. This practice ended just before 1994, and staff noted an increase in dust after this practice was stopped (Rick Toomey 2022, personal communication). Use of calcium chloride to suppress dust is common practice during construction and roadwork [e.g., 60], and dust-suppressant mixtures containing calcium chloride are also used in mining [e.g., 61 p. 48, 62]. Sodium chloride was often

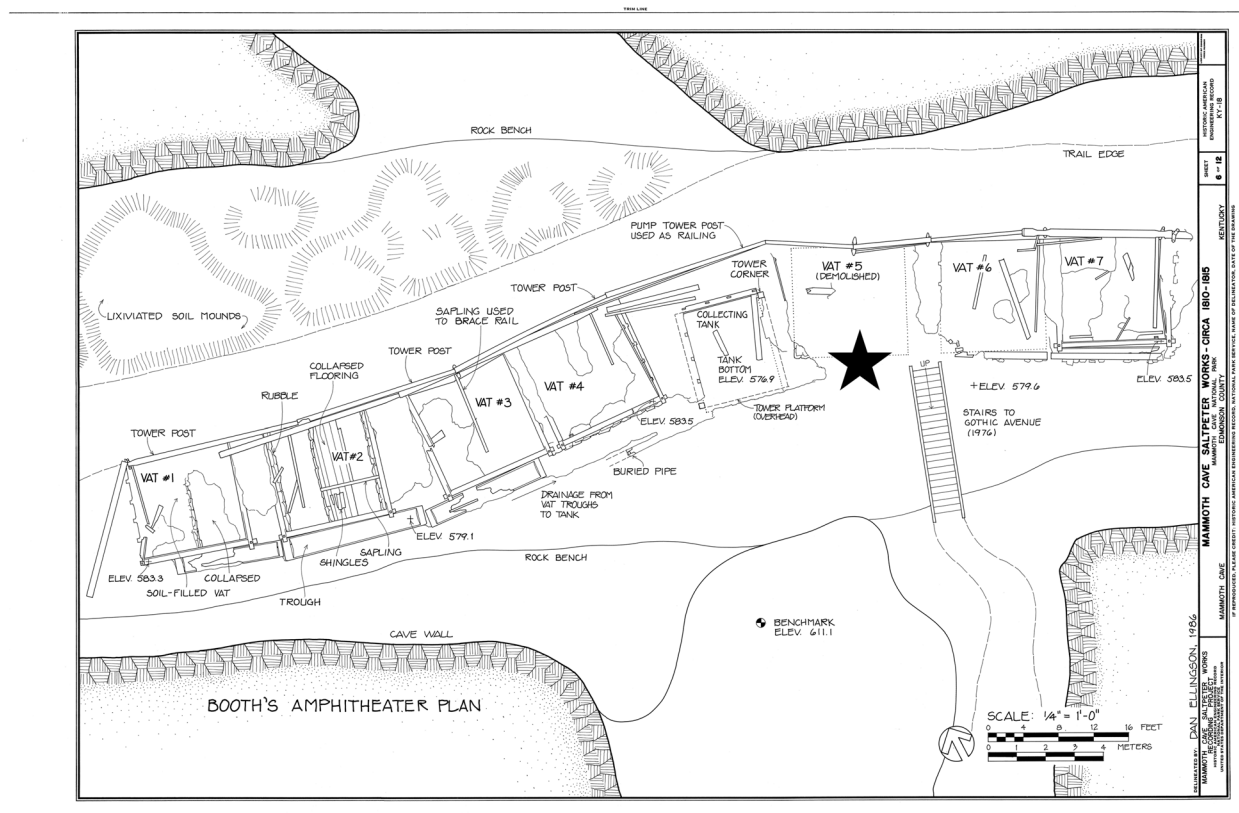


Fig. 9. 1986 plan of the salt piter processing remnants in Booth’s Amphitheater, a large chamber within Mammoth Cave. The Webb Museum trough is likely the missing trough from the now-demolished Vat #5 (former location of trough indicated by star) on the west side of the old tourist trail stairs [68]

used for the same purpose in earlier times, and it is thus likely that application of a salt solution to the trails in the 19th and earlier 20th centuries when Mammoth Cave had been developed into a major tourist attraction is the source of the salt crystals on the Webb Museum trough.

Although there are a number of other caves in Kentucky where salt piter mining also took place, including some geographically close to Mammoth Cave (e.g., Forestville Salt piter Cave [63]), the presence of the salt crystals suggests that the Webb Museum trough was indeed used in Mammoth Cave: sodium chloride application as a dust suppressant on walkways was probably only utilized at Mammoth Cave, which was the only major “show cave” (e.g., one developed for public, fee-paying visitors [64]) in the area.

The defibration of the trough’s interior may be partially due to the contact with salt. A study of the deterioration of wood in Chacoan great houses in the U.S. Southwest found that high salt concentrations can in some environments lead to the chemical degradation of wood. In the Chacoan study, dissolved salts appear to have migrated onto archaeological wood remains, and repeated wet

and dry cycles resulted in the buildup of ever-higher salt concentrations [57 p. 206–208]. Defibration from salt exposure has similarly been noted to occur in polar, desert, and Alpine environments [65–67]. The wooden remains in Mammoth Cave are subjected to deterioration from condensation and fungal action from the cave’s natural environment [18], which may have impacted the trough even before its removal. Since the trough’s long-term storage location at JMF would have subjected it to changes in humidity, this also may have led to amplified defibration because of the presence of the sodium chloride on the wood.

It is possible that calcium nitrate remains embedded in subsurface layers of the trough. Future work could test this by analyzing multiple subsurface samples across the interior bottom of the trough and verifying their chemical composition with additional techniques, such as X-ray diffraction analysis (XRD) and ion chromatography, although doing so would require destructive analysis on this relatively fragile artifact.

A missing trough in Mammoth Cave's saltpeter works

The Booth's Amphitheatre section of Mammoth Cave contained seven saltpeter vats with drainage troughs (Fig. 9). Six of these vats remain in place today; however, one of the vats (Vat #5) was dismantled at some unknown time to make way for a walking bridge that was constructed from the main cave passage to a stairway that ascends to the upper-level passage of Gothic Avenue. This is the only known vat in the cave for which there is no known trough. It is our contention that the trough in the Webb Museum is the Vat #5 trough, which was likely removed from the cave when the walkway was constructed.

Before the walking bridge was built, the path to the Gothic Avenue staircase wound down and around three of the Booth's Amphitheater vats; the last, now missing, vat was at the base of the staircase. Because Gothic Avenue is a historically popular section of the cave, it was shown on many tours, and the old cave trail was adjacent to Vat #5 and its trough. The sodium chloride identified on the Webb Museum trough is consistent with it being adjacent to a well-traveled tourist trail that was presumably treated with salt to reduce the amount of dust aerosolized by visitors' passage.

Conclusions

Based on our analyses and the known history of the trough, we can state that the Webb Museum trough was made from a tulip poplar tree that likely grew in the vicinity of Mammoth Cave. Dating suggests that the tree was felled in A.D. 1804. The trough was possibly constructed and likely utilized by enslaved laborers. Based on the drip marks, the trough appears to have been positioned in the same location within a cave for an extended period of time. The interior and exterior surfaces of the trough were exposed to sodium chloride.

As Mammoth Cave was the major cave attracting tourists in this region, it is most likely that, of the caves in the area, a sodium chloride solution was applied to the trails and walkways of this cave to suppress dust; a calcium chloride solution was applied in Mammoth Cave into the 1990s for the same reason. This solution is most likely to have inadvertently coated those wooden artifacts located near the main trails and walkways. In future work, sampling the existing troughs from Booth's Amphitheater and wooden components located near the historic trails for structural and chemical analysis (e.g. SEM-EDS, XRD, and ion chromatography) and comparing them to the trough analyzed in this study could further substantiate the connection of the trough to Mammoth Cave.

Based on the lines of evidence presented here, we posit that the Webb Museum trough is likely the missing trough from the base of Vat #5 in the Booth's

Amphitheatre chamber of Mammoth Cave. This trough was located next to the old tourist trail and likely came into contact with the salt solution applied to the trails to suppress dust.

The oral provenance of the trough (Mammoth Cave → Louisville → Jefferson Memorial Forest → University of Kentucky Webb Museum of Anthropology) can be supported and tracked through these analyses as well as the known history. Numerous questions concerning the trough's provenance remain, however. When was the trough removed from Mammoth Cave, why, and by whom? Was it simply a souvenir from the cave, or was it removed with the intention of some form of reuse? Where was it located after its original removal from the cave? When did it come into possession of JMF? These questions may remain unanswered unless new oral or written information comes to light.

This heritage science study, employing a variety of methods to analyze the wooden trough, illustrates the value of archaeometric analysis for bolstering the oral histories of underprovenanced artifacts. We are currently discussing the return of the trough to MCNP with park staff.

Abbreviations

| | |
|---------|---|
| ITRDB | International Tree-Ring Data Bank |
| JMF | Jefferson Memorial Forest |
| MCNP | Mammoth Cave National Park |
| NOAA | National Oceanic and Atmospheric Administration |
| SEM-EDS | Scanning electron microscopy-energy dispersive X-ray spectroscopy |
| XRD | X-ray diffraction analysis |

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40494-023-01075-3>.

Additional file 1. Ring width measurement in microns for the outer portion of the trough.

Additional file 2. Three-dimensional optical scan rendering of the Webb Museum trough.

Additional file 3. EDS maps of identifiable elements within Sample 1; all crystals across all three samples were identified as sodium chloride via EDS.

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Author contributions

Project conception and design: KGN, GMC, CSH, LG, LJW, HR-C, PM. Data collection: KGN, GMC, CSH, LG, LJW, HR-C, JK, MI. Digital archival research: KGN, GMC, LG, MI, EJ, AM, PBM. Figure preparation: KGN, GMC, CSH, LJW, HR-C, JK, MI, PBM. Draft manuscript preparation: KGN, GMC. All authors contributed to, read, and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are present in this publication and its supplementary information files or are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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