Multi-offset GPR surveys for complex targets

L. Baradello, J. M. Carcione, and D. Nieto Yabar
Istituto di Oceanografia e di Geofisica Sperimentale – OGS Sgonico,Trieste, Italy

This paper was prepared for presentation at the 9th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, 11-14 September 2005.

Abstract

During the last twenty years Ground Penetrating Radar (GPR, georadar) has been successfully used to discover and map several subsurface structures. The mono-static georadar (one single antenna) is fast and inexpensive for these surveys. Often, in archaeological and geological investigations the structures can be very complex: ancient walls and debris in chaotic mixtures of sediments or fractures in rocks. These cases are difficult to interpret with conventional single-offset (SO) records because there is scattering and poor signal-to-noise (SN) ratio. The present paper shows how the GPR multi-offset (MO) technique can provide more information about complex targets and enhance weak reflections. We compare the multi-fold (MF) stack and the MO section to investigate which method gives the best performance.

Introduction

The geophysical high-resolution techniques have evolved very rapidly over the past decades. Ground Penetrating Radar is without a doubt the non-invasive methodology widely diffused and employed in investigations at shallow depths for geological, environmental, archaeological and engineering explorations (e.g., Botelho, 2002; de la Vega et al., 2005). Usually, the objective in GPR applications is to detect the targets and not to discover the real geometry and depth of the structures. If the last objective is important, then mono-static surveys are not very helpful (Baradello et al., 2004), because SO profiles do not give information about the electromagnetic-wave velocities and variations of amplitude versus offset. On the contrary, more information can be extracted from GRP MO data, because this technique permits to enhance the response of buried objects at several dipping angles. In this work, we discuss the main aspects of the GPR MO acquisition, and the processing and interpretation of very complex targets such as archaeological and geological sites.

Multi-offset GPR acquisition

As with all geophysical methods, one of the main objectives of the GPR acquisition is to minimize the errors. First of all, the topographic variations must be small compared to the electromagnetic wavelength. The choice of the nominal frequency depends on the type of application, the depth of investigation and the desired resolution. The correct method for choosing the frequency is to carry out a frequency test, i.e. a series of common mid points (CMP) with different antennas (50, 100, 200 and 400 MHz). In the datasets presented in this work, we prefer to have high resolution instead of penetration and we chose the 200 MHz for the archaeological survey and 100 MHz for the geological survey.

The more obvious use of MO dataset is the creation of the traditional MF stack. MF data are described as "a sum of constant-offset profiles" (SCO). To optimize the system and to have a coverage equal to the number of the profiles, these start at the same point and the offset must increase by double of that of the emissions. In our cases, the offset is increased by 10 cm and we emit every 5 cm, thus obtaining a maximum coverage of 1000 % (see Figure 1).

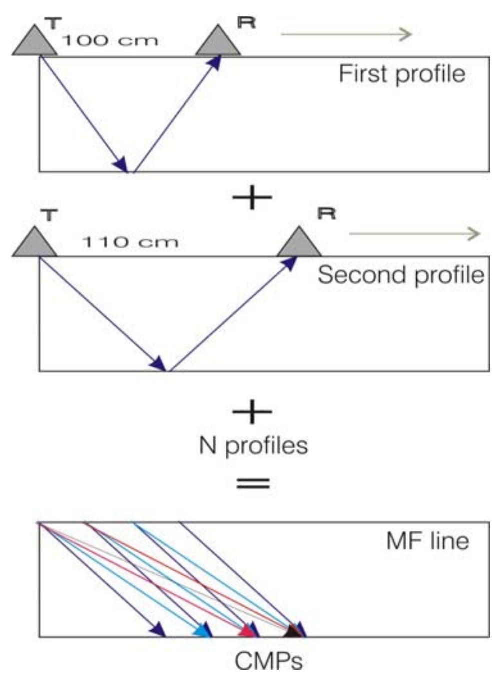

Figure 1: SCO is a method to obtain MF lines: several profiles with different constant offset are collected and then assembled with a suitable geometrical configuration (CMP gathers).

Other methods for building MF stacks assemble single CMPs or shots (WARR); they have large fold but need a long acquisition time.

For a more detailed analysis of the electromagnetic wave velocity in the ground it is advisable to acquire some CMPs by increasing the offset from 20 cm to 600 cm with spacings of 10 cm. Figure 2 shows a typical CMP, where the B signals are reflections with velocity of 10 nearly cm/ns.

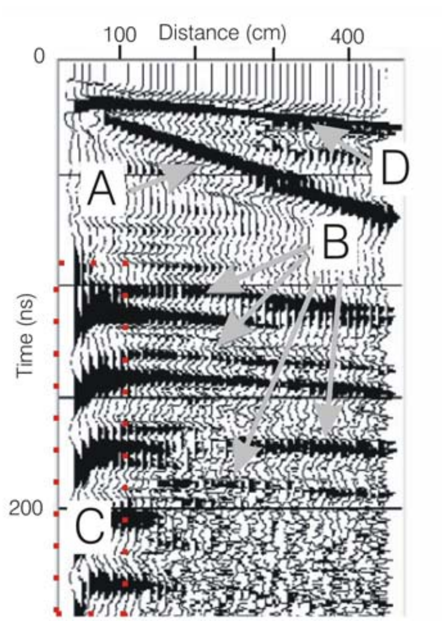

Figure 2: Example of CMP gather collected in rocks (100MHz, raw data, with spherical divergence). A) ground wave, B) refections, C) low frequency (ringing), D) air wave.

GPR processing

The processing of GPR MO data is divided into two parts: real amplitude and gained data. The first step is to assemble the MO data into MF profiles and then create the appropriate geometry. The first consideration is about amplitude, i.e. the presence of parts with strong attenuation or reflectors having amplitude variations with offset.

The amplitude is related to conductivity (Davis and Annan, 1989; Carcione et al., 2003): strong amplitude decay means high conductivity. The processing for this analysis is simple and is composed by two steps:

a) Offset corrections on the single profiles to eliminate the shift of the signal introduced by the lack of instrument stability during the acquisition.

b) Normalization relative to the air wave in the same CO profile, and spherical divergence correction.

During the amplitude study it is not possible to apply any filter or gain algorithm (such as automatic gain control, a typical tool used to gain data), because these tools change the amplitudes. It is obvious that in this case the data must have a good SN ratio.

The second part is the traditional MF processing for increasing the SN ratio (Fisher et al., 1992; Pipan et al, 1997). After having recovered the signal amplitude it is possible to apply a 2D filter. One of these filters is the FK-filter that is used to attenuate noise linear with offset (for example, a ghost reflection from a hole). The traditional sequence of processing continues with velocity analysis (normally a semblance), normal move-out and stack. Finally, for a better visualization of the target, a migration is applied (Stolt migration is an excellent tool). The MF method is good for deep and flat reflections. For complex or very shallow targets (for example, ruins or ancient walls in archaeological surveys, or fractures in rocks), the stack does not improve the SN ratio, on the contrary, the final section can be degraded and loose resolution. In this case, the best method is the MO analysis (e.g., Carcione et al, 1994). This is similar to MF processing but without stacking. The advantages are the use 2D tools for removing noise in CMP or shot gathers and the visualization of more images with different geometries of the same line.

Results

Figure 3 shows three profiles with different offset (110, 150 and 220 cm). The data were collected with bi-static RAMAC antennas (nominal frequency of 100MHz) in a karstic region in northern Italy. (The purpose was the investigation of aquifers). These sections are processed with pre-stack steps on MF data (gain and filter). Figure 4 shows the stacked section (fold 1200 %, offset from 110 cm to 220 cm, with 10 cm spacing).

We may conclude that:

- Several fractures are visible in the MO sections (dotted lines), while the stacked section does not show them.
- The same fracture is not visible in all MO sections.
- There is not a big difference of signal penetration with increasing offset.
- As expected, the stacked section has a higher SN ratio

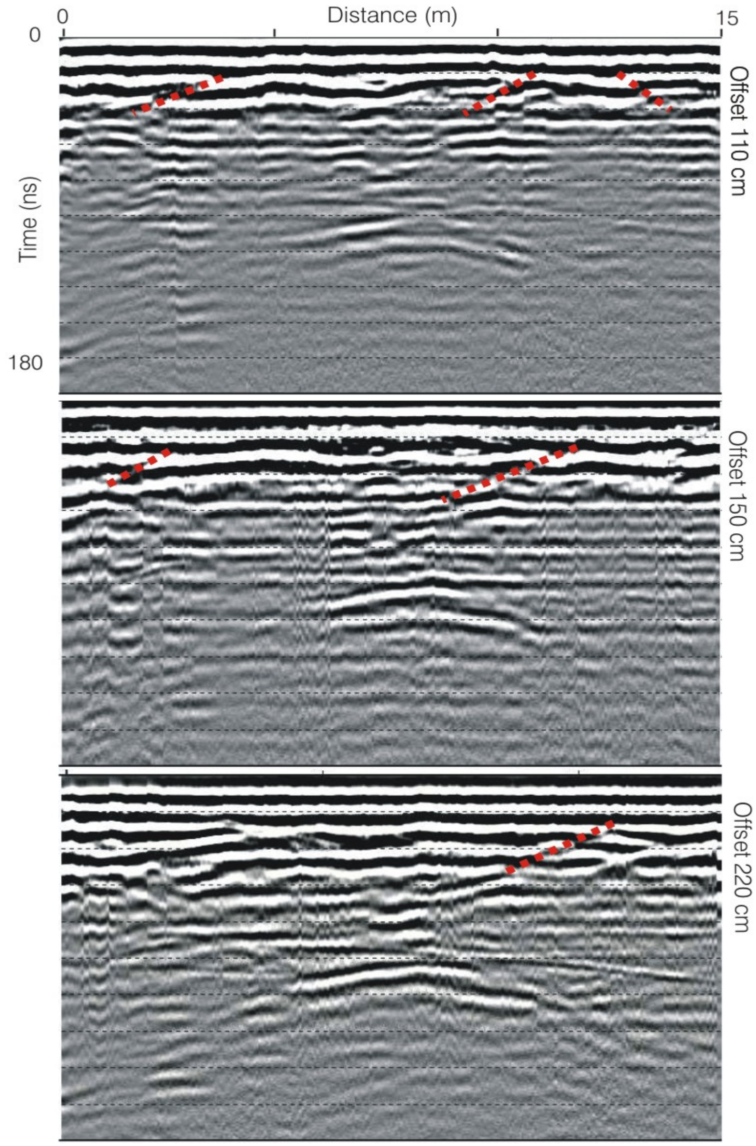

Figure 3: Common-offset profiles collected in a karstic area (100MHz).

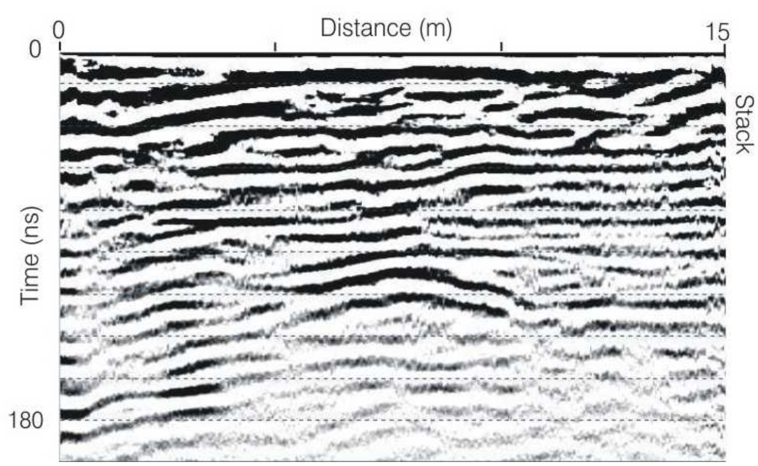

Figure 4: Stacked section, with a fold of 1200 %.

An example of an archeological complex target is showed in Figure 5. The data were collected for detecting and mapping iron-age graves in Ush Bulak (Kazakhstan) (Pipan et al., 2001) . The reflection from the base of tomb has a weak signal in all single common offset profiles but after stack its SN ratio is increased. The stack has lost most of the details of reflections/diffractions from the debris present on the base of the tomb.

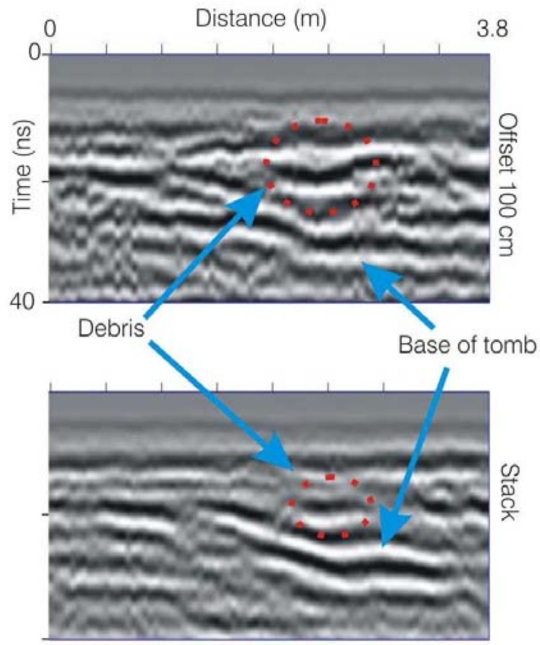

Figure 5: Common-offset profile (100 cm) and stacked section (1200 %) collected on an ancient tomb with a 200 MHz GPR. The blue arrows show the interesting targets. In the stacked section, the reflection from the base of the tomb is stronger and more continuous, but the response of the buried debris inside the tomb is more clear in the common-offset profile.

Conclusions

The first conclusion of this work is that MO GPR processing yields more information than the stacked section despite the lower SN ratio. However, not always the stacked sections exhibit a substantial enhancement of the SN ratio. In the presence of complex targets, the acquisition geometry (the distances transmitter – target – receiver) is critical, because the signals reflected from a discontinuity can change as a function of the scattering angle. The best approach is a multi-offset (MO) analysis: assembling the CMPs, using the typical processing steps for removing the noise in MO data and then separate the common offsets to interpret the signals.

Acknowledgments

The authors thank Prof. Michele Pipan and the Exploration Geophysics Group – DISGAM, University of Trieste for the support in the data acquisition.

References

Baradello, L., Carcione, J. M., and Gei, D., 2004, Fast monostatic GPR modeling, Geophysics, **69**, 466-471.

Botelho, M. A. B., 2002, Análise tridimensional de maciços cristalinos para implantação de lavras de rochas ornamentais. XLI Cong. Bras. Geologia - A Geologia e o Homem, João Pessoa.

Carcione, J. M., Böhm G., and Marchetti, A., 1994, Simulation of a CMP seismic section, Journal of Seismic Exploration, **3**, 381-396.

Carcione, J. M., Seriani, G., and Gei, D., 2003, Acoustic and electromagnetic properties of soils saturated with salt water and NAPL, J. Appl. Geophys., **52**, 177-191.

Davis, J. L. and Annan A. P., 1989. Ground-Penetrating Radar for high-resolution mapping of soil and rock stratigraphy. Geophysical Prospecting, **37**, 531-551.

de la Vega, M., Osella, A., Lascano, E., and Carcione, J. M., 2005, GPR and geo-electrical simulations of the Floridablanca archaeological site data, Archaeological Prospection, **12**, 19-30.

Fisher, E., McMechan, G. A., Annan, A. P., 1992. Acquisition and processing of wide-aperture ground-penetrating radar data, Geophysics, **57**, 495-504.

Pipan M., Baradello L. and Finetti I., 1997, Target identification and noise removal in multi-fold ground penetrating radar data, 59th Conference, European Association of Geoscientists & Engineers, Extended Abstracts, paper E027

Pipan M., Baradello L., Forte E. and Finetti I., 2001, Ground penetrating radar study of iron age tombs in south-eastern Kazakhstan, Archaeological Prospection, **8**, 141-155