Econ. Environ. Geol.
Vol. 29, No. 6, p. 745-752, 1996.

Application of Ground Penetrating Radar for Archaeological Monuments

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ABSTRACT : A ground penetrating radar survey with a 500 MHz radar antenna was applied to make archaeological investigation in Nakajima of Ishikawa Prefecture, Japan. The ability of the radar system to aid in the archaeological preservation of burial ground was the primary concern of the experiments. The average variance of the radar wave returned from progressively deeper reflectors in a tomb were contoured at 2.4 nanoseconds intervals. The results of analysis indicates the location of trenches and the coffin area at the tomb site. The orientation of the coffin is clearly defined on contour maps made below 9.6 nanoseconds horizon. The general features detected by the GPR were also reconfirmed by electric resistivity survey made at the site. The radar was accurate in ascertaining the location, orientation, and the general construction style of the coffin.

INTRODUCTION

Geophysical method is rapidly becoming a common practice by the geologist and archaeologist in the field. Geophysical method can speed up the process of archaeological excavation by directing attention to the most important features at a site. In the case where archaeologically important areas are protected by law, geophysical method is the only means to ascertain the nature of the buried resource. Geophysical method is an invaluable tool in the preservation of these protected areas.

Because of new application of geophysics to solving archaeological problems, standards in the general practice or application of geophysical equipment are still in the developing stage. A working knowledge of the capabilities as well as the limitations of geophysics in ascertaining features about buried archaeological resources, is an important objective of present day archaeometry.

In Nakajima of Ishikawa Prefecture, Japan, a study to examine the application of a geophysical probing device known as ground penetration radar (GPR) was conducted. The main goal of the research was to examine the ability of GPR to image subsurface structures in archaeologically important areas. These burial grounds date back to the period between 300-700 AD. The GPR system was used in a "real time" mode for making estimations of archaeological trends while out in the field. The GPR system was also used in the preservation of a burial ground. In this application, the radar data was collected at the burial ground to learn as much as possible regarding the nature of the buried resource. The nature of the buried resource would include such information as the actual location, orientation with respect to north, the depth, and if possible, to learn as much about the construction of the tomb.

To accomplish this goal, radar data taken along parallel profiles, is combined into a 2-dimensional representation of reflecting horizons measured at the tomb. Contour maps of the radar wave variance are made at progressively deeper depths in the tomb. This data is examined for its potential to image some of the important reconnaissance feature of the top several centimeters of penetration, are examined for their ability to estimate the location of boundaries and trenches at the tomb site. The radar wave variance maps from progressively deeper reflecting horizons can be used to approximate horizontal cross sections across the tomb. The detailed structural features of the tomb are examined from single radar profiles. The resistivity data are used for reconnaissance surveying of the burial mounds. The data are compared with the reconnaissance information obtained from radar.

GROUND PENETRATING RADAR METHOD

Application of Geophysical Methods for Archaeological Monuments

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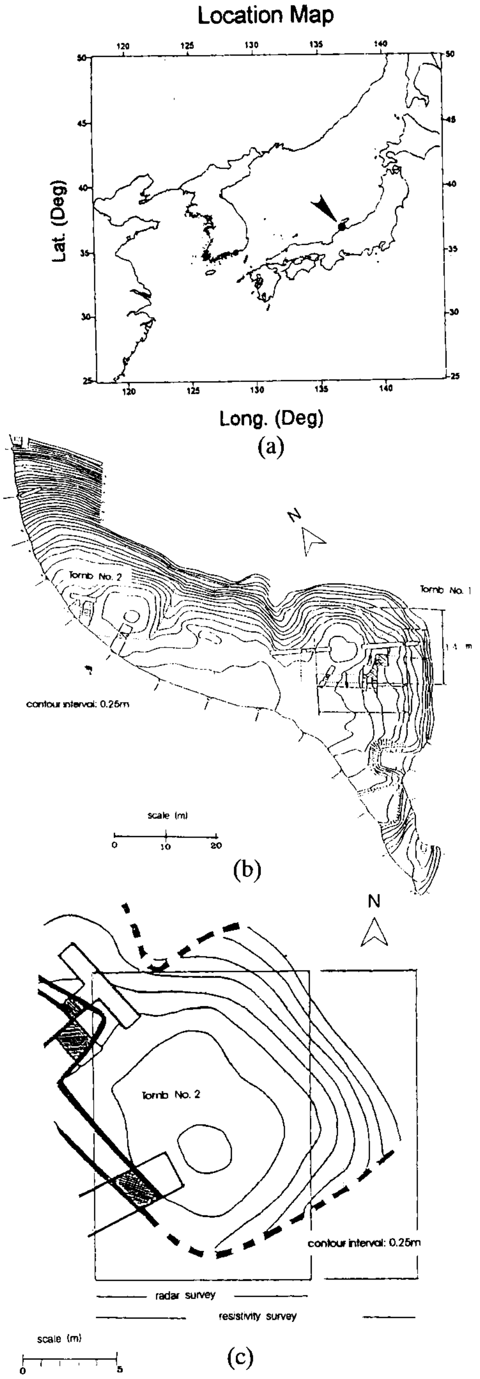

Fig. 1. Location map of studied site. (a) Location in Japan (b) Topographic contour map of the Kanmachi Tomb Area. Two tombs have been identified at this site. (c) Detailed topographic contour map of Tomb No. 2. Three exploration trenches had been dug 10 years prior to this study. The suspected outline of the tomb from topographic estimation is shown with a dashed line.

Radar survey along with electric resistivity measurement was made at the burial ground in Nakajima of Ishikawa Prefecture, Japan (Fig. 1). The sites were suspected as being tombs based on topographic relief found at the area. The tombs are measured about 25 meters in length. The tombs are believed to originally be keyhole shaped tombs. Over the years the topography at the site has been eroded. The sharp square edges corresponding to the keyhole shaped tombs are no longer appeared. There remains some speculation that perhaps these tombs may be of the circular keyhole shaped burial grounds type. During their initial discovery these tombs had exploration trenches dug. Shown in Fig. 1c is an enlarged topographic map of tomb No. 2. The hatched area shows the locations of the exploration trench. The original tomb trench was discovered within the exploration trench in several locations. The eastern boundary of the tomb is a steep hill. It was not believed that a trench was dug on this side of the tomb. The extent of the tomb on this eastern boundary is not accurately known, but is believed to follow topographic contour.

The geophysical methods has been applied at the burial ground in Nakajima of Ishikawa Prefecture, Japan. The purpose of geophysical probing was to accomplish several goals. Frist, to determine through geophysics if indeed a tomb was present. Secondly, if geophysical probing indicated the tomb did exist, to ascertain the nature of the tomb. This would include determining the followings:

1) the location of coffin within the tomb
2) the orientation of the coffin with respect to north
3) the depth to the coffin
4) the structure and style with which the coffin area and tomb were built.

To accomplish these goals, several geophysical techniques, ground penetrating radar and resistivity surveys have been employed (Fisher *et al.*, 1982; Goodman, 1994; Ulriksen, 1982; Vaughan, 1986).

The radar survey was designed to obtain as much reconnaissance and structural information about the tomb as possible. A special section -radar variance contour map -on 3-dimensional analysis of the ground penetrating radar data, addresses the reconnaissance information collected at the tomb. This section examines the location, orientation and depth of important archaeological features at the tomb. Radar profiling was designed to sample the construction style of the tomb and associated coffin. The resistivity measurement was to be used as a backup to radar reconnaissance mapping. These analyses provide further corroboration of the results found from the radar survey.

Radar Survey

Field procedures

The tomb was surveyed with a 500 MHz radar antenna. Parallel east-west profiles were collected at 0.5 meter intervals. The data density along the profile was collected at a sampling rate 25.6 samples/sec. Since the antenna velocity over the ground varies because it was pushed by hand, the amount of data collected between profiles is not constant. The average rate at which data were collected along the profile was approximately 1 sample/cm. The radar profiles were reference to actual ground location from markers that were recorded (within the data) at 1 meter intervals. The depth of penetration included all reflectors with in a 24 nanosecond time windows. A deeper penetration was tried at the tomb, but below 24 nanosecond the data became very noisy. The total area surveyed at tomb No. 2 was 11 m × 16 m.

The two-way travel time to a known reflector buried to a depth of 0.3 m was measured. A velocity of 6 cm/ns was measured at a site just outside of the tomb trench. An error of approximately ±1 cm/ns is assigned to this method of velocity estimation. The average velocity information was used to transpose travel time in nanoseconds into depth representation. Some obvious errors exist in transforming all the radar records into depth with this average velocity value. Local velocities can change significantly across the study area. For this reason the depth representation may contain significant errors.

Radar profiling

The structure of the coffin was investigated from radar profiling. A 500 MHz radar profile beginning at (0 m east, 4 m north) and ending at (11 m east, 12 m north) was collected. This profile was approximately a perpendicular across the suspected coffin. Fig. 2 shows a portion of this profile which traversed the coffin. The displayed data begins at the 3.5 m mark along the profile. The data were digitally applied gain for the deeper in the record section. A 2-dimensional spatial Fourier filter was also applied to the data. The spatial filter was a high frequency cutoff filter.

The filtered data clearly show a radar anomaly from the 5 to 9 m mark on the profile. The radar anomaly is fairly symmetric. The anomaly begins near the 5 m mark and traces out a trough to about the 6.6 meter, where a much stronger and shallower reflector is observed. Just past this anomaly all the reflected radar energy abruptly drops off. The region between the 6.6 m and 7.3 m mark is relatively void of radar reflectors. The mirror image of these anomalies are again observed at the start of the 7.3 m mark, beginning with the abrupt appearance of a radar reflector. A trough is then observed between this reflector, and ending just past the 9 m mark.

The data indicate that two large trenches flank both sides of the suspect coffin center. The material which fills the trenches is thought to be brought from an outside location. The trench material sometimes contains small stones. The interface between the trench material, and the soil below the trench should lend itself to be a relative strong contrast in electromagnetic impedance, which would yield a relatively strong radar reflection. At the inside wall of the trench and bordering the outside of the coffin is a wall of the trench and bordering the outside of the coffin is a wall composed of stone slabs. The coffin is composed of wood material. In time the coffin would have caved in and/or decayed. Outside material would have filled in from the top, but also material from the side may have moved in to fill the void. The walls flanking the coffin, if composed of small stone slabs would be the strongest reflectors. The wall like reflectors measured by radar at the 6.6 m and 7.3 m mark may indicate

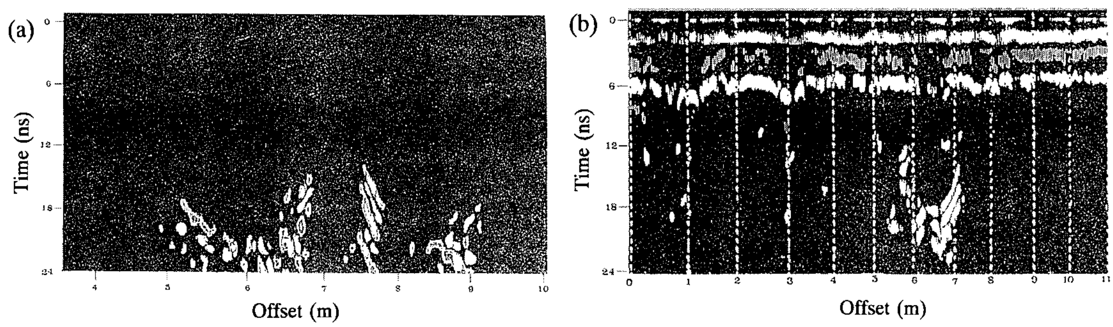

Fig. 2. (a) Radar profile measured across the center of the suspected coffin center, (b) radar profile measured across the small subsidiary radar anomaly occurring to the northeast of the suspected coffin center.

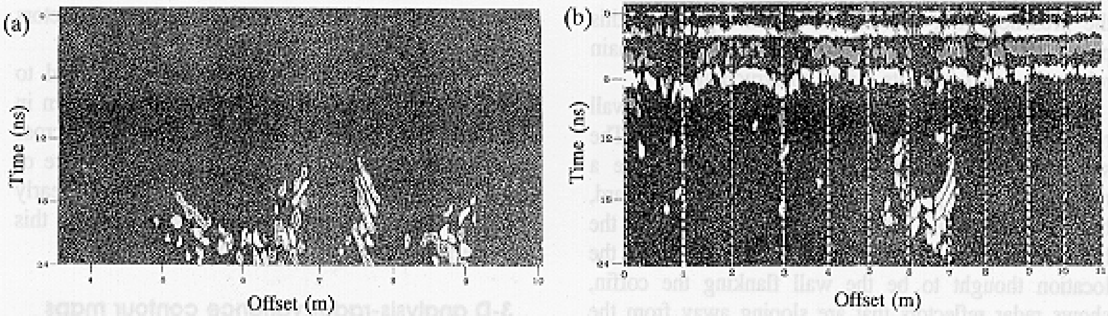

Fig. 2. (a) Radar profile measured across the center of the suspected coffin center, (b) radar profile measured across the small subsidiary radar anomaly occurring to the northeast of the suspected coffin center.

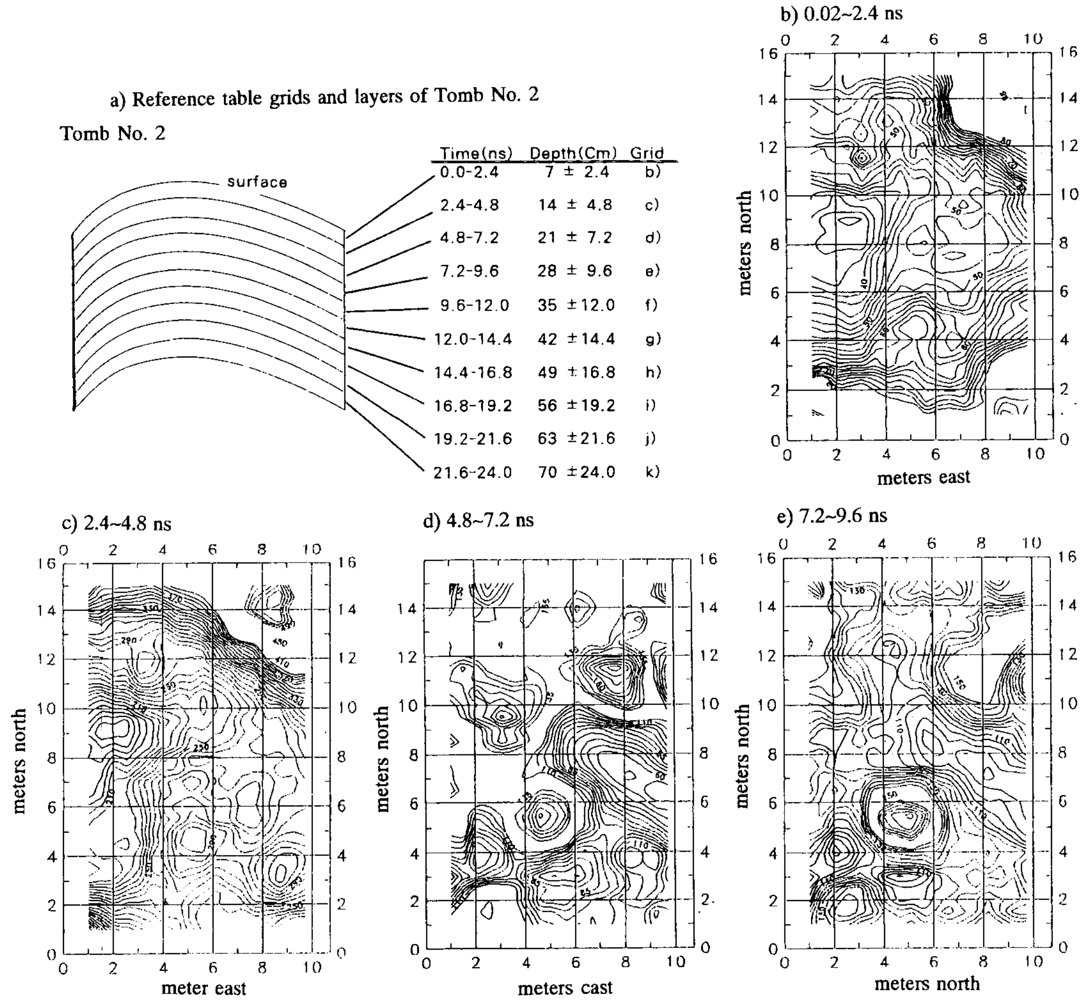

Fig. 3. (a) Reference table of times and depths for radar variance contours made ar Tomb No. 2, (b) radar variance contour map 0.0~2.4 ns, (c) radar variance contour map 2.4~4.8 ns, (d) radar variance contour map 4.8~7.2 ns, (e) radar variance contour map 7.2~9.6 ns, (f) radar variance contour map 9.6~12.0 ns, (g) radar variance contour map 12.0~14.4 ns, (h) radar variance contour map 14.4~16.8 ns, (i) radar variance contour map 16.8~19.2 ns, (j) radar variance contour map 19.2~21.6 ns, (k) radar variance contour map 21.6~24.0 ns.

the presence of a wall in the coffin region. In this particular location the coffin wall may remain relatively intact from its initial construction.

The most plausible explanation of the strong wall reflections is due to the shape of the coffin floor. The suspected walls of the tomb from radar may be a result of a clay or some other relatively hard, basement material. The coffin is laid within the hollowed-out area. Examination of Fig. 2 at the location thought to be the wall flanking the coffin, shows radar reflectors that are sloping away from the center on each side. This observation is consistent with the clay floor design found in Ishikawa. The slope measured from the trend of the radar reflectors at these location is approximately between 5-15°.

A profile across the subsidiary anomaly found to the northeast of the main coffin structure is shown in Fig. 2b. The profile is an east-west traverse across the structure, located at 6.5m north. The structure of the anomaly is shown to be a basin having nearly vertical walls. The width of the structure on this traverse is estimated to be approximately 1 meter.

3-D analysis-radar variance contour maps

Since the raw field data contain various amounts

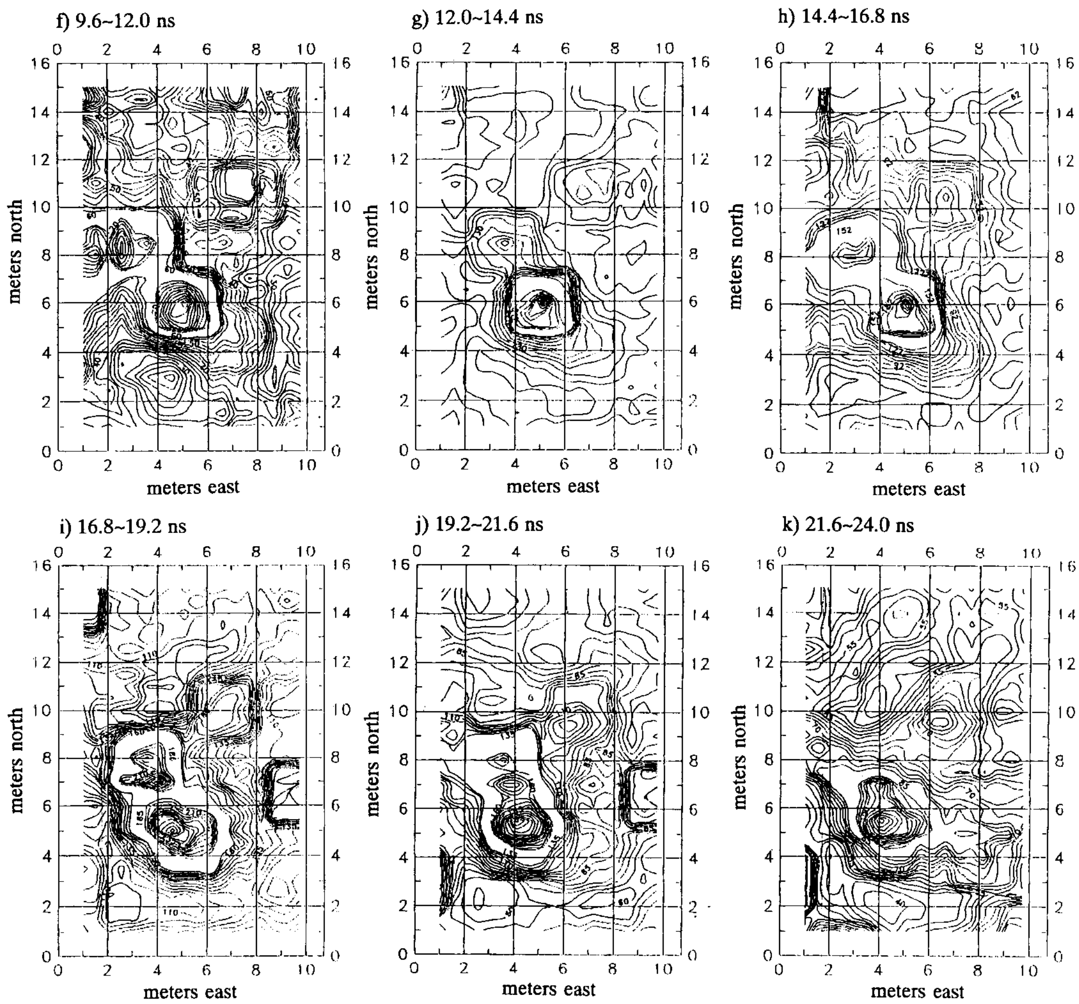

Fig. 3. Continued.

of data due to varying antenna speed, the first important process was to "regrid" the data. Markers recorded within the data were searched and stored. The data between two consecutive markers were then averaged. An average of the radar variance was made every 0.25 meters along the profile. The radar wave variance was averaged in the vertical as well (Shon *et al.*, 1992; Yamamoto *et al.*, 1991). The radar scan was divided into 10 windows. The average radar variance was computed within 2.4 nanoseconds intervals from the surface to the deepest time (depth) penetration. Data between profiles were combined to yield 10 datasets containing the average radar variance at progressively deeper depths. Shown in Fig. 3a is the table of times and estimated depths for each of the datasets. The contour maps for the ten depth horizons, are designated Grids b-k and follow Fig. 3b-k. Some matrix smoothing of the contours were applied.

Grid b represents all the reflected energy measured within the first 2.4 nanoseconds (approximately 7 cm). The radar wave variance is shown to be lower on top of the tomb, and higher outside of the tomb. Comparison with the suspected outline of the tomb from topography, shows reasonably agreement. The trench corresponds to roughly between the 50~90 contour interval. This result is important in that it indicates that the radar is sensitive to slight variations in soil properties and/or conditions which exist within and outside of the tomb boundaries. In Grid c, the shape of northern contours in this region are similar to the topographic contours (Fig. 1c). The southern boundary of the tomb is not apparent at this depth horizon.

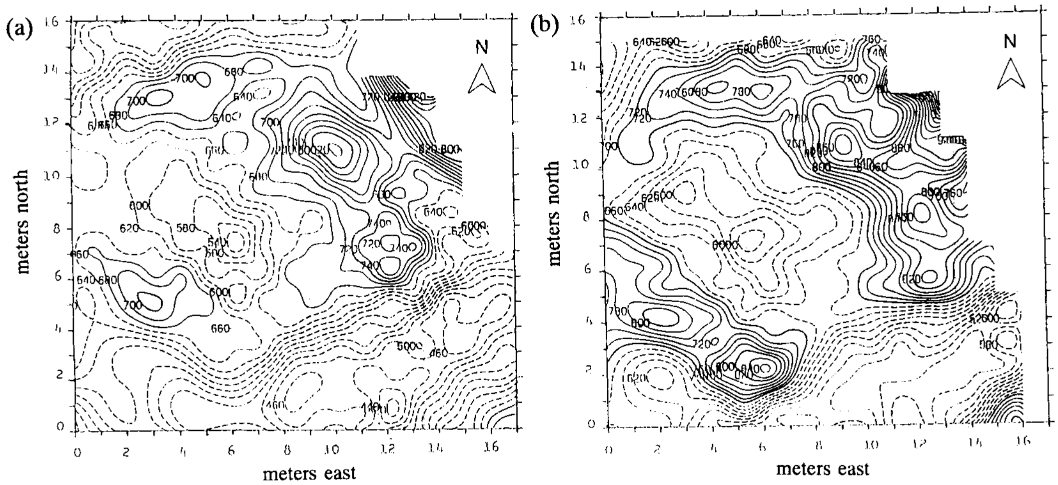

Fig. 4. (a) Schlumberger resistivity survey of Tomb No. 2, (b) Wenner resistivity survey of Tomb No. 2

At the next time (depth) horizon displayed in Grid d many relative radar variance anomalies become visible. This depth interval, approximately 14-21 centimeters, can be considered to be transitional to the deeper anomalies which exist at the site. In Grid e, the appearance of a relatively strong reflector is in the vicinity of (5 m east, 5 m north). This anomaly becomes more distinct on Grid f and Grid g. Grid f indicates that the anomaly extends to the northwest as well. The anomalies also have a rather squarish appearance to them. From Grid f the anomaly is shown to trend in a northwesterly (southeasterly) direction, approximately N40° W. The anomaly is approximately 5 meters in length and 2-3 meters wide. This anomaly is shown to be present on all the grids below 9.6 nanoseconds. On Grid k, however, the shape of the anomaly has become less defined at this deeper depth. This anomaly is suspected of being the actual location of the coffin within the tomb burial ground.

Several subsidiary anomalies are also seen. In particular, another squarish appearing reflector occurs on Grids f-k. The anomaly begins near (7 m east, 11 m north) on Grid f. The anomaly progresses slightly southwesterly to about (6 m east, 9.5 m north) by the time Grid f is encountered. On Grid i this anomaly along with another squarish looking anomaly which is slightly off the surveyed region is apparent. This anomaly is located near (9.5 m east, 6.5 m north). The anomaly however, is not registered on any of the shallower maps. The nature of these squarish anomalies are not clearly understood. There is some speculation they may represent the burial of several funeral objects near to the deceased.

Resistivity Surveys

Resistivity measurements were made at the tomb No. 2 using both Wenner and Schlumberger array configurations. The current and potential electrodes spacing(a) for the Wenner array was 0.5 m. The current electrodes spacing for the Schlumberger array was also set to 1 m. Apparent resistivity at tomb No. 2 was surveyed down to about 0.5 m in the search for buried objectives

Shown in Fig 4a and Fig. 4b are the Schlumberger and Wenner array contour maps, respectively. The data were collected at 1 meter intervals along east-west profiles. The north-south distance between profiles was also 1 meter. The tomb trench is identi Shown in Figure 4a and Figure 4b are the Schlumberger and Wenner array contour maps, respectively. The data were collected at 1 meter intervals along east-west profiles. The north-south distance between profiles was also 1 meter. The tomb trench is identified by the strong resistivity values measured around the mound. The squarish shape of the resistivity contours in the areas believed to be the trench, may corroborate previous archaeological evidence that this topographically weathered tomb is indeed a keyhole shaped tomb. The Schlumberger data (Fig. 4a) show a large rectangular, low apparent resistivity anomaly, located on the top of the tomb. The anomaly is trending in a direction approximately N40° W. The length of the anomaly measured to the 195 ohm-m contour for Schlumberger array is about 6 meters in length and about 3 meters wide. The Wenner array data (Fig. 4b) shows a similar result. A large rectangular anomaly on the burial mound is also found to be trending in a similar orientation. The length and width of the anomaly measured by the 195 ohm-m contour is close to that measured by the Schlumberger method. The resistivity data agree closely with the location and trend of archaeological features imaged from the radar survey. The location and orientation of the coffin, trench, and their overall size and shape agree remarkably well. In strikingly good agreement are the Schlumberger resistivity contour map (Fig. 4a) and the Grid i radar variance contour map (Fig. 3i). In addition to the coffin anomaly, the two subsidiary anomalies found on Grid i of the radar survey near (7 m east, 10 m north) and (9.5 m east, 6.5 m north), are also seen on the Schlumberger contour map. The rather squarish shape of, the anomalies are accurately corroborated between these two independent geophysical techniques as well. The Wenner shows these subsidiary anomalies predicted from the radar and Schlumberger surveys. The shape of the anomalies are somewhat smoother on the Wenner contour map, however.

A highly speculative, but interesting observation with regard to the suspect coffin is seen in the data. The largest anomalies, indicated by the lowest apparent resistivity as well as the relatively high radar variance anomalies, are located near the southern end of the suspected coffin region. Assuming that the coffin was buried with sword, then the normal position of this burial symbol is near the head of the deceased. Should the tomb still be intact, then a relative low resistivity within the tomb would be off to either end of the tomb. The inclusion of metallic material would significantly lower the resistance of the surrounding bulk material. The data, particularly from the Schlumeberger survey, show a relatively strong low apparent resistivity anomaly within the coffin which is in a location near the suspected southern end of structure. Correspondingly, the reflected radar energy from any metallic objects at depth would also result in relatively higher reflected energy. The highest radar reflections are from the southern end of the coffin structure. These observations would be consistent with the existence of sword within the coffin.

CONCLUSION

In this study the use of ground penetrating radar imagery was applied to tomb. The use of radar variance contour maps conveyed a wealth of information regarding many of the archaeological features of the tomb. The location, orientation, and burial style of the coffin were successfully determined.

ACKNOWLEDGEMENTS

The author would like to thank Drs. Dean Goodman and Tokuo Yamamoto of Geo-Acoustics Lab. of the University of Miami in Japan, for their comments and supports to this research. The research was funded by a grant from the Basic Science Research Institute Program (BSRI-95-5419) of the Ministry of Education of Korea and a grant from 1995 Academic Research Fund in the field of Ocean and Fishery Sciences of the Ministry of Education, and a grant from Korea Science and Engineering Foundation (KOSEF 95-0703-03-01-3).

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Manuscript received 14 November 1996

지하레이다를 이용한 고고학 탐사

손 호 웅

요 약 : 일본 이시카와현 나카지마시의 고분에서 500 MHz 안테나를 사용하여 지하레이다를 이용한 고고학 탐사를 실시하였다. 이 연구의 주목적은 지하레이다를 활용하여 고분내 매장물에 손상을 주지 않고 탐사하는데 있었다. 탐사지역을 격자상태로 탐사하였으며, 교차점의 수신레이다파 자료를 2.4 nanosecond 간격으로 나누고 구간내의 대표 값으로 분산치를 취하여 횡단면 등고선도를 만들었다. 자료처리 결과 레이다탐사로 깊이에 따른 고분의 중요 특징들을 발견할 수 있었으며, 고분내 관의 방향은 수평면하 9.6 nanosecond 아래에서 잘 보여지고 있다. 레이다 탐사자료는 전기비저항 탐사결과와 비교 분석되었으며, 고분내 관의 위치, 방향 및 건축양식에 대한 정보를 주고 있다.