Thoughts on the Integration of Slice-Maps and Reflection Profiles in GPR Analysis

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Abstract

Any comprehensive interpretation of GPR data must include the integration and analysis of both amplitude slice-maps and two-dimensional reflection profiles. Often one method can yield results that the other cannot, producing important insights. One example from Ireland shows how slice-maps produced very useful images of subtle post molds, which outlined a crannog in a pond or lake. These molds were invisible in the 2-D profiles. From Long Island, New York, the amplitude slice-maps were very busy and confusing, and only through detailed analyses of reflection profiles were cellars of historical houses visible.

Introduction

In the last decade, most GPR companies, appealing to their customers, have trained users to use amplitude slice-maps almost exclusively. These are very powerful data processing tools that can integrate and display amplitudes from many tens or hundreds of reflection profiles quickly and efficiently, producing displays that can sometimes be easily interpreted and buried features quickly recognized. Often, this method is taught at the expense of two-dimensional reflection profile analysis, as this more tedious method is considered by some to be difficult to interpret or “old school” and no longer necessary. The “modern” idea is that slice-maps are now capable of producing most of what is needed for a project, so there is no reason to return to methods used in the early days of GPR from the 1990s through about 2010.

I chuckle a bit at this idea, as in the early 1990s a few of us (there were very few of us in the GPR world back then) were madly trying to create slice-maps to speed up our laborious manual interpretation of profiles. No sooner had slice-maps become available than many GPR practitioners jettisoned reflection profile analysis and moved almost completely toward what would become an increasingly “big data” analysis approach. Now, many decades later, many of us realize that the slice-map approach, while efficient and quite good, often ignores important information that remains within the reflection profiles. That information can be crucial to an overall site interpretation, and it is unfortunate that many practitioners are not incorporating it into their analyses.

So that readers do not think I am negative toward the amplitude slice-map method, I provide an example below where this method is far superior to 2-D reflection profile interpretation. The point is that prudent GPR users need to employ both methods to produce a more complete analysis of survey data.

Ireland Dataset with Superior Amplitude Slice-Map Results

In western Ireland, there was a small rise in an otherwise low and boggy area that included a shallow pond in a sheep pasture. Other interesting archaeological features had been discovered nearby using GPR and magnetics, but this area was often avoided because ground conditions were not ideal for data collection. The hypothesis was that a crannog might be present, which in Ireland and elsewhere were houses or other structures built in ponds, lakes, or swamps.

A quick analysis of reflection profiles showed that the small rise visible in the middle of this waterlogged area was a horizontal floor of something interesting (Figure 1). The profile analysis could be quickly annotated to show this feature in the middle of the pond.

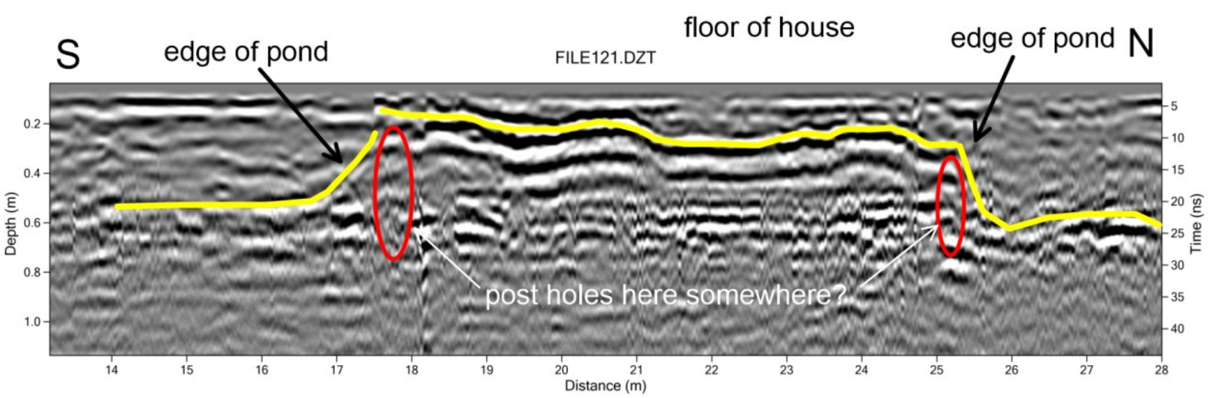

Figure 1: Reflection profile across a low, waterlogged area in western Ireland showing a raised flat surface surrounded by lower areas, later interpreted as a shallow pond.

Amplitude slice-maps of the GPR grid were revealing and showed features not visible in the reflection profiles (Figure 2).

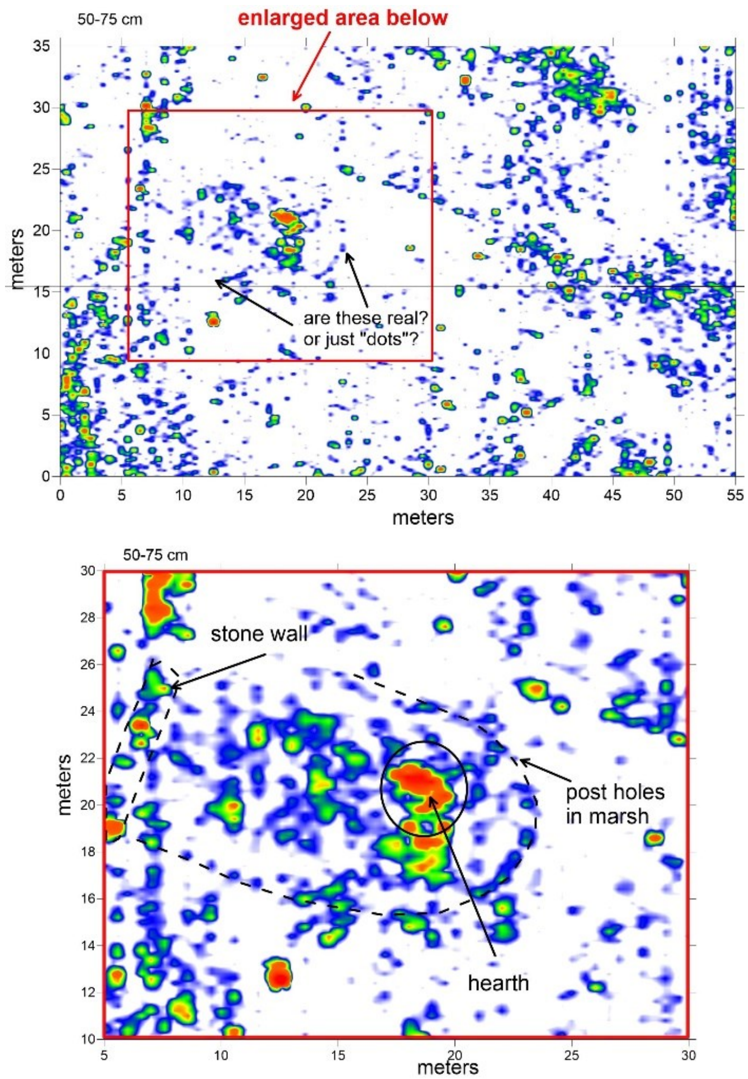

Figure 2: Amplitude slice-maps showing the outline of a house, or perhaps a house as part of a crannog, located on the raised surface visible in the reflection profiles.

In the amplitude slice-maps, a variety of low-amplitude "dots" were visible (Figure 2), which in some locations were straight and connected to curved dots. In the upper image of Figure 2, a red-outlined area of greater detail was used for further analysis. When a feature was identified in the slice-maps using visual pattern recognition, the reflection data were re-sliced with a very small search radius to produce pixels between profiles and many resampled data points along transects. This produced a more detailed amplitude map from 50–75 cm depth, which clearly showed these subtle dots (lower image in Figure 2). These are interpreted as post holes used to produce the raised construction in the ancient pond. These subtle reflection features likely result from differences in organic matter between decomposed wooden posts and surrounding pond sediment.

The important aspect of this study is that these subtle post mold features were only visible using amplitude slice-mapping, as the small amplitude differences were not visible in the reflection profiles (Figure 1). Here, the "large data" method of batch processing many profiles at once demonstrated its value, as computer analysis revealed features not discernible by the human eye using profile analysis.

Long Island, New York Site Where Reflection Profile Analysis Was Key

In contrast to the Ireland example, reflection profiles from a test site on Long Island, New York, produced such a wealth of reflection data that initial visual analysis was difficult. One example profile displays numerous reflections that vary considerably from profile to profile throughout the grid. In Figure 3, the reflection profile shows a variety of planar reflections and large hyperbolic reflections generated from the apex of buried objects. It is very busy and somewhat overwhelming in its complexity.

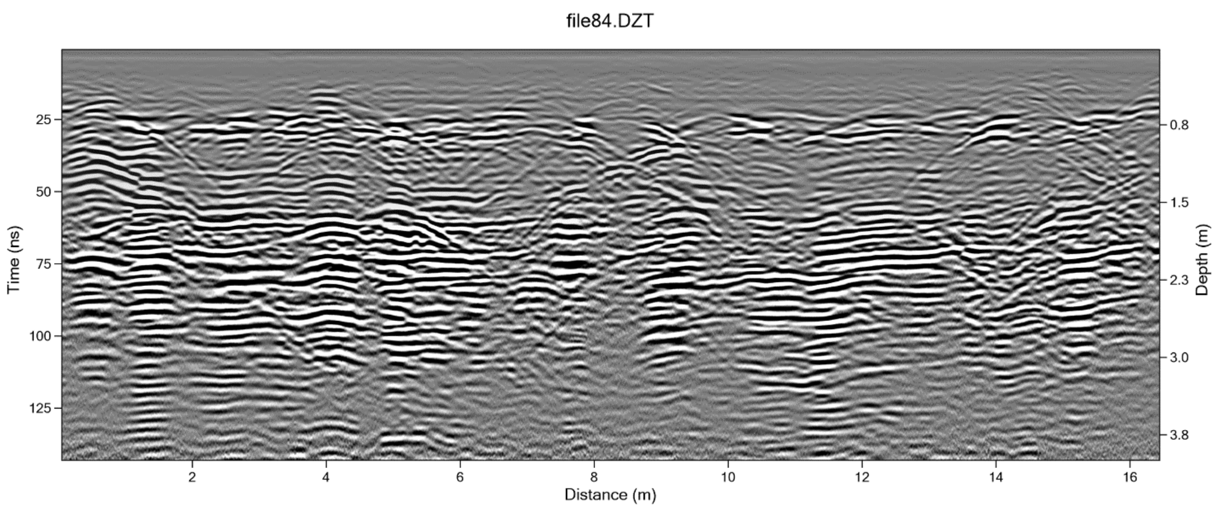

Figure 3: Sample reflection profile from the Long Island grid showing a variety of complex reflections.

I will not belabor this point; we all produce amplitude slice-maps first, hoping buried features will "jump out." However, a cursory look at the many tens of amplitude slice-maps produced from this grid only caused confusion. Although there were potentially important reflections, no clear, recognizable patterns emerged. Despite varying slicing depths and using migrated and filtered data, no definitive patterns were apparent.

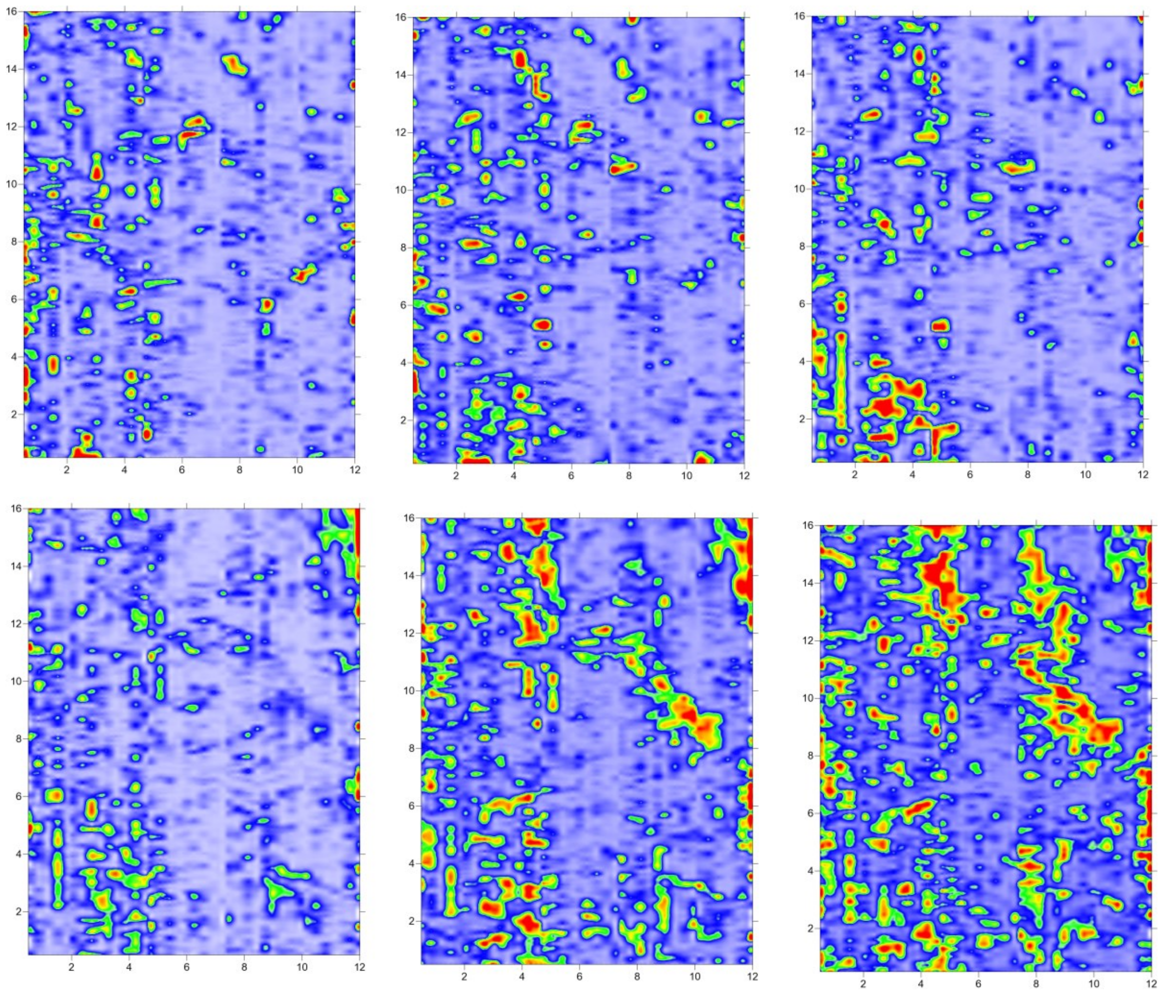

Figure 4: A small part of amplitude slice-maps created from the Long Island data, none of which showed definitive buried features identifiable by patterns.

In this example, failure to identify patterns in slice-maps and the difficulty of interpreting reflection profiles led some team members to conclude the project was a failure. Over the years, I have learned how easy it is to discard complex data and give up in such cases. Saying no is always easier in the short run than saying yes and persevering when a project seems daunting.

Instead, following a "perseverance method of GPR analysis," I encouraged the team to examine profiles more closely for two-dimensional reflection patterns. Beginning with one profile where something interesting appeared, the data were migrated and a portion displayed (Figure 5). Although still busy, some distinctive reflection types became apparent. With hyperbola axes removed during migration, many short planar reflections were visible. Their origins were unclear, but some stacked planar reflections ended abruptly while others were spatially restricted or continuous across the profile. Important buried features were clearly present, but until they could be defined spatially and interpreted within the profile, they were too complex for the human brain to interpret.

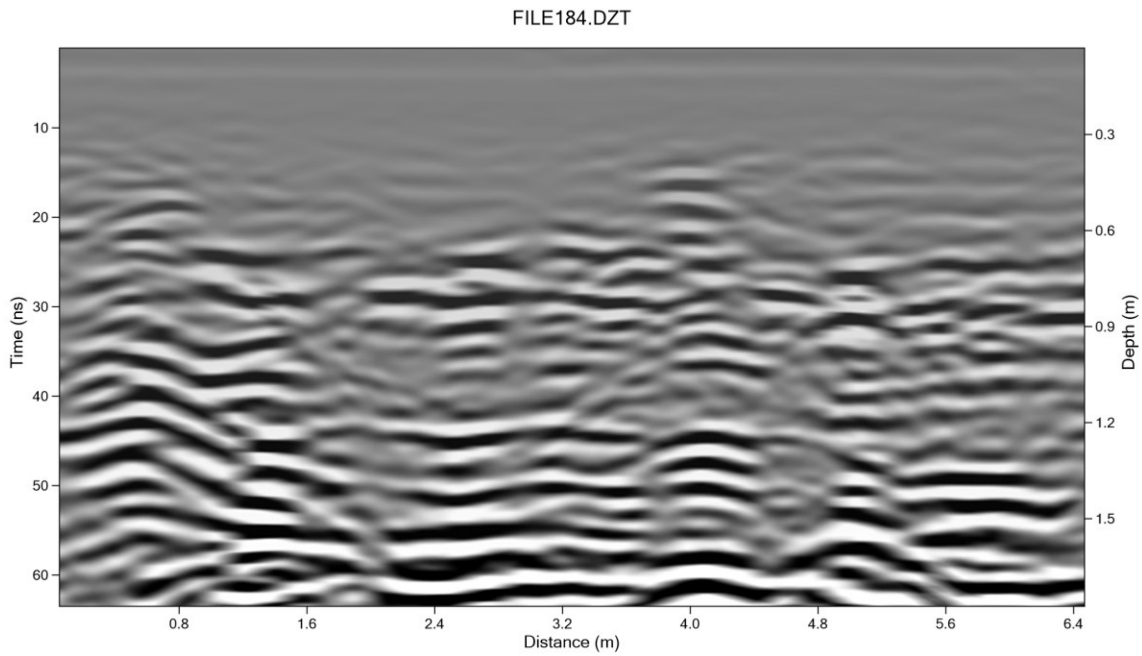

Figure 5: Migrated reflection profile from Long Island showing a variety of planar reflections.

Remembering how radar waves move through the ground from a surface antenna and reflect in various directions, it becomes clear that vertical interfaces are generally not visible (Figure 6), as radar waves pass by them. Horizontal interfaces produce most reflections.

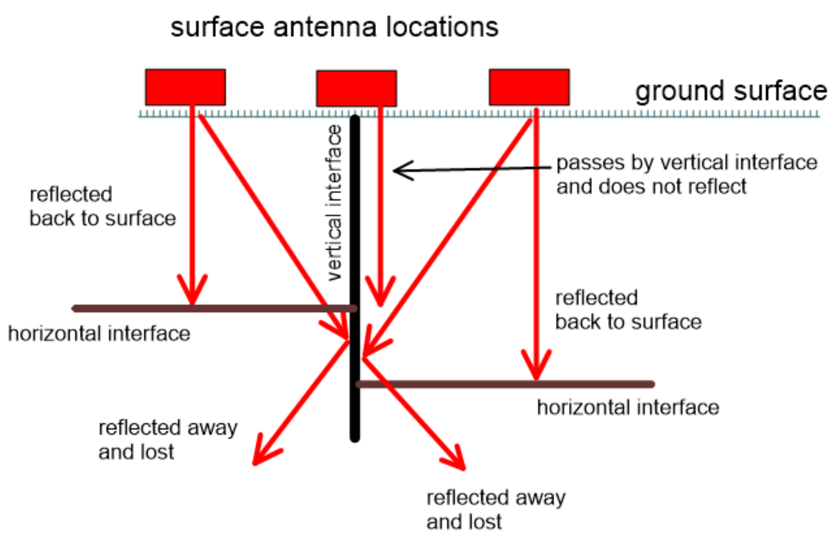

Figure 6: Diagram showing how radar waves intersect and reflect from horizontal and vertical interfaces in the ground.

Using this analysis of ray pathways, both vertical and horizontal interfaces can be identified in the annotated profile (Figure 7). Deeper planar reflections that extend across the profile indicate untruncated features, while shallower reflections abruptly terminate at inferred vertical interfaces (shown in pink). These vertical interfaces are non-reflective and defined by the termination of horizontal reflections.

This buried feature becomes visible only after careful two-dimensional reflection analysis. One cusp-shaped reflection (shown in yellow) provides insight into the origin and later abandonment of the feature.

It is apparent that this incised feature is likely a house cellar. In early Colonial times, cellars were often constructed first, with houses built above them and accessed through a floor trapdoor. Remains of a stone wall or chimney may be preserved (outlined in purple), with individual stone courses visible as radar-reflective layers. The cellar floor appears as one or more brown layers at the base of the incision, possibly representing multiple construction or resurfacing episodes. The structure was later abandoned, and a red layer marks the ground surface at the time of abandonment. The area was then gradually covered by sand, which is not reflective near the top of the profile. The yellow layer within the cellar likely represents a fill layer where sediment accumulated preferentially along the vertical cellar walls, producing a cusp-shaped reflection.

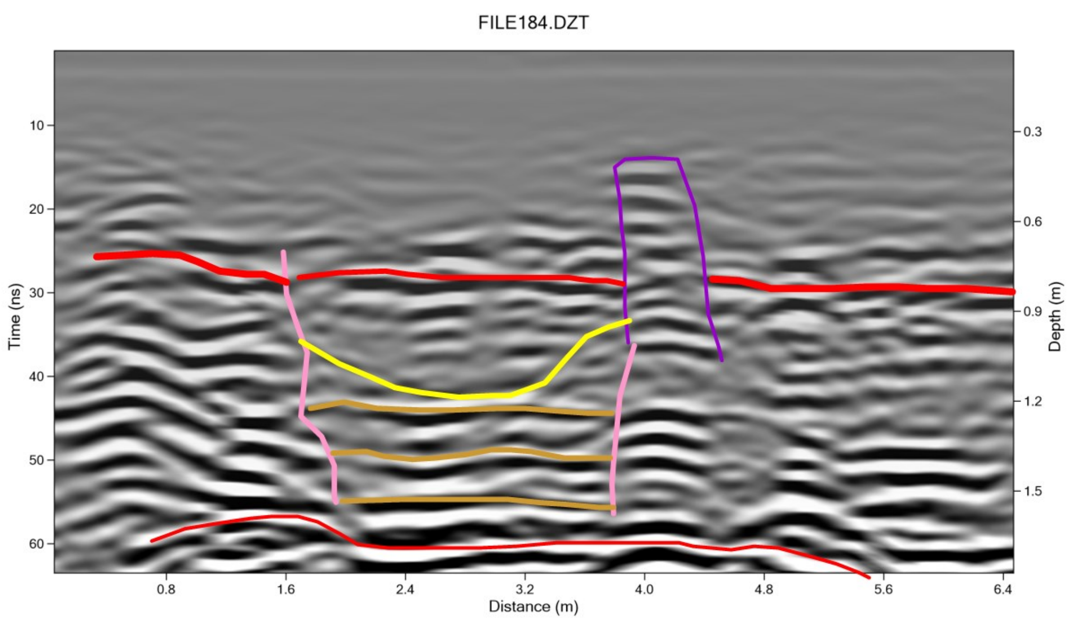

Figure 7: Annotated reflection feature of the profile shown in Figure 5.

Only after careful consideration of radar wave behavior in the ground can such profiles be accurately interpreted. Similar analyses were conducted across all reflection profiles in the grid, and the base of the cellar and surrounding living surface were digitized. This allowed construction of a three-dimensional image of the cellar feature (Figure 8).

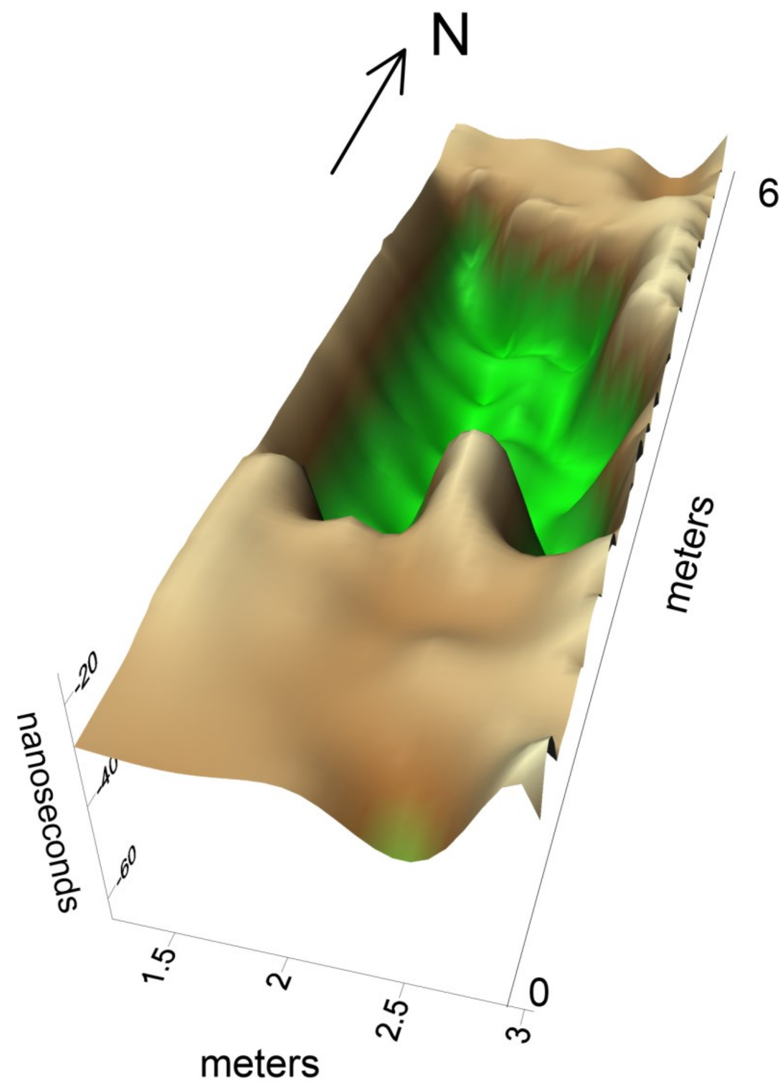

Figure 8: Three-dimensional image of the cellar feature defined by two-dimensional profile analyses.

Conclusion

Two different interpretation methods were applied to two datasets. In Ireland, slice-maps revealed subtle reflections not visible in 2-D profiles, making amplitude mapping superior for detecting small features. In the Long Island dataset, the abundance of reflections made slice-mapping ineffective, as amplitudes were sampled across unrelated reflection units. Vertical features critical to identifying cellars were invisible in slice-maps. Only by considering radar wave behavior and carefully interpreting 2-D profiles could these features be accurately identified and digitized to produce a reliable image of the buried structure.