GPR AS AN IMAGING TECHNIQUE FOR SUBTERRANEAN FEATURES

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ABSTRACT

Non-destructive methods for investigating subsurface archaeological remains include electro-resistivity, geomagnetic, and ground penetrating radar (GPR) prospection. Among these, GPR is often selected for its speed of measurement and the richness of its data.

In addition to observing as pseudosections the vertical profiles obtained by GPR, compilation of horizontal sections from these profiles by the method known as Time Slice has come into use. In this technique, data from a series of adjacent profiles are selected for a particular time value, corresponding to a uniform subsurface depth, and transposed onto a horizontal plan. In other words, the patterns of reflection, refraction, and attenuation of the micro-wave signals are represented in terms of their horizontal distribution.

For archaeological purposes, it is desirable to know the horizontal outlines and dimensions of features and artifacts, in order to make inferences from these of the nature of the subterranean remains.

1. GROUND PENETRATING RADAR (GPR)

Archaeological prospecting is a non-destructive method which can detect subsurface historical remains without applying destructive excavation procedures. Among those geophysical prospecting methods, GPR has an advantage over other methods because it can collect dense profiling information about a site whereas other methods are generally limited to point data collection at specified locations within a survey grid. The GPR method was first employed for archaeological applications in 1982 in Japan, during a field survey conducted by The Board of Education of Gunma Pref. under a contract survey from The Agency of Cultural Affairs. Since then, GPR has been utilized at various archaeological sites, but did not become overly familiar to archeologist because it was not easily understood.

2. GPR PROFILE MEASUREMENT

In GPR surveying, an antenna which transmits and receives microwave signals, is pulled over a survey grid which is marked off with a measuring tape. Microwave penetrating into ground returns to the antenna after being reflected by soil interfaces or from remains like stone or metal which are buried in different surrounding (electromagnetic) soil material. If the soils are electromagnetically homogeneous, microwaves are not reflected at soil interface. The radar profiling interval is usually decided according to the target size of the subsurface structures desired to image. The antenna frequency used in the survey is also chosen based on the target size and its estimated depth. A high frequency (500 or 700 MHz) antenna can identify the small size targets, but its penetration depth is limited to shallow exploration. On the other hand, low frequency (300 or 400 MHz) antennae can collect reflections from depth also depends on the electrical nature of the soil. In wet condition soils prevent deep penetration using microwaves, whereas in dry soils the attenuation is lower thereby allowing for deeper interrogation(Fig.1).

Fig. 1

A radargram profile (Fig.2) from Nyutabaru, Miyazaki Pref., shows a clear image of four soil layers and several anomalies associated with microwave reflections from a tunnel burial tomb and moats surrounding it. Even though these data are obvious to the trained geophysicist, it has been difficult for the field archaeologist not trained in GPR to understand the information contained in the raw radargrams. After the introduction of a method of "Time Slice", many archaeologist came to have a better opinion about GPR.

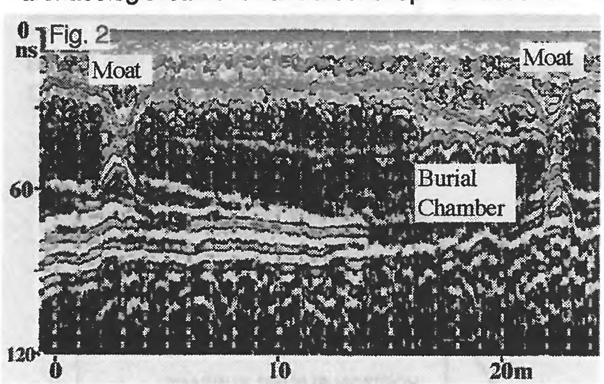


Fig. 2

3. GPR TIME SLICE METHOD

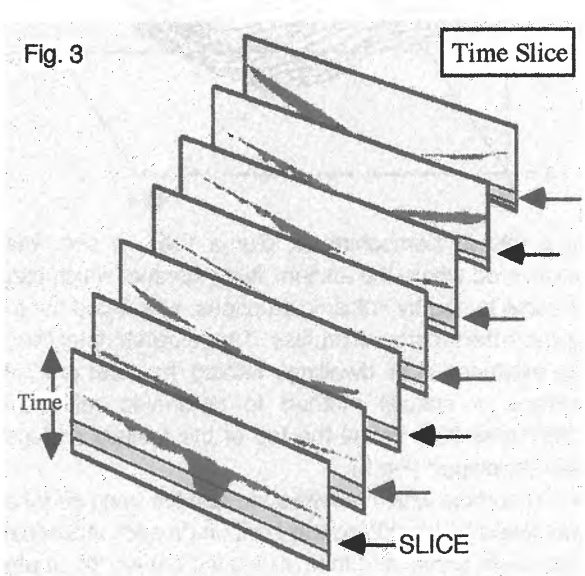


Fig. 3

It is desirable to have an image showing the location, shape and size of subsurface features associated with archaeological remains that is derived from the radar survey. For this purpose, GPR Time Slice method has been introduced into the archaeological survey. In the time slice method for GPR, all profiles are first transferred to a computer as digitalized values.

The data contain digitized information of the reflected signals down to a specified time window which can be converted to depth if the average microwave velocity is known for the soils at the site. The time slice image compares radar amplitudes from the 3-D GPR dataset at a specified depth interval. The time slices can be said to be a distribution map of averaged microwave reflection, refraction and attenuation and computed at a user specified depth in the dataset (Fig. 3).

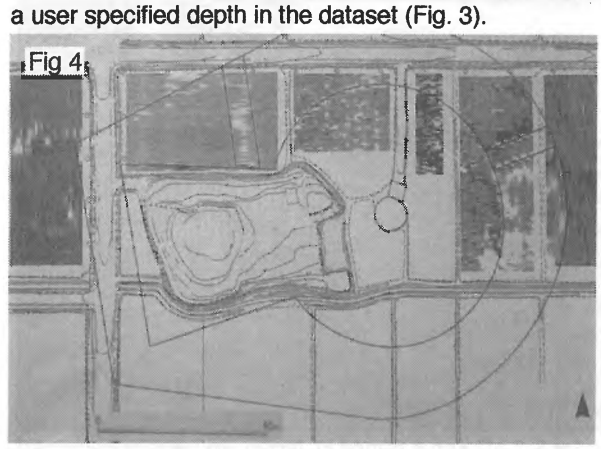


Fig 4

One example of time slices from Nagatsuka Kofun located in Ogaki-shi, Gifu Pref. revealed the existence and general shape of a moat, as well as a feature associated with an earthen bridge crossing the moat. From the time slice image the subsurface location of the round part of the keyhole shaped mounded tomb moat (Fig. 4) could also be completely imaged (Nishimura et al., 1993). Since the time slice method can provide the "plan" image of archaeological features, it has become a common method in the world as a powerful tool in understanding archaeological features.

4. HORIZONTALLY CORRECTED TIME SLICE

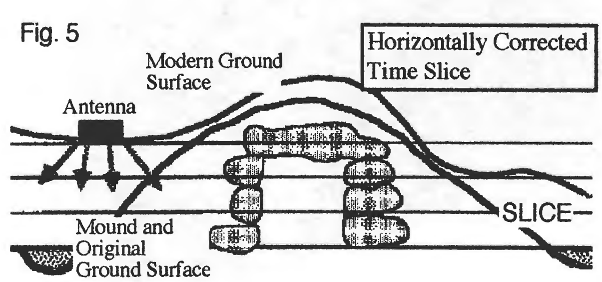
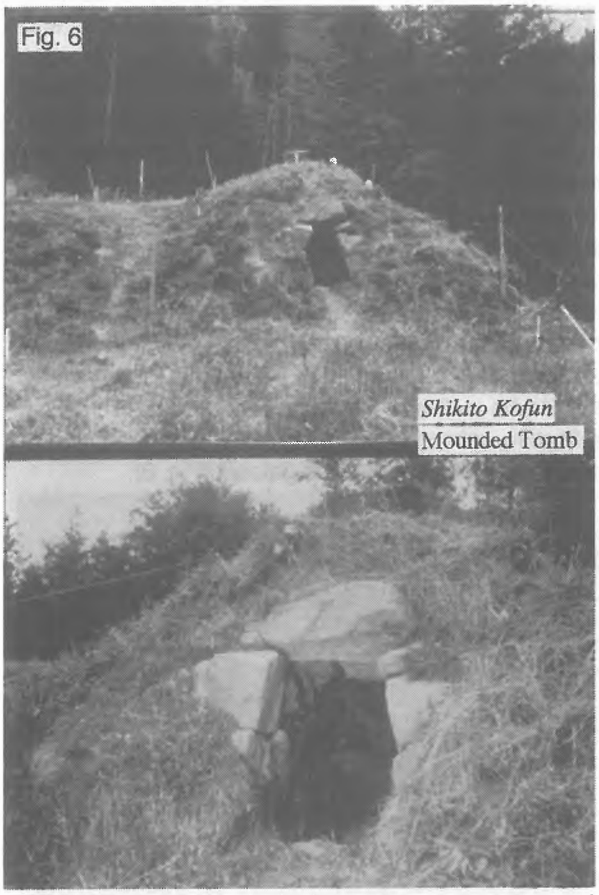


Fig. 5

In many cases, archaeological remains do not exist under a flat modern ground surface like a rice field. For example, a stone chamber in a small mounded tomb, the Shikito Kofun in Hyogo Pref. belongs to the

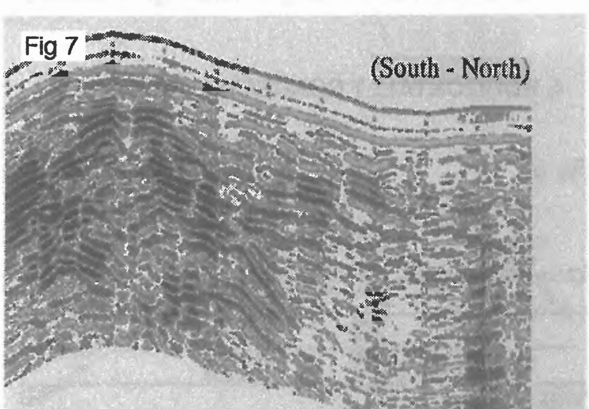
Fig. 6



later 5-7 AD Kofun period in Japan, and was constructed originally on level ground (Fig. 5, 6). The surviving mound surface today that covers the chamber is not flat but often higher in center and has lower topography in outer part surrounding it.

By the normal time slice method, the data from a constant depth parallel with the modern ground surface is normally imaged. This way of imaging subsurface structures which are built level to the ground may create a distorted image when viewed in simple time slice analysis.

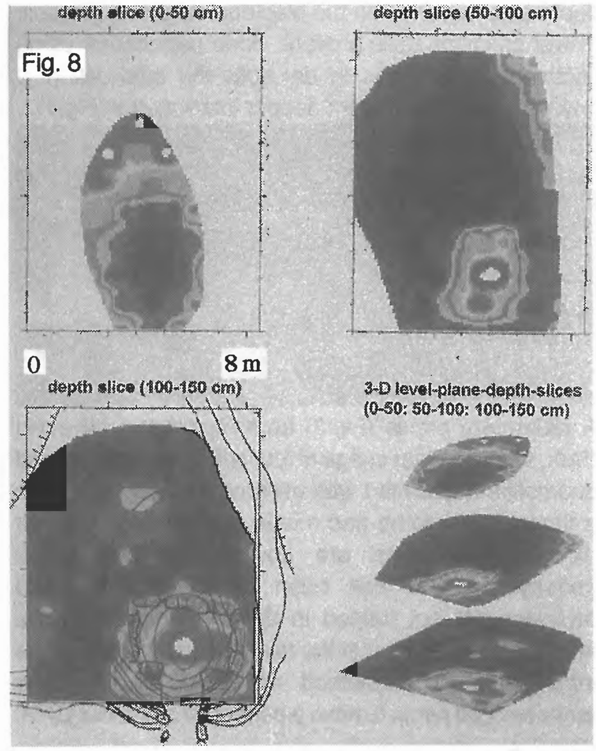
Fig 7



Radar Profile Across the Top of the Stone Chamber.

In order to obtain a time slice parallel to a level plane, the data are first corrected for topography (Fig 7) and then horizontal slices were made. The time slices by this method shows stones which situated between the

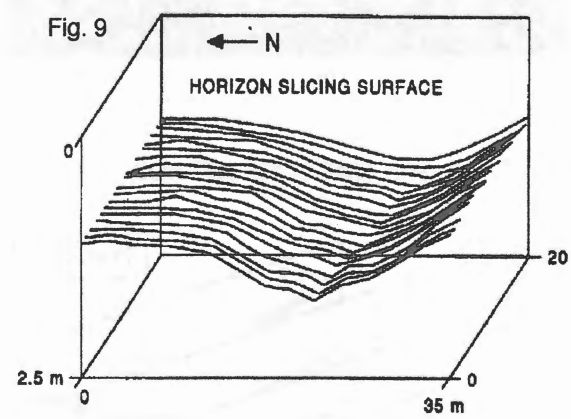
Fig. 8



chamber and corridor is clearly visible, as well as the general thickness of the chamber walls (Goodman, D et al. 1992) (Fig.8).

5. HORIZON SLICE

Fig. 9



At a site in Komochimura, Guma Pref., a site was discovered where the ancient living surface, which had become buried by volcanic eruptions, was found not to be flat in the radargram profiles. To accurately determine the existance of pit dwellings withing the older ground surface, a special method to determine reflection amplitudes from below the top of the ancient surface was developed (Fig.9).

A 3-D surface which followed the ancient living surface was found by identifying this horizon on each individual radargram profile and then slicing the dataset to create a horizon slice. A possible pithouse existing on one

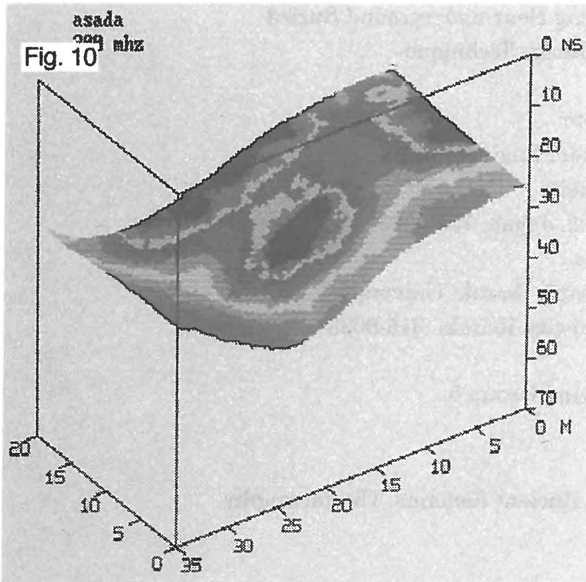


Fig. 10

side of a subsurface depression is clearly identified in this method (Conyers, et al. 1997) (Fig. 10).

6. AMPLITUDE RENDERING METHOD

In order to give an 3-D image of buried features, the amplitude rendering method has recently been introduced into the GPR method.

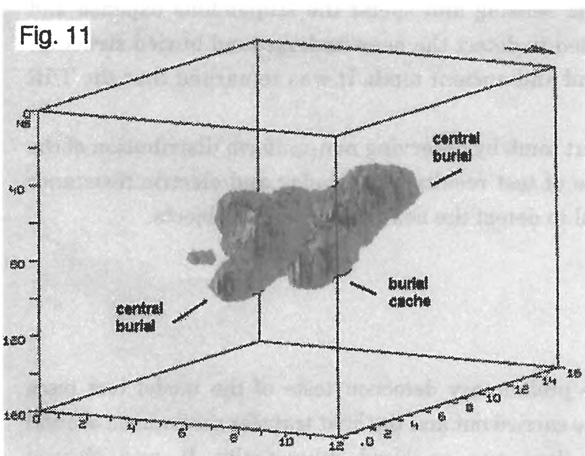


Fig. 11

In this method, artificial light using a computer is transmitted into the data volume and a specified amplitude surface is illuminated. An appropriate threshold determined from the time slice dataset can be used to render the subsurface target. An examined example of Saitobaru Burial Mound No.13 was once excavated in 1915. The burial consisted of a wooden coffin with an adjacent burial cache and was overlayed by large stones. This was revealed by the early excavation and afterwhich the coffin area was re-buried. Prior to newer excavations, a GPR survey was conducted and rendering method was applied. A tilted central burial and cache are clearly imaged on the 3-D reflection amplitude render (Goodman et al,1998) (Fig. 11).

7. CONCLUSION

Archaeological remains usually do not consist of simple homogenous materials nor of simple geometric structures. For this reason every research technique, including excavation has to be carried out with very much attention and preparation. Specially in excavation, identical excavation procedures do not always fit at a similar site because of the essentially unique ground situations. To help prepare the archaeologist in understanding the subsurface remains before excavating, geophysical methods can help to elliminate some uncertainties about these structures.

The GPR method has evolved from simple observations of raw radargrams to 3-D rendering analysis in less than ten years. Further improvement will be expected not only by archaeologist but also by the geophysical surveyor engaging in civil engineering. One of the possibility will be a multi antenna survey in GPR.

References from Journals:

Conyers, L. and Goodman, D., 1997. GPR: An Introduction for Archaeologists, Alta Mira Press, Walnut Creek, California, ISBN 0-7619-8927-7

Nishimura, Y., et al. 1993. Archaeological Prospecting. The Excavation Report of Nagatsuka Burial Mound Kofun, The Board of Education of Ogaki city, pp20-54

References from Books:

Goodman, D., and Nishimura, Y., 1992. Radar archaeometry and the use of synthetic radargrams to investigate burial grounds in Japan, Abstract, Archaeometry '92, p.167.

Goodman, D., Nishimura, Y., Hongo, H., Okita, M., and Edwards, W., 1998. 3-D GPR amplitude rendering of Japanese tunnel burials, Antiquity, in print.