SUBSURFACE VIEWS

QUARTERLY NEWSLETTER
PUBLISHED SINCE 1993

October 2020 - Vol. 29, No. 63

In this issue

Using GPR to Locate 18th Century Utilities

While we typically associate utility locating with modern times, one recent GPR survey in Nova Scotia has located buried infrastructure from Canada's early colonial period.

French families – Acadians – began moving to the rural community of Grand-Pré in the beautiful Annapolis Valley in the late 17th century. Their community came to a horrible end in 1755, when, during the lead-up to the Seven Years' War, Britain's colonial government deported the inhabitants. Mapping their destroyed settlements is now a task for archaeologists, and GPR is a valuable tool in their toolkit.

Based on the artifacts found at the site, the survey area appears to have been an Acadian house. Colonial-era homes generally had shallow root cellars with some having drystone walls, while others were simply dug into the subsoil with sloping sides to prevent slumping and collapse. With the building's wooden superstructure long gone, the best archaeological evidence remaining is usually the old root cellar, often crammed with debris.

Using a Noggin® 500 SmartCart by Sensors & Software, GPR data were collected over a grid of 30 x 40 m (1200 m²) with a line spacing of 50 cm and a step size of 2 cm in both x and y directions. Data were then processed using the SliceView module in the EKKO_Project GPR analysis software.

At a depth of about 15cm, the building's stone footing is revealed by a familiar rectangular plan (Figure 1). Colonial houses were not always set on foundations, but the data suggest this one was, and that it has largely survived intact despite over 250 years of farming activity at the site since the house was abandoned.

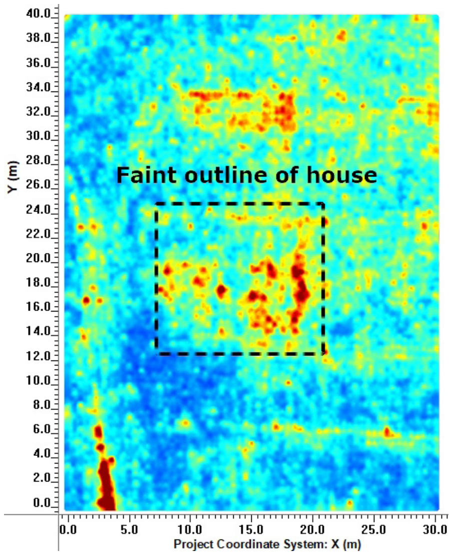

Figure 1: The stone foundation of the house is evident on the ~15 cm depth slice.

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The most prominent features in the data are agricultural drains installed in the early 1970s, which can be seen running from left to right at regular intervals across the grid area. Two pipes can be seen in Figure 2 and three pipes trenches in Figure 3. The more archaeologically interesting features are seen between these drain lines.

Slightly deeper, two interesting rectangular features appear in the data: an area of low reflectivity and, adjacent, a zone of more reflectance (Figure 2). Both have architectural significance. The area with no reflections is an area of signal attenuation such as one would expect in soils dominated by clay. Architecturally, either a tamped clay floor or elements of the clay-rich fireplace and oven complex could be responsible. The highly reflective square patch, likely caused by stones and other debris, to the right of the clay-rich patch soon resolves itself into a cellar.

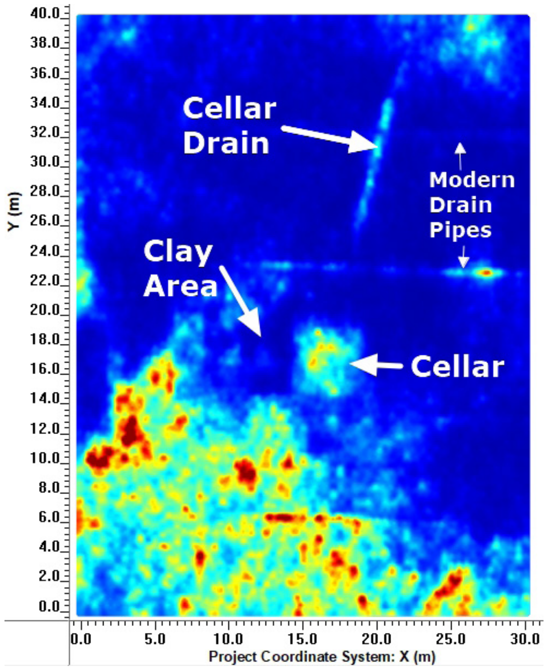

Figure 2: Two architectural details emerge at approximately 65cm deep: a rectangular, clay-enriched area, and a square, rubble-filled cellar. Other features include the cellar drainpipe and modern agricultural drainpipes.

Furthermore, near the base of the cellar and leading out to the upper right of the survey grid, a slightly curving reflective feature was seen (Figure 2). It runs perpendicular to and at the same depth as the agricultural drains, suggesting the construction of the cellar drain that is unrelated to this 20th century infrastructure, and that these later intrusions may have impacted the older structure in place.

The cellar drain appears to run nearly to the upper edge of the survey grid for about 22 m (Figure 2). It was set into a trench measuring approximately 60cm wide and excavated to a depth of just over 1m. That required a lot of digging, but it was no great chore for our colonial-era ancestors, for whom prolonged bouts of physical labour were a daily fact of life. It was dull iron shovels and determination.

This drain was probably a channel lined and capped with carefully selected fieldstones; based on previous ones that were excavated in the neighbourhood. Some drains are still working centuries later, despite having been half clogged with burned debris from the house that formerly stood overhead.

What is fascinating is that when we slice down through the layers in the GPR data, we can not only see the drain itself, but also the outline of the trench into which it was set (Figure 3). This linear feature of low reflectance is a result of the natural soil layers having been broken up by the builders.

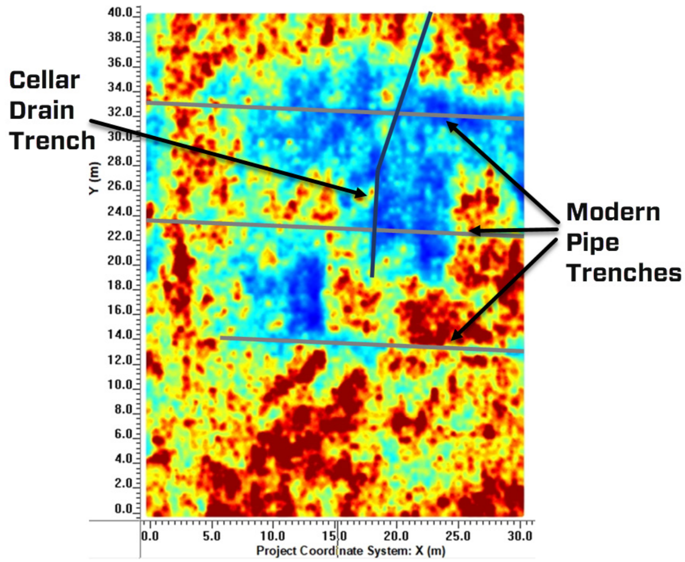

Figure 3: At about 40cm deep, the mixed fill of the cellar drain and modern pipe trenches contrast against the ambient soils, which are more reflective. Presumably, the clay cast up during the trench excavations was thrown back in as fill and is the cause of the low reflectivity.

The mixed fill of the construction trench, no longer exhibiting its natural stratigraphy, now contrasts with more reflective soil layer boundaries around it: yet another instance in which a void in the data offers clues to past events.

GPR systems are adept at locating utilities in a variety of modern settings and have become a standard tool of civil engineers and technicians. They are also a powerful and welcome addition to the archaeologist's toolkit. With the proper methodological and theoretical grounding, archaeologists can use GPR to locate more ancient utilities and map archaeological sites.

Story courtesy of Dr. Jonathan Fowler, Saint Mary's University in Halifax, and Northeast Archaeological Research Inc.

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Mapping Cavities in Limestone

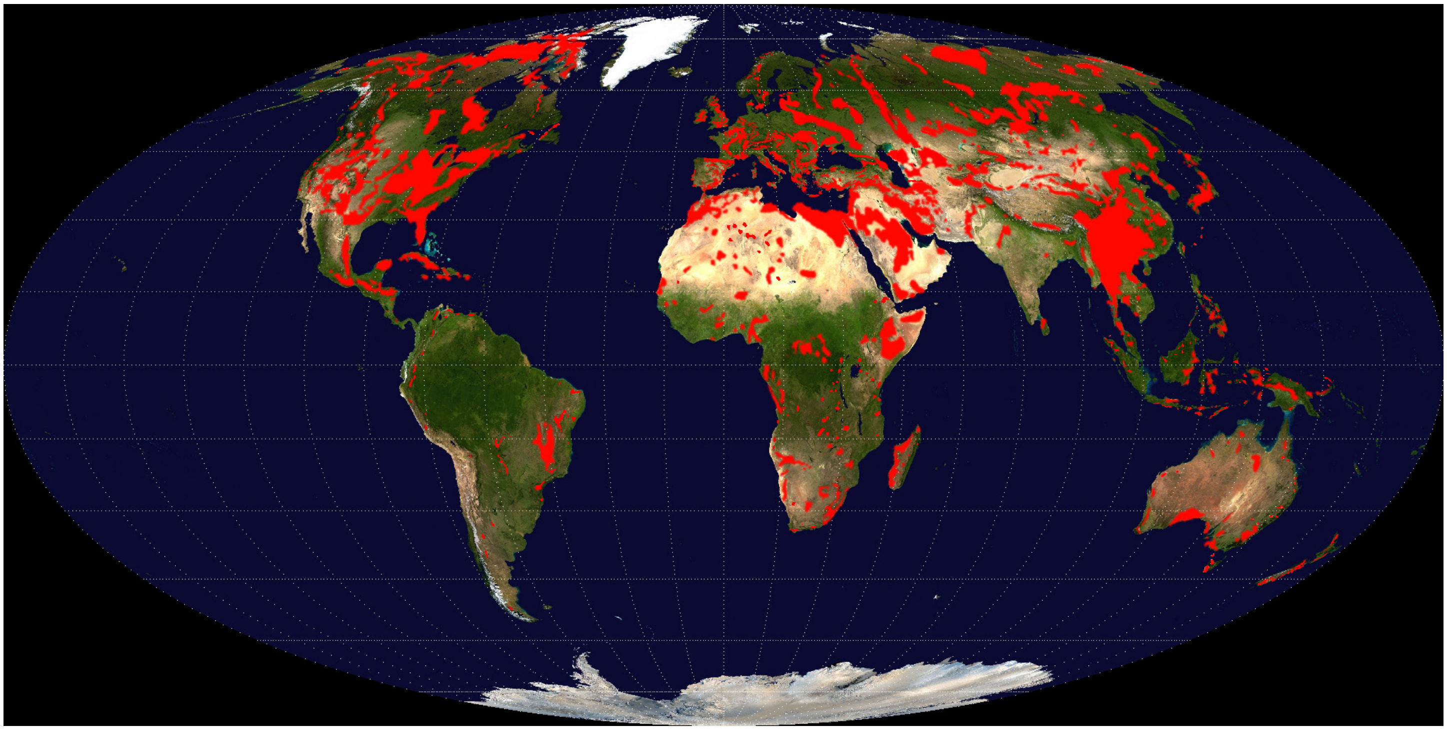

Figure 1: Surface or near surface limestone around the world. Source: Carbonate-outcrops world by Ulrichstill under a CC-BY-SA-2.0-DE.

Many areas of the world, especially land that formed in tropical parts of the world, are underlain by limestone (Figure 1). Limestone is a carbonate sedimentary rock that often consists of the calcium carbonate bodies of trillions of sea creatures, like coral and shells, cemented together to form rock.

Calcium carbonate is water soluble which means that it dissolves in water; not a high level of solubility like salt, but enough that, as water moves through limestone over hundreds or thousands of years, the limestone rock can slowly dissolve, and cavities form inside it. For areas with limestone bedrock, like Florida in the USA, this can cause significant problems when humans build a structure on the surface. News reports show us the results: sinkholes suddenly opening and swallowing buildings, roads, cars and tragically, even people.

GPR has been successfully used for finding underground cavities, both large and small, for decades. The spectrum goes from using high center frequency (1000 MHz) GPRs to find voids a few inches deep under slab-on-grade concrete in warehouses and factories, to using medium center frequencies (200 to 500 MHz) for finding larger voids under roads and runways, and also, to using low center frequency GPRs (12.5 to 100 MHz) for finding large caves for geotechnical surveys and geological research. In all cases, the physics is the same; the transition from material such as rock, concrete or asphalt to the air or water in the void results in a very highly reflective boundary for GPR signals to reflect from.

This case study features a GPR survey collected on a Caribbean island where a large electrical generating station was to be built. Before the start of the project, geotechnical engineers wanted to find any cavities that could disrupt the construction. Forrest Environmental of Virginia, USA, was contracted to survey a site with a pulseEKKO® system using 100 MHz center frequency antennas and the Ultra Receiver. The site had been flattened enough to allow the data to be quickly collected using a SmartCart configuration (Figure 2). The system included a GPS for data positioning.

Figure 2: pulseEKKO® 100 MHz SmartCart used for detecting cavities.

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Several grid surveys were collected at the site. Grid 1 consists of 31 parallel lines, each about 30m long and spaced 1m apart. The total line length for the grid is 930 meters.

During data collection, a strong, spatially limited reflector plus many smaller ones were visible on many of the GPR grid lines, suspected to be the top of cavities (Figure 3).

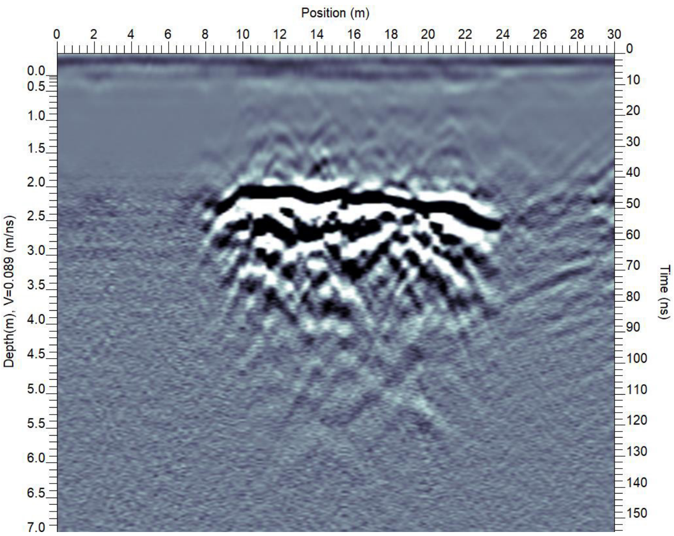

Figure 3: GPR cross-section from the grid survey, showing a strong reflector 2 meters from the surface in the limestone bedrock.

After the grid GPR data collection was finished, the data were transferred to a computer and the SliceView module, part of the EKKO_Project™ GPR analysis software, was used to process the grid data into depth slices; each slice is 25 cm thick, the default thickness for 100 MHz center frequency data. Slicing downward through the data, the strong reflector spans a well-defined area, at a depth of approximately 2.25 meters, increasing the confidence that the reflector was from the top of a cavity (Figure 4).

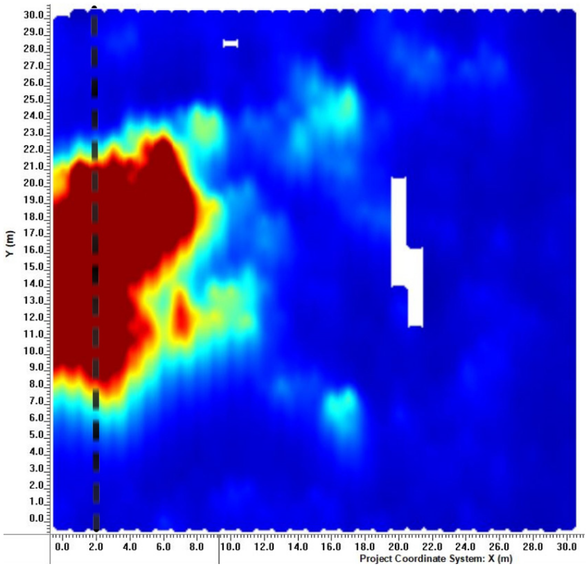

Figure 4: Depth slice at 2.25 meters, with a strong GPR reflection (red), interpreted as a cavity. The GPR line in Figure 3 is indicated by the dashed line.

Based on the GPR maps, the project geotechnical engineers decided to excavate to confirm that the strong reflector was a cavity (Figure 5).

Figure 5: Excavating the GPR targets confirmed the large cavity in the limestone. Inset: A close-up inside the cavity shows stalactites hanging from the ceiling, formed by water dissolving and precipitating the limestone for thousands of years.

As a result of the successful GPR survey to identify cavities before the start of construction, site engineers were able to plan construction around the cavities and fill-in others for the project to go safely ahead, saving time and money in the process by avoiding surprises and costly engineering change-orders.

Story courtesy of Andy Forrest, Forrest Environmental Inc based in Virginia, USA.

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TIPS for Estimating GPR Penetration

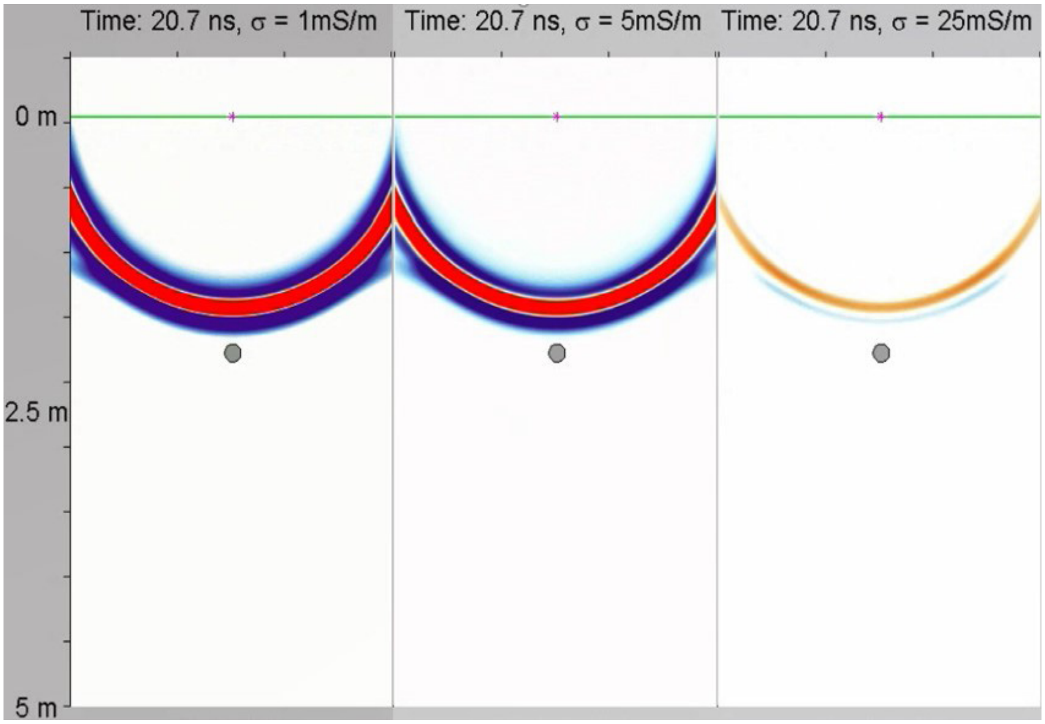

Figure 1: The electrical conductivity of the material being scanned controls the attenuation of the signal. Lower electrical conductivity (left) allows GPR signals to travel deeper into the medium than high electrical conductivity (right).

The very first question that someone usually asks about GPR is, "How deep can it see?". Although we hear this question daily, we still do not have a quick, straight-forward answer for it. The shortest answer is, "It depends". A better answer, but still not very specific is, "If you are working on fresh water, 1 to 40 meters, on the ground, 1 to 100 meters, on ice, even deeper".

The reason that we cannot answer this question simply is because the depth of penetration of GPR depends on many factors, including the GPR antenna frequency, the GPR transmitter power, the number of stacks, scattering losses in heterogeneous materials and the level of background radio frequency noise. However, the biggest factor is the electrical properties of the material being scanned, specifically the electrical conductivity of that material.

Most people have heard that clay soils are "bad" for GPR penetration. The underlying reason that clay-rich soils are not good for deep penetration with GPR is because clay has high electrical conductivity. Other common materials with high electrical conductivity are silty soils, sea water and, of course, metal. One of the first lessons that GPR operators learn is not to expect to see through metal.

Estimating GPR Penetration in the Ground

Occasionally, we have a customer that has a measurement of the electrical conductivity of an area they are interested in scanning with GPR. This information is often from another geophysical survey conducted in the area, such as an electrical resistivity survey or an electromagnetic (EM) survey. With this information, the depth of penetration that would be achieved with GPR in meters can be estimated by the expression:

$$\boldsymbol{Depth\ (m)} = \frac{\mathbf{40}}{\sigma}$$

where, σ is electrical conductivity expressed in millisiemens per meter (mS/m)

If the measurement is resistivity in ohm-meters, the formula becomes:

$$\boldsymbol{Depth\ (m)} = \frac{\rho}{\mathbf{25}}$$

where, ρ is resistivity expressed in ohm-meters (ohm-m)

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Estimating GPR Penetration in Fresh Water

If you are interested in using GPR on fresh water, there is also a formula, related to the ones above, for estimating the depth of penetration when using GPR. It requires a property of water, commonly measured by hydrologists, called the total dissolved solids or TDS. If you have a measurement of TDS of the water you want to scan with GPR, use this expression to estimate the depth of GPR penetration in the water:

$$Depth\ (m) = \frac{1850}{TDS}$$

where, TDS is measured in milligrams per liter (mg/L) or parts per million (ppm)

The table below summarizes these formulas using typical values for electrical conductivity and resistivity values for the various materials. Remember: the formulas provide a best-case estimate of the depth of penetration; additional factors, including antenna frequency, transmitter power and receiver sensitivity as mentioned above, also need to be considered. As well, rarely are GPR surveys conducted through a pure material; most often the subsurface is a heterogeneous mixture of different materials resulting in signal scattering which also reduces penetration.

Material	Electrical Conductivity (mS/m)	Electrical Resistivity (ohm-m)	Total Dissolved Solids (ppm)	Depth of Penetration (m)
Air	0	0		∞
Ice, Snow,	0.1	10,000		400+
Granite, Marble	0.4	2,500		100
Dry sand, Limestone	1	1,000		40
Wet sand, gravel	2	500		20
Silt	20	50		2
Clay, concrete	50	20		1
Fresh water (low TDS)			45	40
Fresh water (high TDS)			3,700	0.5
Sea water			40,000	0.01

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NEW Effective immediately, all sales of LMX & Noggin systems will include 2 free registrations for the Nulca-accredited Utility Locating with GPR course on SensoftU. Look for your coupon with your next system purchase.

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Upcoming Events

- (GSA) Geological Society of America - Online, October 26-30 , 2020
- The Buildings Show - Online, November 30 - December 4, 2020
- AGU 2020 Fall meeting - Online, December 1-17, 2020
- Transportation Research Board (TRB) Show - Online, January 25-29, 2021

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