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GIS: A Rising Tool in the Geoarchaeologist's Toolbox

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GIS

Researchers use GIS to see ancient landscapes, trace historical water use and preserve archaeological sites.

In a valley high in the Peruvian Andes lie the remnants of the ancient temple Chavín de Huántar. The Chavín people erected the ceremonial site more than 2,000 years before the Inca built Machu Picchu. If you visit the site today, you can stroll across grass-covered circular plazas and walk up crumbling stairs that lead to deteriorating stone temples. You can explore the buildings' subterranean passageways and admire the carvings that adorn the walls. You can imagine the activities of people in the first millennium B.C.
But when Daniel Contreras visits the site, he sees even further into the past, envisioning the landscape before the first stone of Chavin de Huántar was ever laid.

Contreras, an archaeologist at Stanford University in California, is able to see beyond the ruins because of GIS (Geographic Information Systems). “GIS is basically a means of organizing information,” he says. It's a collection of computer tools that allow researchers to store, analyze and visualize massive amounts of data all in one place.

The visual component of GIS is especially useful to archaeologists. GIS software puts data into a spatial context. Researchers can take any number of archaeological and environmental variables — such as the location of artifacts and structures at an archaeological site, the location and type of animal bones found in the area, the region's topography, pollen data that reveal forest cover and soil data that relate to land stability and arability — and put them all on one map to see how the variables relate to each other and to get a sense of the past landscape.

“GIS makes data come alive,” says Charles French, a geoarchaeologist at the University of Cambridge in England. “It immediately gives you a new spatial perspective,” he says — in a way that's not possible when looking at numbers in rows and columns on an Excel spreadsheet.

GIS is particularly well-suited to archaeology because “almost everything [archaeologists] do has some spatial component to it,” Contreras says, such as marking the locations of stone tools relative to butchered bones within an excavation site. In fact, over the past decade or so, GIS' spatial and analytical tools have become an integral part of archaeology, allowing archaeologists to ask — and answer — new questions about past human behavior and evolution.

The Chavin people greatly transformed the Andean landscape by building stone structures and terraced walls. They also redirected the routes of rivers. Today, crumbling structures are all that remain of Chavin de Huántar.
Trends and Innovations

Daniel Contreras reconstructed the pre-Chavin de Huántar topography (top) with the help of GIS. The bottom map shows how the landscape has changed since the first millennium B.C.

One way archaeologists have employed GIS is in predicting where archaeological sites might be. This has been especially useful for state and federal agencies that have to consider the preservation of cultural resources before developing new building projects. In these instances, archaeologists use GIS technology to develop a model of where archaeological sites are, based on the presence of certain environmental variables, and then use the model to predict where other archaeological sites in an area might be located, archaeologists Mark McCoy of the University of Otago in New Zealand and Thegn Ladefoged of the University of Auckland in New Zealand explained in a 2009 issue of the Journal of Archaeological Research.

In more recent years, archaeologists have turned to GIS to better understand how humans interacted with ancient landscapes. In Contreras' case, he relied on GIS to grasp how the Chavin people coped with living in a “risky” environment, one prone to landslides, floods and other natural hazards. To understand how the Chavin people modified their Andean home, Contreras reconstructed what the area surrounding Chavin de Huántar looked like before the temple was built.

The effort wasn't as simple as erasing the decrepit structures from the ground on which they sit, Contreras says, because over hundreds of years, people and nature altered the landscape in ways that aren't obvious just by looking at the site's modern topography. Contreras created a contour map of the pre-Chavin landscape by collecting information about the site's past elevation from a range of archaeological and geological investigations conducted over the past few decades. This left him with 140 data points marking elevation across the area of Chavin de Huántar. He plotted the points using GIS and then modeled the rest of the topography.

The results, published in 2009 in the Journal of Archaeological Science, show that the landscape looked quite different prior to Chavin de Huántar. In some places, the ground was once 18 meters lower than where it is today. The findings indicate the Chavin people engaged in a lot of landscape engineering, Contreras says. They terraced walls, changed the course of rivers and laid down fill to make level platforms on which to construct buildings. Contreras has also documented that the Chavin followed a "repeated pattern of ignoring hazards," by cutting into the surrounding hills as the monument expanded over time. This activity destabilized the hills' slopes, making landslides more likely, he says. It's analogous to the way modern societies often ignore the potential for natural hazards, he adds, which leads him to wonder why people keep creating these hazardous living conditions for themselves.
With the help of GIS, researchers can map the "topography" of modern teeth and compare the wear patterns to fossil teeth to better understand the diets of extinct hominins.

Over the years, archaeologists have become quite "inventive" with how they use GIS, says Erich Fisher, an archaeologist at Arizona State University in Tempe. They've turned the concept of a landscape on its head, transforming bones and teeth into geographic surfaces that can be plotted on a map. For example, scientists have developed GIS methods of mapping all of the nooks and crannies on a molar surface. By comparing the "topography" of an older individual's tooth with that of a young, unworn tooth, researchers can study how "erosion" and "deposition" change a tooth over time. This is helpful in learning about patterns of aging or diet. Kierstin Catlett, a graduate student at Arizona State, is using such methods to study how young primates manage to chew "adult" foods with their baby teeth. Such a technique could also be applied to the fossil record to learn more about the diets and behavior of our ancient hominin ancestors, such as Australopithecus afarensis.

GIS makes data come alive.
– Charles French, University of Cambridge

Using GIS to address smaller-scale questions has also helped archaeologists investigate both the human and non-human factors that play a role in altering or accumulating bones and artifacts at a site. For instance, there are a number of reasons why a researcher might find piles of cow bone fragments during a dig: The bones might be evidence of butchering and human meat-eating or they might be the remains of a wolf's dinner. Then again, the fragments might have originally come from different stratigraphic layers and were brought together via the action of physical processes. These different causes can be discerned because they create characteristic bone fragment distributions — leftovers of a carnivore's meal tend to have a disproportionate number of foot bones, for example, because those parts of an animal aren't digestible.

One of the first steps in addressing such questions is assessing which body parts are represented in the sample and in what quantities. To streamline such analyses, Curtis Marean, an archaeologist also at Arizona State, and colleagues developed a GIS-based technique of digitizing the shape of bone fragments and then mapping them onto the outlines of bones to see where on a bone a fragment comes from. Such a program helps researchers see the concentrations of different fragments, allowing them to determine if there is any particular pattern.

And because GIS can handle a lot of data, collections of bone fragments across multiple sites and time periods can easily and quickly be compared.

Because GIS can provide such powerful spatial analyses, the technology has forced archaeologists to be much more precise in the way they collect and record data, Fisher says. It's now routine to use laser-based survey instruments to record the exact location of artifacts, Fisher adds. This new level of precision has allowed archaeologists to create digital, 3-D reconstructions of their excavation sites in GIS programs. These virtual sites are so accurate that a researcher can log on to his or her computer and re-excavate a site from the comfort of his or her office, Fisher says. Such virtual expeditions also allow researchers to view digs from new perspectives and investigate the layout of a site from new angles, he adds, opening their minds to new questions and observations that they might not otherwise contemplate.

With the myriad benefits that GIS has to offer, the technology has become an integral part of modern archaeology. Nowhere is this more evident than in help-wanted ads, says Michael Harrower, an archaeologist at Johns Hopkins University in Baltimore, Md. "GIS has become a really big specialty," he says. "It's moved from being something that was a fad to something so popular that my job was advertised as an archaeologist who specializes in GIS."

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Archaeologists rely on GIS to solve a variety of problems — everything from investigating past irrigation practices to recreating ancient coastlines to saving threatened archaeological information from the forces of Mother Nature. The following are three examples of how archaeologists are putting GIS to work.
Where the Water Flows

Michael Harrower created a digital elevation model of Yemen using satellite images to better understand drainage patterns in the region.

Archaeologists have long been interested in water, because access to water was crucial to the development of agriculture and civilization. Traditionally, studying water's relationship to an archaeological site meant taking out a map and measuring the distance between rivers and ancient human landmarks, says Michael Harrower, an archaeologist at Johns Hopkins University in Baltimore, Md. GIS allows for more sophisticated analyses.

Harrower has been investigating the water management practices of farmers living in southern Arabia as early as the fourth millennium B.C. Agriculture developed much later there than in more northern parts of the Middle East. Some of Harrower's recent work has focused on why that's the case, and how farming in Yemen was different from farming that occurred to the north across the Fertile Crescent, home to some of the early seats of agriculture.

Six thousand years ago, Yemen was not the arid desert it is today; cattle remains show the region was wet enough to support the grassy pastures that bovines need to thrive, Harrower says. Through archaeological surveys in the Wadi Sana watershed of eastern Yemen, Harrower has located almost 175 ancient irrigation structures, including channels that divert water from hillslope runoff. GIS modeling has helped him understand the reasoning and strategies behind where early farmers placed their irrigation systems.

With satellite data from NASA's ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument, Harrower created a digital elevation model of his study area. Next, he used a GIS module called ArcHydro to model water flow. The digital elevation model is divided into a grid, and ArcHydro determines the direction of water flow from higher to lower elevation squares. Once this is done for every square, the results can be used to create drainage maps.

Harrower then mapped the irrigation structures on his digital elevation model to see if there were patterns he could discern. "Intuitively, you'd think they'd be built in areas with the most water flow, but that's not the case," he says. Instead, statistical analyses revealed that farmers were building their irrigation structures in areas of moderate to low flow, Harrower reported last year in the Journal of Archaeological Science. This strategy actually makes a lot of sense, he says, because moderate amounts of
water are easier to manage and divert than faster-moving, high-energy flows.

Harrower has done similar analyses for an area of northern Ethiopia, another region where the transition to agriculture has not been well-studied. Unlike eastern Yemen, however, farmers in Ethiopia were not as reliant on irrigation. Harrower’s analyses, published with colleagues in 2008 in the Journal of Field Archaeology, show that ancient settlements were placed in low-lying areas where the most rainwater was likely to accumulate and saturate the soil with moisture.

Although GIS is popular among archaeologists, not many researchers have applied it to the question of water management, Harrower says. “One purpose of [my recent paper] is to encourage wider applications of GIS hydrological modeling because it certainly has a lot of potential.”

Where's the Coast?

In 2007, archaeologists led by Curtis Marean of Arizona State University in Tempe announced in Nature that they had found the earliest evidence of modern humans eating seafood. In a cave at Pinnacle Point along the coast of South Africa, Marean and colleagues found the remains of shellfish at an archaeological site dated to roughly 167,000 years ago.

The addition of seafood to the diet was a crucial development in human history for a number of reasons, says Erich Fisher, an archaeologist also at Arizona State who worked on the project. The ability to exploit coastal resources probably enabled humans to expand out of Africa and migrate around the world. In addition, Earth was experiencing a dry glacial period 167,000 years ago, he says, so many land-based resources that humans had once relied on were probably scarce. Finding new sources of food was therefore critical.

However, Fisher notes, ethnographic and archaeological evidence indicates hunter-gatherers weren’t willing to travel more than 10 kilometers to collect seafood. Although Pinnacle Point sits on the coast of the Indian Ocean today, it would not have been ocean-front property during glacial periods because the sea level would have been lower. Thus, one lingering question was: Exactly how far away from the coast was Pinnacle Point? If the ocean was far beyond the 10-kilometer threshold, Fisher says, it might make you question whether the site containing evidence of seafood was dated correctly.

To “strengthen the reliability of the dates,” Fisher modeled the “paleoscape,” as he calls it, by developing a GIS-based method to estimate the ever-changing position of Pinnacle Point’s coastline in 1,500-year intervals over the past 420,000 years. He created an elevation model of the area’s topography and seafloor bathymetry with ArcGIS software. Then he added in sea-level heights from published sea-level curves. For any point in time, Fisher can see where the ancient sea surface intersected with the model’s topography — in other words, where the coastline was and what it looked like. This method works, he says, because South Africa is tectonically stable, which means the topography wasn’t substantially uplifted or lowered during this time due to tectonic forces.

The model confirms that people living at Pinnacle Point 167,000 years ago had easy access to the coast; it was just five kilometers away. But the coast was only within sight for a geologically brief period of about 3,000 years, Fisher and colleagues reported last year in Quaternary Science Reviews. For example, 10,000 years later, the coastline was
Researchers excavate a cave at Pinnacle Point in South Africa, where the earliest instance of human seafood consumption was discovered. The rise of GIS has caused archaeologists to be more precise in the way they collect and record data in the field.

GIS helped Erich Fisher determine how the coastline at Pinnacle Point in South Africa has changed over the past 420,000 years. Today, the ocean is visible from the caves at Pinnacle Point, but that wasn't the case 152,000 years ago (reconstruction pictured left). Back then, sea level was lower and the coast was 88 kilometers away, implying any humans living in the area probably did not gather seafood.

If people were living at Pinnacle Point at that time, they probably weren't eating shellfish, Fisher says, or they may have followed the shoreline as it moved away, leaving Pinnacle Point behind. Now as new archaeological sites are found in the area, Fisher can see how close coastal resources were.

So can other archaeologists: Fisher and colleagues published online digital videos along with their 2007 and 2010 papers. These videos provide 3-D reconstructions of the Pinnacle Point cave and coastline. Such videos will allow the whole scientific community to better understand the team’s findings and give researchers a new perspective on the conditions early people experienced in this part of the world. "It's hard to visualize complex spatial data without seeing it in 3-D," Fisher says. He expects such videos will become more frequent in the next few years.
GIS to the Rescue

GIS can do more for archaeologists than illuminate past landscapes and human behavior. It can also save precious artifacts and excavation sites. In 2007, the state archaeologist of Georgia and other officials in the state's Department of Natural Resources were concerned that dozens of Native American archaeological sites, some dating back to 4,000 B.C., on Georgia's barrier islands might soon be lost to the sea. They turned to research technician Mike Robinson and his colleagues at the Skidaway Institute of Oceanography in Savannah for help.

To assess how erosion is damaging 21 of the barrier islands' archaeological sites, Robinson and colleagues plotted the sites' locations in a GIS map. They also gathered and digitized U.S. Coast and Geodetic survey maps of the islands dating back to the 1850s and aerial images dating back to the 1940s so they could measure changes in a shoreline's position over time. A GIS program called SCARPS! (Simple Change Analysis of Retreating and Prograding Systems) calculated the net loss (or gain) in each island's coast and the rate of erosion (or accretion).

With those estimates, the team checked to see which sites in their project were most in danger of being destroyed. They found that two sites are in areas accreting new land, and eight sites sit near stable coasts. The remaining 11 sites are being eroded, and important cultural information buried in these locations is being lost each year, the team reported last year in the journal Geoarchaeology.

Knowing the rate of erosion, the team calculated the expected "lifespan" of the endangered sites. If rates of erosion remain the same, most of the sites have about a century left before being completely destroyed. One site has only 18 years left.

The estimates offer officials a way to prioritize the order in which these sites should be documented or protected, Robinson says. "In Georgia and elsewhere, state agencies tasked with management of cultural resources have had budget cuts," he says. "By having this prioritized list, it allows them to target the resources most efficiently."

Robinson's work hasn't ended. The success of the barrier island project has led to a second study of archaeological sites on the state's back barrier islands, smaller islands located between Georgia's coast and its main barrier islands. The findings will provide officials in Georgia even more information on how to protect the state's cultural heritage.

Barrier islands line Georgia's coast and are home to dozens of archaeological sites that are in danger of being eroded away.