An Experimental Project to Conduct Digital Survey for Ring-Midden Features Using Lidar Data

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and

New Mexico Bureau of Land Management
Carlsbad Field Office

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San Andres limestone outcropping along the Box Canyon escarpment, situated in the Sacramento Mountain foothills.

Overview

The foothills of the Guadalupe and Sacramento Mountains in southeastern New Mexico lie within a rugged area of canyons and draws rising as high as 6,500 feet above mean sea level. Thin sediments blanket Permian-age dolomite and limestone formations. A variety of desert plant communities are found here, and various species of agave and sotol are common.

Human occupation of southeastern New Mexico began during the Late Pleistocene, more than 10,000 years ago, when the climate here was wetter and cooler than it is today. Lakes, springs, and cienegas (marshes) were common, and coniferous forests and woodlands covered the land. The climate became hotter and drier during the early Holocene, causing the water table to drop and many lakes and springs to dry up. Forest and woodland vegetation retreated to higher elevations. With these changes in vegetation and climate, a vast sand sheet was laid down by wind over the Mescalero Plain. By 8000 B.P., the vegetation had changed to desertscrub- and semi-desert-grassland, much like what is seen today.

Under the National Historic Preservation Act of 1966, the Bureau of Land Management (BLM) is responsible for the preservation of important archaeological and historic resources in its care. The foothills of the Guadalupe and Sacramento Mountains constitute the western portion of the area overseen by the BLM's Carlsbad Field Office. This vast area is known to contain a large number of archaeological features known as ring middens, which are important to understanding ancient lifeways and human adaptations in southeastern New Mexico. However, comparatively little of this area has been field-surveyed, and only a small portion of the ring middens likely to exist in the area have been identified and documented. In order to manage these resources and protect them from disturbance, the BLM needs to know where they are located. Locating all these ring middens through field survey alone would take decades and cost millions of dollars. This booklet describes an experiment by the BLM in applying more-efficient, digital methods to conduct a computerized archaeological survey for ring middens using data gathered remotely through aerial reconnaissance and lidar technology.

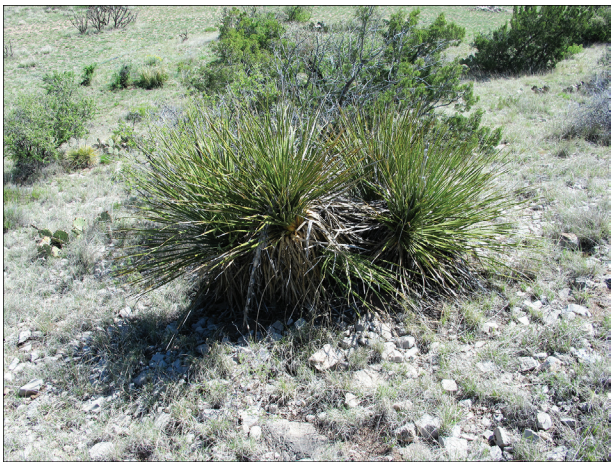
What are Ring Middens?

A "ring midden" is basically a pile of discarded material (a midden) in a ring shape. One of the most common archaeological features in the foothills of the Guadalupe and Sacramento Mountains, these features are interpreted by archaeologists as the result of repeated use of an earth oven—an earth-covered pit in which food is cooked using heated rocks. Each time an earth oven was used, fractured rocks and sediment were removed from the oven and raked out of the way, resulting in the formation of a large, ring-shaped deposit of fire-affected rocks surrounding the earth oven. Stockpiles of rocks intended for use as heating elements in earth ovens were also occasionally placed adjacent to ring middens for anticipated future use of an earth oven. As an earth oven was cleaned out and reused multiple times, the ring surrounding the earth oven would grow larger and taller, making these distinctive features highly visible from the ground surface.

Judging by the abundance of ring middens, earth ovens were used extensively in this region. The oldest ring middens here date from approximately 2500 B.C. Archaeological evidence shows an increase in use by approximately 500 B.C., and the most intensive use between A.D. 500 and A.D. 1450. Indigenous groups like the Mescalero Apache who lived here during the time of European occupation also used earth ovens. In southeastern New Mexico, agave and sotol appear to be the food resources that were most commonly processed in earth ovens, although other resources could have been processed as well.

The appearance of large ring middens in a region is taken to be one form of evidence for what archaeologists call resource intensification. The use of earth ovens indicates an attempt to exploit more food resources per unit area, likely in response to social and environmental pressures like population packing or drought. In other words, as the population in the region increased and the more readily available foods were depleted, earth ovens were used to make greater use of existing food resources—such as agave and sotol—that required extended cooking time to detoxify and render digestible. The use of earth ovens may have also been spurred by periods of drought, when more-easily attained wild resources or agricultural productivity dwindled. Earth ovens also make better use of limited fuel resources because the rocks used retain heat and radiate it slowly, unlike open fires, which dissipate heat immediately. This becomes important when fuel resources in a region are depleted by drought or increased settlement and land use.

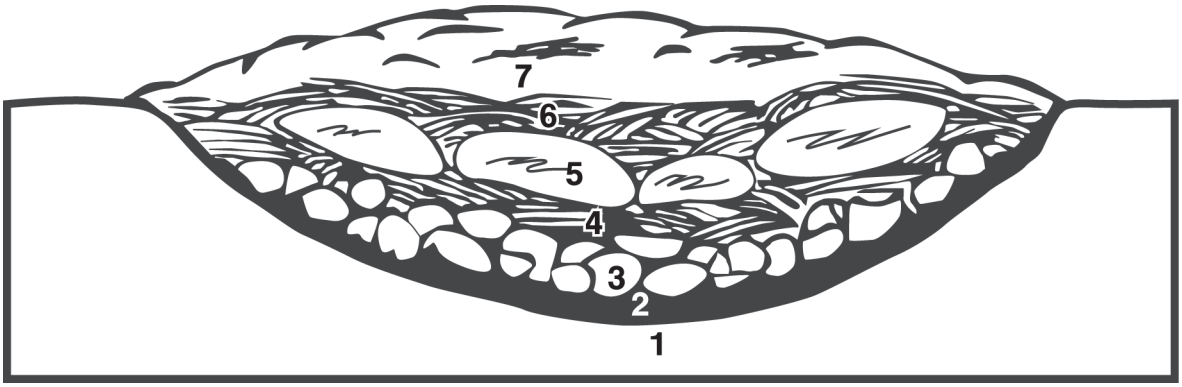
One of the great advantages to the study of ring middens is that, because they have a unique, recognizable shape—a circular above-ground midden surrounding a central depression or pit—they are highly visible on the landscape. Most known ring middens were discovered during archaeological pedestrian survey—that is, by archaeologists walking across a specific area in regularly spaced, linear strips of land, or transects, closely inspecting the ground surface in search of archaeological remains. But the BLM administers large areas of land in south-eastern New Mexico, and only a small percentage of that land has been surveyed by archaeologists. Surveys in some areas of southeastern New Mexico, such as in the foothills of the Guadalupe and Sacramento Mountains, have found ring middens to be very numerous, often occurring in clusters. This suggests that there may be thousands more ring middens on BLM lands than have been documented by survey.



Example of green sotol (Dasylirion leiophyllum) observed at LA 181702.

Example of slimfoot century plant or slim-footed agave (Agave gracilipes) observed at LA 181702.

Example of a large ring midden. Note the raised berm of fire-cracked rock surrounding the central roasting pit.



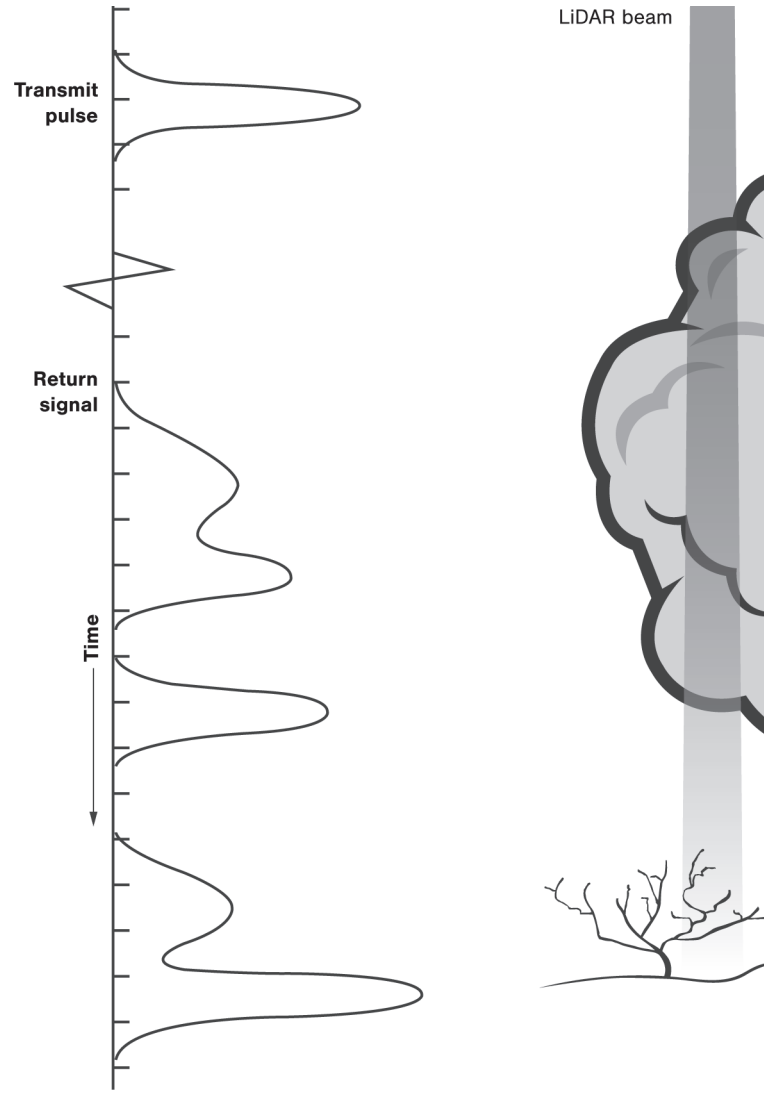
Schematic of an earth oven showing the various components proposed by Black and Thoms (2014): (1) oven pit; (2) fire; (3) hot rocks; (4) plant material (packing); (5) food; (6) plant material (packing); (7) earthen cap. Adapted from Black and Thoms (2014:206).

Ring Middens and Lidar

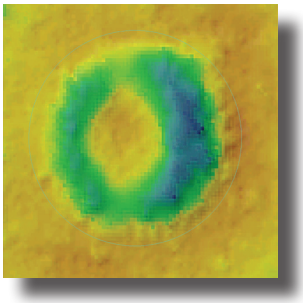
In order to manage and study these resources, the BLM needs to have a better idea of where they are—or are most likely to be—and where they may be most threatened by disturbance or land use. Locating all the ring middens on these BLM lands by pedestrian survey would take decades and considerable effort. However, the unique shape and prominence of ring middens suggest that they may be particularly suited to disovery by other, more efficient, digital methods, like remote sensing.

Remote sensing refers to various ways of collecting information about the physical Earth using non-contact methods, which can range from simple photography to measuring the intensity of electromagnetic radiation. One method particularly well suited to archaeology is lidar (an acronym for light detection and ranging), which uses laser light in a way similar to how radar uses radio waves. A lidar unit scans a given area with numerous pulses of laser light and uses a sensor to measure the amount of time it takes for the reflection of each pulse to bounce back. Software can then calculate the distance between the sensor and the target, and as this distance data accumulates, construct an image of the area being scanned. The collection of lidar data permits the creation of high-resolution topographic maps that can be used in a geographic information system (GIS) to identify and map archaeological and other features across a landscape surface.

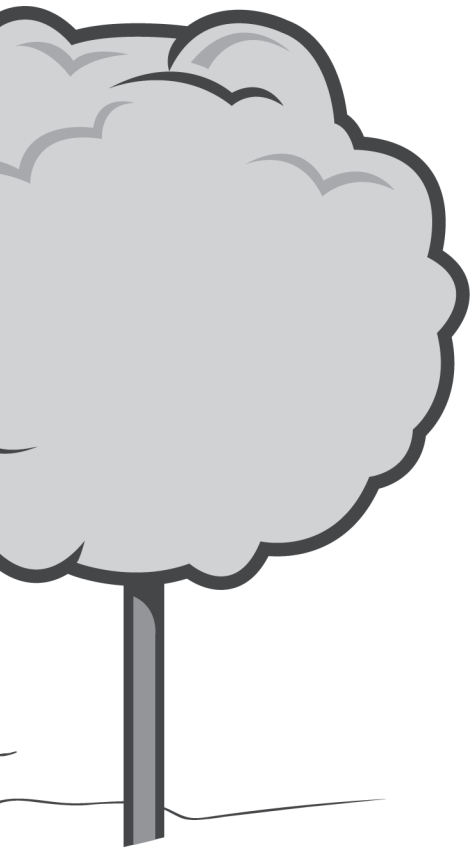
For this project, the BLM tasked Statistical Research, Inc. (SRI), with conducting a digital survey for ring middens in three study areas using aerial lidar data. These study areas are quite large, and despite the considerable efficiency of digital survey compared to field survey, the scope and funding of this project did not allow SRI to complete a full digital survey of the study areas. However, the methods for visualizing ring middens developed for this project may easily be applied across the entire study area in the future. The purpose of this project was to collect lidar data, develop methods for visualizing ring middens using this data, test whether ring middens could be located using the data, predict where the middens are likely to be located, survey portions of the three study areas, and test whether the digital approach is effective by ground-truthing a sample of the middens that were identified digitally.



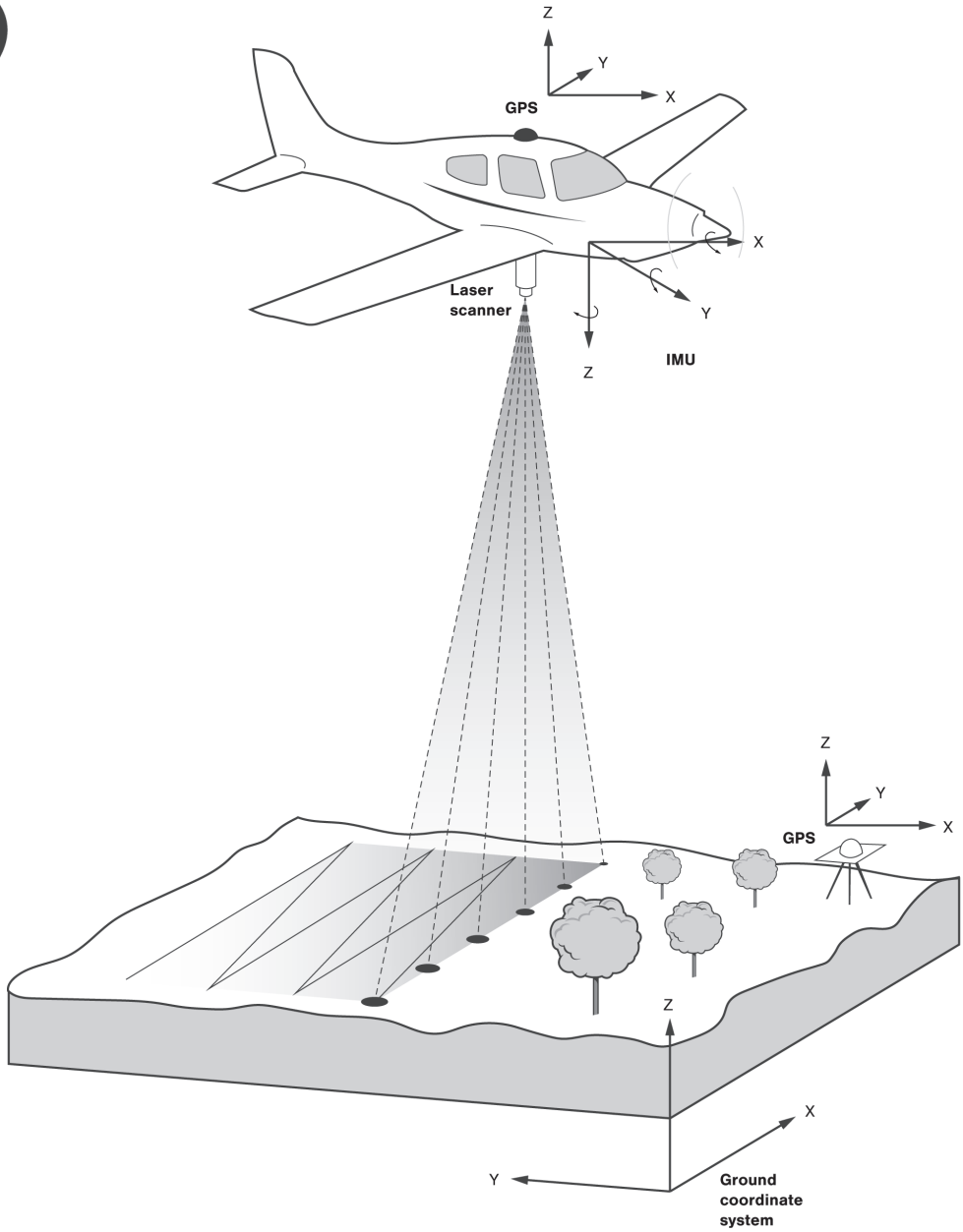
The lidar pulse and return. Adapted from Lillesand and Ki



Possible ring midden visualized rim lidar data.



efer (1999).



The airborne lidar system (ALS) survey method. GPS = Global Positioning System; IMU = inertial measurement unit. Adapted from Lillesand and Kiefer (1999).

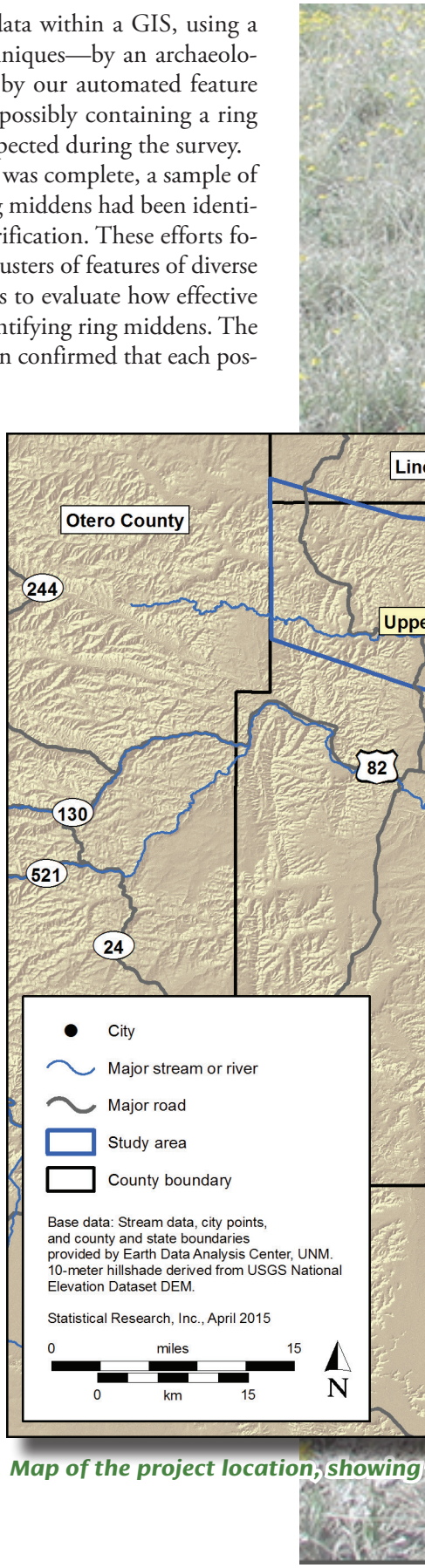
The Project Approach

The three study areas—Azotea Mesa, Box Canyon, and Upper Rio Felix—lie west and northwest of Carlsbad, New Mexico. The Azotea Mesa study area is approximately 54 square miles, the Box Canyon study area is approximately 64 square miles, and the Upper Rio Felix study area is approximately 254 square miles. Each of the three study areas contain entire drainages, including both named and unnamed tributaries of Box Canyon, Rio Felix, and West Fork Little McKittrick Draw.

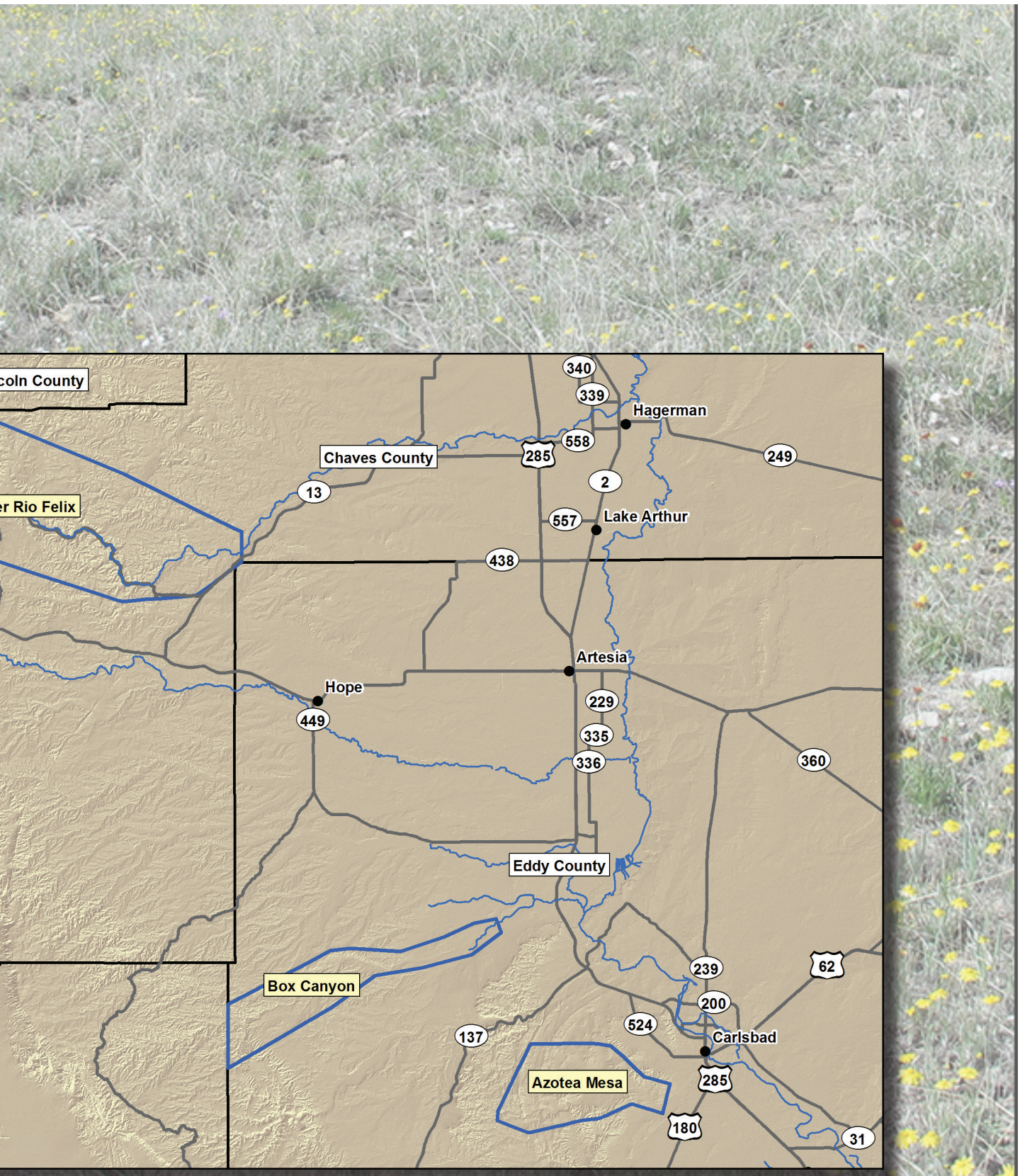
SRI hired Surdex Corporation to obtain aerial lidar data for each of the three study areas. SRI used the locations of known ring middens to develop a way to identify middens in the lidar data and to create a mathematical model predicting where within the three study areas ring middens were more or less likely to be located. The size-and-shape characteristics of known ring middens were then used to create an automated GIS method for identifying similar characteristics in the lidar data. Based on the results of the location model, a sample subset of each of the three study areas was selected and subjected to a systematic digital survey—a detailed inspection of the data within a GIS, using a variety of visualization techniques—by an archaeologist. Each location flagged by our automated feature identification algorithm as possibly containing a ring midden was also closely inspected during the survey.

Once the digital survey was complete, a sample of the areas where possible ring middens had been identified was chosen for field verification. These efforts focused on ground-truthing clusters of features of diverse sizes, shapes, and conditions to evaluate how effective the digital survey was in identifying ring middens. The results of the field verification confirmed that each possible ring midden identified digitally was, in fact, a ring midden. However, the digital survey did not properly identify ring middens with very low relief or that had been disturbed to the point where their shape was altered.

Upper Rio Felix Canyon in southeastern New Mexico.



Map of the project location, showing



the three study areas: Azotea Mesa, Box Canyon, and Upper Rio Felix.

"Filling the Pit." Edward S. Curtis, Spring 1906, south of Black River; NAA Neg. No. 76-4670, SIRIS No. NAA INV 3012400.

Earth Ovens: An Ancient Technology of Modern Importance

For thousands of years, people throughout the world have used earth ovens to cook food. The basic principle is relatively simple: scarce fuels are used to heat rocks that retain and slowly radiate the heat from the fire to cook food for an extended period within an insulating earthen covering. Often, the foods used require a long cooking time to break down toxic chemicals and render them safe and nutritious to eat. To build an earth oven, a pit is dug in the ground and a fire is made within the pit. Rocks are placed within the fire amongst the coals to absorb heat and act as heating elements, storing and slowly radiating heat that would otherwise escape into the atmosphere. The heated rocks and coals are then covered with a bedding of green plant materials upon which the food to be cooked is placed. The uncooked food is then covered with additional green plant material that envelops the food and protects it from direct exposure to hot rocks, coals, and earth used in constructing the earth oven. The package of food is then covered with earth collected from around the oven. This covering insulates the contents of the oven, preventing heat from escaping into the atmosphere and greatly extending the time during which the food can be cooked using a given amount of fuel.

Archaeologists believe that in the American Southwest, earth ovens were used primarily to cook plant foods. Meat, which generally did not require the lengthy cooking times needed for some plant foods, was cooked in earth ovens in other areas. The major plant foods that archaeologists believe were cooked in earth ovens in southeastern New Mexico were agave and sotol. These plants have large, carbohydrate-rich central stems, or "hearts," that can be trimmed of their leaves and cooked to prepare a nutrient-rich and storable food supply. Uncooked, agave and sotol contain complex carbohydrates, such as inulin, that plants use to store energy. Some subspecies and plant parts may also contain toxins that must be broken down before the plant is safe to eat.

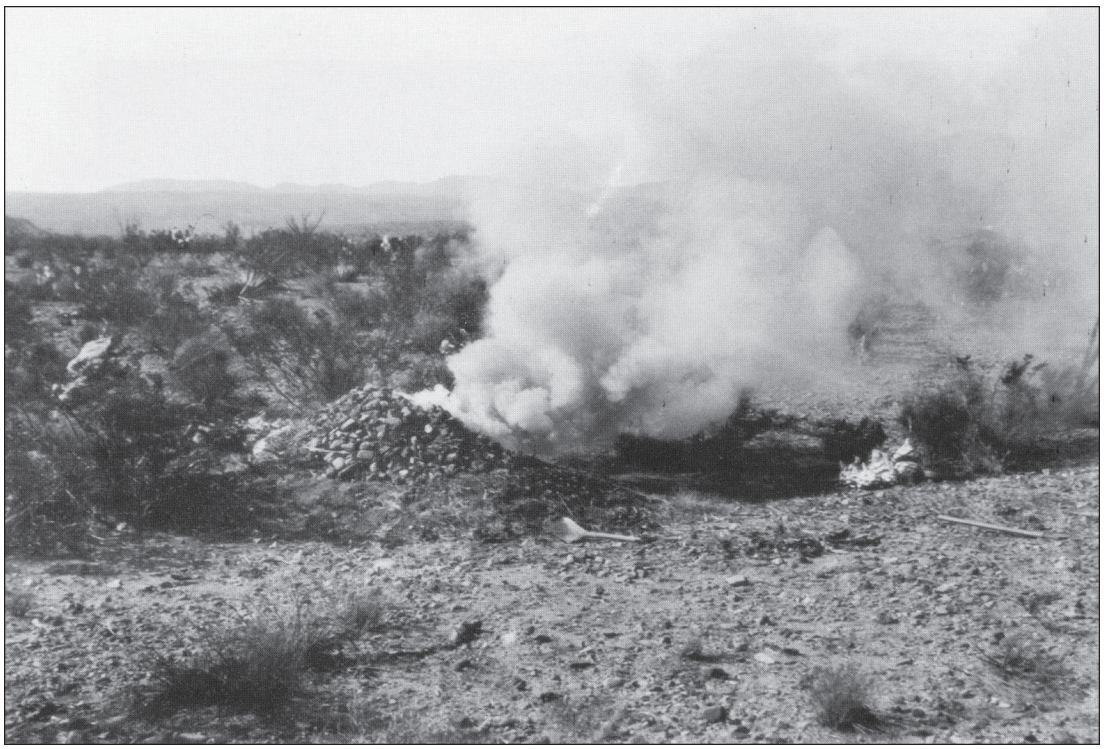
In humans, inulin cannot be digested in the stomach or small intestine and is instead metabolized by bifidobacterium residing in the colon. Consuming raw inulin has some positive health benefits in that it can prevent constipation and support the growth of beneficial bacteria living in the colon. When cooked

for long periods, however, the long polymer chains of inulin molecules are broken down, producing fructose and glucose. These more simple sugars are very sweet to the taste and are more readily digested than the inulin from which they are derived. In other areas of the American Southwest where earth ovens were common, such as in west-central Texas, the major foods cooked in earth ovens were small geophytes, such as wild onions, that contained similar chemicals that required breaking down to make them digestible.

Ethnographers have documented the use of earth ovens by indigenous people in many parts of the world. The basic technology is similar among many groups, but the ways in which the technology is implemented and the specific characteristics of the ovens differ according to the environment and the food being cooked. In New Mexico, ethnographers have documented Mescalero Apache cooking agave. Agave hearts were trimmed and collected just prior to the plant beginning to flower. The window of opportunity for collecting these plants was a matter of weeks, requiring the plants to be closely monitored. If collected too late, the carbohydrates stored in the heart would be used by the plant to support flowering, decreasing the nutritional content and palatability of the food to be cooked. Since the flowering time of agave is later at higher elevations, the harvesting season could be extended by moving to higher elevations to harvest plants as they were ready to flower. Once harvested, the agave hearts had to be cooked within a few days to prevent spoiling. Multiple hearts were heaped within an individual oven. When fully constructed and covered with earthen packing material, such ovens may have extended a meter or more above the ground surface, resembling a small, dome-shaped hump with smoke coming out of it.

Agave and sotol were cooked from 24 to 72 hours. Once a sufficient cooking time had elapsed, the earth oven was opened up and the food taken out. The cooked food, still warm from the fire, was kneaded into cakes or loaves that could be dried in the sun or further baked to remove moisture. The resulting dried food product could then be stored for long periods, sometimes for years, providing a valuable source of nourishment in times of scarcity or drought.

A great advantage of earth ovens in southeastern New Mexico is that they made useful an otherwise unusable food source. In the dry and fuel-poor desert grassland of southeastern New Mexico, the efficiency of earth ovens also allowed people to conserve scarce and fast-burning fuels, and because the fast-burning fuels that are more common in the desert could also be used to heat the rocks used as heating elements, the rarer and slower-growing hardwoods—which can be



"Heating the stones for cooking the century plants." Pliny E. Goddard, 1914, Calva, AMNH Neg. No. 242716.

"Tbe pit containing the century plants while cooking." Pliny E. Goddard, 1914, Calva, AMNH Neg. No. 242720.

rapidly depleted in these environments when used as fuel—could be conserved as well.

Some archaeologists have argued that earth-oven use may often be a response to population packing and related intensification of the available resources in a given area. This theory is based on the idea that, as the population of a given area grows, more food must be extracted or produced using the same land area. This requires the use of different and less accessible food sources, as well as greater investments in processing technologies, such as earth ovens, that extract more nutrients from the food and allow it to be stored for longer periods. A negative consequence of using plants like agave and sotol for food is that communities of these plants can be swiftly depleted unless carefully managed. The long time needed for such plants to mature enough to be useful as a food source means that decades may be required for the plant community to regenerate when overexploited. In some areas of the American Southwest, agave was deliberately cultivated to be used as a food source, but it is not clear whether cultivation of these plants was practiced in southeastern New Mexico.

Research suggests that earth ovens were reused several times. Perhaps this was because they were located near sources of the foods and/or fuels used in them. Suitable rocks and earth for covering were also needed. These raw materials could have been more readily available in some areas than in others, and it was likely most efficient to create earth ovens in areas where the multiple resources needed (green plant material, rocks, earth, and agave or sotol) were most accessible. Moreover, less effort was required to open and clean a previously dug pit than to dig a new pit. Some of the sediment and rocks used for previous cooking episodes could also be reused. As populations grew, individual earth ovens may have been used repeatedly by social groups that maintained a claim to the resources of a particular area. Establishing land tenure and rights to particular resources may have been necessary under conditions of population packing and resource intensification that gave rise to greater use of earth ovens.

Rocks used as heating elements, as in an earth oven, are subject to thermal stress that causes them to fracture and spall. Large rocks are preferred, because they can retain heat for longer periods. As heated rocks fracture and break apart into smaller and more angular rocks, they retain less heat and radiate it faster, losing their efficiency and effectiveness as heating elements. Thus, as the rocks originally placed within an earth oven broke into smaller pieces, they were removed from the earth oven and discarded, to be replaced with larger, more energy-efficient rocks. The fractured rocks, along with the earthen covering removed to extract the cooked food, were raked out and discarded in an increasingly large ring, eventually extending as much as 1–2 m above the surrounding ground surface. Theoretically, the amount of rock that built up in this discard midden is related to both the amount of rock placed in an oven for a typical cooking episode and the number of cooking episodes that were undertaken in an individual earth oven. Archaeologists have documented discard middens ranging from few hundred fire-affected rocks to hundreds of thousands of rocks piled high in massive middens that weigh several tons.

Archaeological evidence indicates that individual earth ovens were reused over extended periods of time. Chronometric dating (such as radiocarbon) and indirect dating (using artifacts known to date from particular times to assign a date to an associated feature) of earth ovens indicates that some were used intermittently over the course of centuries or, in some cases, millennia. One of the problems with dating the use of earth ovens, however, is that their repeated reuse resulted in the mixing of materials from multiple cooking episodes. This makes it difficult to isolate cooking episodes.

Another problem with dating a ring midden is that the earth heaped onto the oven for insulation is likely to have introduced artifacts and cultural deposits from other parts of a site that are unrelated to when and how the oven itself was used. Archaeologists have found various kinds of artifacts in ring middens that suggest that multiple activities took place in the vicinity of an earth oven in addition to the cooking of succulents, such as the preparation of other foods or the manufacture or repair of tools and other items. However, such artifacts may just as easily have had little or nothing to do with that particular use of the earth oven.

Despite these problems, radiocarbon dates obtained for ring middens in southeastern New Mexico are useful for gaining a generic understanding of when earth ovens were used and how intensively they may have been used during different periods. While substantially more work is needed to better understand the chronology of earth-oven use, it appears that they were especially important as agricultural villages came to be settled in the surrounding region, leading to population growth and greater restrictions on the availability of land and resources that could be used to support local populations. Periodic droughts that further diminished available resources may have also made desert plants like agave and sotol more attractive, resulting in more frequent and intensive use of earth ovens during droughts to address food scarcity.

The Use of Digital Technology in the Study of Ancient Technology

Lidar systems can be classified into two groups: stationary and mobile. A stationary system consists of a sensor mounted on a tripod. This kind of system is used for scanning specific stationary targets that need to be mapped accurately and precisely in three dimensions, such as buildings or bridges. Stationary systems are also used in land survey and small-scale terrain mapping, such as in the mapping of an individual archaeological site or landscape feature.

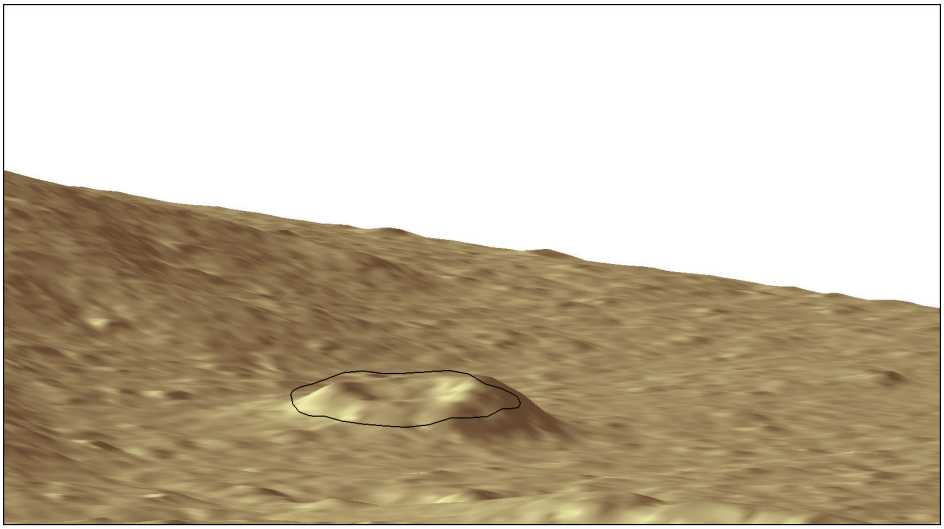
A mobile system can be mounted on a truck, boat, or airplane and is used to map large areas that cannot be directly accessed using a stationary system. Because it is moving through space as measurements are taken, a mobile systems must include a navigational system so that both the location of the target and the sensor can be known for each measurement made by the system. Mobile systems are used for large-scale projects, such as the mapping of utility corridors, railroads, or shorelines, and are particularly useful for conducting high-resolution topographic mapping over large areas, as was done by Surdex Corporation for this project.

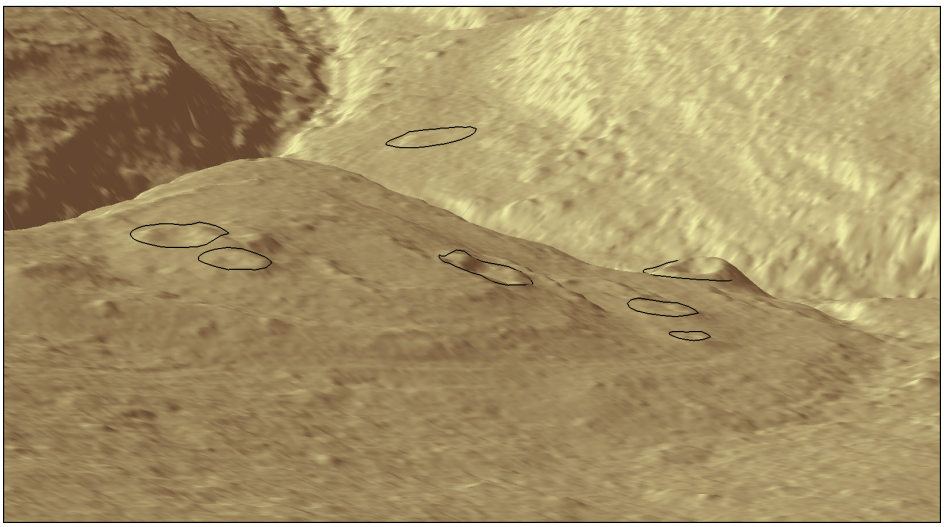
To map the three study areas for the current project, an airborne lidar system was used. Such a system has three components: a lidar sensor that sends the laser pulse and measures its return time and intensity, an inertial navigation system that measures the direction and speed of the sensor as it moves through space, and a differential Global Positioning System (GPS) unit that records the location of the sensor in x, y, and z dimensions. An airborne lidar survey can cover about 50 km^2 per hour, depending on the speed and altitude used to conduct the survey.

Lidar measurements result in a dense point cloud consisting of millions of points that record the shape of a land surface as well as surface features, such as trees or buildings. Accurate recording of the spatial location of each point in the lidar data requires the use of ground control, consisting of several GPS base stations. These continuously record GPS satellite data that are needed to correct the spatial location of points in the lidar data. Once collected, the lidar data are processed with software that removes noise and places each point accurately in space with respect to a geographic coordinate system. Each point in the lidar data is also classified into standard classes (such as bare ground, low vegetation, building, or water) that allow landscape features to be differentiated and mapped.

ASPRS Standard LIDAR Point Classes

Classification Value (bits 0:4)	Meaning
0	Created, never classified
1	Unclassified
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key-point (mass point)
9	Water
10	*Reserved for ASPRS Definition*
11	*Reserved for ASPRS Definition*
12	Overlap Points
13-31	*Reserved for ASPRS Definition*



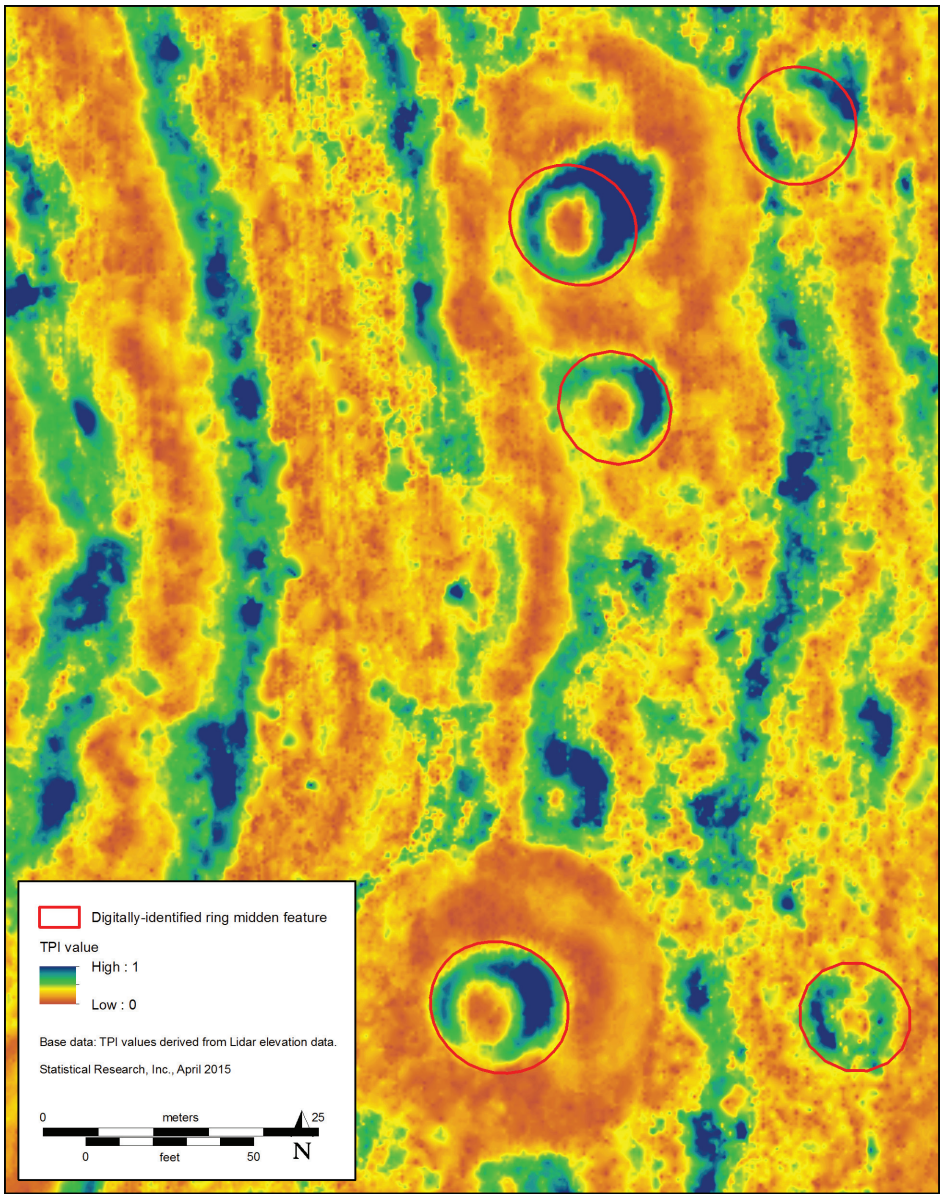


(Top) three-dimensional rendering of a ring midden identified on Azotea Mesa during digital survey; (bottom) three-dimensional rendering of a series of ring middens clustered around a drainage confluence on Azotea Mesa.

Visualization of the Lidar Data

Visualization refers to the methods used to observe patterns in remotely sensed data, such as lidar data. Lidar data can be processed to produce a number of "layers" in a GIS application that can represent the land surface, buildings, power lines, roads, or other elements of the landscape. The most common product created using lidar data is a digital elevation model (DEM)—a grid of uniformly sized cells, each with its own elevation, that together represent the topography of the land surface as measured by the lidar system. The points in the lidar data are divided into a standard set of classes, such as bare ground, building, water, or low vegetation. This is important, because classifying the lidar data inappropriately can have the effect of erasing archaeological features, as points corresponding to small archaeological features protruding above the land surface may be misclassified as low vegetation. For the current project, DEMs for individual survey areas were made using points classified as either bare ground or low vegetation and at an especially high resolution so that ring-midden shapes could be recognized in the data.

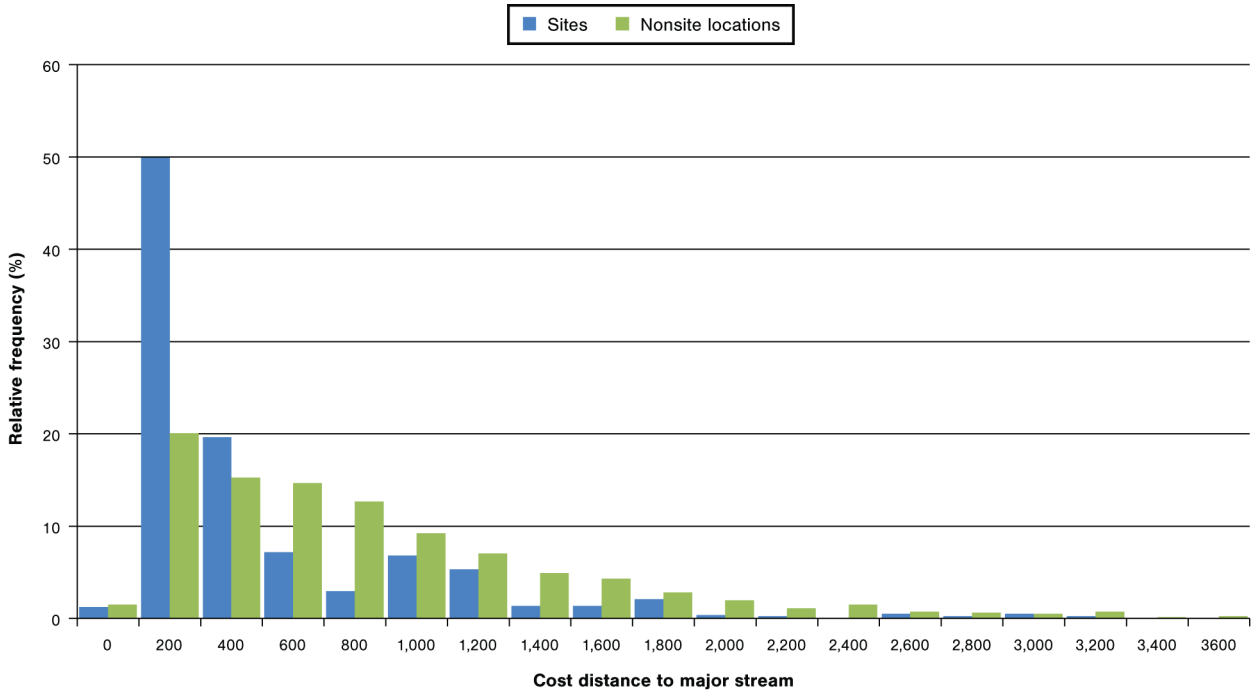
By itself, a DEM is not very useful for identifying archaeological features. The DEM must be transformed into other representations of the land surface that can be used to more clearly distinguish different characteristics of that surface, such as slope and aspect. One of the most common GIS layers derived from a DEM is a hillshade. A hillshade is made by modeling



A cluster of ring middens identified during digital survey, as visualized using the topographic position index (TPI).

a light source, like the sun, as shining on the land surface from a specific angle and direction. The modeled light source, along with elevation data from the DEM, is used to create a surface that looks like a landscape when viewed from above, as if from a plane. Hillshades are commonly used to identify archaeological features using lidar data, but, like DEMs, they have limitations. When visualizing lidar data to look for archaeological features, it is useful to also create layers that make different characteristics of those features stand out more clearly in order to distinguish the feature from background noise.

We experimented with a variety of visualization techniques to find what works best in visualizing ring middens in the three study areas. We found that, in addition to hillshades, two techniques for representing the land surface worked well: topographic position index (TPI) and local relief model (LRM). TPI layers use elevation values within a neighborhood of grid cells to identify whether a specific grid cell is high or low with respect to the grid cells in its immediate vicinity. This allows us to clearly identify a ring-like shape in the lidar data and to hone in on possible ring middens during digital survey. Creating an LRM is another way to visualize the lidar data. An LRM essentially removes broad-scale changes in topography from the data so that small-scale, local changes in relief, such as ring middens, are more easily recognized. Particularly when viewed in combination with a hillshade, an LRM makes the shape



Frequency diagram comparing cost distance to nearest major stream of sample sites and nonsite locations.

of a ring midden stand out clearly in comparison to the surrounding land surface.

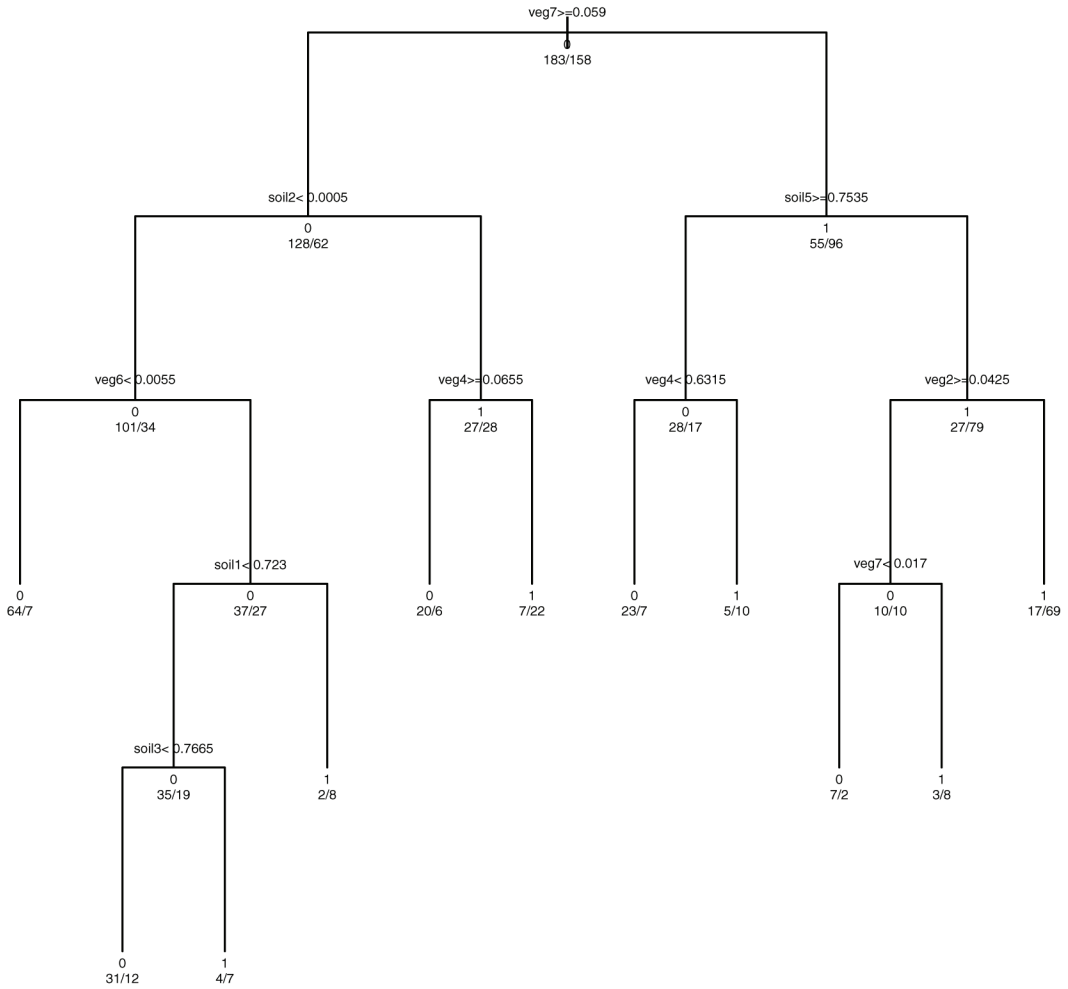
Ring-Midden Modeling

In addition to processing the lidar data in order to better see ring middens in a GIS, SRI also created two models to help find ring middens in the lidar data. The first was a model of the environmental factors that make for a likely ring-midden location. This was created by analyzing the relationships between archaeological sites with ring middens and several environmental variables in comparison to surveyed locations where no such sites have been found. The environmental variables that were examined included soil attributes, distance to water, distance to stream confluences, elevation, slope, aspect, topographic position, and various measures of topographic ruggedness and relief. How each of these variables corresponded to the locations of known ring middens was evaluated.

The results indicated that, in comparison to non-site locations, sites with ring middens tend to be closer to streams and confluences and are located at lower elevations above water than non-site locations. Sites with ring middens also tend to more often be located at lower mid-slope positions, in comparison to non-sites, and to be located in areas of lower relief, topographic ruggedness, and slope than non-site locations. The biggest differences were in distance to streams and confluences and elevation above water.

Using the most important environmental variables and a sample of ring-midden sites and nonsite locations, a statistical model was created using a sophisticated modeling method called Random Forests. The Random Forests method essentially takes a sample of cases of site and nonsite locations and a sample of the variables used to predict site and nonsite locations to create a decision tree that specifies the conditions under which sites are expected or not expected to occur. The algorithm performs this process of sampling variables and cases thousands of times, resulting in the creation of thousands of individual decision-tree models. These are then statistically compared to arrive at a model that combines the best aspects of all the individual decision trees. The result is a model that performs best based on a robust analysis of all the cases and variables used to create the model.

The resulting statistical model was then used to create a sensitivity map that divides the study areas into

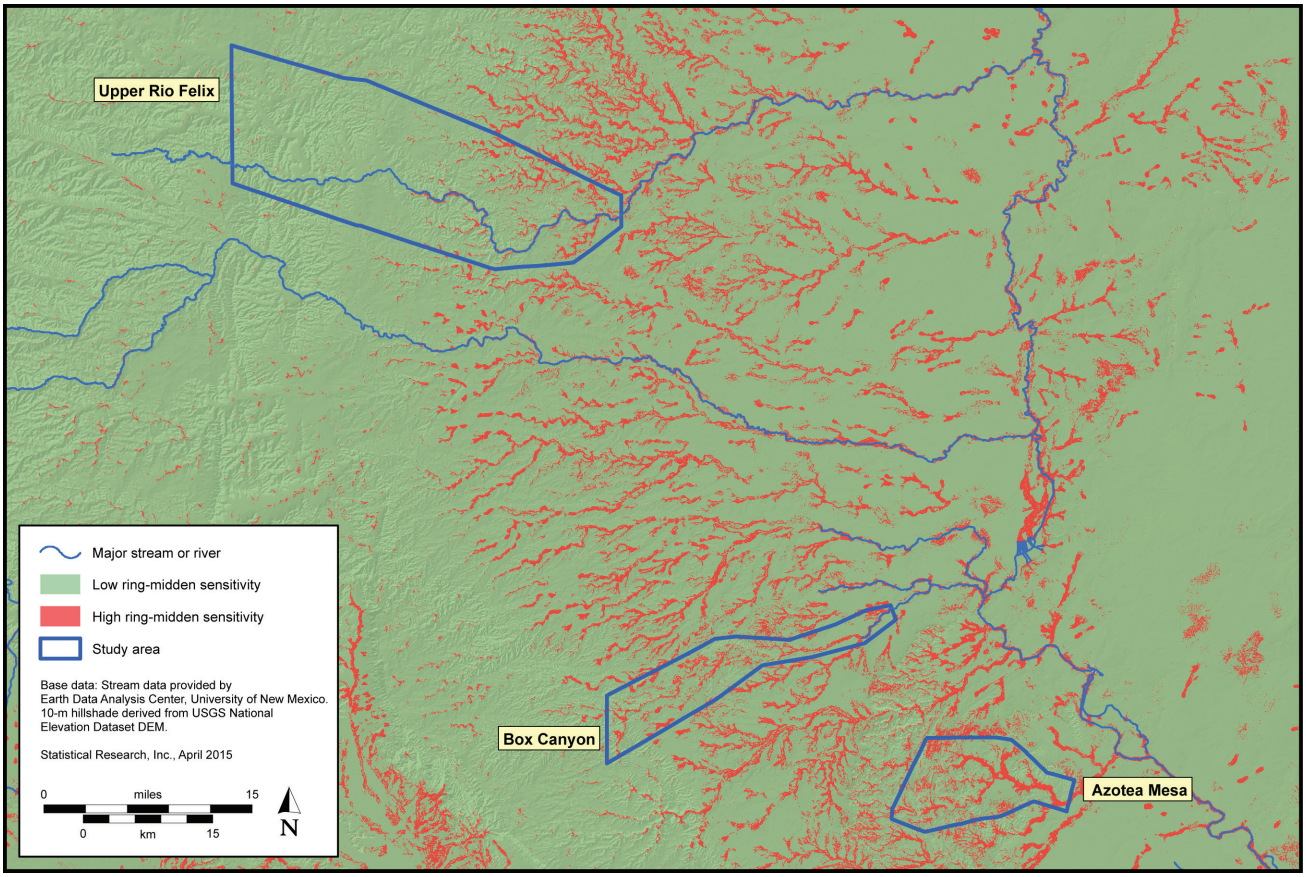


Example of a Random Forests tree graph, showing the variable states for which parent nodes are split into child nodes for a binary response variable: e.g., site presence or absence.

zones where there is a high likelihood of ring-midden sites and a low likelihood of ring-midden sites. The predictive ability of the sensitivity map was tested using a sample of ring-midden sites and surveyed nonsite locations that were not used to create the underlying statistical model. Measures of model performance indicated that the model appears to work well in differentiating zones within the study areas where ring-midden sites are more or less likely to occur.

In addition to the statistical model, we also created a process for filtering the lidar data to identify specific topographic features that meet the shape and size characteristics of ring middens, a process we refer to as automated feature identification. So, whereas the locational model discussed earlier identifies broad zones where environmental conditions suggest that ring middens are likely or not likely to be present, the automated-feature-identification process, by contrast, attempts to identify individual ring middens by finding local topographic features that match those of ring middens. These kinds of models are difficult to develop, because they have a tendency to generate a large number of false positives. However, they can be useful in narrowing the search for features when faced with examining large amounts of remotely sensed data.

To create the model, we developed a series of expectations about where in the lidar data the size and shape characteristics of ring middens are met, based in part on measurements taken in a GIS of known ring middens. The measurements, derived by generating 3-D profiles of the middens from the GIS data, included height, span, the difference in height between the central depression and the highest portions of the midden, and the estimated aboveground volume of the midden. We also identified a number of conditions wherein topographic features that share some characteristics with ring



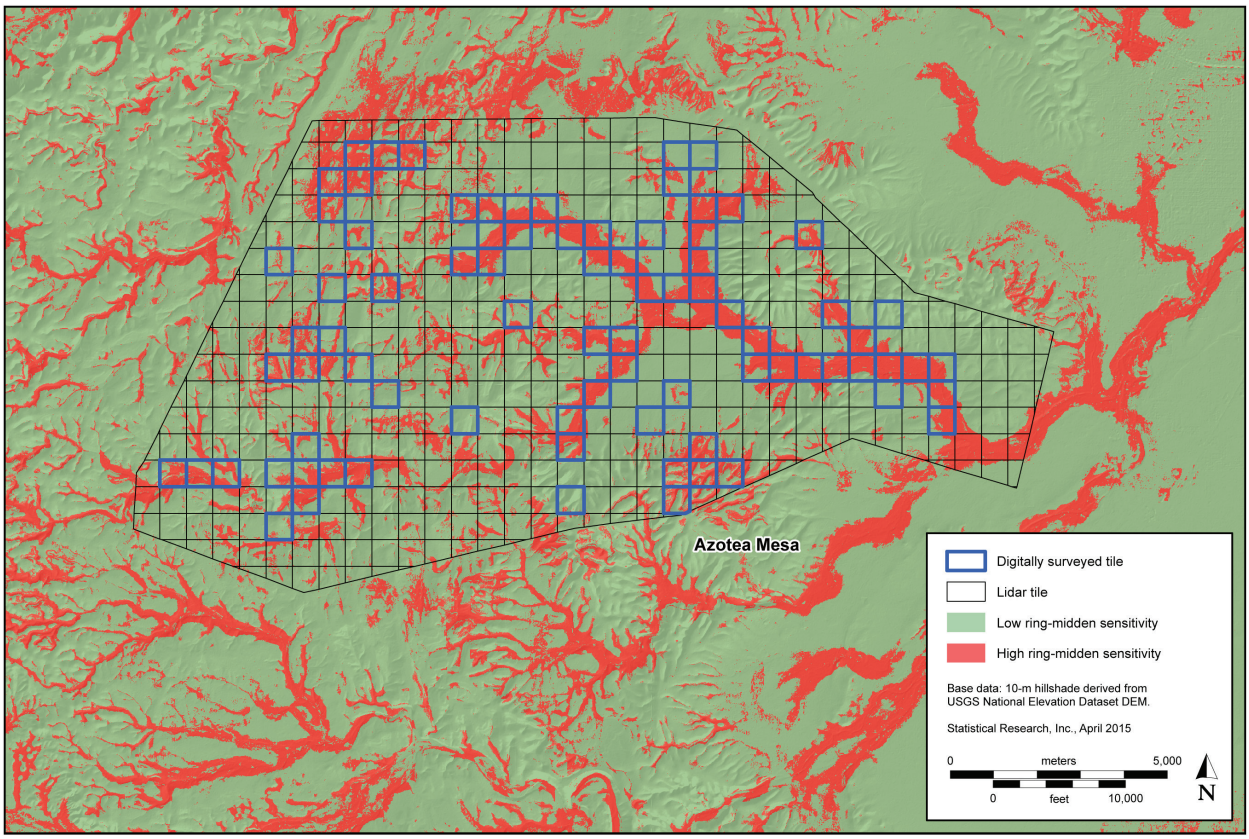
Preliminary sensitivity model encompassing the three study areas.

middens but lie within areas where ring middens are unlikely to exist—essentially, areas that are rugged or on steep slopes—can be ruled out as possible ring-midden locations. Using these expectations and conditions, we then created an automated process that generates a series of layers in a GIS, evaluates a series of conditions, and then creates a layer of point locations where possible ring middens could be located.

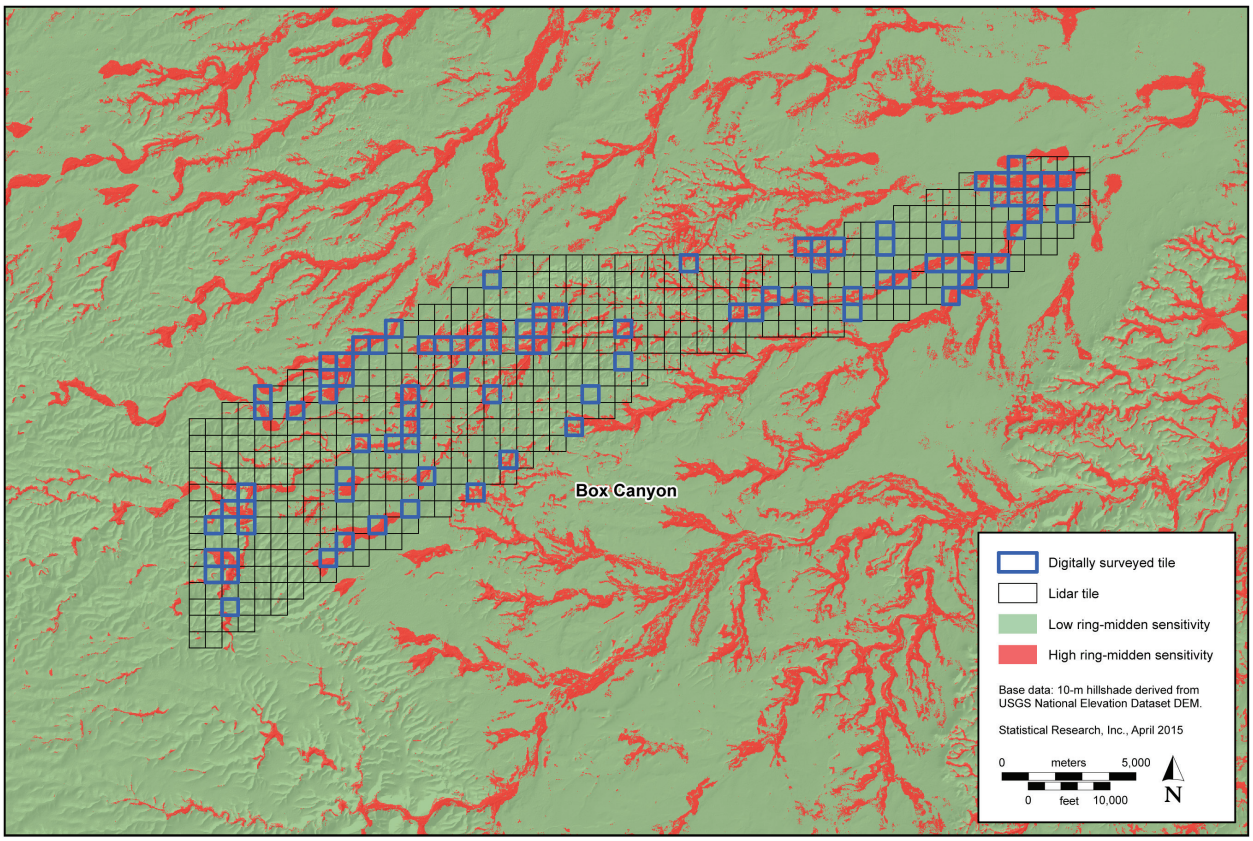
A common problem with this kind of automated feature extraction is striking a balance between generating a large number of "hits," many of which may be false positives, and strictly limiting the number of possible features identified. Taking a conservative approach with respect to missing any real ring middens, we opted to cast a wide net. This approach was successful in identifying many of the ring middens in our sample of known ring middens, but it also resulted in a large number of possible features that, upon close examination, were not likely to be ring middens. In any case, the approach demonstrates some promise for being able to identify ring middens and could likely be improved to reduce the number of false positives.

Digital Survey Approach

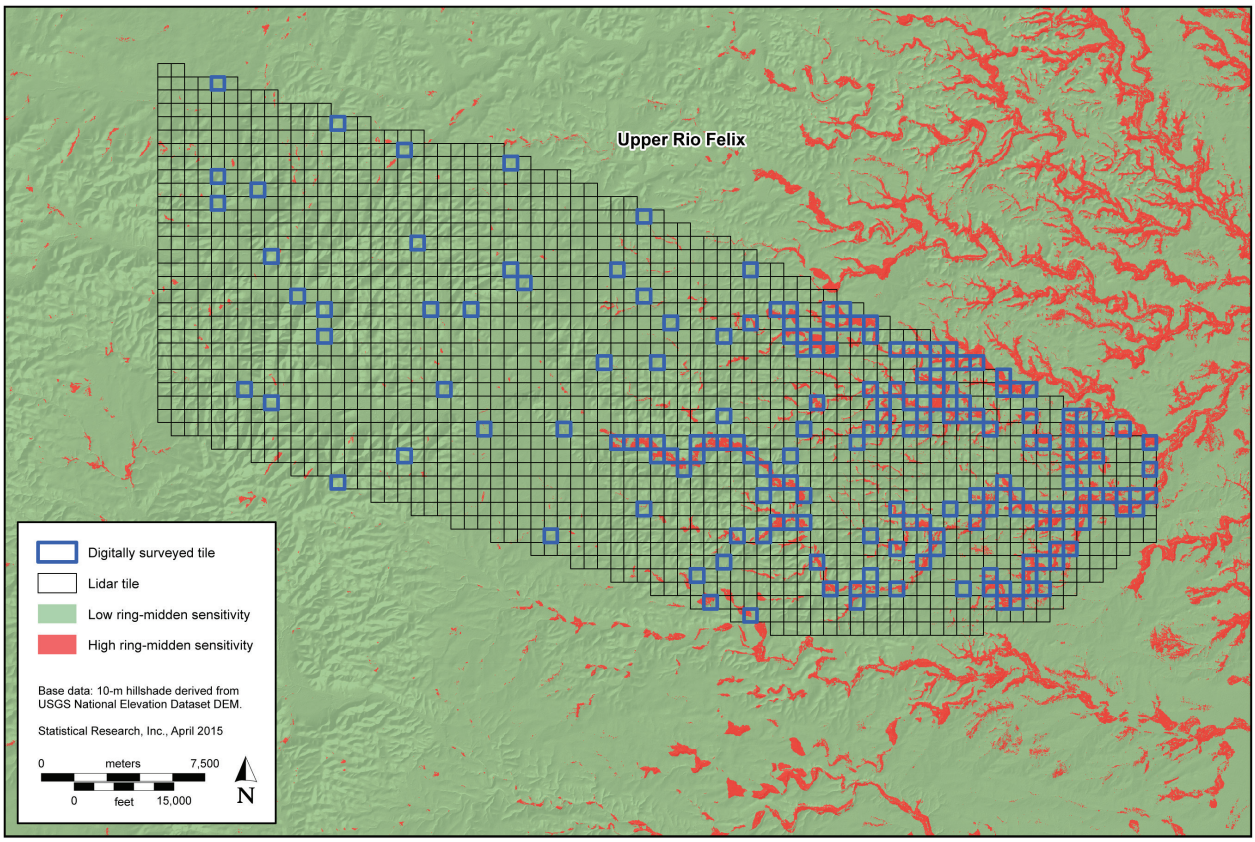
To collect and organize the lidar data for the project, Surdex divided each of the three study areas into a 2,000-by-2,000-foot (609.6 × 609.6-m) grid of square tiles. These grids were used as sampling frames for selecting land parcels for digital survey using the results of the locational model. To conduct the sample survey, we used the locational model to identify survey tiles where ring middens were more or less likely to occur. We then identified tiles in each study area that had large and small percentages of high-sensitivity zones or a small percentage of high-sensitivity zone. Using these data, we then selected survey tiles for digital survey such that 75 percent of survey tiles contained a large percentage of high sensitivity zone, where ring middens were most likely to be found, and the remaining 25 percent



Map showing the locations of survey tiles selected for digital survey in the Azotea Mesa study area.



Map showing the locations of survey tiles selected for digital survey in the Box Canyon study area.



Map showing the locations of survey tiles selected for digital survey in the Upper Rio Felix study area.

had a comparatively low percentage of high sensitivity zones. This sample-selection process resulted in an approximately 19.8 percent sample for digital survey from the Azotea Mesa study area and a 17.2 percent sample from the Box Canyon study area. In light of its much larger size and low archaeological sensitivity in comparison to Azotea Mesa and Box Canyon, a 10 percent sample of the Upper Rio Felix study area was selected for digital survey.

Our approach to the digital survey was systematic. For each of the tiles selected for survey, we used the lidar point-cloud data to generate a DEM using the approach discussed above. The DEM was then used to generate LRM, TPI, and hillshade layers for each survey tile. The DEM, LRM, and TPI were also used in our automated feature-identification process, ultimately resulting in a point layer representing possible ring-midden locations. All of these layers were created using automated, systematic procedures and were generated using computerized scripts developed specifically for the project.

To survey an individual tile, the LRM, TPI, and hillshade layers were loaded into the GIS application and visualized using the same color and display schemes. Once loaded, the surveyor first searched for ring middens at the scale of the entire tile. At this scale, prominent ring middens can be readily identified in the LRM and/or TPI layers. Any possible ring middens identified at this scale were then closely examined. The tile was then systematically searched at a finer scale (approximately $^{1}/_{9}$ of the entire tile). During this second combing of the data, each feature identified by our automatic-feature-identification model was closely inspected, along with any other feature that resembled a ring midden. Likely ring middens were delineated in a GIS with elliptical polygons, each of which was associated with two variable attributes: definition and shape. Definition was recorded from a set of pre-defined

Definition Categories for Ring Middens
Well defined
Moderately well defined
Subtly defined
Faint but possible
Not likely to be a ring midden, but recorded for comparative purposes

Shape Categories for Ring Middens
Closed ring
Open ring
Irregular/discontinuous ring
Ring with mounded lobe
Atypical

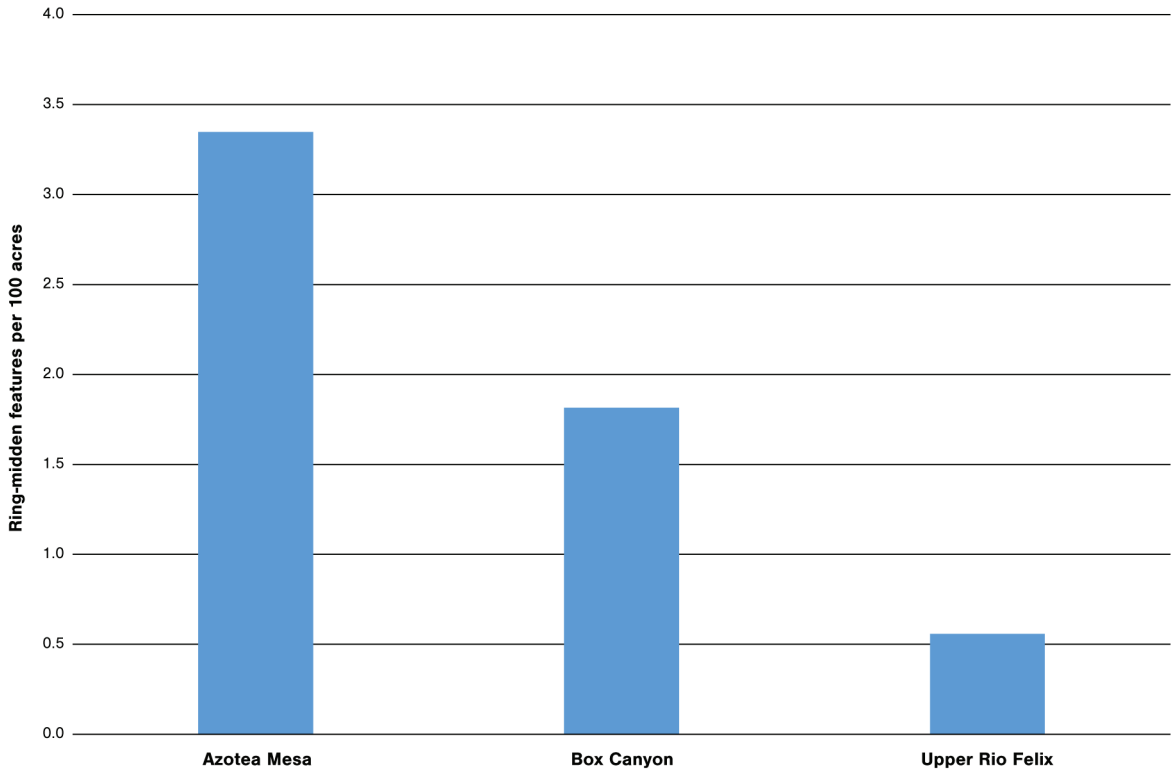
categories, listed below. The category of "faint but possible" was intended to be used when a possible midden was present near other, more definite ring middens, but there was minimal feature definition.

The categories for the shape variable are listed above. The last category was reserved mostly for features that had unusual shape characteristics, such as straight lines or an especially deep depression in the center. The ring-with-mounded-lobe category was intended for ring middens with a large mound attached to one side of the ring. Rings of this type were observed in multiple locations during preliminary feature characterization and were distinctive and recurrent enough to warrant a special shape category. Examples of each definition and shape category were provided to the surveyor prior to digital survey in order to attribute polygons in a consistent manner.

Another piece of information gathered about the digitally identified ring middens was the location of the high side of the feature. This is because investigators have noted that ring middens tend to have one side that is higher than the other. The measurements we made of ring-midden dimensions using 3-D profile data confirmed this. To gather information on the location of the high side for each digitally identified ring midden, we used a GIS tool that measures the azimuth of a line. For each feature, a line was drawn from the center of the feature to the center of the highest portion of the feature. The azimuth of the line was then calculated using the GIS tool to develop the necessary data indicating which side of each feature was highest with respect to other portions of the feature.

What We Learned from the Digital Survey

In total, 359 land tiles covering a total of 32,965 acres were digitally surveyed. The digital survey resulted in the identification of 511 possible ring middens (254 in Azotea Mesa, 155 in Box Canyon, and 102 in Upper Rio Felix), as well as 25 features that could be confused

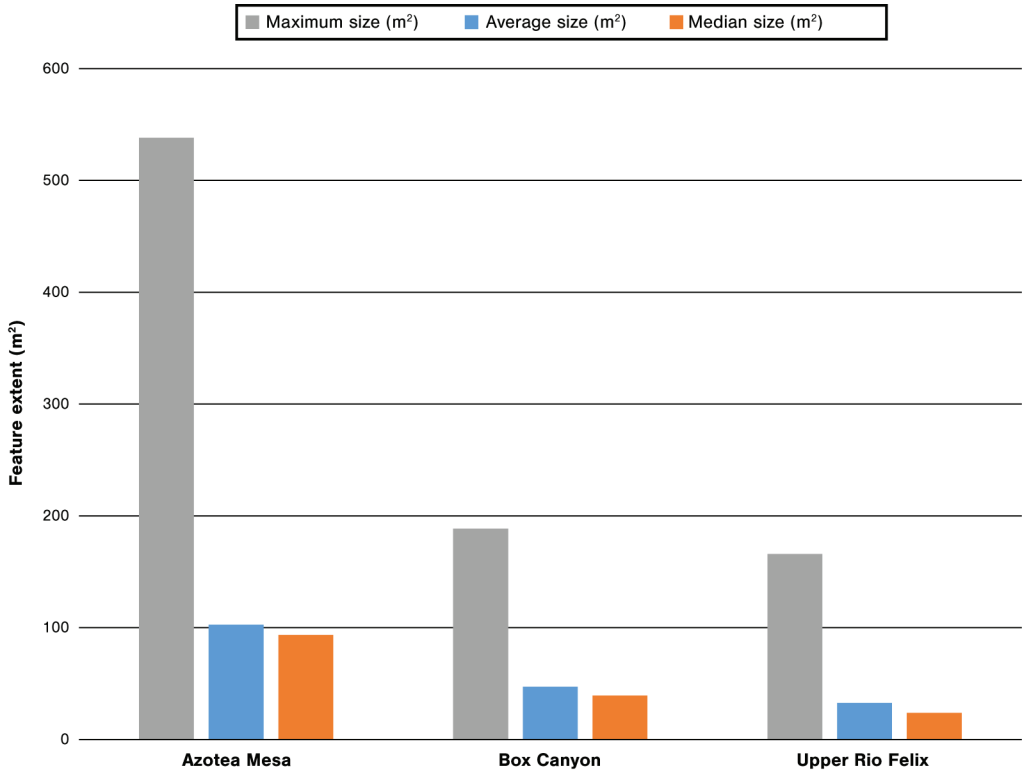


Ring-midden densities based on the digital-survey results, by study area.

with ring middens because of similarities in shape. A total of 33 (6.5 percent) of the possible ring middens identified during digital sample survey were located within previously recorded sites; most of these were located within the Azotea Mesa study area, where pedestrian survey has been more extensive and many sites with ring middens have been recorded. The remaining ring middens identified during digital survey were located outside of known archaeological sites, greatly increasing our knowledge of where ring middens are located in the three study areas. The density of middens in the three study areas varies widely, with the highest density in Azotea Mesa and the lowest density in Upper Rio Felix.

Ring-Midden Size

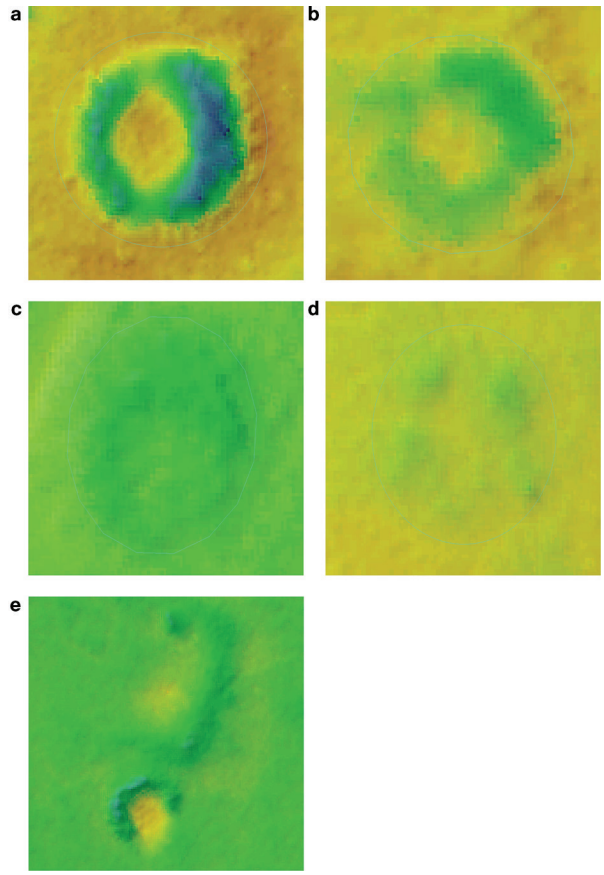
Ring middens also vary considerably in size among the three study areas, with the largest ring middens found, on average, in the Azotea Mesa study area and the smallest in the Upper Rio Felix study area. These size variations suggest one of three things. If we assume that higher densities of ring middens and larger individual middens indicate more intensive or more frequent use of earth ovens, then there are clear differences in the intensity of earth-oven use among the three study areas. Another possibility is that different types or quantities of materials were processed in earth ovens in the different study areas. Finally, perhaps as a result of differences in disturbance, sedimentation, and/or vegetation, it may be that ring middens are simply less obtrusive, and thus less visible, in some areas (Upper Rio Felix) compared to the others (Azotea Mesa). Disturbance processes could explain differences in ring-midden size among the study areas, at least in part, if we assume that such processes might bury the lower portions of features, making the exposed portions smaller, as well as displace discard-midden materials, making the features appear smaller and more variable in size as observed from a surface perspective.



Maximum, average, and median ring-midden areal extents (m²) based on the digital-survey results, by study area.

Ring-Midden Definition

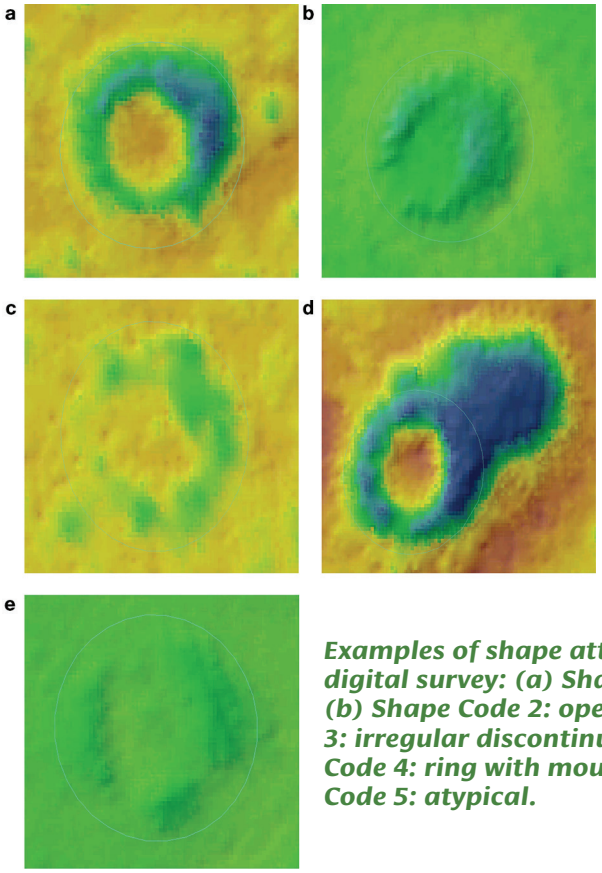
How well-defined a ring midden is may be related to how many times the earth oven it represents was used, how much disturbance it has seen, or variation in the way different peoples discarded heating rocks and earth. Ring middens were most often well-defined in Azotea Mesa and least often well defined in Upper Rio Felix. By contrast, moderately well defined ring middens were most common in Upper Rio Felix. There is not a clear trend for subtly defined ring middens. Features identified as faint but possible ring middens are comparatively more common in Azotea Mesa and least common in Upper Rio Felix. Differences among study areas for the categories of well-defined and moderately well-defined conform to our hypotheses that earth ovens were either most intensively used in the Azotea Mesa study area and least intensively used in the Upper Rio Felix study area and/or were least affected by disturbance processes in Azotea Mesa and most affected by disturbance processes in Upper Rio Felix.



Examples of definition attributes used during the digital survey: (a) Definition Code 1: well-defined; (b) Definition Code 2: moderately well-defined; (c) Definition Code 3: subtly defined; (d) Definition Code 4: faint but possible; (e) Definition Code 5: not likely to be a ring midden but recorded for comparative purposes.

Degrees of Feature Definition for Digitally Identified Ring Middens, as Observed in the Lidar Data, by Study Area

Degree of Definition	Azotea Mesa		Box Canyon		Upper Rio Felix		Total	
	No. of Features	Percentage of Study Area Features	No. of Features	Percentage of Study Area Features	No. of Features	Percentage of Study Area Features	No. of Features	Percentage of Total Features
Well defined	60	23.1	27	16.6	15	13.3	102	19.0
Moderately well defined	114	43.8	74	45.4	55	48.7	243	45.3
Subtle	68	26.2	48	29.4	31	27.4	147	27.4
Faint but possible	12	4.6	6	3.7	1	0.9	19	3.5
Not interpreted as a ring midden	6	2.3	8	4.9	11	9.7	25	4.7
Total ring middens	254	97.7	155	95.1	102	90.3	511	95.3
Total features	260	100.0	163	100.0	113	100.0	536	100.0



Examples of shape attributes used during the digital survey: (a) Shape Code 1: closed ring; (b) Shape Code 2: open ring; (c) Shape Code 3: irregular discontinuous ring; (d) Shape Code 4: ring with mounded lobe; (e) Shape Code 5: atypical.

Ring-Midden Shape

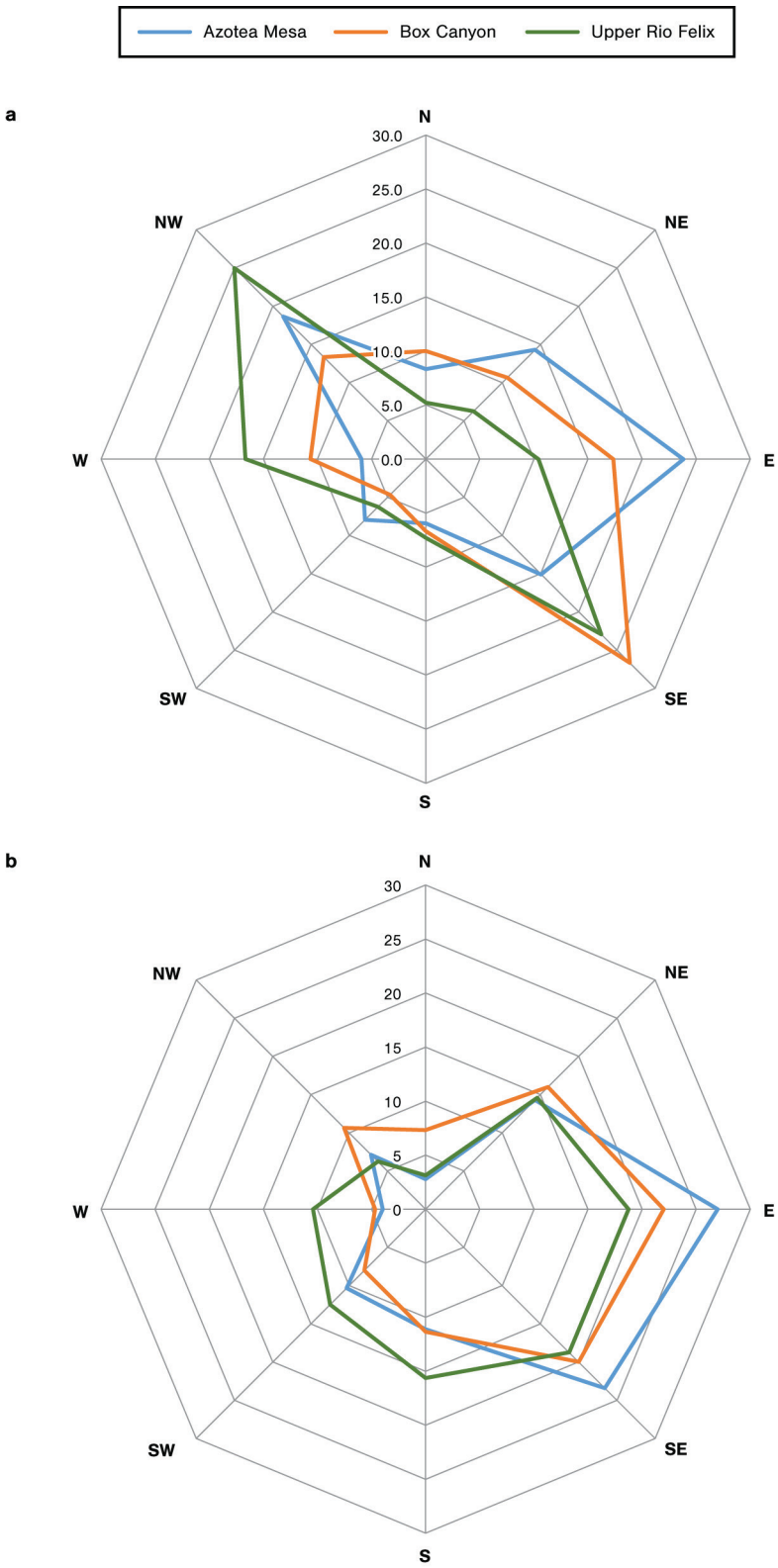
With regard to ring-midden shape, the three areas are similar in one aspect: they all have comparable proportions of closed rings. However, there is a distinct difference in the proportion of open rings and middens with atypical shapes, the lowest being in Azotea Mesa and the highest being in Upper Rio Felix. By contrast, rings with irregular, discontinuous shapes and ring middens with mounded lobes are most common in Azotea Mesa, less common in Box Canyon, and least common in Upper Rio Felix. It's possible that the relatively high incidence of ring middens with mounded lobes in the Azotea Mesa study area is related to more intensive, repeated use of earth ovens.

Ring-Midden High Side

Investigators have noted that ring middens tend to have one side that is higher than the other, but the reasons for this are unclear. There is a notable pattern in high-side orientation among the three study areas. In Azotea Mesa, the east side of the midden tends to be the high side, but it can sometimes be the northwest side. In Box Canyon, the southeast side is most often the high side. In Upper Rio Felix, the high side tends to be either the southeast or northwest side.

Distribution of the High-Side Azimuths of Ring Middens Identified during Digital Survey, by Study Area

Intercardinal Azimuth of Ring-Midden High Side	Azotea Mesa		Box Canyon		Upper Rio Felix		Total	
	No. of Ring Middens	Percentage of Study Area Ring Middens	No. of Ring Middens	Percentage of Study Area Ring Middens	No. of Ring Middens	Percentage of Study Area Ring Middens	No. of Ring Middens	Percentage of Total Ring Middens
North	21	8.3	15	10.0	5	5.2	41	8.2
Northeast	36	14.3	16	10.7	6	6.3	58	11.6
East	60	23.8	26	17.3	10	10.4	96	19.3
Southeast	38	15.1	40	26.7	22	22.9	100	20.1
South	15	6.0	10	6.7	7	7.3	32	6.4
Southwest	20	7.9	7	4.7	6	6.3	33	6.6
West	15	6.0	16	10.7	16	16.7	47	9.4
Northwest	47	18.7	20	13.3	24	25.0	91	18.3
Total	252	100.0	150	100.0	96	100.0	498	100.0



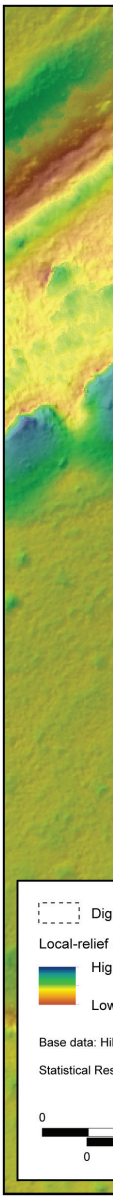
Comparison of (a) the azimuths of the high sides of digitally identified ring middens and (b) the aspects of the land surfaces on which digitally identified ring middens were located.

The aspect of the land surface on which ring middens are situated tends toward the east and southeast in all three study area and ranges from NE to SW for most ring-midden locations. In general, these data suggest that the high side of a ring midden tends to be on the downslope side of the feature. Perhaps this is because it is easier to discard rocks and other material downslope than upslope. However, this does not explain why, in the Upper Rio Felix study area, a substantial number of ring middens have a northwest high side when they are situated mostly on land surfaces that trend downward in the opposite direction. It could be that ring middens here have been more heavily affected by disturbance processes like erosion or sedimentation on the downslope portions.

Ring-Midden Clustering

Many of the possible ring middens identified during the digital survey occur in clusters. In more specific terms, it's fairly common for possible ring middens to be located within tens of meters of one or more other ring middens. This suggests that people repeatedly revisited the same locations to process foods in earth ovens, or, in some cases, that multiple earth ovens were used simultaneously.

Statistical analysis of ring-midden clustering showed that roughly half of possible ring middens were located in a cluster of two or more features, while the other could be described as isolated. Most (59 percent) of clusters consisted of just two possible ring middens, and the vast majority (93 percent) of clusters contained five or fewer middens. Clustered ring middens were comparatively more common in Azotea Mesa, where 59 percent were part of a cluster of two or more. By contrast, in both Box Canyon and Upper Rio Felix, approximately 41 percent of ring middens were part of a feature cluster. These data suggest that (1) ring middens are often located in proximity to each other; (2) they commonly occur in clusters of two to five,



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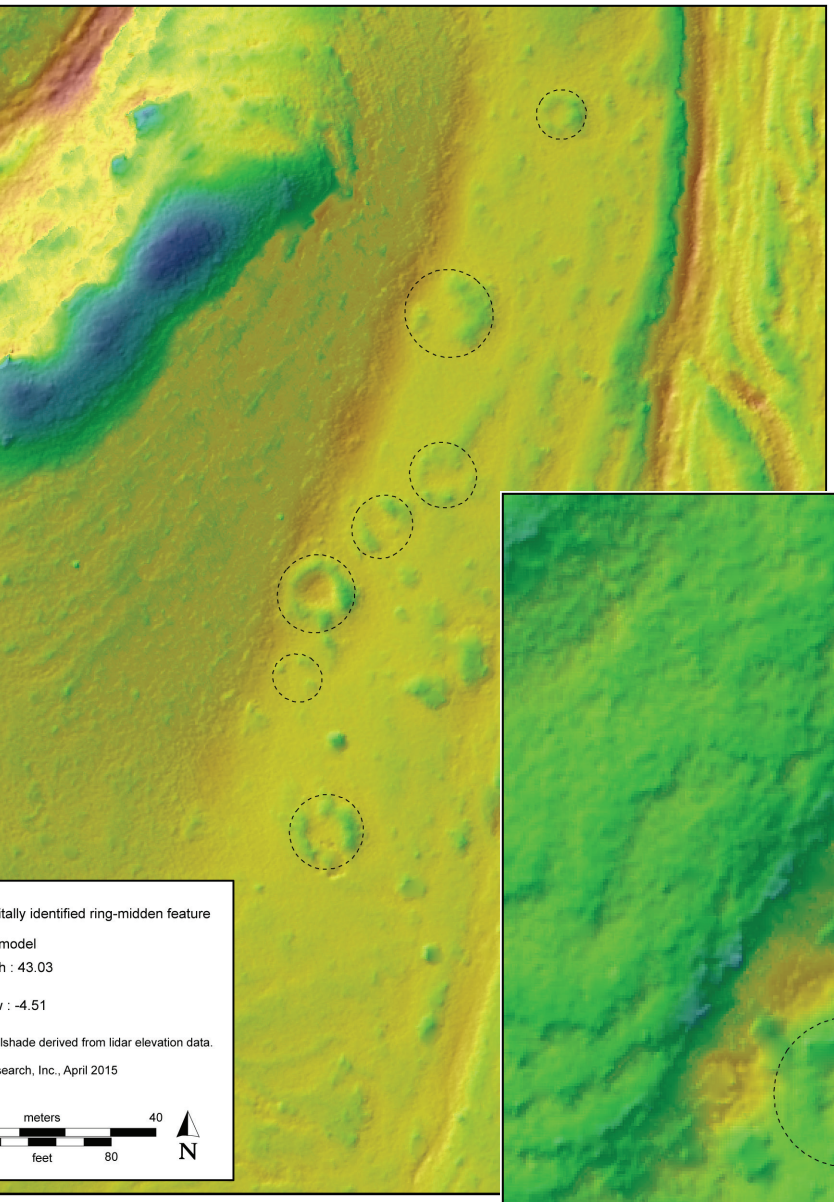
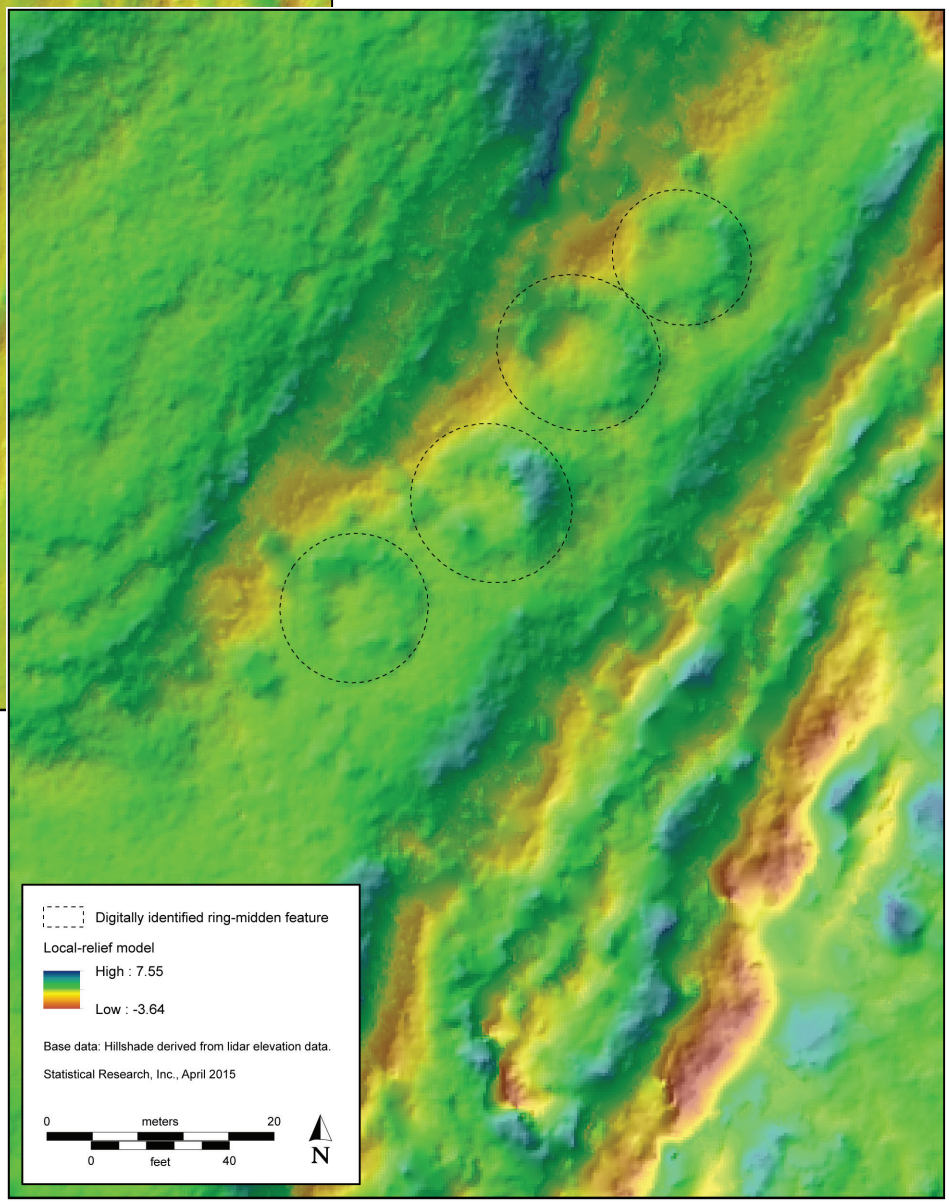
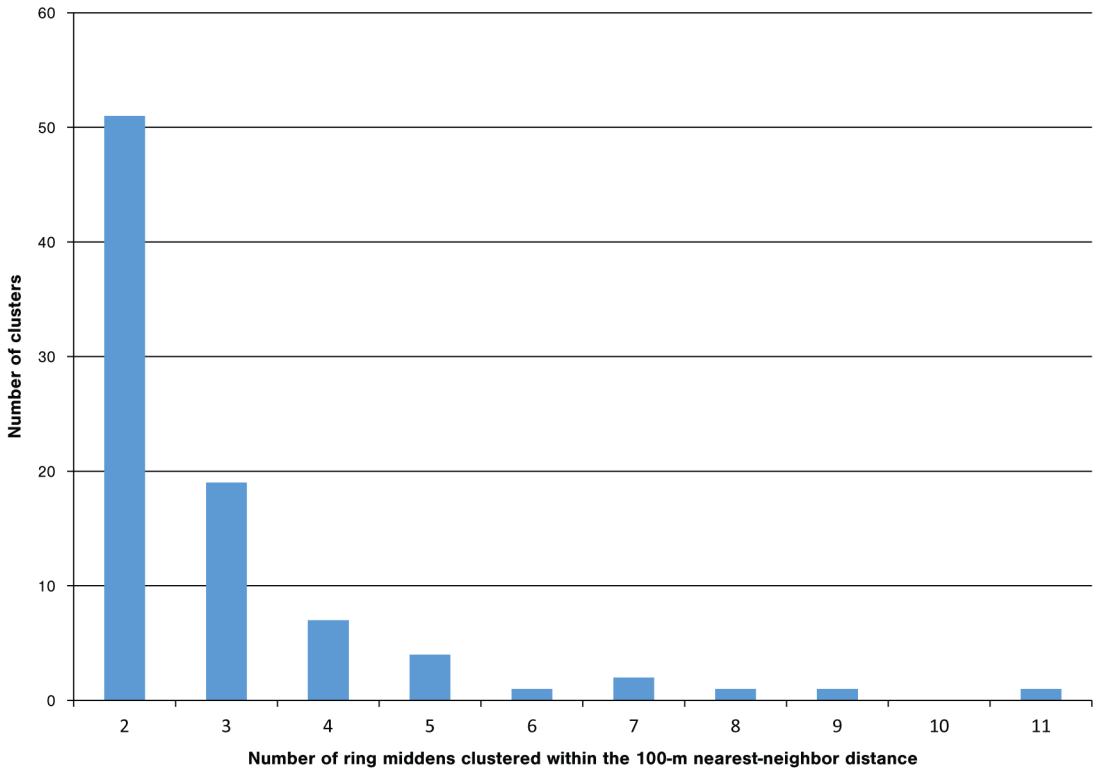


owing the linear cluster of four l ring middens identified during urvey as distributed along a narrow n the Box Canyon study area.



Map showing the linear cluster of four potential ring middens identified during digital survey as distributed along a narrow terrace on Azotea Mesa.



Frequency diagram showing the number of clusters of two or more ring middens identified during digital survey, based on nearest-neighbor hierarchical clustering analysis using a fixed distance of 100 m.

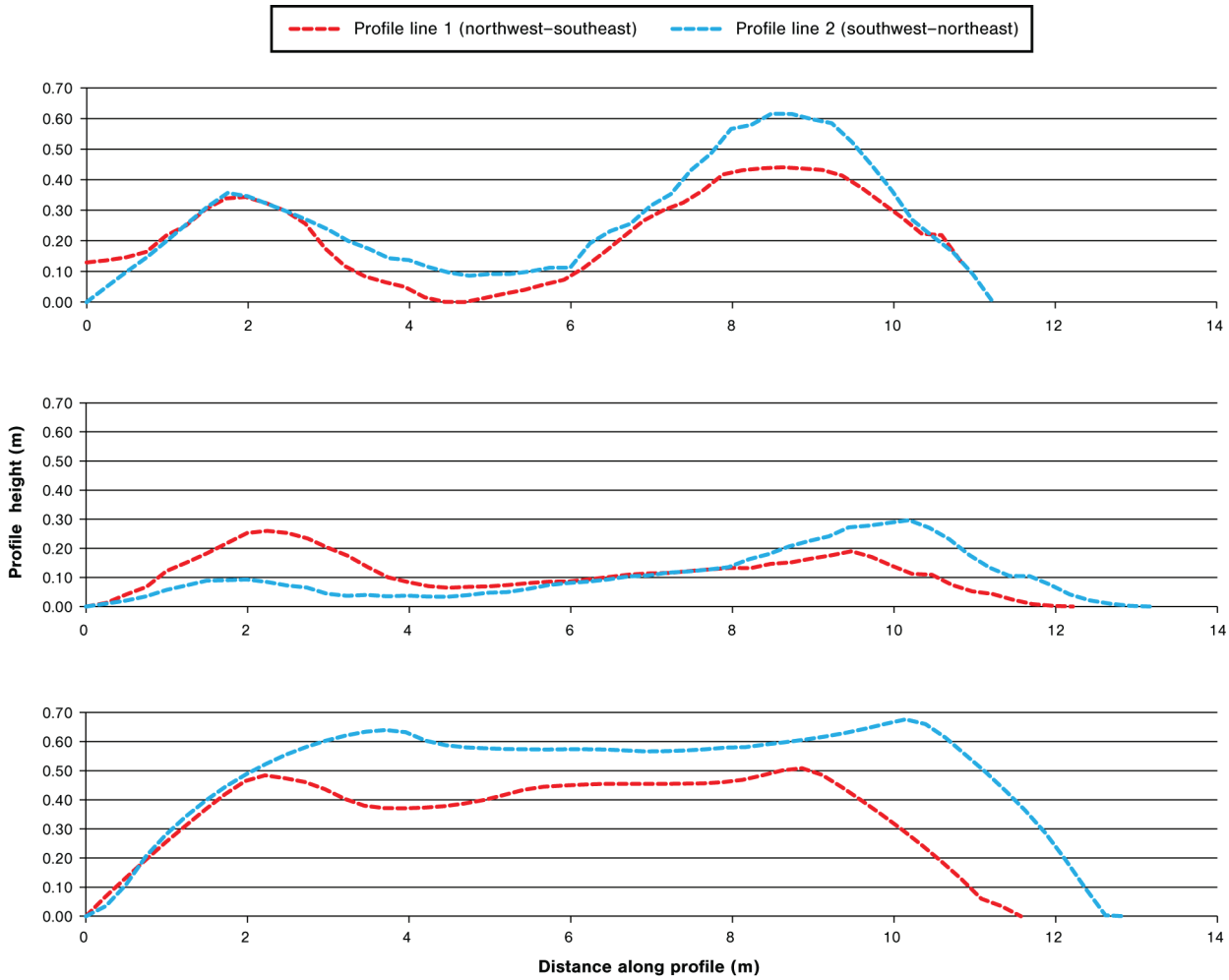
but may also occur in larger clusters; (3) clusters were most common in the Azotea Mesa study area; and (4) on average, the largest clusters are in Azotea Mesa and the smallest are in Upper Rio Felix. Because we probably cannot reliably detect low-profile ring middens using the lidar data, it's likely that this analysis underestimates the degree of clustering and that some clusters contain many more ring middens than are documented here.

Intersecting Rings

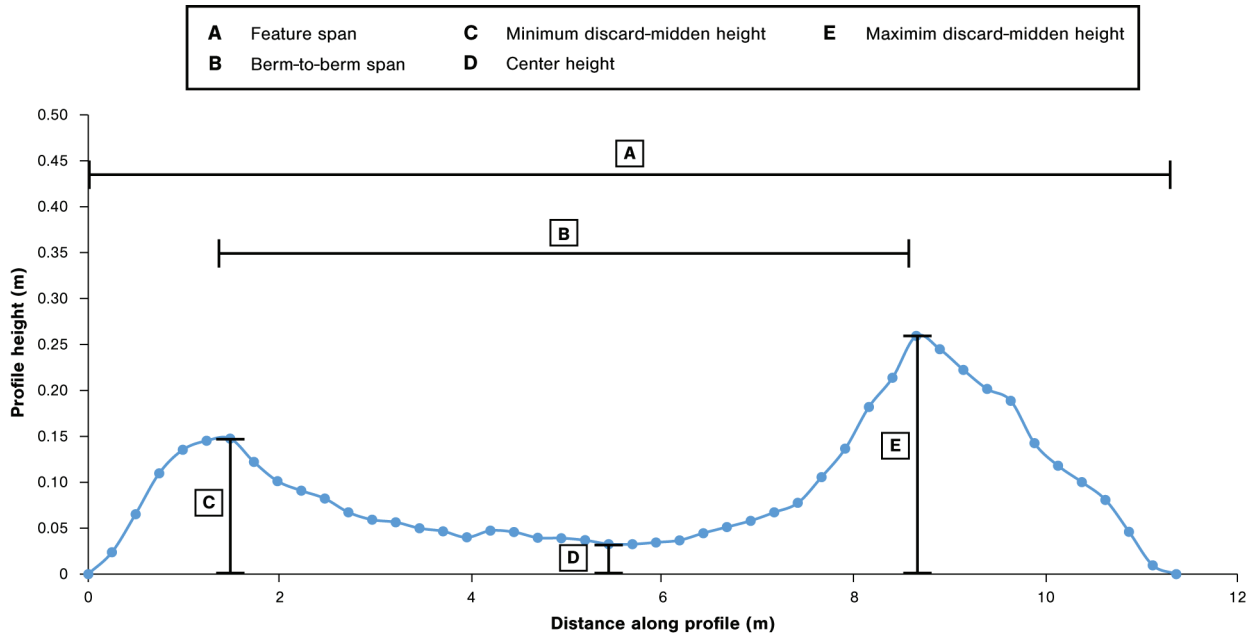
Intersecting ring middens are sometimes considered to indicate the passage of time—when closely situated earth ovens were used, over time, the adjacent ring middens expanded to the point of intersecting each other. Although ring midden clusters were relatively common in the digital survey data, intersecting rings within clusters (and overall) were comparatively rare. The few cases observed appeared to be in areas where the space available for earth-oven use was limited, causing earth ovens to be placed more closely together than in other areas and resulting in discard middens that overlapped, or intersected, those of nearby ring middens

Midden Profiles

In order to understand more about the different shapes of possible ring middens identified during the digital sample survey, we selected from each of the three study areas a random sample of surveyed tiles that contained possible ring middens. Several of the measurements made using the 3-D profile data showed a distinct pattern: feature size, average profile height, maximum profile height, span, and estimated above-ground feature volume all decreased with elevation. A possible reason for this is that earth-oven use was less intensive at higher elevations. This does not necessarily mean that fewer resources were acquired or processed at higher elevations but, more likely, that the need to conserve



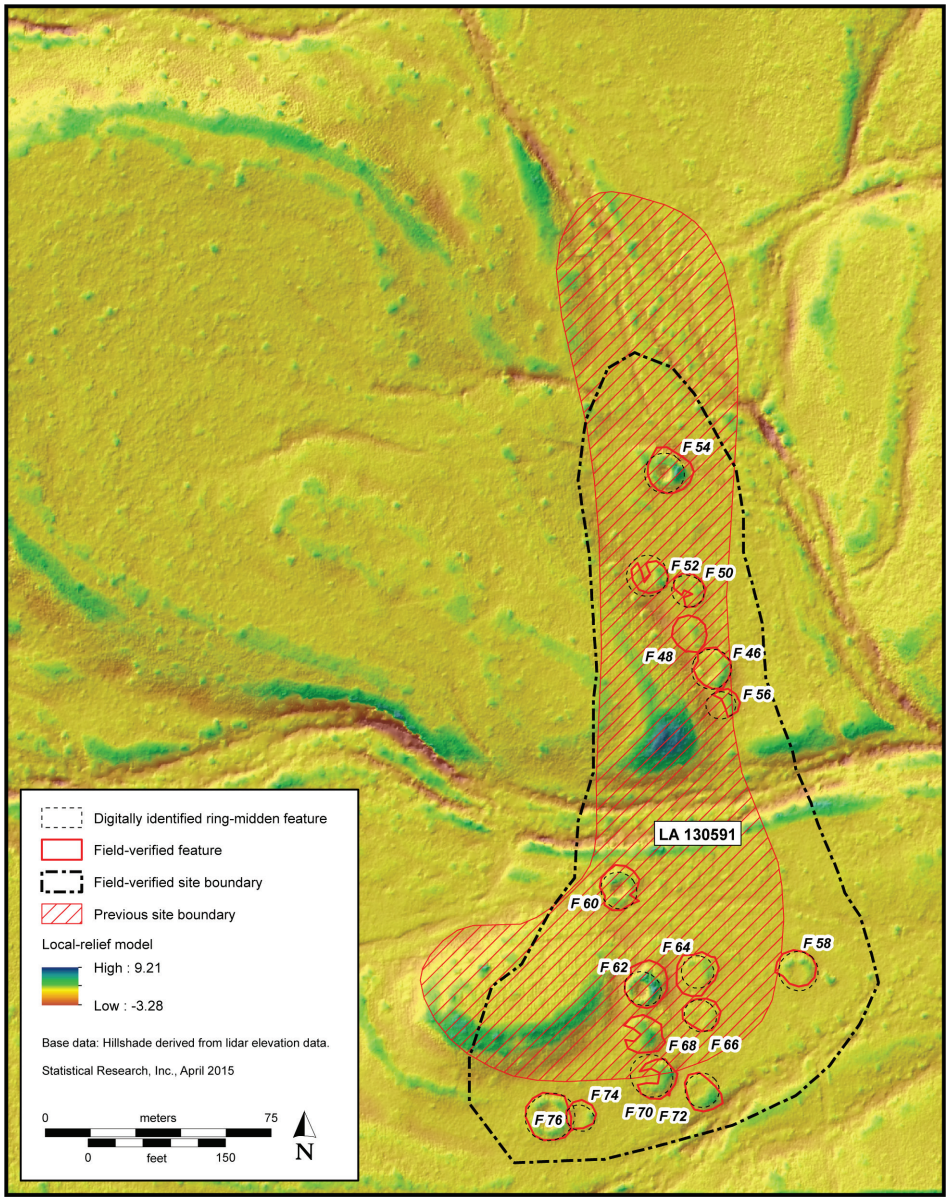
Three examples of ring-midden profiles derived from lidar data.



Key measurements obtained from profile data for morphometric characterization.

fuel (one of the drivers of earth-oven use) was less at higher elevations because of the greater availability of fuel wood. Another explanation, one not exclusive of the fuel-availability hypothesis, is that resources were more often processed repeatedly in earth ovens that were closer to residential bases, located at lower elevations, whereas more-distant earth ovens at higher elevations were used less often.

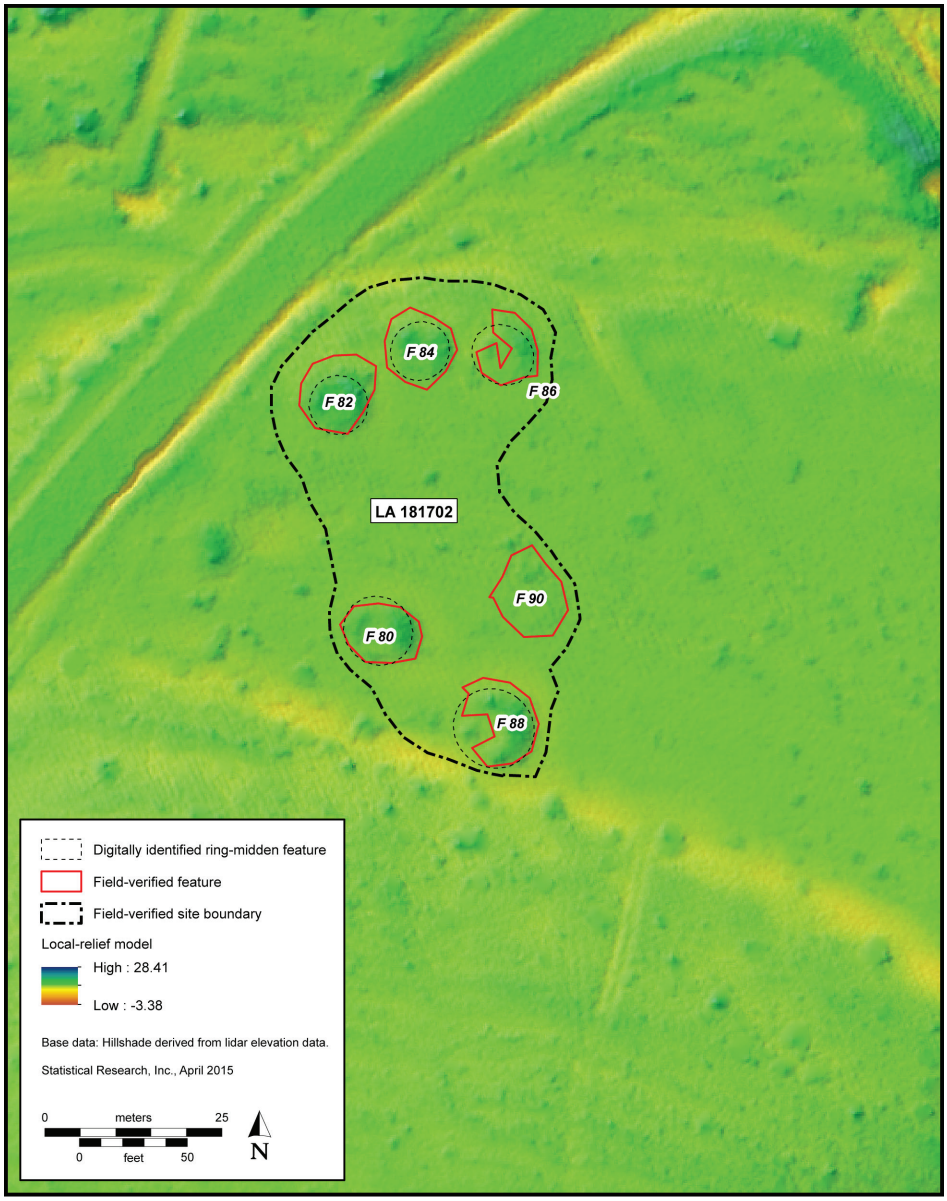
Similarly, these same measurements also decrease as distance to streams increases, particularly average height and maximum profile height, suggesting that earth-oven use was more intensive closer to streams and less intensive further away from streams. This suggests that plants growing along streams were likely important as fuel and perhaps also that the availability of water was important to earth-oven use (for use in steaming earth-oven contents, for example). Another reason for the apparently more intensive and frequent use of earth ovens close to streams could be that rocks deposited by streams were used as heating elements.



Map showing the locations of the 14 features identified during digital survey on Azotea Mesa (Tile 0104) that were selected for field verification.

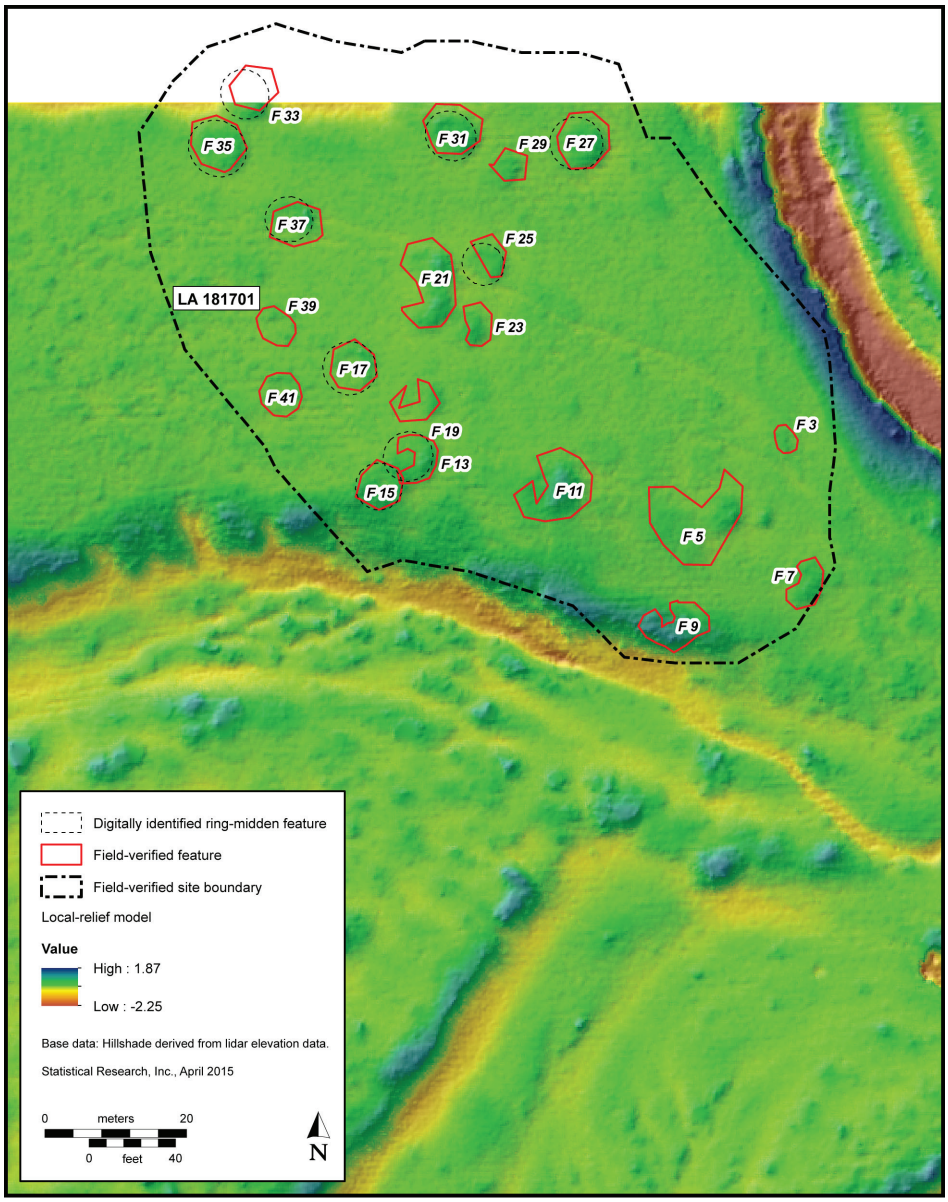
Ground-Truthing the Model

To test the validity of these results, a sample of areas containing digitally identified ring middens was inspected in the field. Field verification focused on inspecting as many ring middens with different characteristics as possible during the allotted field time. A total of 43 ring middens were recorded. Of this total, 14 were not identified by the lidar digital survey (11 were found at a newly recorded site in the Upper Rio Felix study area), but they were much smaller and had substantially lower relief than nearby middens that were identified by the digital survey. Moreover, 3 of these middens, although containing fire-cracked rock, were not consistent with the shape or other characteristics we used to define ring middens. All of the middens identified during field verification but not during the lidar survey were either disturbed by floodplain erosion or deposition or, in a few cases, had very low relief and uncharacteristic shapes.



Map showing the locations of the five features identified during digital survey on Box Canyon (Tile 0368) that were selected for field verification.

Overall, the field verification efforts indicated the lidar survey was highly successful in identifying ring middens, but failed to detect those that were heavily disturbed or of very low relief. These results suggest that lidar data can be successfully used to identify large numbers of ring middens on BLM land in southeastern New Mexico that would otherwise be unrecorded and do it faster and more cost-effectively than pedestrian survey. The option of conducting digital surveys gives the BLM the opportunity not only to better manage and protect ring middens, but also to gain a substantial understanding about how these fascinating and important resources are distributed across the landscape, how they vary in shape and size, and how they were used to support indigenous populations of both the ancient past and more recent times.



Map showing the locations of nine of the features identified during digital survey on Upper Rio Felix (Tile 1199) that were selected for field verification.

Conclusions

This project was more successful than anticipated. At the outset, whether ring middens could confidently be identified in lidar data was open to question. Experiments with visualization techniques and comparison of lidar data with records of existing ring-midden sites had suggested that the technique had good potential. Additional analysis showed that there was also good potential to make observations on their size, shape, and degree of definition. Modeling of ring-midden location showed that ring middens tend to be located near streams and stream confluences and at relatively flat areas in low topographic positions at the bases of hills. Digital survey for ring middens indicated that large numbers of ring middens are likely to be present in many areas that have yet to be surveyed, and that there are distinct differences between the study areas in ring-midden size, shape, degree of definition, and clustering. The results of the sample survey suggest that there are thousands more ring middens in this area than have been documented. Field-verification efforts showed that all of the ring middens identified in the digital data and visited in the field were, in fact, ring middens, providing that the digital survey results are a good reflection of the distribution of ring middens in the study area.

A ring midden in the Azotea Mesa study area.

The field verification suggested that failure to detect ring middens during digital survey can be attributed to a few factors. As discussed above, features that went unrecognized in the lidar data were mostly disturbed and lacked the relief necessary to be confidently detected using lidar data. This suggests that ring-midden densities are likely underestimated in the digital survey, particularly in the Upper Rio Felix area, where the obtrusiveness and visibility of ring middens have been dramatically affected by disturbance processes. Moreover, the field verification suggests that some of the differences between study areas in ring-midden density, size, and other characteristics may be the result of differences in disturbance among the study areas, but may also be due to differences in how ring middens were used in different areas.

Admittedly, the sample of ring middens visited in the field is comparatively small (only 5.7 percent of digitally identified ring middens). It is likely that some of the possible ring middens identified during digital survey are not, in fact, ring middens, but we have no way of documenting this without further field checks. The field verification efforts suggest that many of the possible ring middens identified during digital survey will turn out to be ring middens when field-checked, but it is also likely that at least some of them will turn out to be other types of archaeological features or, in a few cases, not an archaeological feature at all.

A great deal more can be learned from the data developed during this project by further analyzing the distribution of ring middens with respect to other sites and to environmental variables. With some additional effort, the remainder of the three study areas that were not digitally surveyed as part of the current project can be surveyed using the data and methods developed for this project. Many of the locations where ring middens have been digitally identified should be visited so that additional ground-truthing can be conducted and the sites recorded as they appear on the ground. Overall, the project has shown that modern digital technology can be used to study ancient earth-oven technology and to shed light on this interesting and informative heritage resource managed by the BLM.

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