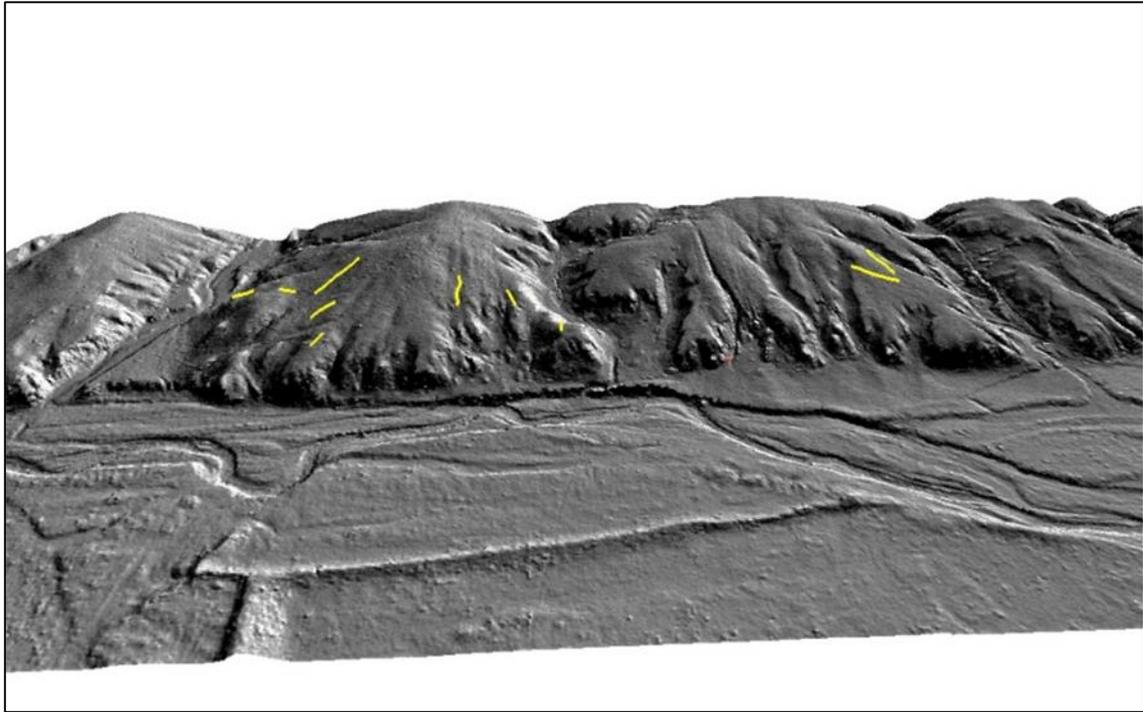


# Remote Sensing Survey Report

## Badger Hole, Woodward, OK

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LiDAR hillshade digital terrain model with interpreted intact palaeo-arroyos near Badger Hole, Woodward, OK.

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## Overview

As part of the Time Team America television program, airborne LiDAR and ground based geophysical surveys were completed to help map the landscape of the Badger Hole bison kill site in Woodward, OK. LiDAR data provide a digital terrain model of the immediate area (approximately 1.5 x 0.5 km) centering on the Badger Hole site. This model helps illustrate the erosional effects caused by the activity of the Beaver River as well as identifies other intact filled ancient arroyos that may date to the same period as the Badger Hole, Jake Bluff, and Cooper sites. Seismic tomography, electrical resistivity imaging (ERI), and ground penetrating radar (GPR) surveys were conducted the day before and during the filming of the television program. ERI identified at least two knick points that may be related to the Badger Hole kill site but excavation located over one of these knick points (with a backhoe) did not confirm any buried bones or artifacts. While seismic tomography effectively mapped the stratigraphy of the focus area, data were too coarse to provide any useful features for archaeological investigation. GPR surveys (at Badger Hole and Jake Bluff) were not effective in mapping sub-surface features due to the conductive nature of site soils.

On May 9, 2012 the airborne LiDAR survey was conducted by Paul Kinder and Adam Riley from the Natural Resource Analysis Center, West Virginia University. As part of the flight, Meg Watters (Time Team America, Oregon Public Broadcasting, OPB) and Leland Bement (Badger Hole site director, University of Oklahoma) were filmed in the air discussing the Badger Hole site, LiDAR technology, and what might be captured in the LiDAR data. The goal of the airborne LiDAR survey was to identify additional ancient arroyos (intact or otherwise) that would be contemporary to Badger Hole to provide some estimate as to potential site location and concentration in the region.

On June 10, 2012 the Time Team America geophysical survey team, with Bereket Derie from Round Rock Geophysics, conducted seismic tomography, ERI, and GPR surveys at the Badger Hole site (GPR was also conducted at Jake Bluff over the following two days). The focus of the surveys was to map the structure of the filled ancient arroyo and to identify possible knick points that would be related to the bison kill event at Badger Hole.

## Introduction

Geophysical survey methods of the sub-surface and 3D laser scanning of existing environments provide cost-effective means for capturing archaeological information for site recording, investigation, and management. Using non-invasive sub-surface and surface mapping methods can document the basic structure and layout of site. These methods can guide placement of excavation units and contribute to site impact strategies when dealing with upgrade of site infrastructure (such as utilities and landscape management); thus providing cost savings while reducing destructive impact upon important archaeological remains.

These survey methods can provide primary information on site settlement patterns. The continued application and development of broad area coverage for archaeological assessment has begun to introduce an alternative perspective into regional, or landscape archaeology (David and Payne 1997; Kvamme 2003, Crutchley and Crow 2009). Because geophysical surveys are able to cover large areas in comparison to the limited extent of archaeological excavations, the information they provide introduces a new component to the concept of the archaeological landscape. Broad area geophysical surveys

provide information on the structure and organization of a site enabling the study of spatial patterns and relationships relevant to research questions. In addition to the large-scale perspective of the site, geophysical survey results also provide a high-resolution focus on individual site features.

Geophysical surveys measure different subsurface properties at regular intervals across broad areas. Contrasting properties in a relatively homogeneous soil can identify buried objects or features such as foundations, compacted earthen surfaces, pits, stone walls, middens, hearths and any number of archaeological features. The different physical properties of the features, measured either in contrast to their surrounding matrix, or as recorded at the surface are referred to as 'anomalies' until they are able to be ground-truthed through excavation or other methods such as soil coring.

Different geophysical methods are sensitive to specific properties, such as magnetic fields, or the flow of an electrical current in the earth. Employing a combination of methods over a survey area can help provide information as to the nature, or material, of an anomaly thus providing insight to site interpretation. Mapping the distribution of anomalies over a large area can help in the recognition of anomalies generated through cultural activities revealing the spatial distribution and association with site features (Kvamme 2003).

Geophysical surveys can provide important information for help in site planning and preservation. These non-invasive methods can help establish priorities and identify areas for further invasive investigations, or for preservation and management. They are a fast and cost-effective method for gaining insight to what is buried beneath the ground. Geophysical survey results can be spatially integrated with other data relevant to archaeological investigations to provide a comprehensive record of the site environment, both below, and above ground.

## **Geophysical Methods, Principles, and Results**

Seismic tomography and ERI surveys were conducted at the Badger Hole site (Figure 1 A). GPR transects were collected over the Badger Hole site, but GPR was determined to not be effective in this area due to the conductive nature of the soil. Limited amounts of data were collected at Badger Hole as survey time was a single day. A GPR survey was conducted during the filming of Time Team America at the Jake Bluff site (Figure 1 B). The ancient arroyo in this location is more eroded than that of the Badger Hole site, thus we investigated whether GPR would be effective, despite the conductive site material, in an area where the bedrock would be closer to the ground surface.

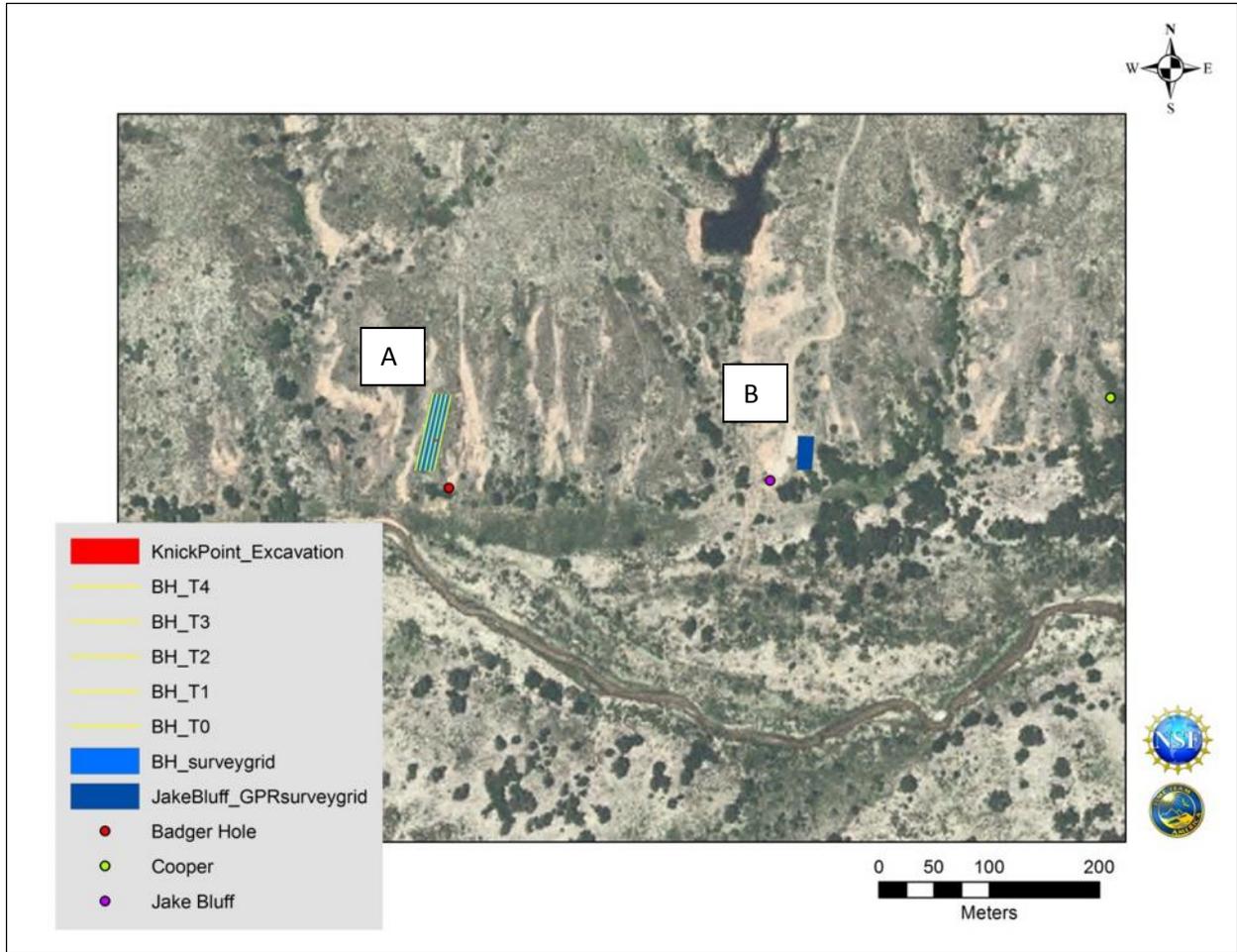


Figure 1 Geophysical survey grid locations at Badger Hole (A) and Jake Bluff (B).

## Seismic tomography

Seismic tomography is a method where vibrations are sent into the earth and the reflection strength is recorded at a series of points on the ground surface, or geophones. This method records the velocity, density, and permittivity of earth materials. The RAS24 Seistronix seismograph was used with 24, 8Hz vertical geophones. Data were collected on transects (straight lines) that were oriented north south across the survey area (Figure 2, A). Geophones are placed in the ground with 1 m spacing and a 16 pound sledgehammer was used as the seismic source, hitting the 'strike plate' and sending a vibration into the earth (Figure 2, B). That wave travels through the ground and the velocity of the energy is recorded at surrounding geophones. Rayfract (Intelligent Resources) was used for data processing.

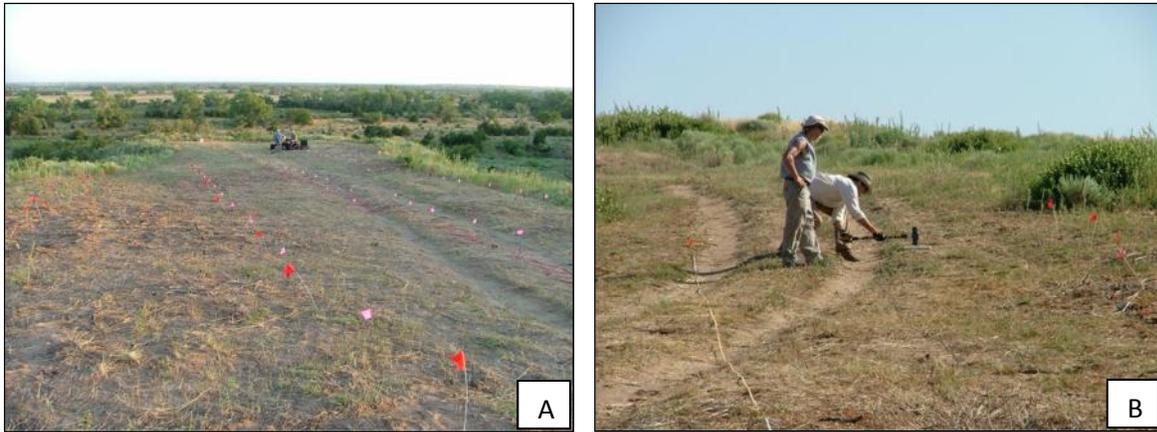


Figure 2 Geophysical survey transects (A) at Badger Hole with Alan Macca hammering the 'strike plate' with Jeff Brown (B).

Once collected, data are 'elevation corrected' which means entering the elevation value for each of the geophones along the survey transect. After transformation, a post processing method, resulting data are presented as a vertical slice into the ground representing the structure of the subsurface.

Three transects of seismic tomography data were collected (Figure 3) at Badger Hole. Geophones spacing was 1 m along 70 m transects.

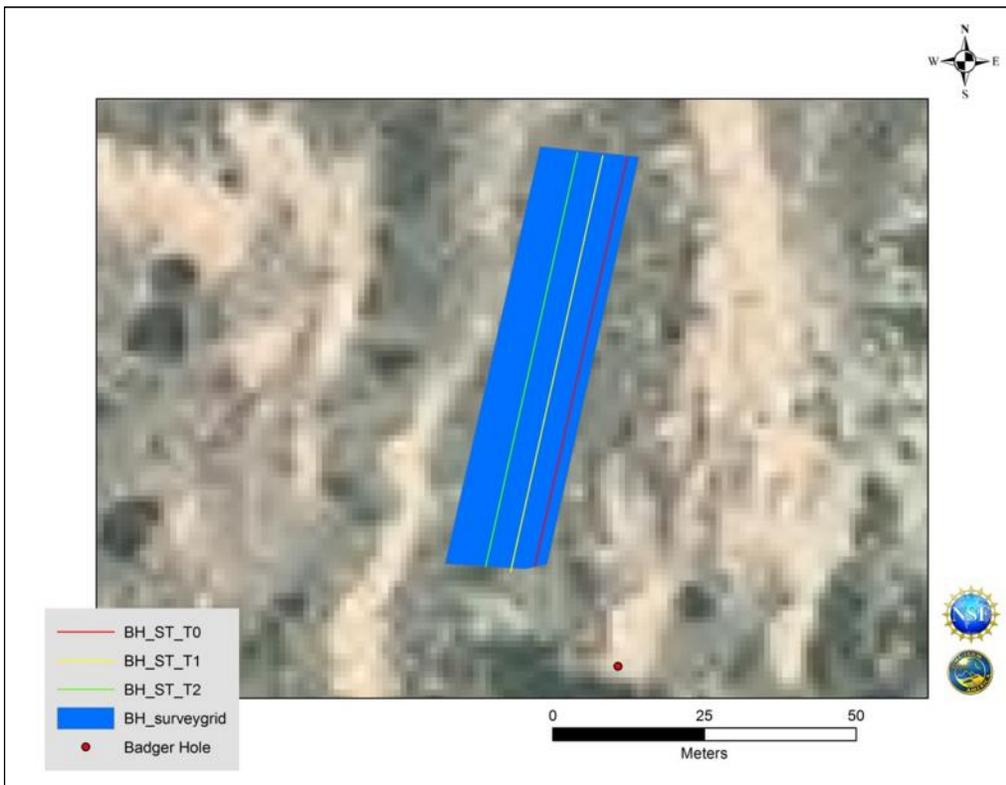


Figure 3 Location of seismic tomography transects.

After elevation correction and transformation, the resulting data represent the changing stratigraphy of the subsurface but images are too coarse to extract information on the individual knick points that were the target of our survey (Figure 4). The color scale represents the velocity of the sound wave as it travels into the earth; the dark blue is a low velocity, gradually changing to higher velocity with depth. Dark blue represents the surface unconsolidated soil and sands with transition to light blue, into the sandstone bedrock formation.

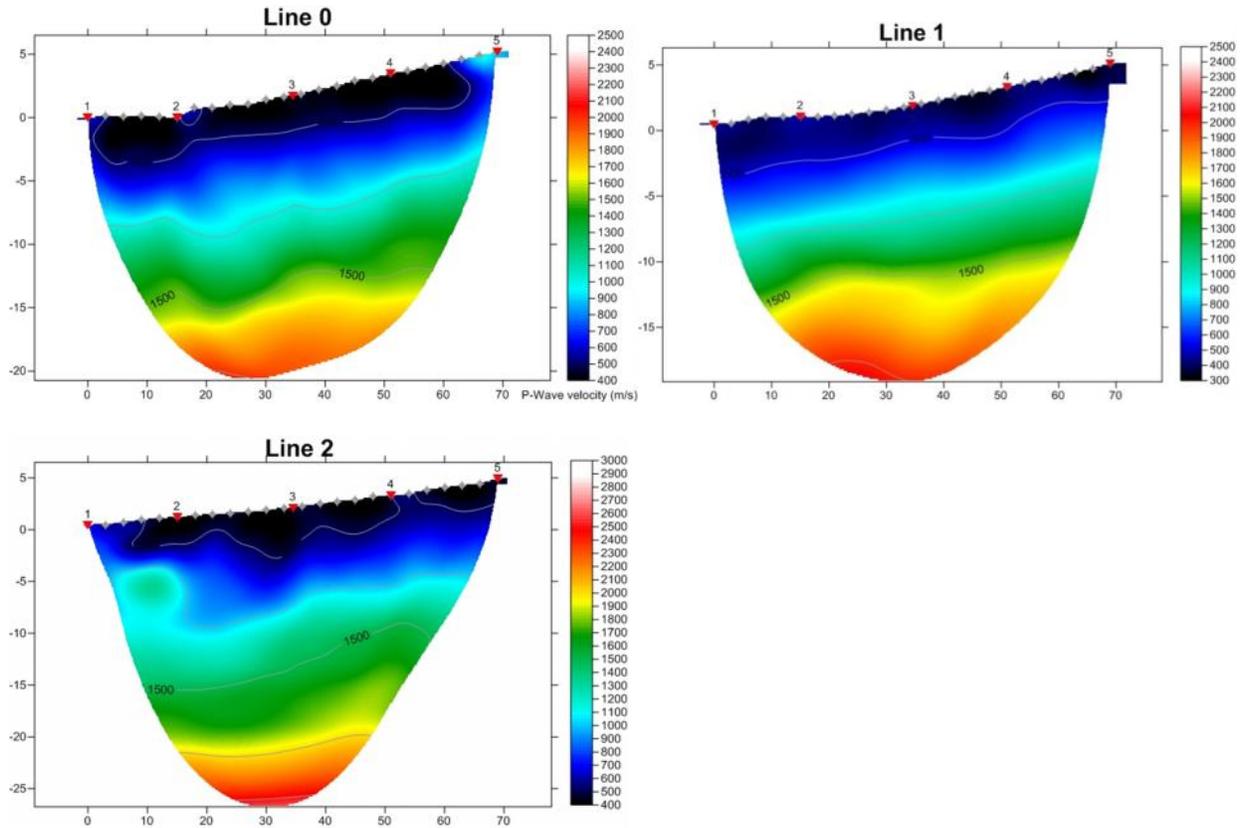


Figure 4 Badger Hole Seismic tomography transects after elevation correction and transformation.

## Electrical Resistivity Imaging

Resistivity survey measures the resistance to an electrical current that is sent into the ground through an array of electrodes. At Badger Hole ERI was used to determine the depth and geometry of the subsurface in vertical sections. Data are collected along a series of transects (Figure 5) with increased spacing between electrodes along individual transects.

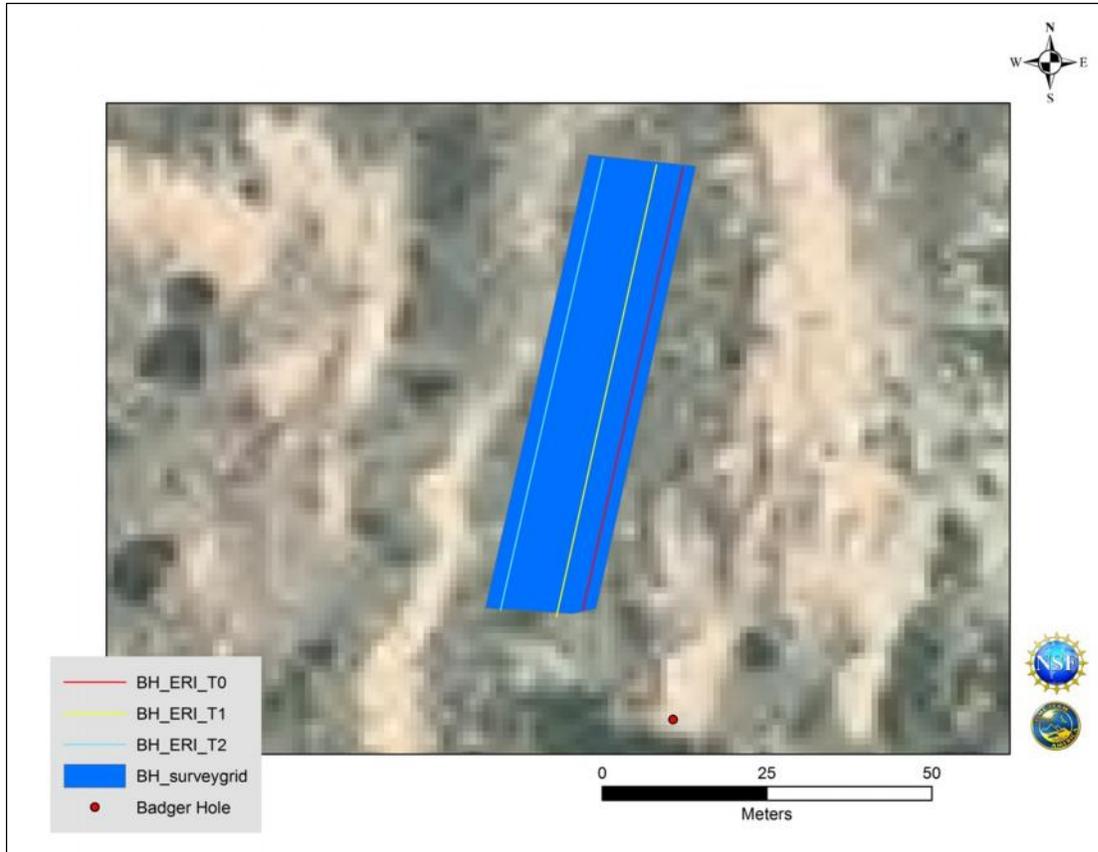


Figure 5 Location of ERI transects.

The Supersting R8 resistivity meter (Advanced Geosciences) was used to collect the ERI data. 56 stainless steel electrodes were placed every 1.5 m along each transect (Figure 6 A) and data collected with increased electrode spacing penetrating to a greater depth (Figure 6 B); the measured apparent resistivities provide information on the lateral and vertical variation in resistivity along the section. Once collected, data are ‘elevation corrected’ and then post processed in Res2D/3D software (Geotomo). Once inverted, resulting pseudo sections represent the true depth and formation of the subsurface.

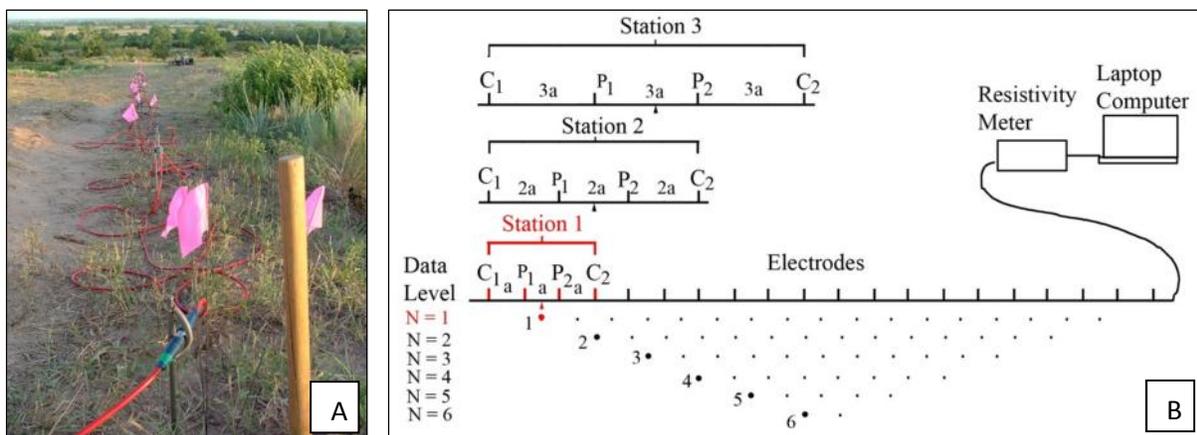


Figure 6 Resistivity electrodes spaced 1.5m along transect (pin flags locate electrodes) (A). Diagram illustrating electrical resistivity imaging (B).

The three ERI pseudo sections (Figure 7) collected at Badger Hole provide clear detail of the ancient arroyo's buried structure. Line 1 identifies two distinct knick points (Figure 7 red and blue arrows). A backhoe trench was positioned over the knick point closest to the exposed bone bed (Figure 7 red arrow, Figure 8).

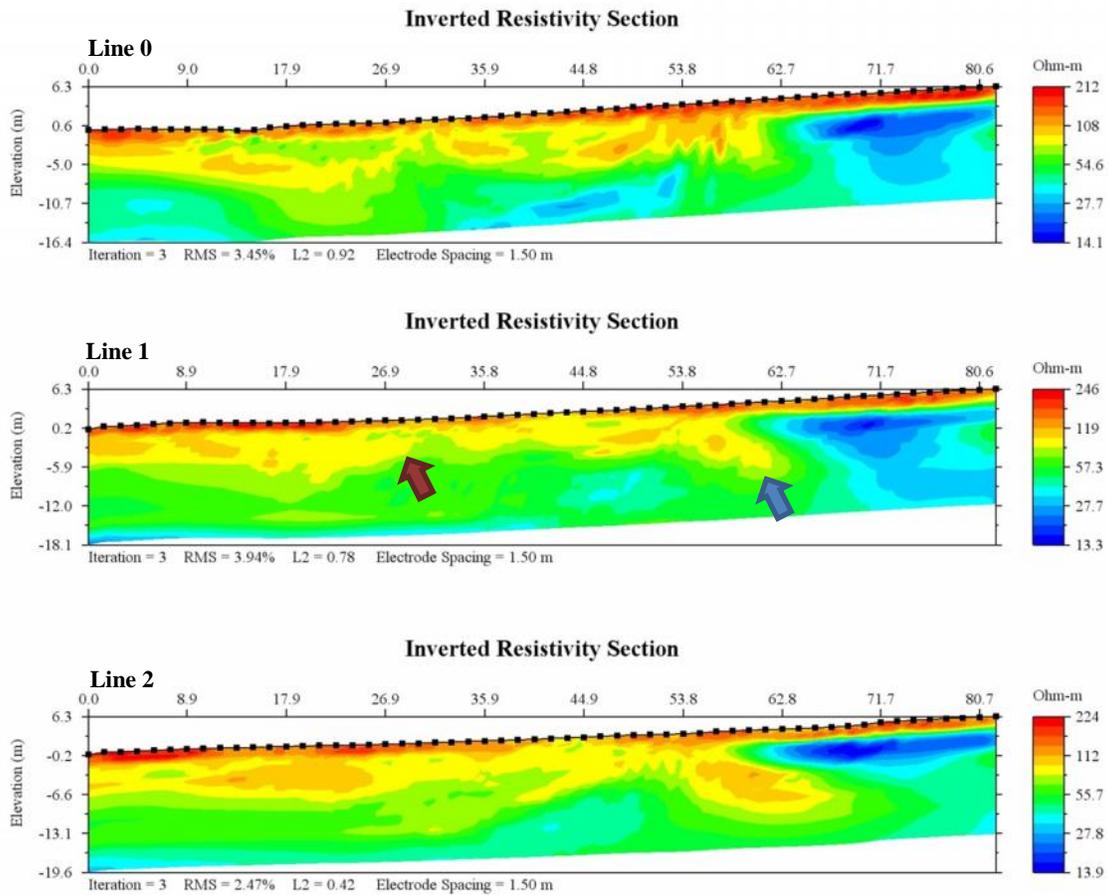


Figure 7 Electrical resistivity imaging transects at Badger Hole. Line 1 shows two clear knick points (red and blue arrows). The red arrow identifies the knick point targeted for excavation.

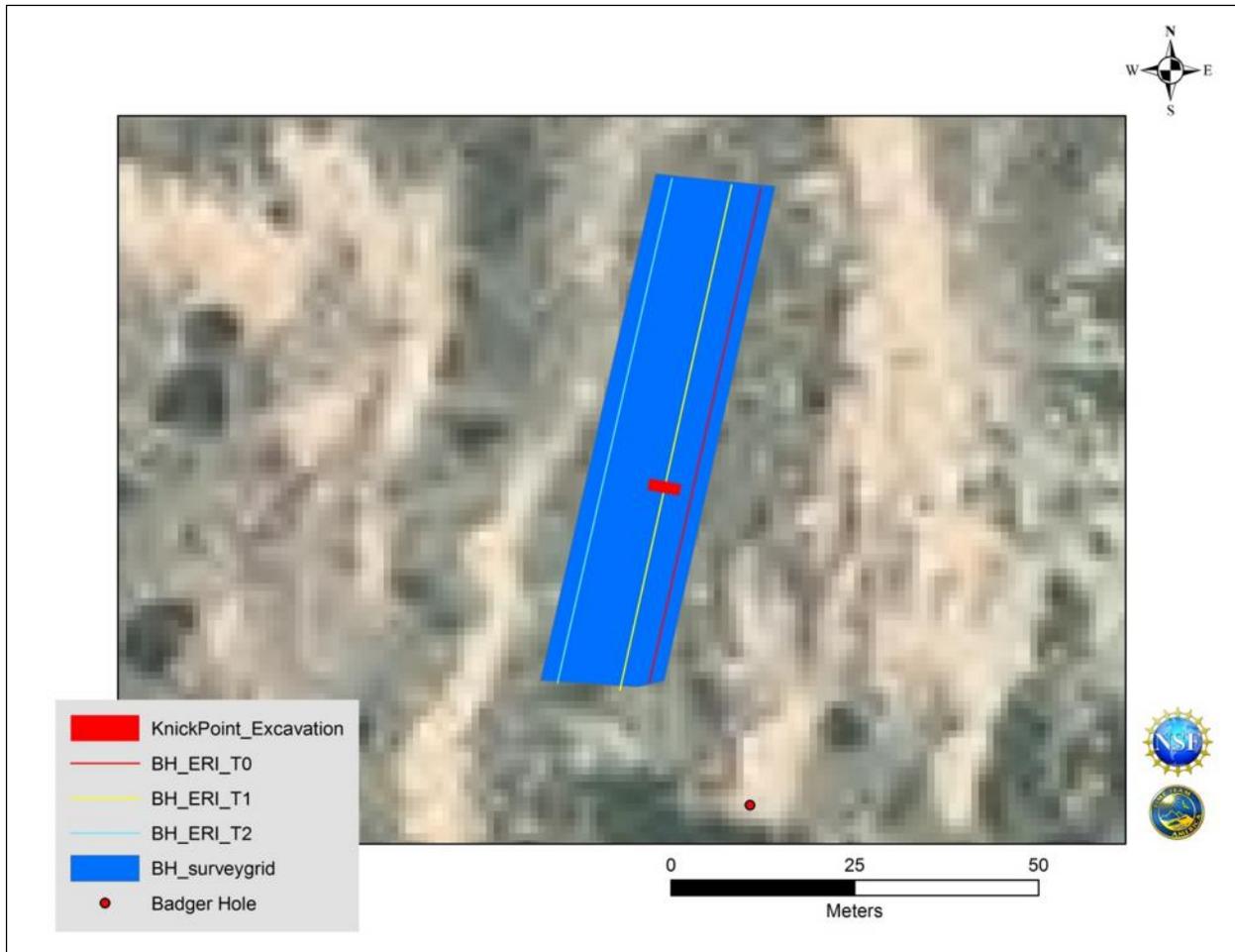


Figure 8 Location of backhoe excavation over knick point identified in ERI survey.

## Ground Penetrating Radar

GPR can provide high resolution records of boundaries between subsurface features with contrasting dielectric properties. A standard method for detecting buried archaeological features, GPR is able to collect large amounts of data, covering moderate areas, over a short period of time. GPR is a geophysical technique that can produce a three dimensional image of the subsurface and provide accurate depth estimates and information concerning the nature of buried features.

GPR maps the form of contrasting electrical properties (dielectric permittivity and conductivity) of the subsurface and records information on the amplitude, phase and time of electromagnetic energy reflected from subsurface features. The results are presented as 2D vertical profiles in the earth. The stronger the contrast between the electrical properties of two materials, the stronger the reflected signal in the GPR profile will be. Because the electromagnetic radar wave is transmitted from an antenna on the surface, reflects off of sub-surface interfaces, and is recorded back at a receiving antenna on the ground surface, surveys are ineffective in highly conductive materials.

The GPR surveys were conducted with a SIR3000 GPR unit and a 270 MHz antenna (Figure 9). The lower antenna frequency was chosen to facilitate penetration depth and should have penetrated to approximately 2-5 m depending on soil properties. While the local site soils were known to be conductive, the surveys were conducted in order to test different areas (Badger Hole and Jake Bluff sites) to confirm that GPR is not an effective tool for subsurface survey in this application.



Figure 9 SIR 3000 GPR unit with a 270 MHz antenna.

A sample of GPR profiles (Figure 10) collected at Jake Bluff demonstrate the conductive nature of the soils.

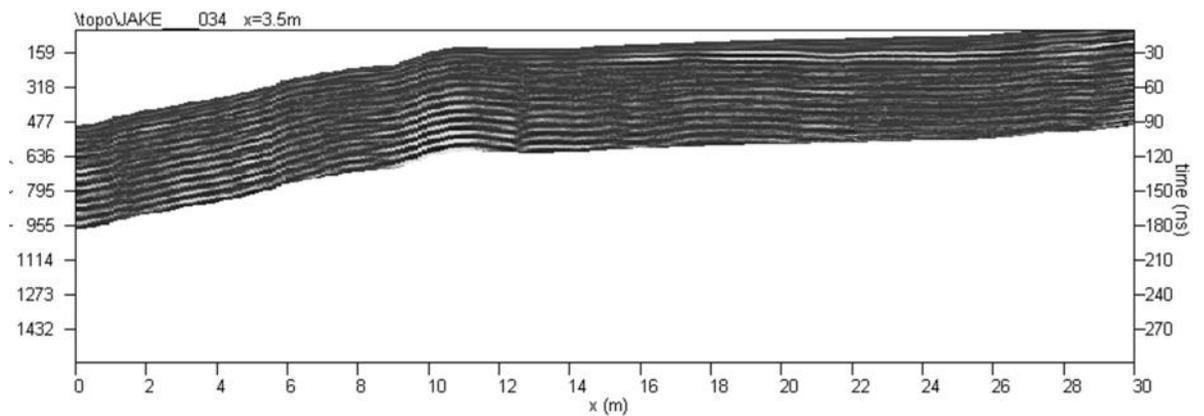


Figure 10 GPR profile from the Jake Bluff site survey.

## Airborne LiDAR Principles and Results

Airborne LiDAR, or light detection and ranging, measures the height of the ground surface and any features (i.e. trees, buildings) that may be on it and provides high definition and accurate models of the landscape to a resolution of 1 m to 0.5 m in archaeological applications. LiDAR uses a pulsed laser beam that scans from side to side as a plane flies at a low altitude over the survey area. 20,000 to 100,000

points per second build the ground model. In post-processing the first returns can be removed from the data providing a 'bare earth' model (or Digital Terrain Model, DTM) that accurately represents the ground surface.

The airborne LiDAR data were acquired by the NRAC, West Virginia University. NRAC operates an OPTECH ALTM-3100C airborne laser (small-footprint) mapping system. The system integrates a laser altimeter, a high-end Applanix Pos/AV Inertial Measurement Unit (IMU), also called an Inertial Navigation System (INS), and a dual frequency NovAtel GPS receiver. This integrated system is capable of 100 kHz operation at an operating height of 1,100 meters (3,609 feet). LiDAR technology offers fast, real-time collection of three-dimensional points that are employed in the creation of Digital Elevation Models (DEMs), Digital Terrain Models (DTM), landscape feature extraction, forest stand structure analysis, as well as many other research applications.

Data were collected in multiple, low altitude acquisition passes over the core area of Badger Hole (Figure 11) to yield ground LiDAR point densities of 15-20 per square meter (vertical accuracy of 15 cm or better). Integrated data have a vertical error of 15cm or less at the 95% confidence level for areas of open terrain and moderate slopes of 10 degrees or less (based off manufacturer's specifications). Data are recorded in the applicable Universal Transverse Mercator (UTM) zone, NAD83 datum (CORS96) while heights are orthometric, referenced to the North American Vertical Datum of 1988 (NAVD88) using GEOID09.

The resulting 'bare earth' model from the LiDAR flight of Badger Hole provides an excellent model of the landscape, highlighting the erosional effects (Figure 12) of the Beaver river and identifying possible intact bone beds in preserved palaeo-arroyos (Figure 13) contemporary with the Badger Hole, Jake Bluff, and Cooper sites.

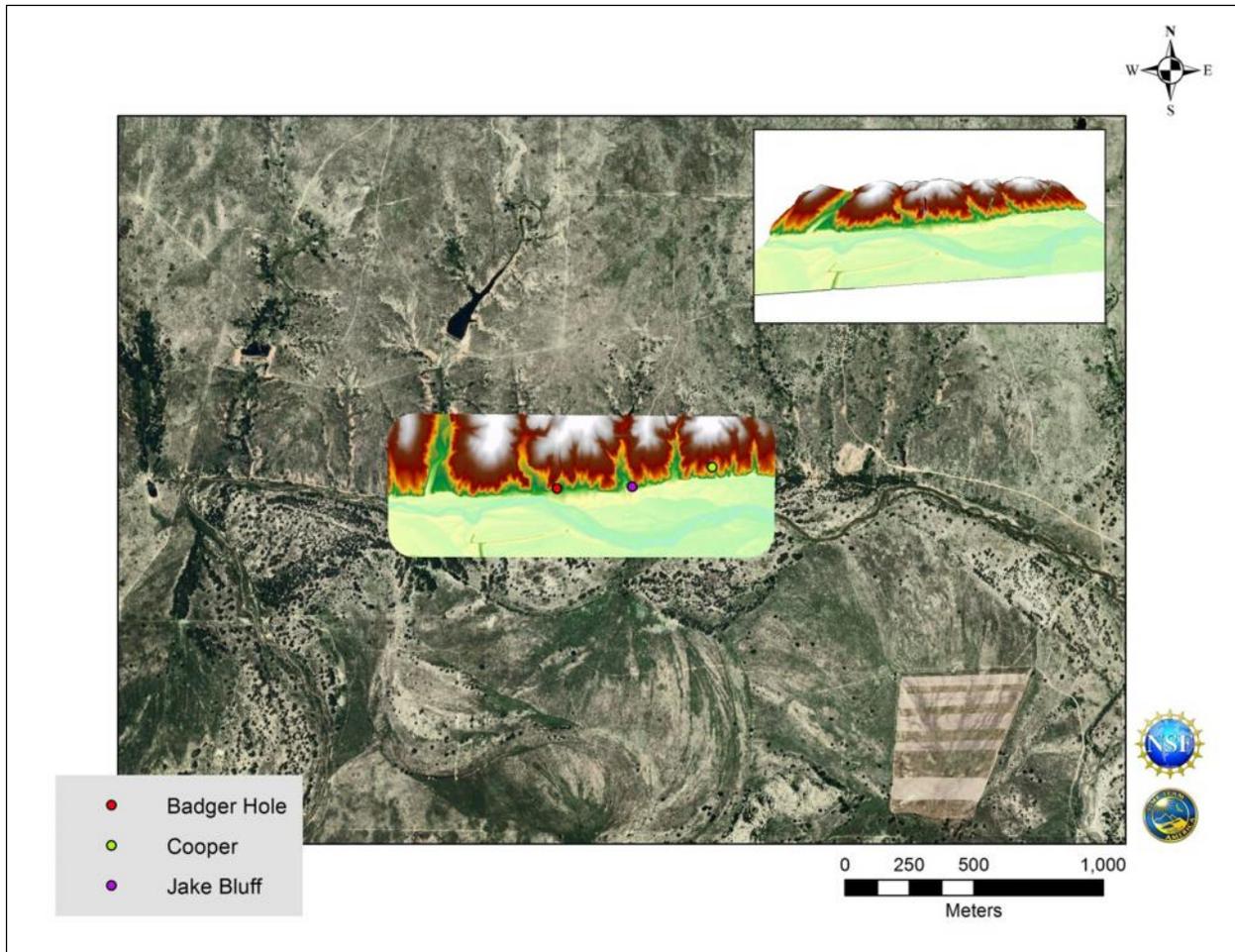


Figure 11 The Badger Hole LiDAR 0.5m contour elevation map over an aerial photo of the region with bone bed sites Badger Hole, Jake Bluff, and Cooper. Inset is the 3D model of the LiDAR 0.5m contour elevation map.<sup>1</sup>

The erosional effects of the Beaver River can be seen in the eastern edge of the LiDAR image (Figure 12) where the edges of the river plain have encroached into the land formation, causing a more ‘saw-tooth’ like pattern on the edge of the land formation, eroding new arroyos and re-activating ancient ones. As the river flows toward the oxbow to the west, the erosion of the land form is less severe with more rounded edges at the river plain. In basic archaeological terms, the area to the west (in the LiDAR data), toward the oxbow, is more likely to contain undisturbed, buried bone beds while in the eastern region any remaining bone beds are more likely disturbed or gone due to the erosion caused by the river activity.

<sup>1</sup> Please note that the auto export within ArcScene does not enable the export of a scale bar or a north arrow. All features are measurable in ArcScene, ArcGIS and Arc Scene projects are included as part of this report.

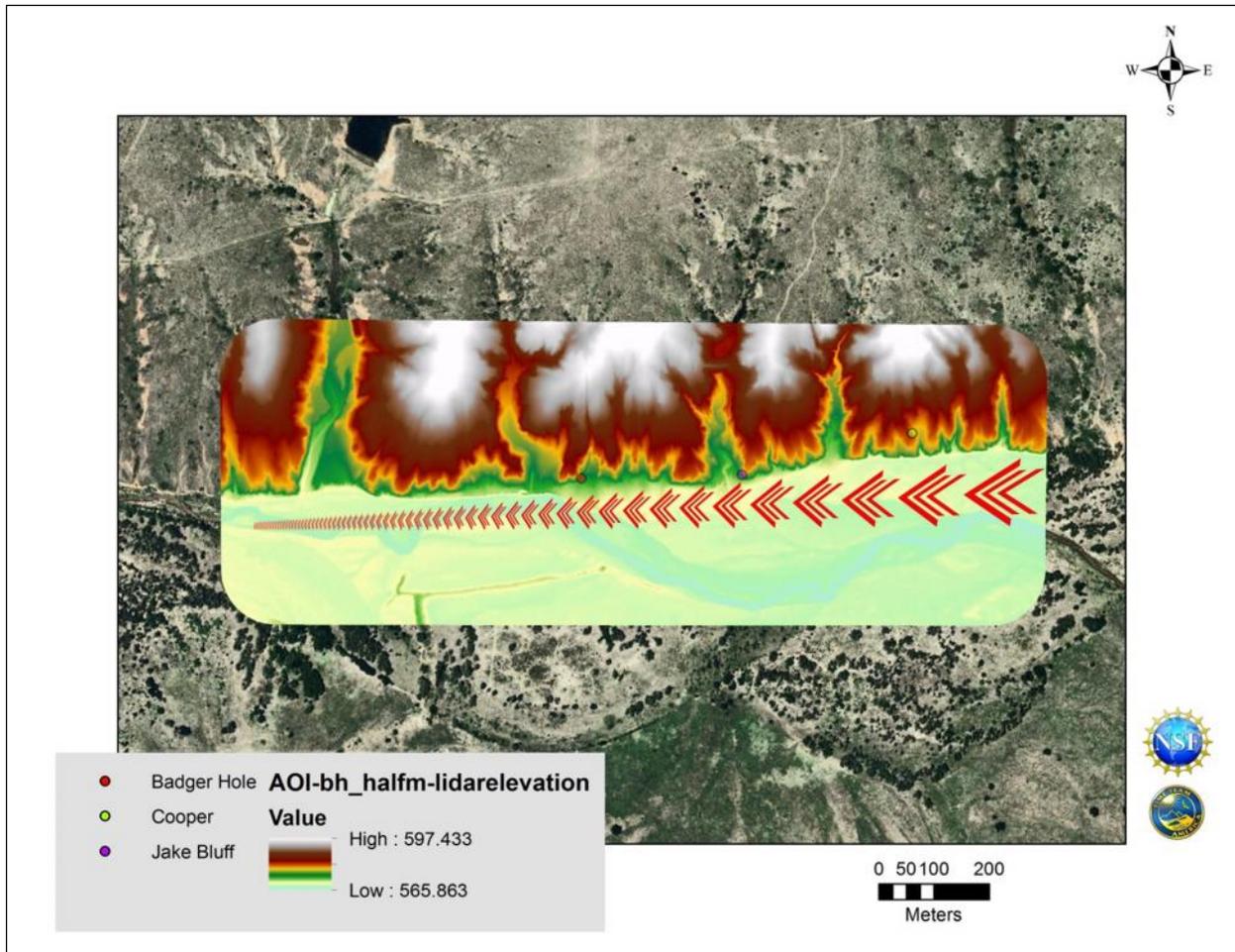


Figure 12 The erosional effects of the Beaver River. The larger red arrows identify areas of greater erosion while the smaller arrows identify areas most likely to have preserved bone beds.

Prof. Bement and Watters examined the LiDAR data to identify potential areas for investigation (through coring) during the filming of Time team America. The most revealing LiDAR data layer was the half meter hill shade with light source 45% from horizon (Figure 13). In this image, slight depressions in the ground surface were identified, characterized by appearing slightly up-slope from the edge of the land form and disappearing toward the cliff edge adjacent to the river plain<sup>2</sup>. Figure 14 highlights one of these features identified in the LiDAR data, note the feature disappears as it approaches the edge of the landform (south toward the Beaver River), thus assumed intact.

<sup>2</sup> As per personal communication with Prof. Bement.

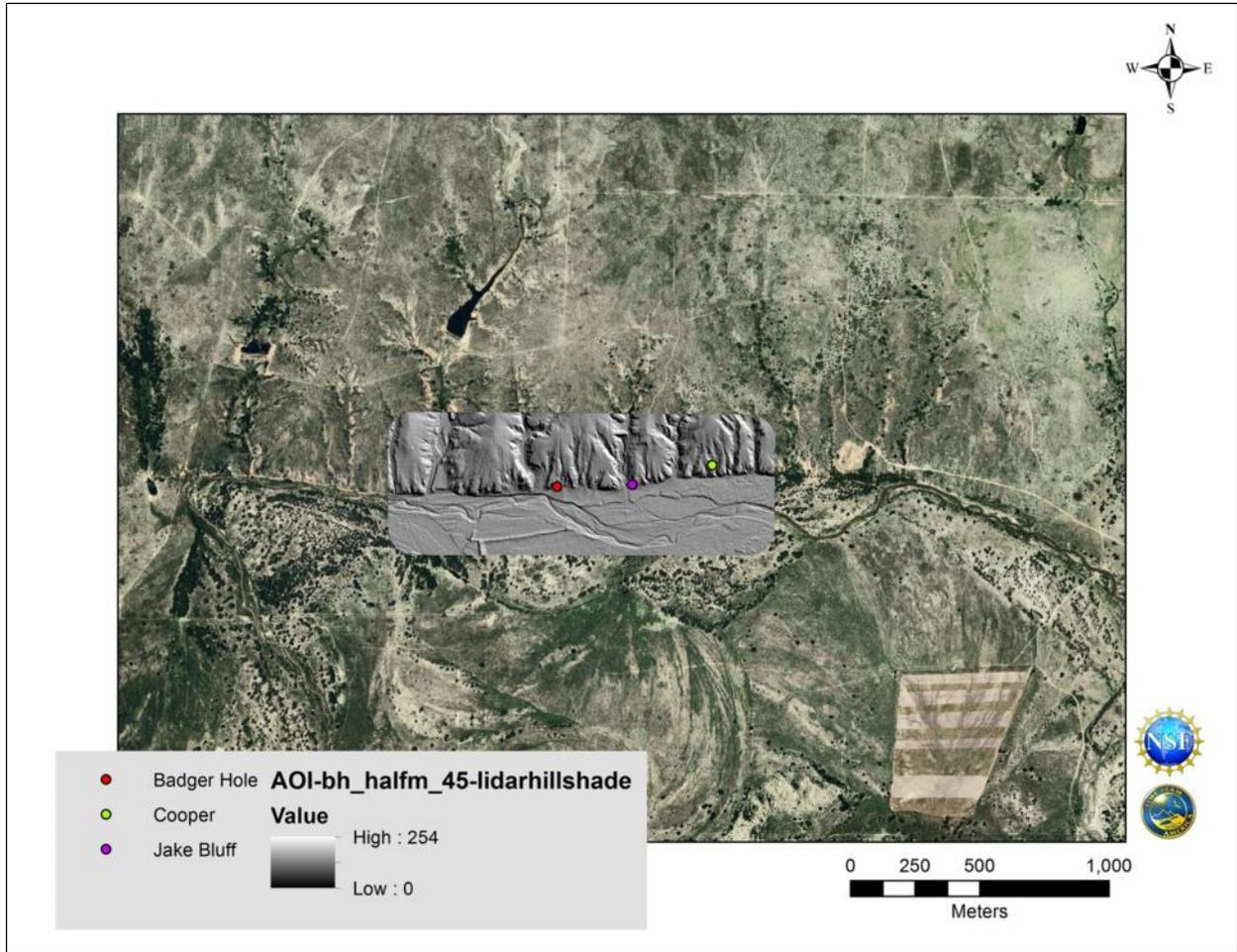


Figure 13 LiDAR hill shade image with bone bed sites.

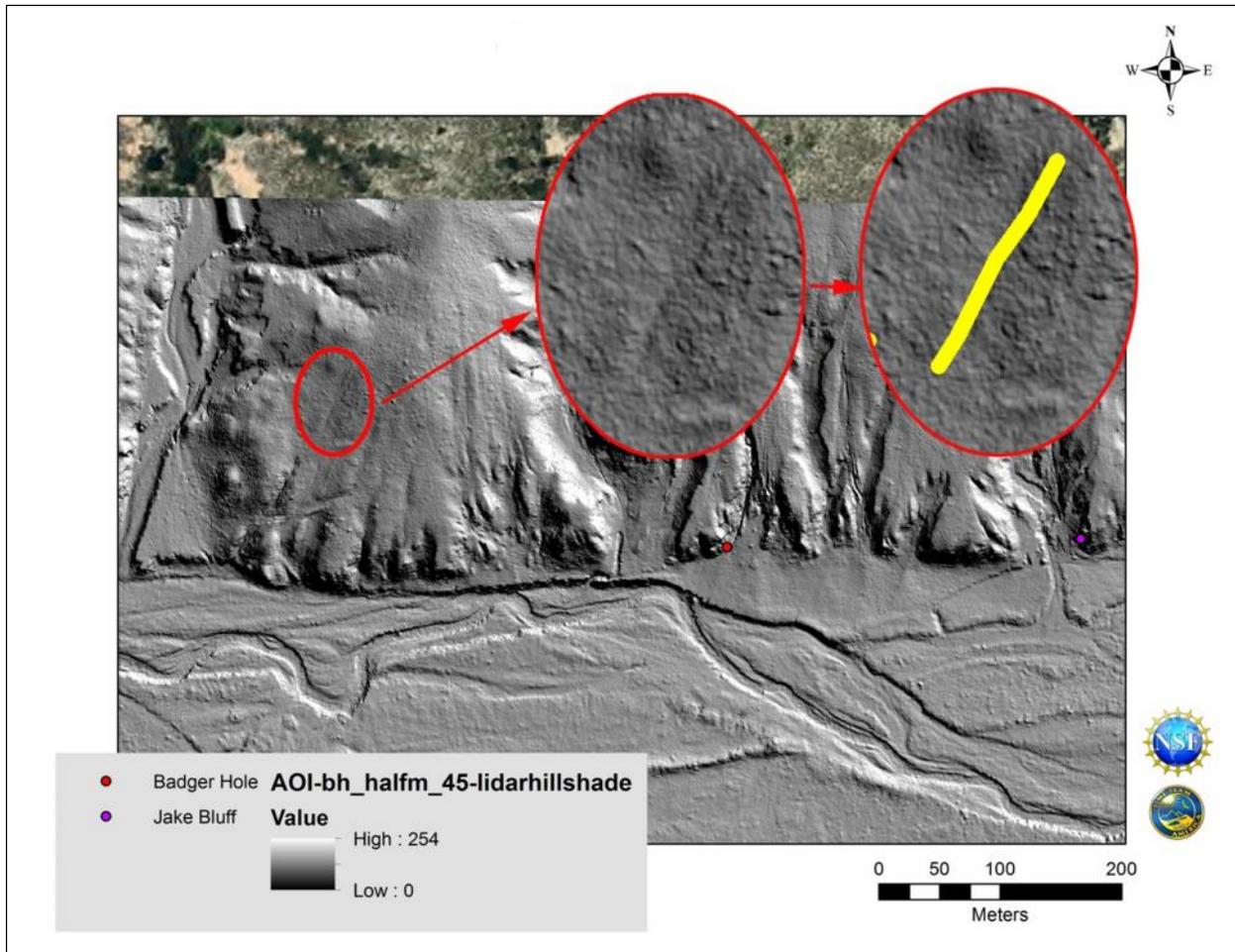


Figure 14 Hill shade LiDAR data with highlighted palaeo-arroyo feature as a slight depression on the ground surface.

The following day, Prof. Bement and Watters located one of the LiDAR features suggesting the location of a palaeo-arroyo. The feature was located and upon examination of the exposed soils in the cliff edge on the river plain, confirmed the feature was a palaeo-arroyo and soils are contemporary to the other three known bone beds Badger Hole, Jake Bluff, and Cooper. The LiDAR data reveals a number of potential intact arroyos and provides targets for ground-truthing in the future (Figure 15).

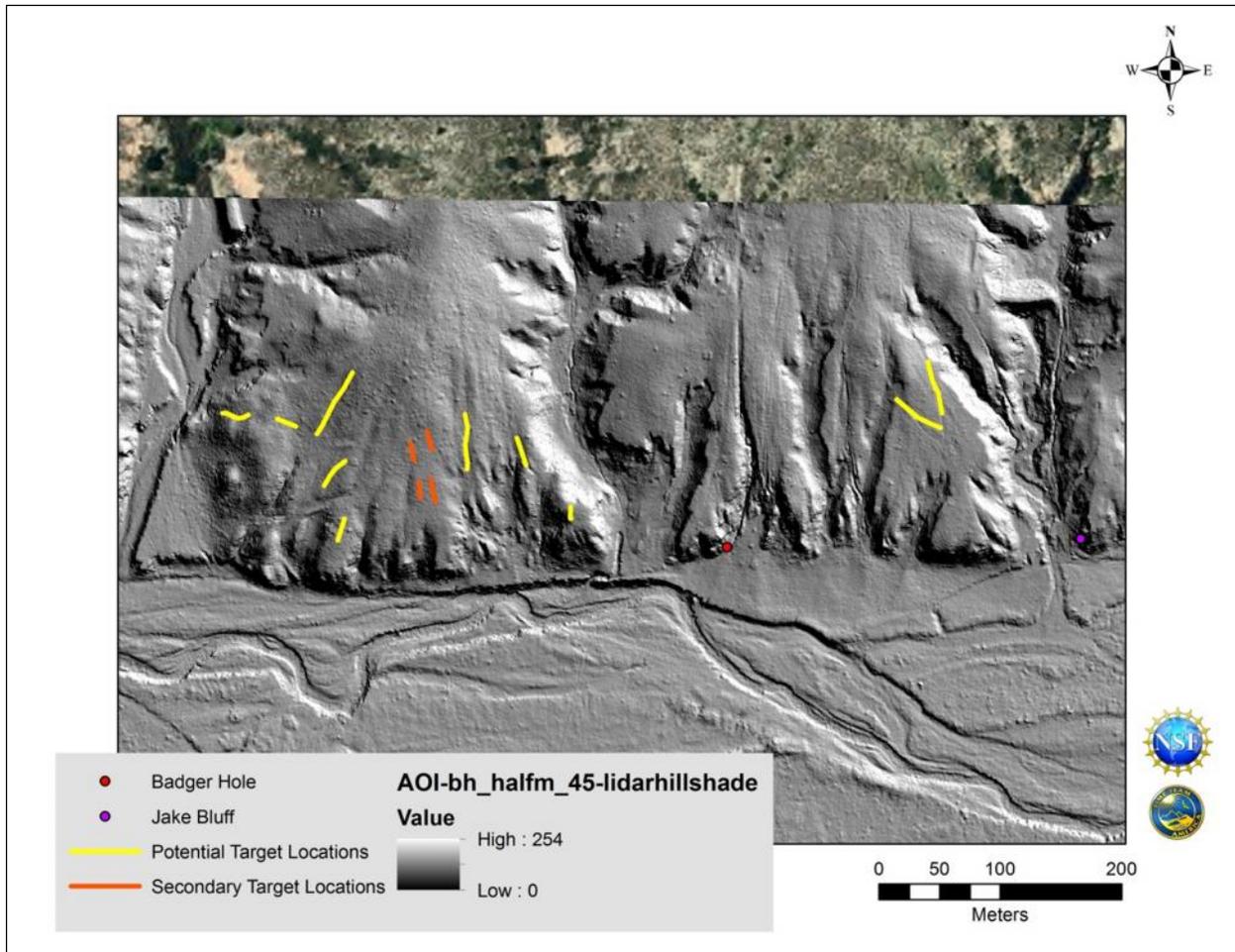


Figure 15 LiDAR data with interpreted palaeo-arroyos along the Beaver River plain.

## Conclusions and Recommendations

Out of the three geophysical survey methods that were used during Time Team America’s work at Badger Hole, ERI is the most effective tool. It is able to record the 3D structure of the subsurface in order to help unravel the complex stratigraphic record of this area. If future surveys are to be conducted, they should be high density (1.5 m electrode spacing, 2 – 3 m transect spacing) and should be inverted and modeled in 3D. Keep in mind that this survey method takes time, we completed only 3, 70m long transects in approximately 6-8 hours. While not able to map the detail of the bone bed itself, ERI has the potential to provide great insight to the site stratigraphy and provide insight to positioning excavation units.

The airborne LiDAR survey of Badger Hole produced information on the erosion of the area as well as potential locations of buried arroyos contemporary to the Badger Hole bone bed. By combining results from the LiDAR survey, ERI surveys, and coring future investigations can be focused specifically on locations with a high likelihood of containing ancient bison bone beds. The LiDAR data can also provide information on erosion in the region, helping plan future investigations focused either on ‘rescue’

targets (in areas of high erosion impact to the east of Badger Hole) or focused on targeting areas that may contain intact bone beds but are in danger of eroding (to the west of Badger Hole). This LiDAR survey can be used as a base line for comparison to data from future LiDAR surveys<sup>3</sup> to better understand the erosional effects, and rates, of the dynamic Beaver River.

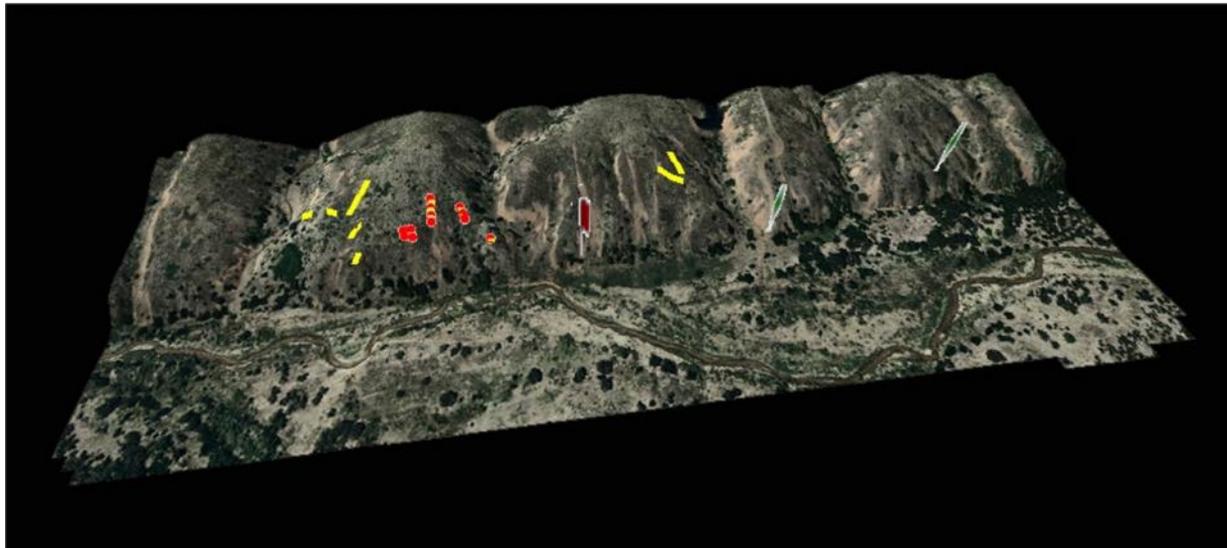


Figure 16 Badger Hole bison bone bed site (red flag) with interpreted potential intact palaeo-arroyos (yellow lines and red points).

## Acknowledgements and Credits

Acknowledgements and sincere thanks go to Professor Leland Bement, K.C. Carlson, and the University of Oklahoma Badger Hole field school for hosting our team, helping with the geophysical surveys, and their contribution to data interpretation and ground-truthing through excavation. Thanks also go to 'Dozer Dan' DeWeese who conducted the ground-truthing excavations with his back hoe and hosted our final day's filming and closing barbeque. Sincere thanks to the OK USDA coring crew Steven McGowen, Troy Collier, and Christopher Hobbs. Thank you to Brian Carter for his contribution of expertise in stratigraphy, site formation, and auguring at Jake Bluff in coordination with the GPR survey.

## Time Team America

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<sup>3</sup> State and Federal agencies are increasingly collecting LiDAR data, in particular along flood plains.

<sup>4</sup> Noel Broadbent, Smithsonian Institute is the other co-PI and Dave Davis from OPB is the project PI.

<sup>5</sup> [Round Rock Geophysics](#); PO Box 5668, Round Rock, TX 78683; T: 512 496 8728

Kinder, West Virginia University, Natural Resource Analysis Center, performed the LiDAR survey and delivered processed data to Watters.

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## References

Crutchley, S. and Crow, P. 2009. *The Light Fantastic: Using airborne LiDAR in archaeological survey*, Swindon: English Heritage.

David, A. and Payne, A. 1997. Geophysical Surveys within the Stonehenge Landscape: A Review of Past Endeavour and Future Potential. *Proceedings of the British Academy* 92:73-111.

Kvamme, K. 2003. Geophysical Surveys as Landscape Archaeology. *American Antiquity* 68 (3):435-457.