2015

Terrestrial and Airborne LiDAR Digital Documentation of Kosciuszko Mine, Ninety Six National Historic Site

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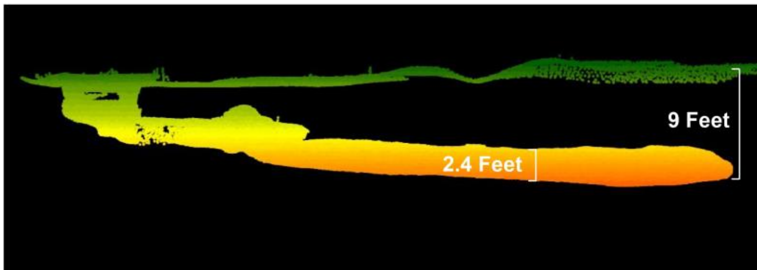

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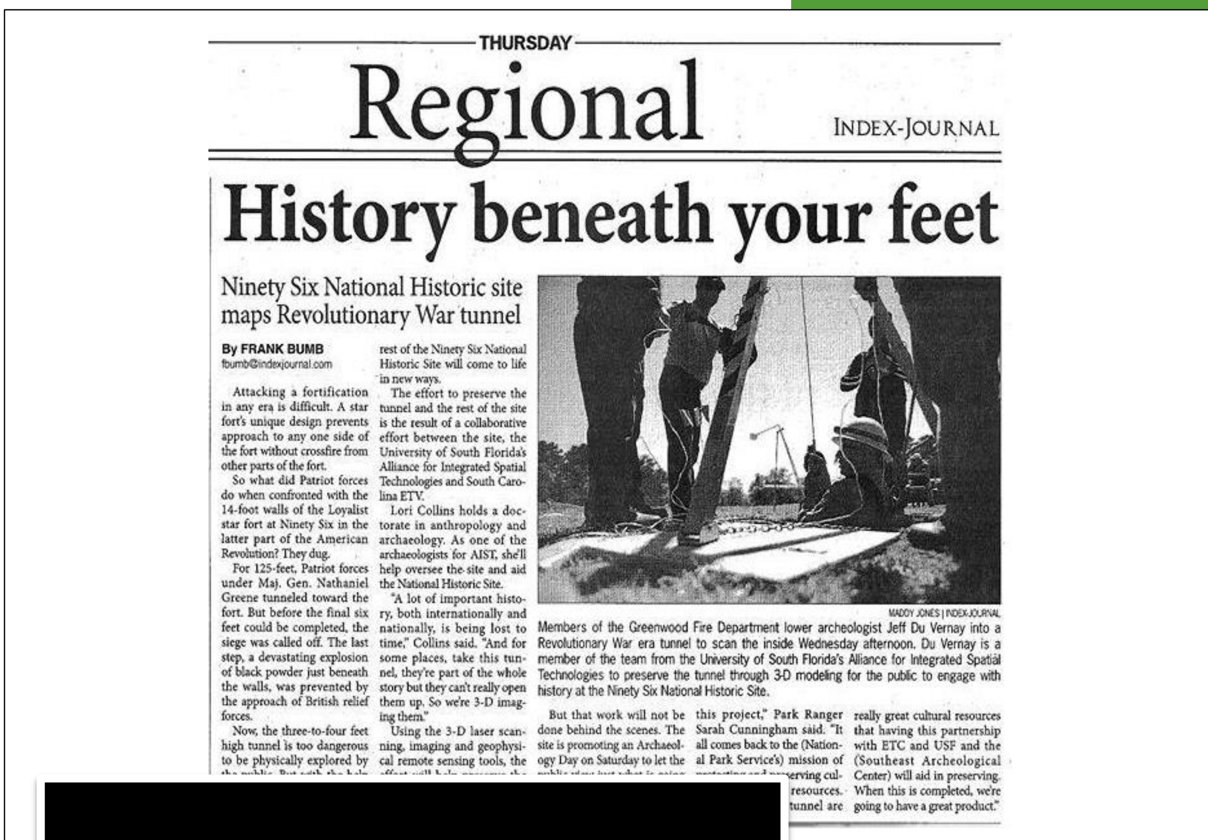

THURSDAY

Regional

INDEX-JOURNAL

History beneath your feet

Ninety Six National Historic site maps Revolutionary War tunnel

By FRANK BUMB
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Attacking a fortification in any era is difficult. A star fort's unique design prevents approach to any one side of the fort without crossfire from other parts of the fort.

So what did Patriot forces do when confronted with the 14-foot walls of the Loyalist star fort at Ninety Six in the latter part of the American Revolution? They dug.

For 125-feet, Patriot forces under Maj. Gen. Nathaniel Greene tunneled toward the fort. But before the final six feet could be completed, the siege was called off. The last step, a devastating explosion of black powder just beneath the walls, was prevented by the approach of British relief forces.

Now, the three-to-four feet high tunnel is too dangerous to be physically explored by

rest of the Ninety Six National Historic Site will come to life in new ways.

The effort to preserve the tunnel and the rest of the site is the result of a collaborative effort between the site, the University of South Florida's Alliance for Integrated Spatial Technologies and South Carolina ETV.

Lori Collins holds a doctorate in anthropology and archaeology. As one of the archaeologists for AIST, she'll help oversee the site and aid the National Historic Site.

"A lot of important history, both internationally and nationally, is being lost to time," Collins said. "And for some places, take this tunnel, they're part of the whole story but they can't really open them up. So we're 3-D imaging them."

Using the 3-D laser scanning, imaging and geophysical remote sensing tools, the

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Members of the Greenwood Fire Department lower archeologist Jeff Du Vernay into a Revolutionary War era tunnel to scan the inside Wednesday afternoon. Du Vernay is a member of the team from the University of South Florida's Alliance for Integrated Spatial Technologies to preserve the tunnel through 3-D modeling for the public to engage with history at the Ninety Six National Historic Site.

But that work will not be done behind the scenes. The site is promoting an Archaeology Day on Saturday to let the

this project," Park Ranger Sarah Cunningham said. "It all comes back to the (National Park Service's) mission of ...erving cultural ... resources. ... tunnel are

really great cultural resources that having this partnership with ETC and USF and the (Southeast Archeological Center) will aid in preserving. When this is completed, we're going to have a great product."

CESU task agreement P12AC11168, Piedmont – South Atlantic Coast Cooperative Ecosystems Studies Unit

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Principal Investigators:
Lori Collins, Ph.D. &
Travis Doering, Ph.D. with
Lead 3D Specialist Jorge Gonzalez

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ACKNOWLEDGEMENTS

The PI's and co-authors would like to thank Ninety Six National Historic Site Superintendent, John Slaughter for his foresight, planning, and technology interests and enthusiasm. His assistance with all aspects of the project was integral to its success. Ranger Interpreter, Sarah Cunningham, and Gray Wood with Ninety Six National Historic Site, whose dedication, knowledge, enthusiasm, interest, and efforts helped to ensure all aspects of our work were possible and successful. Dr. Margo Schwadron, Archeologist with the Southeast Archeological Center (SEAC), assisted with the planning, organizing, and implementation of this project and provided support, advice, and suggestions throughout the process. Also from SEAC, archeologists Jayce Michael Hill and Rusty L. Simmons handled gradiometer and geophysics for the NPS and also worked as part of the archeological and surveying team efforts. Our Structural Engineering support and conditional survey specialist was Bert Benders from Benders and Associates, Architects. Bert was important for the field and post assessments for integrity and planning.

There were also several staff, affiliates, and students at the University of South Florida's (USF) Alliance for Integrated Spatial Technologies (AIST) that contributed significantly to the success of this project and we wish to thank: Jeff Du Vernay, Ph.D. (TLS Survey); James "Bart" McLeod (GPS and TLS Survey); and Steven Fernandez, MA, CCM (GIS and GPS Manager). Sarah Kruse, Ph.D. with the USF School of Geosciences, coordinated the geophysical survey efforts. Also helping with the geophysical survey were Abdallah Ammar, USF Geosciences Postdoctoral Fellow; Peter Karashay, USF Geosciences Graduate Student; Christine McNiff, Geosciences Graduate Student. Garrett Speed, Geosciences MA graduate student and AIST Research Assistant, participated in web design and other GIS and visualization applications. Joseph Evans, USF Anthropology graduate student contributed to field work. This project was funded by the National Park Service through the Cooperative Ecosystem Studies Units (CESU) Network.

We would also like to acknowledge the following assistance that enabled this project:

- Kings Mountain National Military Park, National Park Service: Chris Revels and Justin Skewes; and U.S. Army Signal Corps – Fort Gordon, Steven J. Rauch, Command Historian
- The City of Greenwood Fire Department: Welborn Adams, Mayor; Terry Strange, Chief; T.S. "Stewart" McDonald, Shift Commander; Brian Brown; Russell Cline; Al Tumblin and Tim Warren. This confined space rescue specialized team was extremely important and filled a critical role as part of this project, which could not have occurred (and would not have been nearly as much fun) without their dedication and expert knowledge and abilities. We are indebted to them for their tireless work during our field efforts to ensure that our team was kept safe.

- The South Carolina Educational Television Team, who worked side-by-side with us in the field and have continued to work with us in the presentation and dissemination of this project in an effort to promote education and heritage tourism benefits. Special thanks to SCETV's William Richardson-Producer/Director; Gary Stevens-Audio/Video Engineer; Arthur Joseph-Videographer; Xavier Blake-Videographer; Steve Yountz-Videographer; Gaines Halford-Videographer; Don Godish-Assistant Director Broadcast Content. All were an integral part of the project from its inception to completion.

PROJECT OVERVIEW

In this project, technologies that allow us to see, assess, interact with, and present spatial data were chosen in an effort to map and visually interpret and understand the Kosciuszko Mine and the Ninety Six National Historic Site environs (Figure 1), in ways never before possible. These mapping and geospatial tools allow a way to preserve our nation's heritage while also providing digital access to an area of the park that lies beneath the ground and is inaccessible- too dangerous to allow public entry and not viewable from above the ground surface. In a unique partnership between archeologists and researchers, work was performed that assists the park in the stabilization and long term preservation of the Kosciuszko mine, the only existing military tunnel during the American Revolution. The 125-foot tunnel is 2.5-5 feet in height and was dug in the subsurface soil by Patriot soldiers from American lines toward the British-held Star Fort during the course of the 1781 siege that is today commemorated at the park.

The University of South Florida's (USF), Alliance for Integrated Spatial Technologies (AIST), in collaboration with the National Park Service and the Southeast Archeological Center (SEAC), used 3D terrestrial laser scanning (TLS) and imaging along with geophysical remote sensing tools to provide accurate, precise and representative survey of the mine and environs that assists with conservation, management, and public interpretive development of this unique American Revolutionary period site features. 3D laser scanners in combination with global positioning systems (GPS) and other geospatial survey tools were used to create the most accurate model of the Star Fort and the tunnel beneath, creating a lasting digital record.

This cooperative project documented, provided baseline data, and produced 3D digital records of the critically threatened Kosciusko's Mine and other historic features at Ninety Six National Historic Site. Using three-dimensional terrestrial light detection and ranging (LiDAR) equipment, Ground Penetrating Radar (GPR) and gradiometer geophysical techniques, advanced high-resolution photographic techniques along with carrier-phase RTK and mapping-grade GPS, researchers captured and documented the contextual terrain and site details, including sections of the Kosciusko's tunnel (mine) and the above ground Star fortification area. Additionally, airborne LiDAR and high-resolution aerial imagery were used to examine the larger environment and this along with other data, assisted in documenting the present state of the site and has provided valuable larger scale terrain modeling, visualization and educational information. Public interpretive media have also been developed and can be used by the park and NPS for web site interpretation and visualization, enhancing, encouraging, and supplementing visitor experience. Additionally, the survey results and documentation of the project by South Carolina Educational Television (SCETV) extends the reach of the project to include multimedia presentation and incorporation of the efforts into additional learning and educational outreach materials.

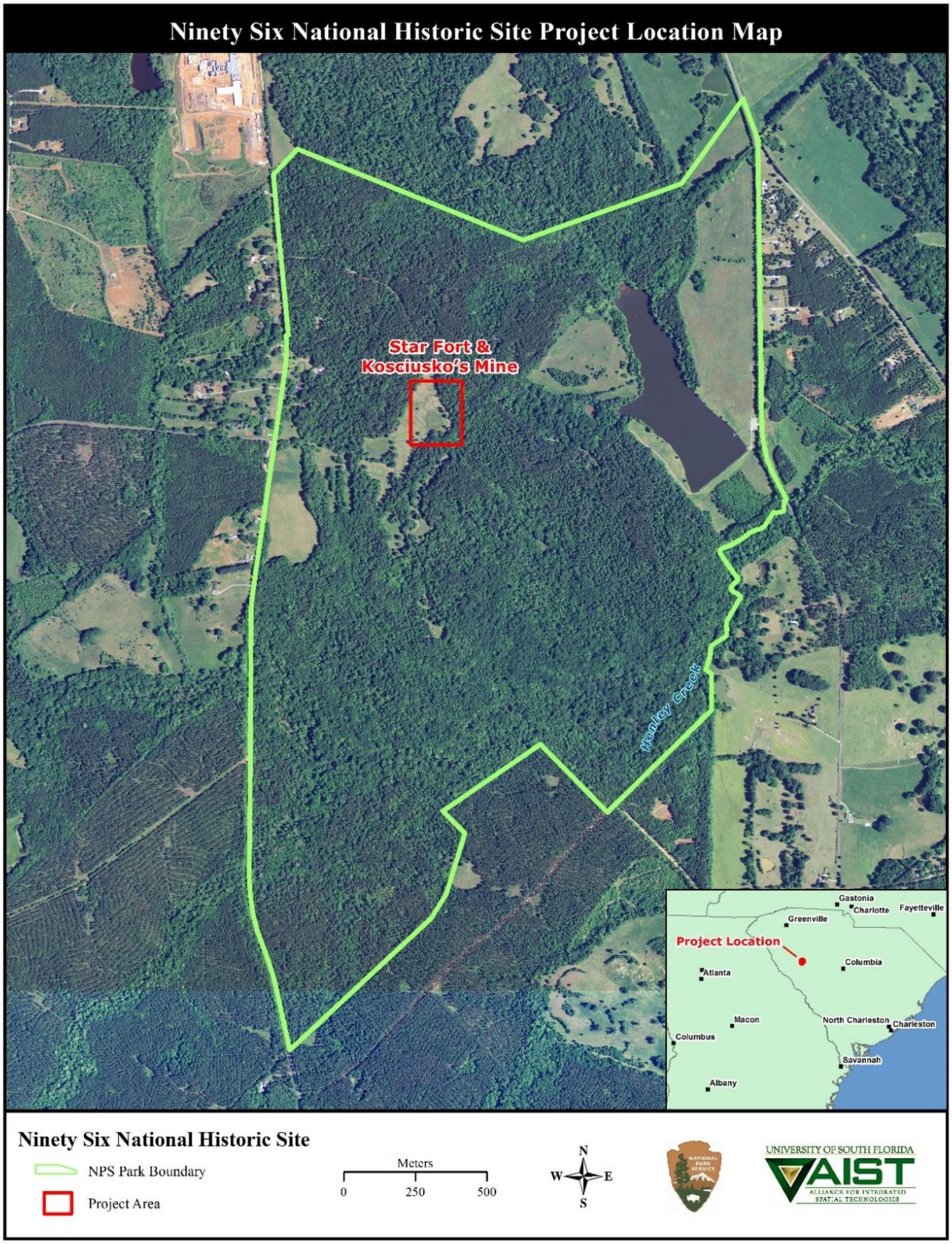

Figure 1. Project area showing the NISI Star Fort and primary area (red) of various survey methods for the Kosciusko's mine and environs documentation.

The tunnel areas were last archaeologically surveyed and visited in 2004 (see Ek 2004), and were also documented using photography and hand-drawn measured mapping technologies in 2001, and were reported on in 2002 (Sturdevant 2002). The tunnel area has been previously recorded with photographs, measurements, and descriptions in the David Ek (2004) report. The current project utilized less invasive and more accurate, precise, and representative means including remote sensing, geophysical (GPR and gradiometer surveys), and LiDAR (TLS and aerial), to completely map all opened and accessible areas of the mine and relational above surface features. These data are used to create not only virtual models of the site but for creating tangible exact models from applications such as 3D printing, that will allow for future research, education, preservation, and visitor engagement. Survey data collected were utilized in the creation of accurate spatial consideration and cartography of the site and to provide conditional assessment and an archival digital record of the site.

HISTORICAL BACKGROUND

“At the beginning of 1776, South Carolina was becoming one of the more openly militant of Great Britain’s colonies” (Greene 1979:76). The continuance of this militancy was demonstrated by the fact that during the American Revolutionary War, more battles- 200 of them - were fought in South Carolina than in any of the other 13 colonies. This frequency of conflict was perhaps a result of the broadly based loyalist desire within the colony to remain under British rule. A display of early belligerent actions were centered in the small, but prospering, remote colonial town of Ninety Six, in a region referred to as the upcountry or backcountry of western South Carolina.

According to Llewellyn Toulmin (2012), the first land battle of the Revolutionary War in South Carolina that pitted Americans against British rule occurred at the village of Ninety Six on November 19, 1775, when Major Andrew Williamson tried to recapture ammunition and gunpowder that had been taken by Loyalists. During the conflict, Patriot soldier James Birmingham was mortally wounded and became the first South Carolinian to lose his life in the war for independence. Over the next six years, ensuing encounters at Ninety Six would contribute to turning the war in favor of the Patriots (Greene 1979).

The origin of the town’s distinctive name remains in debate. A common explanation is that English traders believed the town was located ninety-six miles from the Cherokee village of Keowee, the principal settlement of the Cherokee "Lower Towns" (Malone 1956). Undermining this premise, however, is that in actuality the distance is only seventy-eight miles. Nonetheless, the colonial town was located at the intersection of several roads and trails that connected coastal and central South Carolina to the great Cherokee Nation to the west. Ninety Six was a commercial and transportation hub, and its control was considered logistically critical to the military, political, and economic power in the region. For this reason, the British strengthened

their military fortifications there in 1780, by building the Star Fort to defend the northern approach to the Loyalist town.

The Star Fort proved critical to the success of British defenses during a military encounter that was the longest siege of British emplacements by Patriot troops of the war. This military operation, which extended from May 22 through June 18, 1781, centered on the British defensive earthworks, known as the Star Fort or Redoubt, and the Kosciuszko Tunnel or Mine. Both are unique military constructions that still exist at Ninety Six National Historic Site. The Continental forces attempted to oust the British troops by initiating a siege of the fort. The Star Fort's defenses proved too strong to be overrun by customary 18th century siege tactics, however. A mine or tunnel was started that was to extend from the American lines to under the northern wall of the Star Fort. When completed, the end of the subterranean passageway would be packed with gunpowder, and its detonation was intended to blow a hole in the fort's defensive wall allowing the Patriots to mount a direct attack into the fort's interior (National Park Service 2006). Unfortunately for the patriot troops, the approach of 3,000 British reinforcements ended the tunneling before it could be completed, and the siege was abandon soon after, on June 19, 1781.

There are numerous other historic features at Ninety Six that include eighteenth and nineteenth century roads and trails, campsites, towns, villages, fortifications, cemeteries, trading posts, and sites related to the French and Indian War. Old Ninety Six and the Star Fort were listed on the National Register of Historic Places on December 3, 1969, and officially designated a National Historic Landmark on February 17, 1974. On August 19, 1976, as part of the American Bicentennial, then President Gerald Ford signed into law the establishment of the Ninety Six National Historic Site. On December 28, 1976, the land that included "the primary historic sites and related natural features" was donated to the National Park Service (Rehm 1988:17), and official control over the site by the NPS was initiated in October 1977.

Many of the historic features, resources, and their remnants at the site are threatened by environmental and human activities. Foremost among these cultural assets is the Kosciuszko Mine, whose preservation, maintenance, and use as an educational medium is a major concern to the National Park Service. In 2009, a comprehensive assessment and report on the cultural landscape at NISI was prepared to address the tunnel and other management issues (see Wiss 2009). This report, along with more recent concerns of the park's administrators, led to the development of an interdisciplinary research and technology project specifically designed to address the long-term management of the stabilization, protection, and preservation of the Kosciuszko Mine.

THE STAR FORT

Construction of the earthen Star Fort, or Star Redoubt, began in December 1780, and was completed early in 1781 (South 1970). The fortification and defensive bastions, erected to protect and defend the northern approach to the loyalist village of Ninety Six (Greene 1979:102), were constructed by British soldiers and slaves from nearby plantations and farms under the direction of British Lt. Col. John Cruger. The eight point star design had been selected by British military engineer Lt. Henry Haldane because of its perceived advantages over the more traditional square-shaped fort design. The alternating wall directions took the best advantage of the topography and landscape and provided the best defense against cannon fire. One star point along the south side was left open to serve as an entryway from a communication trench that directly connected the fort to the nearby town (Figure 2).

Figure 2. NPS interpretative signage that illustrates the Star Fort design.

A negative aspect to the star design was that it was difficult to construct and could not hold as many troops as the square defensive arrangement. The defensive star-shape first appeared in Italy in the mid-15th century in response to the introduction of gunpowder and the newly developed siege cannons, and later the French further refined the design (Duffy 1979). The design minimized the exterior area exposed to direct cannon fire, and the earthen construction would

absorb and dissipate the impact of the cannon shot. Conversely, the star shape allowed the defenders to fire muskets and cannons outward, in all directions (Thompson 1987).

The walls of the fort at Ninety Six were originally raised to a height of 14 feet, and a ditch that was dug around the perimeter of the exterior wall further elevate the embankment. The ditch also as acted as a readily accessible borrow pit for the fort's earthen construction. Sand bags were placed on top of the wall adding another three feet to its elevation. A sixteen-foot high traverse, or elongated earthen mound, was erected in the interior of the fort during the siege. This feature ran perpendicular to the direction of the American troop attacks from the north, and was designed to provide additional protection of equipment and personnel from cannon and musket fire. A well for water supply was dug near the eastern interior perimeter, but according to South (1970), no water was ever reached. Although the Star Fort is mainly intact and retains most of its original form, it has suffered from erosion and exposure over the centuries.

HISTORY OF THE KOSCIUSZKO TUNNEL AND PREVIOUS MAPPING SURVEYS

In May, 1781, Maj. Gen. Nathanael Greene led 1,000 Continental Army troops and militia to Ninety Six. He found that the town was strongly fortified with stockades and a massive earthen star-shaped fort. His opponent was Colonel John Cruger, who had over 500 Loyalist troops (Americans loyal to the Crown) to hold Ninety Six. Greene's troops constructed a series of approaches and siege trenches, cannon emplacements, and installed a 30-foot tall log rifle tower that allowed them to fire down into the fort.

The construction of the siege network of parallels and approaches (Figure 3) was a slow process due to the hardness of the clayey soil, which was compared to "digging in soft stone" (Haiman 1972:112). On June 3, 1781, when the American troops had pushed their siege trenches to within 40 yards of the ditch in front of the Star Fort, the digging of the tunnel was initiated. When the siege ended and the digging of the tunnel was terminated, two centrally connected galleries, one estimated to be 102 feet and the other 81 feet in length, had been completed (Sturdevant 2002; Wiss 2009:117) (Figure 4). The tunnels remained open and basically untouched for more than 150 years following the troops' departure. In the 1920s, the entrance portion of the tunnel was stabilized with brick and mortar (Greene 1979:144), and in 1973, two areas of collapse were observable at the surface (Holschlag and Rodeffer 1976 :60).

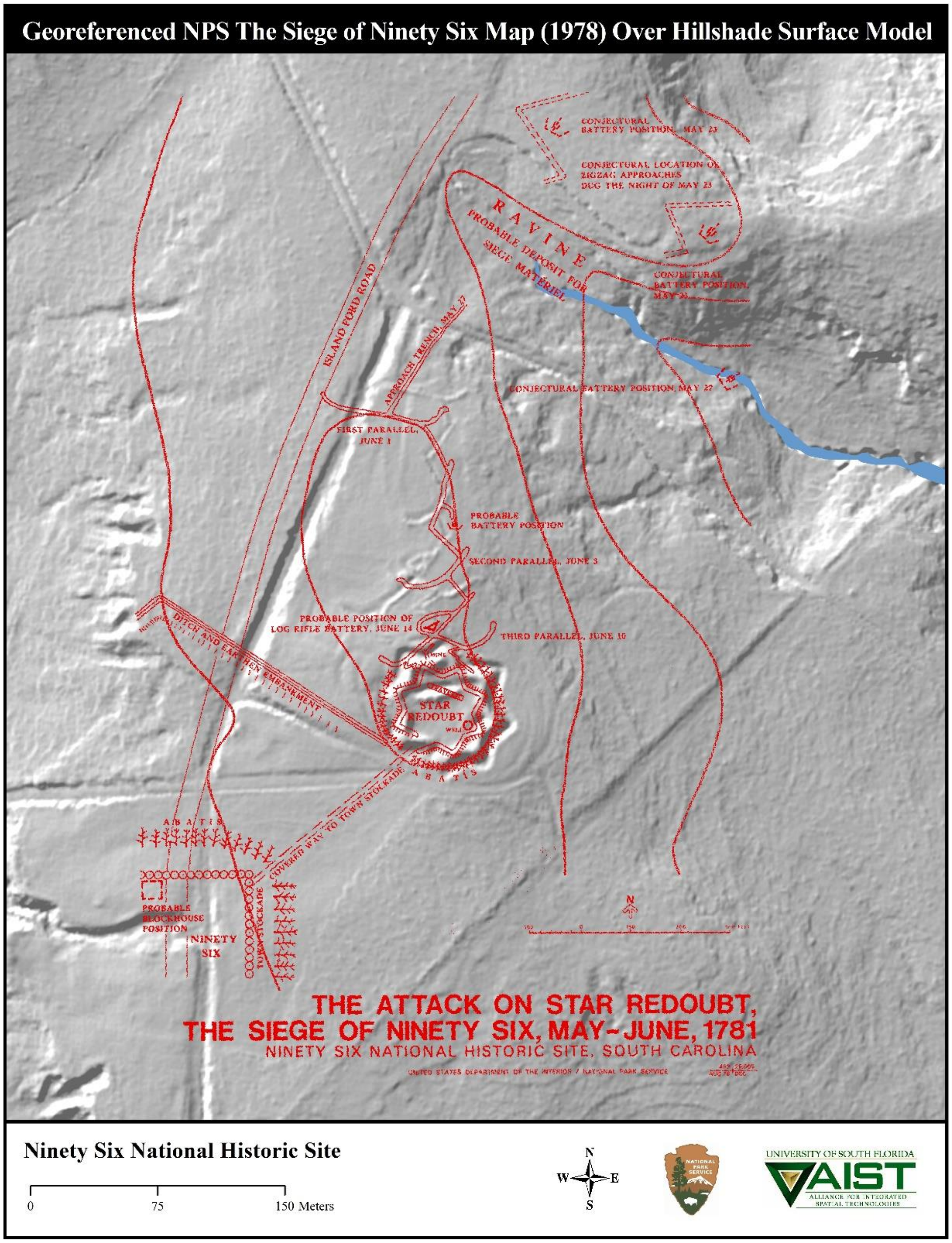

Figure 3. Georeferenced map from the NPS Historic Resource Study report (Green 1979:289), shown with aerial LiDAR data to depict overview of the Star Fort area and siege features. Noted errors are evident in the drawing when compared to the terrain elevation, especially in regards to position and orientation.

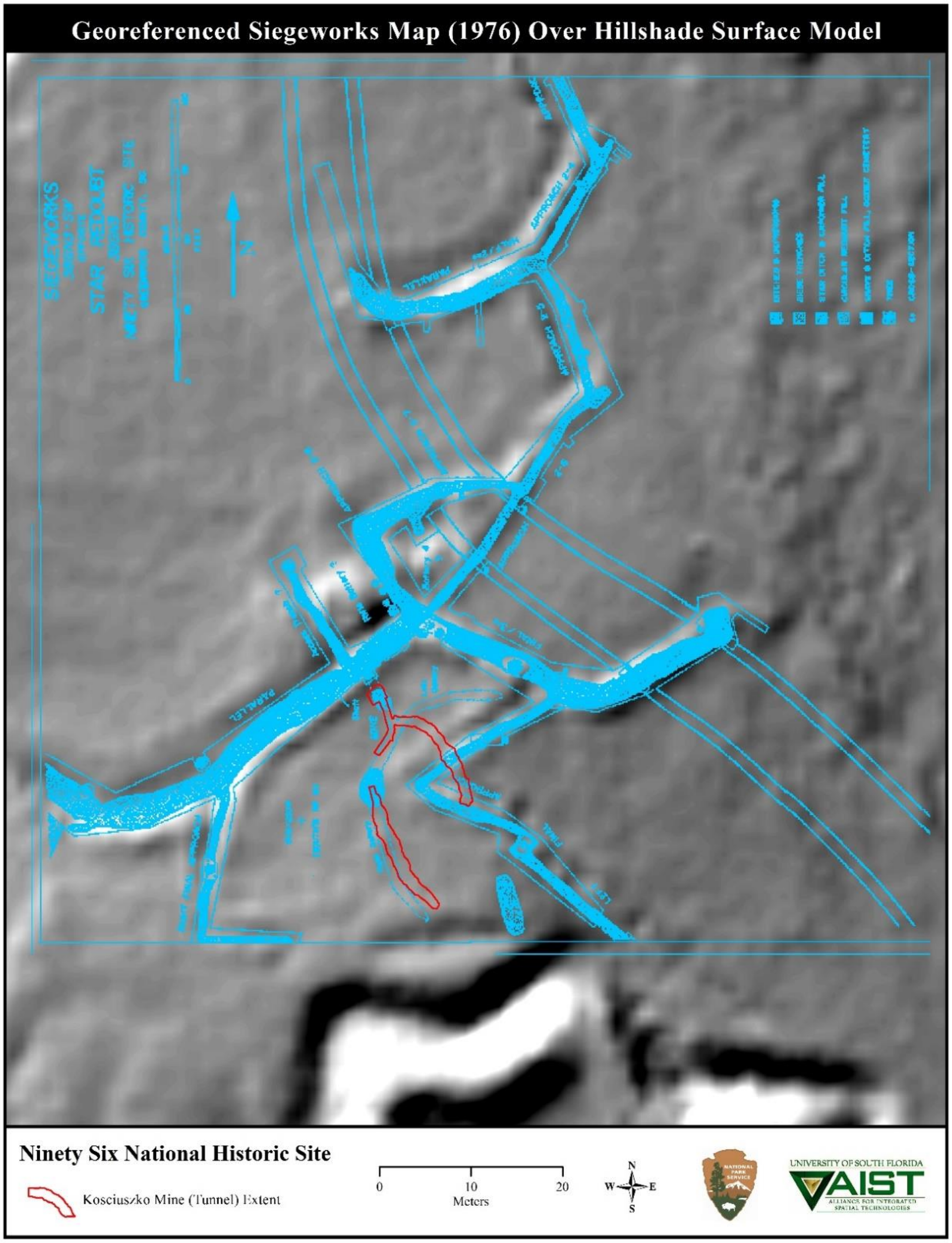

Figure 4. Georeferenced map from the Holschlag and Rodeffer SEAC report (1976:32), shown with aerial LiDAR data to depict siege works nearest the Star fortification. Note that the map is in error in regards to the newly recorded position of the mine location and extent (shown in red).

The earliest documented exploration of the tunnel appeared in the early 1800s when Robert Mills (1826:350) offered an early account of the mine.

> *"The shaft of the American mine (observes a gentleman who visited the works some years ago) was choked up. I had the clay dug away, and went down with lighted torches and my compass to trace its course. First it ran S. 20, E. eight yards, then divided, the right S. 45 W. and S. 30 E.; then S. 50 E.; in all thirty-four yards. This branch I traced above ground, and found that it just reached the ditch of the redoubt. The left hand branch ran S. 34, E. nineteen yards, in all twenty seven yards. I think it evident that the Americans worked without a compass in their mine…both mines were entire, retaining all the marks of the hoe, but for some distance near the redoubt they were half leg deep in water."*

Early maps showing the Star Fort and siegeworks vary in the depiction of the star shape from idealized to actual, and in the shape and position of the siegeworks and location and depiction of the mine. The Johnson (1822) map was created from memory some 40 years after the event (South 1970), and is largely inaccurate as to spatial location of the siegeworks and fort (also the fort is shown with a stylized number (21) of points. The mine area is shown as a "D" symbol and is inaccurately positioned when considered with known spatial locations (Figures 5 and 6). The Avery map from 1909 is first to show the mine from a stylized "D" shaped symbol to a location symbol with an "X" through it (Figure 7). The location given for the mine in relation to both the siege works and the fort are still not accurately portrayed.

William Edwards (1961) from the University of South Carolina worked in the areas of the Star Redoubt, the Village and at the offensive siegeworks area. His maps of excavations, including eight trenches in the Star Redoubt area, are shown in the South (1971) report. Stanley South (1970:18-20) conducted a cursory survey of the mine in 1970, and states that an estimate of 125 feet of open tunnel remained and an additional 35 feet has collapsed. South utilizes maps created by others such as Edward (1961), but also publishes a map of his exploratory excavations, which show the mine and the fort locations in relation to one another (South 1970), although scale and positional details are not accurate (Figure 8). South called for the accurate mapping and depiction of the site, stating that "Hopefully, the series of maps now being drawn from archeological evidence will lay a new foundation of understanding of the site of Ninety Six for the use of future historians, whom it is hoped, will no longer be forced to copy, and add to, the 1822 map of Johnson for their illustration of the site on which such significant historic events took place" (South 1971:63).

From 1973 to 1975, archaeological investigations by Holschlag and Rodeffer (1976 :60-65) provide more information about the tunnel, and produced a map of the underground elements in relation to the fort and earth works (Figure 9). Their primary focus was on locating the tunnel

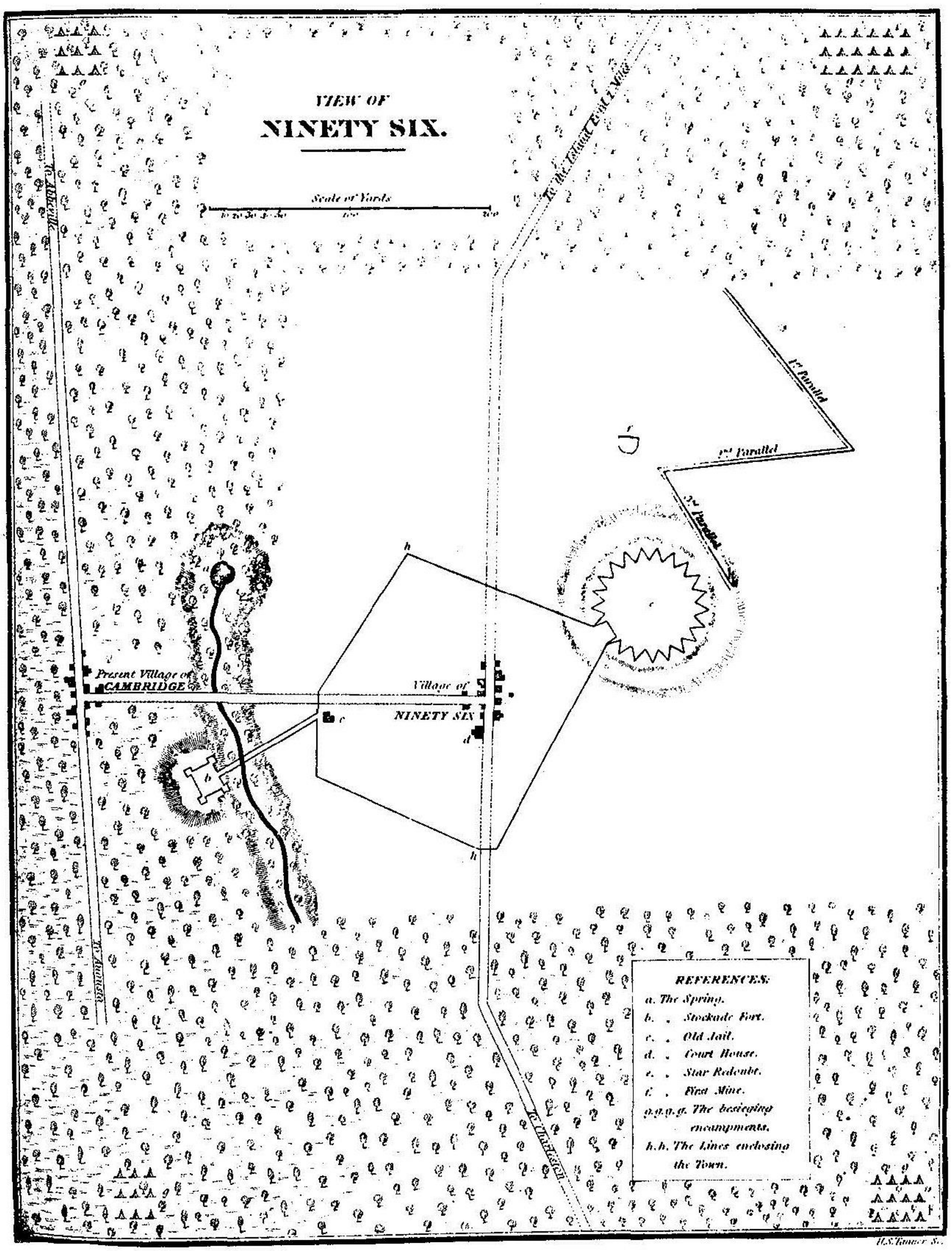

Figure 5. The Johnson (1822) map showing the stylized star fortification, siegeworks locales, mine feature, and camps.

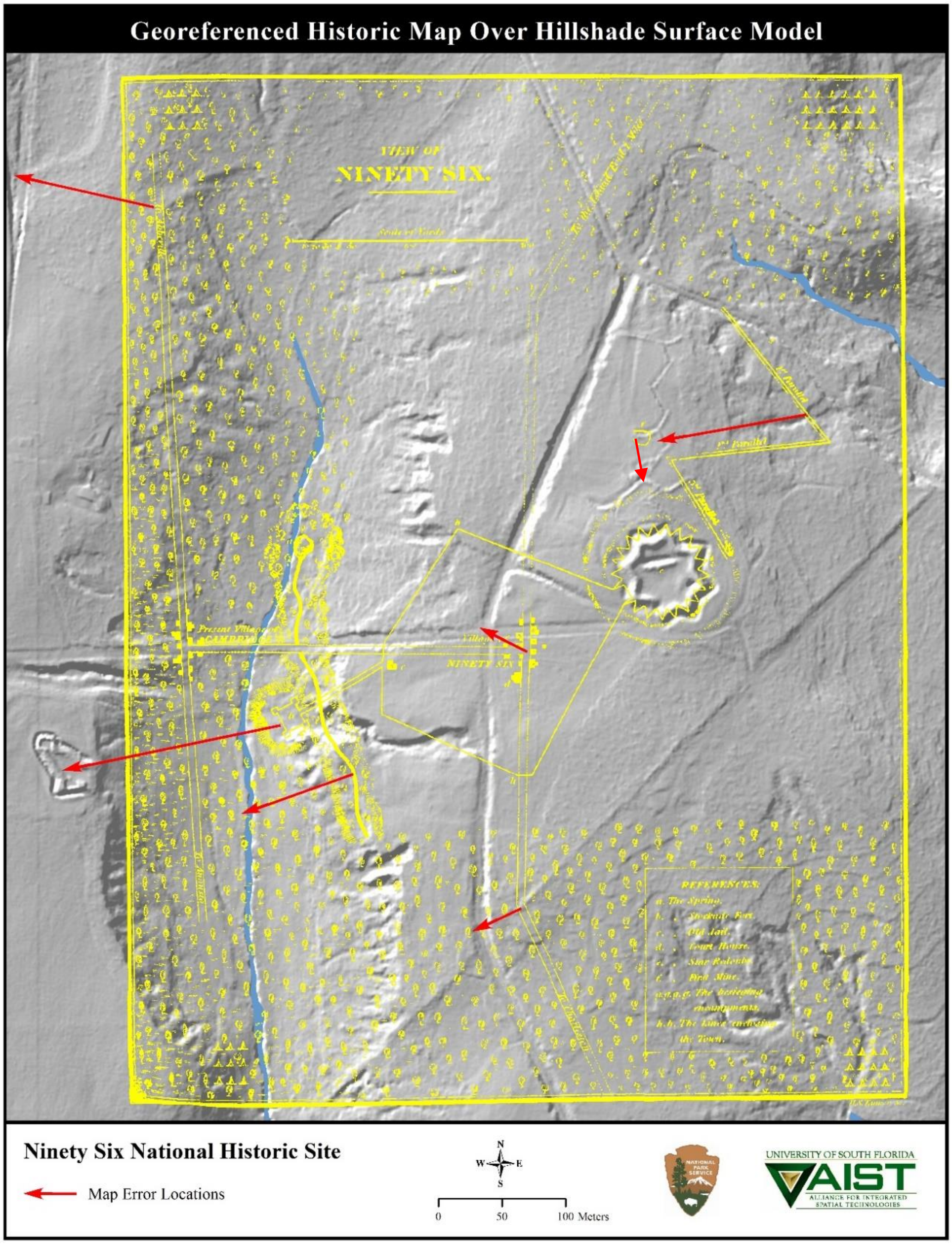

Figure 6. The Johnson (1822) map georeferenced to hillshade aerial LiDAR data for the site area. Red arrows indicate feature shift locations required to make the map accurate in its spatial depictions.

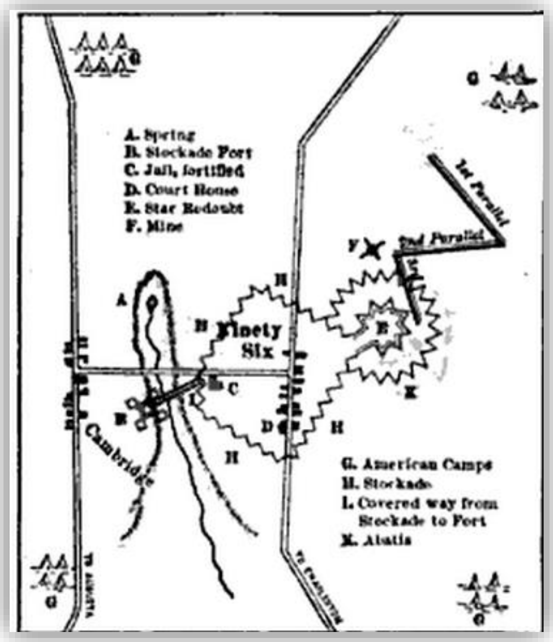

Figure 7. The Avery (1909) map, depicting the mine location in relation to siegeworks and star fortification.

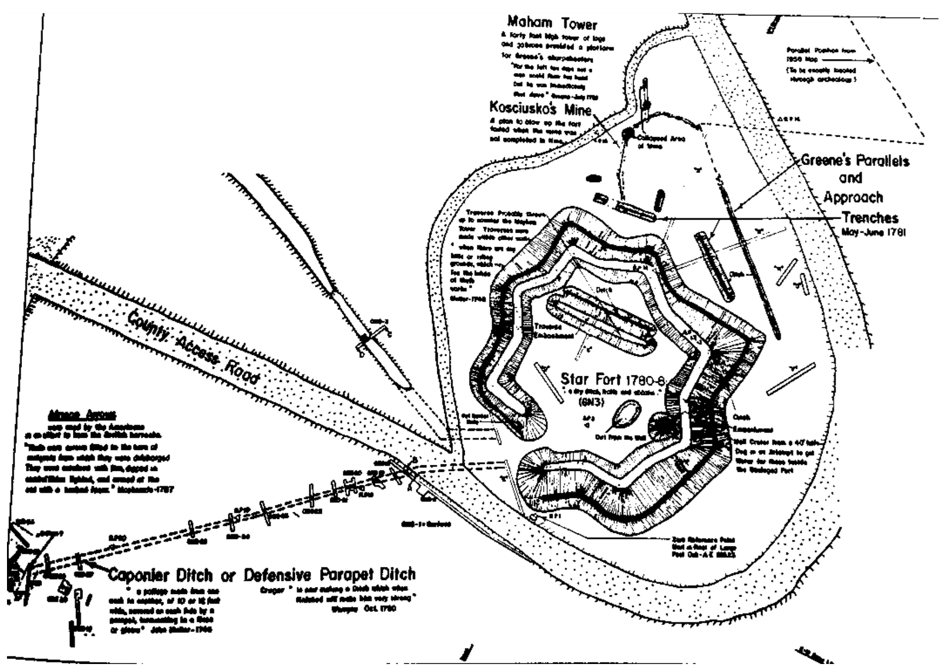

Figure 8. Map showing exploratory trenches from archeological excavations in relation to the Star Fortification and siege works, including the mine location (South 1970), shown in Prentice and Nettles (2003:67).

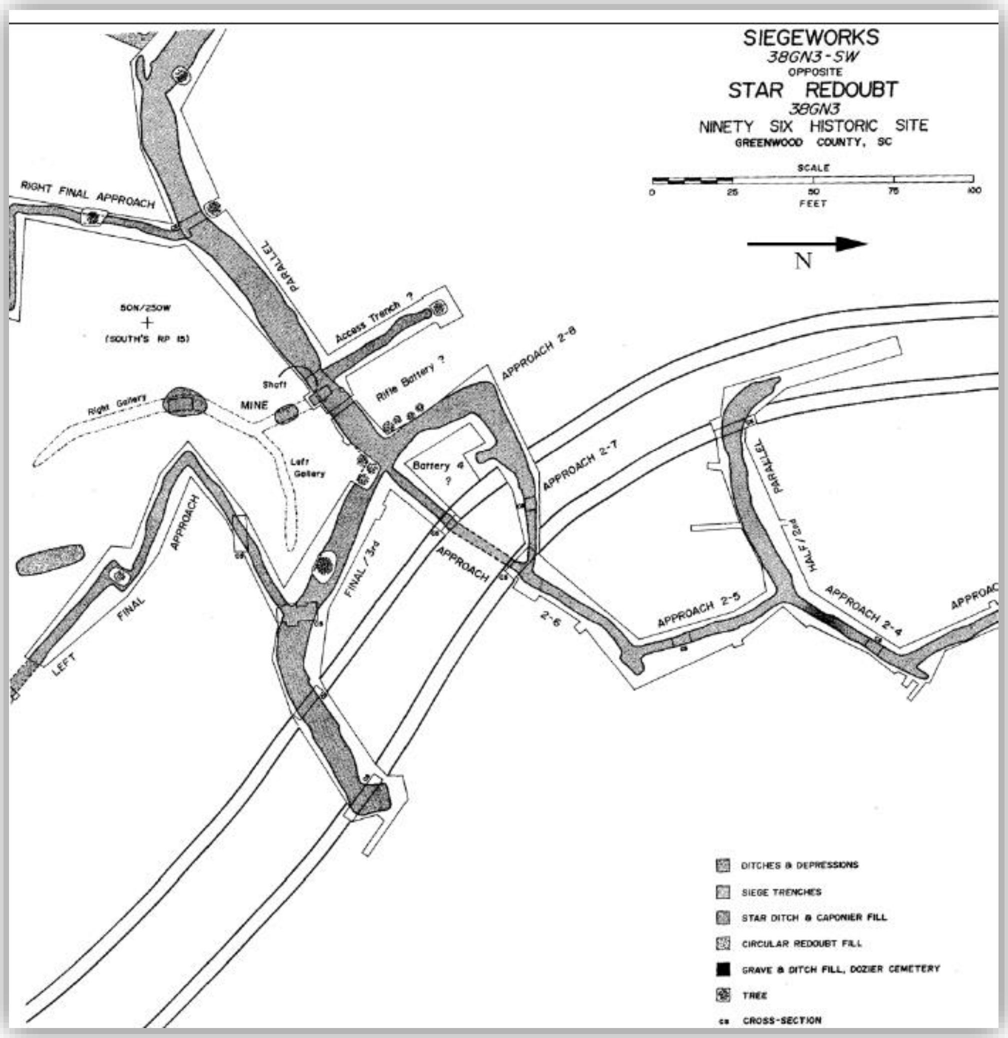

Figure 9. The Holschlag and Rodeffer SEAC report (1976:32), map zoomed-in view, showing the mine area. The map indicates the collapsed areas encountered, however the left gallery is incorrectly oriented.

entrance and exploring "two sections of the mine [that] were visible in collapsed sections." They confirmed that the entrance had been reinforced by brickwork installed in the 1920s, and other than the two collapse areas, the tunnel was said to be clear. When their exploration at the entrance and collapsed areas of the tunnel were completed, they backfilled the openings with a coarse sand, which could be readily differentiated from the original clay soil matrix, and the tunnel was covered and sealed. Their map of the siegework excavations also shows locations for the Circular Redoubt and the Dozier Cemetery locations adjacent to the Star Fort, and the series of offensive approaches and parallels in proximity to the mine location, including a narrow trench parallel and facing the Star Fort that sits just in front of the mine (Figure 10).

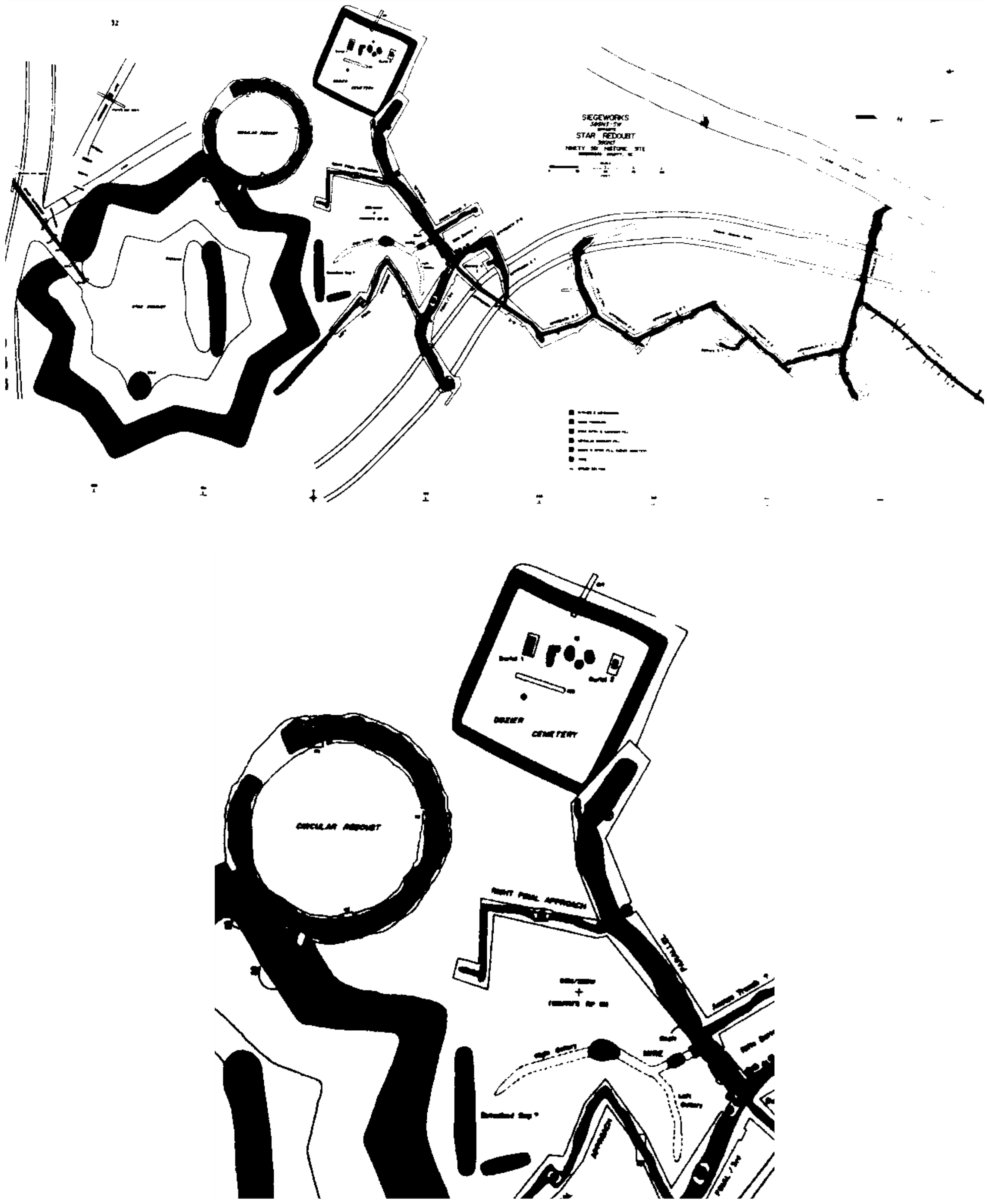

Figure 10. Above is the map of siegeworks and excavations at the Star Fort (Hilschlag and Rodeffer 1976:32-33). Below shows the layout of the Circular Redoubt and the Dozier Cemetery as well as parallels and approaches and the narrow trench fronting the Star Fort.

Jay Sturdevant (2002) was next to investigate and provide spatial details relating to the mine. His archeological monitoring of a stabilization effort of the Kosciuszko's tunnel occurred between October 22 and November 1, 2001. Sturdevant re-utilizes the Holschlag and Rodeffer maps in his report. In this effort, the backfilled sand was removed from the entrance, to assess areas of previous collapse (Figure 11). The brickwork at the entrance was found to be intact except for a 1.5 m wide x 2 meter long portion located approximately 10 to 15 feet from the entrance. Identified as Collapse Area 2, this location is where "the roof and supporting brickwork had collapsed" (Sturdevant 2002:11). Figure 12 shows the brickwork entrance to the tunnel and Collapse Area 2, after they had been cleared.

At Collapse Area 1, described as a 10 to 12 foot long section in the right (or west) gallery, a vertical entry shaft was placed at the southern terminus of the collapse to allow access to the remainder of the right galley. Sturdevant explains, "A remote control vehicle with a real time video camera mounted on the front was then used to explore the tunnel and check for any additional unstable or collapsed areas…" (Sturdevant 2002:11). The left gallery was thought to be clear and estimated to be about half the length of the right gallery, although it was not photographed or fully explored by the remote vehicle. Collapse Area 1 was stabilized with wood and plywood, and the entire tunnel resealed and covered (Wiss 2009:170) (Figure 13).

Guy Prentice and Wendy M. Nettles (2003) completed a detailed archeological overview and assessment of Ninety Six National Historic Site. Their work provided specifics on the content, condition, and research potential of resources known at the site, and provides information for guiding future archeological activities and work. Several maps such as those from South's work in the 1970s and earlier historical maps such as the Johnson 1822 map are re-presented in their report, as well as a thorough coverage of archeological activities, including results from geophysical as well as excavation surveys. The report also overviews the archives and collections maintained by the NPS, and provides site descriptions for all the area loci.

In 2004, the tunnel was again reopened for a stabilization plan reconnaissance and a mapping project (Ek 2004). The mapping of the tunnel included the use of a 110 foot fiberglass measuring tape and a tripod mounted Suunto brand compass and clinometer. The "surface mapping was conducted using the same equipment, however additional loop closures were conducted to ensure accuracy. In addition, elevation data was also collected using a tripod-mounted engineering level (Figure 14).

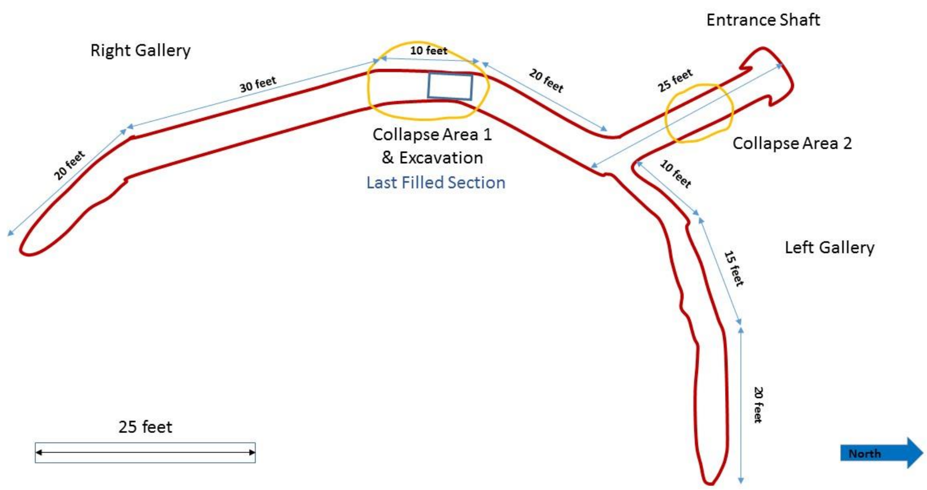

Figure 11. Sketch map after Holschlag and Rodeffer (1976), showing what they considered to be the configuration of the mine, along with measurements generated from their scale, and areas of known collapse. This map proved accurate in terms of collapse areas marked, but inaccurate in terms of spatial configuration, proportions, and layout.

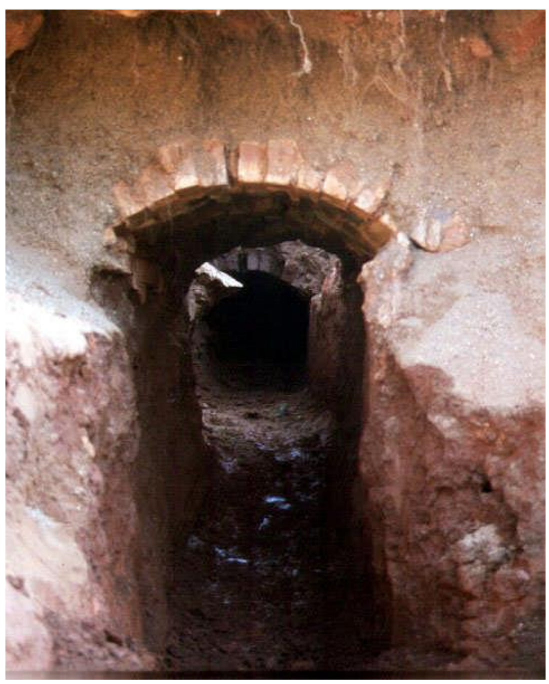

Figure 12. Photograph showing the brickwork arched entrance to the tunnel and Collapse Area 2 after clearing (Sturdevant 2002: 12).

Figure 13. Photographs showing the stabilizing framework constructed for tunnel access near Collapse Area 2 (Sturdevant 2002: 18). The cribbing remains in place today and was re-examined during the current survey.

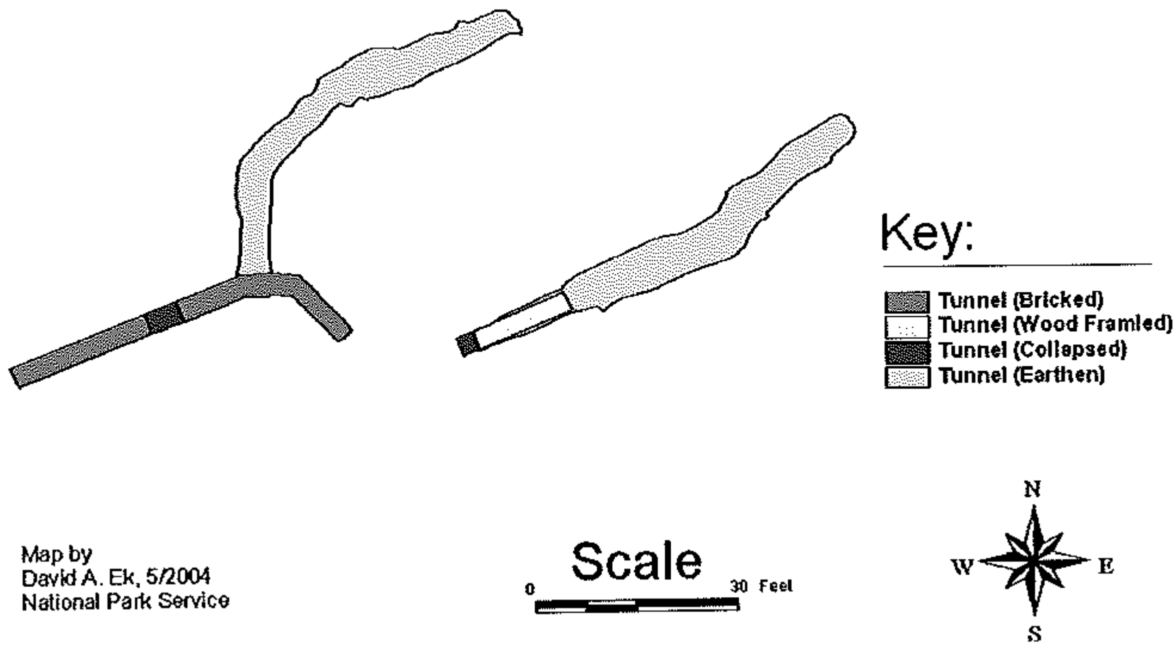

Figure 14. The Ek (2004:3) map of the Kosciuszko Mine is largely improved over previous maps in terms of shape and configuration, however scale and the directional aspects (north is 90 degrees in error on his maps) are not shown correctly.

Several surface features were also mapped using a Trimble Geoexplorer II global position system (GPS)" (Ek 2004:2). Ek divided the tunnel into six sections, and provided the length, width, height measurements of each. He also supplied volume measurements that he calculated for each section. The map is very useful for demonstrating areas of collapse and construction methods (earthen and bricked areas). Ek also took extensive images in his survey which serve as useful comparison for conditional aspects. From his data, he produced plan view, elevation, and cross-section drawings of the tunnel (Figure 15). His noting of details and features and photographs within the tunnel proved to be of great assistance in the planning of the current project. Following the mapping and reconnaissance in 2004, the tunnel was backfilled, resealed, and re-covered. Today, no part of the tunnel is visible from the ground surface (Wiss 2009:117). A small, unobtrusive circular patch of earth was retained by the park staff to identify the location of the opening to collapse area 1 (Gray Wood 2013, personal communication).

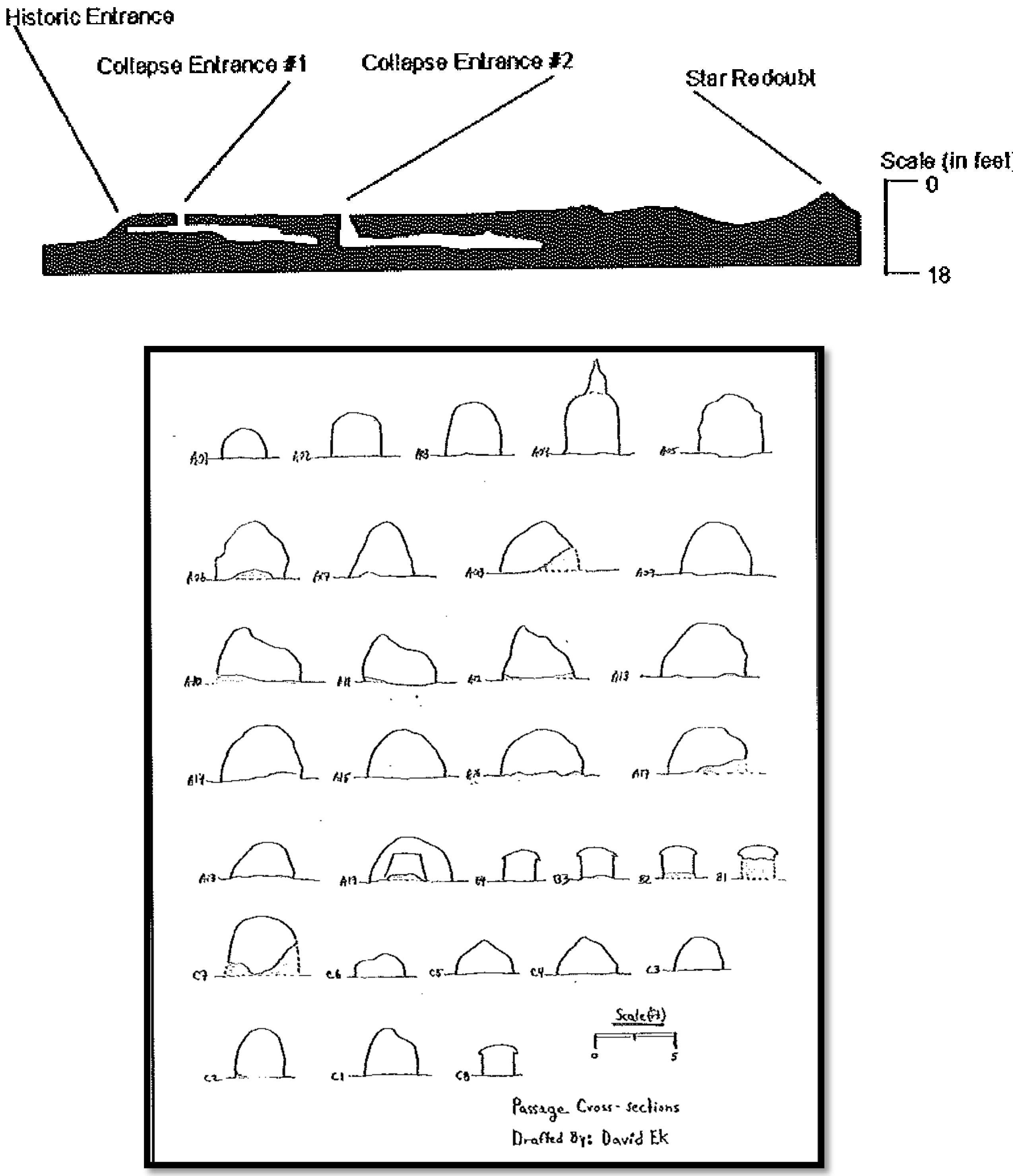

Figure 15. The Ek (2004:4-5) sketches of the Kosciuszko Mine, showing profiles and sectional details.

METHODS

After reviewing the archival material and previous mapping and investigations of the Star Fort and Kosciuszko Mine, it was determined that a multicomponent spatial and geophysical approach would be undertaken to accurately record and visualize the historic features and terrain. Three-dimensional laser scanning and high-resolution imagery would capture and document the subterranean tunnel; and aerial imagery and LiDAR, subsurface remote sensing, and terrestrial laser scanning of the surface would provide significant new data about these features and accurately map their spatial relationships. Importantly, these methods would allow the surface and subsurface datasets to be tied to together to improve analysis and visual interpretation, and assist with management and conditional assessment and planning.

The laser scanning and imagery of the interior of the tunnel presented a physical and technological challenge. The size of the tunnel, its restricted entry points, and safety requirements were critical factors of consideration. The scanner chosen for this project needed to be small enough and portable enough, yet allow for high precision and accuracy and be able to also acquire color data for contextualization. Additionally, remote capabilities (ability to start and stop the scanner without being in the scan) was important under certain situations, as was the ability to register the acquired data using limited targeting for reference. The scanner chosen (FARO Focus3D) was a phase shift type scanner, with integrated camera and battery, providing a smaller configuration than other instruments such as Time of Flight instruments. The scanner measures of 9.5 × 8 × 4 inches and weighs 11 lbs., dimensions that would allow it to operate in a confined space that ranged from approximately 2.5 to 5 feet in height and 3 to 4.5 feet in width. The scanner captures data accurate to within +/-2 mm (0.07873992 inches) within a minimum distance of 23.6 inches.

Major environmental factors of consideration included: the confined space, dirt and dust problems, lighting, moisture, safety concerns for operators, and leveling of the instrument and set up time required. The scanner utilized has a dual axis compensator that allows accurate leveling on the tunnel floor, a critical factor when registering and processing multiple scans. It also has an integrated color camera that produces 70 megapixels parallax-free color overlays, and its onboard power battery and SD card for data management eliminated the need for data transfer and power cables being run through hundreds of feet of tunnel. AIST staff designed a scanner mount and transport vehicle, along with registration targets to be used in the small, confined space. A system of LED lighting was also developed that proved ideal for improvement of lighting for the scanner’s onboard camera as well as the videos taken with the helmet-mounted digital (Go-Pro) video camera.

Kosciuszko Tunnel conditions and tunnel size were replicated for the testing of the equipment and accessories, with trials conducted in the AIST labs (Figure 16). AIST staff became familiar with

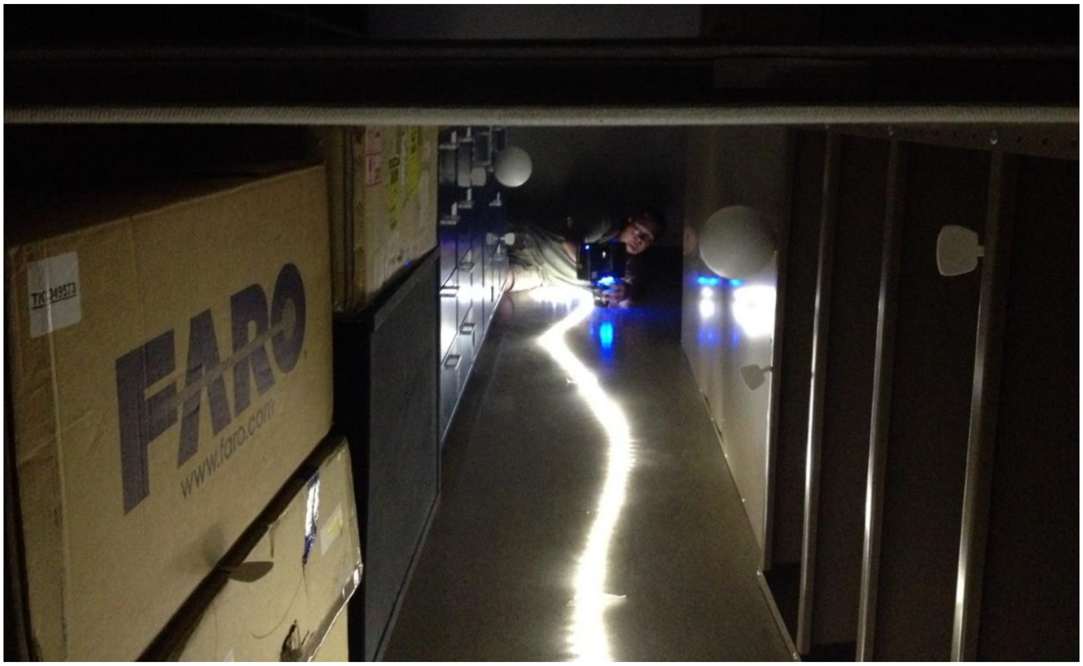

Figure 16. The AIST 3D scanning crew practiced conditions in a mock tunnel environment, approximating lighting and confined space parameters and testing equipment prior to field data collection.

working in this confined space, and various adjustments and alternative solutions were devised to address any negative conditions inside the tunnel. Additional condition-related issues included the necessity for safety gear which can be bulky and cumbersome, including harnesses, helmets, monitors and other safety equipment that were needed for entry and performance within the tunnel. Confined Space OSHA permits and training were required for all personnel who were to enter the tunnels, and an elaborate safety plan and procedure were collaboratively developed to ensure safety and adequate planning procedures were met.

The Occupational Safety and Health Administration (OSHA) permit required that confined spaces regulations (OSHA 1910.146) had to be met prior to entry into the tunnel by any AIST or affiliate personnel. Staff members received OSHA approved confined space training and certification prior to the project, and a safety plan was approved and implemented as part of the effort. The NPS acquired the necessary OSHA permits, and the project was exceptionally fortunate and grateful to have had the services of the Greenwood Fire and Rescue Confined Space Specialty Team, who made themselves available throughout the tunnel portion of the project. Their expertise and professionalism facilitated all aspects of the subsurface portion of the project and ensured that all safety measures were met or exceeded (Figure 17).

Figure 17. The Greenwood Fire and Rescue Confined Space Specialty Team set up and assessed the conditions for mine entry, participated in all levels of safety planning and response, and monitored all access to the mines during the project. Air quality monitors, helmets, and harnessed safety lines were mandatory kit for those entering the mines, and underground time and other parameters were monitored throughout the effort.

THE 3D TERRESTRIAL LASER SCANNING SURVEY OF THE MINES

The mapping of the Kosciuszko Mine at NISI was known to be a dangerous and challenging proposal, with unknown present conditions, previous collapsed areas and underground confined space requirements and issues. These elements of safety concern were also coupled with the fact that we needed not only accurate and precise topographical understanding, but the data needed to be representative – clearly depicting and conveying the condition and structure of these tunnels in a way that would be useful for their management and also for their interpretation. Although previously mapped utilizing best available techniques of the times, these representations lacked a connection with the above ground location, were suspected to be inaccurate, and did not provide much in the way of useable products for management or interpretive value. Three-dimensional laser scanning technologies proved to be the best possible solution to this archaeological project documenting a Revolutionary War Era tunnel system.

This current mapping of the mine utilized a combination of documentation strategies, including videography and digital imaging, 3D terrestrial laser scanning (TLS) survey, aerial LiDAR digital elevation modeling, combined with remote sensing (GPR and gradiometer) and RTK-GPS survey. The below surface features were documented in their entirety to an accuracy of +/- 2mm, and were tied to the above surface terrain through the TLS, geophysical, and GPS surveys. From these combined surveys, our researchers documented, prepared conditional analysis, and developed public interpretation methods that extend management, preservation, and interpretation potentials that yield insight into important historical events in our Nation's history.

This project featured a unique partnership between the University of South Florida, the National Park Service, and Public Broadcasting Service (PBS) affiliate, South Carolina Educational Television, who recorded the project as part of a television documentary. This project provides baseline data and produces 3D digital details of the critically threatened Kosciusko's Mine and other historic features at Ninety Six National Historic Site. These data provide valuable larger scale terrain modeling, visualization and information and Ninety Six National Historic Site. Public interpretive media were also developed from these data, showing how these technologies can be used to enhance and improve the visitor experience.

At NISI, the mapping of the Kosciuszko tunnel was performed to more fully understand the site and features for management, research, and conditional stabilization purposes; for education and interpretation factors; and for heritage preservation and archival documentation. After more than 230 years, the Star Fort and the unfinished tunnel remain major features at NISI, and both are endangered by natural and anthropogenic threats. This project was designed as an assessment of the actual conditions of these cultural resources that would assist in “preserving

the earthworks and rehabilitating the surrounding landscape to more accurately convey historic conditions" (Wiss 2009:1). The resulting virtual modeling of the tunnel system and above ground features met all of the survey needs and extended an opportunity to visit the site through virtual presentation (online and through augmented and onsite presentation). Broader distribution of the project and resultant models is being made through public television (SCETV) and documentary production, as well as online applications that are utilized for curricular and virtual presentation for wider dissemination.

Three dimensional laser scanning surveys can offer a method of rapidly and accurately producing highly representative and precise 3D details of complex terrains and structures. Industrial applications for 3D surveys often include uses in mines and underground structures, including the 3D scanning of caves. Geoscience and geo-archaeology applications and cave exploration using these technologies are on the increase (Lerma et al. 2010; Puchol et al. 2013; and Rüther et al. 2009). Archaeological applications in very narrow and confined cave and tunnel spaces are more rarely encountered, but published reports and articles have included detailed discussion of successes and difficulties encountered in somewhat similar environments (Tyree et al. 2014). Visualization potentials for public interpretation of underground heritage have been more widely explored, especially in cases of European heritage, with results showing the great promise for these new techniques for digital archiving, research, and interpretive engagement (Marsico et al. 2015).

In the case of the Kosciuszko Mine at NISI, not only were conditions unfavorable for documentation due to space and confinement issues, but researchers faced the threat of collapse and air quality worries, and had to contend with environmental aspects such as lighting, as well as the debris and surroundings of dirt, dust and wet clay/mud concerns that were all factors of survey planning and consideration in methods and approach. Prior surveys provided researchers with fairly reliable details concerning space and confinement and conditional issues. Previous collapsed areas were stabilized in 2004. With a reviewed and permitted collaborative safety plan in place, 3D and digital documentation of the mine was undertaken in conjunction with safety gear, stabilizing equipment, and oversight and onsite monitoring from the Greenwood Fire and Rescue Confined Space Specialty Team.

During initial project scoping and planning meetings with involved partners, it was decided that to more fully understand the purpose, construction, and historical relationships of the mine, it should be placed in context with the Star Fort. Thus, both features were considered in the project's scope of data capture. The tunnel presented the greatest challenge for recordation. A series of collapses were evident in the early 1970s (Holschlag 1976:70; South 1970). At the

completion of a monitoring project of the tunnel in 2001 (Sturdevant 2002), and again following the Ek (2004) survey, the collapse areas and openings to the tunnel were closed and sealed. The tunnel could not be opened for our survey's preliminary reconnaissance of its current conditions due to safety regulations and costs. Therefore, a variety of potential options and contingency plans for documentation were prepared in order to overcome any potentially adverse conditions that might exist in the tunnel (e.g., flooding, collapse, or contamination). A related factor was that the stability of the tunnel was unknown, and the space within the tunnel, based on previous investigations, was exceedingly confined and restricted (Figure 18). These conditions would significantly limit the types of measurement and documentation methods that could be utilized in the survey.

Our TLS survey utilized a phase-based FARO Focus 3D laser scanner that was chosen for reasons of portability and size as well as robustness and accuracy in spatial metrology and representative documentation needs for the project. The on-board imaging capabilities of this instrument as well as the virtualization workflow with post-processed data were also important factors of instrument choice. Software registration utilizes targeting schema in laser scanning surveys, and options for limited visibility of targets and geometric positioning and distribution of targets were planned out ahead of the survey. For example, targeting for scan point cloud registration can prove difficult in straight line confined and largely symmetric locations, which are challenging for constrained matching and registration of point clouds and surfaces in the post-processing of data (Bellekens et al. 2014). These challenges were all part of the pre-planning and workflow procedure development for the project, and involved not only choice of equipment, but modifications and adaptions for these conditions.

Modifications made to the scanner included the mounting of the scan head on a portable fixed cupped shaped platform, due to the fact that it was not possible to use a tripod. We re-engineered a pan that allowed us to affix the scanner and provided a stable platform (Figure 19). Additional needs included the utilization of target tags for image matching in the software. Non-standard smaller targets that could be pushed into the cave's clay surface were used (Figure 20). In this manner, we had redundant target options that allowed for registration in the event that the more linear placement of spherical targets did not work in the post-processing of data. These

Figure 18. Confined spacing within the tunnel was a challenge for survey mobility as well as for scanner set up and targeting.

Figure 19. The TLS survey instrument was affixed to a re-engineered pan surface to allow for stable scanning from the tunnel floor and to keep the scanner free of debris from mud conditions.

Figure 20. Tags that could be pushed into the surface of the tunnel were used as a remedy to any issues that might arise from the nearly linear geometric placement of spherical targets for point cloud registration. Also shown in this image is the strip lighting that was utilized in the survey as an improvising method for evenly lighting the tunnel for imaging needs.

targets were tested in the lab prior to field application. Need for even and consistent lighting in the confined space was required not only for safety but for purposes of photographic imaging results. Previous cave surveyors have often reported less than optimal results for any photographic documentation and it has been a noted complaint with laser scanning surveys in cave and tunnel settings. We opted to utilize readily available cord lighting in plastic tubing, which we tested first in the lab and successfully utilized in the field (Figure 21).

Figure 21. Example of lighting strip used in the survey. Ropes seen in photo are measured safety lines that are hooked to harnesses on scan crew members, so that rescuers above can locate and know where they are within the tunnel. Note that wooden stabilization cribbing that was previously erected (Ek 2004), is actually not supporting anything. Loose clay is from the shaft that was dug down into the tunnel for the 2004 entry.

Laser scanning fieldwork took place during the week of April 13 through April 20, 2014, with TLS survey performed on the 4/14 through 4/18. The first portion of the mine to be documented was the tunnel segment 6 area, with work conducted on 4/14 and 4/15 (Figures 22-24). The above ground terrain area coming out of segment 6 was linked to the registered below surface data on 4/16. Fieldwork continued below surface on 4/17, with scanning of the eastern section, capturing segments 2, 3 and 4 including all of the brick tunnel portion (Figures 25 and 26). These scans were tied together with above surface terrain, and the entire Star Fort earth works were scanned on 4/18 to conclude the TLS survey portion of the project (Figure 27). Concurrent to the scanning, other survey documentation was ongoing, including geophysical survey with GPR and gradiometer, RTK GPS and mapping grade GPS surveys, GPS photographs, and videography and standard imaging across the site.

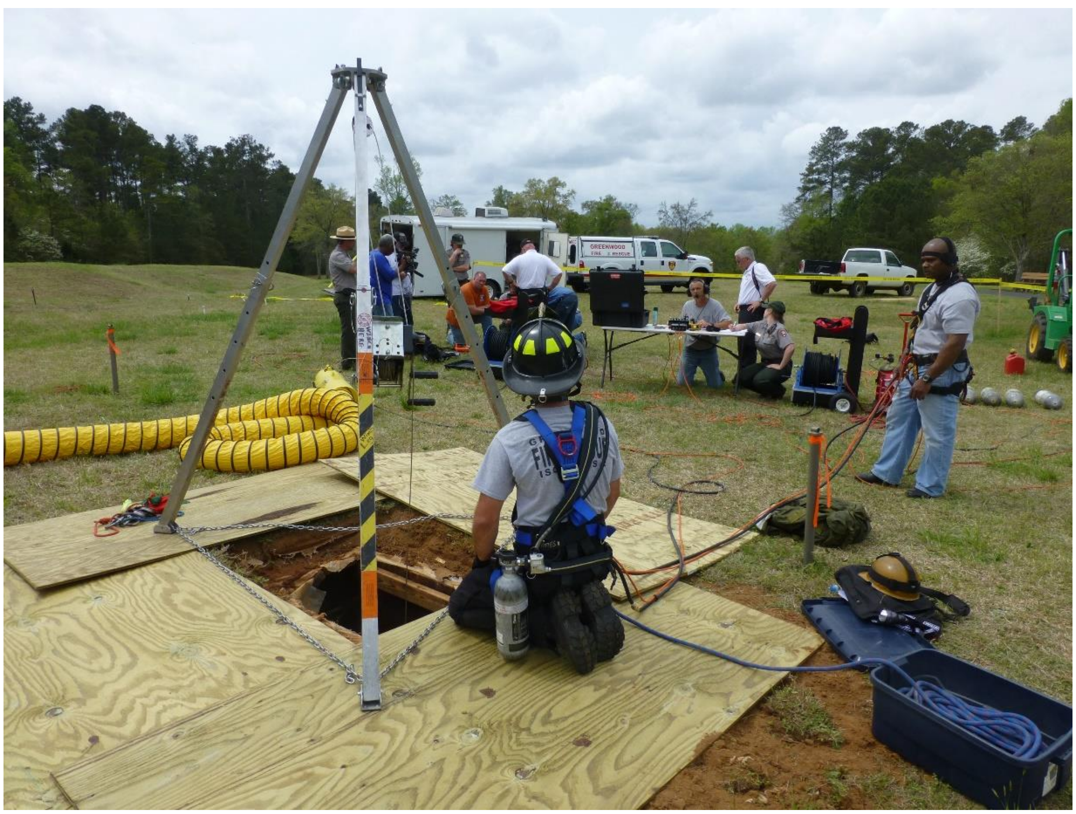

Figure 22. Photo showing the above surface monitoring and staging area at the segment 6 portion of the mine.

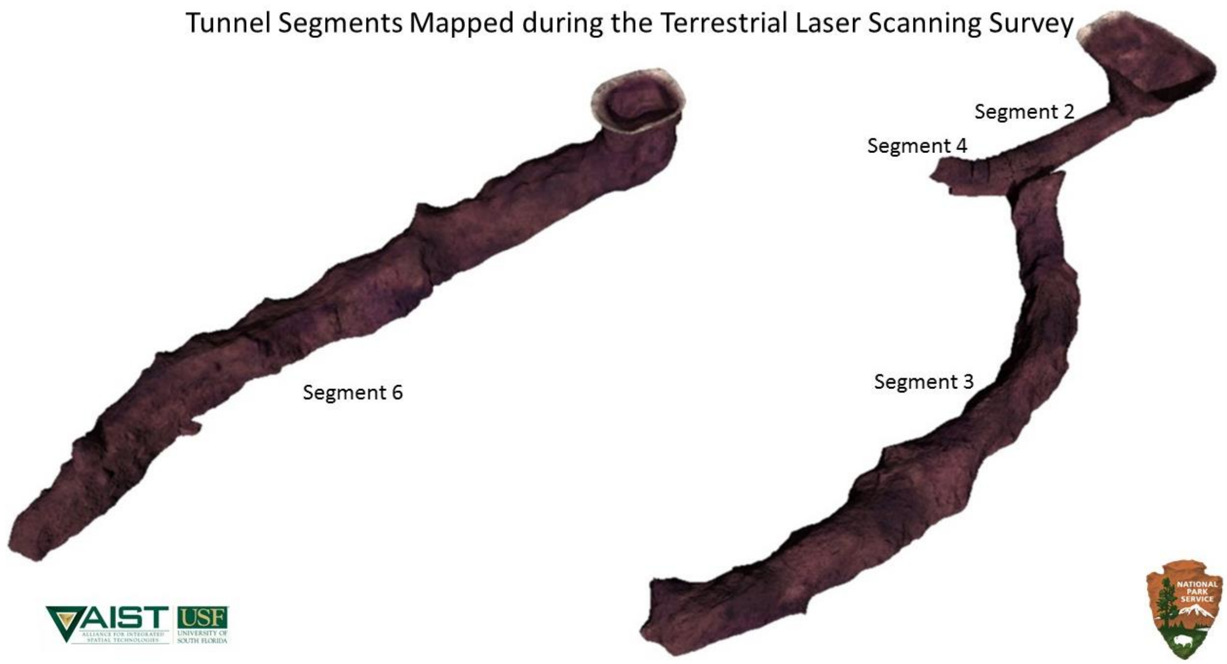

Figure 23. Depiction of the TLS segments of the tunnel that were mapped in the current survey.

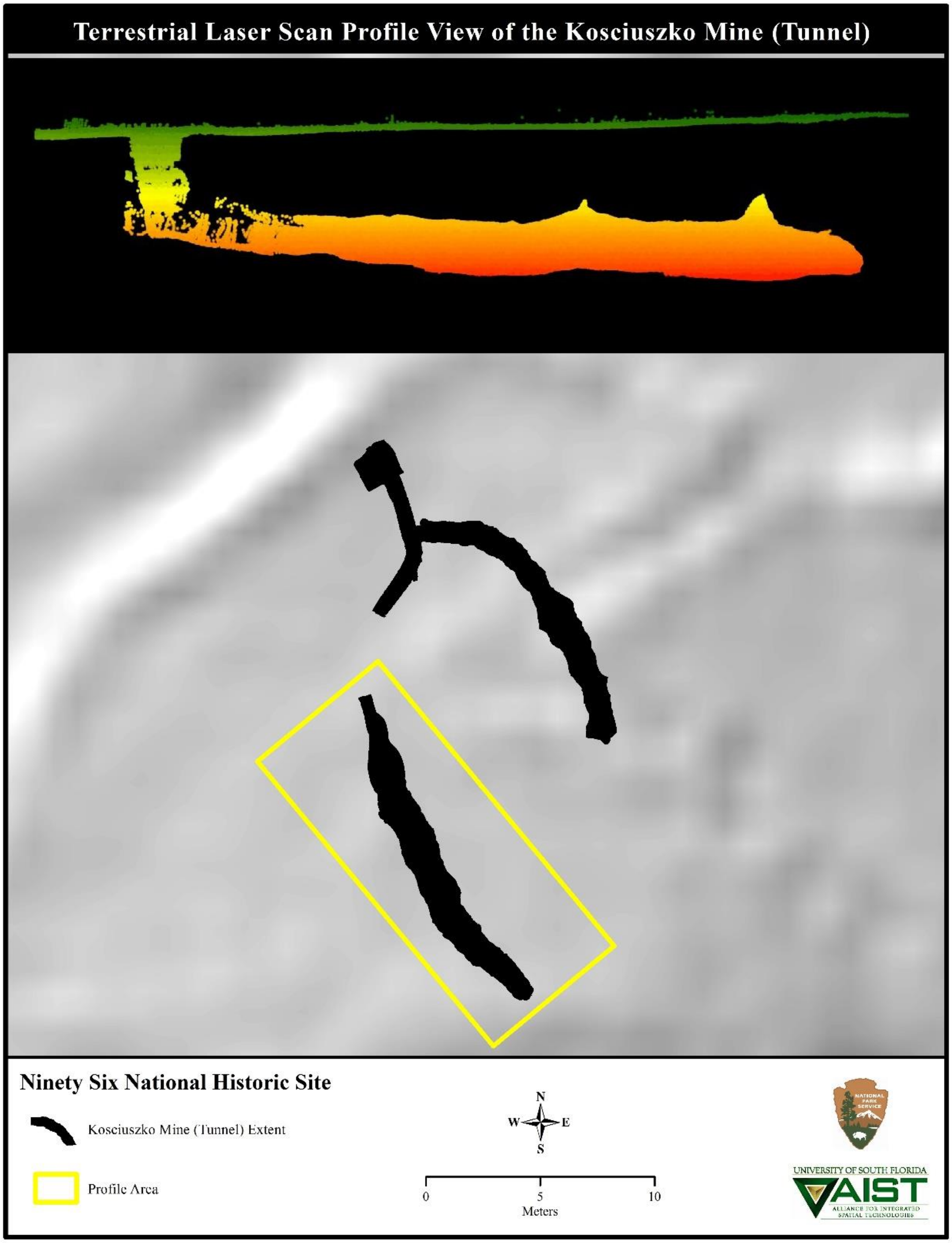

Figure 24. Segment 6 of the western portion of the mine was the first portion of the tunnel to be surveyed with TLS.

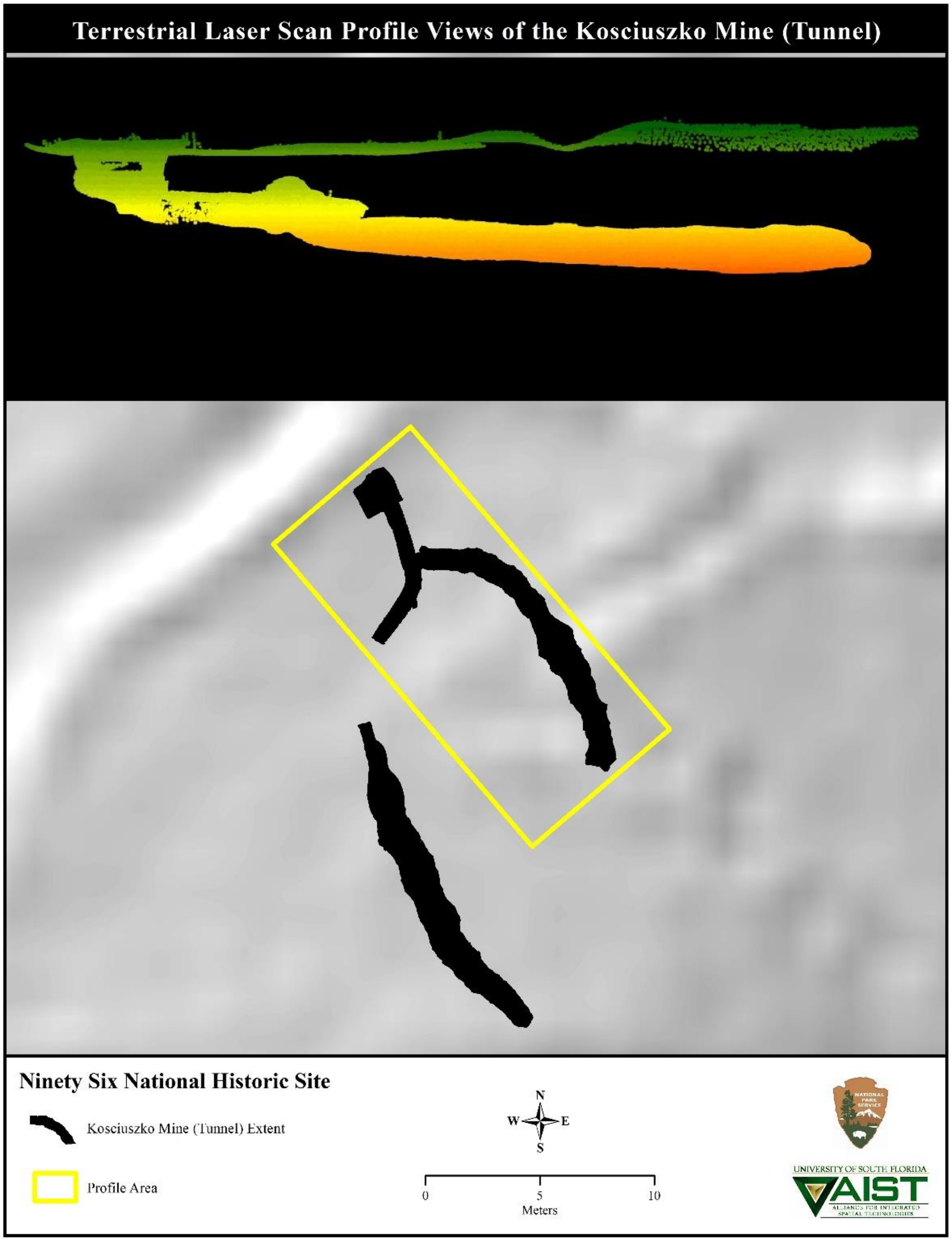

Figure 25. Segments 2, 3 and 4 on the western portion of the mine were surveyed with TLS after surface scanning of the terrain above and emerging from segment 6 was performed.

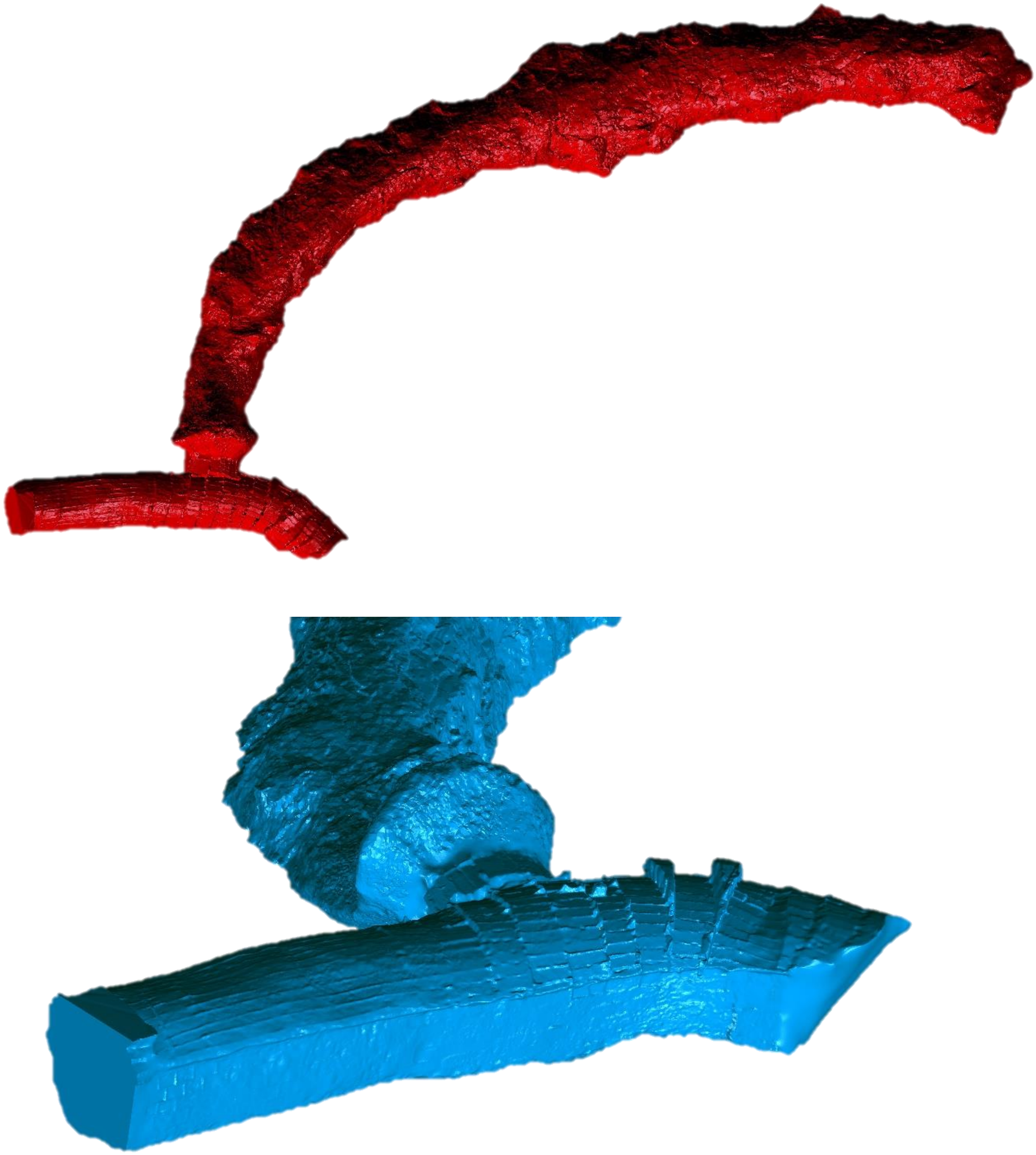

Figure 26. TLS data visualization showing the bricked portion of the tunnel connecting to the earthen segment3 (eastern gallery).

Figure 27. TLS survey data showing above ground terrain in profile (above) and underground mine configuration aspects mapped in relation to terrain.

Post-processing of the laser scanning data involved registration of the point cloud data captured in the two galleries of the mine, adding spatial control and tying in to the above surface point cloud data to provide above and below surface TLS perspectives together (see Figure 27 above). These data were also brought into modeling software to create solid surface mesh polygonal models from the point cloud data. Solid meshed models are useful for visualization and creating virtual models, as well as having potential for 3D printing and rapid prototyping applications (Figure 28). The TLS data were also exported for use in GIS applications. The GIS exports entailed bringing the TLS data together with aerial LiDAR to provide a more comprehensive overview of the site inclusive of the Star Fort and siegeworks (Figure 29). LiDAR for the entire landscape has been further rendered into a useable digital elevation model (DEM) for the site, and this layer has proven useful for applications with field verification of features and for conditional and site management applications (Figure 30).

Sectional analysis and research into the stability and conditional aspects of the mine are also possible with a high degree of accuracy and representativeness using the TLS data. Sections were taken from similar locales to that of the Ek (2004) survey in order to assess any variation either due to differences in survey methodologies or due to instabilities or changes in the mine (Figures 31 and 32). The TLS data also enabled accurate calculation of volumetric details of the tunnel, with findings important from a structural assessment perspective as well as from an interpretive perspective in regards to the construction methods and historical engineering. Findings from these analyses and visualizations are shown and discussed in greater detail in the Appendix A and B portions of the report, which provides a complete overview of the visualized mine sections using TLS data and provides a conditional analysis and structural engineering assessment of the mine.

Use of TLS data of the above ground terrain for subsidence monitoring below surface has proven beneficial in the mining industry sectors (Gu and Xie 2013). Utilizing the current survey as baseline data could allow for future monitoring of tunnel/mine subsidence at NISI, repeating above surface terrain laser scanning across the site. This would offer the NPS a cost effective means of comparison and method of monitoring and analyzing below surface movement and change. Additionally, repeat analysis of terrain using the TLS data and the aerial LiDAR can offer a method of monitoring changes to the site terrain caused by maintenance (mowing, equipment, vehicular traffic) at the site.

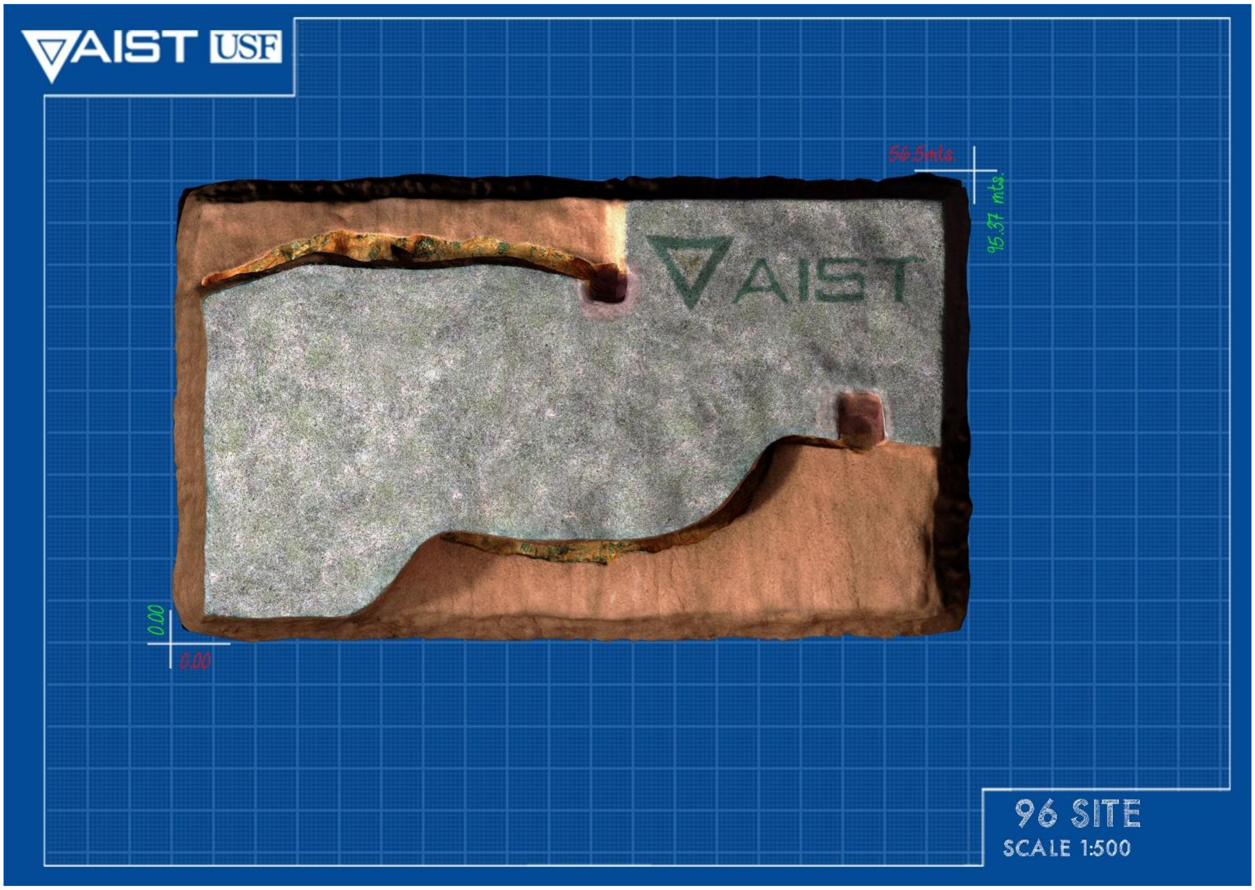

Figure 28. Polygonal mesh model showing a plan view orthographic projection of a three-dimensional cross section of the mine.

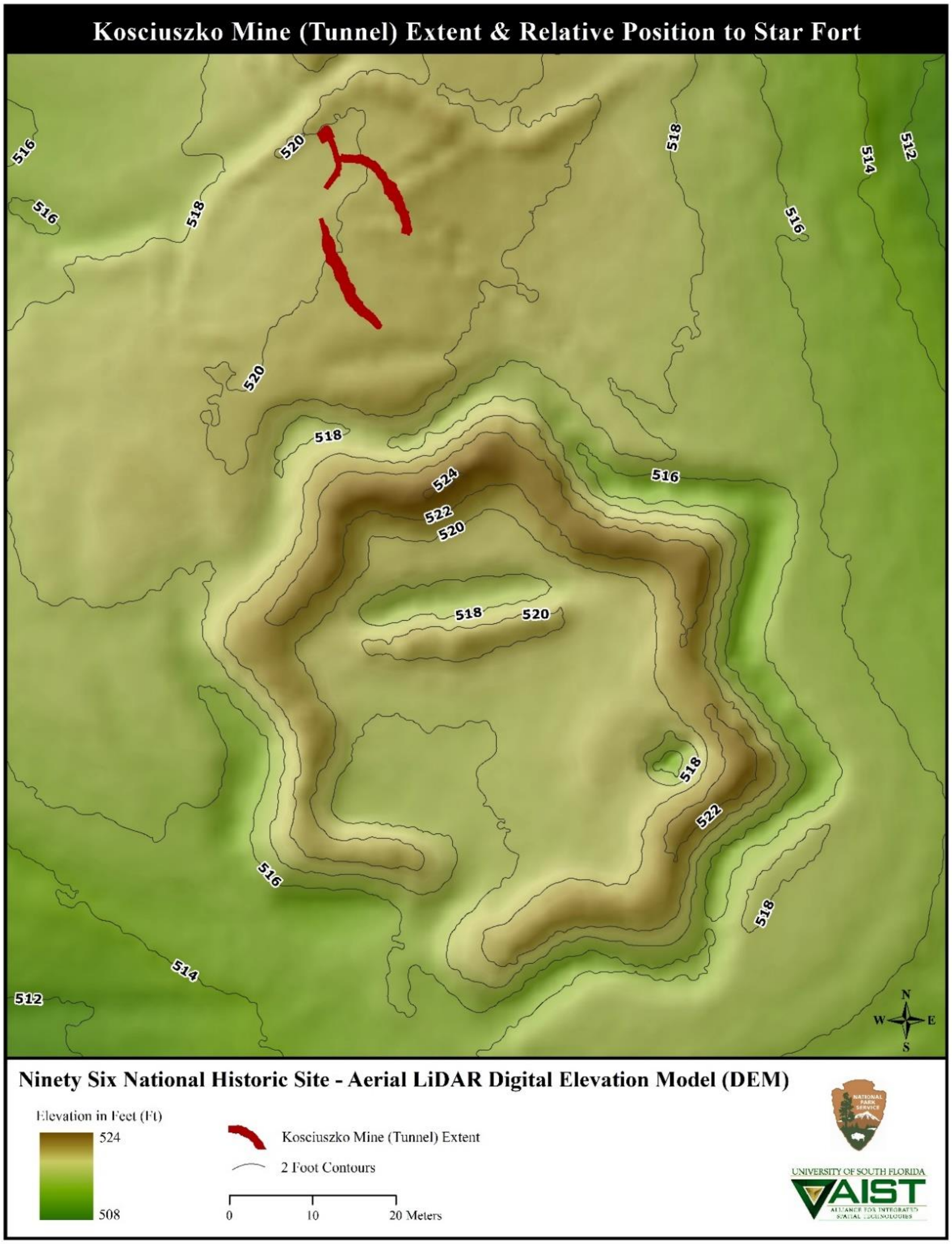

Figure 29. The position of the mine in relation to the broader landscape can be shown by bringing TLS data together with aerial LiDAR in a GIS.

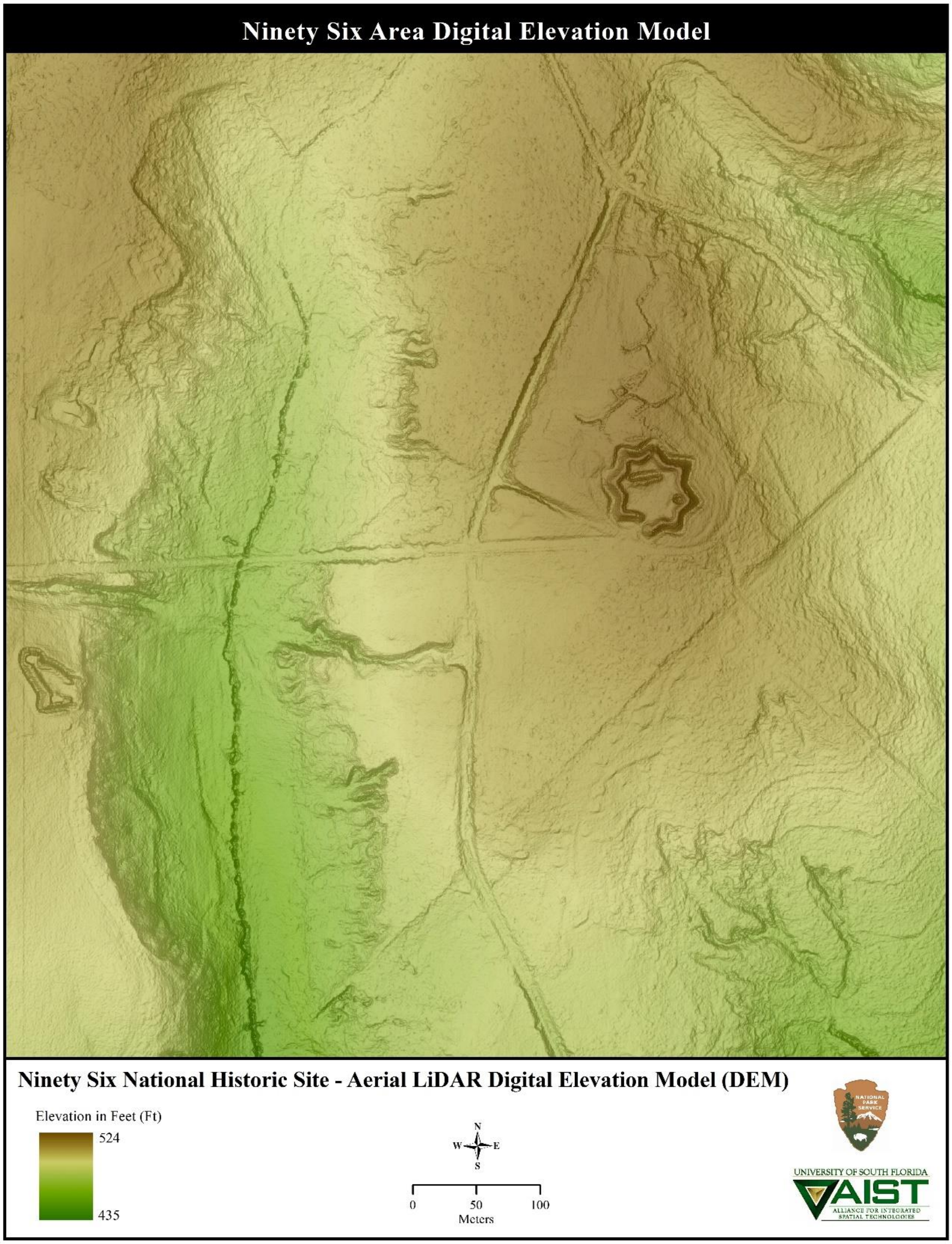

Figure 30. Digital Elevation Model produced from airborne and terrestrial LiDAR data.

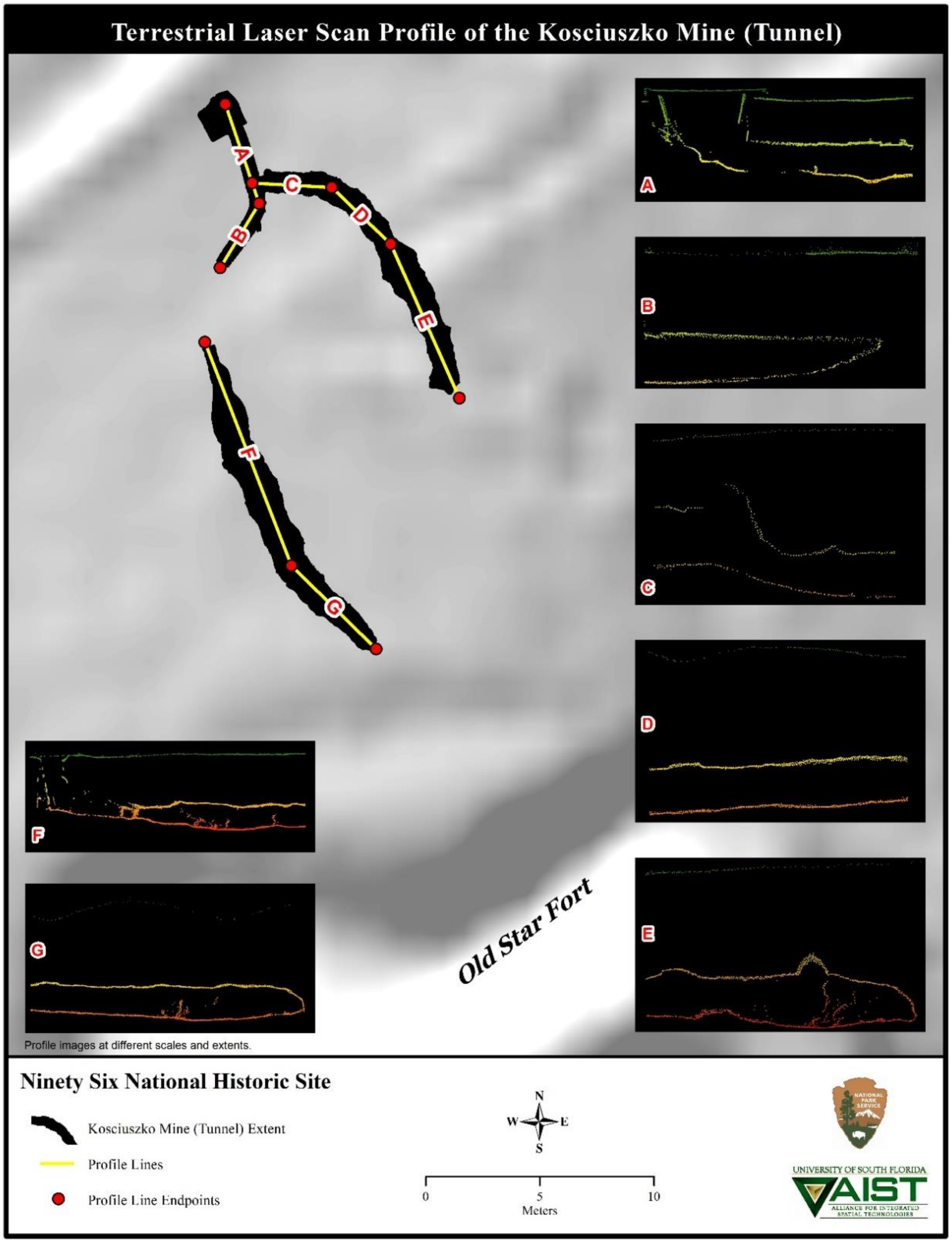

Figure 31. Sectional analysis using the TLS survey data is possible from any portion of the scanned area, and can include consideration of above surface terrain.

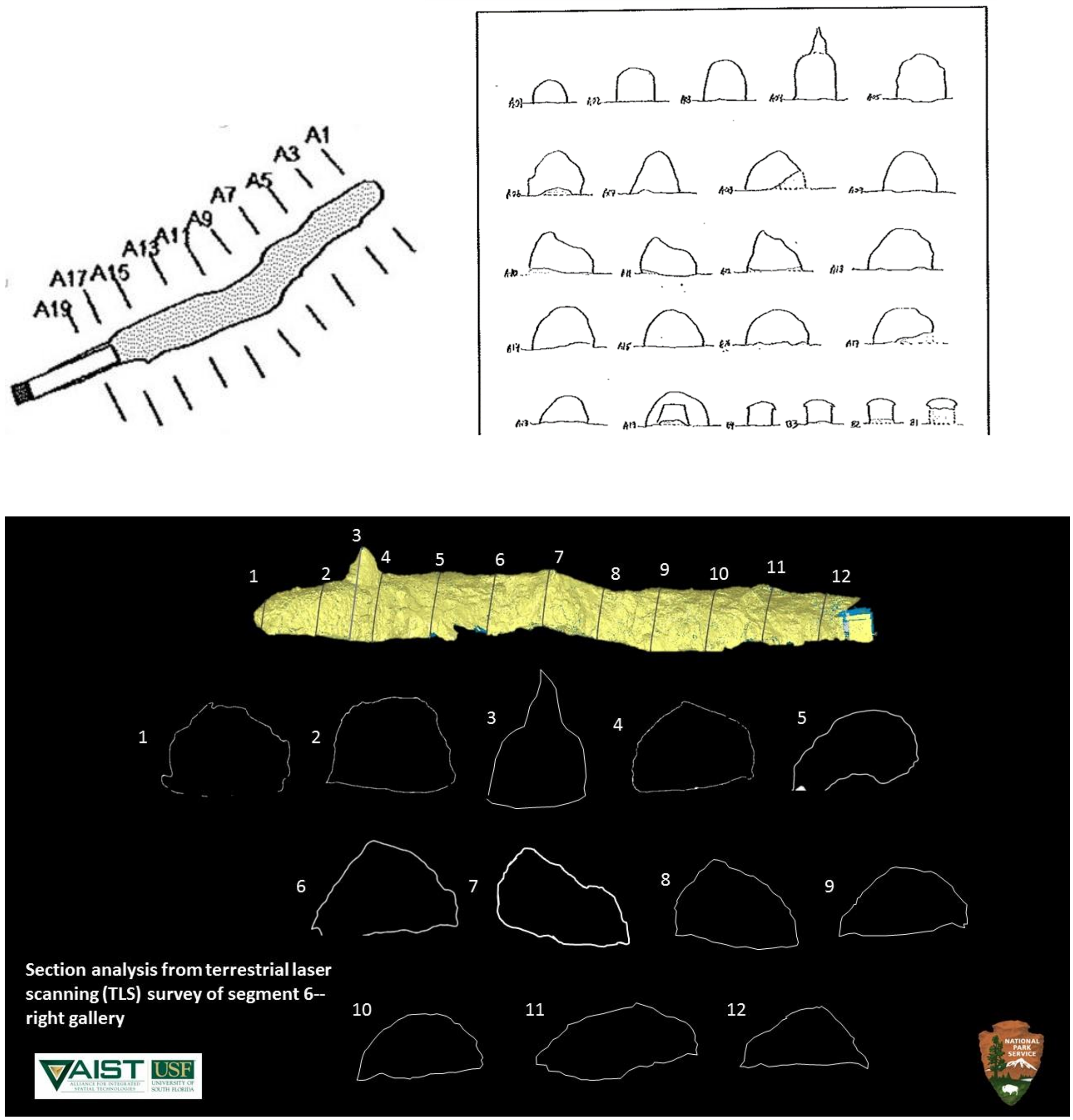

Figure 32. Sectional analysis and comparison to previous survey by Ek (2004) above with TLS data (below). Ek's views are shown from flipped perspectives, and differ slightly in configuration and shape.

PHOTOGRAPHIC TECHNIQUES

The mine tunnels and fort landscape areas in this project were recorded using a variety high-resolution photographic techniques, equipment, lighting, and software applications. Panoramic and spherical color images were taken from the interior of the tunnels utilizing the camera onboard the laser scanner. These images provide full coverage of the scan area (see Appendix A). Additionally, standard photography was taken at key areas and noticed feature locales within the tunnel segments (Figure 33). GoPro videography (Figure 34) tools from helmet mounted positions were also taken throughout the length of each tunnel, and this video stream was useful in the assessment of safety conditions prior to survey crew members entering the tunnels. Additional photographic aspects above ground included the use of GPS receiver cameras used to record attribute and positional data in conjunction with other spatial documentation information. Google glass and videography tools (see: https://youtu.be/aT-2Lw3wgV0) were utilized throughout the project as a form of documenting the documenters, and photos and videos in this way were also shared via social media (Facebook, Twitter, Instagram and Pinterest) as a means of education and in the generation of project interest.

Figure 33. Image taken in the eastern brick portion of the mine using standard camera during below surface survey. Crew members had camera and GoPro mounted video capture equipment with them during the TLS survey, and additional images were acquired by the laser scanner system. Image shows the arched entrance into the earthen segment 3 from the bricked segment 2.

Figure 34. GoPro video cameras were utilized on surveyors and rescue team members who were entering the mine. The video served not only for documentation and visualization of the mine area, but allowed for real time assessment of safety and conditions through a connected above surface viewing of the video stream.

GLOBAL POSITIONING SYSTEM (GPS) SURVEY AND GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

GPS survey was conducted at multiple locations and times throughout the project sites and as a way to document and provide spatial control for our locations of investigation. Differential Global Positioning System (DGPS), RTK-GPS, and GPS photography were used to provide from sub-centimeter to sub-decimeter level locational accuracy of all features and site locations. Differential correction techniques were performed in real-time and in the post-processing to improve the quality and accuracy of locational data gathered and post-processing was also performed with collected RTK-GPS. The GPS data was combined with other forms of documentation to provide researchers and site managers with the ability to store, retrieve, visualize, and interpret the spatial locations and conditional details of the site. A site-specific Geographic Information Systems (GIS) geodatabase was developed and includes all GPS data collected, inclusive of photographic points and linked images obtained with the GPS camera (Figure 35). The geodatabase contains collected point, polygon, and line features as well as GPS image attachments and attribute details. Additionally, aerial LiDAR imagery elevation data was acquired by AIST and combined in the GIS to produce a detailed Digital Elevation Model (DEM) for the NISI area (see Figure 30). At NISI, LiDAR from terrestrial laser scanning survey was integrated to produce a more site-specific DEM. These data were combined with other spatial information to establish a GIS geodatabase and Google Earth deliverable product (Figure 36). These tools provide valuable information and spatial understanding that is beneficial for management and landscape understanding.

GPS data was utilized in assigning real world coordinate positions for our TLS and geophysical surveys. Control was established utilizing RTK-GPS (Figure 37). Positional data was also collected with sub-decimeter level instrumentation for field points of interest including features across the park such as the town site plan as designated with signage, the cemetery and fortified features, park infrastructure, roads and trails, and park signage. GPS photographs were also attained for all of the park signage positions. The GPS data collected is useful for displaying site attribute and setting features within the geodatabase, and also for use with developed online visualization deliverables, such as an interactive site map that was produced from our survey (Figure 38). Please visit http://aist.usf.edu/flexviewer2/NPS_NinetySix/ for an example of a Flex GIS interactive map page for the site (Figure 38), as well as a City Engine GIS interactive map page: http://usfaist.maps.arcgis.com/home/item.html?id=2e78a655fe684a5d947e8266d0298832 (Figure 39). To use the Flex and City Engine pages, you should utilize the Chrome internet browser. These internet deliverables are useful for site interpretive development and website display.

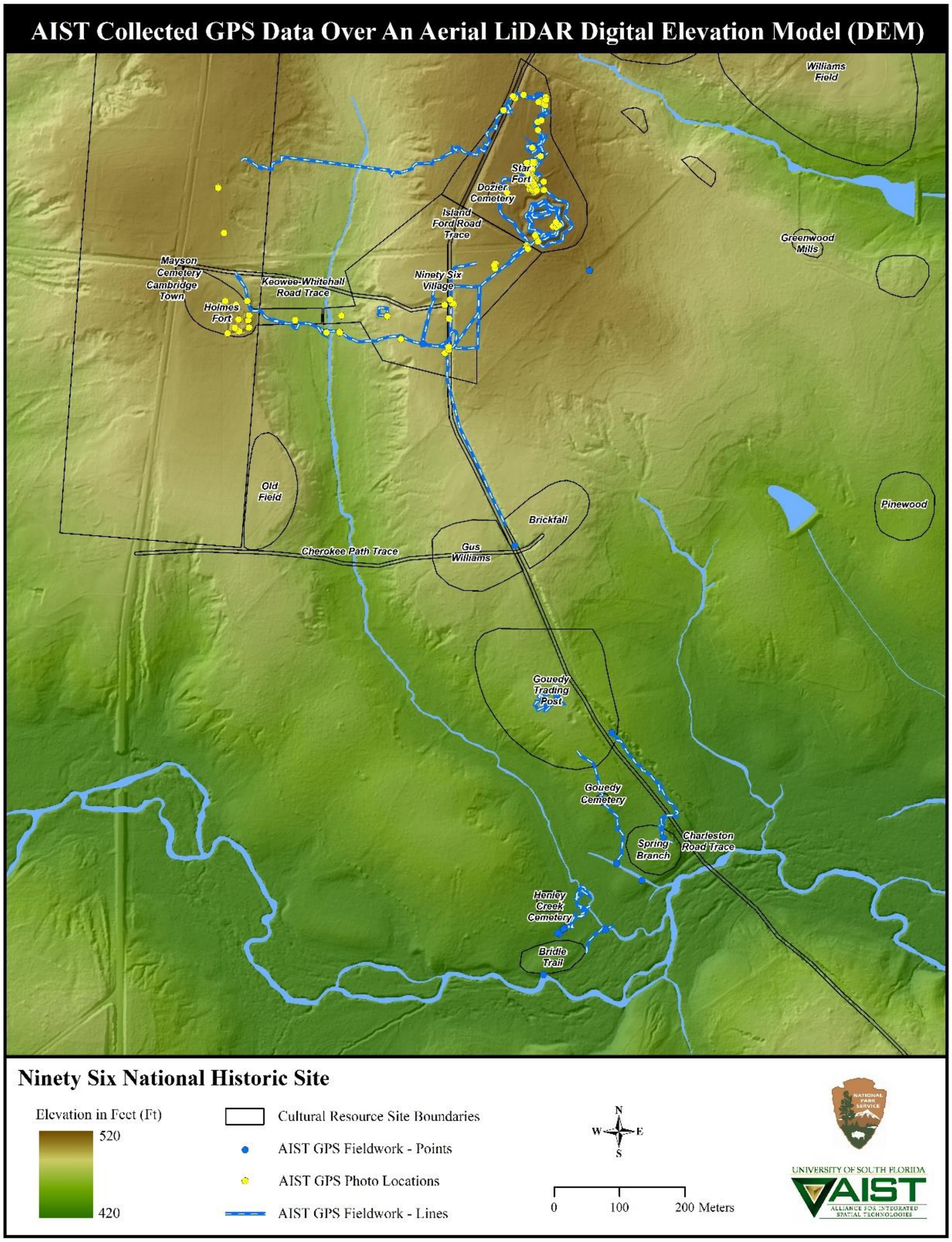

Figure 35. Map depicting GPS data collected during fieldwork (map layout does not include RTK spatial control and reference points). Also shown is the developed DEM from aerial LiDAR and a newly digitized and accuracy checked water (hydrography) layer made from the aerial LiDAR data.

Figure 36. The customized Google Earth .kmz file can be linked to and shared on web portals and made available as data layers for researchers and site managers. Containing many of the geodatabase tools, GPS locations, historic base maps that are georeferenced, and video and photo documentation for the site, the Google Earth tool allows usage without the need for special software or analysis skills. This digital database can also be useful for classroom applications.

Figure 37. RTK GPS set-up of base station (above) and rover unit for mobile site level data collection (below).

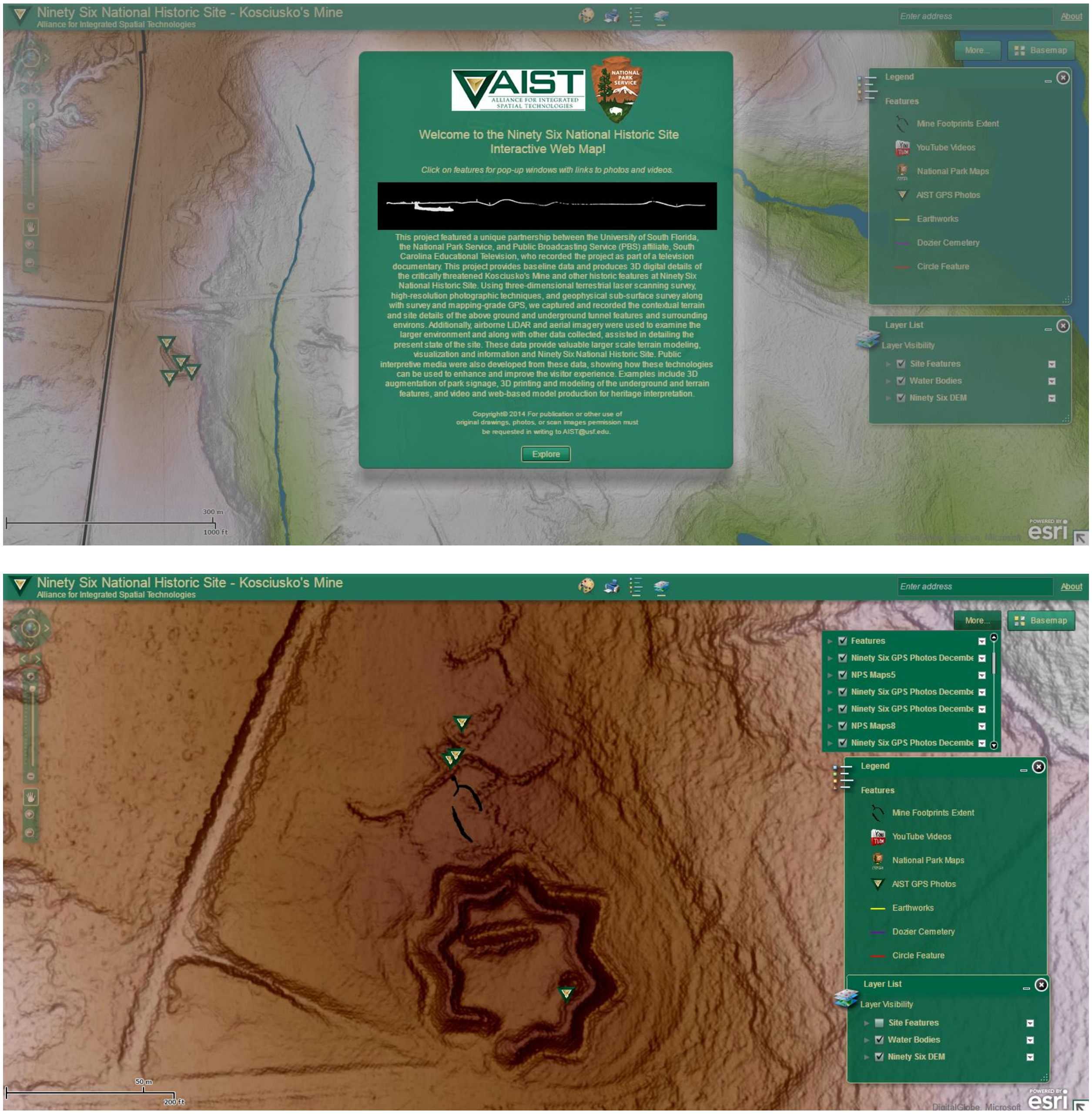

Figure 38. Web portal entry page for the Flex ArcGIS interactive map page for the Ninety Six National Historic Site survey. The page contains spatial locations as well as interactive links to videos, models, images, aerial imagery and LiDAR (terrestrial and aerial blended) elevation data. Shown is an example of the processed DEM from aerial LiDAR data that was created to examine terrain details and features. Of note are the Dozier cemetery and circular fort feature that are evident from our LiDAR as well indications of vehicular depression impacts cutting across features (bottom image).

Figure 39. The City Engine Interactive Map produced for Ninety Six National Historic Site allows the comparison of aerial imagery with digital elevation model data to view terrain and site feature data across the historic landscape.

GPS field data collection for this project provided spatial control for survey precision and accuracy, location and attribute information for database development and for use with interpretive and interactive tools, and provided data for use in georeferencing historic maps that were utilized to view, understand and portray the historic landscape. The USF AIST webpage hosts a project page for the Kosciusko Mine 3D Documentation Project at Ninety Six National Historic Site (Figure 40), and this web URL contains most of the GIS cartographic products utilizing the GPS data collected, as well as an online version of the interactive map. (see: http://aist.usf.edu/projects/KosciuskosMine.aspx).

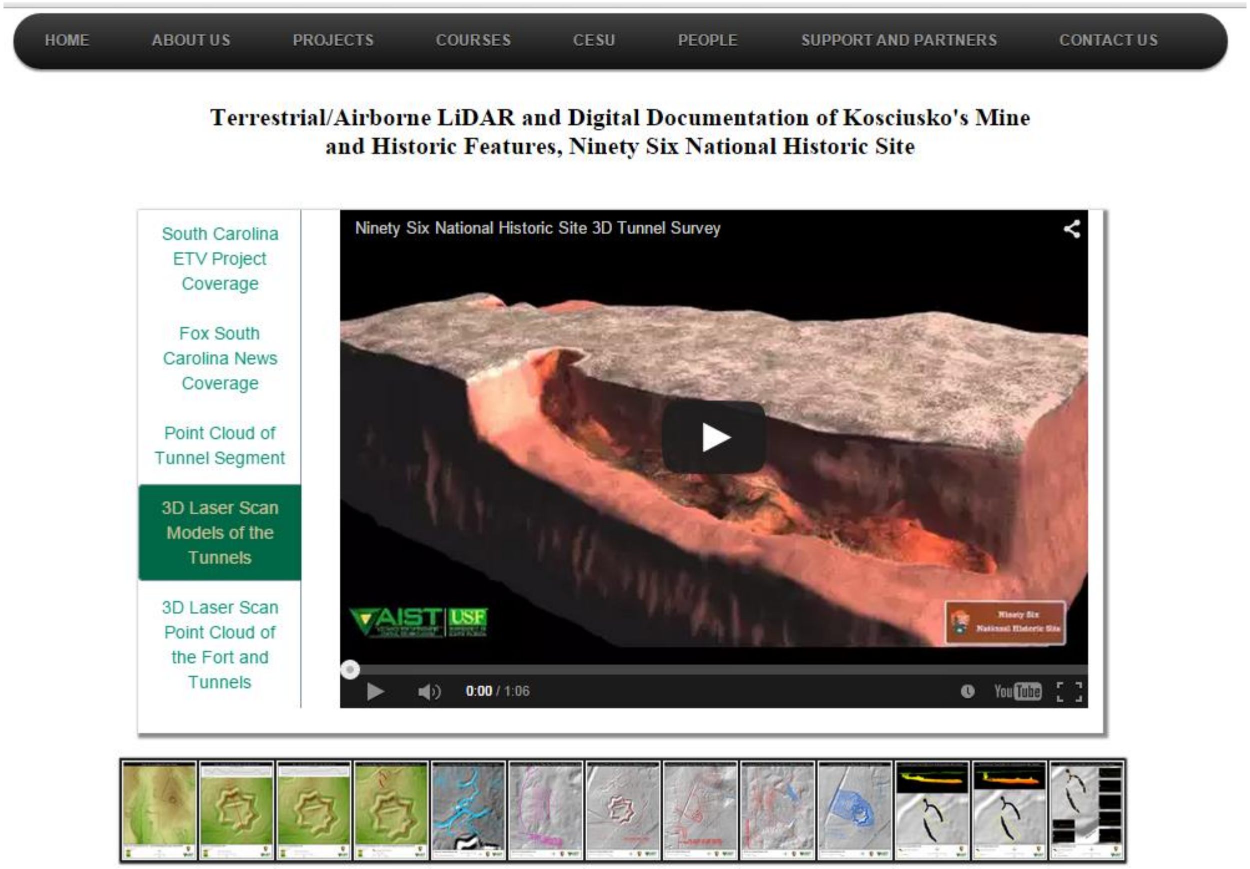

Figure 40. screen capture showing the USF AIST project website page containing maps and interactive media produced.

GEOPHYSICAL SURVEY

Ground penetrating radar profiles were run on selected sub-grids within the Ninety-Six Historical Site. On the larger grids, 250 MHz antennas were run with a spacing of 25 cm between parallel lines and a 2.5 cm along-line sample interval. On the smaller grids, we used 500 MHz antennas with a line spacing of 10 cm and a 2.5 cm along-line sample interval. Sampling was triggered by an odometer. Positions for each sample were recorded both in distance along-line and in GPS coordinates, with an RTK-GPS mounted approximately 1 m above the radar antennas. The antennas were pushed on a cart that maintained contact between antennas and ground wherever possible. String stretched across the ground was used as a guide for pushing the GPS cart along grid lines (Figure 41).

Figure 41. Geophysical equipment utilized on the project included real-time RTK survey grade GPS instrumentation running in conjunction with the GPR instrumentation

Each line collected was processed as a separate profile in a grid dataset. Data were processed with time-zero corrections for each profile, background removals, and uniform gains throughout grid. To correct for small offset position from one profile to the next, a data cube was built, and time slices were used to find the offset that maximized the correlation from one profile to the next. After positioning corrections, data were migrated with a 3D Kirchoff migration. Diffractions and reflections presumed to indicate objects and layers in the subsurface were identified in the GPR profiles and time slices. Depth of penetration was clearly limited by the conductivity of the clayey soil. GPR profiles show no signal coming from depths below approximately 1.5 meters. GPR profiles were collected over known tunnel locations, and had the GPR signal penetrated to the depth of the tunnel roof, there would have been a detectable GPR response. Geophysical survey location areas were documented using the RTK-GPS with coverage of features of note carried out from review of aerial LiDAR data (cemetery and circular fort areas, trench and fort areas, and atop tunnel portions) (Figures 42 and 43). Equipment and software used included a Mala ProEx GPR system, Trimble R10 RTK GPS system, and for processing we utilized Reflexw from Sandmeier Software.

IMPRESSIONS

Horizontal reflections in the fort walls and interior wall suggest older layers/horizons of material have been truncated by younger layers. These layers are most likely comprised of the same surficial sediments, silts and clays, found throughout this region of South Carolina. The horizon images in these structures suggests layers of material were built in succession, suggestive of a layer-by-layer construction technique (Figure 44 and 45). Gradiometer mapping in the areas of the Dozier cemetery and the circular fortification areas also provided congruent verification suggesting that the LiDAR data signatures seen in these areas are relational to the historic features.

AIST also further post-processed data from the collected gradiometer survey (collaboration with SEAC NPS). The area corresponding with the Dozier cemetery reveals the squared off feature and several anomaly areas that correspond with historic information as noted on the Holschlag and Rodeffer (1976) map, and also seen clearly on aerial LiDAR (Figure 46). Correspondence to several burial locations and delineation of the outer walls is evident in the gradiometer data, however there appears several anomalies (possible burials and other subsurface features), and a diagonal feature not shown in previous mapping. Also of interest are anomalies seen in the southeast corner of the above grid, located near the circular fort feature, and the presence of terrain

Figure 42. Geophysical survey area locations including the GPR and gradiometer coverage areas.

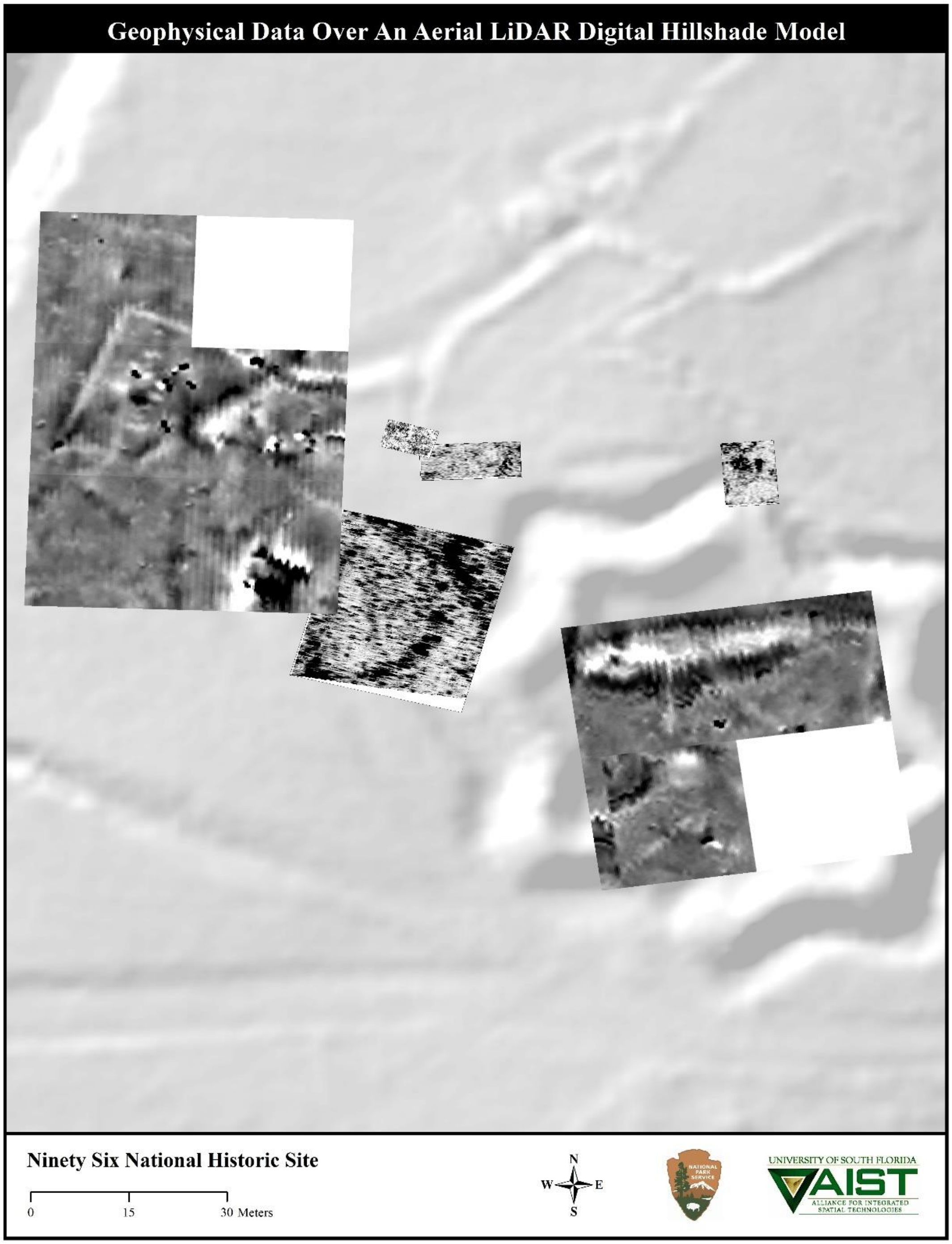

Figure 43. Overview images showing results from gradiometer and GPR surveys. Images are georeferenced and draped over aerial LiDAR.

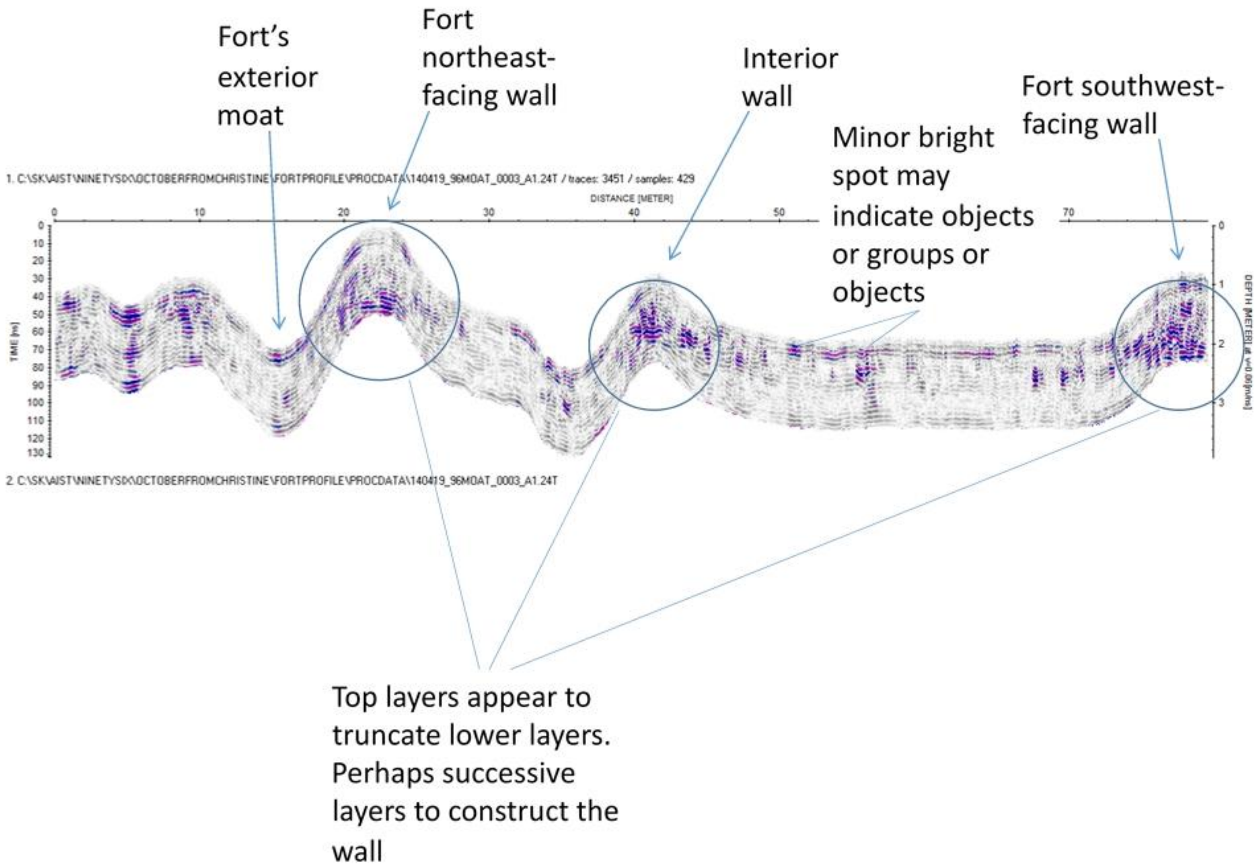

Figure 44. GPS data from section through frontal trench and wall of Star Fort showing successive construction episodes and subsurface objects.

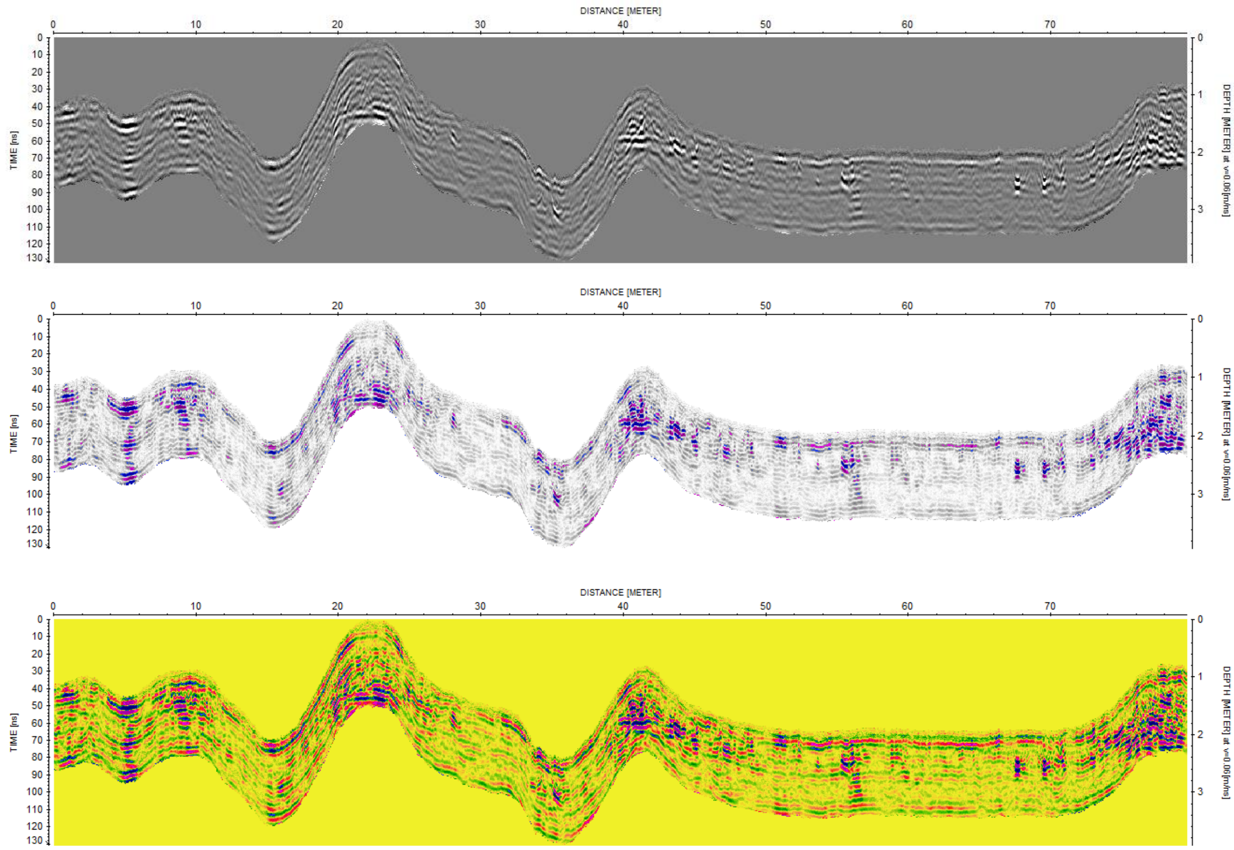

Figure 45. Black and white and color images showing results from GPR survey shown in profile through the earthen works associated with the Star Fort. Numerous areas of suspected buried objects are noted, as are construction techniques associated with the successive building at the fort.

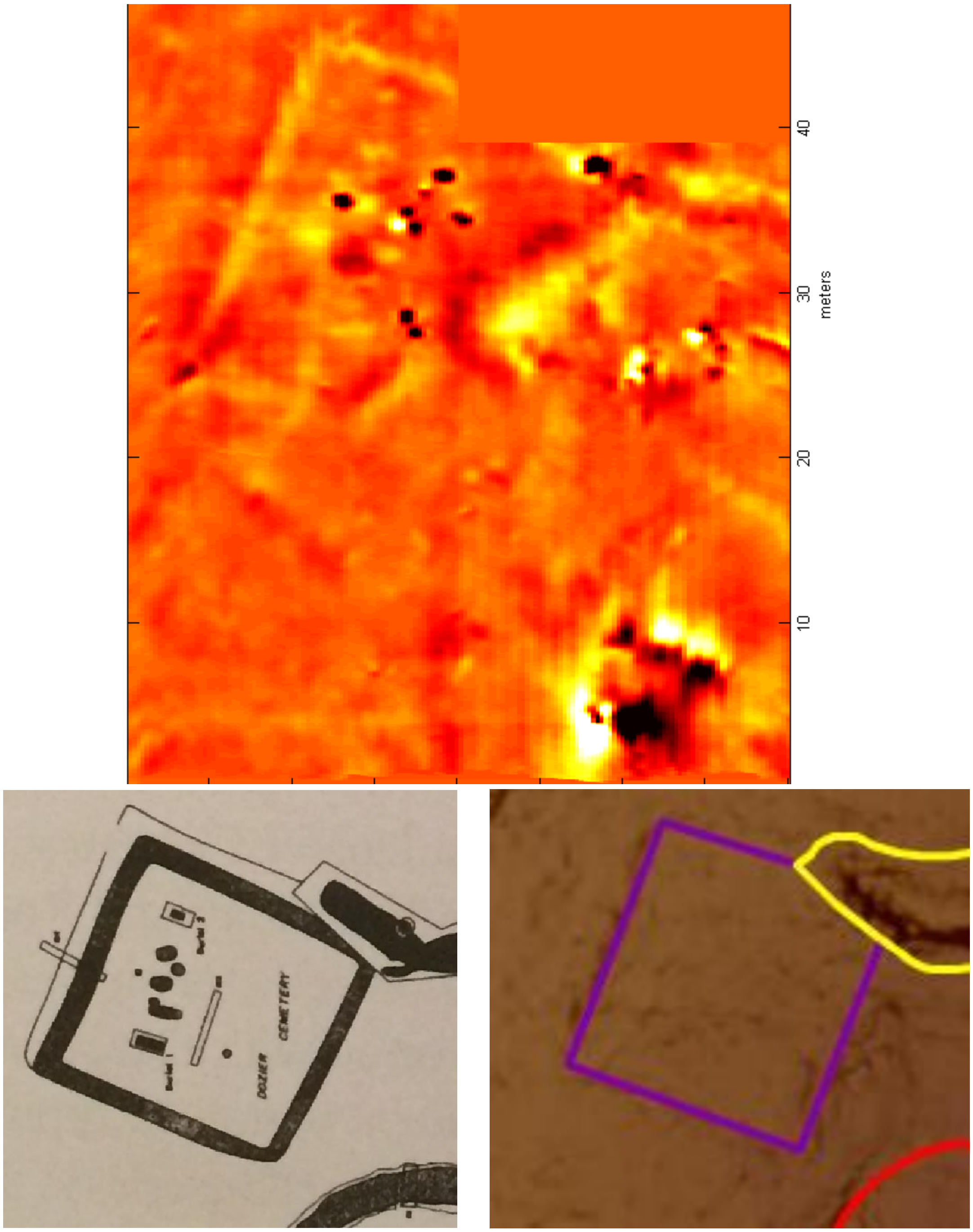

Figure 46. Post-processed data from the collected gradiometer survey, with shown correspondence with historic location of the Dozier cemetery and the circular redoubt areas as noted on the Holschlag and Rodeffer (1976) map (below left) and also seen clearly on aerial LiDAR (below right image).

depressions (also noted on aerial LiDAR) from impacts occurring from machinery and vehicles in this area. The gradiometer grid did not capture the entirety of the cemetery feature, and the

siege work area noted on previous maps and seen clearly in the LiDAR data is missing from this grid coverage. A portion of the circular redoubt feature area was also examined with geophysical techniques. This area was mapped with RTK GPS and GPR was utilized across a portion of the feature area. The processed data revealed and confirmed the previously identified features (Figure 47). Additionally, the circular redoubt area is clearly seen in the airborne LiDAR data, and can be easily delineated on the GIS digital elevation model (Figure 48).

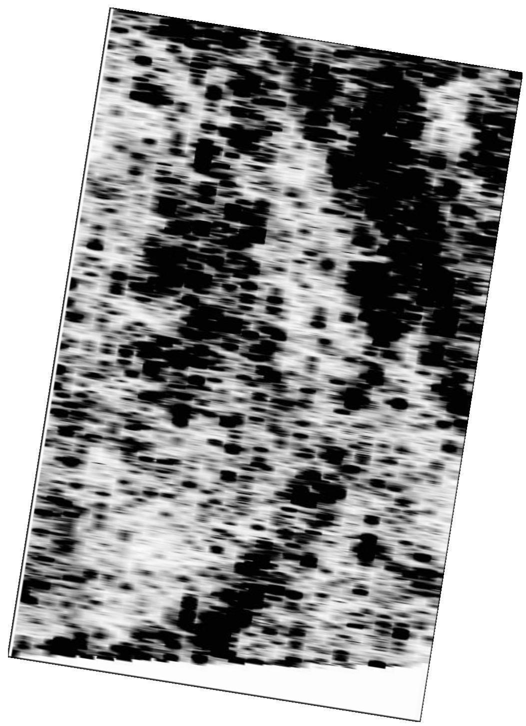

Figure 47. GPR timeslice taken at 0 .5 m and showing portion of the circular redoubt feature.

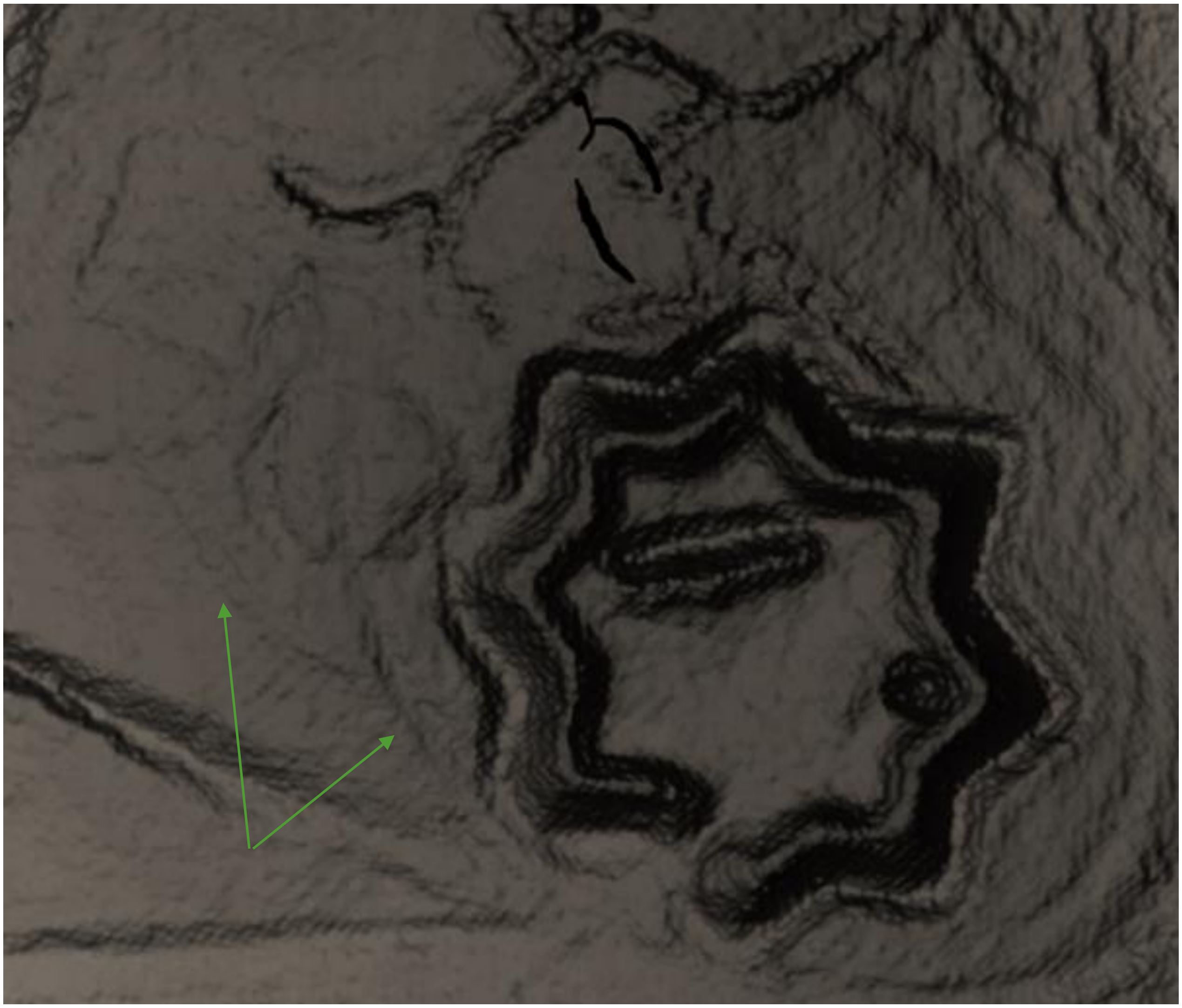

Figure 48. The circular redoubt, siege works, Star Fort and Dozier cemetery are clearly indicated on aerial LiDAR data (below) as are impacts from machinery and vehicular traffic (examples indicated by green arrows).

3D MODELS, 3D PRINTING, AND INTERPRETATION

Data collected from the terrestrial laser scanning survey of the above surface terrain Star Fort feature and the below surface mine feature were processed in formats that include point cloud and polygonal mesh models. Possible deliverable products from point cloud data include export applications for use in GIS, use for detailed metrology, 3D and 2D image and video rendered visualizations, archival documentation, and for creating tomography and section details and renders. Point cloud data were also brought together with aerial LiDAR data to reveal above and below ground features that can be viewed and examined together. Examples of point cloud applications include:

https://youtu.be/gcCqxFAi098 - shows aerial and terrestrial LiDAR for the Star Fort and mine features.
https://youtu.be/oyik3wJqwfM - terrestrial laser scanning survey point cloud visualization showing segment 6 (right gallery) of the Kosciusko Mine.
https://youtu.be/novvCENxB44 - terrestrial laser scanning survey point cloud visualization showing the left gallery of the Kosciusko Mine.

Polygonal models are created by exporting select portions of the point cloud data and bringing it into reverse engineering, inspection, design, and 3D modeling software. These data are then processed, filtered, and inspected prior to the creation of a solid surface, made of points, edges, vertices (where points and edges meet), and polygons. Models derived from the laser scan data, are textured with photographs acquired from the laser scanning and/or from external cameras. These realistic models can be used for research, education, and interpretive development. Additionally, these solid surface, water-tight models are used to produce 3D printed models that also offer much in the way of research, education and interpretive value. For example, models and 3D prints can be made that reveal interior and underground features not otherwise seen, and can provide tactile and visually engaging experiences for classroom and site applications (Figures 49- 55).

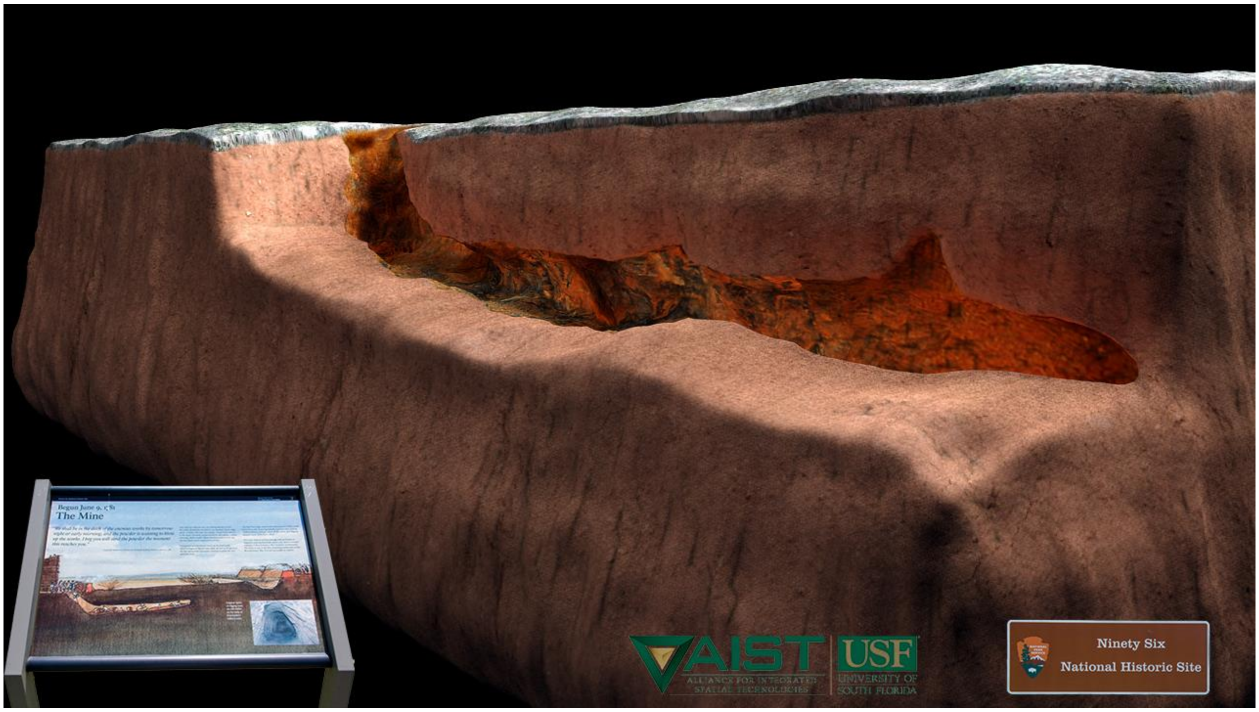

Figure 49. Polygonal mesh derived from TLS data showing a below surface cross section of segment 6 right gallery (western).

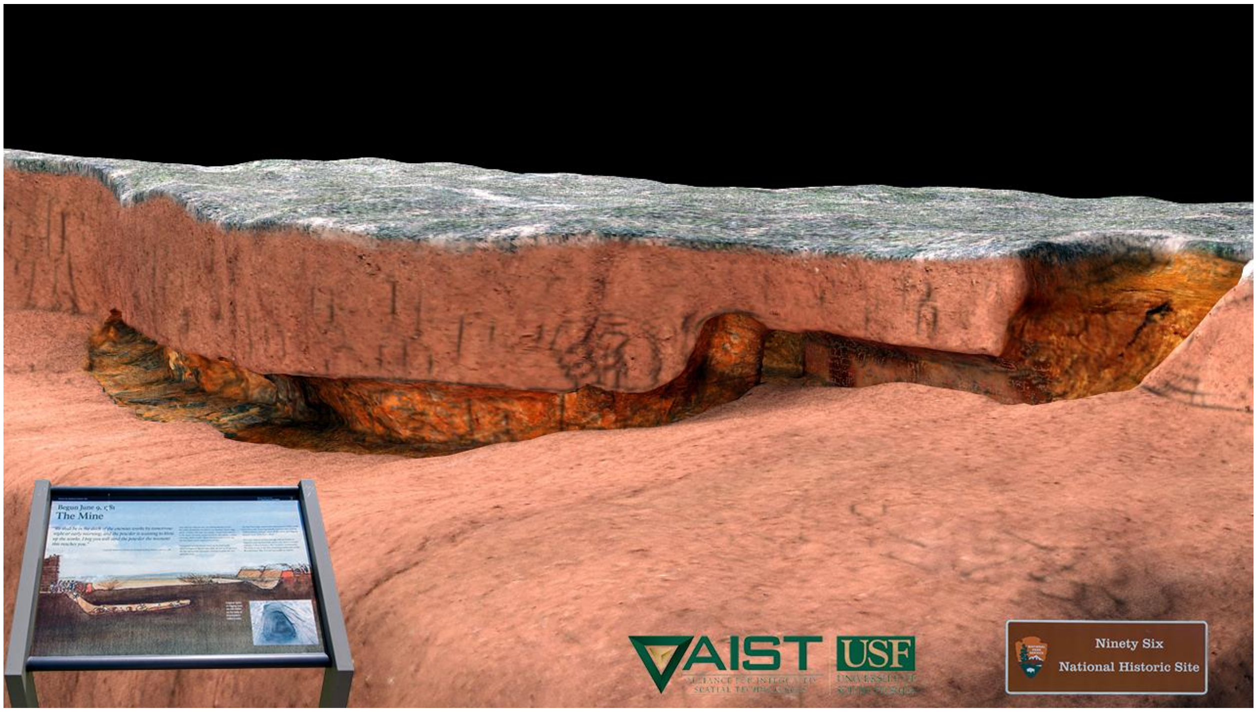

Figure 50. Polygonal mesh derived from TLS data showing a below surface cross section of the left (eastern) gallery.

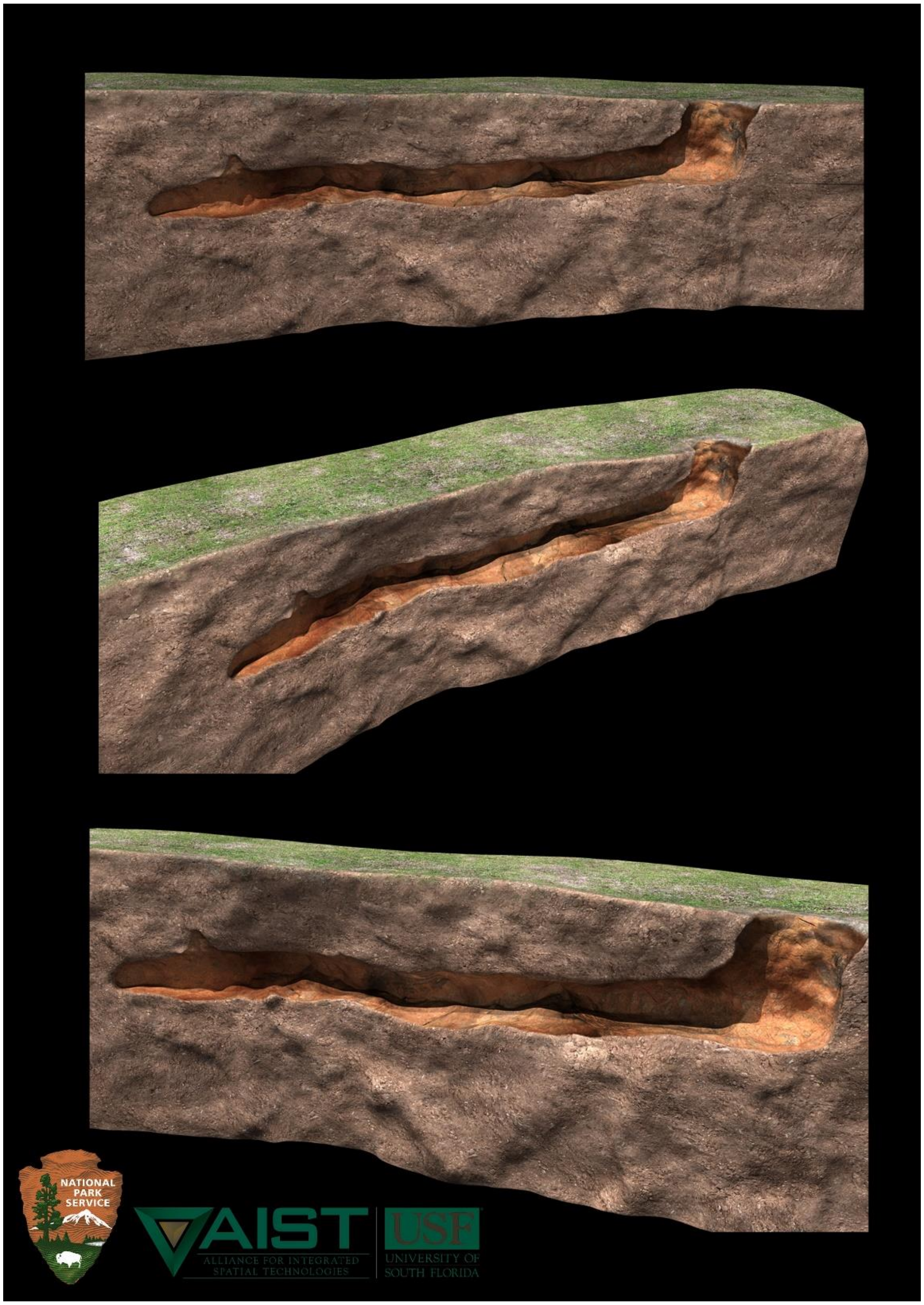

Figure 51. Example of 3D visualization made from the TLS data showing the right or western gallery (segment 6) of the mine.

Figure 52. The polygonal 3D models are able to show aspects such as depth below surface, and can be used in conjunction with existing signage to improve visitor experience and understanding.

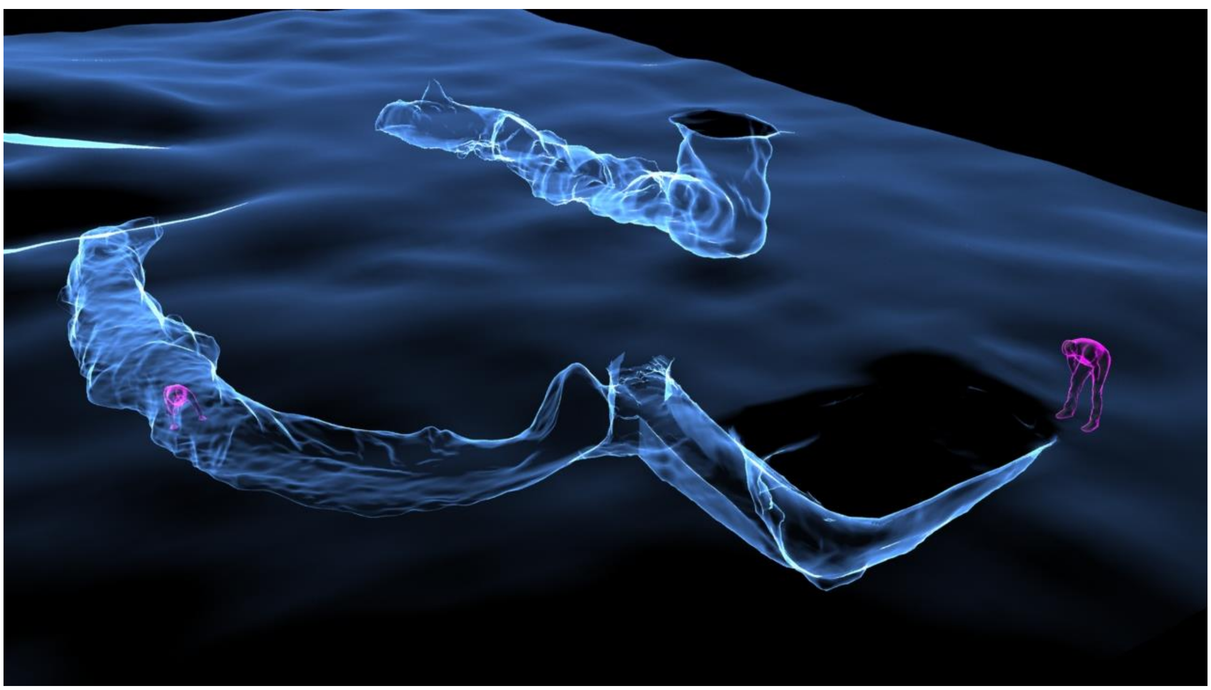

Figure 53. Model of mine galleries and terrain, showing human figures above and inside for scale.

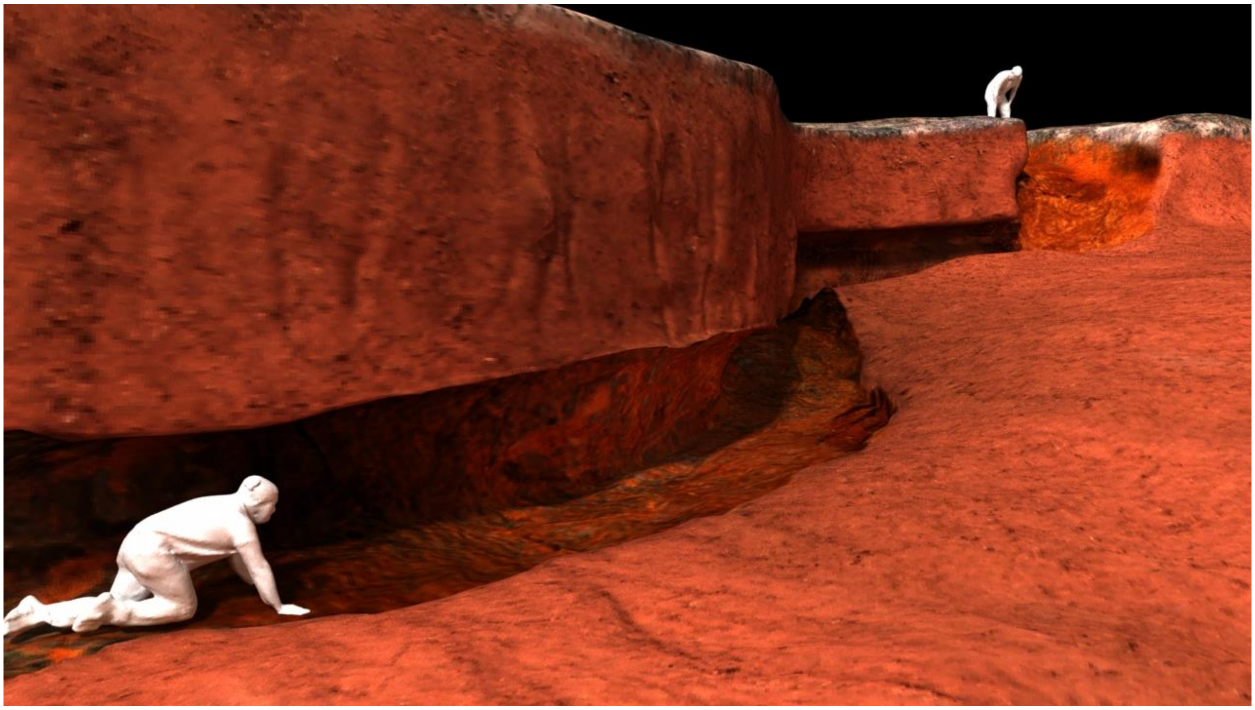

Figure 54. 3D mesh model of human figures in relation to section profile of the mine.

Figure 55. 3D print of the segment 6 (right gallery) of Kosciusko's Mine.

RESULTS

The goals of the NISI Kosciusko's Mine 3D digital documentation survey work were to record this important and imperiled feature and to document the above and below surface terrains in such a way as to be able to produce data that will support management, preservation, and interpretation into the future for this one of a kind, fragile and diminishing cultural feature from the Revolutionary War era. Through our survey efforts, we have produced the following data deliverables that can be used for these conservation and education endeavors:

1) A GIS geodatabase for NISI that contains processed LiDAR elevation data for the landscape region, collected GPS data, including all GPS photo points and images acquired (given as GPS photo reports and as a data layers in the geodatabase)
2) A custom .kmz Google Earth file for park use (internally and for public interpretive development
3) 3D modeling data files and visualizations for park use
4) 3D laser scan archive and project data in multiple formats for use and archival applications
5) Webshare 2Go files with the entire laser scanning project information from the tunnel mine features
6) 3D prints of the tunnel segments for use in display and other purposes
7) Images and videos associated with the project fieldwork
8) Conditional assessment report on structural integrity, inclusive of laser scanning images showing all portions of tunnel interior and sectional analysis.
9) Final report

All deliverables are provided to the NISI in the form of digital files, archival data sets, and report PDF copies that are copied to an external hard drive. Additionally, the project has broader impact benefits for education and curricular development as well as potentially extending park heritage tourism and outreach opportunities. To date, several professional papers and presentations (Collins et al 2014) have been made showcasing the project and its results, as well as a TV documentary and television segments produced from fieldwork and related historical context information. A public archeology day was also held in conjunction with field activities, and media and press coverage of the site and project have increased visibility to the public. Students in graduate and undergraduate courses in GIS, history, anthropology, field methods, 3D printing, and archeology at USF are also benefitting from and continue to develop data from this effort.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This report documents and shares results from a dangerous and challenging underground confined space archaeological project, recording a Revolutionary War era tunnel/mine system. This project was part of collaborative work with the National Park Service and the Southeast Archeological Center (SEAC). The project also included a documentary of the fieldwork, produced in coordination with the South Carolina Educational Television (SCETV).

Using digital imaging, terrestrial laser scanning, and aerial LiDAR combined with remote sensing geophysical and GPS survey, researchers documented, prepared conditional analysis, and developed public interpretation methods that extend management, preservation, and engagement potentials. This survey also yields insight into important historical events in our Nation's history. Three-dimensional survey allowed for the critical assessment of tunnel construction and conditions, and data were used to create virtual models and 3D printed replicas for display and educational purposes. The Kosciusko Mine at NISI is a unique and important heritage feature, that helps to tell the story of our Nation's independence. Due to safety concerns and potential for degradation, these tunnels cannot be opened to the public or to site managers that are charged with their care. As an alternative means for assessing stabilization and long term conservation and to provide important contextual information and site visibility for the public, this 3D survey utilized best available spatial documentation and virtualization strategies.

Three-dimensional laser scanning survey, advanced imaging techniques, GPS and geophysical survey, were used as part of the documentation workflow that enabled not only detailed study, but allowed the site to be digitally preserved and recorded in its entirety. These same technologies utilized as the best available documentation methods as part of this project, will also assist in addressing public interpretation and access needs with these resources in the future. Data collected can be imported to 3D printers and milling machine systems that replicate sections of the mine using the exact dimensional and surface information collected. These replicas- scaled models or 1:1 replicas, can assist in allowing public access and information and help to tell the site's rich story. Importantly, these data also establish a foundational level on which future monitoring and assessment of the assets can be based. Spatial data collected will also prove useful for any future archeological work at the site, and brings together previous mapping and survey work in a real world coordinate system. The deliverable products and survey strategies utilized represented by this work demonstrate the full range of capabilities for these emerging and evolving recordation techniques and show how they can be used in an integrated approach as part of archeological survey.

Conditional assessments (see separate reports: Appendix A and B) show that the tunnel segments are largely in good condition. Our analysis of the TLS and aerial LiDAR data show that there are some impacts occurring to portions of the site near the tunnels, and that the tunnel areas have been spared from this since they have been more protected. Vehicular and lawn maintenance tracks are noted in aerial LiDAR data (see: Figure 48). Use of TLS data of the above ground terrain for subsidence monitoring below surface has proven beneficial in the mining industry sectors (Gu and Xie 2013). We recommend that the NPS utilize the current survey as baseline data, and repeat above surface scanning of the main fort and mine areas on a five year basis. These comparative data sets can be analyzed against the present survey with deformation and subsidence measurements used to examine change across the surface. This would offer the NPS a method of monitoring below surface features without the need to re-enter the tunnel. These analyses would need minimal fieldwork and post-processing, and would provide a cost effective means of comparison and method of monitoring and analyzing below surface movement and change. Additionally, repeat analysis of terrain using the TLS data and the aerial LiDAR can offer a method of monitoring changes to the site terrain caused by maintenance (mowing, equipment, vehicular traffic) at the site.

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