Archaeological Prospection
Archaeol. Prospect. **13**, 159–163 (2006)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/arp.284

Correcting for Topography and the Tilt of Ground-penetrating Radar Antennae

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ABSTRACT Static corrections of radargrams can account for the tilt that the GPR antenna encounters on sites with topography. Radargrams that are topography-tilt corrected, show that changes in the imaged locations of subsurface structures can be significant. The results of these corrections indicate that tilt corrections are necessary to improve the accuracy in imaging subsurface structures on sites with significant topographic changes. Copyright © 2006 John Wiley & Sons, Ltd.

Key words: ground-penetrating radar; static corrections; topography; antenna tilt

Introduction

The complex ray paths of ground-penetrating radar (GPR) waves from surface antennae can often produce distorted images of the ground, which are especially pronounced when reflection data are collected on topographically complex features such as burial mounds. Experiments that involved the antenna tilt and subsurface distortion have shown that these conditions can often drastically affect the results of GPR surveys over complex ground surfaces (Leckebusch and Rychener, 2005). As antennae are moved up and over mounds of this sort, the majority of radar energy transmitted from the antenna can often be focused in various directions, and the energy reflected back to the surface is also received from features that are not directly below the antennae. The computer, however, records the reflections as if they were directly underneath the antenna. Antenna tilt therefore must be determined in order to calculate the primary direction of energy transmission as well as the origin of the received reflections. In correcting for the direction of the vertically transmitted radar wave emanating from the GPR antenna, ‘crossover’ or intersecting ray paths can also occur when topographic variations are dramatic and ground microwave velocities are fast enough (Figure 1).

The test site

The Saitobaru Burial Mound number 111 in Miyazaki Prefecture, Japan, which has several metres of topographic relief, was used as an initial test site for the correction of reflections due to antenna tilt. Antenna tilt analysis was conducted using static correction options in GPR-SLICE v5.0

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Contract/grant sponsors: Nanao City Cultural Department; Department of Education, Miyazaki Prefecture.

Received 15 November 2005
Accepted 24 March 2006

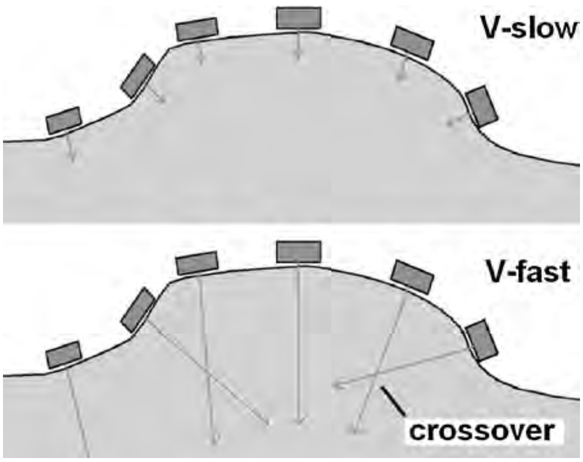

Figure 1. Geometry of vertically transmitted radar waves from a tilted antenna illustrating why topographic and tilt corrections are necessary. Higher velocities can also create conditions where reflection trace 'crossover' occurs.

Software (www.GPR-SURVEY.com). Static corrections in GPR data processing are usually conducted in order to correct for normal topographic variations, or sometimes velocity variations along reflection profiles, but they can also be used for these types of corrections. In the tilt processing data analysis continuous topographic grids are made from digitized contour maps of the ground elevation for the site. To estimate the tilt that the GPR antenna encounters along each transect in a grid, the first derivative of the topography, which is ground slope, is computed. The slope is used to project the normal ray emanating from the tilted antenna. The horizontal distance the rays travel from an antenna that is tilted is a function of the microwave velocity and is given by $d = \sin(\mathrm{tilt})vt/2$, where v is the average velocity and t is the travel time. The tilt angle is given by the arctangent of the ground slope, $\mathrm{tilt} = \mathrm{arctangent}\ (\mathrm{d}z/\mathrm{d}x)$, where $\mathrm{d}z/\mathrm{d}x$ is the local change in elevation over a small range. The normal topographic corrections assume that d is 0, and therefore there is either no tilt and/or the velocity is 0. If the tilt is not taken to be 0 then the horizontal distance the ray travels during its two-way travel time must be accounted for as a function of microwave velocity at the site.

To exemplify the effects of velocity on the tilt correction, the same reflection profile is corrected for tilt and topography using three different velocities (Figure 2). Figure 2a indicates how traces were recorded with topographic correction only, ignoring the tilt of the antenna. Figure 2b illustrates how tilt corrections calculated from an average velocity of 7 cm ns^{-1} 'distort' the resulting reflection in a two-dimensional profile. The distortion becomes even more pronounced as the average velocity of the ground increases to 12 cm ns^{-1} (Figure 2c). An understanding of how velocity changes, accompanied by topographic as well as tilt corrections of the antenna, affect the reflection geometry is very important in the final interpretation of features in a three-dimensional sense. At the site used for this study velocity was calculated from hyperbola fitting of point-source reflections recorded when the antennae were on flat ground.

Implementation of topography and tilt correction is done by converting the reflection profiles to depth sections using the average velocity calculated for the site. This adjusts all the reflection traces for surface elevation change and converts time to depth. The angle of the antenna with the ground surface is then calculated as well as the angle of the transmitted beam into the ground, variables of which are dependent on ground slope change and velocity. All wavelets are reassigned their correct location in space within each reflection profile based on these calculations and a new binary file of reflection amplitudes in space is created. It should be noted that the tilt correction implemented does not make adjustments for reflections that might have been recorded off to either side of the antenna. Also the cone of transmission, which always produces very complex ray paths that are not directly perpendicular to the antennae, is also disregarded. Those very complex three-dimensional transmission patterns of the GPR antenna are effectively not included in this analysis but are corrected for by migration prior to the tilt correction analysis. The conical transmission pattern is also accounted for as the method assumes that much of the energy that is ultimately reflected back to the surface follows a narrower cone that is roughly perpendicular to the transmitting antenna. Even with those variables not accounted for the tilt corrected radargrams provide a much closer match of the true geometry of

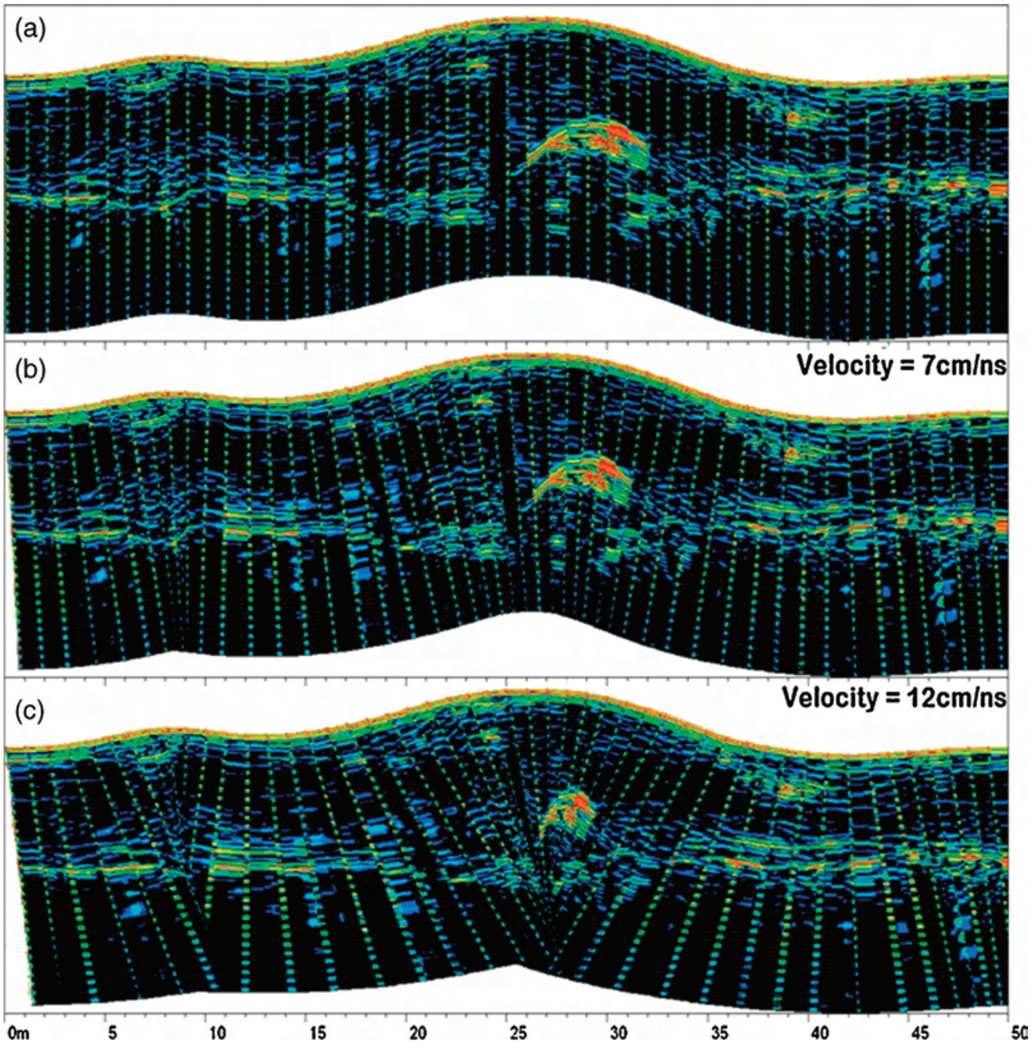

Figure 2. An example of topography and tilt corrections applied to the same reflection profile. The upper figure (a) has no correction for tilt but the lower two are corrected using velocities of 7 cm ns^{-1} (b) and 12 cm ns^{-1} (c).

buried features collected on sites with topography, than usual topographic correction procedures.

In Figure 2c the reflection from the ceiling of a burial chamber is much smaller in aerial extent than in the non-corrected profile (Figure 2a). When the burial chamber was exposed (Figure 3), it was shown to be very close to the dimensions from the corrected profiles (Figure 2c) using the tilt as well as topographic corrections.

Any three-dimensional analysis of topographically complex sites, such as those discussed above, must take into account these corrections if accurate amplitude slice-maps are to be constructed. Once the topography and tilt corrected binary radargrams are made, time-slice data analysis can then be applied (Goodman *et al*., 2005; Conyers, 2004; Conyers and Goodman, 1997). A comparison of amplitude maps constructed from topographically corrected traces alone with those that were also antenna-tilt corrected is shown in Figure 4. The tilt corrected map shows the ceiling of the burial chamber to be distinctly rectangular in size and its location offset by almost 2 m (Figure 4a). In the uncorrected slice this feature has been not only distorted but also is located incorrectly (Figure 4b).

(a)

(b)

Figure 3. Excavation photographs of the burial chamber within Saitobaru Burial Mound number 111, reflections of which are in Figure 2.

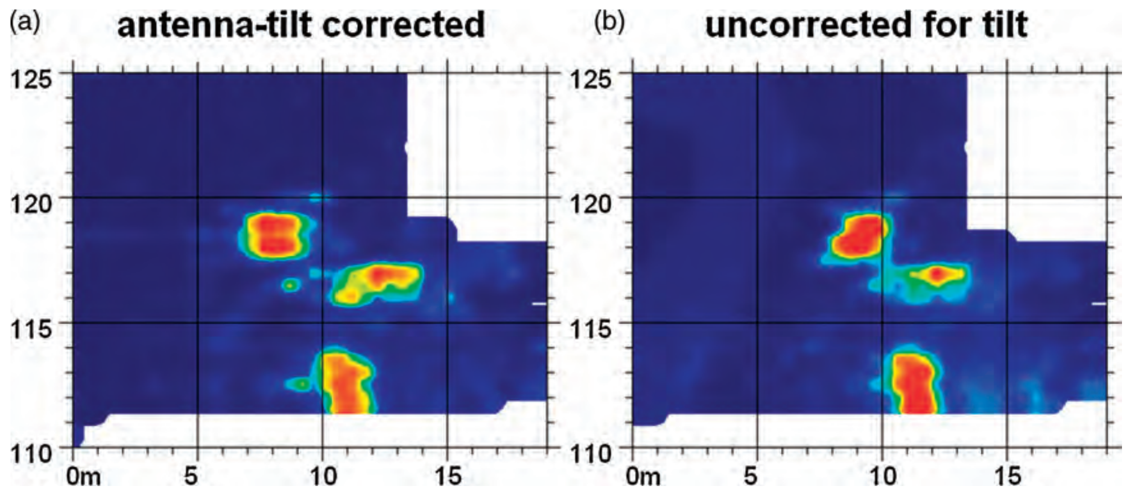

Figure 4. A comparison of amplitude time slices made from topography and tilt corrected reflection profiles (a), with those that were made from uncorrected profiles (b). These amplitude time slices illustrate reflections from the chamber ceiling from 3.5–4 m below the ground surface of Ikime Burial Mound number 7, Miyazaki City, Japan.

Subsequent excavation confirmed the correct geometry and location of the feature, as predicted in the tilt-corrected amplitude maps (Figure 3).

Conclusions

Static corrections that include both elevation and antenna tilt are necessary when conducting surveys over topographically complex areas. If these corrections are not made the location of subsurface structures can shift significantly when mapped in plan view, in addition to its shape becoming distorted. The amount of reflection trace shift is dependent on the velocity of radar energy in the ground and the distance to and from the reflection surfaces buried in the ground. These corrections are especially important when reflections are recorded from deep within the ground where travel paths to and from reflections are longer and the offset from the surface antenna location greater. As antenna tilt is an important factor that previously has been uncorrected for, GPR equipment that includes tilt meters might, in the future, help to increase the accuracy of subsurface imaging.

Acknowledgements

This research was supported by the Nanao City Cultural Department in Ishikawa Prefecture and through grants from the Department of Education; Miyazaki Prefecture, Japan.

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