A comparison of GPR performance at various frequencies - a guide to improved survey design

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BIOGRAPHY

Thabang Kgarume, Fatheela Brovko and Michael van Schoor are part of the Mining and Mineral Resources group of the CSIR's Natural Resources and the Environment unit. They have skills and experience in applied mining geophysics and seismology, but are also active in other applications of high-resolution geophysics, including the application of ground penetrating radar, borehole radar, electrical resistance tomography, induced polarisation imaging etc. to hydrogeophysics and civil engineering problems.

SUMMARY

This paper aims to demonstrate, through practical examples and numerical modelling, the trade-off between range and resolution in ground penetrating radar (GPR) prospecting. GPR surveys can easily fail when the target and host rock properties and geometry are not well understood, resulting in an inappropriate choice of operating frequency. We include selected results from a 2D study aimed at investigating GPR performance across the frequency band 100-1000 MHz and also include selected case study results.

Key words: GPR, frequency

INTRODUCTION

Ground penetrating radar (GPR) is one of the most widely used geophysical methods in near surface geophysics and its application in a range of diverse fields such as mining geophysics, hyrogeophysics, environmental geophysics and civil engineering is well documented in the scientific literature (e.g., Grandjean et al. 2000; Pettersson and Nobes, 2003; Travassos, and Menezes, 2004; Vogt and van Schoor, 2005).

Despite its versatility, the applicability of GPR to a given problem is highly site specific and depends to a large extent on the physical properties of the subsurface and the user only has a certain measure of control over the performance of GPR. The relationship between the subsurface physical properties and GPR performance is often described as a 'trade-off' between range and resolution, which can be controlled to some extent by selecting an appropriate operating frequency.

The success of a GPR survey often hinges on the selection of an appropriate operating frequency, and hence, a good understanding of the relationship between frequency, range and resolution for different ground conditions.

This paper aims to highlight the above, often neglected, aspects of GPR prospecting, and includes results from a basic model study and selected case study examples.

RANGE vs. RESOLUTION

Most commercial GPR systems have single-frequency antenna options in the frequency band 100-1000 MHz. In this paper four discrete frequencies spanning the above range will be considered, namely 100, 250, 500 and 1000 MHz. As was mentioned earlier, the performance of GPR is strongly dependent on the subsurface physical properties. Table 1 shows, for example, the calculated wavelength and typical range (depth of investigation) in a moderately conductive ground of between 400 Ωm and 500 Ωm.

Operating frequency (MHz)	**Approximate Wavelength (cm)**	**Typical depth of investigation (m)**
100	100	12-15 m
250	40	6-8 m
500	20	4-5 m
1000	10	1-2 m

Table 1. Typical GPR performance figures in moderately conductive ground of ~400-500 Ωm.

However, if the survey area, in contrast to the above example, is characterised by a relatively conductive soil with a resistivity of approximately 150 Ωm (three times more conductive than previously), the signal attenuation will also be three times higher and the corresponding predicted ranges will be proportionately less as is shown in Table 2.

Operating frequency (MHz)	**Approximate Wavelength (cm)**	**Typical depth of investigation (m)**
100	100	4-5 m
250	40	2-3 m
500	20	1.3-1.7 m
1000	10	0.3-0.7 m

Table 2. Typical GPR performance figures in realtively conductive ground of ~150 Ωm.

The wavelength provides a measure of mapping accuracy or resolution, which is often quoted as being of the order of approximately 1/2 of a wavelength. It should also be emphasised that resolution is also dependent on the target depth; that is, resolution deteriorates with increasing target depth and is consequently more realistically closer to the order of a wavelength in practice.

SELECTED MODEL AND FIELD RESULTS

The 2D simulation results in Figures 2 and 3 illustrate the impact of changing the operating frequency: In Figure 2 attempts at resolving two closely spaced thin reflectors are depicted. The gap between the two reflectors is 40 cm, which is approximately equal to the wavelength at 250 MHz. It is evident from the simulation results that it is only the 500 MHz and 1000 MHz antennas that are capable of unequivocally discriminating two distinct layers.

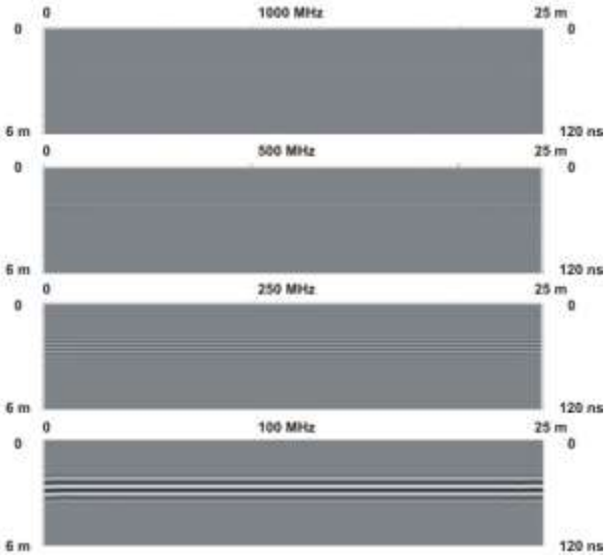

Figure 1. 2D GPR simulation - imaging two closely spaced thin reflectors using different frequencies.

The simulation depicted in Figure 3 is similar to the above, except that the targets are two closely spaced point reflectors separated by 30 cm. In this case, the gap between the point reflectors are not only smaller than in the previous example, but the targets are also located ~25% deeper. The result is that an operating frequency of 500 MHz is not quite high enough to enable the discrimination of two distinct targets. In practice, however, the next highest available frequency (1000 MHz) may struggle to achieve the desired range of approximate 2.5 m.

The aspects investigated in the model studies are also evident the field results. Figure 3 shows 250 MHz and 100 MHz versions of the same profile. The survey area was a dolomitic terrain and the purpose of the survey was to detect structural features in the upper 6-8 m. The lower frequency provides an increased range, but the higher frequency clearly provides a greater mapping accuracy / discrimination ability in the upper 4 m.

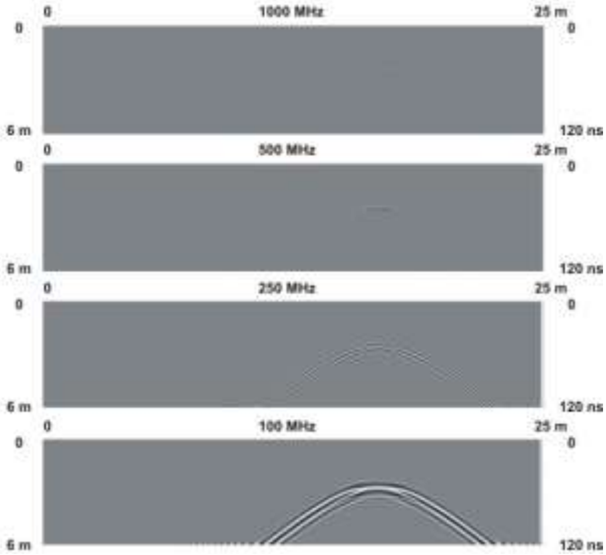

Figure 2. 2D GPR simulation - imaging two closely spaced point reflectors using different frequencies.

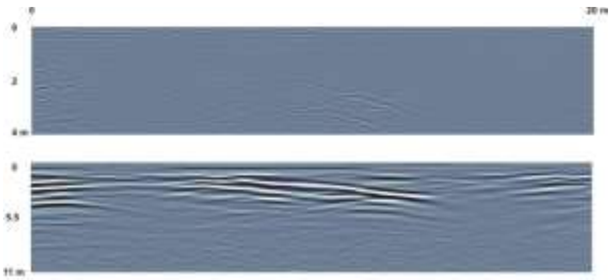

Figure 3. GPR profile acquired with a 250 MHz system (top) and 100 MHz system.

CONCLUSIONS

GPR surveys often fail because of an inappropriate choice of operating frequency. It is shown through model studies and field examples that both range and resolution are typically overestimated in practice. Improved survey design through a combination of pre-survey multi-frequency trial measurements and numerical modelling is strongly advocated. The use of multiple frequencies (budget and logistics permitting) is also recommended in cases where the target and ground properties are not well known of difficult to predictable.

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