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Resolution of Ground-penetrating Radar Reflections at Differing Frequencies

MICHAEL GREALY*

Department of Anthropology, University of Denver, Denver, CO 80208, USA

ABSTRACT Ground-Penetrating Radar data that are frequency filtered will produce a variety of data sets, each with a differing subsurface resolution. At the site of Petra, Jordan, filtered reflection data were processed to produce discrete categories of low (200–350 MHz), middle (500–650 MHz), and high (650–800 MHz) frequency wave amlitudes. The high frequency reflections were especially effective in identifying construction techniques from a buried Nabataean age wall. The results suggest that post-acquisition GPR data frequency filtering may be helpful in identifying some differences in construction techniques and building materials in otherwise difficult to interpret subtle buried features.

Key words: ground-penetrating radar; frequency analysis; resolution

Introduction

The resolution of buried features and the depth to which energy can be transmitted are variables that must be considered when planning any ground-penetrating radar (GPR) survey (Conyers, 2004 p. 39). Lower frequency transmitted waves will penetrate deeper into the ground but can only resolve relatively large targets, and resulting profiles and maps from these data can potentially overlook some of the smaller features of archaeological interest. The opposite is true when higher frequency antennae are used, which often resolve only the shallowest features, but with high resolution. Often with only one or two antennae at one's disposal, the challenge is to simultaneously maximize depth of transmission and resolution with the antennae at hand. As GPR antennae transmit radar energy in a broad band (Annan and Cosway, 1994) some energy is always collected that is much higher or lower than an antenna's centre frequency. Some frequencies of reflected energy will therefore often be 'hidden' within the overall reflected wave traces used to produce reflection profiles or amplitude maps. Frequency filtering, however, can potentially produce data sets of selective bands of energy collected by one antenna, which can alternatively discriminate targets that are deeper (and then resolve features larger in size) using the lower frequency energy or shallower (with great resolution of smaller features).

Experiments were conducted that filtered and then processed both higher and lower frequencies using reflection data from GSSI 400 MHz centre frequency antennae that originally had been filtered in the field between 200 and 800 MHz. Reflection profiles were collected at the site of Petra in Jordan using a GSSI SIR-2000 system, where the overburden was aeolian sand, and the targets were Nabataean and Roman stone foundations at depths ranging from approximately 0.5 m to 2.0 m. The purpose of the filtering tests

* Correspondence to: M. Grealy, Department of Anthropology, University of Denver, Denver, CO 80208, USA.
E-mail: mgrealy@du.edu

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was to determine if the same data set of reflections could produce images resolving archaeological features that were both shallow and deep in order to define certain important construction techniques, which varied over time.

At Petra, construction materials and techniques differed between the earliest Nabataean architecture, characterized by medium sized limestone boulders packed with smaller stones and clay facing and later Roman construction that tended to be of massive sandstone blocks (Parr, 1970). Nabatean walls were commonly remodelled by adding sandstone facing to these existing walls throughout their use. It was hoped that construction techniques (and therefore the age of buried features) could be determined solely by their GPR reflection signatures using data of various frequencies collected by the same antenna.

Reflection data filtering

As it is known that the earlier phases of occupation are characterized by rubble construction with some facing material they should appear in reflection profiles as many small point sources in the reflection data. But as they are often buried more than 1.5 m, the small point sources are often obscured by reflections of the lower frequency energy, which tends to smooth and average out the small targets. In contrast Roman age large-block walls should appear as individual large reflection targets irrespective of the frequency of energy reflected. Frequency filtering and amplitude mapping was therefore conducted to test the resolution of both of these types of buried features.

Maximum resolution of buried features is roughly correlative to the size of the energy

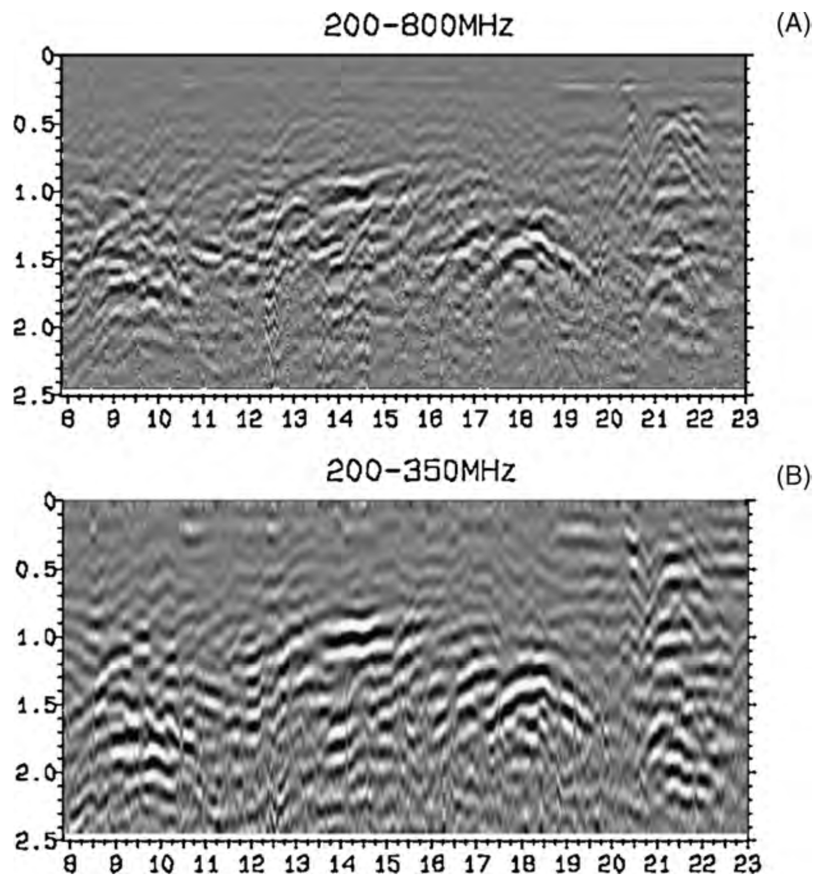

Figure 1. (A) Unprocessed reflection profile showing full bandwidth 200–800 MHz data recorded in the field. (B) Low-frequency range 200–350 MHz. (C) Mid-frequency 500–650 MHz. (D) High-frequency 650–800 MHz.

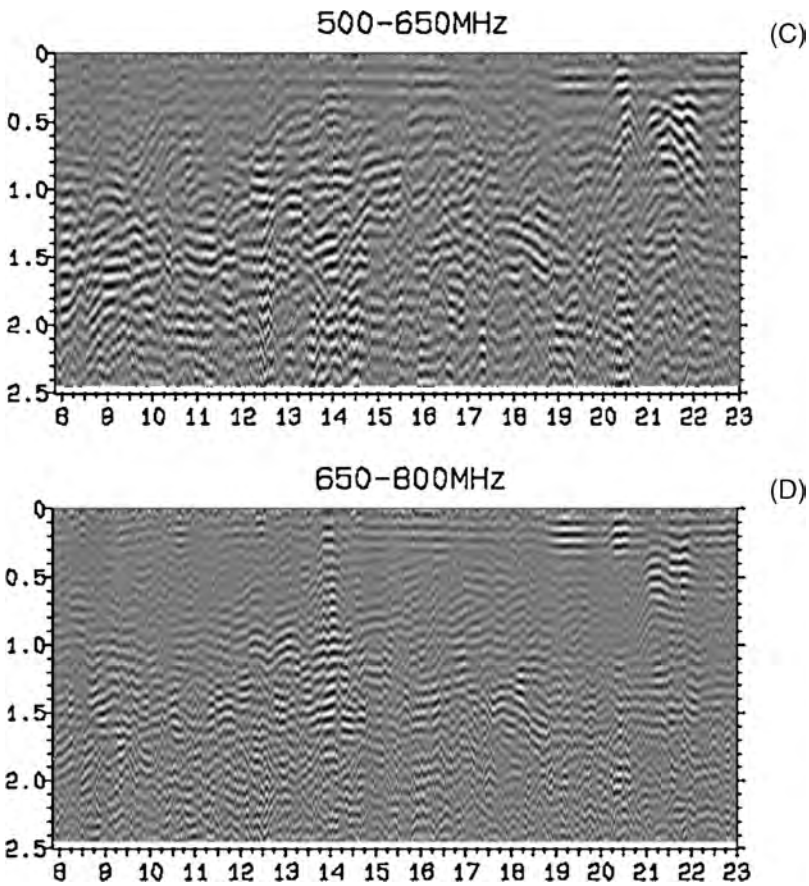

Figure 1. *(Continued)*

footprint (area of illumination) at a given depth, which varies according to frequency as well as depth in the ground (Annan and Cosway, 1992). Therefore frequency filtering of reflection data is in effect a resolution filter. As the buried features to be resolved are all approximately the same depth in the ground, the only variable that needs to be adjusted in order to change potential resolution is frequency. Reflection data from a 9×23 m grid collected in a 60 ns time window were filtered into three data sets (200–350 MHz, 500–650 MHz and 650–800 MHz) (Lucius and Powers, 2002). Very different resolutions of the same buried wall are visible in reflection profiles of these filtered data sets (Figure 1). All data sets were processed identically with identical background removal and horizontal and vertical exaggerations applied.

Results

All profiles in the grid were amplitude sliced at 4 ns intervals and the resulting database was spatially interpolated using the inverse distance cubed gridding method. A distinct linear feature was found in the amplitude map of the 200–350 MHz bandwidth (Figure 2B). In contrast this same reflection feature in the 650–800 MHz bandwidth appears as two parallel linear structures, indicating that it is a composite feature consisting of a facing material with rubble fill that probably dates from the earlier Nabatean construction phase (Figure 2C). An excavation trench was placed just to the north of this grid in the 1960s and uncovered Nabatean age occupational deposits, suggesting that the reflection feature mapped by GPR is the extant wall

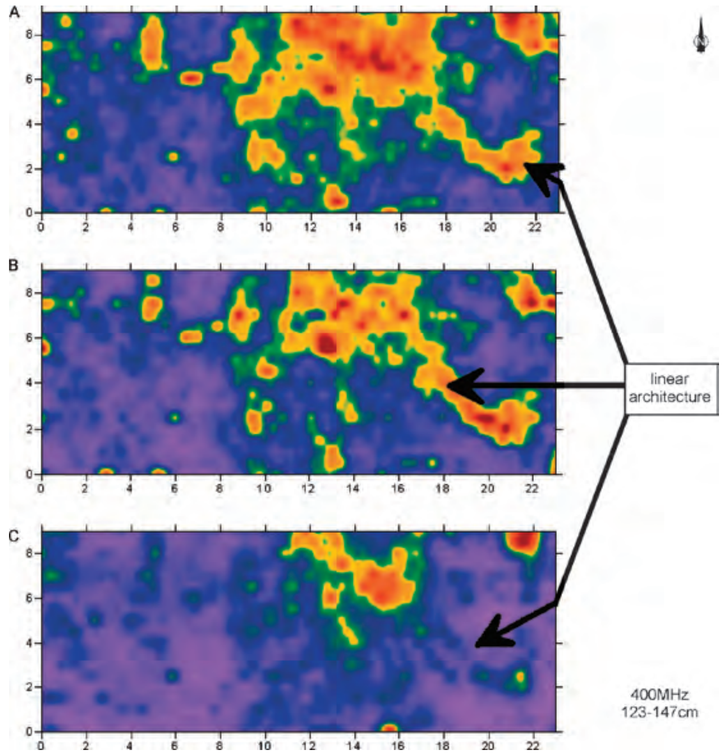

Figure 2. Amplitude slice maps showing a linear reflection feature. (A) Full bandwidth 200–800 MHz. (B) Low-frequency 200–350 MHz. (C) High-frequency 650–800 MHz.

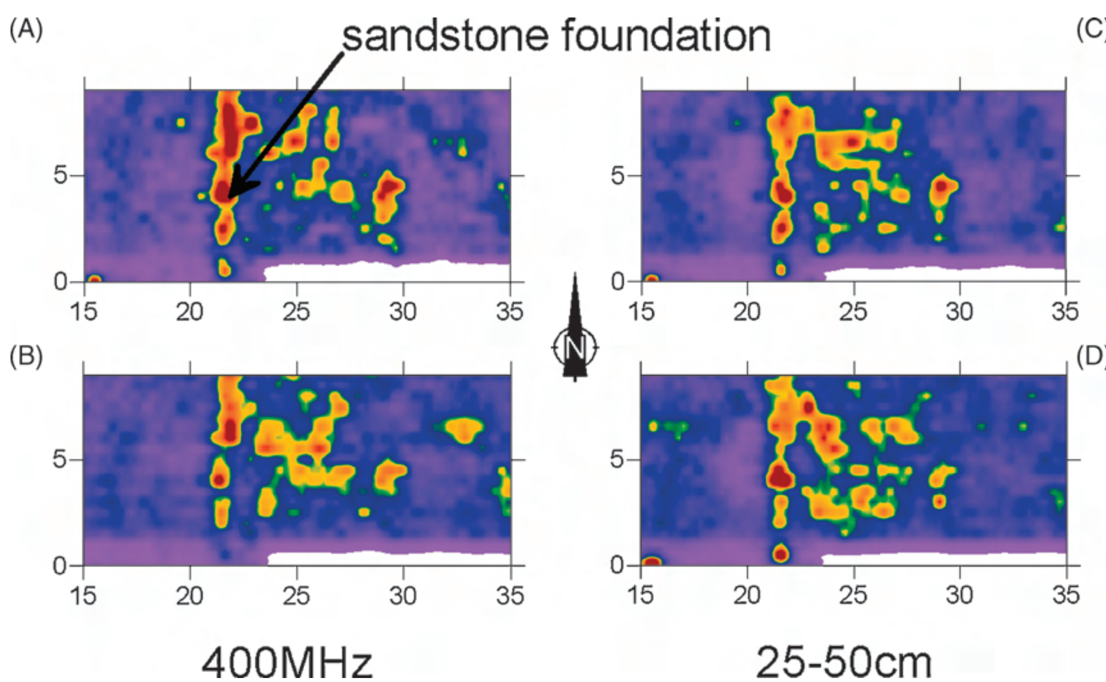

Figure 3. Amplitude slice map of Late Classical architecture. (A) Full bandwidth 200–800 MHz. (B) 200–350 MHz. (C)500–650 MHz. (D) 650–800 MHz.

from a habitation structure. An amplitude map constructed using the full antenna bandwidth (Figure 2A) shows only one distinct wall, illustrating how this important architectural style is effectively masked when using all the frequency reflection data. Without filtering the reflection data to emphasize targets of different sizes, the relatively thin veneer would have been impossible to detect.

In contrast later Roman (or perhaps post-Roman) architecture, characterized by monumental sandstone construction, is visible in the amplitude maps in Figure 3. This wall has been excavated (Conyers *et al.*, 2002) and its construction technique confirmed. What is clear in the amplitude slice maps is that this broad stone wall appears very similar in all the maps produced from many frequency ranges, as the large sandstone blocks are ample reflection targets irrespective of the wave frequency. The different frequency maps, however, are beneficial even here as the higher frequency data will produce imaging of each individual stone block in the wall as well as features within the interior of the building, which are probably portions of a stone floor (Figure 3C).

Conclusion

Through frequency filtering of GPR reflection data, reflection targets of different sizes can be resolved and emphasized in amplitude slice-maps as well as reflection profiles. The ability to make determinations of specific construction techniques using GPR is important at multi-component archaeological sites where construction methods varied over time. At Petra two different architectural styles were imaged using these filtering techniques providing a method to date buried structures using GPR maps and profiles alone.

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