Ground-penetrating radar investigations at a Maya ruin site: Belize, Central America

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Abstract
During the summer of 2002 seismic and ground-penetrating radar (GPR) surveys were conducted at a Maya ruin site in northwestern Belize, Central America. The 2002 field season was initiated with the purpose of non-invasively exploring the Ma'ax Na site and assisting archaeologists in focusing excavation activities. This paper describes the GPR surveys carried out over several caves and over one of the plazas at Ma'ax Na. The GPR lines were acquired using Sensors & Software Inc.’s Noggin® and Smart Cart® monostatic system with an antenna frequency of 250 MHz and a transmitter and receiver separation of 27.94 cm. Most areas had loose soils and forest debris overlying rubble or competent carbonates. Preliminary analysis of the reflection data gives velocities from 0.072 m/ns (for a depth of 1 m) to 0.106 m/ns (for a depth of 0.7 m). Based on our measured velocities, the dielectric permittivity of soil and limestone is 8 and 16 respectively. The data were processed using filtering, deconvolution, velocity analysis, and migration algorithms. Refinement of the processing flow is ongoing. Using the velocity values determined during acquisition, we estimate that the maximum reflection depth is between 1 and 3 metres. A good comparison between two reversed lines indicates that the method provides repeatable results. The cave project provided reasonable imaging of these cavities and indicated the applicability of the method in a carbonate environment. The depth of penetration of the GPR for the plaza lines is about 1.8 m. Resolution based on a velocity of 0.072 m/ns and the antennae frequency of 250MHz is approximately 8 cm. The plaza project results showed reasonable quality records with good signal penetration. Surficial discontinuities (roots) and anomalous buried features were identified. Excellent ties between intersecting plaza lines inspired confidence in the acquisition method. Modeling of the GPR based on changes in the property of dielectric permittivity revealed a good correlation between the synthetic radargram and the GPR record.

Introduction
Ma'ax Na is located in the Corozal Basin of Northern Belize, which is comprised of a thick sequence of non-clastic deposits and is characterized by a predominately carbonate sequence. The geography of the Three Rivers region consists of a series of escarpments formed by faulting, slumping and weathering. Rolling hills, low lying plains and lakes formed by sub-terranean karsting characterize the region (Aitken, et al, 2002). Maya architecture accommodated
local topography and many of its massive structures are built on limestone outcrops of Early Tertiary age (Miller, 1999).

Ma’ax Na is one of a number of Maya sites in the Rio Bravo Conservation area of Belize (Figure 1). The Maya civilization flourished in the area of Central America culminating in the Classic Period (A.D. 300-900). Monumental architecture in the form of pyramids, temples, and plazas, built within great cities, were erected with a view to honor the gods and bring balance to the cosmos. The Ma’ax Na archaeological site was discovered in 1995. The subsequent excavation has revealed more than 25 intact structures (Moldoveanu, et al, 2002). Today, buried within the jungles of Belize, archaeologists continue to uncover these ancient landmarks in an attempt to understand and reconstruct the history of the Maya culture. Due to cost and timing constraints, archaeologists excavate only a small fraction of an archaeological site. Potential field and electrical methods have in the past identified buried features and structures, which aid the archaeologist in high grading areas of excavation focus. Research at the University of Calgary has attempted to not only identify buried features but to improve the geophysical records through enhanced processing techniques and improved acquisition parameters (Fisher, et al, 1996).

**GPR Survey**

Ground penetrating radar (GPR) involves the transmission of radar pulses into the subsurface. These pulses of energy reflect from stratigraphic interfaces, walls house floors, pits or rubble, and the recorded data reveals information about the lithology of the near surface (Goldberg, 2001). The velocity of the radar pulse changes as a function of the electrical properties of the propagating medium. Those properties include the dielectric permittivity, the electrical conductivity, and the magnetic permeability. The recorded signal is measured in nanoseconds (ns). The velocity of the subsurface was determined from the hyperbolic fitting of curves to point diffractors (Aitken, et al, 2002). Velocities recorded were 0.106 m/ns @ 0.7m and 0.072 m/ns @ 1m. The dielectric permittivities of the soil and limestone, based on these velocities, are 8 and 16 respectively.

Acquisition parameters were set at a spatial sampling (station interval) of 5 centimetres and a temporal sampling (sample rate) of 0.4 nanoseconds. Several cross lines were surveyed on the Ma’ax Na plaza as outlined in Figure 2, to establish tie points and to test the accuracy of the method. The cave project was shot over three holes or karsts within the massive limestone bedrock approximately one kilometre from the plaza.

**Modelling and Interpretation**

A recent excavation of a one metre deep pit at the plaza revealed up to 7 previous plaza levels. Based on the theoretical resolution of the GPR data, it should be possible to identify some of these levels. Those levels containing cobble or rubble zones provide pathways or conduits for fluid, specifically the
migration of water, and could increase the dielectric permittivity. Assuming a low loss and non-magnetic medium, and a constant radar velocity, a reflectivity model based on the pattern of rubble layers, and the expected change of the dielectric permittivity due to the presence of water, was created (Figure 3). The resultant synthetic radargram (using a synthetic seismogram program) correlated surprisingly well with the GPR section (Figure 4).

When interpreting the GPR sections, one looks for discontinuities in the events or apparent amplitude variations much like seismic interpretation. Buried objects are often located by the presence of point diffractors. The surrounding material is often disturbed and the continuity of the geological layers is compromised. On Figure 4, black circles highlight several anomalies on the filtered and migrated stack of N-S Plaza Line 2. An excellent tie between the Plaza Line 2 and Line 3 filtered stacks is exemplified in Figure 5. The section is displayed in variable area and wiggle trace. Note the tie point is difficult to spot, which validates the integrity of the GPR data.

The caves are interpreted as "blank" or "dead" zones on the GPR line as shown in Figure 6. The processing steps include a median filter and subtraction to remove horizontal events. The top of the cave is estimated to be about 2 metres below the surface.

Conclusions
The GPR method provides coherent and interpretable images of the plaza and caves at the Maya site of Ma’ax Na in Belize, Central America. The GPR lines have highlighted a number of interesting features which may be helpful to the archaeologists studying and excavating at Ma’ax Na.

The depth of penetration is 1-3 metres. Vertical resolution is approximately 8 centimetres.

A processing flow has been established and fine-tuned, using various filtering, deconvolution and migration algorithms. A GPR model was created based on the archaeological information from the excavated pit.

An interpretation procedure similar to that employed by exploration seismologists to identify subsurface horizons has been developed.

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References


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FIG. 1 Location of the Maya site of Ma'ax Na in Belize Central America (The Ma'ax Na Archaeological Project, 2001).
FIG. 2 Layout of GPR lines at the Ma'ax Na plaza complex (Henley, 2002). Note the excavated pit dimensions are not to scale.
FIG. 3 Archaeological information from the excavated pit based on a description by Shaw (pers. comm., 2002). A pseudo-radar slowness log (blue), a pseudo-dielectric permittivity log (red) and a synthetic radargram are aligned for comparison.
Fig. 4 Filtered migrated stack of N-S Plaza Line 2. Black circles highlight several anomalies.

FIG. 5 Tie point between Line 2 and Line 3 filtered stacks displayed in variable area and wiggle trace. Note the tie point is hardly noticeable on this display.
FIG. 6 A GPR line over an area with known caves. The data have been processed via a median filter and subtraction, to remove horizontal events. We interpret the “blank” or “dead” zones, outlined in black as caves. The top of the cave is at ~45 ns (~2 m depth).