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Imaging in the Ground-penetrating Radar Near-field Zone: a Case Study from New Mexico, USA

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ABSTRACT It has long been suggested that the near field zone in GPR data contains no usable information, and should be ignored. This paper shows that there can be usable information in the near field zone when accurate time-zero is chosen, and near-surface reflections are processed. Reflection data from a Pueblo site in New Mexico were filtered and then re-gained to reveal floors within the upper 3 nanoseconds, and their presence was confirmed by excavation. Copyright © 2006 John Wiley & Sons, Ltd.

Key words: ground-penetrating radar; near-field; amplitude analysis

Introduction

The immediate vicinity of a ground-penetrating radar (GPR) antenna (within 1–1.5 wavelengths), called the 'near field', is characterized by strong electromagnetic fields that theoretically preclude true wave propagation, as this energy has not yet coupled with the ground (Conyers, 2004). The near-field zone in reflection profiles contains a combination of events, including the direct ground wave and the direct air wave (energy moving from the transmitting to the receiving antenna along the ground–air interface and in the air), and at times antenna 'ring-down', all of which may impair the detection of sought-after objects close to the surface. It is noteworthy, however, that although this zone is clearly visible in computer models that use far-field approximations (Annan, 2003), many have noticed that in practice when antennae are placed at the air–ground interface, reflections are visible in profiles from objects on and very close to the ground surface (Turner, 1994; Goodman *et al.*, 1995; Conyers, 2004). This may be because antennas transmit in a broad band, so some higher frequency radar energy will couple at very shallow depths and generate reflections from targets just below the surface (Conyers, 2004). In addition, as dielectric permittivity increases, antenna coupling and ground wave amplitudes are diminished (Slob and Fokkema, 2002), so very shallow features might also be detected by changes in the amplitude of the ground wave. Accordingly, amplitude changes in the near-field may be the product of high frequency energy reflections as well as changes in the ground-wave due to differences in near-surface physical properties. At a site in the American Southwest called Pueblo Escondido, reflections (or changes in the amplitude of ground waves) from shallow archaeological features well within the antennas' near field were revealed after some basic reflection data processing. Slice maps produced from these processed profiles showed the location of house floors and walls, which were later confirmed by excavations.

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Data processing

The dominant wavelength of transmitted energy from a 400 MHz centre frequency antenna in the ground at Pueblo Escondido (with a relative dielectric permittivity of 5) is 34 cm, making the near-field zone 0–34 cm thick, but potentially extending to about 50 cm. To accurately analyse

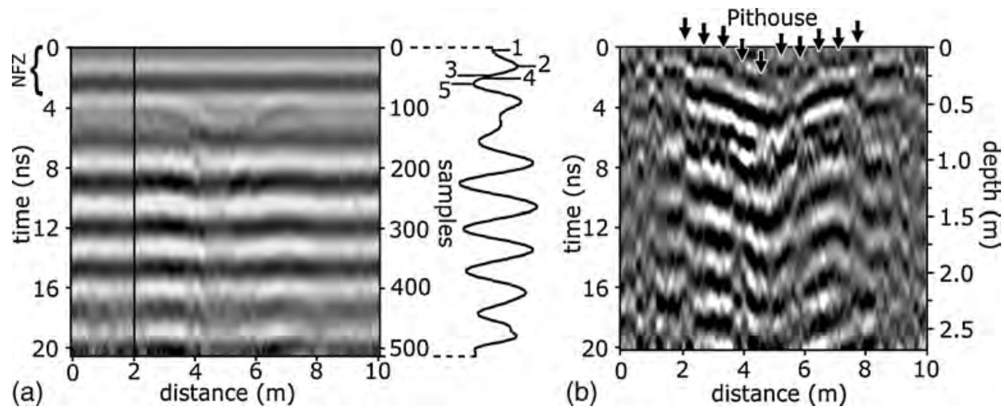

Figure 1. Reflections in the near-field zone are found after basic processing. (a) Unprocessed Pueblo Escondido reflection profile with time zero picking positions shown after Yelf (2005): NFZ denotes the near-field zone, 0–3.34 ns two-way travel time (TWTT). (b) Processed version of the reflection profile revealing a pit house floor just below the ground surface.

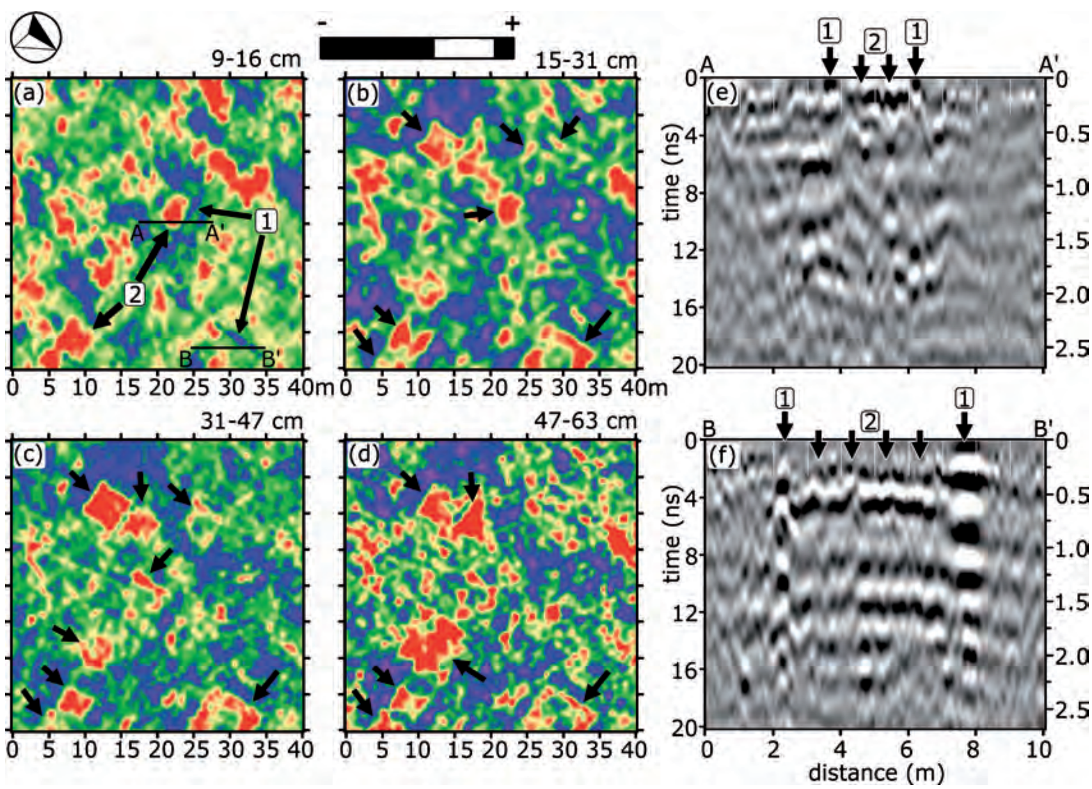

Figure 2. Pueblo Escondido depth slices and reflection profiles for a small portion of the area surveyed: (a) 9–16 cm slice showing that the uppermost portions of house features are visible within the near-field zone. Deeper slices (b) 15–31 cm, (c) 31–47 cm, and (d) 47–63 cm reveal additional deeper structures indicated with arrows. (e) Reflection profile A–A' showing a room floor very near the surface. (f) Reflection profile B–B' showing another floor, slightly deeper than the previous. 1 = house wall; 2 = house floor.

reflections within this near-surface zone, the precise zero time (location of the ground surface in time) must first be determined. Yet surprisingly there is no consensus on how to do this, and it is a matter of considerable disagreement among practitioners and manufacturers of different GPR systems. Recent analysis by Yelf (2004) determined that there are at least five different locations along the first recorded wavelet that are commonly chosen to set time zero, and therefore denote the ground surface on reflection profiles (Figure 1a). This is because the true location of the ground surface in a reflection trace depends on the transmitted frequency and near-surface electrical properties, and a very precise determination often can be arrived at only with field tests. For mid-range GPR frequencies (200–900 MHz) typically used in archaeology, on ground that is not too conductive, it has been suggested that the zero position is best located at the 'first break' or the beginning of the first amplitude deflection from the mean (Yelf, 2004).

Using the first deflection time-zero location all reflection profiles from Pueblo Escondido were adjusted, which removed only the upper 8 out of 512 samples used to define each trace (Conyers, 2004, p. 30). Background was removed and new gains applied to enhance the remaining amplitudes near the surface (Figure 1b), revealing distinct reflections produced from the floor of a pit-structure recorded at less than 1 ns two-way travel time (TWTT). These reflections would have been at least partially removed had any of the other time zero picking methods (that place the ground surface deeper within the time window) been used.

All profiles were time-corrected and processed in this fashion, including amplitude time-slicing. A very thin, shallow depth-slice (0.7–1.2 ns, 9–16 cm) yielded both linear and rectangular features that were hypothesized to be floors and walls of the ancient pueblo based on their geometric pattern (Figure 2a). Several of these were subsequently uncovered and confirmed to be the remains of habitation structures. One of these (Figure 2e) was composed of a 25-cm wide, 10-cm high adobe wall visible at 12 cm below the ground surface, surrounding a 20-cm-deep floor overlain by cultural fill layers that included pottery sherds, charcoal and wall/roof rubble. Additional tests were made of a number of the very shallow rectangular shaped features seen in the amplitude slice-maps, all of which confirmed either the wall or floor reflections visible in the GPR map. All these features were located well within the antennae's near-field zone and could have been overlooked, or not even mapped, using standard GPR processing methods.

Conclusion

Amplitude changes within the first 1–1.5 wavelengths of a GPR pulse have often been disregarded due to the misconception that there are no usable reflections at these depths because they are within the antennae's near-field zone. Important shallow reflection or direct wave events can also be accidentally removed if time zero is placed too deep within the time window. This study shows that regained reflection profiles and very shallow depth slices within the near field can accurately portray otherwise hidden or unnoticed archaeological features, and that precise correction of time zero is critical for preserving these very shallow features in the data.

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