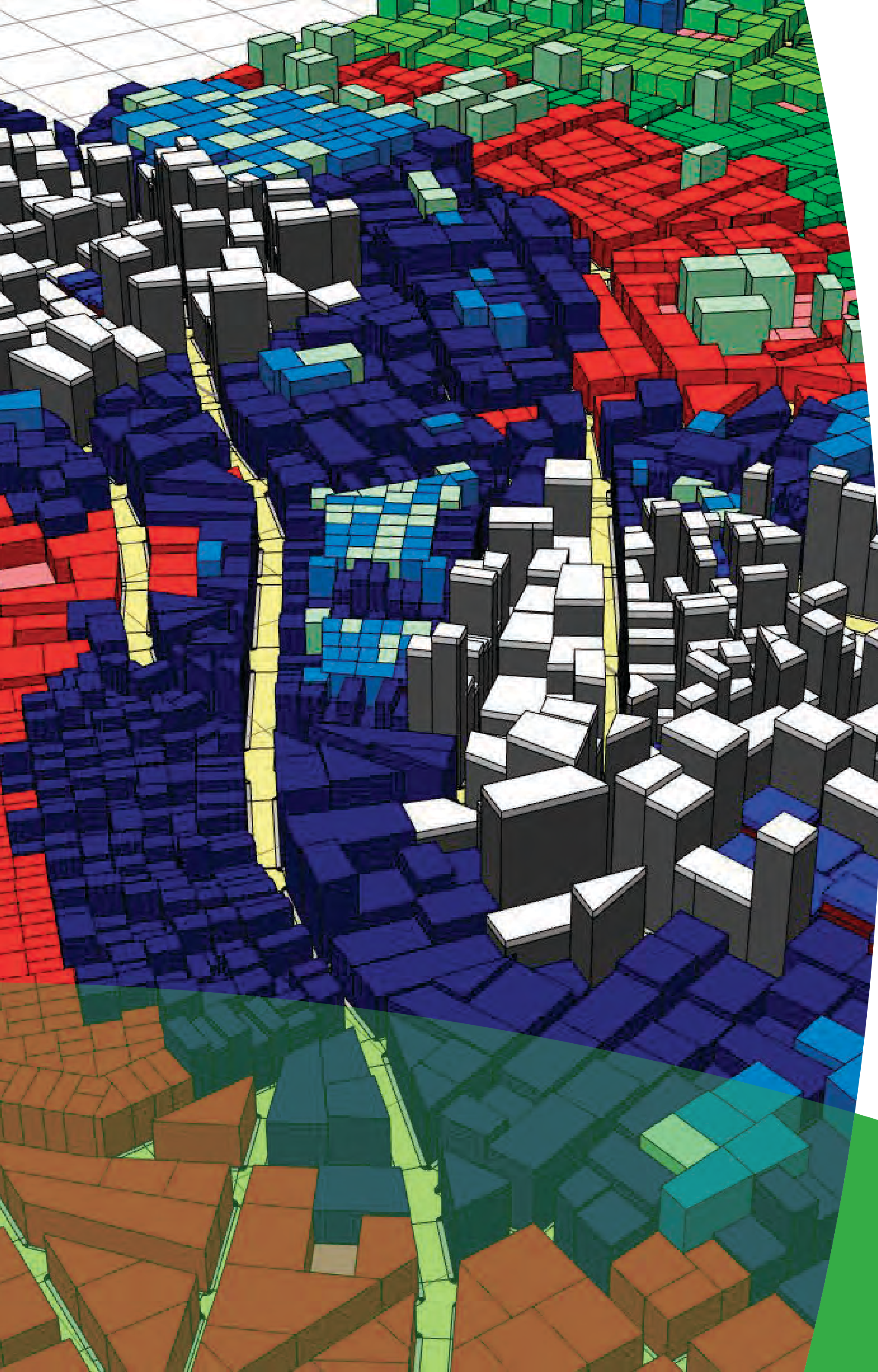

July 2013

New Eyes on the Old World

GIS Helps Us Understand the Past While Preparing for the Future

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Introduction

Archaeologists, historians, and cultural resource managers understand the importance of geography. Its variables exert a strong influence on human behavior today, just as it did in the past. Geography also influences the degree to which archaeological and historical sites are exposed to and impacted by human activity and natural forces.

GIS facilitates mapping to analyze depositional patterns, catalog and quantify cultural resources, and provide a well-structured descriptive and analytical tool for identifying spatial patterns. It is also an invaluable tool for protecting and stewarding cultural resources into the future.

What Is GIS?

Making decisions based on geography is basic to human thinking. Where shall we go, what will it be like, and what shall we do when we get there are applied to the simple event of going to the store or to the major event of launching a bathysphere into the ocean's depths. By understanding geography and people's relationship to location, we can make informed decisions about the way we live on our planet. A geographic information system (GIS) is a technological tool for comprehending geography and making intelligent decisions.

GIS organizes geographic data so that a person reading a map can select data necessary for a specific project or task. A thematic map has a table of contents that allows the reader to add layers of information to a basemap of real-world locations. For example, a social analyst might use the basemap of Eugene, Oregon, and select datasets from the US Census Bureau to add data layers to a map that shows residents' education levels, ages, and employment status. With an ability to combine a variety of datasets in an infinite number of ways, GIS is a useful tool for nearly every field of knowledge from archaeology to zoology.

A good GIS program is able to process geographic data from a variety of sources and integrate it into a map project. Many countries have an abundance of geographic data for analysis, and governments often make GIS datasets publicly available. Map file databases often come included with GIS packages; others can be obtained from both commercial vendors and government agencies. Some data is gathered in the field by global positioning units that attach a location coordinate (latitude and longitude) to a feature such as a pump station.

GIS maps are interactive. On the computer screen, map users can scan a GIS map in any direction, zoom in or out, and change the nature of the information contained in the map. They can choose whether to see the roads, how many roads to see, and how roads should be depicted. Then they can select what other items they wish to view alongside these roads such as storm drains, gas lines, rare plants, or hospitals. Some GIS programs are designed to perform sophisticated calculations for tracking storms or predicting erosion patterns. GIS applications can be embedded into common activities such as verifying an address.

From routinely performing work-related tasks to scientifically exploring the complexities of our world, GIS gives people the geographic advantage to become more productive, more aware, and more responsive citizens of planet Earth.

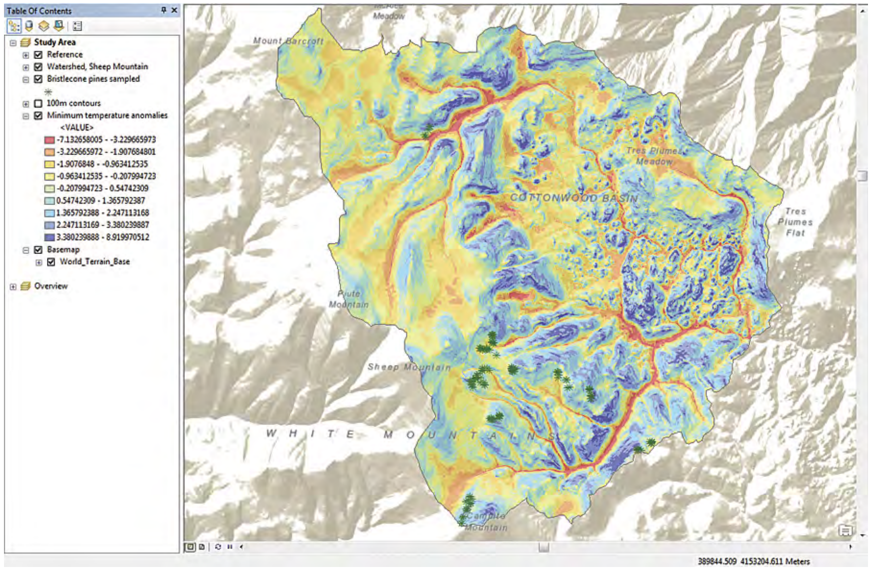
GIS and Ancient Trees Reveal Past Temperatures and Climate Change

Matthew Salzer, University of Arizona’s Laboratory of Tree-Ring Research, and Andy Bunn, Western Washington University

Highlights

- GIS helps determine the varying climate conditions individual trees experience in complex mountain environments.
- Using mountainside temperature data, ArcGIS Spatial Analyst spotlights summer variations of several degrees for individual trees.
- ArcGIS shows that over centuries, positions of trees have fluctuated up and down the mountain slope as temperatures changed.

Walking among living trees that have stood on the side of a mountain since the times of Christ and Buddha is a humbling experience. In the White Mountains of California, ancient bristlecone pines grow to about two miles above sea level; above that, the weather is too harsh for trees to thrive or to even survive. Many of these trees are more than 3,000 years old and have made a living in an intensely harsh climate that is very dry, very cold, and very windy. The slopes are rocky and steep. The topography is complex. There is almost no vegetation—just rocks and sand underfoot. The great ecologist Edmund Schulman called this amazing feat of survival "longevity under adversity."



Minimum temperature anomalies are derived using topographic indexes in conjunction with relatively cheap temperature loggers arrayed over a rugged mountain landscape. These anomalies can be used to understand the microclimates experienced by individual trees.

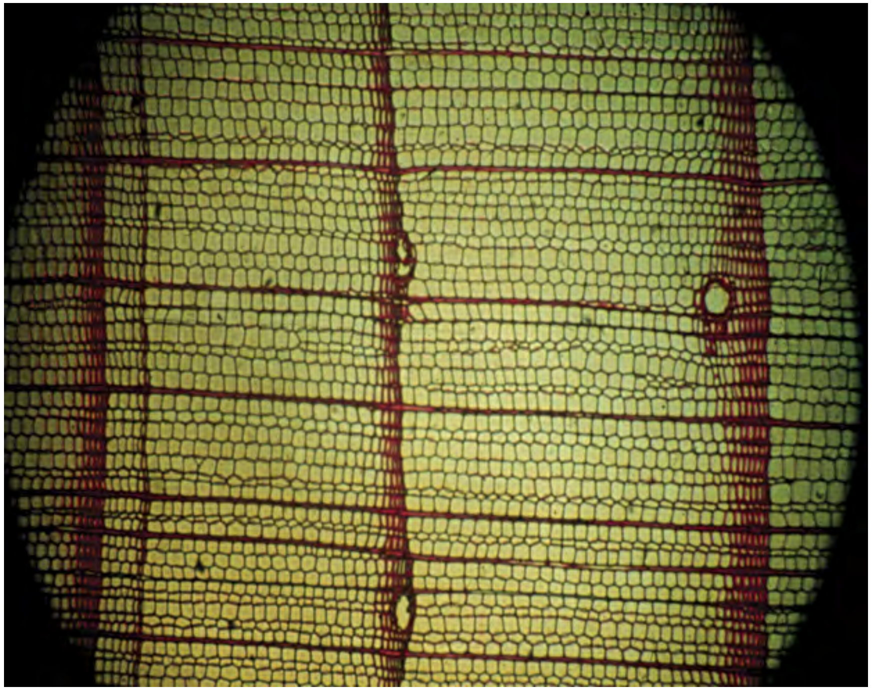
These trees, and others like them, represent an amazing opportunity to unravel a tricky problem: How do we better understand what the climate was like in the times before instrumental records? Some ancient trees can be considered the rain gauges and thermometers of the past. The annual layers of growth (tree rings) put down by trees are influenced by the environmental conditions during which they form. There is abundant evidence that tree-ring width in dry regions can provide a first approximation to the total rainfall over an interval of many months. In the high northern latitudes and in alpine tree line ecosystems, tree-ring width most closely approximates summer temperature. But, of course, trees are not rain gauges, nor are they thermometers. Trees are biologic organisms potentially subject to the influence of multiple environmental and biologic factors that affect their growth during their lifetimes. It is the job of dendrochronologists (*dendro* = tree; *chronology* = time) to interpret these growth records.

Work done at several universities, but most notably at the University of Arizona's Laboratory of Tree-Ring Research, over the last 50 years has shown that the growth of ancient bristlecone pine (*Pinus longaeva*) growing at the highest elevations in the mountain ranges of the Great Basin in western North America is sensitive to temperature. Recently, researchers have become more interested in exactly which individual trees are most sensitive to temperature and how a spatial approach can improve understanding. For instance, using ArcGIS for mapping (through an Esri university site license), recent research has shown that the position of the trees themselves on the mountainside have fluctuated up and down the mountain slope as temperatures have changed over the last several thousand years. There are stands of dead, twisted, and gnarled trees rooted in the ground more than 100 meters above the current tree line. These dead trees are

This ancient bristlecone pine (*Pinus longaeva*) growing near the top of Mount Washington in the Snake Mountain Range in Nevada is very near the upper elevational limit of growth for the species. It is trees like this whose ring-width records reflect past variability in temperature.

reminders that the earth's climate is dynamic. They were alive during a period called the Holocene climatic optimum—a warm period that lasted from about nine thousand to about five thousand years ago. The climate then was more suitable for these high-elevation trees (summers were warmer), and the tree line was higher than it is today. As the earth's orbit changed over thousands of years, the climate cooled, and those trees eventually died. However, these mountains are so dry and cold, and the bristlecone pinewood is so tough, that the wood has remained on the landscape for thousands of years. The record of growth in those rings speaks volumes about how climate has changed in the past and how it might change in the future.

Dendrochronologists strive to develop the best possible tree-ring chronologies of year-to-year changes in temperature obtainable from ancient bristlecone pine. Meteorological records of temperature from actual thermometers are only available for these regions for roughly the past century. A much longer time frame is required to adequately understand the evolution of the earth's climate. By using the bristlecone pine chronologies as a proxy record of temperature, tree-ring scientists can better understand how variable the earth's climate has been over several millennia and test climatic theories and output from climatic models that many view as important for the future sustainability of modern society.



Tree rings are produced annually as large thin-walled cells grow during the early part of the growing season, followed by smaller cells with thicker walls as the end of the season nears. The ring boundary is the abrupt change in cell size from the small thick-walled dark cells to the large cells formed at the beginning of the next growing season. In this image, the direction of growth is left to right, and the large openings are resin ducts. Note that some annual rings are relatively narrow and some are relatively wide; this is the result of different climatic conditions encountered during the growing seasons.

For decades, dendrochronologists have been working with the long bristlecone pine record to infer variability in past temperatures—if you can build a mathematical model between current climate and tree growth, you can apply that model back in time and determine the climate. But the challenge is in knowing exactly which climate variables are limiting a tree's growth. As the botanical and ecological literature can attest, cambial growth (tree-ring width) in high-elevation trees is a complex biologic process. Thus, the most appropriate trees must be selected for field sampling—trees whose annual growth rings will reflect variability in past temperature rather than, say, variability in growing-season soil moisture. The advent of precision GPS and detailed elevation models help determine which trees are the best temperature recorders based on their precise location.

GIS technology can help determine the climate conditions that individual trees experience in these rugged and complex mountain environments. For example, micrometeorological models of temperature anomalies from cold air pooling, solar radiation models (like the Solar Radiation toolset in ArcGIS) that take topographic shading into account, and remotely sensed information on the timing and direction of water from snowmelt all can be used to determine the physiological factors limiting tree growth. More specifically, combining data from inexpensive temperature loggers deployed on the mountainside with the hydrologic modeling tools in the ArcGIS Spatial Analyst extension shows that individual trees are experiencing variations in minimum daytime temperatures of several degrees in the summer. A tree growing in a colder microclimate resulting from cold air draining down the mountain might be limited by temperature more so than one of its neighbors growing only a few meters away if that neighbor is located on a patch of ground that is relatively warmer by comparison. Indeed, the ring widths of trees growing on the same mountain slope vary in conjunction

This very large dead bristlecone pine (*Pinus longaeva*) in the White Mountains of California stands at an elevation over 11,500 feet above sea level and looks down on the harsh tree line environment. The ring series sampled from this tree date from 663 BC to AD 1024.

with their biophysical setting in predictable and measurable ways. Determining exactly which climate variables were limiting growth was not possible at such a fine scale before dendrochronologists began to exploit the power of geospatial data. Now that these tools are becoming easier to use, the collaboration between those that are interested in time and those that are interested in space is poised to move the field of paleoclimatology onto firmer, clearer ground.

About the Authors

Dr. Matthew Salzer is a dendrochronologist with the University of Arizona's Laboratory of Tree-Ring Research and an expert on paleoclimatology. Andy Bunn is an environmental scientist at Western Washington University who brings geospatial tools to bear on a variety of ecological questions. He's been using Esri software since the command line days and currently uses ArcGIS 10 on a site license for Western Washington University.

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Cultural Heritage Management and GIS in Petra, Jordan

Geospatial Technology Drives Research

Thomas R. Paradise, Department of Geosciences, University of Arkansas, and
Douglas C. Comer, Principal, Cultural Site Research and Management

Highlights

- Researchers use satellite data to build a GIS database for research and management.
- Mapping in ArcGIS reveals rapid pace of deterioration from weathering and erosion.
- Data informs plans for mitigating the effects of rain runoff and tourism in the area.

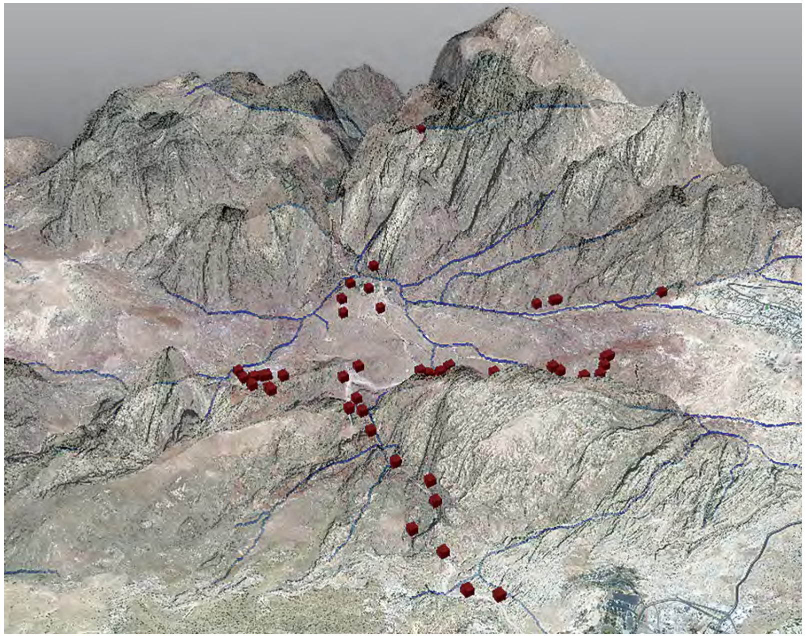
The now-ruined city of Petra lies hidden in a deep valley surrounded by steep, eroded sandstone walls and winding earthquake-created gorges in the arid expanse of Jordan's great southern desert. However, it is the allure of Petra's mesmerizing rock-hewn architecture rather than its beautiful geologic setting that primarily draws tourists to the area. The brilliant craftsmanship and urban planning of Arab Nabataeans two millennia ago ensured the city's place in history. Those Nabataeans carved elaborate structures directly into the towering reddish-brown cliffs and ingeniously harvested meager rainfall to create fountains and water pleasure gardens under a sun hardly ever hidden by clouds.

Ad-Deir, or the Monastery, high above the valley—one of the largest of the hewn structures in Petra. (Photo courtesy of Thomas Paradise.)

Twenty years ago, Cultural Site Research and Management (CSRM) and the University of Arkansas Department of Geosciences embarked on a project to begin understanding the accumulating effects of nature and foot traffic at Petra. Over time, researchers constructed a sophisticated system for managing, accessing, and analyzing aerial and satellite views of Petra. Through that research, the teams learned that human influence and meager rainfall have greatly increased Petra's physical decline. Remote-sensing imagery and geospatial technology have revealed the effects of commercial development and precipitation in Petra, increasing the urgency of conservation efforts there.

Gathering and Processing Imagery

The effort to construct a GIS database for use in research and management in Petra began in 1997 through the Cultural Landscape Analysis Initiative of the United States Committee for the International Council on Monuments and Sites (US/ICOMOS), with the financial support of the Kaplan Fund and software donated by the Esri Conservation Program. Researchers led by professor Talal Akasheh spent two months acquiring on-ground coordinates with early postprocessing GPS equipment. These coordinates were used to rectify synthetic aperture radar imagery developed from data collected by the space shuttle *Endeavor*, declassified US Corona satellite imagery acquired during the Cold War, SPOT and Landsat imagery, and scanned versions of black-and-white aerial pairs dating to the 1950s provided by the Royal Geographical Society of Jordan. Soon after, GeoEye donated IKONOS four-band satellite imagery, and the National Aeronautics and Space Administration (NASA) provided Advanced Spaceborne Thermal Emission and Reflection Radiometer imagery, which Michael Abrams of the Jet Propulsion Laboratory (JPL)/NASA processed to create a digital elevation model (DEM).



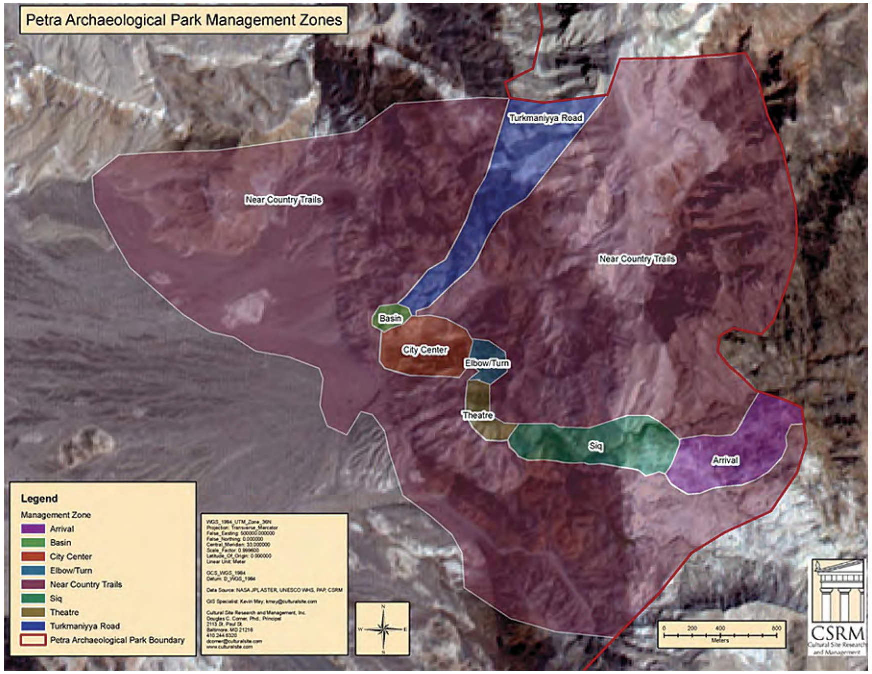
Oblique view of Petra with the Bedouin village of Umm Sayhoun (upper right) and the adjacent city of Wadi Musa (lower right). Blue lines represent ephemeral watercourses (wadis), and red cubes represent GPS markers at primary tomb facades. The map was created by Christopher C. Angel in ArcGIS (2012).

That gold mine of satellite and DEM data formed the backbone of a dynamic and ongoing GIS program in Petra, the Petra GIS Project, which explores technology for the furtherance of preservation research at Petra. Powered by ArcGIS and the cooperation and collaboration of many organizations, the project has contributed greatly to the understanding of this fabled city. Petra's GIS functions as a model of the archaeological landscape. Beyond its conservational purpose, it aims to help researchers answer important archaeological questions, such as why the nomadic Nabataeans, who had amassed great wealth by controlling the trade in precious goods over the vast desert, decided to settle in the area and build one of the most spectacular cities of the ancient world. Because of its historical and cultural significance, the model is currently being developed and applied by CSRM and a research team from the University of Arkansas Department of Geosciences to explain why the millennia-old monuments in Petra have drastically deteriorated in recent years.

GIS for Interpretation and Preservation

Field studies in Petra conducted by the University of Arkansas's Department of Geosciences over two decades originally included the assessment of sandstone weathering across Petra at Al-Khazneh (the Treasury), the "theater," Urn Tomb, and various tombs and facades. New studies have attempted to link the various aspects of this diverse landscape and have included physical components, like fungus identification, measurement, and mapping, and the assessment of climatic influences, such as rainfall, on the environment. Researchers used ArcGIS to analyze the imagery data of the Petra landscape in ways that highlighted changes in regional hydrology produced by tourism development in nearby communities. Analysis revealed that these changes have vastly increased the pace of structural deterioration at Petra. Specifically, the construction of roads, hotels, restaurants, and other visitor amenities have created impermeable surfaces that prevent the absorption of rain runoff. During rare but intense storms, that water rushes into the canyon where the tombs are located. The water, which contains salt, is absorbed by the porous sandstone, leaving salt crystals in the structure that force sand grains apart. This cyclical process obliterates the delicate tomb facades. Development in Petra has also destroyed ancient Nabataean agricultural terracing and the barrage dams and channels that once directed water to cisterns and reservoirs that were used by the approximately 30,000 people who once inhabited the area.

Petra's GIS has also played a pivotal role as a database from which to develop management zones, such as those used in urban planning. Management zones specify the appropriate uses and conditions within a given area. GIS also provides the framework for an automated monitoring system that will eventually be used to detect changes in conditions that, left unchecked, would ultimately destroy irreplaceable archaeological remains.



Petra Archaeological Park management zones in Petra.

Natural and Anthropogenic Influences

Across Petra, the University of Arkansas research team make use of submeter scales to investigate the effects of microclimatic variations on the development and growth of tafoni (small cave-like features found in granular rock, such as sandstone), honeycomb weathering, and the overall surface recession of Petra's tombs, structures, and monuments. Work at this scale is vital in assisting deterioration research, since weathering has the greatest influence on surface recession and the overall integrity, stability, and condition of the architectural surfaces.

Studies in Petra at the meter-to-decameter level also help researchers examine both natural influences, such as aspect and sunlight effects on recession, and anthropogenic factors. As researchers study more surfaces, monuments, facades, and structures, they spatially correlate their data to weathering features, dimensions, and deterioration rates in ArcGIS. The

View overlooking the carved theater, and the main roadway into the valley. (Photo courtesy of Thomas Paradise.)

measurements, mapping, and assessment of these features and surfaces, though typically not thought about as being useful at this scale, increasingly have proved instrumental in evaluating the effects of the anthropogenic and natural influences on large human-made objects from antiquity.

Anthropogenic influences, such as surface recession from human contact, are now being assessed, measured, mapped, and linked within GIS. To understand the erosion and weathering of Petra from tourism alone, research teams counted visitors across the valley, noting location, time of day, and number of tourists. They compared those numbers to each day's total visitor numbers and linked them to elevation (isohypsometric) and structure (footprint, planimetric) maps of the valley. After a month of data collection and mapping tourist movement over time and space, they were able to assess who was where, when, and for how long; which paths and corridors they used; previous sites visited; and subsequent destinations and paths each day. These synoptic cartographic methods not only helped the team understand the erosive effects of tourism in Petra but also helped researchers create diurnal visitor movement models.

Spatial Data Networks

The linking of point-specific relationships to integrated spatial and temporal networks has been a crucial advancement in preserving Petra's unique setting and sustaining and protecting its cultural resources. Petra GIS is now working toward the continual development of spatial data networks from various study sites across Petra to create a broader association of factors that influence Petra's physical, cultural, and human landscapes. What began as the modeling and assessment of a sensitive architectural and archaeological site has grown into an extensive arid lands project that links various scales and influences across different sites and elevations using ArcGIS, remote-sensing imagery, and GPS technologies with the goal of better understanding and protecting a truly unique World Heritage site. Only when enough point-based data has been collected site by site, then classified, analyzed, linked, and mapped across the valley, can trends and influences be identified, links understood, and possible causes and effects comprehended. This seems the best approach to understanding desert landscapes and sandstone architecture while effectively managing one million visitors each year.

The next objective of the Petra GIS project is to acquire more lidar data to build an extremely precise surface model that will guide engineering efforts to mitigate the flooding problem at Petra and prevent further deterioration of the tombs. Further research that investigates the natural, anthropogenic, and geospatial influences on architectural decay and environmental degradation in Petra must be done before the effects become irreversible.

About the Authors

Thomas R. Paradise, PhD, professor, Department of Geosciences, and former director of the King Fahd Center for Middle East Studies, University of Arkansas, comes from a diverse background in geography and geology, architectural history, stone conservation, cultural heritage management, Middle East and North Africa geography, and cartography/GIS. His expertise in stone architectural deterioration has been requested by countries across the Mediterranean and Middle East.

Douglas C. Comer, PhD, is principal for Cultural Site Research and Management, Inc., president of the CSRM Foundation, and copresident of the ICOMOS International Scientific Committee on Archaeological Heritage Management. He is the recipient of research grants from a number of organizations and agencies and has published widely on the use of aerial and satellite remote-sensing technologies in archaeology and cultural resource management.

(This article originally appeared in the Summer 2012 issue of *ArcNews*.)

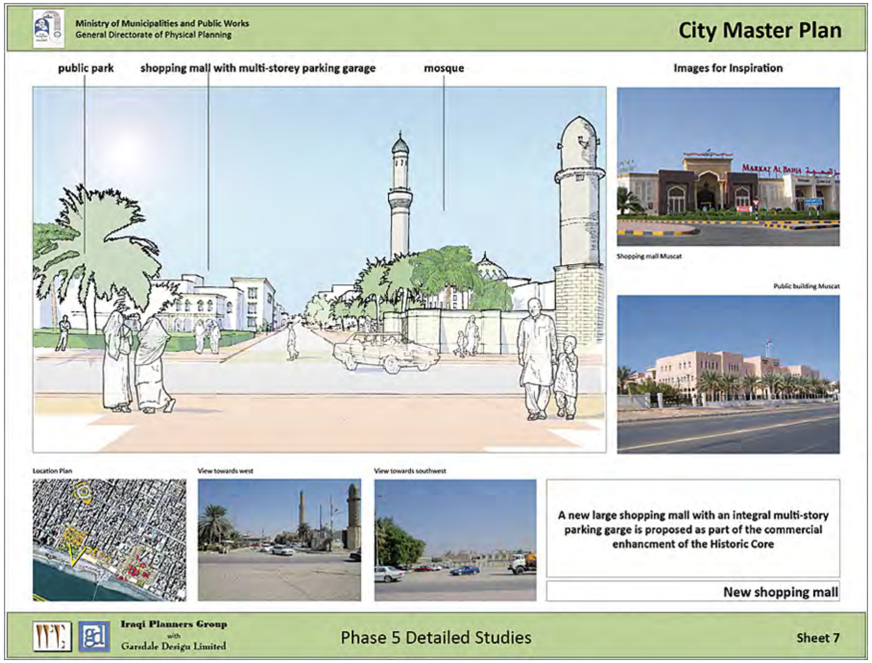
CityEngine Creates New Solutions for Historic Cities

Highlights

- Employing Python scripting allowed staff to go back and forth between conventional mapping and 3D modeling.
- CityEngine goes beyond standard visualization into actual creation of data based on specific urban planning standards.
- Using CityEngine, 3D models from previous jobs were imported and their preexisting 3D assets and rule files put to use.

Iraq has had a rough ride in recent times, and many of its cities are showing the scars of years of neglect and warfare. A lack of investment in basic infrastructure, combined with a brain drain of professionals, has left many Iraqi cities in a very poor state of repair and with limited plans for the future. But with the fall of the previous regime have come opportunities to revive and repair these aging and often historic cities.

In 2007, the Iraqi Ministry of Municipalities and Public Works (MMPW) awarded a British firm, Garsdale Design Limited (GDL), and its Iraqi Planners Group (IPG) the contract to develop a master plan for the city of Nasiriyah in southern Iraq. The project was to deliver urban planning for the new dwellings,



This Nasiriyah display sheet for detailed study presents a proposal for a large shopping mall.

infrastructure, sewerage, water, and electric systems needed over the next 30 years. Nasiriyah is the capital of Dhi Qar province in Iraq. Almost 500,000 people call this city their home, located 225 miles southeast of Baghdad on the Euphrates River and close to the ancient city of Ur.

Garsdale Design is a planning, architecture, and heritage consultancy based in Cumbria in the United Kingdom. It has extensive experience in the Middle East, and many of its projects have entailed urban design and city master planning in the Gulf Arab states.

"Master planning any city is a complex task," says Elliot Hartley, director of Garsdale Design, "but Iraq's cities face huge additional challenges from lack of investment in infrastructure to training of planning departments." Hartley manages and analyzes the spatial data that is required for planning projects like the Nasiriyah City Master Plan.

The stages of any workflow are important, but it is the visualization of the small details that can have dramatic impact, such as the placement of palm trees.

Magical Modeling

The staff at GDL focused on planning a contemporary community in Nasiriyah with an integrated public transport network that still reflects the culture and history of the almost 150-year-old city. The goal is to help the city grow sustainably over the next 30 years.

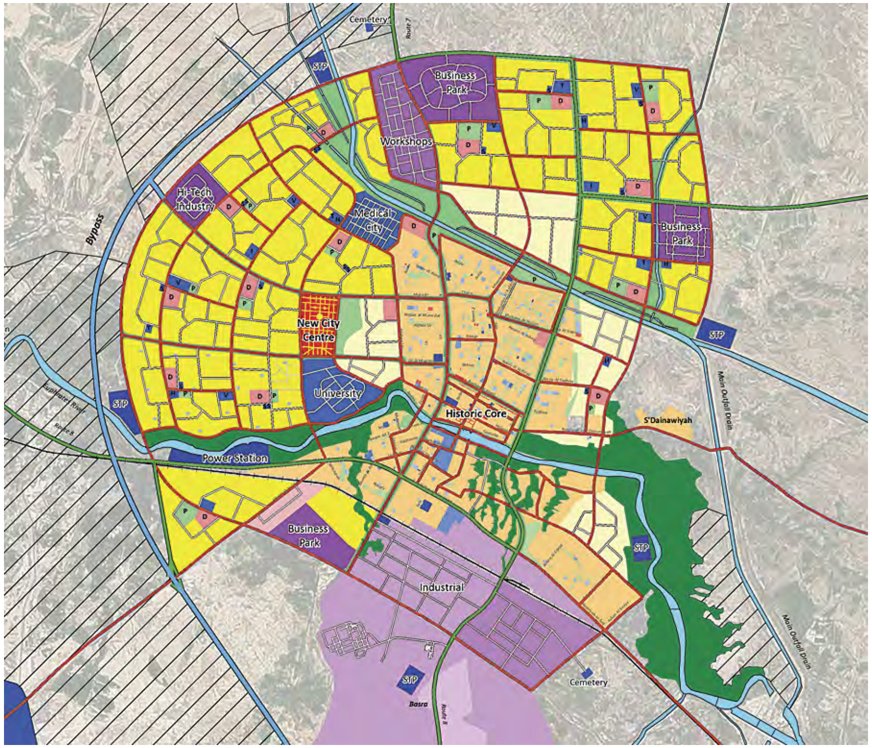
Over time, GDL had experience with various time-consuming spatial packages that did not meet its needs. Pursuing a better solution, GDL and IPG concluded that ArcGIS with Esri CityEngine met and exceeded the needs of MMPW. On production of some of the 3D modeling, GDL staff found that they were able to remodel iteratively in response to new data or late requests. This created results that Hartley describes as "almost magical."

"When presented with this reality, we thought, what if the project team could change detailed plans with ease, taking into account new data instantly and avoiding the laborious redrawing of layouts?" says Hartley. "This is the promise of the 'instant city' and what we can achieve with GIS."

Creating a Responsive Model

The GDL team quickly realized that CityEngine could be part of the master planning process and not just a visualization tool.

"Unfortunately, we can't just jump into a new workflow in the middle of a project. This could have unacceptable impacts for us and our clients," says Hartley. However, the company quickly learned that using CityEngine on elements of master planning projects helped to visualize where the pieces best fit.



This is a typical Nasiriyah City Master Plan sheet.

The first task performed with the 3D modeling software was building a new neighborhood with basic block models. Data from previous phases of the project was used to visualize elements of the master plan quickly in realistic 3D visualizations in just a matter of hours.

"This would have taken many hours, if not days, to produce in-house using other 3D modeling packages," says Hartley.

Mining Its Stock of 3D Models

Over the years, GDL has built up a stock of 3D models used for previous jobs that provide inspiration for current work. Using CityEngine, these models were imported and their preexisting 3D assets and rule files put to use, with a few quick adaptations. For example, staff employed a rule file that tests the size of a plot and places an appropriately sized building model accordingly. A specific set of vegetation models that included native trees was also used, with one tweak—existing tree rules were replaced with a new definition. Streets were then modeled with these trees—palm trees—and the trees were randomly inserted on lots to give a more natural look to the model.

Employing Python scripting allowed staff members to go back and forth between the ArcGIS environment for conventional mapping and CityEngine for 3D modeling. For example, a street centerline was created in ArcGIS and then brought into CityEngine, where curbs, central medians, streetlamps, and trees were added in accordance with the rule file. The result was then exported back to ArcGIS for analysis and mapping. This data was then used to create plots and place building types according to the underlying land use in CityEngine, then brought back into ArcGIS for further analysis.

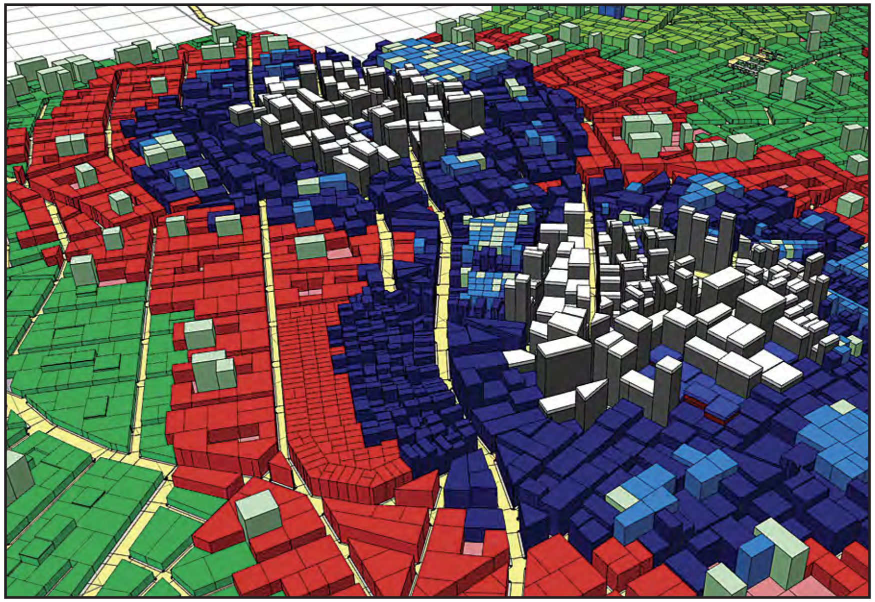
"This goes beyond standard visualization and into actual creation of data based on our specific urban planning standards," says Hartley. "The ability to dynamically add attributes to plots with rules allows for a more responsive model."

When the Future Means Change

Underlying data, such as relief or geology, can also be used. For example, a raster with a red color can be used to restrict development in particular areas, and elevations can be used to restrict building heights or types.

Staff used the modeling rules they need for each individual project, no matter how general or detailed, so different issues can be modeled at either micro or macro scales.

"Sometimes we have started with a relatively simple rule file for land uses," says Hartley, "but have then combined it with a previous dwelling rule file that links to yet another one to locate small elements, such as water tanks and satellite dishes."



This is a simple demonstration of a density-based concept.

Intelligent modeling in this manner is starting to generate questions, such as the following, and quickly provide answers:

- What size of plot is needed within a particular land block?
- Can building height be varied to recognize the underlying geology?
- How can lots smaller than a certain size be shown as playgrounds within a residential area?
- What lane and sidewalk width is required for the different grades of roads?

- How wide should the central median be for higher-order roads?
- Can streetlamps be modeled differently to suit the various grades of road?
- Can buildings be modeled at different heights depending on how close they are to a center or transport node?

"In the future, we are going to be able to create a city plan that changes very quickly as new data arrives from the client," says Hartley. "This is a game changer for firms like ours, as last-minute client requests at a late stage are inevitable."

A Living Model

When Garsdale Design staff started working with CityEngine, the primary appeal was the software's ability to work with GIS data and export it into a variety of 3D modeling and rendering packages to provide the materials required by the client. "But once we started to explore the potential of the software, we saw that it could be more useful as an urban planning tool," says Hartley. "In fact, it has also shown us an exciting new direction for planning cities in the future. We can start to use these sophisticated 3D visualizations in a variety of media, including printed reports, websites, video, and full interactive walk-throughs. Our clients want to see how their cities would look when their plans are implemented."

(This article originally appeared in the Spring 2013 issue of *ArcNews*.)

The Greek Island of Kythera Jumps to the Forefront of Historical Research

Mapping Citadels and Churches with GIS

Richard MacNeill

Highlights

- GIS supports the rediscovery of a forgotten way of life.
- ArcGIS has been successfully integrated into a toolbox for historical research.
- Spatial analysis with GIS reveals historical changes in land use.

Over the centuries, the island of Kythera, nestled between the southern peninsulas of the Greek Peloponnese, has been subjected to the fortunes of war; occupation; piracy; and, occasionally, the quiet solitude of poverty and isolation. Mass migration to Australia after the Second World War was only one in a series of fundamental changes for the island.

The small churches and chapels across the island have been a consistently significant part of the way of life of Kytheran families.

Today, villages of the north of the island lie abandoned, the roofs of the houses fallen and the exposed rooms forests of brambles. The paths that once led to springs by the bright, running streams have been lost, and the springs, mills, and washing troughs that once sustained the communities lie derelict. But something is changing. Some villages show new life as people return to the island. Professor Tim Gregory and Dr. Lita Gregory are two people who have returned. Academics at Ohio State University with close connections to the Kytheran community, they are leading projects designed to bring to light the forgotten history of Kythera.

History is never straightforward. For an island, most of its history being nowhere near the hubs of commerce or empire building, historical records consist of accounts written by the two literate classes: the clergy and the Venetian powers that were overlords of the island after the 13th century. Written history, largely accounts of the lives of the saints and administrative data, is therefore incomplete, inconsistent, and subjective.

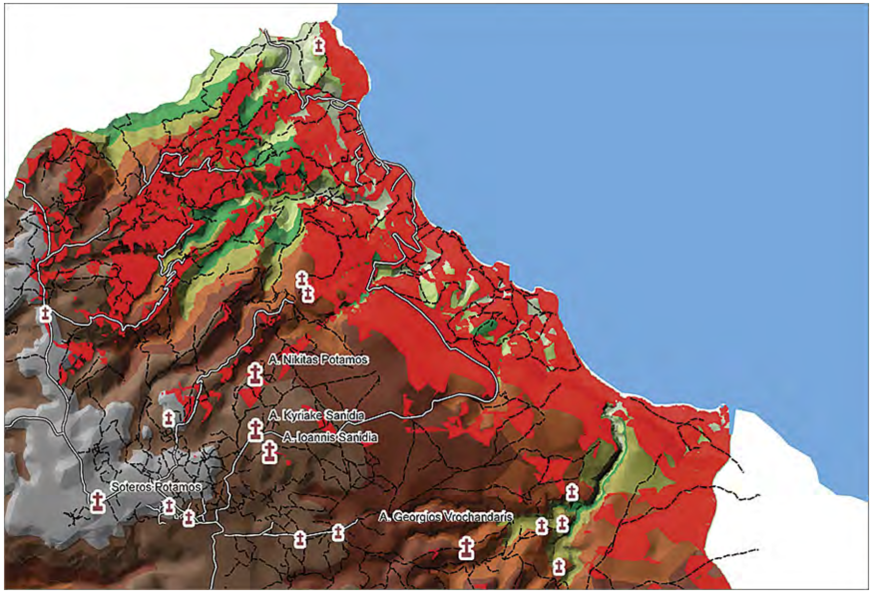
How did the history of the island play out for the local communities in the small, scattered towns? How did the vast majority of island inhabitants live? What was their response to the piracy, depopulation, and ruin that characterize written accounts of the island's history? Were these accounts in fact accurate? Spatial analysis supported by geographic and cultural surveys is working to shed light on local history across the island and, by asking these questions, put the "official" accounts to the test.

The work of uncovering a forgotten history involves constant interaction between field surveys, locating and recording features, spatial analysis synthesizing information from these records, and a constant generation and testing of theory. The ability to use a suite of capabilities to compile and refine spatial data, review maps and plans presenting area-based summaries, and explore spatial relationships and distributions is critical.

ArcGIS originally came into the picture with staff of the University of Sydney, Australia, in the beginnings of this work. At this time, ArcGIS was emerging as the system of choice, under the aegis of Dr. Ian Johnson (Archaeological Computing Laboratory, University of Sydney), replacing an initial reliance on a legacy GIS. Staff currently make use of an Esri university site license provided to Ohio State University.

ArcGIS contributes in each of these areas. It provides the resources to compile digital spatial data by georeferencing scanned maps and field plans. Its basic editing and coordinate geometry capabilities allow users to integrate recorded measurements. Heads-up digitizing capabilities enable users to efficiently digitize map- and plan-based topographic and architectural features. Large-scale elevation data resulting from this work forms the source for fine-detail triangulated irregular network models and derived surfaces generated using the ArcGIS 3D Analyst extension. The ArcGIS Spatial Analyst extension explores spatial relationships and distributions making use of these results. Moreover, the ability to efficiently and rapidly integrate the processes of compiling, representing, and analyzing spatial data allows researchers to work interactively with spatial information sources that complement textual and oral sources.

Researchers have used spatial systems to support fieldwork in Kythera since 1999, when staff from the University of Sydney and Ohio State University joined to form a team under the Australian Paliochora-Kythera Archaeological Survey (APKAS) project. Over the years, this work has developed into a series of community-based projects, working in close cooperation with the Kytheran community to reveal more of the island's past and preserve knowledge of a way of life that existed on the island until the end of the Second World War.



The relationship between the location of churches in the landscape and areas visible from the sea (in red) helps researchers assess the reality of the historical threat of coastal raids and the presumed reaction of the local population.

The baseline in the hierarchy of spatial systems is an extensive topographic dataset providing details of roads, paths, terraces, and other public infrastructure. This work, commenced by staff at the University of Sydney, is continually being extended as the geographic scope of the project increases.

This level of data forms the basis for cultural datasets comprising features and attributes associated with social and cultural activity from the earliest records to the present day. These datasets include the location and characteristics of churches and the results of diachronic (spanning historical eras) archaeological field surveys.

These two levels of data combine to form the base for spatial analysis designed to prompt, support, and test theories about social and cultural change and practice across the history of Kythera.

An example of this work is the use of the locations and characteristics of 58 churches spanning nine centuries to test historical accounts by determining changes in their distribution over time.

In the absence of reliable and consistent records, churches and their location in the landscape can provide insights into the locations of local settlements and the routes by which people moved, traded, and communicated.

Tradition and written sources tell us that two significant events influenced life on Kythera during the period that these churches were built and used. After the Fourth Crusade in 1250, Kythera came under the rule of Venetian interests. Less well known but more dramatically documented was the sack of the citadel of Paliochora, then capital of the island, by the Turkish admiral Barbarossa in 1537.

The mass of records resulting from the Venetian occupation of the island, largely official census records and correspondence, indicate the start of a colonial exploitation of resources that was to continue into the last century. The sack of Paliochora, characteristically for Kythera, is said to have resulted in massive ruin and long-lasting depopulation.

The study involves two analyses. The first uses a deceptively simple nearest-neighbor tool to determine the degree of clustering within the locations of churches by comparing the average distance between points with a hypothetical random dataset. The reporting coefficients provided by the tool and the ability to vary the algorithm allowed the information resulting from this analysis to be interpreted in the light of the terrain. This analysis was applied across combinations of three periods defined by the above events.

The second analysis reconstructed likely routes of communication by applying the least cost path analysis tool to link a randomly distributed set of points across the study area to two alternate centers associated with the flux of power in the island: Potamos, a market town reflecting the dominating Venetian influence, and Paliochora, the old Byzantine capital of the island.

The results of these analyses are not conclusive and indeed can never be so. However, the spatial analysis shows a trend toward greater clustering of churches in the years following the 16th century. While suggesting general changes in land use and settlement perhaps at odds with accounts of depopulation, these results prompt further research into the Venetian archives for information on corresponding changes in population and local economic conditions. The real significance of these results is the role they play within the processes of historical research.

This work is long term and tightly integrated with the Kytheran community. Its objectives will expand as more geographic and cultural surveys take place across specific areas of the island. The results of this work prompt and support new ways of looking at the past that involve a finer focus and a deeper understanding as information is gleaned from the character and distribution of features. Already, the results of spatial analysis are prompting new ways of looking at the past on the island of Kythera.

About the Author

Richard MacNeill is a senior staff member of the APKAS project and has participated in work on Kythera since 2003. He has maintained spatial systems and provided GIS analysis and data management for a variety of cultural heritage and ecological organizations and agencies.

(This article originally appeared in the Spring 2013 issue of *ArcNews*.)

A New Probe for CSI?

GIS Offers a Novel Way to Analyze Human Bones

Highlights

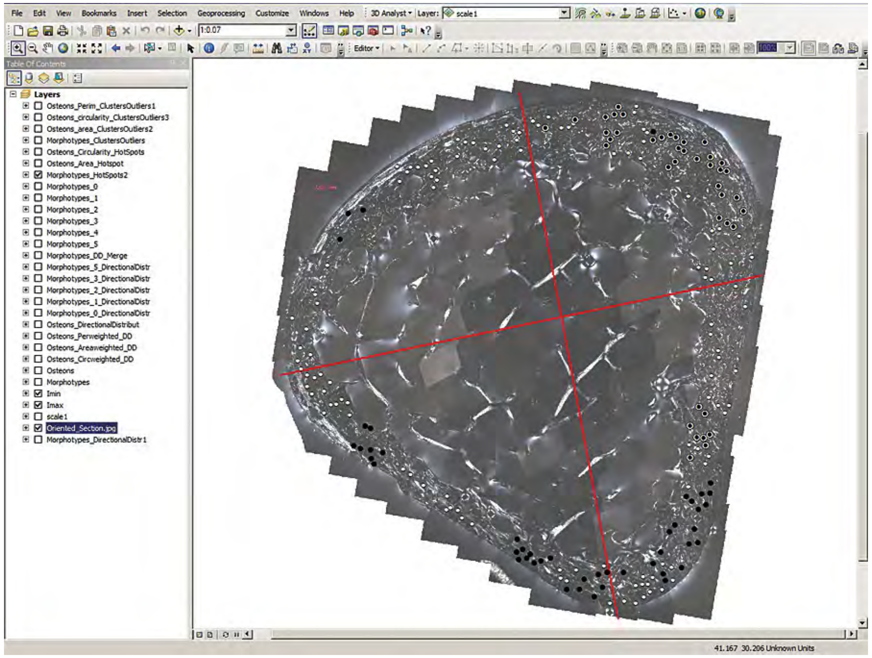
- ArcGIS software is used for the first time to map and analyze human bone microstructure.
- Mapping reveals spatial relationship of microscopic structures and how bone was used during life.
- University researchers prove that ArcGIS offers uses in forensic medicine, skeletal biology, and anthropology.

Bone researcher David C. Rose straddles two worlds.

The Ohio State University (OSU) doctoral student in anthropology is also a captain in the University Police Division, a unique vantage point in which he sometimes deals with forensic investigations involving human remains.

That exposure—and his focus on skeletal biology—prompted Rose to launch a project to determine if patterns of change inside human bones might reveal how they were used during life.

Rose and coinvestigators Amanda M. Agnew, Timothy P. Gocha, Sam D. Stout, and Julie S. Field used ArcGIS (through Ohio State University's Esri university site license) to identify and map features inside a human metatarsal (foot) bone—an entirely new



A full bone cross-section from the metatarsal (long bone in the foot) sample. The bone picture is assembled from images taken through a microscope using polarized light.

way to study human skeletal and biologic variation. "I've got more than one career's worth of work here," quips Rose.

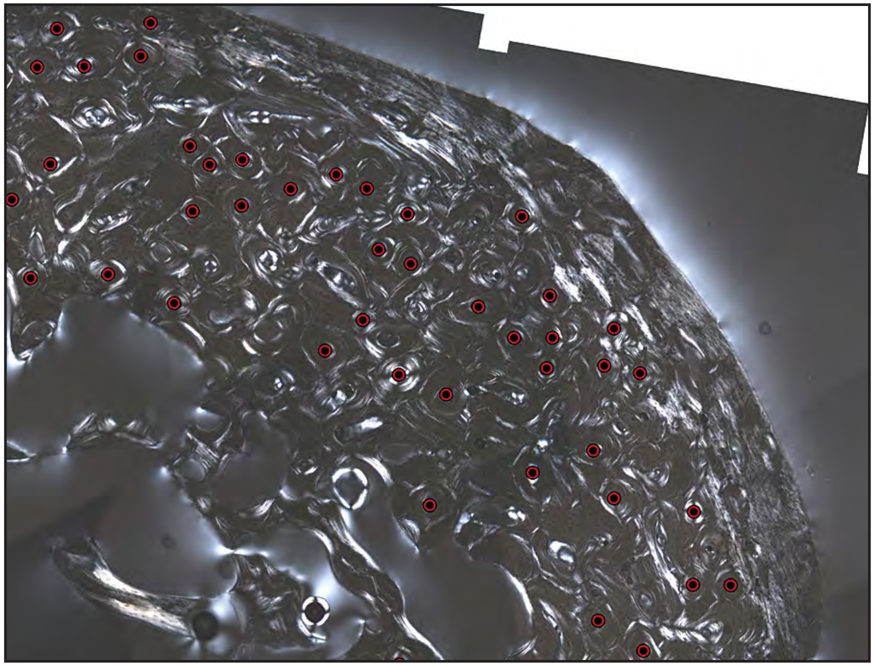
Rose began the project to explore how bones grow quickly, adapting to the load that is placed on them. "Patterns of tension and compression show up in our internal bone structure, and this software lets us look at those patterns in a new way," he says.

The research is relevant for studying not only human internal bone structure but also that of other species, such as horses, says Rose. "We can use GIS to compare species and see how animals differ from us."

Coresearcher Stout, professor of anthropology at Ohio State and Rose's doctoral adviser, explains why the findings—first published online in the June 14, 2012, *American Journal of Physical Anthropology*—are important:

"Dave's work allows us to visualize, analyze, and compare the distribution of microscopic features that reflect the development and maintenance of bones. We can then relate this to skeletal health and disease—for example, bone fragility in osteoporosis."

One other study—published by researchers in Madrid in the June 2012 *Journal of Structural Biology*—used ArcGIS to map human long bone differentiation in shape, size, and tissue type during development from embryo to adult. But to the Ohio State research team's knowledge, this is the first time anyone has used ArcGIS software to map and analyze the spatial distribution of bone microstructure.



A close-up of the metatarsal showing marked features of interest in GIS.

The Genesis of a New GIS Application

How did Rose hit upon the novel notion of enlisting GIS into bone research?

Early on, he knew that GIS software could analyze nearly any kind of spatial data, from crime statistics to flood models. He even used it to map line-of-sight views while developing security plans for events on campus.

As it turned out, Rose had to take upper-level archaeology classes as part of his graduate school curriculum. His instructor, Field, an assistant professor of anthropology at Ohio State, used GIS extensively in her fieldwork to map the location of objects uncovered at excavation sites.

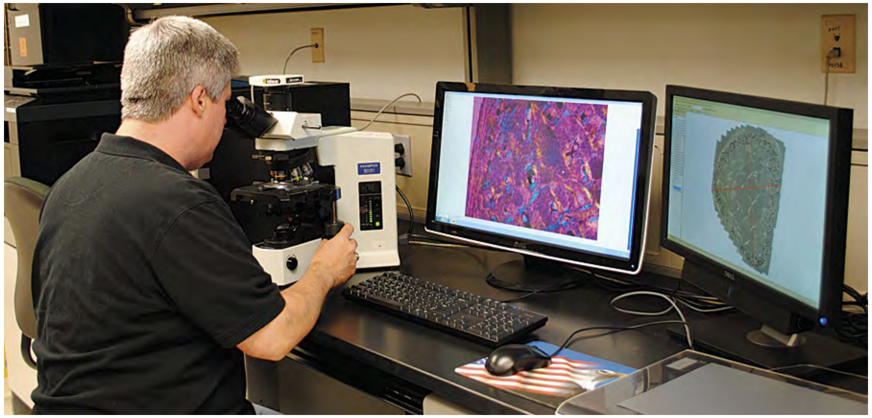
Field emphasized the need to identify important clusters of objects, such as household tools or agricultural tools, that would indicate patterns of human activity, recalls Stout. "Based on whatever scientific criteria you establish, GIS gives you a statistical measure of whether the objects you're looking at actually constitute a cluster."

According to Stout, Field saw the potential of Rose's and his use of GIS as a research tool in measuring the distribution, size, shape, and strain history of bone microstructure.

"You're trying to describe how strong a bone is for bending, tortion, and use," Stout says. "How much of a load can it experience, and how much at risk is a person for a fracture? For example, this is useful data for designing air bags in cars to minimize the chance of incurring skeletal fractures."

Small Bone Yields Big Results

For this study, which became his master's thesis, Rose examined the cross-section of a metatarsal—a long bone in the foot—from a deceased woman who generously gave her body to the Division of Anatomy's Body Donation Program. Using this bone cross-section, the team demonstrated how the software could be used to show the loads experienced in the foot during gait, or walking.



The computer monitor (right) shows ArcGIS 10 running with a bone map displayed. The left image is a bone cross-section under magnification. (Photo courtesy of David Rose, pictured.)

Rose recorded an extremely high-resolution image of the bone cross-section under a microscope. He used ArcGIS to map the location of key structures called osteons—the fundamental functional unit of compact bone.

Osteons are roughly cylindrical structures that are typically several millimeters long and around 0.2 millimeters in diameter. They are present in many bones of most mammals and some bird species. Also called the Haversian system, the structures are created throughout life to fix small cracks or maintain mineral levels in the blood. The size and shape of osteons, along with the direction of the collagen fibers from which they are made inside bone, are influenced by the loads placed on bones during life.

In this case, says Rose, the donor's metatarsal bone showed the predicted pattern of normal bone remodeling. It had concentrations of particular types of osteons along the top and bottom of the bone that could have been formed by forces exerted as she walked.

"This was just where you would expect to see telltale signs of foot flexure and compression," he says.

Rose acknowledges that his current technique is invasive and cannot be used on a living person. "But in the future, 'nano-CT' may examine a person's bones to determine the risk of fragility and fracture," he says.

Promising Technique Needs Refinement

Both Rose and Stout caution that this study provides only a proof of concept and that many more types of bones would need to be studied before GIS software could provide meaningful insight into bone biology.

Nevertheless, foot bones today are especially useful in forensics due to the sometimes gruesome reality of unidentified remains: often only foot bones are intact, having been protected by shoes. "Other bones may be chewed up by animals, but a well-preserved foot bone can be a very useful forensic application," says Stout.

Rose added that to reliably use this tool for forensic applications calls for a better understanding of spatial distribution. "But that's still some years away," he says. "This is a new area of research, and right now only one group is working on this, and that is ours."

At OSU, under Stout's supervision, Rose is combining very basic concepts in GIS and skeletal biology. However, he foresees a tremendous opportunity for advances at the intersection of both disciplines.

"The real advantage to this method is that it offers a new scale for the study of human physical variation, offering to shed light on how we adapt to our surroundings."

(This article originally appeared in the Winter 2012/2013 issue of *ArcNews*.)

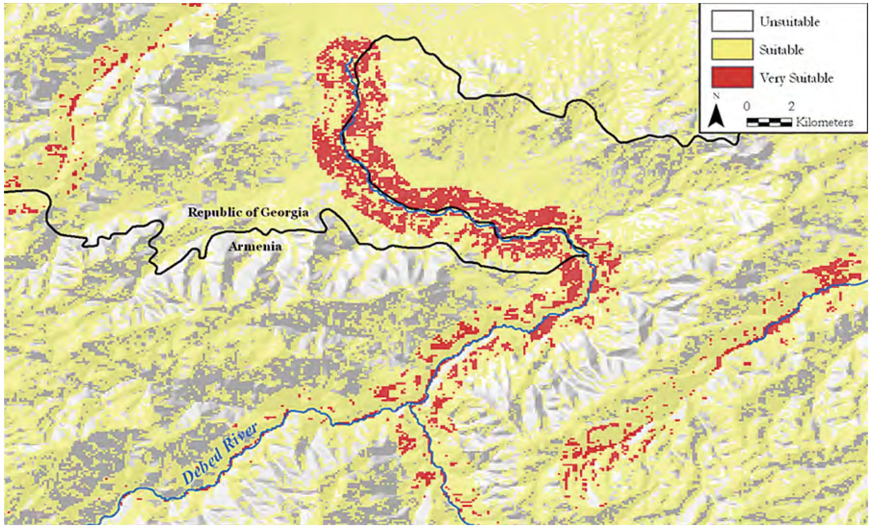
Predicting Prehistoric Site Location in the Southern Caucasus

Christopher M. Nicholson, Charles P. Egeland, and Boris Gasparian

Highlights

- ArcGIS Spatial Analyst extension modeling focused on the identification of areas with the potential for site preservation.
- Site suitability analysis enters geographic variables into a GIS model.
- Survey efforts in other areas and time periods can benefit from predictive modeling.

The southern Caucasus mountains (which includes the modern republics of Armenia, Azerbaijan, and Georgia), nestled between Africa, Europe, and Asia, has served as an important thoroughfare for human populations throughout the Paleolithic period (about 2.6 million to 12,000 years ago). Although the region has a rich record of Paleolithic research, many of the sites have not been analyzed with modern archaeological methods. Therefore, the identification of new sites in the region that can be excavated and analyzed with modern techniques is imperative. Relative to sites of later time periods, those of Paleolithic age are typically rare and nondescript.



Raster map of site suitability scores for the Debed River Valley.

With Esri university site licenses, researchers from the University of North Carolina, Greensboro, and University of Wyoming, with the National Academy of Sciences, Republic of Armenia, utilized ArcGIS for Desktop with Spatial Analyst to predict the location of Paleolithic sites in northern Armenia. The ArcGIS Spatial Analyst modeling focused on two issues: the definition, in a very broad sense, of potential survey regions and the identification of areas within the survey region with good potential to preserve sites of this remote age.

Ancient Pathways and Modern Survey Regions

One of the major sources of Eurasian populations throughout the Paleolithic period was Africa. Therefore, a theoretical migration route between northeast Africa and the Paleolithic site of Dmanisi (Republic of Georgia) was constructed. Dated to about 1.8 million years ago and preserving both stone tools and the fossil remains of extinct animals and *Homo erectus*, Dmanisi is the oldest well-accepted evidence for a human presence outside Africa. A simple cost path analysis (CPA) model was employed, which determines the path from a source to a destination while taking into account impediments to travel. Assuming that humans would have selected a path that minimized the cost (energy) of travel, the goal of the CPA was to identify a least cost path (LCP). This function was performed in ArcGIS 9.3 using Spatial Analyst. The cost raster was represented by modern terrain (a digital elevation model), which created the "cheapest" cumulative route relative to cost.

Based on this, the cheapest route runs northeast across Syria into western Turkey and skirts along the northwestern border of Armenia. Once in the Lesser Caucasus of northern Armenia, the LCP passes north before terminating at Dmanisi. Given its reliance on modern terrain, the CPA was not meant to predict the precise location of Paleolithic sites but rather to isolate potential survey regions. That the CPA matched well with the distribution of known Paleolithic sites in Armenia supports the idea that the region was an important corridor for the movement of Paleolithic human populations.

Site Suitability and Site Location

The next step was to identify specific areas in or near the LCP for focused pedestrian survey. It was soon evident that northern

Middle Paleolithic stone artifacts from Bagratashen.

Armenia's Debed River Valley was deficient in Paleolithic sites, despite the fact that numerous sites have been documented in surrounding areas.

Given this and the river's location near the modeled LCP, a site suitability analysis was run. Site suitability analysis enters variables into a GIS model that geographically displays areas that are most (and least) likely to preserve sites based on suitability scores (the higher the score, the more conducive an area is to site preservation). The location of previously identified Paleolithic sites in Armenia was used to identify predictive variables for site location. The variables most closely associated with site location were slope, aspect, elevation, land cover, and proximity to rivers. Using a linear scale transformation (LST), numerical values for each variable were assigned based on the number of sites that occurred in a particular category. The LST values for each variable were then summed using the raster calculator and averaged to remove potential outliers. This resulted in a suitability score that ranged from 0 (lowest suitability) to 100 (highest suitability). In general, the highest suitability scores were associated with areas located near rivers, with low slope and relatively open vegetation.

The calculated raster values were reclassified into three suitability categories: Unsuitable, Suitable, and Very Suitable. These values were then used to produce a raster map to visualize the potential location of Paleolithic sites in the Debed River Valley, which in turn served to focus survey efforts.

Conclusion

Guided by the site suitability analysis, preliminary pedestrian survey during the summer of 2009 in the Debed River Valley identified 25 new Paleolithic sites spanning nearly two million years. Notable among these sites are Bagratashen 1, which contains a very well-preserved Middle Paleolithic (~100,000 years ago) stone tool assemblage, and Haghtanak 3, which preserves stone tools that are similar to those of nearby Dmanisi. There are, in fact, several areas with high suitability scores that have not yet been surveyed.

About the Authors

Christopher Nicholson is the interim director of the Water Resources Data System at the University of Wyoming. Charles Egeland is an assistant professor of anthropology at the University of North Carolina, Greensboro. Boris Gasparian is a researcher at the Institute of Archaeology and Ethnography, National Academy of Sciences of the Republic of Armenia.

(This article originally appeared in the Winter 2011/2012 issue of *ArcNews*.)

Photogrammetric Modeling + GIS

Better Methods for Working with Mesh Data

Rachel Opitz, University of Arkansas, and Jessica Nowlin, Brown University

The authors describe how to bring photogrammetrically derived meshes into a GIS so that the 3D relationships between features can be easily understood, descriptive data can be integrated, and spatial analysis tools in GIS can support analysis and interpretation after the field project has ended.

Photogrammetric Survey in Archaeology

Close-range photogrammetric survey is increasingly popular as a recording method in archaeology. Photogrammetric survey uses a series of photographs of an object to deduce and accurately model its geometry.

This technique is commonly used to document features with complex geometries or large numbers of inclusions, including walls, pavements, rubble collapse, and architectural elements. These types of features can be quite time-consuming to document thoroughly by hand or using conventional surveying in the field.

The use of photogrammetric recording can greatly benefit projects by saving time and creating a visually rich final product. Photogrammetric models might be used in excavation to record a

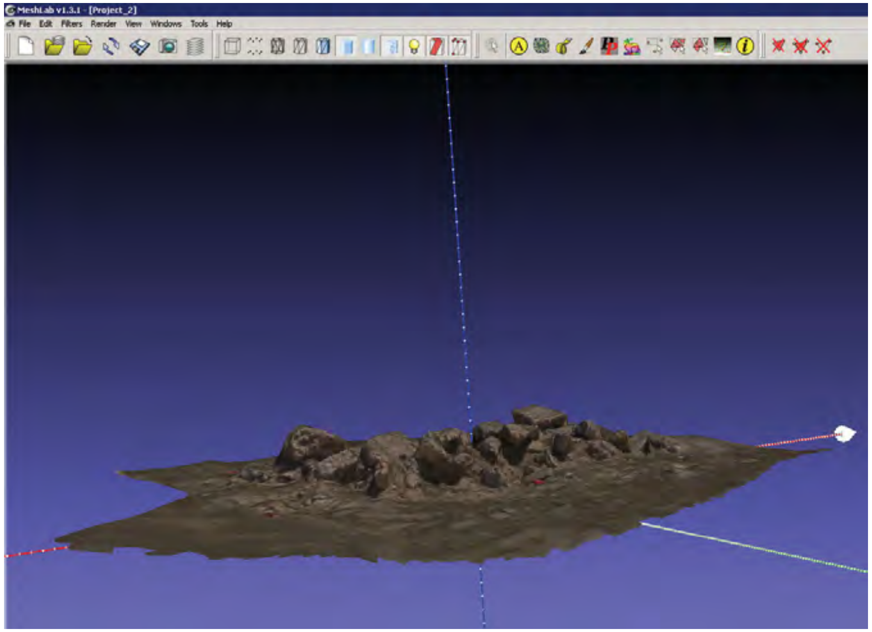
The method of bringing photogrammetric data into a GIS to create simple visualizations described in this article is being used in ongoing University of Michigan excavations at Gabii, Italy.

complex sequence of walls or a tomb or on a survey to document the environment around a rock art panel.

Photogrammetric models are typically assembled and processed in specialized software including PhotoModeler Scanner, Autodesk's 123D Catch, and Agisoft's PhotoScan. Information on photogrammetric modeling is available from these companies.

A typical final product from a photogrammetry project is a textured polygonal mesh combining color and geometry data. In archaeology, the geometry of the features recorded is often complex, and both the position and shape of these features are important, so keeping the data in a mesh format—designed to handle complex geometries—is desirable rather than converting to a simpler geometry type or a voxel model. *[Voxel models use elements that represent a value on a regular grid in three-dimensional space.]*

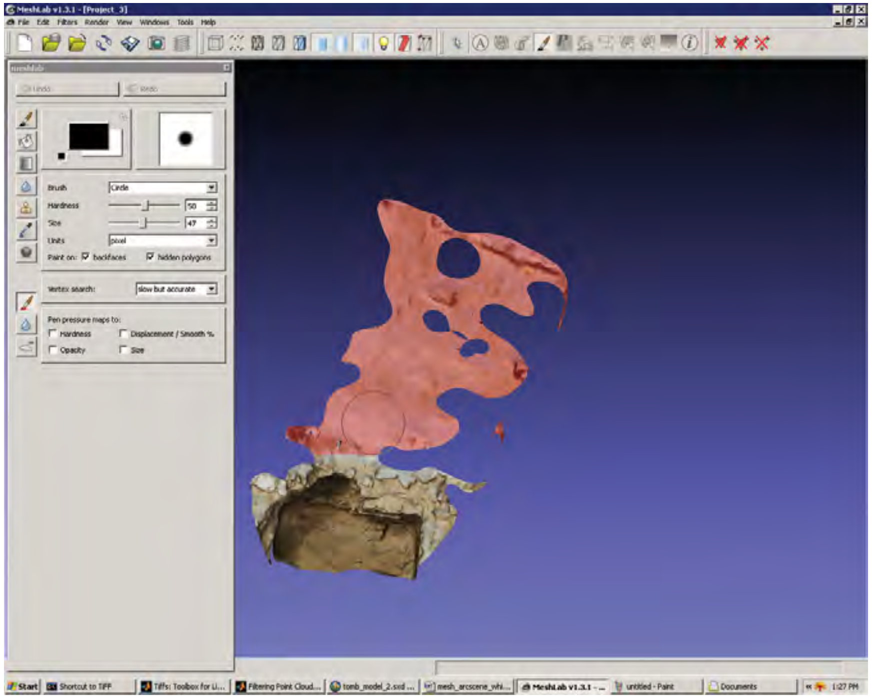
Looking at these models on their own can be useful, but to really exploit their potential, they should be viewed in context along with other data, such as survey data, photos, descriptions, and models of adjacent features that are collected in the course of a project.



A textured mesh of a typical archaeological feature, a pile of rubble, viewed in Meshlab.

Why Manage Photogrammetric Models in ArcGIS?

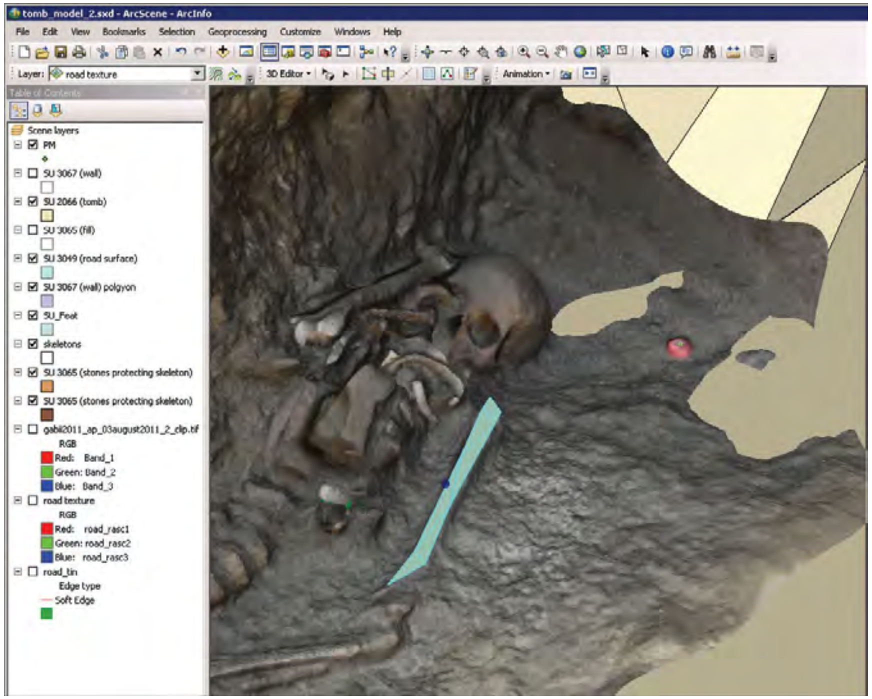
Many excavations already use ArcGIS to manage their spatial data and maintain links with other relational databases containing information such as stratigraphy, environmental data, ceramics, and osteology. Managing the results of photogrammetric surveys within an existing GIS environment is a practical solution to the problems of organizing, visualizing, and creating documentation from the 3D models. Bringing the models into a GIS facilitates the integration of photogrammetric and conventional survey data, making it easy to place the photogrammetric models in their proper locations. Finally, storing the models in ArcGIS allows archaeologists and managers to continue to work in a familiar software environment.



Working in Meshlab, unwanted polygon faces are selected and deleted.

The Basic Process

Much of the work required to bring photogrammetrically derived meshes into a GIS involves the production of a clean mesh. Once this is achieved, importing the mesh into the GIS is straightforward using the tools provided through the ArcGIS 3D Analyst extension. The creation of related information (making polygonal models of individual features, adding written descriptions, associating finds or sample data) can take advantage of GIS functionality for connecting to relational databases and managing attribute data.



Top-up digitizing tasks, like producing a georeferenced sketch of a skeleton, are done using the photogrammetric model, snapping the polygons to the mesh while outlining individual bones.

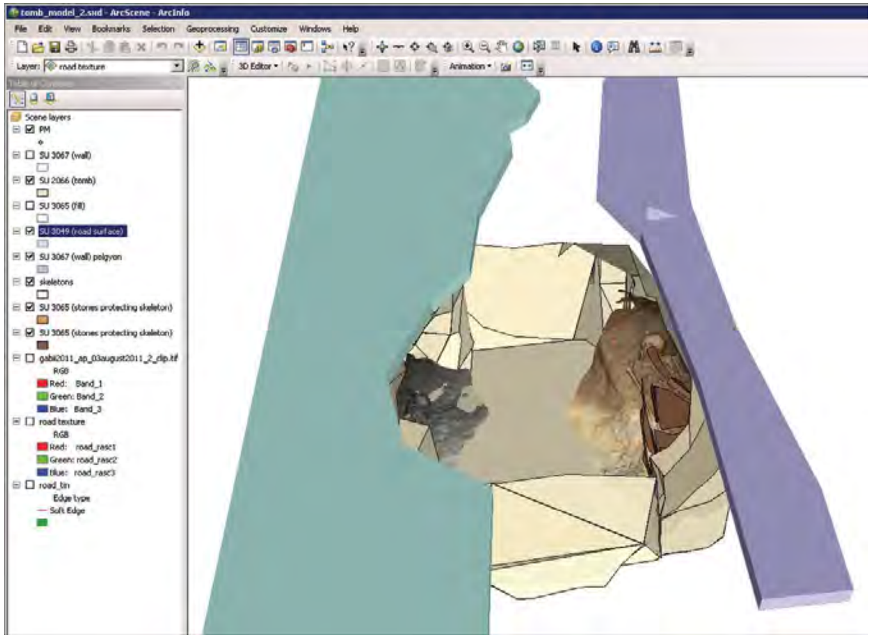
The process of bringing photogrammetric data into a GIS and using it to create some simple visualizations is outlined here using an example from the ongoing University of Michigan excavations at Gabii, Italy. There are three phases for the ingestion of each model: the creation and cleaning of the mesh; proper formatting for import into the GIS; and geolocation of the mesh, along with the creation or linking of related information and metadata.

The Initial Mesh

The mesh produced by photogrammetric modeling software will be (substantially) internally consistent but without real-world coordinates or a sense of orientation. ArcGIS does not support editing individual nodes or faces of a multipatch, so it's essential that you clean the mesh data before importing it. Closing holes, removing any areas of extraneous data, and despiking are all done at this stage. There are a number of commercial and open source software packages designed for mesh editing. [Meshlab](), a popular open source product for mesh creation and editing, is being used for the Gabii Project.

Export from Modeling Software

ArcGIS imports both VRML and COLLADA format files. Most photogrammetric and mesh editing software packages export to these formats. To minimize file sizes and improve performance, export files without color or normal data appended, as ArcGIS only uses the texture files.



The relationships between features are easily communicated through visually rich models.

Creating good texture data is an important part of making models look right. Large, high-quality textures will look good but likely cause navigation to be slow and jumpy. Producing optimized textures, including enough detail to support interpretation but without slowing navigation on-screen, is therefore an important step. Using optimized textures where possible can make a big difference in the performance of the final model.

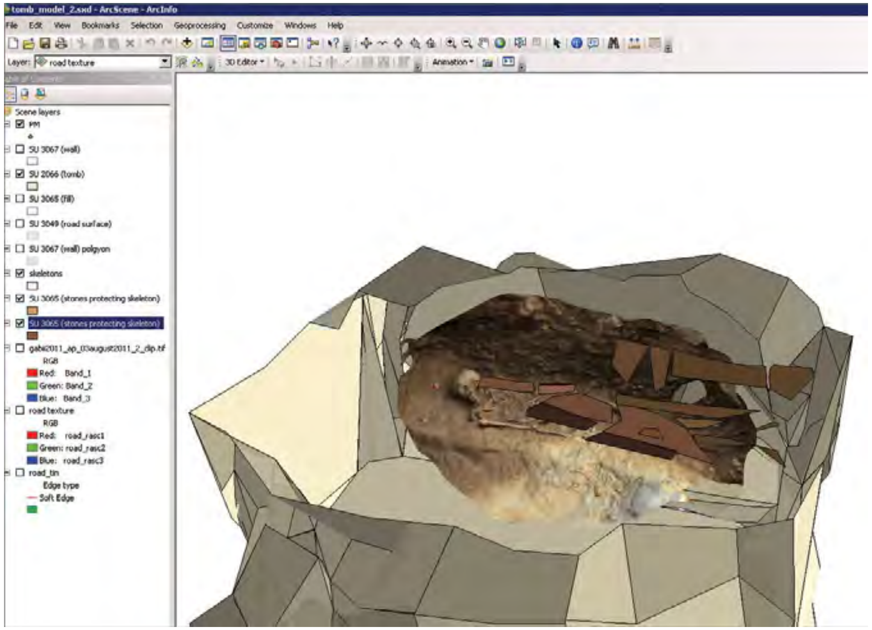
Import and Transformation: 3D Pseudoreferencing

Mesh data needs to be aligned with surveyed data to get the models into their real-world locations. One approach is to survey in points on targets that appear in the photogrammetric model. Another approach is to survey in key components or a simplified outline of the feature in question, to which natural features in the model can be aligned. For good results, at least three reference features distributed across the model are needed.

The imported mesh is aligned with surveyed reference targets (green points and red bottle caps), and its alignment with surrounding features is checked.

Related Data: Creating Features on the Mesh

Using the 3D editing tools in ArcScene, polygons, polylines, and points representing individual features like a bone, pot, or stone can be digitized directly onto the model. These digitized features can then be used for simplified representations of the model, in the creation of 2D plans, or for spatial analyses in the GIS. Alternatively, this characterization could be carried out in the modeling software and imported and transformed in parallel with

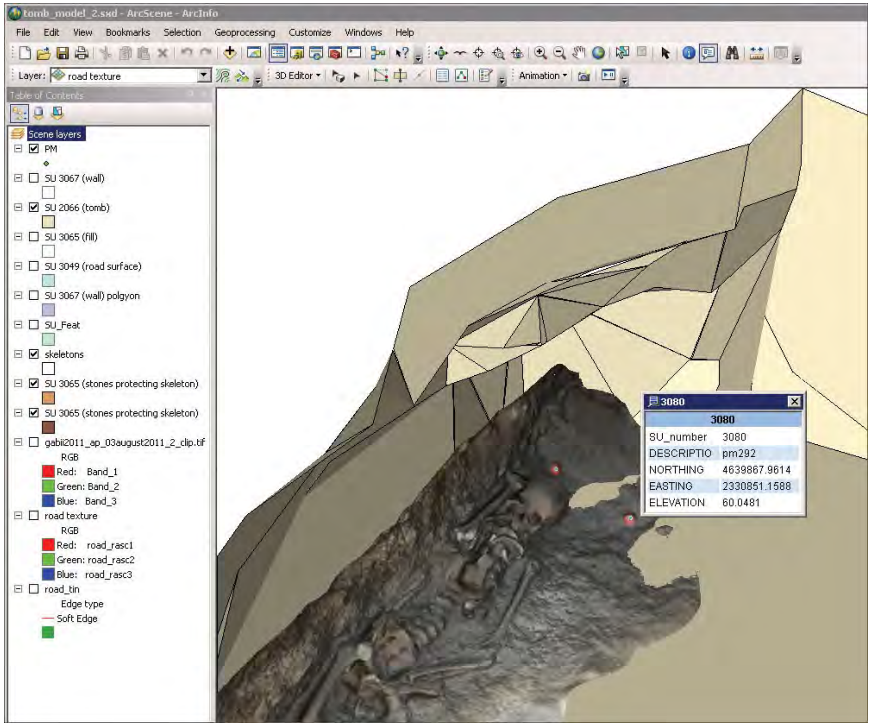


Mesh data can be viewed in combination with surveyed features. The skeleton, modeled using photogrammetric survey, can be seen with the slabs placed over it at the time of burial, modeled from survey data.

the model. Relationships between the models, digitized features, and descriptive attributes are maintained within the geodatabase.

Working with Mesh Data in a GIS Environment

Importing the models created through photogrammetric survey into a GIS makes it easy to understand at a glance the 3D relationships between features. Integrating these visually rich models with descriptive data and providing easy access



Metadata, like the model number and stratigraphic unit number, can be stored in related point and polygon feature classes.

to spatial analysis tools through the GIS supports analysis and interpretation after the field project has ended or when working in the lab. And, of course, 3D models make for compelling visualizations for use in teaching and publication, helping students, researchers, and the public explore and understand the archaeology.

Detailed workflows for bringing mesh data into ArcGIS can be found at the CAST GeoMetaVerse (gmv.cast.uark.edu).

More information about the Gabii Project can be found at sitemaker.umich.edu/gabiiproject/home. The Gabii Project is supported by a grant from the US National Endowment for the Humanities.

Acknowledgments

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About the Authors

Rachel Opitz received a doctorate in archaeology from the University of Cambridge in 2009. She works for the Center for Advanced Spatial Technologies at the University of Arkansas and leads the GIS and Survey team for the University of Michigan excavations at Gabii, Italy. Her research interests include landscape archaeology, GIS, and laser scanning.

Jessica Nowlin is a doctoral candidate at the Joukowsky Institute for Archaeology and the Ancient World at Brown University. Her research interests include landscape archaeology, the application of GIS and remote sensing, economy and trade, road networks and boundaries, public archaeology, and archaeological ethics. She leads the photogrammetric survey for the University of Michigan excavations at Gabii, Italy.

(This article originally appeared in the Spring 2012 issue of *ArcUser*.)

Temporally Discrete Prehistoric Activity Identified

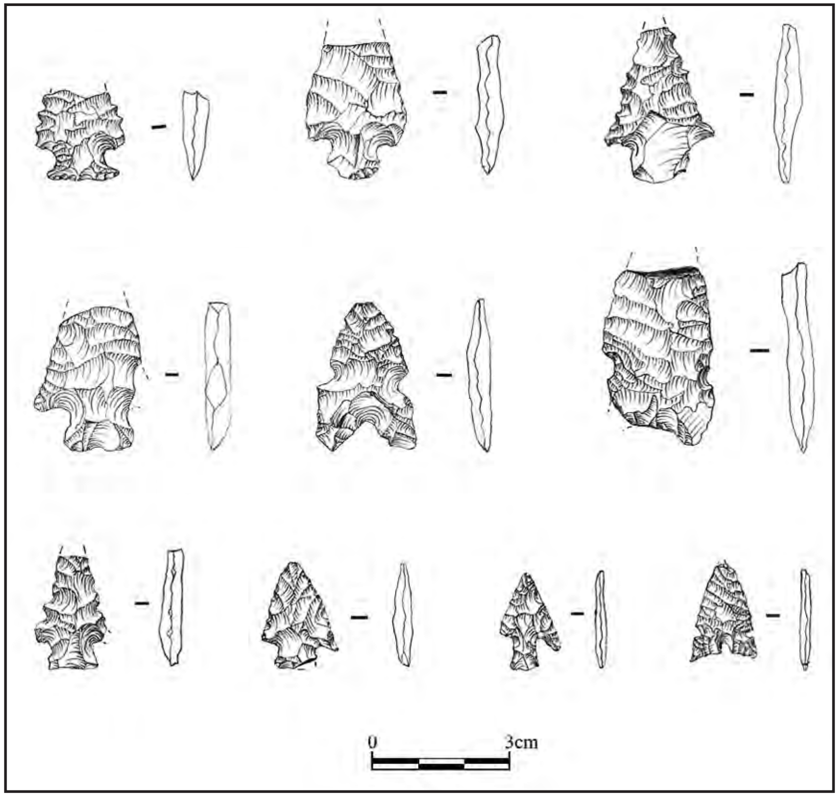
Mitigating Impacts of Transmission Line Upgrades in Western Colorado

By Matthew J. Landt and Seth Frame

Highlights

- Spatial modeling with ArcGIS focused on the distinction of discrete prehistoric activity areas.
- ArcGIS 3D Analyst displays of the activity areas enable an understanding of overlapping occupations.
- GIS improves archaeological understanding in ways not readily available through classical statistical software analyses.

Electric power provider Tri-State Generation and Transmission Association, Inc., is owned by 44 electric cooperatives and serves 200,000 square miles of Colorado, Nebraska, New Mexico, and Wyoming. When Tri-State planned to upgrade the 92-mile, 115-kilovolt Nucla-to-Sunshine Transmission Line in San Miguel and Montrose Counties, Colorado, because of the potential to disturb archaeological deposits associated with numerous prehistoric and historic sites on public land, the United States Department of the Interior Bureau of Land Management (BLM)—Uncompahgre Field Office requested the involvement of archaeologists to mitigate the impacts of construction. Alpine Archaeological Consultants, Inc., was hired to conduct archaeological investigations and monitor construction activities during the transmission line rebuild.

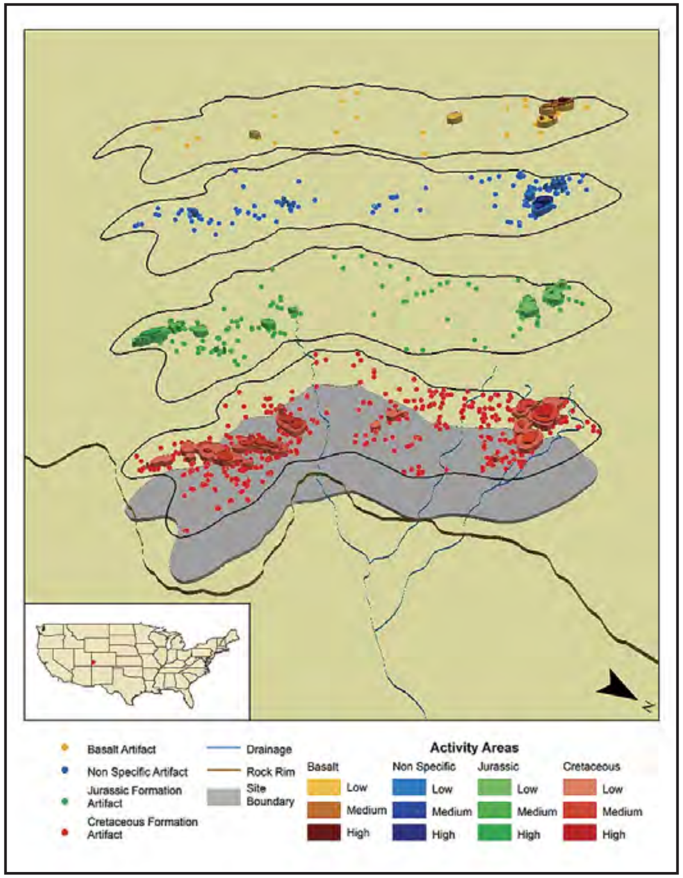


Projectile points recovered during the study of site 5MN8324. (Drawn by Jenn Mueller.)

Western Colorado has been occupied for at least the last 10,000 years, and numerous sites represent the overlap of many temporally different occupations. Traditional archaeological mitigation in western Colorado has attempted to focus on single occupations by excavating prehistoric and historic structures or fire pits, which generally allows the identification of plant and animal processing events, as well as the definition of stone tool workshop or activity areas.

One prehistoric site along the Nucla-to-Sunshine Transmission Line, site 5MN8324, was inappropriate for such excavations because of a lack of suitable subsurface deposits. At that site, archaeological investigations focused on the mapping of surface artifacts in an effort to define intrasite activity area clusters and any association those clusters may have had with temporally discrete prehistoric occupations.

Fieldwork at the 2.45-hectare (6-acre) site began with Alpine carefully flagging individual artifacts for detailed site mapping. The dense pinyon-juniper woodland prevented the line-of-sight requirements of using a total station for site mapping, so an electronic map was created with a survey-grade Trimble 2008 GeoXH device attached to a vertical rod with a circular bubble level. Utilizing multiple base stations, 97 percent of the map data was corrected within a +15 cm margin of error. In this way, 1,550 artifacts were point plotted and described. Artifacts in the mapping protocol include 1,454 pieces of flaked stone debris, 92 flaked stone tools, 3 fragments of ground stone tools, and 1 stone tool cut-marked bone fragment. [ArcGIS 10 Desktop] with the [Spatial Analyst] extension was then used to define discrete activity areas, which were graphically displayed with the [ArcGIS 3D Analyst] extension.



3D modeling allows archaeologists to visualize the degree of overlap between discrete stone tool material activity areas.

Discrete groups of artifacts were created with ArcGIS Spatial Analyst by building nearest-neighbor isopleth gradients. The gradients were based primarily on the geologic source of the stone and secondarily by each artifact's proximity to similar materials. The artifacts were sorted into different geologic groups (e.g., Jurassic-age stone versus Cretaceous-age stone) based on visual descriptions of the stone material for each artifact. Within each geologic group, finer distinctions allowed for further subdivision into distinct geologic nodules (e.g., tan Cretaceous-age stone versus white Cretaceous-age stone). All the stone artifacts were grouped into one of 11 geologic nodule types.

Once each artifact was assigned to a geologic nodule type, ArcGIS was used to create a nearest-neighbor isopleth based on a 50 m2 (i.e., 4 m radius) activity area. Or rather, the number of neighboring artifacts of the same material within 4 m of a single artifact was used to create an amplitude value for that artifact. The amplitude points for all 1,550 artifacts were then turned into a raster with six contour intervals (using the Jenks optimization method). The contour intervals were then displayed as an isopleth map. The higher amplitude clusters are likely representative of activity areas with high archaeologically interpretable value. In essence, by defining groups of artifacts that likely came from the same geologic source, archaeologists can better define and understand prehistoric stone tool use in western Colorado.

Understanding prehistoric use of an area is easier if the spatial clusters are shown to be temporally discrete, which archaeologists frequently accomplish with temporally defined projectile point forms. During the mapping protocol, temporally diagnostic arrow points and atlatl/dart points were found. Those projectile points indicate that the site was occupied between 2000–1200 BC and AD 450–1400. Spatial analyses of the density groups with reference to the projectile points indicate that in only one case were projectile points from two different temporal periods included in the same artifact group. In that case, however, there were subtle spatial differences within the group to separate the two. As such, the cluster analysis performed with ArcGIS Spatial Analyst enabled the spatial and temporal division of artifacts into discrete prehistoric activity areas.

With Spatial Analyst, the hierarchical clustering of artifact groups allows the analyst to focus on areas of likely activity and spend less time dealing with distant or fringe pieces within the analytical dataset. By removing the lowest contour values, which are mostly background noise from thousands of years of occupation, spatial analysis allows archaeologists to concentrate on artifact groups that are more readily interpretable as the product of focused human activity.

About the Authors

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