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GROUND PENETRATING RADAR TO ELECTRICAL RESISIVITY: A DIGITAL MEANS OF SAVING THE PAST FOR FUTURE GENERATIONS

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Introduction

Human land use practices and global warming endanger the preservation of heritage resources in many regions of the world. Development has always been a threat to heritage resources, particularly in areas where there no government regulations in place to ensure that landscapes are surveyed for archaeological sites prior to development: The more subtle surface sites and/or buried sites are most at risk. Yet all cultural resources suffer from development even if they are not destroyed by a bulldozer's blade. Historically significant buildings, structures, monuments and archaeological sites are damaged when an area is opened to increase use. Pedestrian and vehicular traffic often lead to erosion, and casual use of a site area can cause wear-and-tear on heritage resources. In addition to these types of uses adversely affecting sites, overgrazing on marginal landscapes contributes to the expansion of deserts in Asia, Africa and the Americas; deforestation and swidden agricultural practices in other regions leave landscapes susceptible to erosion, denudation, and mudslides, which in turn can destroy heritage resources.

Like development, climate change has often led to the decimation of archaeological sites: Thousands of Archaic and more recent coastal sites lay under 10 to 30 metres of water. Sea level has been rising since the end of the last Ice Age, about 11,000 years ago, only recently has it become news. Heightened awareness about the impacts of climate change on heritage resources has resulted in the United Nations Educational, Scientific and Cultural Organization (UNESCO) conducting a study on the impacts of climate change on heritage resources (UNESCO 2007). In addition to the rising sea level destroying coastal sites, UNESCO (2007) determined that global warming will result in intensified storm systems (hurricanes, tropical storms, and El Niño storms) which will cause flooding, mudslides and erosion at significant sites in different regions of the world. Intensified drought will occur in other regions, such as Australia and California, fuelling the extent and frequency of wildfires.

Whether they are being affected by climate change or human land use practices, the integrity of heritage resources in many regions of the world is threatened. With limited funding dedicated to mitigating the adverse effects of climate change, overgrazing and deforestation on heritage resources, several significant cultural sites may be lost within the next 50 to 100 years. In order to limit the loss of information from significant sites threatened by development and or climate change, but for which there is no funding to conduct data recovery or construct protective measures (e.g. shelters, flood protection barricades, levees), advanced technologies can be employed to document some components of buried archaeological sites. Many cultural materials have a different physical or chemical signature from the sediments in which they are buried and, as such, can be measured and mapped using geophysical techniques. This mapped information can be used to identify areas with the most potential for recovering significant information and can be used to refine areas to be excavated, potentially reducing excavation costs. Additionally, the physical and chemical data for the site can provide insight into how the site and surrounding landscape was developed and used through time, including agricultural uses.

Some common applications used to investigate buried components of archaeological sites include: geophysics (ground penetrating radar, magnetic gradiometry, and electrical resistivity); photogrammetry, satellite remote sensing and three-dimensional laser scanning. These applications are discussed in greater detail below.

Geophysics (Subsurface Remote Sensing)

Geophysical applications in archaeology consist of a suite of tools designed to measure the physical properties of the earth and distinguish them from buried components of the archaeological record. A variety of instruments can be used to document buried cultural resources without disturbing the ground surface. Ground-penetrating radar, magnetic gradiometry and electrical resistivity can all be used to create a virtual window into shallow subsurface deposits. Critically, these methods are non-destructive, can provide significant information about a site and its setting, and concurrently provide a means of archiving important information for use by future generations of archaeologists and preservation specialists. This is particularly important for sites threatened by natural disasters or human land use practices.

Ground Penetrating Radar

Ground-penetrating radar (GPR) is a geophysical method that is beginning to be more widely used by archaeologists to study near-surface archaeological remains. GPR entails transmitting high frequency radar pulses into the ground from an antenna that is passed over the ground surface. The radar pulse is reflected back to a receptor when it contacts sediments, features and artifacts: all materials have physical and chemical properties that affect the propagation of electromagnetic energy. Specifically, the electrical conductivity and magnetic permeability of an object or sediment affects the rate at which the radar signal bounces back to the receptor. When several thousand radar pulses are transmitted through the sediment in systematic transects, the reflected radar pulses are recorded and mapped creating a three-dimensional picture of sediments, features and even some classes of artifacts.

The greatest resolution within the three-dimensional image is created when the radar pulses encounter two layers with greatly varying properties. Higher amplitude reflections occur when these layers are relatively thick, hence providing a higher resolution signature. For example, a compacted clay-, or stone-lined feature (such as a pit house or storage pit) buried by loose sand or silt would stand out prominently in the image created by GPR. In contrast, features composed of the same materials as the surrounding matrix are difficult, if not impossible, to identify using GPR because the physical and chemical properties of the feature are essentially the same. For example, a rock-lined roasting pit located in colluvium or large gravels would be difficult to distinguish in a map created using GPR. Correspondingly, on some sites GPR is not an appropriate application.

Magnetic Gradiometry

The Earth’s magnetic field can be measured and mapped using a magnetic field gradiometer (MFG). Rocks and sediments of varying parent material have a unique magnetic signature and, as such, boundaries between different substrates can be distinguished in maps produced using a MFG. Cultural features also have a unique magnetic signature. In archaeological applications, a MFG is used to map Earth’s magnetic field along a grid pattern. This method can depict shallow subsurface archaeological features such as charred/fired hearths; pit houses and storage pits and rock or brick walls, facilitating production of fairly detailed maps of buried features without excavation.

The capabilities of this technique are aptly illustrated in an MFG map of Titris Hoyuk (an Early Bronze Age site in Turkey) prepared by Dr. Guillermo Algaze of the University of California, San Diego, and Dr. Timothy Matney of the University of Akron (Matney 2009). The MFG mapping program for the project facilitated identification of streets built from pottery shards, limestone wall foundations and kilns (Figure 1).

Electrical Resistivity

The electrical resistance of rocks and sediments from different parent materials varies and as such boundaries between different substrates can be distinguished in maps produced using electrical resistivity (ER). Different types of cultural features also respond to electrical currents differently and therefore can be distinguished from the surrounding matrix using this method. To conduct ER, an electrical resistivity meter is used to pass a weak current of electricity through the ground at regular intervals on a survey grid. A resistivity meter is a square frame with two to four metal bars located on the base of the frame which stick downwards; these are spaced either 50 or 100 centimetres apart and are tipped with electrodes. The bars are inserted into the soil, and a brief pulse of weak electrical current is passed between them. The level of resistance encountered within the grid is recorded in a data logger and then are then plotted or mapped using a graphics program.

The plot/map produced by ER displays patterns of resistance across the survey area. Because electrical currents are conducted by water, moisture content in the soil, or in a feature, affects resistance. Correspondingly, buried features which often retain water, such as pits, wells or irrigation ditches, are clearly depicted when they are located in dry sediments. Similarly, stone features stand out because they typically have a lower moisture content than the sediments around them and impede the flow of electricity. ER can therefore be used to create a map of buried features, which can guide excavations, or inform heritage resource managers about the buried extent of a site which is threatened by natural disasters or human use of the landscape.

An ER map of a prehistoric shell midden site located in southern California illustrates how this technique can facilitate identification of subtle subsurface features at sites which are going to be impacted on by development (see Figure 2). On this map, areas with higher or lower than average resistivity depict locations of probable buried cultural features and helped to guide excavations conducted at the site (Grenda et al. 1998).

Three-Dimensional Laser Scanning

Three-dimensional laser scanning (3-D LS) is one of the newest geospatial technologies to be used to document heritage resources. Tripod-mounted instruments can scan buildings, engineering features, surface topography, rock art, archaeological features, and artifacts. The raw data from scans take the form of X, Y, and Z point clouds containing literally millions of measurements. Data points can be collected, for example, at a 3-millimetre grid up to a distance of 200 metres. The accuracy of close-range artifact scans can be measured in micrometres. These point clouds are turned into complete three-dimensional models that can be used for analysis, or for visualization products. Three-dimensional computer models can also be printed on three-dimensional printers to produce exact replicas of artifacts, features, and even scaled models of structures and engineering features. This information can be digitally archived providing an important virtual source of data for future research, education, and public interpretation. Figures 3, 4 and 5 illustrate how easy it is to use 3-D scanning techniques on an archaeological site to illustrate buried features and develop 3-D reconstructions of artifacts and/or other remains.

Photogrammetry

Although three-dimensional laser scanning is replacing some photogrammetric applications, photogrammetry continues to be a valuable tool for documenting archaeological sites using a non-destructive technique. Simple photogrammetric techniques are only slightly more labor intensive than regular photography and the images provide quantitative data that can be used to accurately map subtle features on the landscape. More robust photogrammetric methods, such as convergent or stereo photogrammetry, enable true three-dimensional measurements, provide very high levels of accuracy and the data can be used to develop digital elevation models and orthophotographs. Photogrammetric methods, such as lidar, has proven to be a useful tool for mapping prehistoric agricultural fields and associated irrigation ditches with a high level of accuracy and with far less time investment than is required using conventional mapping techniques. The data and products derived from photogrammetry can be digitally archived and used by future archaeologists and agronomists to study agricultural practices in different regions and at different times in prehistory and history.

Satellite Remote Sensing

Satellite remote sensing can be used to characterize physiographic settings, classify land cover, identify cultural resources, and analyze changes in the use of the landscape. At present, the United States has 2 satellites (Landsat 4 and 5) equipped with thematic mapping capabilities. These satellites gather digital data in the visible, reflective infrared and thermal infrared spectrums and these multi-spectral data are uploaded to computers and processed. The resulting images reveal extremely slight variations in the Earth’s surface. For example: ephemeral trails and subtle clearings can be depicted on a desert landscape.

Satellites which send out radar signals to earth and then record the reflected signal rely on the same principle as GPR. Satellites equipped with multi-wavelength radar can be used to penetrate the surface of some materials such as sand and leaves, facilitating identification and documentation of buried archaeological sites and features. The use of this technology was first applied in 1981 when NASA launched SIR-A. The radar signal from this satellite detected a series of ancient river beds buried beneath sand in the Sahara Desert. Archaeological investigations performed on the river terraces resulted in the discovery of Paleolithic sites containing a plethora of stone artifacts. A more recent NASA satellite (SIR-C) identified a buried component of the Great Wall of China beneath dirt and sand. This satellite also found previously undocumented water reservoirs and moats beneath the forest canopy in Cambodia which are associated with Angor Wat.

Information on the distribution of archaeological sites and cultural features relative to landforms, water resources, and various types of vegetation, which are derived from satellites can, in turn, contribute to the development of predictive models.

Predictive Models

Using a geographic information system (GIS), predictive models analyze spatial data on vegetation, hydrology, soils, and topography relative to known archaeological sites in a region. In essence, in different geographic regions around the world certain site types are found in association with certain landforms. An archaeologist familiar with heritage resources in a region, can work with a modeler to develop a statistical probability model which predicts the likelihood of archaeological sites being present in different landforms in the study area (Figure 6). Predictive models are refined through ground-verification, and when fine-tuned, can be used by land managers to assess the likelihood of buried cultural resources in an area which is going to be impacted on by development, or in the case of the military, by military exercises or war. These areas can then be investigated using various combinations of the technological methods described above, to verify the presence of buried sites and features, and document buried elements of existing resources non-destructively.

Conclusions

All of the applications discussed above can be used to identify and document subtle surface manifestations of archaeological sites (photogrammetry and Landsat), or buried components of archaeological sites at varying scales and resolutions (GPR, MFG, ER, 3-D LS and SIR). The critical aspect of these technological applications is the ability to document cultural resources non-invasively. Whether utilizing images derived from GPR or ER, archaeologists can better determine the size, nature and extent of buried archaeological sites comprised of cultural features and materials which can be detected by these mediums. This information can, in turn, be used to refine and guide archaeological excavations, or if money is not available for excavation, provides an 3-D archive of the buried resource. Should a site be destroyed after being documented using one or more of these techniques, the digital archive can live on and remain a source for future generations to study and appreciate the past.

References

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Grenda, Donn R., Christopher J. Doolittle and Jeffrey H. Altshcul 1998. House Pits and Middens: A Methodological Study of Site Structure and Formation Processes at CA-ORA-116, Newport Bay, Orange County, California. Technical Series 69, Statistical Research, Inc. (Manuscript available through www.sripress.com).

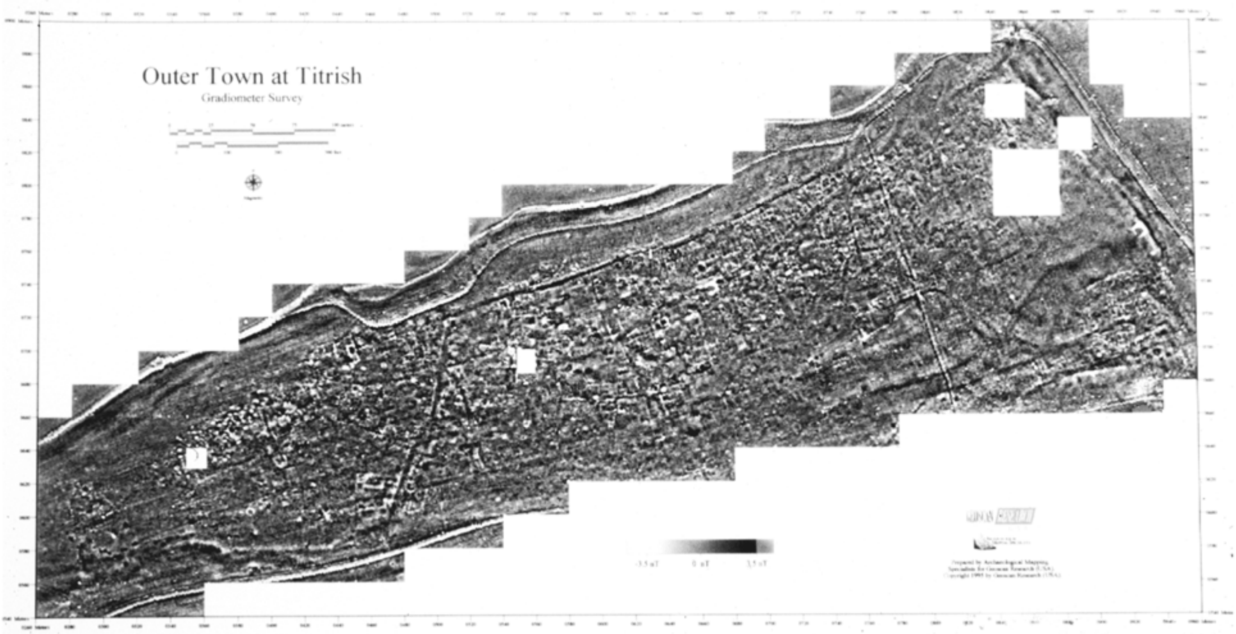

Figure 1. Magnetic gradiometry map of Titrus Hoyuk, an Early Bronze Age site in southeastern Turkey (courtesy of Dr. Timothy Matney).

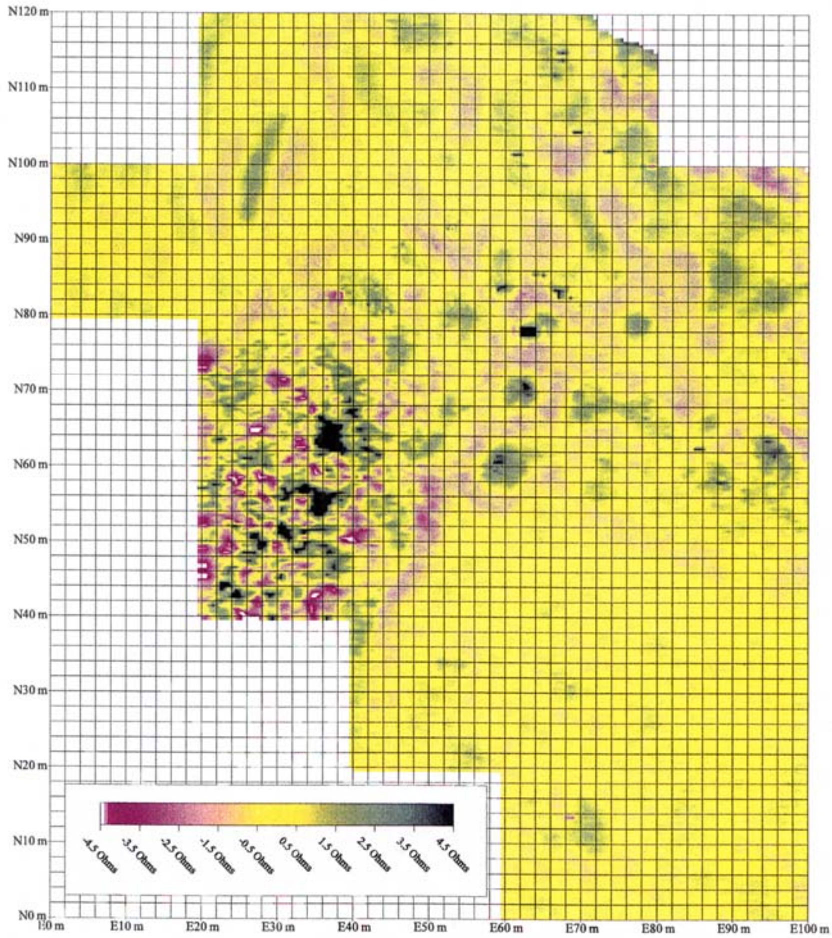

Figure 2. An electrical resistivity map of a prehistoric shell midden site prepared using Surfer, version 6.01. Areas depicted in black, red and white depict potential buried cultural features (from Grenda et. al. 1998).

Figure 3. Photograph of archaeologists using a 3-D scanner at a prehistoric archaeological site in California (courtesy of Statistical Research, Inc.).

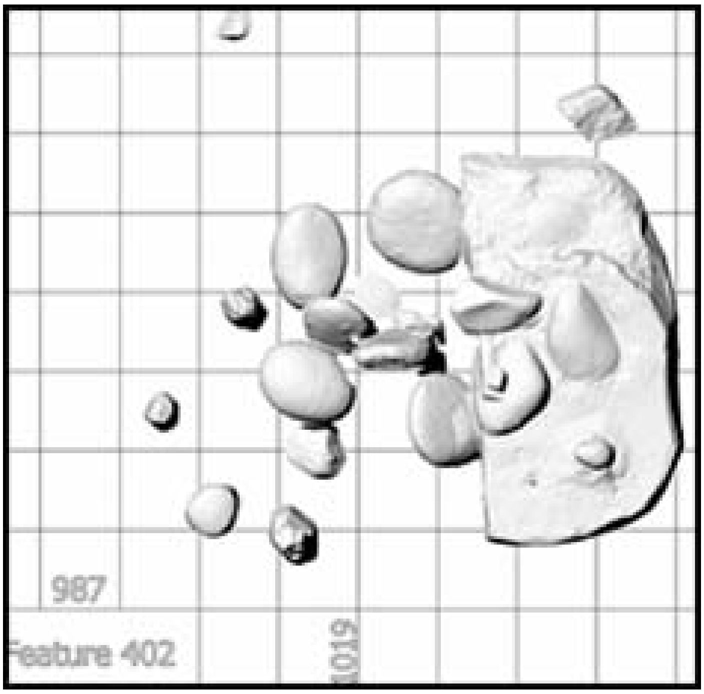

Figure 4. A 3-D map of a buried archaeological feature identified using a 3-D scanner (courtesy of Statistical Research, Inc.).

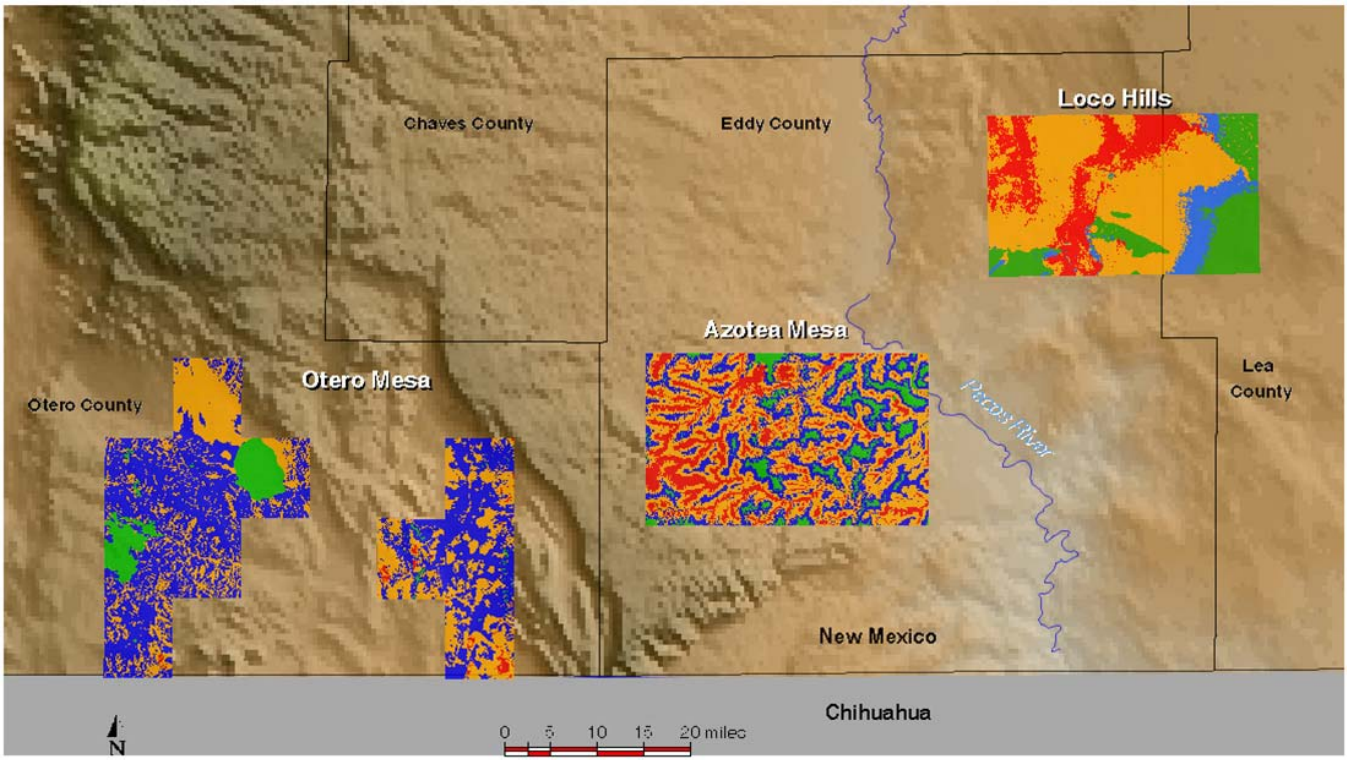

Figure 5. Predictive models of cultural resources developed for the Bureau of Land Management to assist with planning associated with the development Oil and Gas Fields in New Mexico.