Mapping the buried ancient wall using Ground Penetrating Radar (GPR)

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Abstract: With the development of technology and the need for the protection of subsurface culture heritage, it is important to identify the size, shape, depth, and location of subsurface targets and related stratigraphy. Fortunately, Ground Penetrating Radar (GPR) has been a steady increase in the use of GPR solving subsurface problems in the field of archaeology without destructively intervening with the buried materials, and it has become one of the most high resolution geophysical mapping methods. The wall is the main symbol of traditional society and the ancient civilization of city in China. And there are numerous buried ancient walls, which should be found, mapped and protected. GPR is an efficient method mapping the buried ancient wall. We applied GPR to describe the buried ancient walls of Nan-zhao ancient city-site in Yunnan Province and Bei-ting ancient city-site in Xinjiang, China, respectively in the field archaeological survey before. In this paper, we selected two study regions to show the application results. And the area selected in the survey of Nan-zhao ancient city-site was 15m×11.5m, whereas the area selected in the survey of Bei-ting ancient city-site was 9m×15m. Although both the areas were small, the high density of data sampling ensure the accuracy of results. In particular, GPR attribute analysis was applied in the data interpretation, which could describe the buried ancient wall more clearly and intuitively.

Key words: Ground Penetrating Radar (GPR), archaeology, the buried ancient wall, attribute analysis

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1. INTRODUCTION

It is important to identify the size, shape, depth, and location of subsurface targets and related stratigraphy without destructively intervening with the buried materials, with the development of technology and the need for the protection of subsurface culture heritage. Magnetic survey and Ground Penetrating Radar (GPR) are the two most widespread methods, mapping the spatial extent of archaeological features or changes in archaeology. Magnetic method offers the most rapid ground coverage of the various techniques and responds to a wide variety of anomalies caused by subsurface culture heritage, but the applications are also restricted by numerous factors. In contrast, the resolution of GPR is more excellent and the information about buried depth of targets can be obtained through GPR investigation.

The most straightforward way to solve subsurface problems in the field of archaeology is by identifying and correlating important reflections within 2D profile, at depths from a few tens of

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centimeters to five meters (Davis and Annan, 1989). Moreover, a series of 2D profiles can make up of a 3D volume, and the data can be analyzed and visualized in time slice, in which radar reflections are mapped horizontally for archaeological applications (Goodman, et al., 1995). But it is also important to use numerous new visualization techniques in order to improve the quality and efficiency of the archaeological interpretation and describe the details of archaeological interests. GPR attribute technology has gotten great advance since Young et al. (1997) applied seismic attribute to 3D GPR data firstly, and it is shown that the use of GPR attribute could greatly improve the effects of interpretation as attribute analysis could remove or minimize noise and reveal features or patterns not visible on the original data (McClymont, et al., 2008; Forte, et al. 2012).

The wall is the main symbol of traditional society and the ancient civilization of city in China. And there are numerous buried ancient walls, which should be found, mapped and protected. In this study, we applied GPR technology respectively to describe the buried ancient walls of Nan-zhao ancient city-site in Yunnan Province and Bei-ting ancient city-site in Xinjiang, China, based on 2D profiles and pseudo 3D methodologies which are characterized by a cross-line/in-line spacing. The primary object is to map the size, location and the depth of the walls. In addition, GPR attribute analysis is applied in the data interpretation, which could improve the quality and efficiency of the archaeological interpretation.

2. FIELD SITES

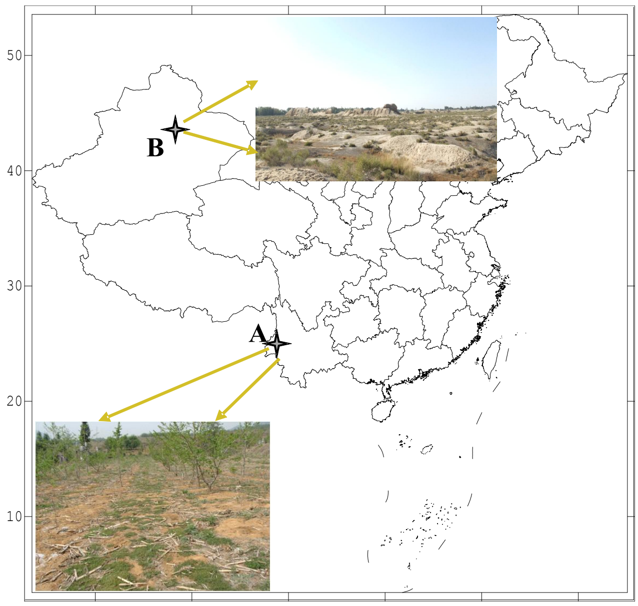

Fig. 1 Location map of Nan-zhao ancient city-site in Yunnan Province (A) and Bei-ting ancient city-site in Xinjiang (B)

Nanzhao ancient city-site is located in Tengchong, in the southwest of Yunnan Province, China (Fig. 1). Tengchong is a multi-dormant volcano region, and the black lave formed by volcanic eruptions in ancient times can be seen everywhere in the region, which causes a strong magnetic field background. Moreover, Nanzhao ancient city-site is at the edge of gentle slope endings formed by the lava eruption. Historically, the ancient city lasted from the Nanzhao-Dali period to the Yuan Dynasty. What’s more, the wall of the ancient city was rammed up by yellow and red miscellaneous soils.

Because of the great age, many walls were severely damaged and some of them have been already buried in the subsurface. In order to check the range of the culture heritage, the form system and the present situation of the remains, geophysical prospection is needed. In addition, the results are beneficial to formulate a plan for future urban construction. Drilling has been carried out for a general survey in this area, so that the information about the location and the orientation of the ancient wall had been known generally, but GPR survey could provide local details about the buried ancient wall for us without destructively intervening with the buried materials.

Bei-ting ancient city is located in the north of Jimusaer, Xinjiang Uygur Autonomous Region, established as the administrative center of northwestern empire in the Tang Dynasty. But it was destroyed during the Ming Dynasty. Consequently, it is commonly known as “Broken City” or “City of Tang Dynasty” for local residents at present. The shape of the ancient city approximates a rectangle. What’s more, there are two walls, located at outside and inside the city, both of which are built with local soils. Furthermore, the residual ancient wall aboveground is about five meters wide, and the rammed layer is very clear. In this study, the investigation area is located on the outer wall remains, where the ground is flat and there is no residual wall on the surface. The purpose is to determine whether there is residual wall buried in the subsurface. At first five groups of magnetic susceptibility measurements for ancient wall remains and natural soil on the surface were held with portable digital magnetic susceptibility meter (Table 1). The results show that there is little difference of magnetic susceptibility between the wall remains and the natural soil.

Table 1. Magnetic susceptibility $\kappa/10^{-5}$ (SI) surveyed in Bei-ting ancient city-site

Survey soil	Test I	Test II	Test III	Test IV	Test V
Ancient wall remains on the surface	111	107	133	120	118
Natural soil on the surface	116	125	126	134	106

3. DATA ACQUISITION AND PROCESSING

PulseEKKO PRO System (Sensors and Software Inc.) equipped with bow-tie shielded 250MHz antennas were applied to data acquisition in the two field sites. Rectangular grids were established with a line spacing of 1m in the both sites. The area selected in the Nan-zhao ancient city-site survey was 15m×11.5m, whereas the area selected in the Bei-ting ancient city-site survey was 9m×15m. Each trace was 128 times vertically stacked in the field in order to reduce some incoherent noises; the sampling rate was set to 0.4ns, considerably smaller than the Nyquist limit in order to avoid any aliasing of the data. More acquisition parameters of these two ancient sites are shown in Table 2.

Table 2. Acquisition Parameters

	Nan-zhao ancient city-site	Bei-ting ancient city-site
GPR system sensors	250MHz	250MHz
Length of the acquisition line	11.5m	15m
Number of the acquisition line	16	10
Number of traces	116	61
Line interval	1m	1m
Trace interval	0.1m	0.25m
Number of Stacks	128	128
Sampling interval	0.4ns	0.4ns

The flow of data processing was sequenced as follows:

Data Editing

Geometry Header Definition

Time-zero-drift correction

DC Component Removal

Amplitude Analysis

Band-pass Filter

Spatial Filter

True Amplitude Recovery

Velocity Analysis

Combination 2D profiles to 3D volume

As the the overall terrain is relatively flat, topographic correction wasn't applied in the flow. Velocities were obtained according to the results of the velocity analysis based on diffraction hyperbolas, resulting in constant velocities of 0.07 m/ns and 0.1 m/ns for survey Nan-zhao ancient city-site and Bei-ting ancient city-site, respectively. Moreover, we applied attribute analysis to describe the target based on processed 2D profile and 3D volume.

4. RESULTS

4.1 Survey site I: Nan-zhao ancient city-site

Magnetic investigation is not an available method in this area as there is strong magnetic field background caused by amounts of igneous. Fig. 2a is one processed GPR profile, which could reveal the primary estimation to the characteristic of buried wall. In this figure, it is exposed that archaeological interests are at the depth range from 15ns to 60ns. The continuous reflections between 2.3m and 6m, depth from 18ns to 38ns are obvious, which can be identified as the buried ancient wall. It can be deduced that the interface depth of the top of the buried wall is at 0.63m according to the velocity 0.07m/ns obtained from the velocity analysis. Moreover, we calculated energy attribute based on the processed profile to help us visually enhance features or the interpretation target (Fig. 2b). The Energy is a measure of reflectivity in the specified time window. It is a simple and robust attribute to describe the reflection intensity with a relative low level of subjectivity. The reflection caused by ancient wall is marked by the white rectangle in Fig. 2b.

In order to map the scope and the overall distribution of the buried wall, 3D display of radar data is essential. Fig. 3a shows time-slice at 29ns, but it is difficult to describe the buried wall due to the serious noise. On the contrary, Fig. 3b, the dominant frequency and Fig. 3c, the instantaneous amplitude calculated based on the time-slice at 29ns respectively can map the scope and the distribution of the buried wall distinctly (the brown lines shows the boundary of the wall in the figures). Dominant frequency attribute, returning the dominant frequency from the frequency spectrum, will change gradually as the sequence of layers gradually changes in thickness or soil composition. Whereas the instantaneous amplitude computed sample by sample turns out to be the amplitude envelope of the GPR trace. It is obvious that both dominant frequency and instantaneous are good indicators of the buried wall.

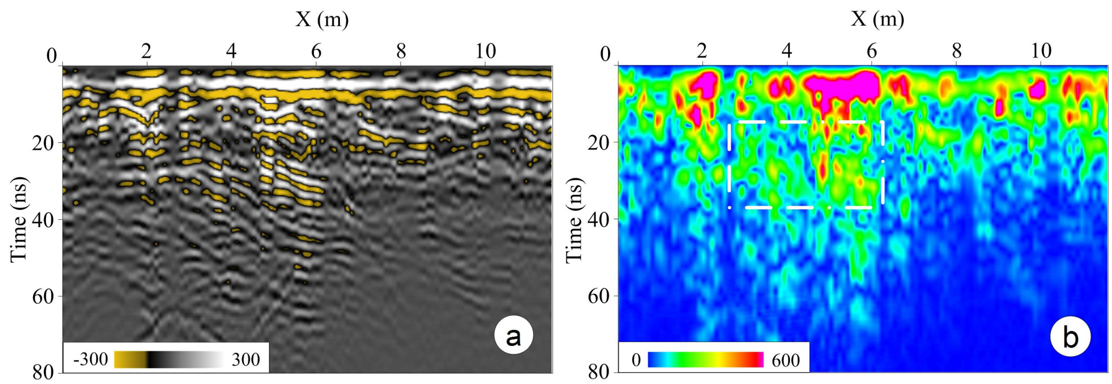

Fig. 2 (a) 2D processed GPR profile; (b) Energy attribute calculated on the processed GPR profile.

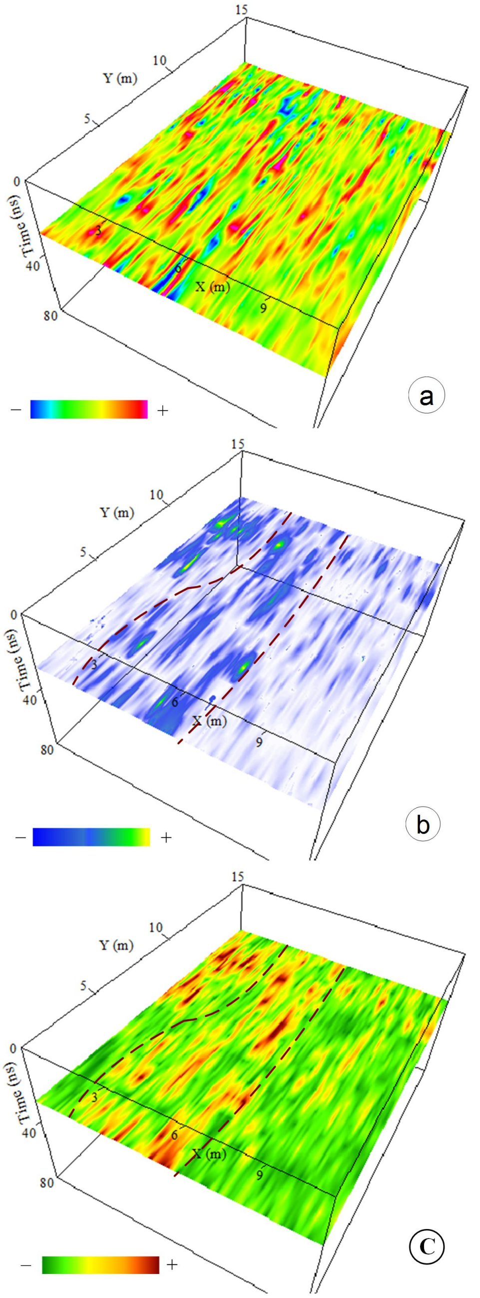

Fig. 3 Comparison among the time slice at 29ns (a), the dominant frequency at 29ns (b), and the instantaneous amplitude at 29ns (c).

4.2 Survey site II: Bei-ting ancient city-site

The difference of magnetic susceptibility between the wall remains and the natural soil is very weak according to the measurements. Accordingly in the study area we selected GPR to have a test to determine whether there is residual wall buried in the subsurface. Fig. 4 is one processed GPR profile. The strong amplitude change between 9.2m and 13m, depth from 5ns to 2ns are obvious, which can be identified as the buried ancient wall. The maximum bottom interface of ancient wall is at about 1m considering velocity is about 0.1m/ns in this area. Different depths (6ns, 16ns, 26ns, 40ns) based on energy attribute are mapped in Fig. 5 to characterize the archaeological interest, as the energy is a simple and robust attribute to describe the reflection intensity previously mentioned. It is obvious for the strong energy value at the shallower depth between the white lines as the figure shows, which could map the distribution of ancient wall.

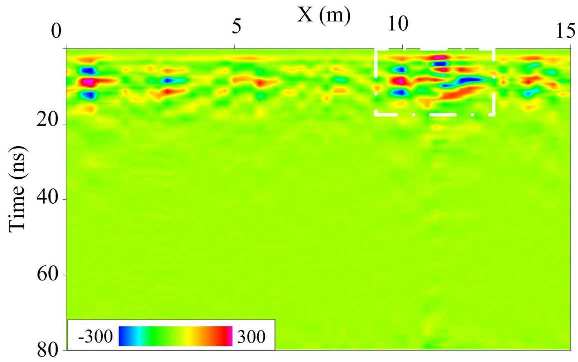

Fig. 4 2D processed GPR profile

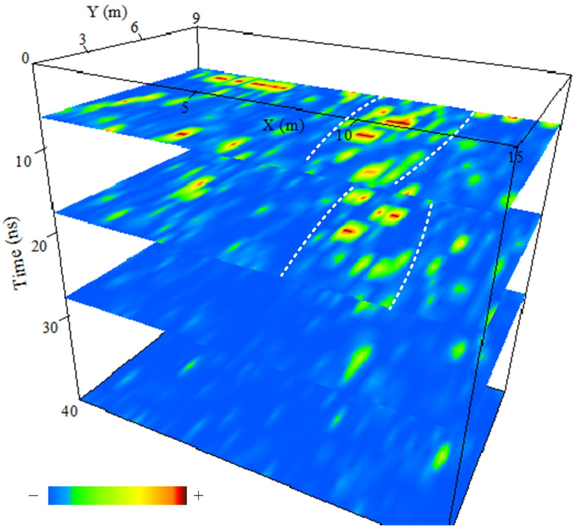

Fig. 5 The result of energy attribute calculated for several time-slices at 6ns, 16ns, 26ns, and 40ns.

5. CONCLUSIONS

Since the application of the magnetic method was limited for either strong magnetic field background or weak difference between the target and the buried environment, we applied GPR to describe the buried ancient walls of Nan-zhao ancient city-site in Yunnan Province and Bei-ting ancient city-site in Xinjiang Uygur Autonomous Region, respectively in this paper. It is noticeable that it is a good choice to map the ancient wall using GPR. The size, location and the depth of the ancient walls are characterized by 2D GPR profiles and 3D slices.

2D GPR profile could supply intuitive and effect subsurface information, but GPR attributes could improve the quality and efficiency of the archaeological interpretation. Besides, although radar attribute technology weakens the subjective estimation of the interpreter to a certain extent, fully with integrated quantitative description results of 2D and 3D attribute analysis, the final interpretation results will be more accurate. Particularly, 3D attribute maps are much better compared with the typical time slice as attribute analysis could remove or minimize noise and reveal features or patterns not visible on the original data.

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