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2-D AND 3-D DIFFRACTION STAKE MIGRATION METHOD USING GPR: A CASE STUDY IN ÇANAKKALE (TURKEY)

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ABSTRACT

In this study, ground-penetrating radar (GPR) method was applied for Clandestine cemetery detection in Çanakkale (Dardanelles), west Turkey. Investigated area was a historical area which was used as tent hospitals during the World War I. The study area was also used to bury soldiers who died during the treatment process in tent hospitals. Because of agricultural activity grave stones were used by local people, thus, most of the graves were lost in the field.

45 GPR profiles were applied with a GPR system (RAMAC) equipped with 250 MHz central frequency shielded antenna. After main processing steps on raw data, migration was applied to improve section resolution and develop the realism of the subsurface images. Although the GPR in results before migration the anomalous zones are visible, after migration the results became much more visible both in the profiles and 3D illustrations, thus, migrated GPR data were preferred to locate the buried martyrdoms.

KEYWORDS: Ground Penetrating Radar, Migration, Martyrdoms, Gallipoli

INTRODUCTION

Shallow geophysical methods have been using to identify buried features. Among these methods, Ground Penetrating Radar (GPR) appears to be the most effective because it is able to obtain high-resolution images of the near surface with relatively simple equipment and in a short time range. Numerous studies have been made of GPR application in the archaeological field. In general, the survey targets include the identification and mapping of buried artifacts or construction features, the localization of tombs, burial mounds, shallow graves and the reconstruction of archaeological layers (e.g. roads, walls, channels) (Vaughan, 1986; Goodman,1994; Goodman et al., 1995; McCann, 1995; Hruska and Fuchs, 1999; Dabas et al., 2000; Piro et al., 2001; Lualdi and Zanzi, 2002; Leckebusch, 2003; Chianese et al., 2004; Persson and Olofsson, 2004; Leucci and Negri, 2006; Leckebusch et al., 2008; Yalciner et al., 2009). Although GPR provides reliable data for locations of buried features, images usually do not represent the real shape of the target because as pointed out by Conyers (2004) point sources generate hyperbolic anomalies in GPR profiles. This spreading usually causes misinterpretation of the buried features. Similar problems occur in seismic industry but such spreading reflections have been removed using migration methods in data processes (Berkhout and Verschuur, 1997; Yilmaz, 2001). Cassidy (2009) reports that migration can be used with GPR in relatively uniform environments (e.g., deep geological and glacial, pavements), but it is less successful in complex, heterogeneous sites. Thus, migration method in GPR studies has been applied either on synthetic data set in laboratory (Christian and Klaus-Peter, 1994; Leuschen and Plumb, 2000; Song et al., 2006; Oden et al., 2007) or in homogenous test sites (Fisher et al., 1992a, 1992b; Sun and Young, 1995; Leckebusch, 2003). Despite the abundance of investigation, migration usually has not been used in the field.

In this study, buried tombs were investigated with GPR near the Çanakkale Strait (NW Anatolia) where the Gallipoli war took place (Fig. 1a). Migration method was applied to improve image quality. The study site was framed on the basis of both historical account (Sayılır, 2010) and detailed geomorphological field studies (Fig. 1b). 45 GPR profiles up to 50 m in length were performed in N-S direction in order to make 3D data set. Processed time slices were generated to identify tombs and quality of images was improved using diffraction stack migration method. Migrated and unmigrated images (2D GPR profile, time slices and iso-amplitude) were compared to demonstrate advantages of the diffraction stack migration method.

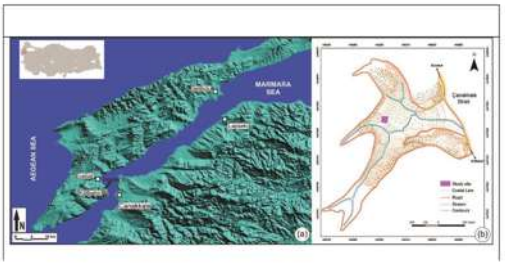

Figure 1: (a) Map of the study area in western Turkey with shaded relief image map (from SRTM data). (b) Topographic map of the study site

STUDY SITE

The study area is located between Kilitbahir and Ecebat in the northwestern side of the NE - SW trending Çanakkale (Dardanelles) Strait (Fig. 1a). There is a wide valley probably carved by the east flowing Ağadere (Fig. 1b) and there are relatively high hills towards north. The surveyed site is situated in the northern side of the Ağadere (Fig. 1b) on a gently east facing talus deposits derived from surrounding hills (Fig. 2).

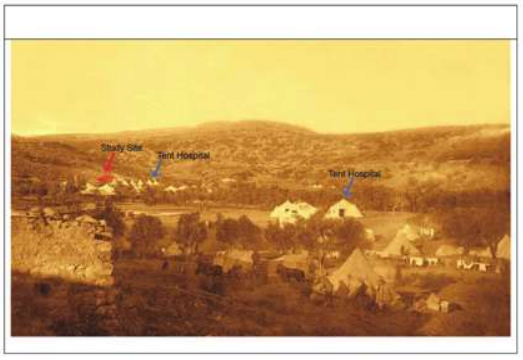

Figure 2: An old photo from 1916 showing the study site (red arrow) and Tent Hospitals (two right arrows).

This area was the frontal side during the Gallipoli Wars of the World War I. Sayılır (2010) reports that tent hospitals were settled in the study area (Fig. 2) for a period of 25 April 1915 and 9 January 1916 to treat injured soldiers. The surveyed site (Fig. 2) was used to bury soldiers who died during the treatment process in tent hospitals (Sayılır, 2010). According to Sayılır (2010), 1000 to 3000 soldiers were buried in the study area during the war. Although the study area has been preserving as a Martyrdom in the National Park, grave stones were used by local people, thus, graves are hardly visible in the field.

GPR SURVEY

Ground Penetrating Radar (GPR) is a near surface geophysical technique that allows us to discover and map buried archaeological features in ways not possible using traditional field methods (Conyers, 2006). GPR data acquisition involves the transmission of high frequency (10 MHz – 2.3 GHz) radar pulses from a transmitter antenna into the ground. The radar waves travel at the speed of light (0.3 m/ns) in air, but quickly slow when it penetrates into the ground. At each interface where its speed changes, some of those waves are reflected back to the surface. The greater the velocity change, the higher the amplitude of the reflected radar waves. The elapsed time between when radar waves are transmitted, reflected from buried materials or sediment, and soil changes in the ground, and then received back at the surface is then measured for depth scale. The system records all those waves (air waves, reflected waves and diffraction waves) as traces. Many hundreds or even many thousands of traces measured and recorded, as antennas are moved along transects within a constant trace interval (1 cm – 50 cm), then two-dimensional profiles created. When the two-dimensional profiles collected as parallel to each other in grid manner three-dimensional maps can be constructed, making the GPR method one of the most precise tools for mapping buried features (Conyers, 2006).

DATA ACQUISITION

The geophysical instrument used for this study was a Mala RAMAC ProEX GPR unit with 250 MHz shielded antenna. The antenna was oriented in the normal position (true orientation) on the ground. When the GPR equipment is used for archaeological applications, a grid search should be employed with equidistant spacing (1 m for 250 MHz) between contiguous transect lines. The GPR system can then be pulling over each of the grid transect lines to collect data. With the antenna positioned at the bottom of the shielded system in close proximity to the ground surface, electro-magnetic (EM) pulses of short duration are emitted downward into the ground from the bottom of the antenna. The most widespread way to display 3D radar data is in "time slice" maps (Conyers, 2004). Time slices are easiest and most rapid way to provide a plan synthetically of anomaly pattern, especially for large areas. On the other hand, for smaller areas, the 3D cubes presentation technique gives more complete understanding of subsurface with clear views and slices parallel to the axes or along arbitrary directions (Leucci and

Negri, 2006). For this work I carry out both 3D-visualisation techniques with our GPR data set.

In this study, the Martyrdom area, which is 44 x 50 m in size, was scanned by GPR with 250 MHz antenna. 45 GPR profiles were taken in NE-SW direction and the aperture of profiles is 1 m. The acquisition parameters of GPR surveys are given in Table 1.

Table 1: Acquisition parameters of GPR survey

Antenna Freq.	250 MHz
Trace interval:	0.05 m
Samples:	512
Sampling freq.:	2607 MHz
Time window:	196 ns
Profile intervals:	1 m

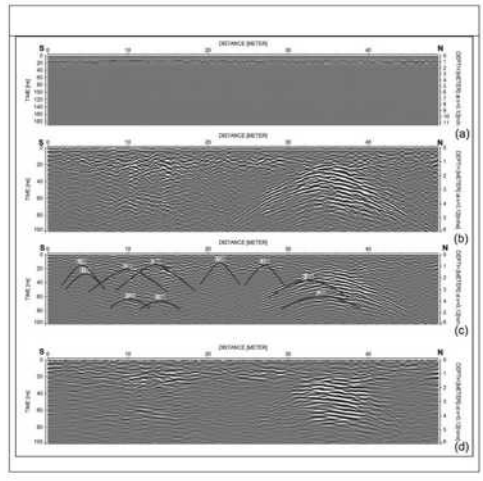

Figure 3: (a) Raw data one of the GPR profile in 3D grid area. (b) Final section after processing. (c) Velocity analysis with the diffraction hyperbolas method. The same profile with diffraction hyperbolas superimposed. The geometrical modeling of diffractions is performed using a constant velocity of 0.2 m/ns. (d) Migrated profile with the diffraction stack migration method by using the velocity.

2D DATA PROCESSING

To improve the quality of the original data and for a better interpretation the processing was performed with Reflex W software (Sandmeier, 2003). Fig. 3 shows an example of processed radar data. The main processing steps can be summarized as follows:

- Time-zero correction (shift the first arrivals by a constant) (Fig. 3a),
- Running average filter with a length of 4 ns in order to filter the DC component (Dewow filter),
- Energy decay with a scaling value of 0.512,
- Subtracting the mean trace (calculated from a sliding window of 61 traces) in order to filter out the continuous flat reflections caused by breakthrough between the shielded antennas and by multiple reflections between the antenna and the ground surface (Daniels, 2004),
- Band-pass filter: 100/200-300/400 MHz,
- Time - cut: 100 ns (Fig. 3b).

The EM wave velocity was estimated in order to define the depth of anomalies. Using the characteristic hyperbolic shape of a reflection from a point source (diffraction hyperbola) is the easiest way to determine the EM wave velocity from the profiles acquired in continuous mode (Fig. 3c). Fig. 3c shows an example of velocity analysis performed by geometrical modeling of diffractions (Bano et al., 2000). By using this method, a value of 0.12 m/ns was found for the velocity which gives an average relative dielectric constant ε_r equal to 7. After main filtering process and velocity estimation, Diffraction Stack Migration method was applied to each profile.

MIGRATION

The final tool in the processing steps of the GPR user is migration. Migration is generally used for improving section resolution and developing more spatially

realistic images of the subsurface and is, arguably, the most controversial of the GPR processing techniques (Cassidy, 2009). Wave migration is a useful technique to refocus collected time responses so that the images more closely resemble the physical target dimensions (Song et al., 2006). Moran et al. (2000) were made a modification on Kirchhoff (Diffraction Stack) integral of Schneider (1978) with inclusion of a half-space interfacial dipole radiation pattern and applied this modified migration equation both on synthetic data and glacier data. Their modified GPR formulation is given by

$$U(r) = \frac{1}{2\pi} \int_{z'=0} \frac{E^{\alpha}(\theta,\phi,\varepsilon_r)}{R^{\beta}\upsilon} \frac{\partial U(r'_0, t_0)}{\partial t} da'_0$$

where "U" is the migration depth image, and "U(r′$_0$,t$_0$)" is the surface wavefield observation. Primed parameters "z′, r′, and a′" give spatial dimensions relative to an array's coordinate origin, "R" is the subsurface diffraction point relative to a surface observation, "r" is the integral evaluation point relative to the array's coordinate origin, "υ" is the propagation speed in soil and "E(θ,φ,ε,)" is the range normalized electric field dipole radiation pattern and "ε_r" is the dielectric constant for the medium. The exponents "α" and "β" are treated as processing parameters to be determined by systematic trial-and-error variation.

In this work, I adopt the Diffraction Stack method with the above equation which is used widely in seismic migration (French, 1974). First, the EM velocity of the anomalous zone was determined (Fig. 3c), then Diffraction Stack method applied to the whole profiles (Fig. 3d) with the parameters listed in Table 2.

Table 2: Diffraction Stack migration parameters

Line specifications: Whole profile	
Summation width:	31
Velocity:	0.12 m/ns
Start time:	0 ns
End time:	100 ns
ε_r:	~ 6.25

The modified diffraction stack method has been assumed as an appropriate method to perform amplitudes to real value after Schleicher (1993). In this method, two dimensional profiles that has a constant velocity is performed using simple time migration (diffraction stack) but the profile must represent zero offset, i.e. shot and receiver have to be at the same position. A zero offset section often does not represent the real positions and shapes of vertical features (such as wall, tombs and pipe). However, migration contracts strong diffractions to a minimum level and provides a clear reflection for buried features. This kind of filter is useful time-slice and 3D presentation.

3D DATA PRESENTATION

The creation of horizontal time slices is a way to obtain visually useful maps for understanding the plan distribution of reflection amplitudes within specific time intervals is (Conyers, 2004). This data representation (Fig. 4) plays an important role in GPR investigations as it allows an easier correlation of the most important reflections found in the area at same depth, thus simplifying the interpretation (Carrozzo et al., 2003b). However, it is worth to note that the depth of time slices is approximate due to possible changes in velocity with depth and lateral distance (Yalciner et al., 2009).

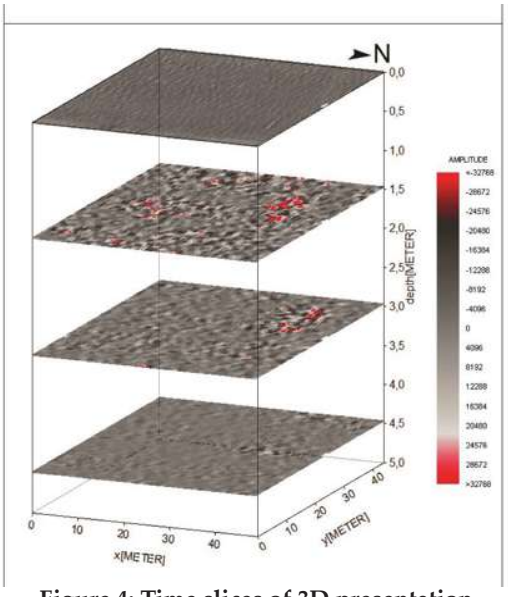

Figure 4: Time slices of 3D presentation. The high amplitude areas (red colored areas) are probably related to a buried tombs.

The same data set is displayed with iso-amplitude surface using four threshold values: 20%, 30%, 40% and 50% of the maximum complex trace amplitude (Fig. 5). Clearly, lower the threshold value, better the visibility of the main reflections and smaller objects. In the mean time lower the threshold value, higher the heterogeneity noise. The threshold value seems to be the most delicate parameter (Leucci and Negri, 2006), and the values of 25% and 30% appear to be the best choice, because they underline better the remnants of archae-ological interest.

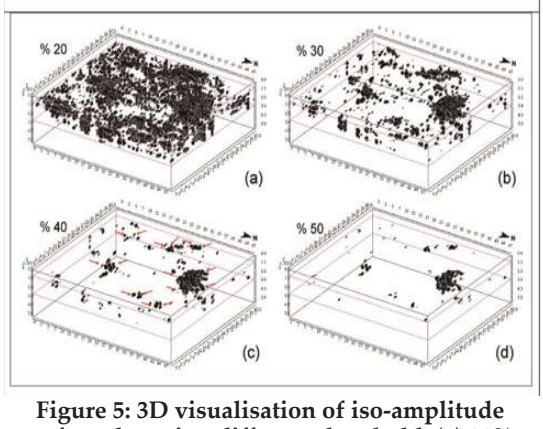

Figure 5: 3D visualisation of iso-amplitude surfaces by using different threshold: (a) 20%; (b) 30%; (c) 40% (arrows are pointing the buried tombs); (d) 50%.

COMPARISON OF UNMIGRATED AND MIGRATED 2D – 3D DATA

New migration methods are yet to be included into typical GPR processing steps, even though most do include some form of relatively sophisticated (if classical) migration algorithm (Cassidy, 2009). Diffraction stack migration can be performed on 2D sections or across 3D volumes of data.

Fig. 6a shows an unmigrated GPR profile and as Fig. 6b shows, the hyperbolas in the same profile collapsed after migration and the main anomalies are much more visible. Layers also became much more clear in the migrated profile (Fig. 6).

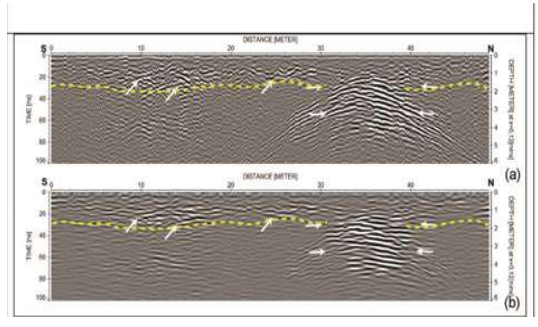

Figure 6 (a-d) Fig. 6: Comparison of unmigrated and migrated 2D GPR section (white arrows pointing the possible tombs and yellow dashed line represents layers). (a) Processed and unmigrated section. (b) Processed and migrated section.

Although layers become clear in the migrated profile, there is no considerable difference in their shape. However, anomalies for point sources became significantly clear in migrated section. For example, the anomaly between 32 and 38 meters appears as hyperbolas in the unmigrated profile and it does not give sufficient information about dimensions (Fig. 6a) but the shape and dimensions are clear enough in the migrated section (Fig. 6b). Similarly, there is a considerable difference in plan views of unmigrated and migrated time slice at ~1.5 m depth (Fig. 7).

As Fig. 7a shows, anomalies are distributed in unmigrated time slice and it is difficult to interpret which anomalies represent tombs. However, migrated time slice for the same area shows clusters in certain locations (Fig. 7b) that can be corresponded to tombs. For example, migrated plan view (Fig. 7b) shows clear anomalies in a-i, a-ii, b-ii, b-iii, c-ii, c-iv, d-ii and d-iv which can be interpreted as tombs. Although unmigrated plan view also shows anomalies in same areas (Fig. 7a), their densely distribution all over the scanned area makes it difficult to distinguish tombs. The same positive effect of migration is also clearly notable in iso-amplitude surface maps of the same area (Fig. 8). As Fig. 8a shows, the un-migrated map includes much more noise effects around anomalies for tombs but migrated map has less noise effects (Fig. 8b).

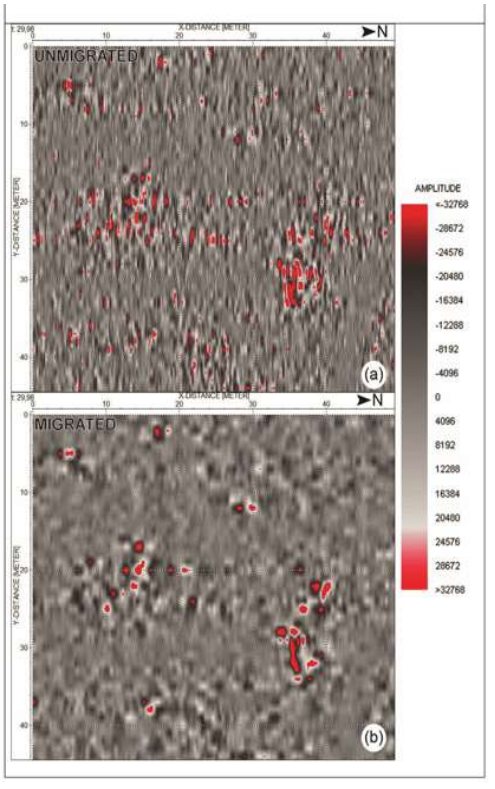

Figure 7: Comparison of unmigrated and migrated time slice at ~1.5 m depth. (a) Unmigrated. (b) Migrated.

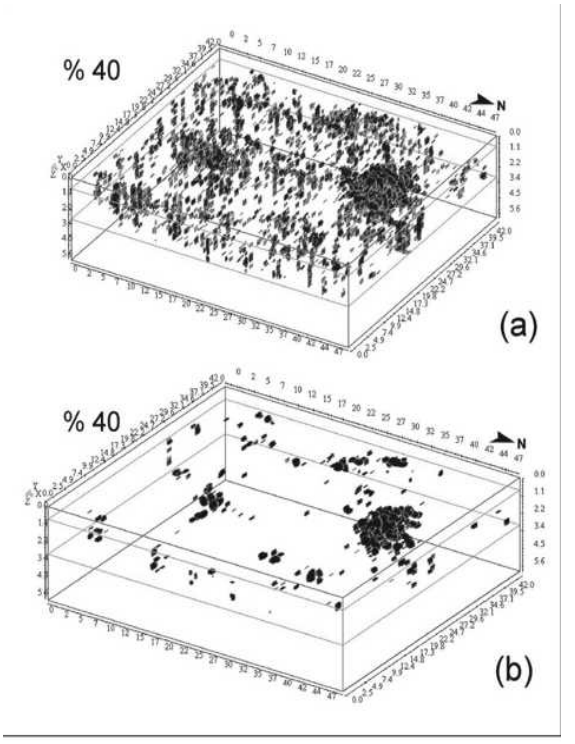

Figure 8: Comparison of unmigrated and migrated iso-amplitude surfaces by using % 40 threshold (red arrows are pointing the buried tombs). (a) Unmigrated. (b) Migrated

CONCLUSIONS

Nowadays Ground-penetrating radar is the most powerful non-destructive geophysical prospecting method used in shallow geophysics. High resolution, acquisition speed and 3D data record capability are the significant advantages of the GPR method. 3D interpretation of GPR data and results display methods such as time slices are recently popular in archaeological and historical investigations (e.g. Leckebusch, 2003; Leucci and Negri, 2006; Leckebusch et al., 2008; Yalciner et al., 2009). However, sufficient GPR results require careful data processing, as well as, a good knowledge of both EM signal processing and geology. Classical GPR processing methods give good results in homogenous field but heterogeneity in the field causes noises in GPR profiles and it is necessary to clean environmental noises to obtain clear

view. Migration has been successfully using in seismic studies to decrease environmental noises (Berkhout and Verschuur, 1997; Yilmaz, 2001). Migration has also been applied to GPR data in laboratory studies (Christian and Klaus-Peter, 1994; Leuschen and Plumb, 2000; Song et al., 2006; Oden et al., 2007). In this study, migration technique which was used in laboratory studies was applied to GPR data collected in the field data. Application of migration to field data showed that if migration is used with suitable parameters (such as EM velocity, bandwidth, start time and end time), it considerably decreases noises in GPR studies and anomalies become much clear and they look in real shape.

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