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Examining Erosion with a Terrestrial Laser Scanning Survey of the Russell Cave Rock Shelter, Russell Cave National Monument

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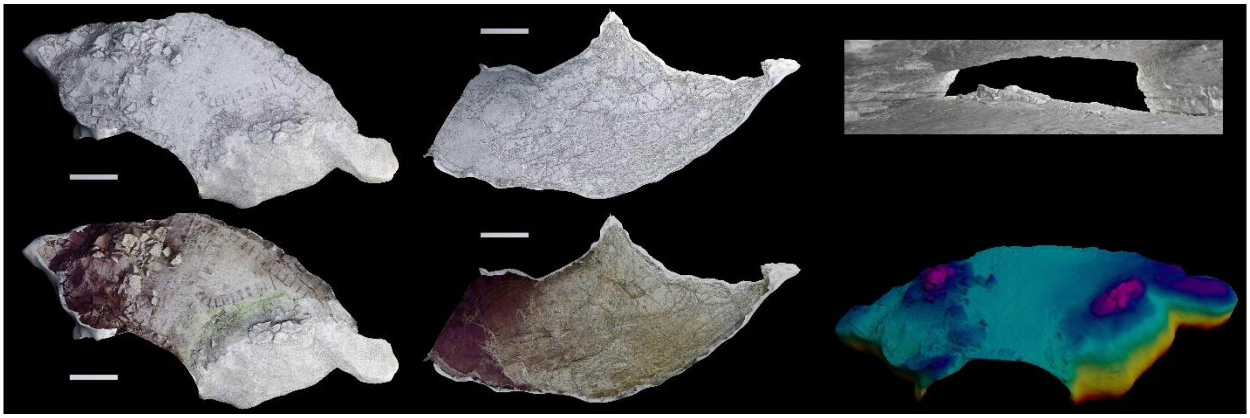

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Drs. Lori Collins and Travis Doering, Principal Investigators,

With Lead 3D Specialist, Jorge Gonzalez

CESU Piedmont South Atlantic Coast (Task Agreement #P15AC01817), in Cooperation with the Southeast Archeological Center (SEAC), National Park Service

2017 Final Report

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"Near the northeastern corner of Alabama, the Tennessee River sweeps down through the Sequatchie Valley, which is bordered on the west by the Cumberland Plateau. The edge of the plateau is notched and scalloped by coves and valleys that are separated by fingerlike spurs. One of these valleys in Jackson County, Alabama, is called Doran Cove, and here Russell Cave is located" Griffin 1974:1.

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PROJECT OVERVIEW

Russell Cave, in northeastern Alabama, is the third largest cave in Alabama, and is one of only seven National Monument sites that was created specifically for the protection of caves. Today, the dry shelter portion of the cave and wall features suffer from the effects of erosional processes. This project represents a collaboration between the National Park Service's Southeast Archeological Center (SEAC) in Tallahassee and the University of South Florida Digital Heritage and Humanities Collections in the USF Libraries, who worked together to perform data capture and post-processing of data derived from the survey, inclusive of a geophysical (ground penetrating radar) survey conducted by SEAC archeologists. This project utilized terrestrial laser scanning (TLS) survey, GPS, and imaging tools, to document and develop 3D models, cartographic mapping, and 3D renderings for the Russell Cave National Monument (rock shelter area).

The Russell Cave rock shelter area is experiencing high degrees of erosion, subsidence, and slumping in the dry shelter area, especially concentrated along the northwestern wall. Over the course of the last decade or more, erosion at this cave has been on the rise with several feet of debris and deposits including rock, sand, and silt from upstream making their way into the dry creek stream bed associated with this cave system. Land management practices further upstream and beyond park boundaries, such as timber harvesting, are impactful and accelerate these erosion processes. Serious undercutting continues to occur at the cave entrance, as well as erosion that has occurred within the shelter floor and along the walls, with potential loss and impact to archeological materials.

This documentation was designed to examine conditional and management concerns and provide baseline spatial datasets that can be used for comparative analytics for stabilization and monitoring strategy efforts. Our project collected imaging and spatial data that can be used to examine areas of change and delineate areas where stabilization efforts have recently occurred, such as the installation of sump-pumps in the cave floor area near the old boardwalk by the NPS SEAC, and the removal of the wooden boardwalk and cave floor exhibit items. Cartographic products will also be utilized by the SEAC for any new archeological inquiry and also in support of any Native American Graves Protection and Repatriation Act (NAGPRA) planning or needs into the future.

Russell Cave had a long period of occupation for at least 9,000 years. It is one of the oldest rock shelters in the eastern United States, and a National Monument site. The rock shelter was created from a sinkhole collapse that formed the shelter, today measuring approximately 30 by 60 meters. The shelter area has a streambed that forms part of the cave floor and suffers from erosional impacts especially along areas of the shelter walls, and in floor areas near past archeological excavation areas and boardwalk areas. TLS survey captured the as-is condition, including terrain and elevation details at +/-2mm. Global Positioning Systems (GPS) were used at the site to record external to the shelter feature locations and attributes, and was useful for ground truth verification and georeferencing location information that was combined with aerial LiDAR data and legacy maps and cartographic products made by previous archeological and environmental surveys. Deliverables include point cloud visualizations and derived products, with contour and digital elevation models showing slope aspects of the rock shelter floor and wall features, and the TLS data used to perform cross section analysis and provide a baseline of information for stabilization and other restoration effort use. Importantly, previous archeological survey maps were able to be georeferenced and provide important details as to where archeological occurrences and items were found and recovered, and also provides a way to look at impacts that have potentially occurred to the cave through time from a variety of activities.

SITE CHANGE AND MODIFICATION DETAILS

Doran Cove is a small valley located just south of the Tennessee state line in Jackson County, Alabama (Figure 1). The Montague Mountain rises about 1000 feet above the west side of the cove, and Russell Cave lies in a limestone escarpment near the base of the mountain, some 50 feet above the valley floor. The cave has two adjacent openings, the larger one, to the south side, is the entrance to an extensive cave system that is one of the longest in Alabama, containing more than seven miles of mapped passageways. The other, to the north side is better described as a rock shelter, and 65 years of archeological investigations have demonstrated it to have been the site of recurrent human occupation for nearly 9,000 years.

Official documentation of the cave was initially made in 1951, during a Tennessee Valley Authority land survey. Later that year, Paul Brown and Charles Peacock of the Chattanooga Chapter of the Tennessee Archaeological Society made a cursory examination of the cave. The presence of worked lithic material and ceramic potsherds was sufficient for them to secure permission from the landowner, Oscar Ridley, to return to the site in November for a more intensive investigation. They eventually obtained a lease on the property from Ridley and conducted excavations from 1953 to 1955 (Brown 1954). The primary activity made by the archeological society was the excavation of a trench located along the north wall of the rock shelter that measured about 40 feet long, 10 feet wide, and 6 feet deep. Brown (1954) and Broyles (1958) describe these initial investigations and the excavation procedures and their products.

The archeological society realized the extent and significance of the site and that further exploration would be a major endeavor requiring substantially greater resources. For that reason, they contacted Matthew Stirling, then Director of the Bureau of Ethnology at the Smithsonian Institution. Carl Miller was sent by Stirling to examine the site and, based on his report, the Smithsonian contacted the National Geographic Society (NGS) for financial support to conduct a

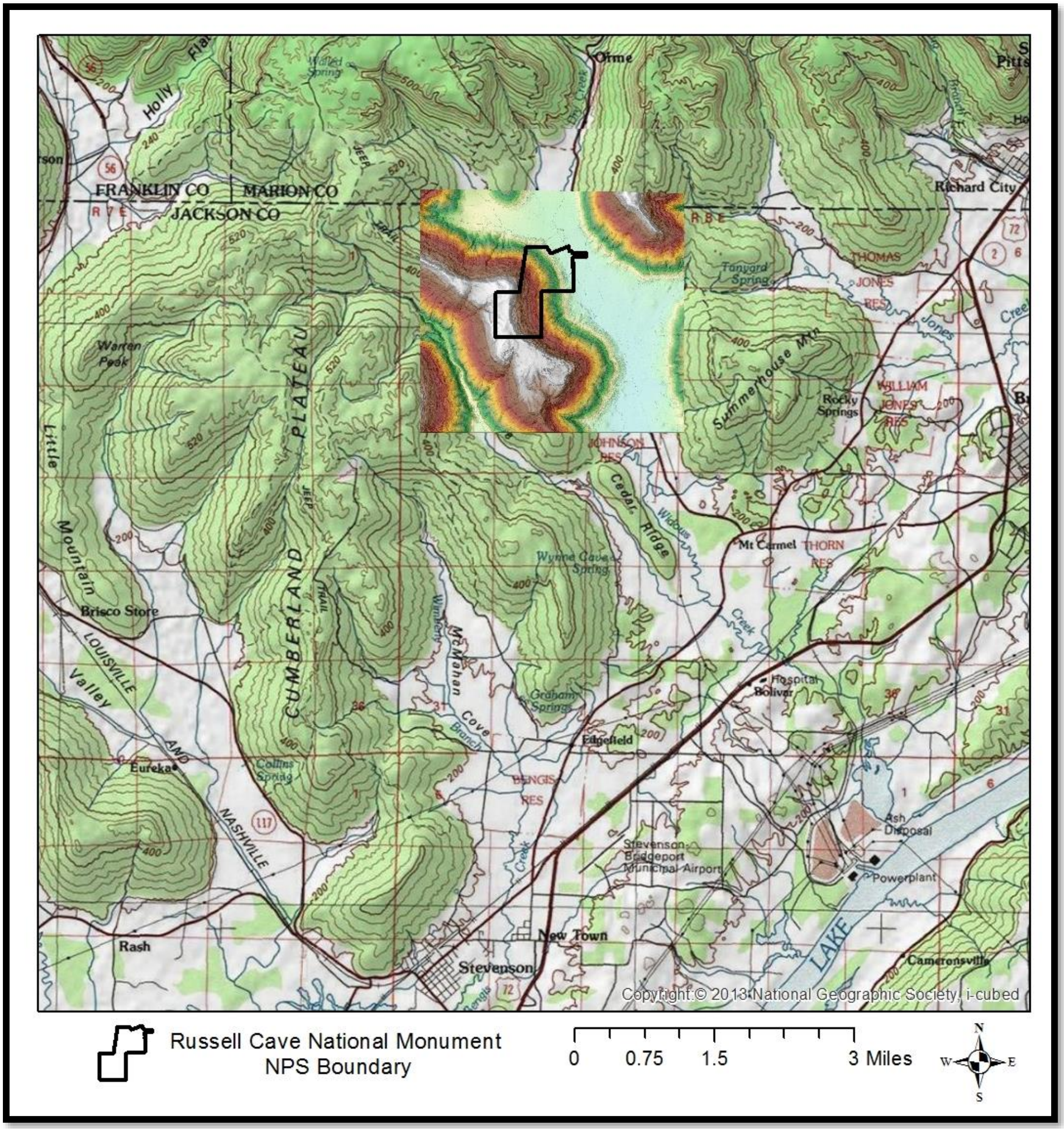


Figure 1. Map showing the Russell Cave National Monument location.

large-scale project at the cave. Upon NGS's acceptance of the proposal, Miller began a series of excavations from 1956 to 1958 (Miller 1956; Miller 1958).

Rainwater running off into the cave was recognized early as a problem within the rock shelter, and one that would continue into the 21st century. One of Miller's first acts in 1956 was to build a stone wall across the front of the cave to divert the rainwater from entering the cave. He also removed the dirt that had been excavated during the archeological society's excavations and dumped it onto the talus that sloped sharply downward from the front entrance of the cave.

Next to the north wall of the cave, he staked out a 30' by 30' excavation grid that was subdivided into five foot by five-foot units. His intent was to penetrate down to the original bedrock floor of the cave. This first year he and his team proceeded to dig down to a depth of 12 feet (Figure 2). At the end of the fieldwork season, in a vain attempt to secure the site, he erected an 8 foot high, chain link fence across the front of the cave entrance and partially back into the cave (Miller 1959)(Figure 3).

In early 1957, the National Geographic Society purchased the Ridley Farm, which included Russell Cave. During that year's fieldwork, Miller reduced the excavation area to 15 feet by 15 feet, and, by the end of the field season, his team breached the 30-foot level. The following year, 1958, the excavation area was slightly widened and continued downward. An interesting excavation technique was also employed. Miller (1961:3) explains that, from around a depth of 38 feet to 43 feet, they encountered "excessive" rock fall in the form of "huge blocks of limestone" that had been dislodged from the cave roof in ancient times. To deal with the obstructions, he used "several boxes of dynamite" to clear the remains of the rock fall.

According to Miller, the original cave floor was encountered between 42 and 43 feet below the present level. Griffin (1974:6) later noted a discrepancy, which he was not able to explain, that the depth of the Miller's excavation was actually about 32 feet, not the 43 feet as claimed (see Roberts 1960:6). Regardless, Miller had achieved his goal of reaching the original cave floor. The excavations had reached a very substantial depth, and, because of the wet earth, potential for collapse, and difficulties encountered the excavation unit had been tapered to 4 feet by 15 feet at the bottom (Miller 1961)(Figure 4).

Before reaching the original cave floor, however, Miller noted that seepage of water into the lower portions of the excavation unit had become constant. This was evidence that water was, and probably still is, present in the lower reaches of the cave. In addition to the vast quantities of earth and rock that had been removed from the cave during the excavations, nearly five tons of cultural material had been sent the Smithsonian for cataloging and analysis.

Figure 2. National Geographic/Smithsonian excavation crew digging initial trench along north wall (to the right) of Russel Cave (Miller 1956:550; color image after Brooks Honeycutt).

Figure 3. Chain link fence erected c. 1956 across the front entrance to the cave. (Photo courtesy of NPS, RUCA 3/7/63).

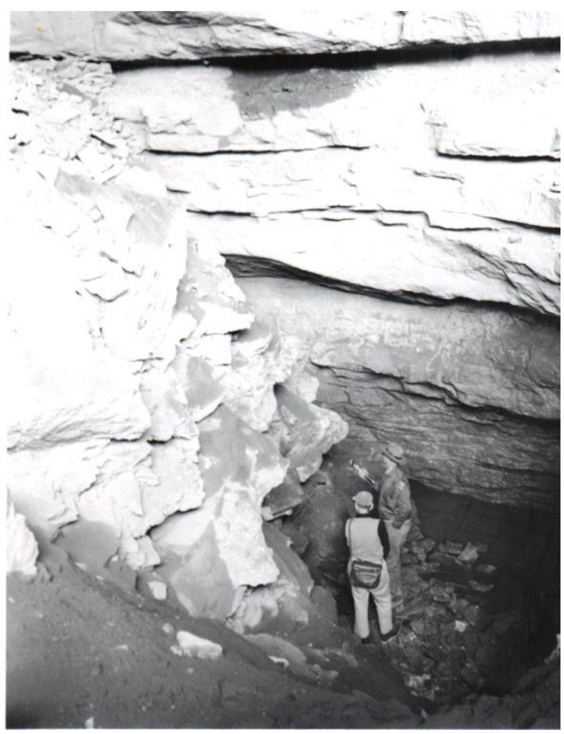


Figure 4. View into pit excavated by Carl Miller of the Smithsonian. (Photo courtesy of NPS, RUCA 4/26/62).

In 1958, following the end of the fieldwork and excavations, the NGS donated the land to the American people (Grosvenor 1958). Then, in 1961, President John Kennedy established the Russell Cave National Monument, and the care of the land and the site was transferred to the NPS, which appointed Zorro Bradley as its first superintendent (Griffin 1974). Russell Cave was listed on the National Register of Historic Places on October 15, 1966.

In 1962, John Griffin led NPS excavations at the site that were “primarily for the development of an in-place exhibit of the deeply stratified layers of cultural remains” that would illustrate the cave’s long occupation (Walker 1974:vi). Attempts to use the still open excavations of Miller’s previous NGS/SI project for this purpose were not feasible, however. Therefore, a new 25’ x 15’ grid was opened with 5-foot square units to a depth of 10 feet (Figure 5). Some of the new excavated units eventually overlapped portions previously dug by Miller.

In the mid-1960s, following the completion of Griffin’s excavations, which were to be the last conducted in Russell Cave, the site underwent substantial constructions and additions that impacted the cave (Figure 6). Large concrete retaining walls and a viewing platform were built in an excavation area to house a display of the cave’s stratigraphy (Figures 7 and 8). Large concrete footers were installed to support a visitor walkway that led from the cave entrance to the subsurface exhibit (Figures 9 and 10). A sump pump (visible at the lower right of Figure 11) was installed to keep water out of the sunken exhibit area, and wood rail fence was also constructed (Figure 12). Concerns over potential cave roof falls prompted a program of “roof bolting” as a preventative measure (Figure 13). A series of roof bolts were installed by Cowin and Company to protect the area above the boardwalk and floor exhibit. Planning drawings retained by the park show the design concept and location of most of the features in relation to the NPS archeological excavation area.

In late 1989, the talus slope below the entrance to the rock shelter began to slump due in part to erosion along the Dry Creek stream bed. The erosion occurred in the form of undercutting that removed the upper slope’s support material and could lead to the endangering of the stratified deposits of the archaeological site. Temporary stabilization measures were initiated to strengthen the embankment (McDade 1992). By 1992, however, the “stream bank erosion at the base of the talus slope had become so serious, there was concern for the integrity of the cave and its cultural deposits” (Ehrenhard 1994).

Personnel from the Interagency Archeological Services Division of the National Park Service, along with civil engineers from the Tennessee Valley Authority, determined that the talus required stabilization and proceeded with plans to reconstruct and reinforce the damaged area. In July 1992, NPS personnel from the Southeast Regional Office and Russell Cave National Monument, were joined by members of Company A of the Alabama National Guard's 151st Engineer Battalion began

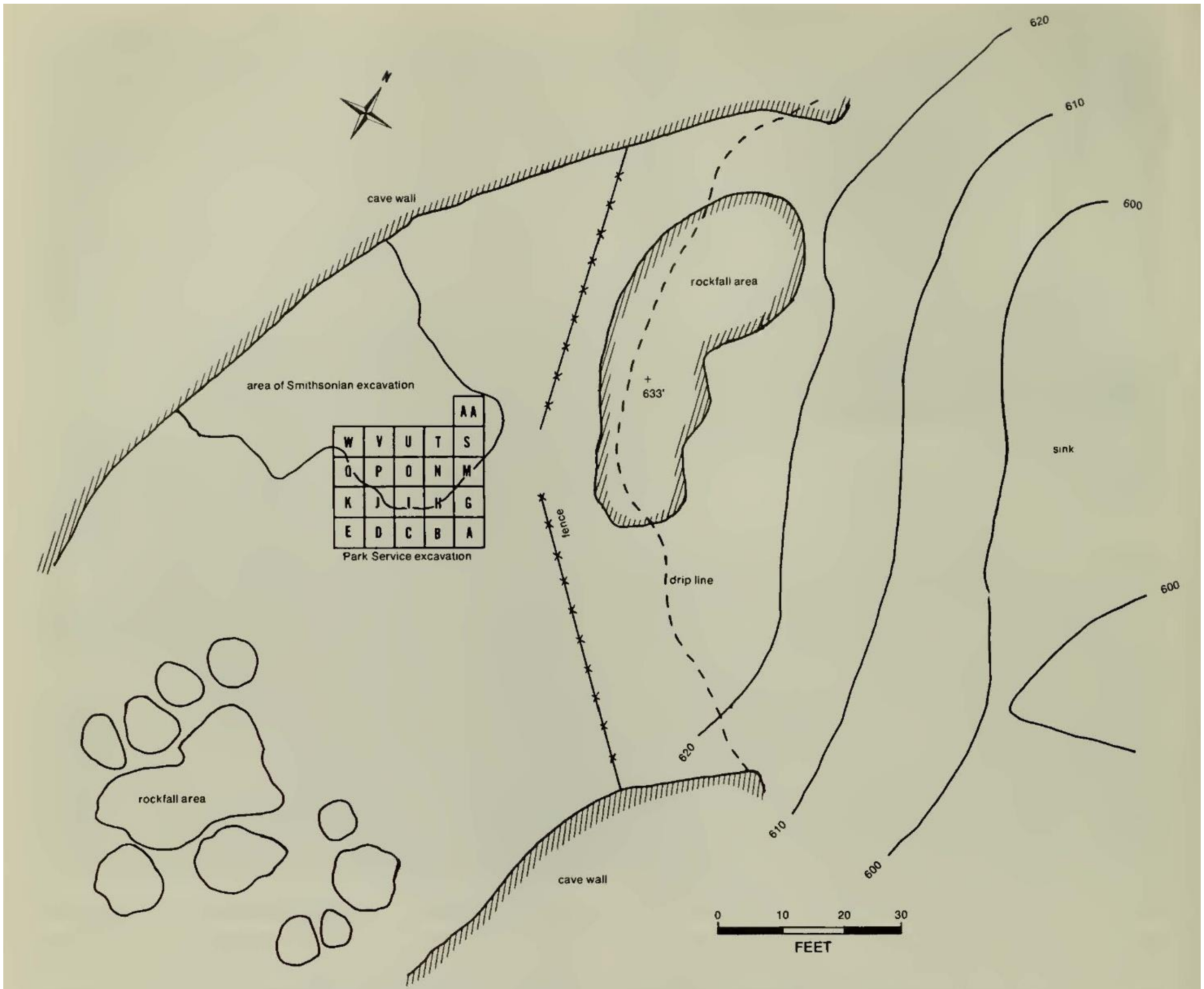


Figure 5.—Plan of area excavated by the Park Service in 1962.

Figure 5. Map of Griffin's excavations illustrating the location of the original Smithsonian excavation area and the 1962 excavation units (from: Griffin 1974:6).

Figure 6. View of excavation prior to exhibit development. (Photo courtesy NPS, RUCA 7/25/64).

Figure 7. Reinforcing steel (rebar) was put in place to secure the retaining walls (9/14/64).

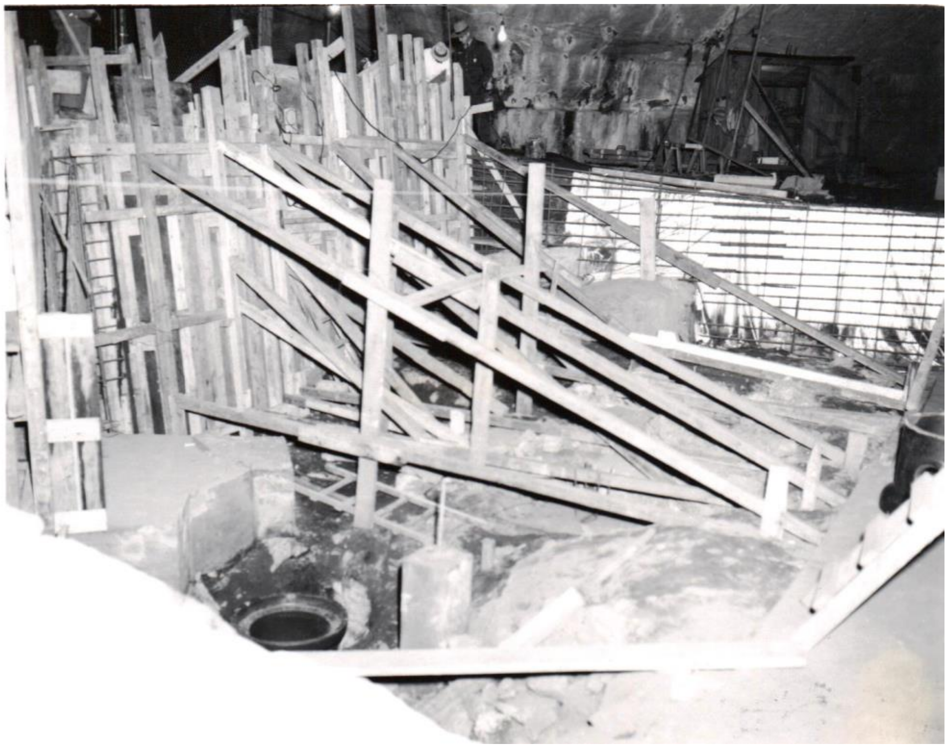


Figure 8. Construction for a viewing platform to allow visitors to see the cave stratigraphy. (Photo courtesy NPS, RUCA 10/16/64).

Figure 9. Cowin and Co. employees installing roof bolts. (Photo courtesy NPS, RUCA 1966).

Figure 10. Exhibit design showing viewing platform and strata cast along with temporary signage. (Photo courtesy NPS, RUCA 3/7/65).

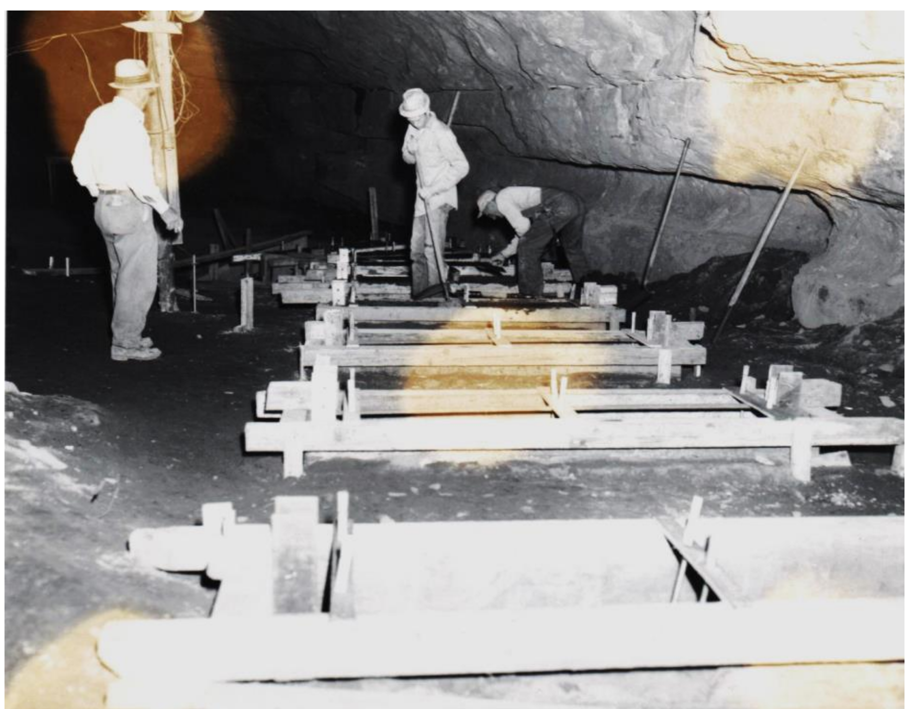


Figure 11. Preparing forms for ramp construction inside cave (Photo Courtesy NPS, RUCA 10/19/64).

Figure 12. Trail inside cave (above) had a set of stairs (below) that went down to the exhibit platform (Photo Courtesy NPS, RUCA images 461-3-65 and RUCA 463-3-65).

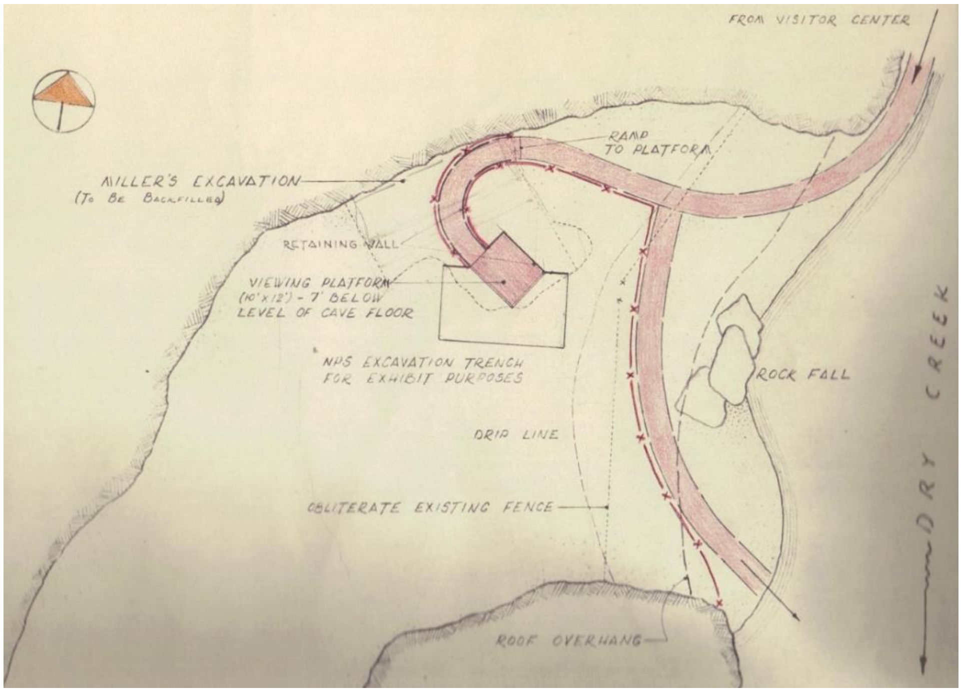


Figure 13. Illustration plan showing ideas for the locations of the viewing platform and entrance walkway and ramp (scanned image courtesy of the RUCA historic park files, no date, style suggests possibly attributable to Robert G. Hall, c. 1963 work at the site). Plan shows the original position of the 1960s walkway.

the major stabilization projects. The National Guard supplied heavy-construction equipment and workers to modify the eroded incline. The slope was reshaped with local material and formed as close to the original morphology as possible. The modified slope was anchored with layers of heavy-gauge filter fabric that wrapped the riprap composed of local stone, and the entire surface was filled and capped with river sand and gravel (Ehrenhard 1994 #11121) (Figure 14).

Further modifications to the cave site were made in 1997. The chain link fence was removed, and the posts were cut off. The 1960's open excavation/exhibit areas were backfilled. The original soil surfaces were covered with a layer of fabric material, and "250 tons of sterile sand to fill the pit" were added (Beane 2011). After compaction of the fill, a layer of filter fabric was laid down, and was overlaid with a layer of topsoil that was brought in from a nearby field. The retaining walls that lined the perimeter of Griffin's 1962 excavations (see Figure 7) were the only concrete known to remain in the cave. Also, at this time, the wood walkway that had been installed in the mid-1960s was removed and the replacement walkway that was installed followed a slightly different route (Figure 15). Ranger Larry Beane in 1989 captured a number of these alterations on a sketch map he created, which also helps in understanding the change sequences and events (Figure16).

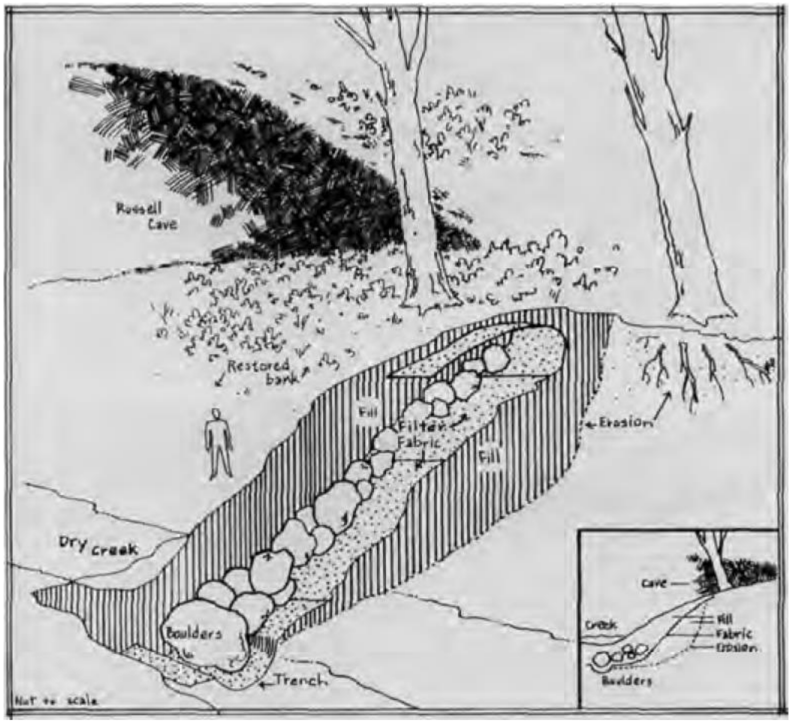


Figure 14. Illustration of a cross-section of the slope stabilization and restoration project carried out in front of the Russell Cave (Ehrenhard 1994:9, figure 3).

Figure 15. Photograph showing the boardwalk as constructed in 1997. (Photo courtesy NPS, RUCA files).

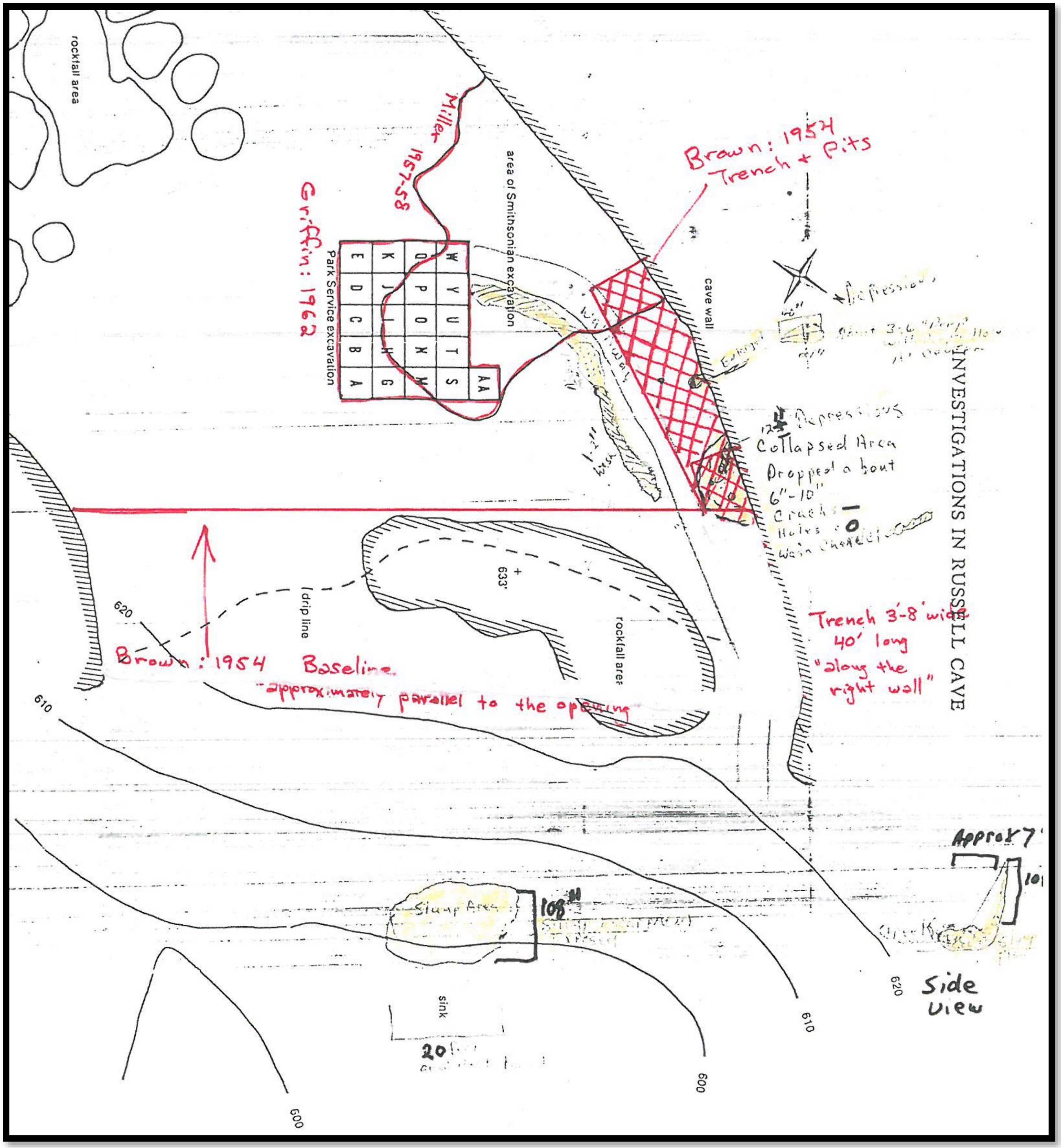


Figure 16. Sketch map from a field visit memo from NPS Ranger, Larry Beane (1989).

More recently, in 2009, an accelerating loss of soils was noted along the north wall near the entrance to the rock shelter by Park Ranger Larry Beane, and surface cracks were observed under the boardwalk as reported by Meiman (2011). Subsequently, during a survey of the northern wall of the cave, an area approximately 10 meters long that coincides with the excavations that were conducted in the 1950s and 1960s had begun to "sink" (Seibert 2010)(Figure 17). The soil loss was attributed to water seepage in 2010. Thornberry (2014) notes that since 2009, visible cracks have extended under the boardwalk (now removed), and that subsidence and slumping were occurring along the northwestern wall area and back corner of the rock shelter. LiDAR surveys, conducted over two monitoring years in the shelter by the USGS, showed that the elevation of the dry shelter floor had dropped at least 5 cm (2 in) in a 1.5-year period, and that rates of change appeared to be increasing with time (Thornberry-Ehrlich 2014)(Figure 18). The RUCA Geological Resources Inventory Report indicates that it is several factors working in concert that is leading to the expressed erosion in the Dry Cave area. Thornberry-Ehrlich (2014:15-16), cites processes of water intrusion into the cave from edge drip and drip pool formation, channelized flowing water creating rills and gullies along the wall area, and that subsidence of the ground surface into inadequately compacted backfill from early archeological excavations is possible. Additional areas of modification, such as the footprint for the boardwalk, is also clearly shown in the current survey, as creating small surface elevation change and disturbance to the cave floor. Also, of likely contribution to the erosion are high flows in the Dry Creek affecting the breakdown sediments buried beneath the dry shelter (Thornberry-Ehrlich 2014:16). Several monitoring and geophysical approaches are suggested to better understand the constellation of change processes occurring in the cave.

The present study is in an effort to examine conditions and provide easier to utilize baseline information concerning the erosion. Additional benefits from the study include added value interpretive aspects, as the removal of the boardwalk now reduces the ability for visitor entry to the cave. The 3D and imaging data can provide a virtual experience and showcase aspects of the rock shelter and cave to the public.

METHODS

The dry shelter portion of the cave and wall features suffer from the effects of subsidence, slumping and erosion processes. These processes threaten existing and as yet to be recorded cultural resources within the dry shelter portion of the site.

TLS survey was conducted using two phase-shift laser scanners with an accuracy of +/- 2mm or less. A total of 78 scans were acquired during two scanning survey days. Additionally, GPS data was acquired to field verify and map in environmental variables and features of note. GPS was used to record the course of the stream bed and features of note from remotely sensed data (aerial LiDAR

Figure 17. Soil loss along north wall (Seibert 2010). Photos courtesy NPS SEAC.

Figure 18. Current (2016) area along northwest cave wall showing scalloping, erosion, exposed conduit, subsidence, and slumping. Ground disturbance from previous walkway and exhibition constructs is also present.

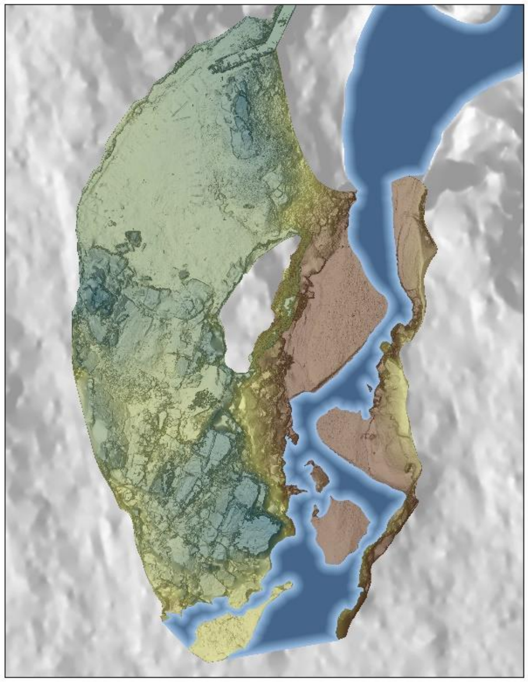
and imagery). Human-made features such as boardwalk, interpretive signage and stops, trails, roads and buildings were largely recorded for the area relating to and in the vicinity of the rock shelter. Standard and spherical images were taken in conjunction with the survey, as were GPS photos and GoPRO videography to record contextual details. Combining these techniques, the entirety of the dry and wet portion openings and stream bed areas in the surrounding environs were recorded, to produce a highly detailed and accurate terrain model of the site (Figure 19). These laser scanning data provide accurate spatial assessment of previous treatment locations, historic archeological activity position information (georeferenced in relation to present-day conditions). These data are used as an assessment tool and documentation measure proving conditional assessment and current as-is baseline information for comparison going forward, and to examine areas of erosion, subsidence, and slumping in the cave, and be used to visualize the site for both research and public interpretation values.

Post –processing of the laser scanning data was done to provide point cloud and terrain model products that could be used in 3D software and also imported into a GIS environment and used in conjunction with aerial LiDAR to provide an elevation model for the larger landscape. The ability to move between scales is of critical importance to studying these types of karst systems, where factors of impact may occur far from the area where they are noted. For example, flooding today could be relational to straightening of bends in the dry creek done in the 1960s and 70s further upstream by the Corp of Engineers and landowners (English 2012). Land-use impacts from logging and mining off-site have also likely caused an increase in flooding and silting in of the creek bed area. Aerial LiDAR, especially when multiple years of collected data are available, help to assess these types of terrain alterations, and provide a forensic method for land change detection (Abby 2014).

All GPS, aerial LiDAR, imagery, georeferenced historic base maps, geophysical data, and the TLS derived data, were compiled in a GIS and presented in a geodatabase format. Additionally, all maps created for the project in GIS are archived as both the GIS projects and map packages for use by the NPS. Archival metadata and storage of the project is with both the NPS SEAC and the USF Libraries.

RESULTS

The TLS survey at RUCA consisted of 78 scan positions, with two different phase shift surveying instruments used. The scans were taken to provide coverage for the entirety of the dry shelter portion of the site where the erosion study emphasis was required, but also to examine the related and connected lower entry opening as well as the area feeding into the cave, including the creek run and sloped banks and related terrain. The survey data area is shown in Figure 20, with the



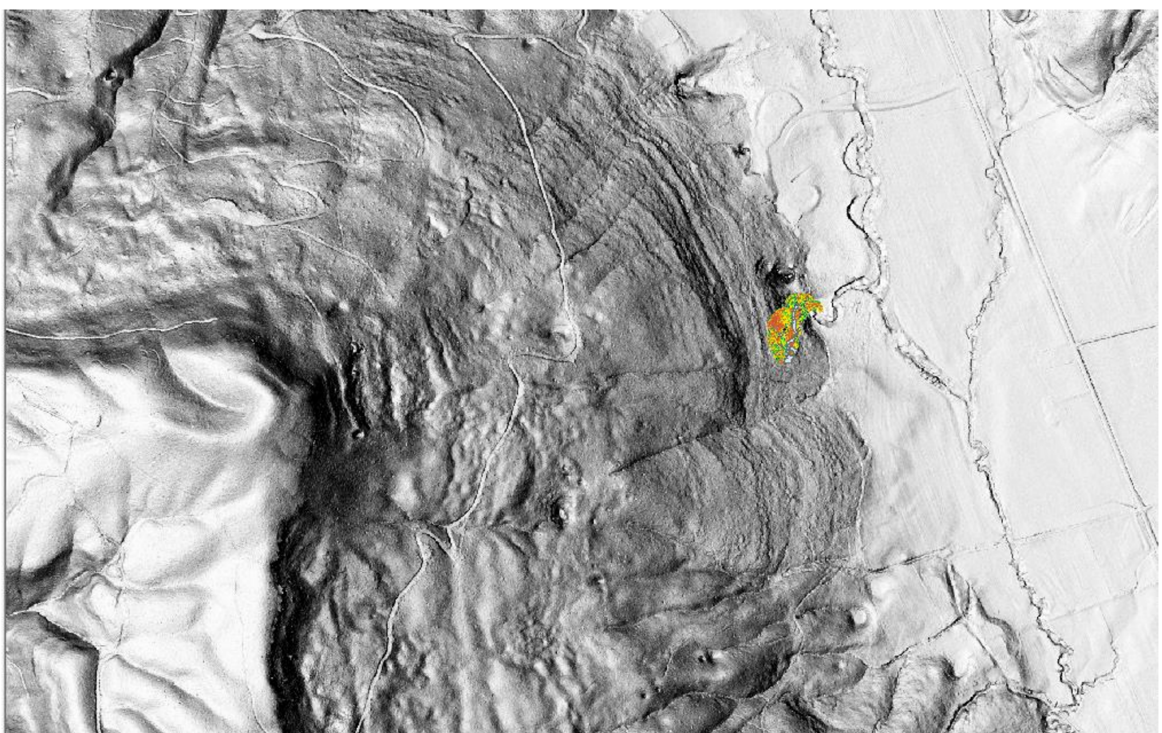


Figure 19. TLS data collected included areas on both dry and wet side cave entrances, and the surrounding environs including the creek bed feeding into the wet side of the cave (above). These data were combined with aerial LiDAR for the greater park area, to produce a landscape GIS that is viewable from a variety of scales (below).

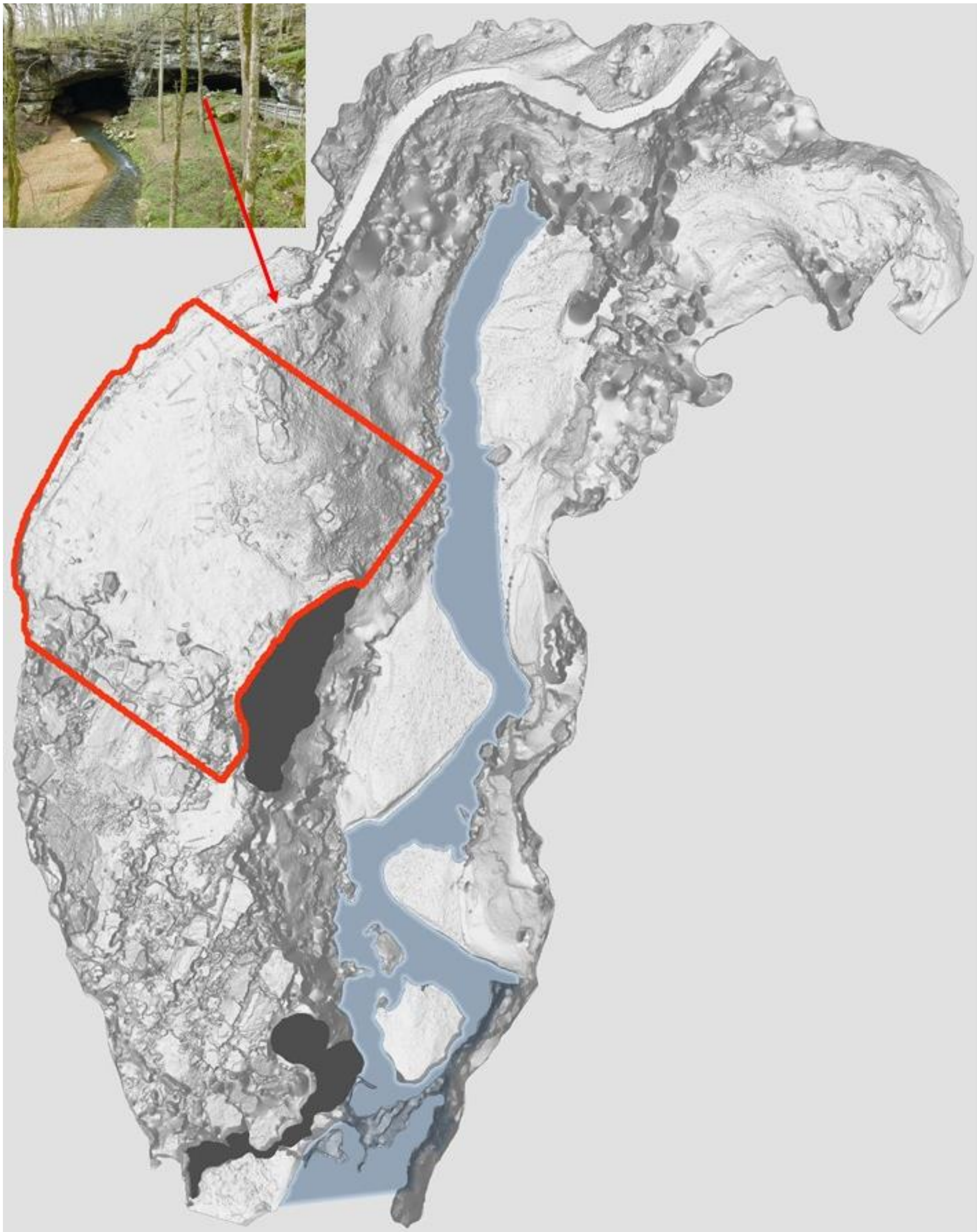


Figure 20. Area of examination for the survey, note that both sides of the cave's rock shelter and surrounding environ were captured with the TLS survey, but emphasis is placed on the dry portion of the shelter for this project.

highlighted area showing the location of the cave floor in the shelter area dry cave or upper section. This figure shows only the ground topography, but because the survey was performed to capture 360 degrees of 3D data and imagery, the roof and complete rock face of the entry to the cave was also captured, as shown in Figure 21, and can be viewed using the link to the following animation: https://vimeo.com/190578421 .

Laser scanning was also performed at close range using a structured light instrument to examine a selected rock boulder face, where noted areas of possible carving were thought to exist. A series of scans and photography were performed to capture the entirety of this boulder rock face area, and these data were processed to examine surface aspects. Line features that were pointed out were found to likely be associated with rodent activity and other natural processes of weathering and did not have indication of carving. One portion of the rock was found to have a number carved into the surface (Figure X). Post-processing of the scan data revealed the number to be "34", and this could be attributable to a designation or marking from the historic archeological survey efforts, which were in close proximity to this boulder rock fall area (Figure 22).

GPS survey at RUCA as part of this project included delineation of the dry creek mid-line, and also was used to map in the boardwalk and interpretive signage and features and other management-related locations in proximity to the cave. Also recorded were points on the face of the rock shelter that were acquired using the laser range finder in conjunction with the GPS positioning, helping to have control points for use with the TLS survey. Trails and related cultural features of note were also mapped, including the location of a historic church and graveyard located across from the park property. These data were collected for background information purposes, and are contributory, but not part of the present survey need (Figure 23). GPS photography was also acquired in relation to the GPS sub-decimeter survey and provide a contextual understanding for condition and field attributes.

KEY FINDINGS

Location control was also established using GPS position information and TLS targets set up on the GPR survey grid as established by the NPS SEAC. Targets were placed on each corner of the grid and show in the TLS data point cloud. This allowed for the precise location of the GPR grid within the point cloud TLS data, and was used in the georeferencing of the GPR data provided by SEAC and also shown in relation to important legacy maps and locations, such as those shown in the Griffin (1974) map that showed archeological grid positions and other important feature information (Figure 24 and 25).

Figure 21. Point cloud views from exterior and interior of dry shelter side of Russell Cave.

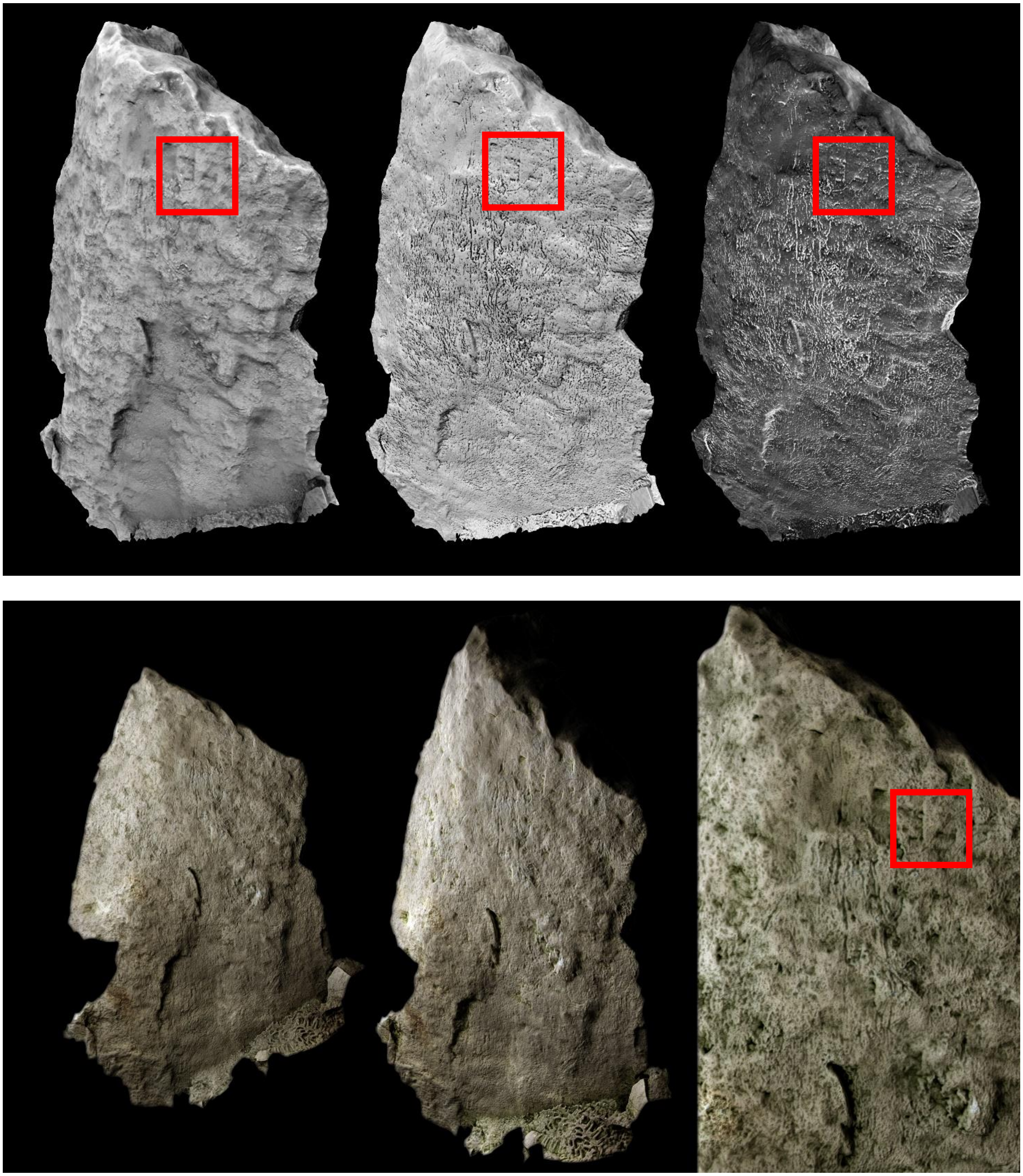


Figure 22. Close range scanning, using a structured light scanning instrument, was performed on a rock with known carving that was not readily discernable.

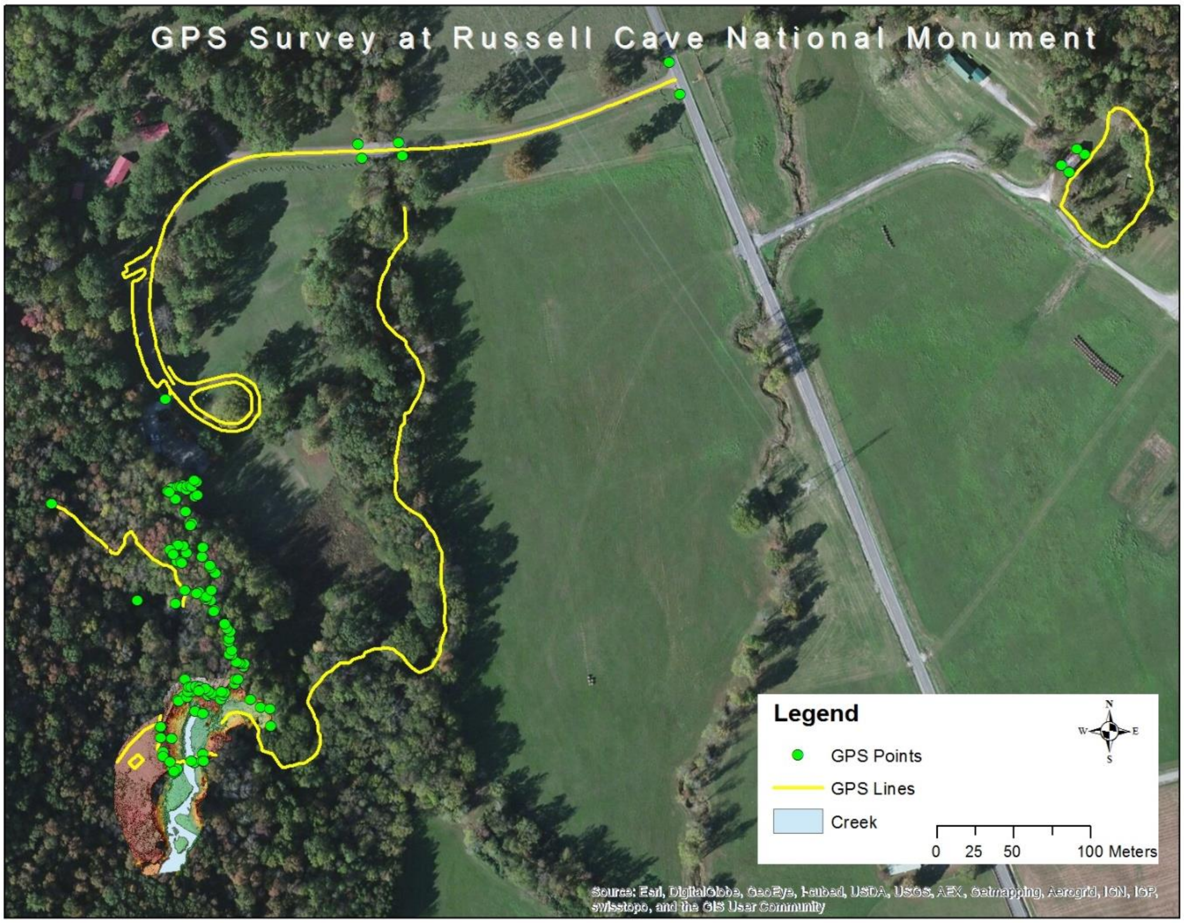


Figure 23. Map showing locations of GPS data collection in relation to the DEM developed for the cave and rock shelter area. Data collected included the creek bed center line, boardwalk and associated trail features, and positions for the front rock face of the cave entrance and for control positions brought to the interior of cave. Additional data was collected on the historic church and graveyard across from the park site.

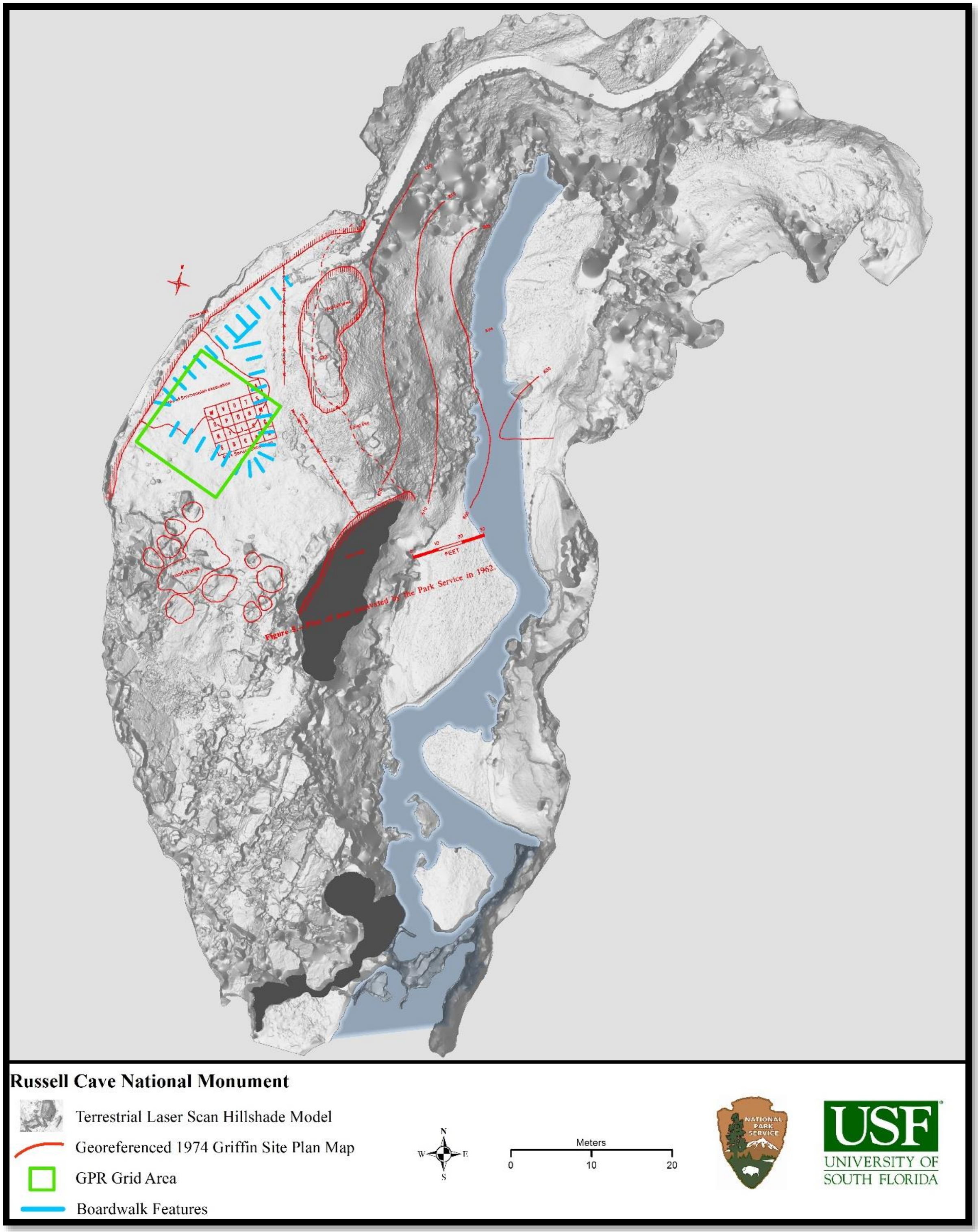


Figure 24. TLS hillshade terrain model showing georeferenced Griffin (1974) map along with position of the removed boardwalk feature and the grid established by the NPS SEAC for geophysical (GPR) survey.

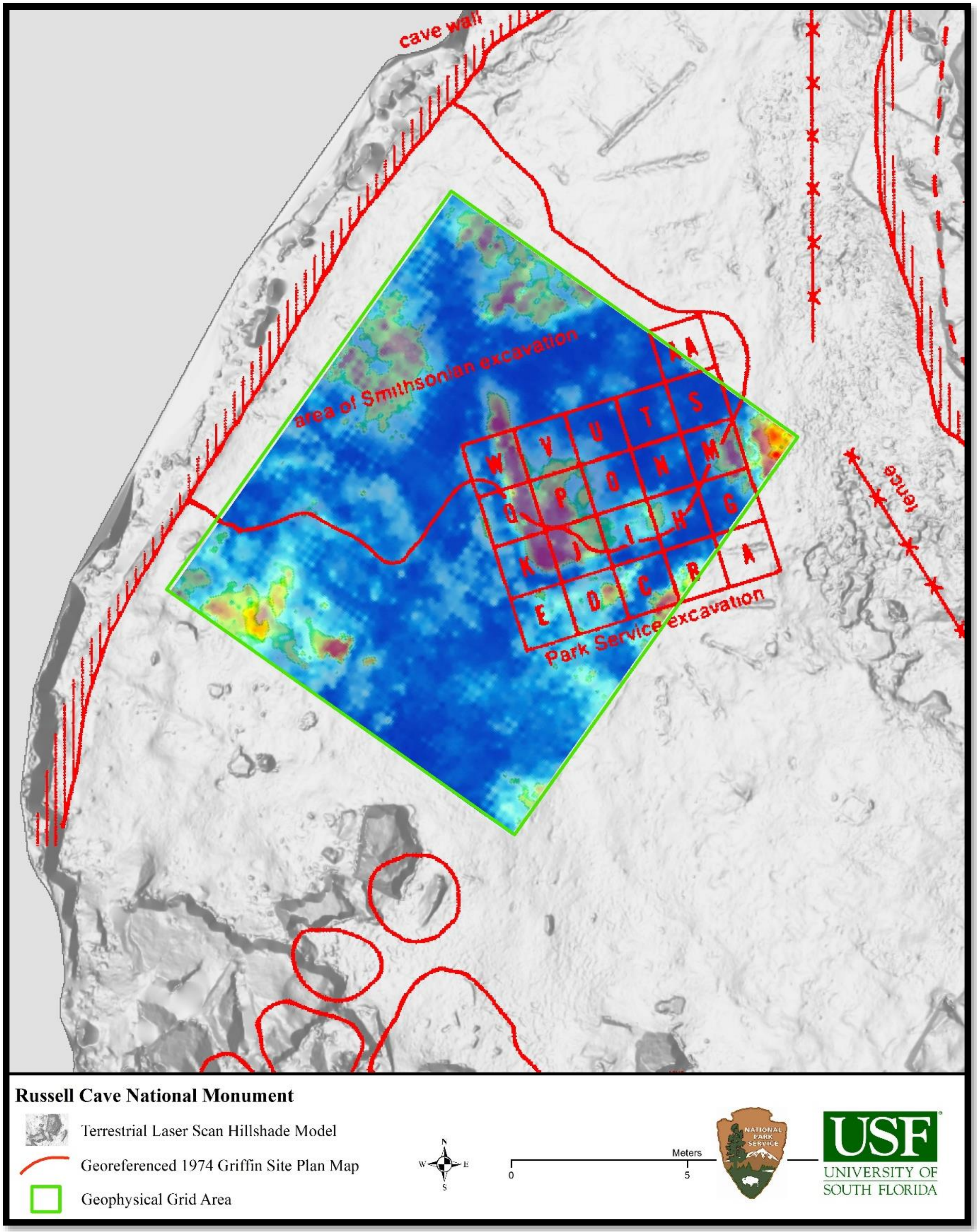


Figure 25. Geophysical (GPR) survey data shown in relation to established grid location, TLS terrain data, and the georeferenced position of the Griffin site plan map from 1974. Note that there are errors in the 1974 position information, with slight drift noted as compared to the TLS data.

Key capabilities and findings coming from the TLS survey, are the ability to create sectional study across any position within the cave (Figure 26). In this way, dimensional study and inquiry can be conducted, and reliable elevation, slope and other metrological studies can be made and used as a basis for comparison going forward (Figures 27-29). These sectional studies are able to be shared and shown in a variety of formats, including a video produced using the laser scanning survey data that helps to visualize the dimensions of the rock shelter (https://vimeo.com/190288329). Repeat measurements using point cloud data will allow for iterative closest point (ICP) analysis and other techniques that can more accurately determine rate of erosion, subsidence, and other change occurrences with the Russell Cave site (Zhang and Glennie 2014). Additionally, combining data sets from TLS, GPS and aerial LiDAR, watershed analyses are more precise, allowing for more holistic understand of the cave environs and connections with landscape variables. Internal to the cave structure, lower cost and targeted measurement methods can also be used on established locations that can provide on-going comparative analysis and erosion rate and assessment going forward. Detailed cartographic and representation of the cave is an importance first step in developing holistic dimension understanding, and has been shown in other cave studies to be useful for a number of research questions, such as light penetration, ceiling thickness, connectivity and karst research questions (Hoffmeister 2016).

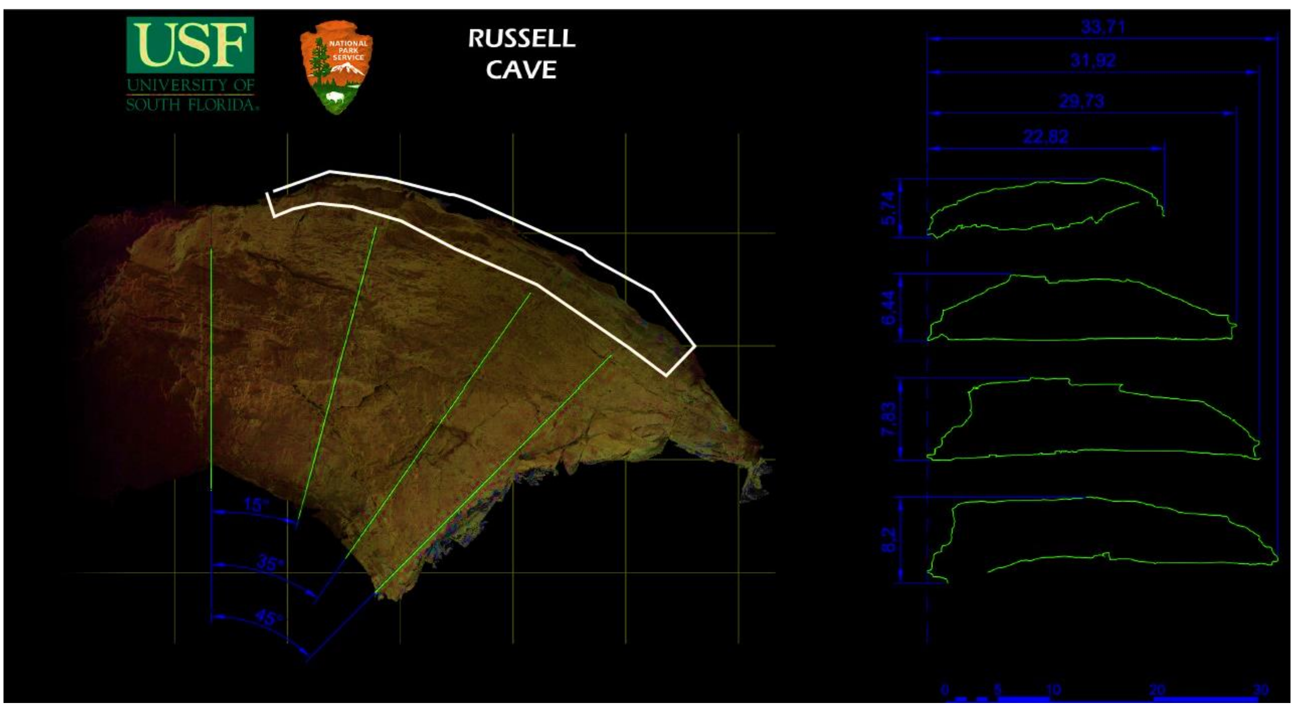


Figure 26. Dimension and cross-section study, including the detailed examination of the erosion area along the northwest wall area, is possible using the 3D data collected in the TLS survey. Shown are slices taken at defined interval locations through the data from ceiling to the cave floor on the dry cave shelter side.

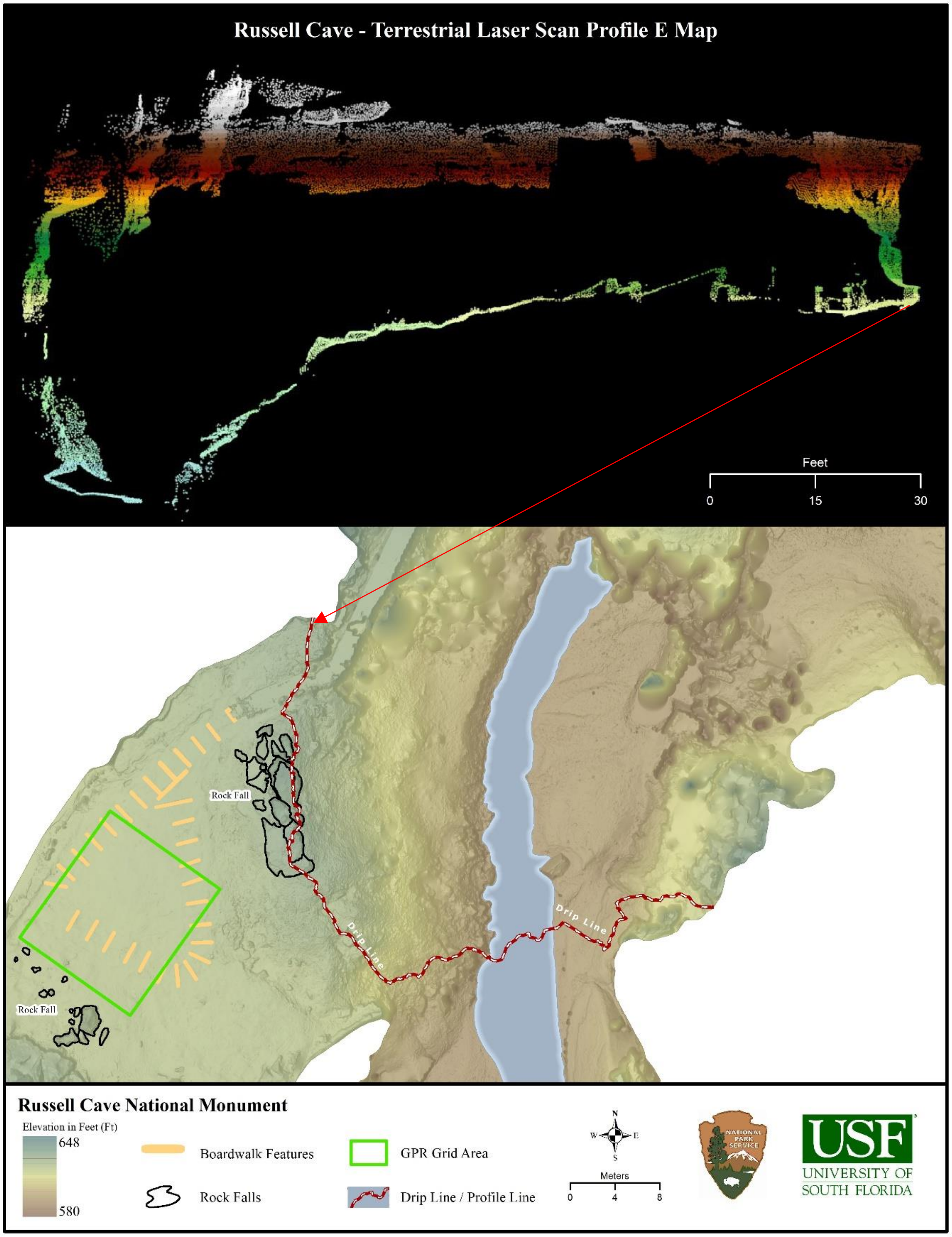


Figure 27. Profile sections derived from the TLS data, allow visualization, measurement, and understanding for various locations through the cave. This section shows the area corresponding to the drip line feature at the mouth of the rock shelter area and extends across upper (dry) and lower (wet) sides of the cave.

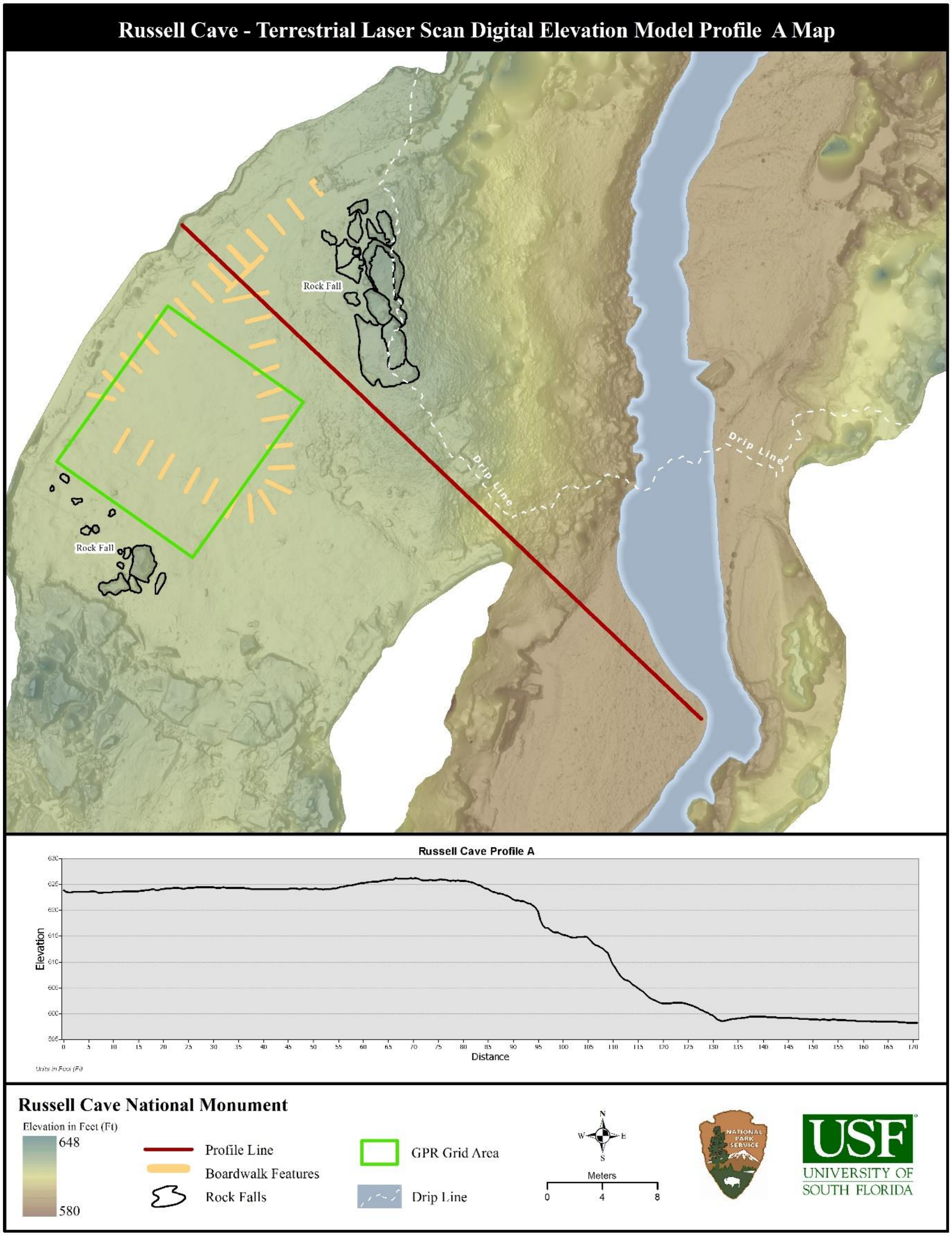


Figure 28. Profile section analysis using the TLS data to view and understand cave morphology and dimensions.

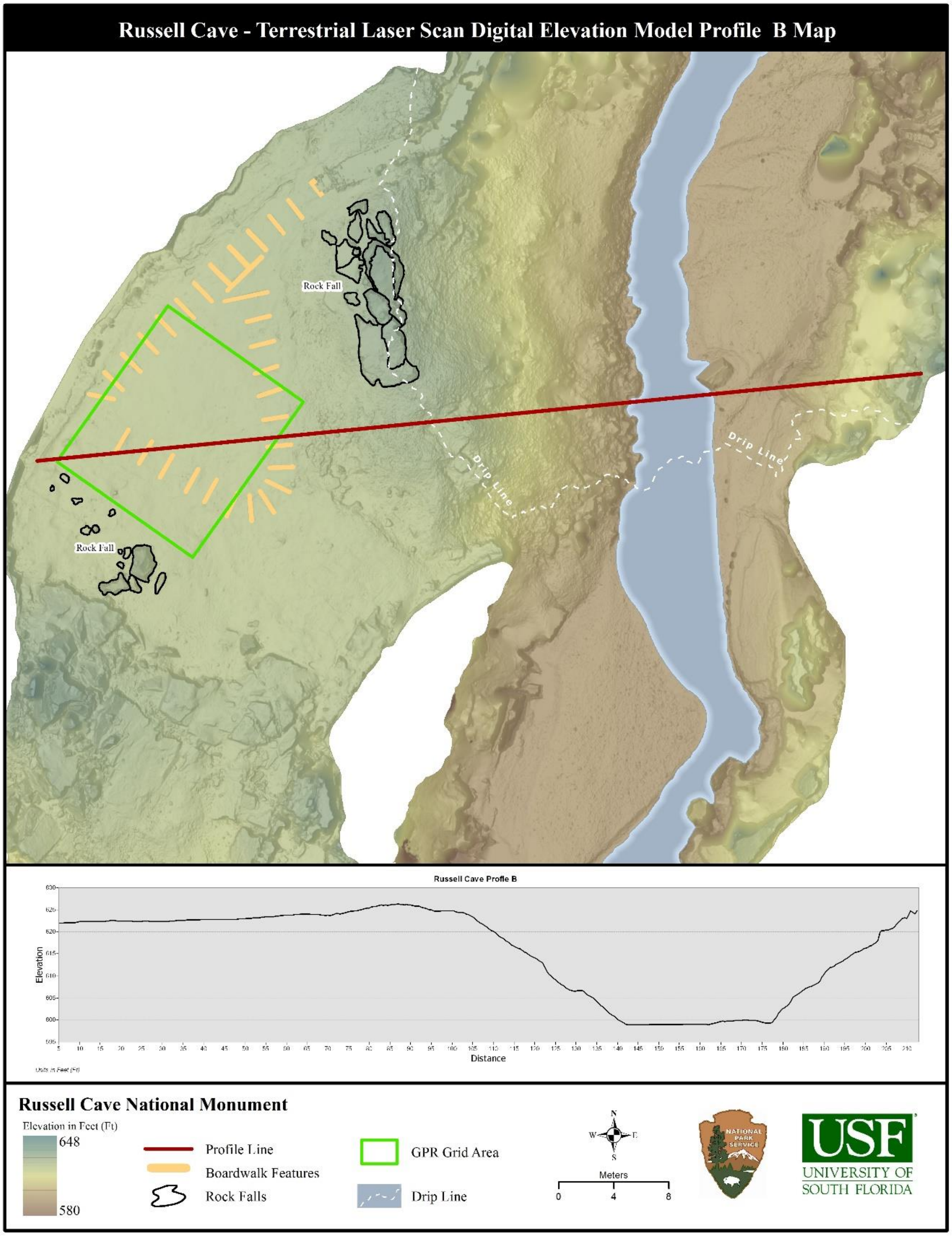


Figure 29. The TLS survey in conjunction with aerial LiDAR data available and processed for the site location area, allowed determination of elevation and the creation of a detailed and measurable model for the cave and its surroundings.

The data from the TLS survey of the Russell Cave, was processed in a variety of ways, including 3D and GIS representation, creating both vector and point based models for these data. Highly detailed elevation models of the cave floor from the dry cave shelter area were created in an effort to examine millimetric level surface features. These models were created using both hillshade/grayscale modeling to show shadowing of features in an effort to better discern, and as true color models depicting a more realistic presentation of the cave environs (Figure 30).

Slope models for the shelter floor were also created using a color scale gradation to examine relative elevation (from high to low areas). Depicting relative elevation in this way allows for an understanding of the millimetric differences in the terrain across the shelter, and how ground disturbance, subsidence and erosion processes could be impacting depicted areas (Figures 31 and 32).

Additional modeling produced from the TLS survey included an updated understanding for the roof bolt features present on the dry cave shelter portion of the site. Installed in 1964, these features stretch across the cave roof and are an important element in the alteration and work that has been conducted in the cave. Our mapping allows understanding not only of position in the inside ceiling, but how these relate to the surface 3D space of the ceiling (Figure 33).

The geodatabase produced in the GIS platform for this project is provided to the SEAC and brings together all pertinent legacy and as-is condition information with the TLS, GPS and processed aerial LiDAR information. This geodatabase allows for a spatial data foundation to retain and continue to build information layers consisting of all future survey work conducted at RUCA, and can be used to better understand impacts from modification and change that occur (Figure 34)

Freely sharable tools that allow for virtual tour potentials and annotated models that can be used for education, outreach, and research alike, have also been created from this survey (Figure 35 and 36). These data are provided in online viewing platforms that can be used with the inexpensive Google Cardboard or any of the major virtual reality viewing platforms. These data can also be viewed freely with no additional hardware or software requirements and are easily embedded and used on NPS website and other application developments (Figure 37). The USF Libraries in collaboration with the NPS and SEAC are continuing to work on digital collection and sharing strategies with these data, and plan to host and share a number of tools and research offerings relating to this effort. See for example:

https://usfaist.maps.arcgis.com/apps/MapJournal/index.html?appid=646513f382f74dff9935d1f0864899fe and https://usfaist.maps.arcgis.com/apps/Cascade/index.html?appid=150ff626b91643a8b43358c857f1586f .

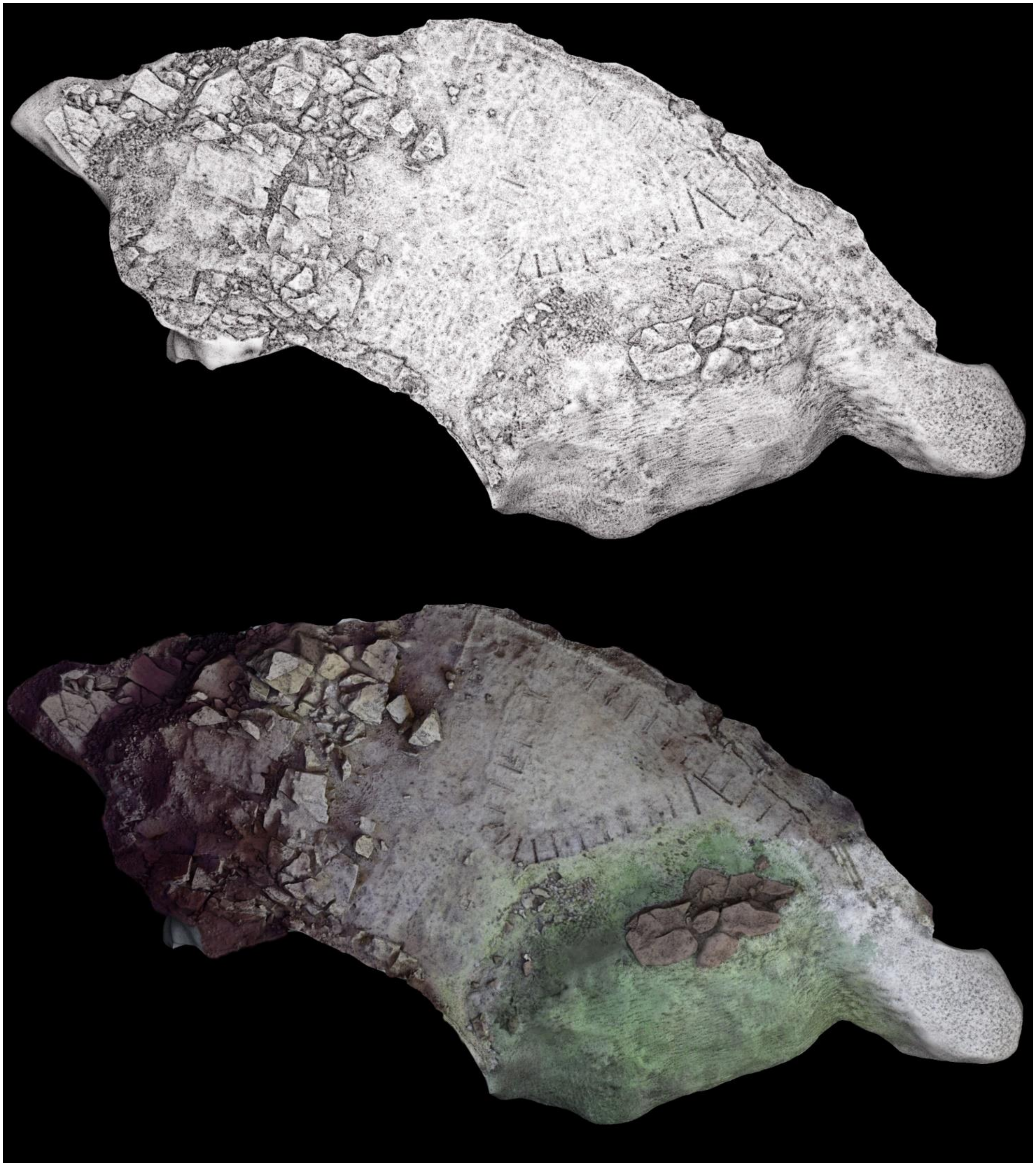


Figure 30. Cave floor maps produced from the TLS data, with the hillshade terrain model above and the colorized texture surface model below. These data allow for metrological understanding of the cave surface at millimeter level scales. Note that issues of subsidence, slumping, and elevation differences from terrain disturbance from the past boardwalk construction are all indicated and able to be visualized and studied.

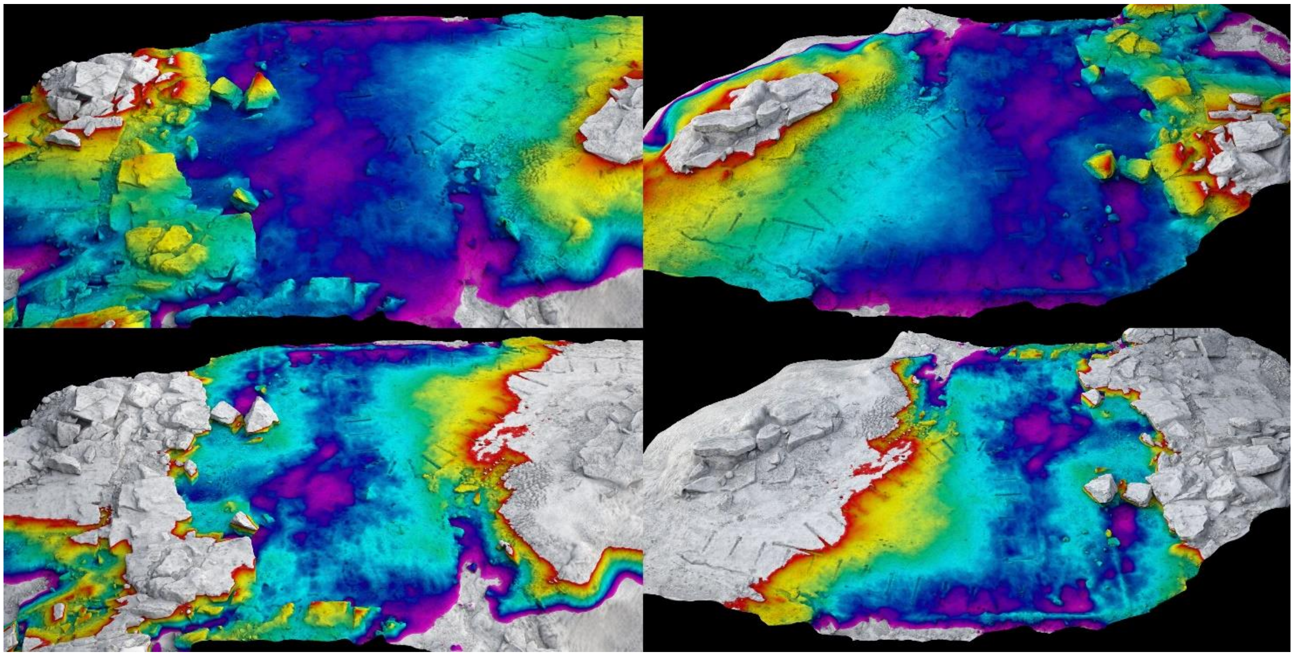


Figure 31. Relative elevation difference map showing discrete areas of the dry shelter at Russell Cave. Red and yellow areas are higher elevation relative to the light and dark blue, and to the purple colors which are lowest.

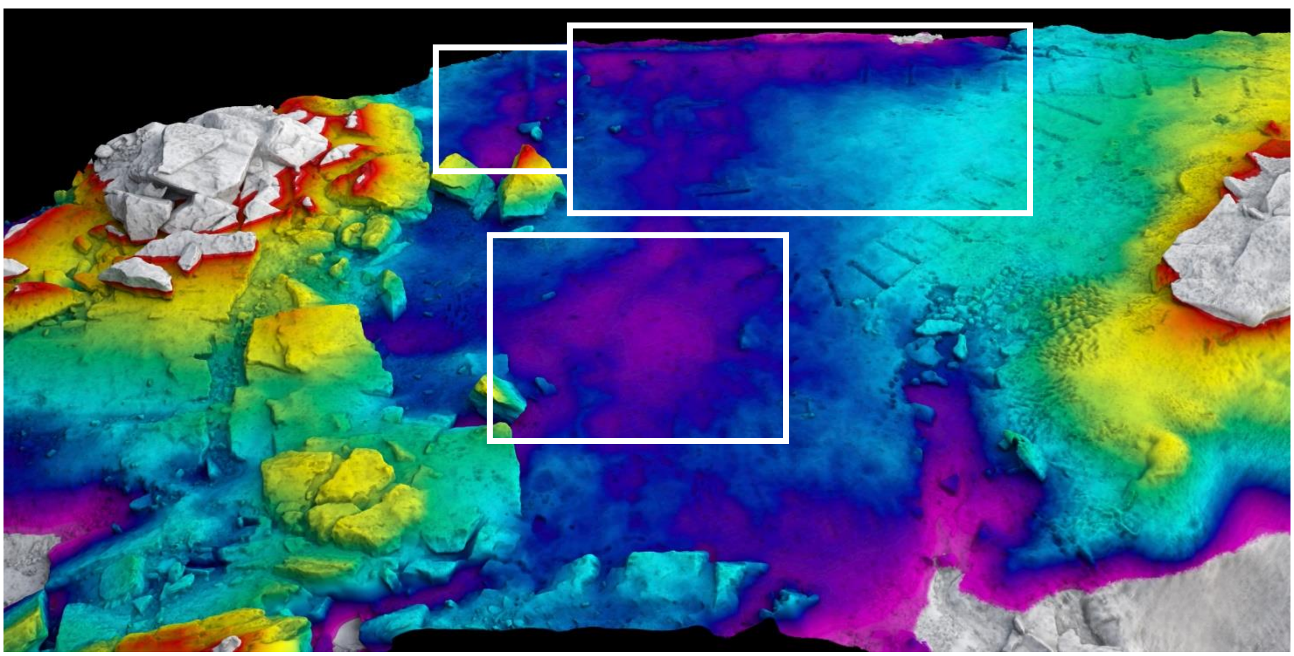
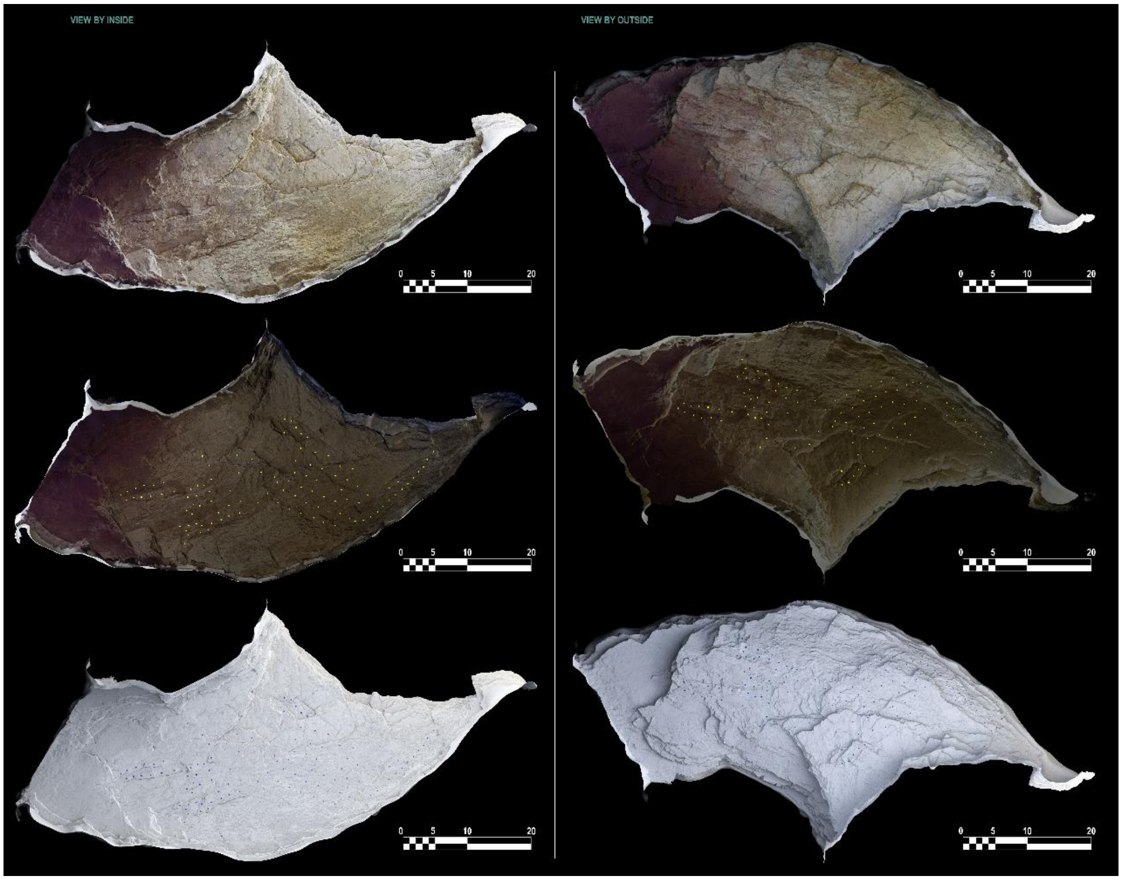


Figure 32. Close-up view showing the relative elevation of the floor surface. Note that several purple areas correspond to previous excavation areas, exhibit area, and to portions of the now removed interpretive boardwalk (areas shown in polygons).



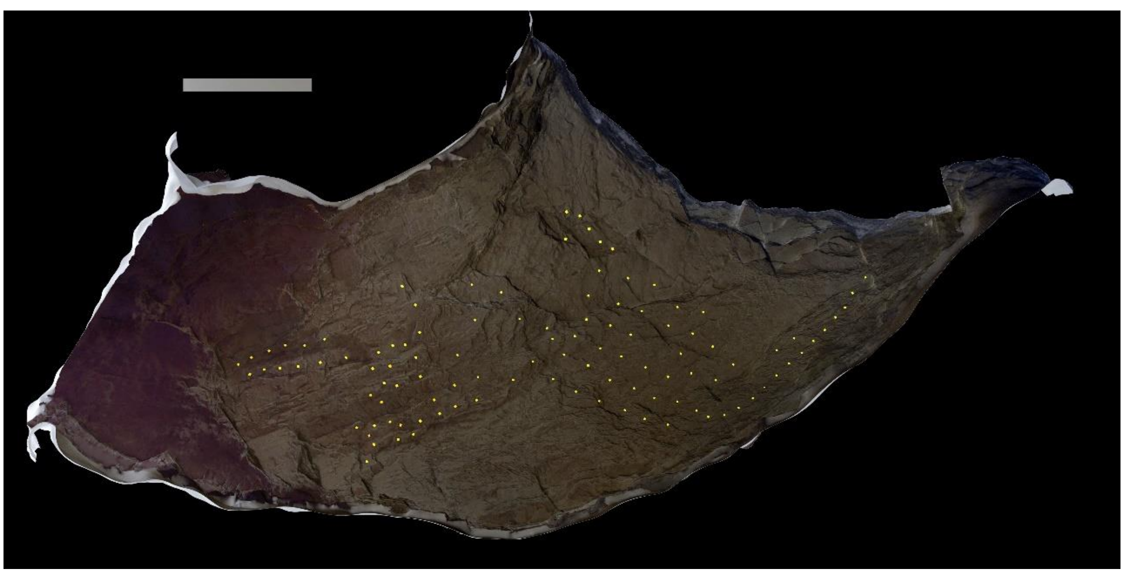


Figure 33. Updated roof bolt map for the dry shelter cave. The bolts were placed on the cave roof in 1964, and a CAD sketch map of their placement was made at that time. Above image shows the bolt locations connected to corresponding location (interior ceiling on left and outer external ceiling location on right) in 3D space. Map below shows detail of interior of the ceiling roof with bolt positions.

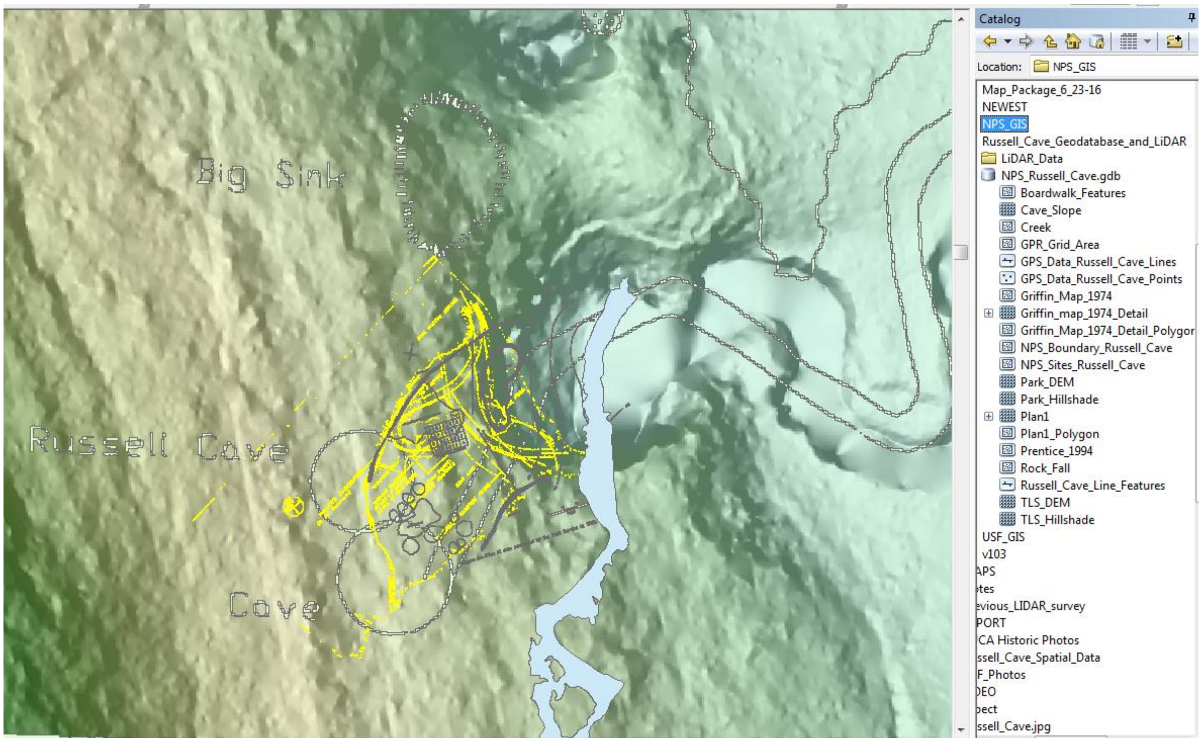


Figure 34. Geodatabase showing several of the georeferenced base maps, TLS and LiDAR data and the listing of ArcCatalog data layers provided in the developed geodatabase structure.

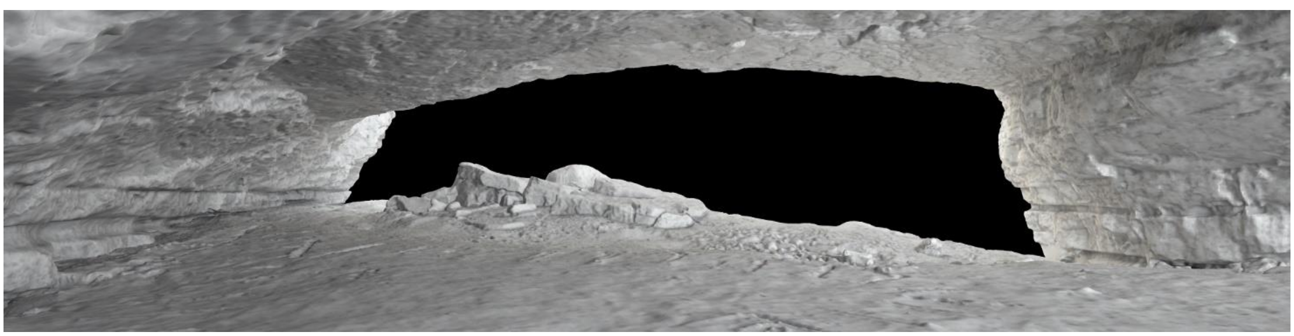


Figure 34. 3D model of the cave with the viewable position looking from inside the cave to the outside on the dry rock shelter side.

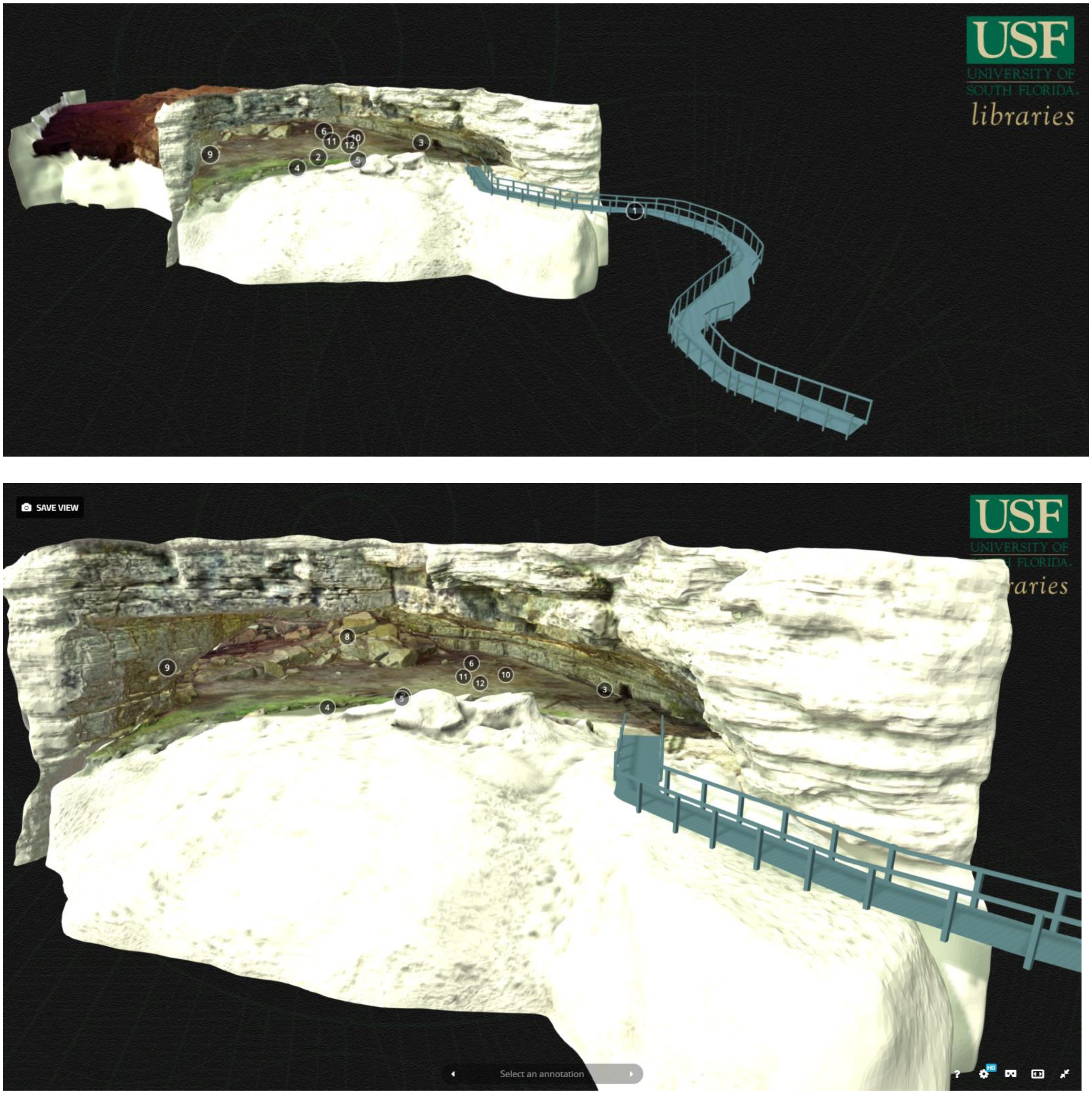


Figure 35. 3D model of Russell Cave, made from the laser scanning survey data, is here annotated to provide a virtual tourism and interpretive experience. Model is available at: https://skfb.ly/VFzV .

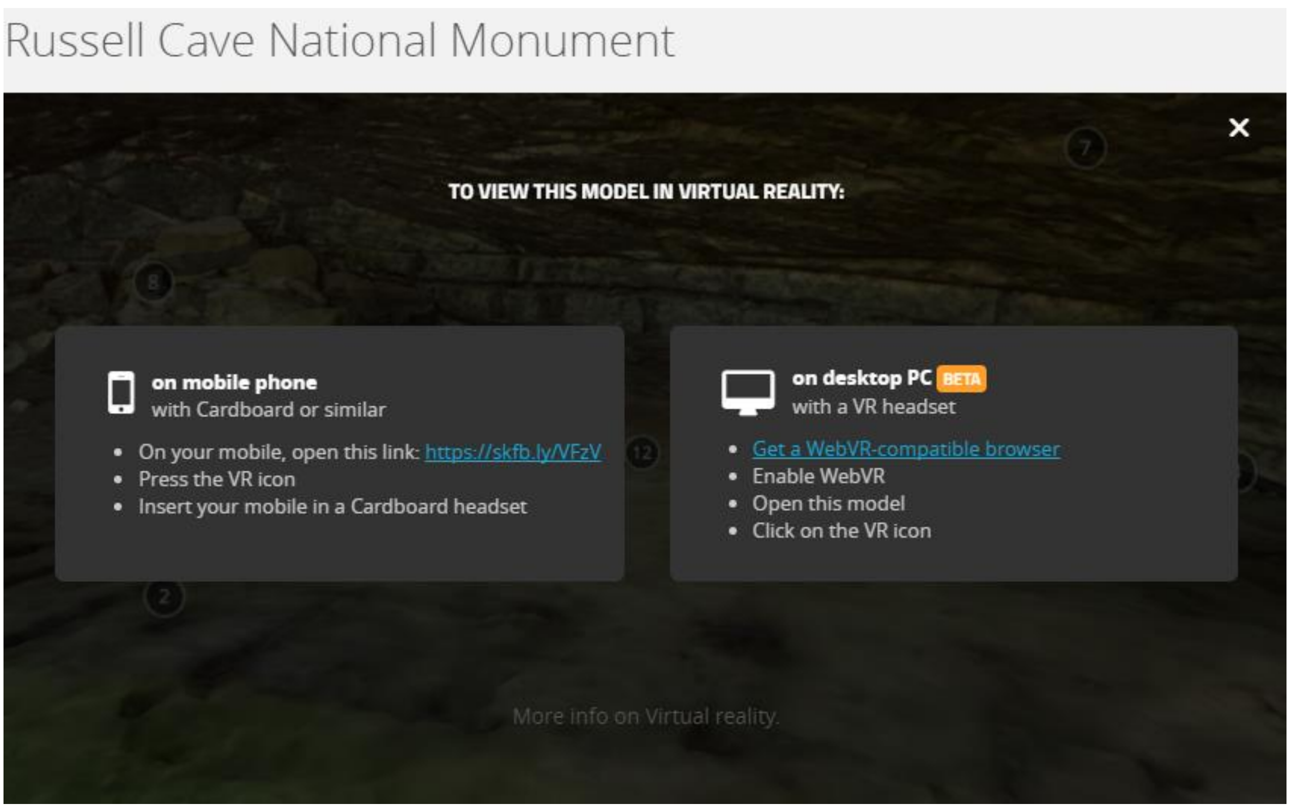


Figure 36. Annotated 3D model allows viewers to virtually walk into the cave and see noted features. The model is also available to view with VR enabled devices (below).

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