AOA GEOPHYSICS - GEODOMISI LTD TECHNICAL NOTE

Application of Ground Penetrating Radar (GPR)
To Archaeological Site Characterization

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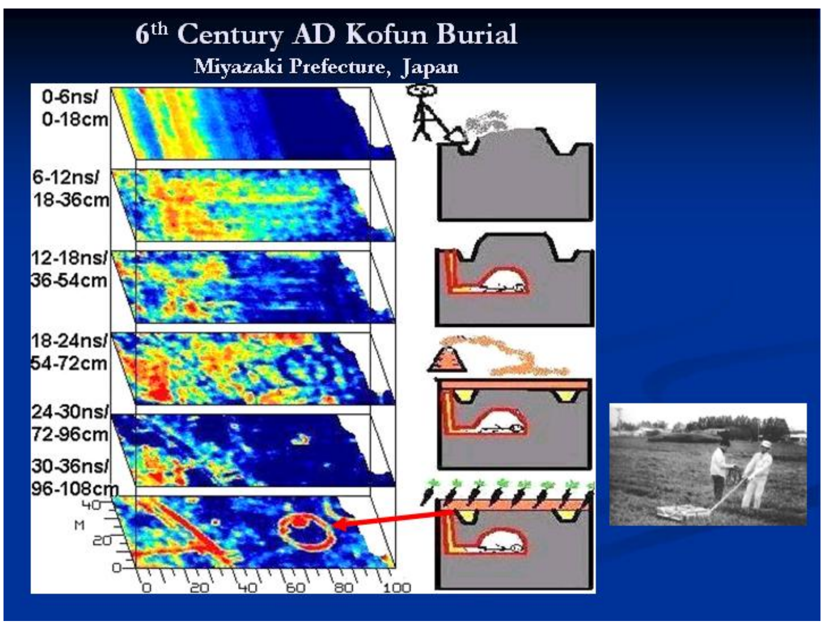
Ground Penetrating Radar (GPR) is one of the most widely used non-invasive and non-destructive geophysical methods for archaeological site characterization. Given suitable surface soil and rock conditions and properties, GPR offers the highest resolution of all geophysical methods for subsurface mapping and locating buried foundations, locating buried artifacts, delineation of ancient graves and tomb structures (depth range: 1 to 10 meters). In areas where archaeological excavations are planned, or where subsurface investigations must be performed prior to planning site excavation for land development, GPR surveys provide a safe, economical, and environmentally friendly means for shallow subsurface site characterization. Advancements with GPR data and application specific graphics processing techniques now give the ability to develop accurate 2D and 3D model representations of the subsurface geology, and of buried objects and archaeological features.

Data Examples

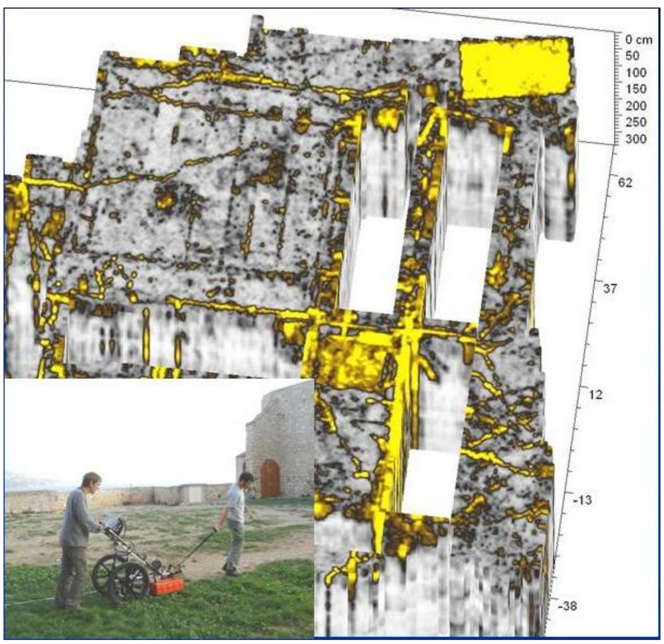
The following application examples represent processed GPR data for several archaeological investigation projects.



Japan – Ancient Burial Tomb

The advantage of using GPR to image the subsurface is that archaeological structures at various levels within the ground can be spatially identified and located using depth-slice mapping. The raw data that is acquired with the GPR equipment represents digitized data of subsurface reflections along a 2-dimensional profile. Using the radar-gram processing method to measure reflection amplitudes, and the GPR signal travel times, horizontal depth-slices are created to help identify and locate archaeological features as a function of burial depth. Using data from a series of parallel GPR survey lines, amplitude and reflection depth-slices were made every 24 cm to locate a burial mound at the Kofun Burial site in Japan. At the deepest level, a 6th century burial 22 meter in diameter was discovered buried beneath 120 cm of volcanic soil. The strong circular reflection is from the floor of a burial moat. The moat, which was discovered at a site in Kyushu, Japan, was originally built by digging material out of circular moat as shown in the cartoon above, and then piling this soil to create a large mound. A shaft/tunnel burial was then carved out and the deceased was entombed. Over time the mound was cut by ancient farmers or erosion and buried by further volcanic eruptions at the site in the 10th century. The large round anomaly within the circular ring moat (depth-slice 96 – 108 cm) is a GPR reflection from the burial chamber.

The application of Ground Penetrating Radar (GPR) has been successfully used on archaeological investigations to locate and map buried foundation walls of ancient ruins in France and Italy. In addition to the mapping of foundation walls, buried cultural artifacts that are also commonly found within the foundation areas can also be located with GPR surveys. Using the processed GPR maps, archaeological “digs” engaged in recovery of ancient artifacts can plan excavation operations more carefully without the risk of disturbing ancient buried structures. For pre-construction planning on land development projects, GPR can provide valuable knowledge of buried foundation walls and cultural artifacts to obtain excavation clearance, or to guide development of any archaeological investigation plan.

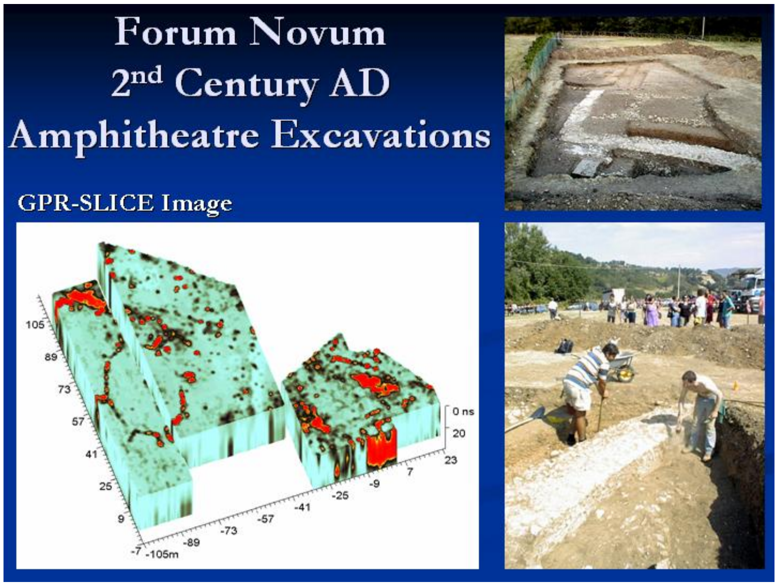


<u>France – Mapping Buried Foundation Walls</u>

Joint GPR surveys were conducted in France on the island of Lerins, off the coast of Cannes. The objective of the GPR survey was to locate subsurface Spanish and Roman foundation ruins beneath a medieval military fort and prison. The Lerins prison is famous for holding King Louise the XIV's twin brother Phillipe - "The Man in the Iron Mask" during the 17th century. Using GPR Slice processing, the buried foundation walls are indicated by high amplitude (yellow) GPR reflection signals. Background soils are indicated as low reflectivity GPR reflections (gray). When combined with the recording of GPS tracking, X,Y locations of foundation walls and other buried artifacts can be plotted on engineering survey and land development overlay maps. In addition to areas where archaeological structures were discovered, GPR was able to accurately locate numerous subsurface utility lines, which are also very important information for future excavation planning.

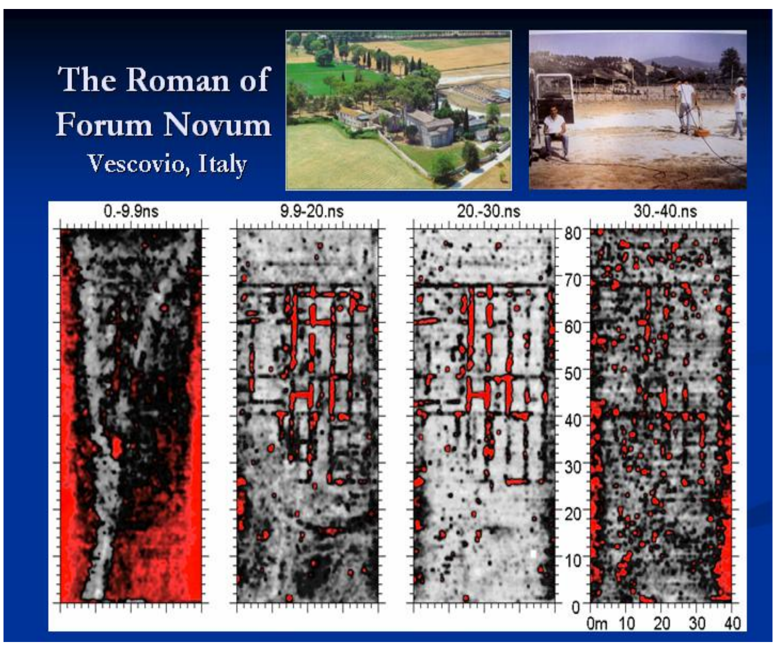
<u>Italy – Archaeological Investigation</u>

At the the University of Siena, under the direction of Dr. Stefano Campana and Dr. Salvatore Piro from Consiglio Nacionale delle Richerche, a GPR field study was conducted in Grosetto over farm lands for the archaeological geophysics seminar in July 2006. GPR data was acquired using a 500 MHz antenna, and processed using GPR-Slice. The final image outlines the remnants of a destroyed Roman Villa as indicated by the very good reflections from the tops of buried foundation walls. The processed GPR data presented in “plan view” shows a high reflectivity (yellow) outline of buried foundation walls.



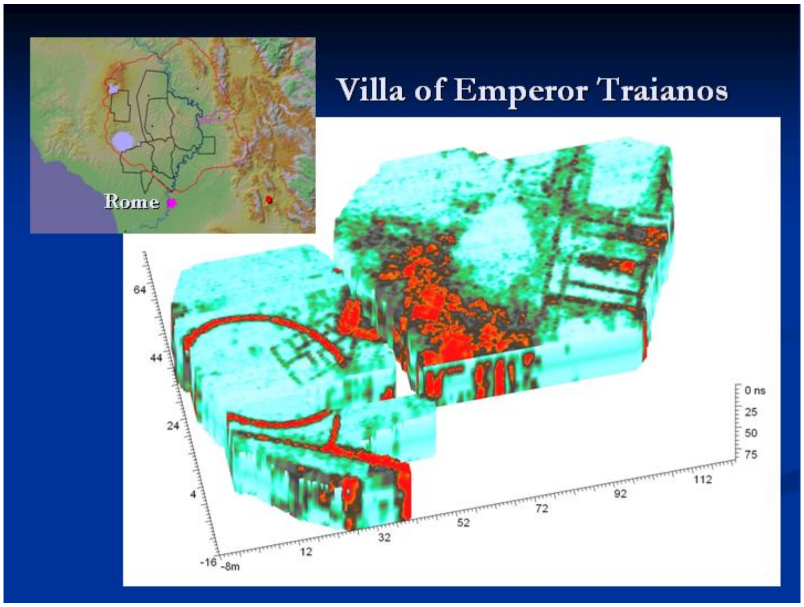
Italy – Roman Forum Novum

In addition to the discovery of an ancient Roman marketplace, a GPR survey was conducted in a nearby field at the Forum Novum site. Remarkably, another unknown subsurface structure, a 2nd century AD amphitheatre was also imaged using GPR-SLICE GPR data processing. One of the 8 entrances into the amphitheatre has since been excavated. *(Photo courtesy of British School of Archaeology Rome).*



Italy – Roman Forum Novum

GPR surveys were conducted jointly with Dr. Salvatore Piro of the Consiglio Nacionale delle Ricerche next to the Romaneque church of Santa Maria in Vescovio, Italy. GPR-SLICE subsurface images revealed numerous buried wall foundations. According to the British School of Archaeology in Rome it is believed that the buried buildings are portions of a Roman marketplace which initially began construction in the 1st century BC and flourished through the 4th century AD in the Roman town of Forum Novum. Archaeologists were able to reconstruct the entire marketplace, including living quarters, storage areas, hallways and door entrances, all of which could be discerned from the radar images. The wall foundations begin at about 30 cm from the ground surface.



Italy – Villa of Emperor Traianos

One area surveyed at the Villa of Roman Emperor Traianos revealed a large oval shaped structure. This is estimated by archaeologists to be a garden pond that was probably used for domesticating eels - eels that were incorporated into a fish sauce to be eaten by the emperor. The rectangular anomalies are believed to be military buildings on the villa premises. In the radar image other buildings colocated under the oval but weaker in reflected amplitude suggest that an earlier occupation of the site may have existed prior to the construction of Traianos' villa getaway. The 3D radar volume was created from radar profiles collected at 0.5m intervals.

The Method

GPR data are usually collected along closely spaced transects within a grid. It is an active method that continuously transmits low energy electromagnetic pulses from surface source antennas into the ground. Wherever subsurface dielectric properties change due to variations with soil-rock composition or the presence of buried objects, the transmitted electromagnetic pulse is reflected back to the surface and detected by a receiving antenna. An integrated PC based GPR instrument and data recording system records the time elapsed between when the pulses are sent and when they are received back at the surface (called two-way travel time). As the radar pulses are transmitted through various materials on their way to the buried target feature, their velocity will change, depending on the physical and chemical properties of the material through which they are traveling. When the travel times of the energy pulses are measured, and their velocity through the ground is known, distance (or depth in the ground) can be accurately measured. Radar travel times are measured in nanoseconds, which are billionths of a second. As the antennas are moved along the ground surface individual reflections are recorded about every 2-10 centimeters along transects, using a variety of collection techniques. The depth to which radar energy can penetrate depends largely upon two factors: 1) the frequency of antenna being used, and 2) the characteristics of the soils and moisture content. The second factor has been shown to be much more decisive with regard to maximum depth the EM pulse can travel, and how much EM energy attenuation occurs. The two major components affecting energy propagation include the soil or rock electrical and magnetic permeability.

The form of the individual reflected waves (called a waveform) that are received from within the ground are digitized into a reflection trace at each measurement location, and when many data traces are stacked adjacent to each from GPR data acquired along a survey line a two-dimensional vertical profile is produced along the transect.

Thousands of reflection traces in many profiles within a grid can then be analyzed to produce both two and three-dimensional images of buried geologic and archaeological features. Buried discontinuities where reflections occur are usually created by changes in the electrical or magnetic properties of the rock, sediment or soil, variations in their water content, lithologic changes, or changes in bulk density at stratigraphic interfaces. Reflections also are generated when radar energy passes through interfaces between anomalous archaeological features and the surrounding matrix. Void spaces in the ground, which may be encountered in burials, tombs, tunnels, caches or pipes, will also generate significant radar reflections because of a similar change in radar wave propagation velocity. In order to create a vertical display of the subsurface reflections, all recorded reflection traces, no matter what the acquisition method, are displayed in a format where the two-way travel time of the reflected waves is plotted on the vertical axis with the surface location, or trace number, on the horizontal axis. Basic two-dimensional profiles are recorded by a portable field computer and displayed in real-time as black, white, and gray horizontal bands. Strong reflections generate distinct black bands, while medial reflections produce gray bands. Figure 1 represents an example of a single GPR profile that shows GPR signal reflections from buried materials that have different electrical and magnetic properties than the surrounding matrix soil.

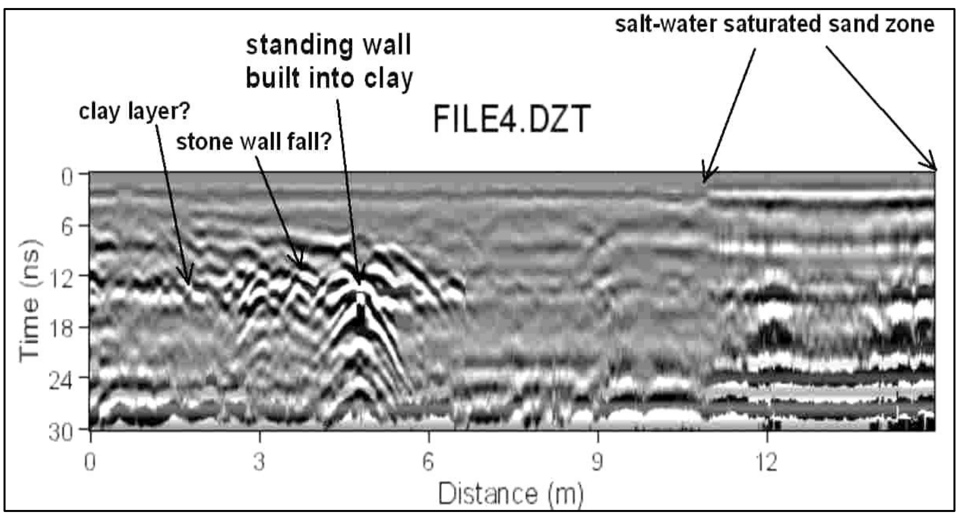


Figure 1 - 2D GPR Reflection profile. Distance along the profile is measured in meters, and the two-way radar travel time measured in nanoseconds, is converted to depth below the surface.

Frequency

Low <u>frequency</u> GPR antennas (10-120 MHz) generate long wave-length radar energy that can penetrate up to 50 meters or more in certain conditions, but are capable of resolving only very large subsurface features. In contrast the penetration depth of a 900 MHz antenna is about one meter, and often less, in typical ground conditions, but its generated reflections can resolve features down to a few centimeters in diameter. A <u>trade-off</u> therefore exists between depth of penetration and subsurface resolution.

Energy Radiation

There is a common misconception that the energy radiated from a GPR antenna is a pencil-like beam. In fact, GPR waves radiated from standard commercial antennas radiate radar energy into the ground in an <u>elliptical cone</u> with the apex of the cone at the center of the transmitting antenna. The lower the antenna frequency, the broader the transmission cone. Higher frequency antennas, such as the 900 MHz or higher, have quite narrow cones of propagation while the 200 and 300 MHz frequency antennas can spread energy outward a meter or more at depths of only about one or two meters below the ground surface. The higher the RDP of the surface material through which the energy passes, the lower the velocity of the transmitted radar energy, and the more focused (less broad) the conical transmission pattern becomes.

An estimation of this radiation pattern (also called the <u>footprint</u>) is important when designing transect spacing within a grid so that all subsurface features of importance are "illuminated" by the transmitted radar energy, and can therefore generate reflections. In general the angle of the cone, and therefore the size of the footprint, varies as a function of the relative dielectric permittivity of the material through which the waves pass, and the frequency of the radar energy emitted from the antenna.

GPR Data Acquisition and Processing

The acquisition of GPR data is generally very economical and efficient. A series of closely spaced GPR survey lines over an area of 1000 sq meters can be acquired in 1-2 days. Depending on the project objectives and subsurface mapping requirements, the data can be processed to produce both 2D and 3D images, and if acquired along with DGPS/GPS positioning data, can be formatted to overlay engineering drawings and charts for correlation with site geodetic or survey coordinate systems.

In addition to archaeological investigations GPR can be used for locating buried pipelines and utility lines, which is useful for damage prevention prior to excavation operations. GPR is also used for mapping depth to bedrock and soil stratigraphy.

Other Geophysical Survey Methods

In some case where GPR cannot be used due to terrain conditions, or because soil and rock properties limit the effective depth of investigation, AOA Geophysics - Geodomisi Ltd employs other geophysical survey methods for archaeological investigations. These include, but are not limited to:

- *Frequency- Domain Electromagnetic Surveying – non-ground coupled electromagnetic method.*
- *Continuous Electrical Resistivity Imaging – mapping of soil or rock apparent resistivity distribution.*
- *High Resolution Acoustic Imaging – continuous subsurface acoustic profiling method.*
- *Magnetometer & Gradiometer Mapping - mapping of buried materials and ancient artifacts by measuring subsurface magnetic anomalies.*

For more information concerning the application of GPR or other geophysical survey techniques for engineering and environmental site characterization projects, contact:

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