A Non-Destructive Method for Archaeological Research using Ground Penetrating Radar: A Case Study in Chiba Prefecture, Japan

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Abstract

This paper discuss the effectiveness and problems in archaeological research through the method of Ground Penetrating Radar (GPR).

GPR transmits a radio pulse into the ground and records its reflection time and intensity to indicate the density and depth of underground remains. GPR enables us to grasp the position and shape of underground remains in a completely non-destructive way. The usual approach of archaeological surveys has been the destructive way like excavation. However, GPR exploration serves to identify and explore underground structures more efficiently and without any destruction.

GPR exploration is an effective approach to grasp the ruins in Japan like ancient tomb with a stone chamber or ancient temple with a foundation and cornerstone. The targeted ruins on this occasion are the remains of an ancient tomb, part of an ancient temple located in the Chiba Prefecture (the Takada 2 go-fun, the Tonozuka and Himezuka Kofun, the Yamadahouma 3 go-fun, the Ohtsutsumi Gongenzuka Kofun, the Yamamurohimezuka Kofun, the Ryukakuji 50 go-fun, and the Shimousa Ryukakuji). Since 2011, Waseda University's archeology laboratory has been actively implementing GPR exploration during the archaeological survey of these sites.

In this paper, I report the findings of the exploration of the ruins, demonstrating the effectiveness of GPR exploration in ruins investigation and research. The GPR exploration has been very effective in investigating these ruins, but it is necessary to check the situation under the ground through excavation. To clarify the problems by demonstrating solutions, it was analyzed the findings and consider how to interpret the results of the GPR exploration.

1. Introduction

Ground Penetrating Radar (GPR) is a geophysical exploration method that has become the main application used for archaeological reconnaissance surveys in Japan. Unlike destructive excavations, GPR enables us to grasp the position and shape of underground remains in a completely non-destructive way. To do this, GPR transmits a radio pulse into the ground and records its reflection time and intensity to indicate the density and depth of underground remains. In this manner, GPR can clarify the depth of an object from the surface as well as its characteristics on the basis of the shape and speed of the reflection. Compared with other geophysical methods, GPR surveys are regarded as superior in speed and resolution for analysis of underground structures.

In Japan, expectations for this method are fairly high, especially in the case of reconnaissance surveys of tumuli (*Kofun* in Japanese). A Japanese *Kofun* generally consists of an earthen mound containing burial facilities made out of stones as well as a surrounding ditch. The reflection speed and strength of a transmitted GPR pulse depend on the amount of moisture in the soil; underground remains like stone chambers, cavities, metal, or stone objects show high intensity, and artifacts which have the same properties as the surrounding soil return at weak intensity. Therefore, GPR has become one of the most effective methods for the illustration of underground structures in mounds without necessitating destructive research.

Although this method has potential, capturing clear images of structures deep underground using GPR is not easy in practice. This is because attenuation of transmitted signals in deep ground presents an operational bottleneck, and selection of the appropriate radio frequency antenna, depending on the stratigraphic position of underground remains at uncertain level, greatly affects the final image. In actual operation, the GPR antenna is installed on a sled and moved along a guide tape laid in the target area. The antenna is connected to a measuring wheel so that a distance correction can be applied and data received can be checked in real time. In addition, this approach is further complicated because different archaeological sites have different soil profiles, and the operator of the GPR device is required to provide appropriate settings via a connected computer by taking into account considerations such as the characteristics of the remains, their estimated depth from the surface, the ground situation, obstacles, and weather conditions, amongst others. It is also necessary to set the guide line to cross at a right angle with respect to estimated underground remains based on the results of the ground survey. This is because the accuracy of an image depends on the number of survey lines (i.e., if survey lines are laid parallel with an underground feature, the number of survey lines required is smaller than the number of cross-setting lines). Thus, in order to obtain good results with a GPR survey, it is essential to set effective survey lines based on observations and to make appropriate settings on the basis of the situation on the ground.

Underground information in the survey area, called a "profile," is recorded as a cross section after applying a distance correction. This profile can then be used to capture the depth and shape of the reaction of each survey line, and can be displayed as a plan with profiles by transecting information at the same depth from each survey line transversely and presenting it side-by-side. This is referred to a "time-slice," and can be used very effectively for grasping the planar development of the underground object. Indeed, a time-slice can be used to analyze both the structure of remains as well as the relationship of each in three-dimensions by combining it with the profile. In addition, applying a range of filters, including reflected wave amplification from deeper parts of the profile or noise removal, will enable the production of a more detailed image.

In this paper, the results of a GPR survey carried out by Waseda University are reported and evaluated. On the basis of this examination, the effectiveness and limitations of the use of remote sensing technology in archaeological studies are also discussed.

2. The Takada 2 go-fun

Site Name: Takada tumulus No.2
Address: Shibayama Town, Sammu Country, Chiba Prefecture
Date: August 2011
Survey body: Waseda University
Site characteristic: Keyhole-shaped mound tomb
GPR equipment: G.S.S.I. SIR-3000 System (400MHz and 270MHz Antenna)

The Takada mound complex comprises two keyhole-shaped mounds (earthen burial mounds, generally constructed in 3rd-7th century Japan) that are referred to as Takada 1 go-fun (also known as Kidomae 1 go-fun) and Takada 2 go-fun. This complex is located on a small hill on a plateau to the west of the Kido river. Because the size of the Takada 2 go-fun is larger than that of the 1 go-fun, the social status of the individual buried in the former is assumed to have been higher.

In order to examine the extent of this monument, a trial excavation was carried out on the 2 go-fun in 1991. As a result of this work, a ditch was excavated running from the test trench in order to determine the edge position of this mound, and a plan for the entire structure, a keyhole-shaped mound tomb with a rectangular surrounding ditch, was approximately estimated. Indeed, based on the results of this excavation, morphological similarities between the Takada 2 go-fun and Tonozuka Kofun, a large mound tomb considered to be the mid-6th century tomb of a chief in this area, were pointed out (Sammugun City Cultural Property Center 1992). However, because of limited excavations at this site and a topographic map that lacks detail, full-scale comparative studies of both mounds have yet to be carried out. In addition, based on result of the preliminary investigation, a Haniwa clay figurine might be installed in the Takada 2 go-fun. The aims of the GPR survey at these sites were:

1. To examine the nature of the ditch, as although the results of earlier excavation work reveal a single ditch surrounding this mound, data from other mound tomb in the area suggest that this might be doubled;
2. To identify burial facilities within the mound as the position and structure of the main area of this mound tomb remain uncertain; and

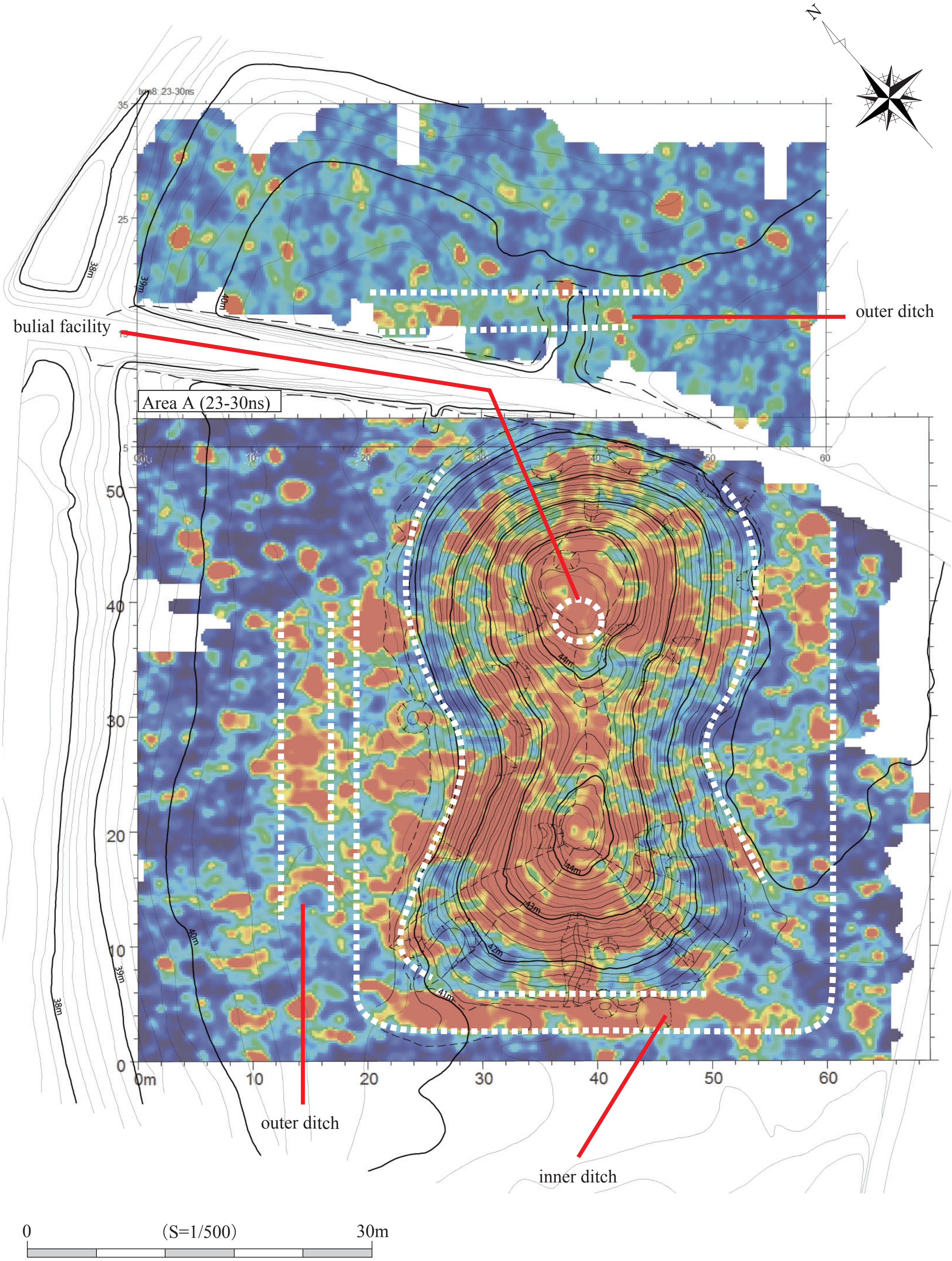

Fig. 1　The results of GPR survey at the Takada 2 go-fun

3. To clarify the arrangement of Haniwa figurines, as GPR generally has difficulty detecting small artifacts. This might not be an issue in this case, however, as the Haniwa figurines in this area are relatively large and their arrangement can be mapped using GPR.

As discussed previously, GPR is superior both in terms of its resolution and speed of data collection when compared to other remote-sensing methods. In this case, the whole research area was probed using the 400MHz antenna because the depth of estimated underground remains was relatively shallow, although the 270MHz antenna was used occasionally for detecting the burial facility in the main part of the mound (i.e., the rounded region of the mound). All data are collected at 0.5m intervals.

All data collected from this area were compiled and illustrated as a cross-sectional diagram and a ground plan for the appointed depth (i.e., a time-slice view). Figure 1 shows a topological map of this research area overlain with a time-slice view (23-30ns). Results show that a strong reflected signal was collected from the square part of the mound as well as from both sides (i.e., northwest and southeast). Taking former studies into account, it can be concluded that these reflections demonstrate the existence of the surrounding ditch, especially as they appear to be linear. This surrounding ditch would have been rectangular in plan, although the northeast part of the mound is crosscut by the modern road so the corner of the ditch estimated here is uncertain. Other strong reflections were seen on both sides of the mound (i.e., at coordinates X=15m and X=64m) that also seem to be linear in plan. These data might provide evidence for the presence of a double ditch surrounding the mound, but further investigations (including the excavation of test pits) are required to confirm this suggestion.

The existence of a burial facility is implied by reflections from the round part of the mound (i.e., at coordinates X=35m and Y=38m), while a strong signal is also seen in the mound in cross-section.

Results reveal a strong reflection along the contour line on the northern side of the mound at an altitude of 42-43m. One conclusion is that this reflection is caused by the presence of Haniwa figurines, or the terrace on which these artifacts are installed. Again, further investigations will be required to confirm these suggestions.

As a result of this GPR survey, the whole plan of the mound and associated features can be illustrated. These data mean that it will now be possible to reexamine the opinion that this mound bears a morphological resemblance to the Tonozuka Kofun.

3. The Tonozuka and Himezuka Kofun

Site name: Tonozuka and Himezuka tumuli
Address: Yokoshibahikari Town, Sammu County, Chiba Prefecture
Date: August to September 2012
Survey Body: Waseda University
Site characteristic: Keyhole-shaped mound tomb
GPR equipment: G.S.S.I. SIR-3000 System (400MHz Antenna),
MALA X3M System (500MHz Antenna)

The Tonozuka and Himezuka Kofun have been designated as historic sites by the national government and are located in Yokoshibahikari Town, Sammu County, Chiba Prefecture. Sammu County is located on the northeastern part of Boso Peninsula, with the Kujukuri coastal plain facing the Pacific Ocean to the south. There are many mound tombs in this region that were constructed around the 6th century on a plateau facing a small river that flows across the vast plain formed by coastline regression.

The Nakadai complex, including Tonozuka and Himezuka, make up a group of 17 mounds most of which have disappeared as a result of the cultivation of farmland. However, the Tonozuka and Himezuka Kofun are important remaining examples of this group, and were excavated in 1956 by Hiroshi Takiguchi, a professor at Waseda University.

The main purposes of this GPR survey were:

1. To confirm the shape and range of the ditches of both mound tombs; and
2. To confirm the burial facilities at the Tonozuka, Himezuka, and Nakadai 3 go-fun.

A GPR survey was carried out in areas defined perpendicular to prospected remains, including ditches and burial facilities using SIR-3000 and RAMAC/X3M. The appropriate antenna frequency was set depending on the depth, using both 400MHz and 500MHz.

The results of this GPR survey are shown in Figure 2, showing the depth time-slice that represents the clearest set of reflections.

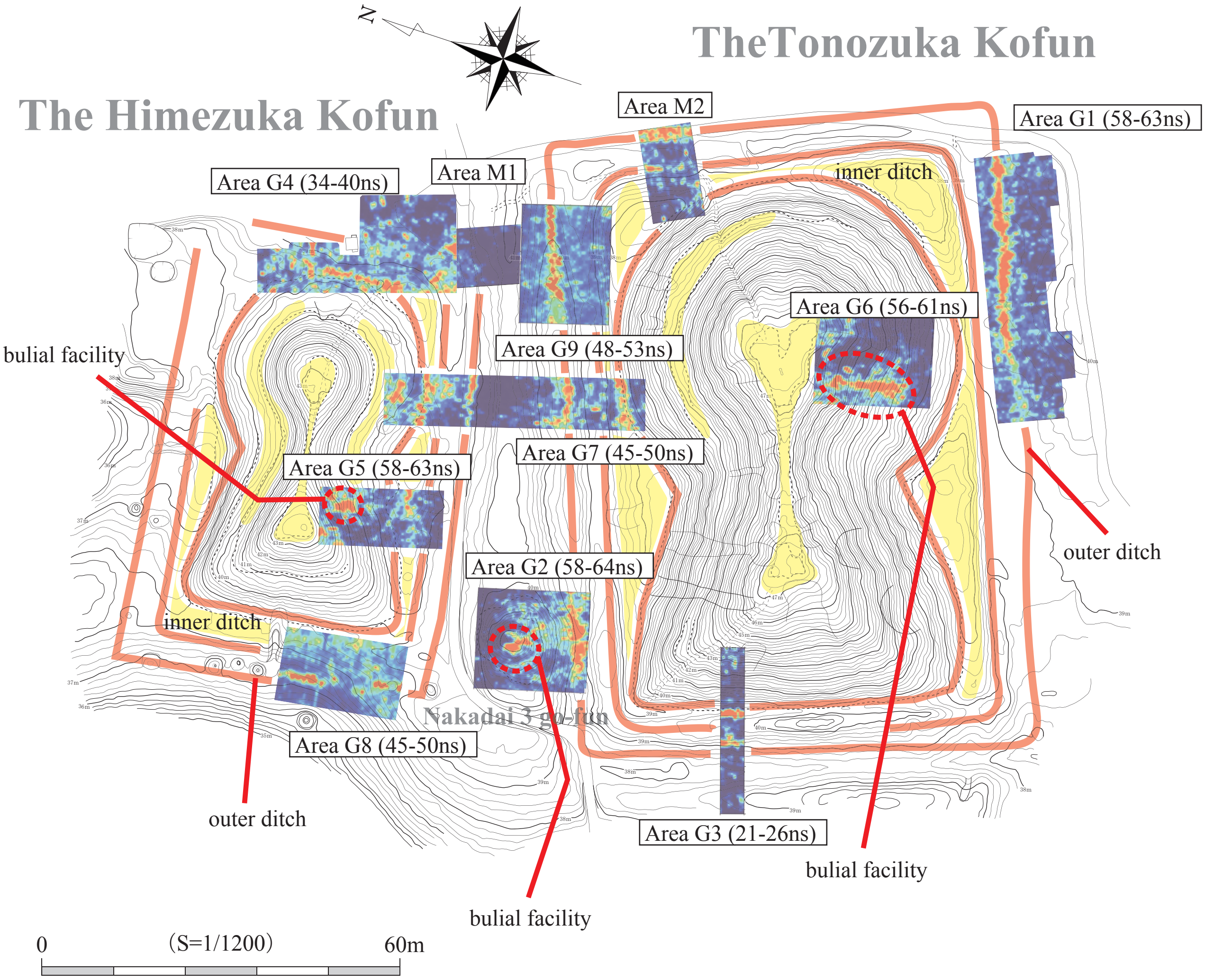

Fig. 2 The results of GPR survey at the Tonozuka and Himezuka Kofun

Fig. 3 The scenes of the GPR survey at the Tonozuka and Himezuka Kofun

In the first place, results reveal the range of double ditches to be rectangular on the basis of reflections of the outer ditch from areas G1, G2, G7, G9, and M2 in the Tonozuka Kofun. In addition, this survey also confirmed the possibility that the inner ditch may not have been modified; data revealed that this outer ditch runs around from the west to the south side and that the road on the south side of this mound tomb coincides with the original outer ditch in areas G7 and G8 in the Himezuka Kofun. Thus, it would have been very possible to avoid 3 go-fun when constructing the Himezuka Kofun. GPR results from areas G4 and M1 also show that each mound tomb was surrounded by a double, rectangular ditch.

Subsequently, results from this area have also confirmed reflections of burial facilities in area G6 of the Tonozuka Kofun, area G5 of the Himezuka Kofun, and area G2 of the Nakadai 3 go-fun. The positions of these reflections, confirmed by GPR, are entirely consistent with the positions of burial facilities shown in earlier drawings of these sites and the positions of previously inferred trenches are confirmed based on these results. Thus, we were able to plot the accurate positions of the burial facilities in both mound tombs on the current survey map. In addition, we also determined that a stone coffin is likely presented in the center of the top of the mound at 3 go-fun, something that has not been recognized in previous surveys.

The most significant result of this survey is the amount of information acquired from these mound tombs using the non-destructive GPR technique, without excavation. We are able to present basic data relevant to consideration of the protection and preservation of these mound tombs even given the fact that the current designated range is limited to the mound.

4. The Yamadahouma 3 go-fun

Site name: Yamadahouma tumulus No.3
Address: Shibayama Town, Sammu County, Chiba Prefecture
Date: January to February 2014
Survey body: Waseda University
Site characteristics: Keyhole-shaped mound tomb
GPR equipment: MALA RAMAC/X3M System (500MHz Antenna)

The Yamadahouma complex are widely distributed on a terrace at an altitude of 40-42m between the Kido and Koya rivers. On the basis of excavation results, these mound tombs are thought to have been made between the later 5th and mid-7th centuries (Habu 2001). Yamadahouma 3 go-fun is the one of the few keyhole-shaped mounds found among this group of mound tombs. However, because this mound tomb has no history of investigation, many issues remain unanswered including the shape of the mound and ditch, and the position and shape of the burial facility.

Thus, the main purposes underlying the use of GPR in this survey were:

1. To grasp the scale, position, and form of the ditch; and
2. To detect reflection of the burial facility.

In order to determine the entire shape of the mound and ditch, and because several burial facilities may exist, GPR was carried out across the entire surface of the mound. Subsequently, we determined additional survey areas including excavation trenches based on the results from the entire surface of the mound. Figure 4 shows results from areas C-F.

Results show first that reflections of the ditch in all areas although the strength is not definite. By taking into account measurement results, Yamadahouma 3 go-fun was thought likely to have had a single shield-shaped ditch. In addition, it is possible to determine that land on the north side of the mound has been modified due to afforestation. It can be inferred that this ditch was not so large because its width is around 1-1.5m.

Secondly, results show strong reactions that correspond to burial facilities at two points within the mound. These reflections have been confirmed in areas B, D, E, and all could be reactions from stone structures based on their profiles. Because the scales of both reactions are small, 2m from north to south, and 1.5-1m from east to west, they are considered to represent stone coffins (Hakoshiki-Sekkan). However, because the depth of these reactions are about 1.5-2m from the ground surface, it is difficult to clarify coffin heights, tomb furnishings, and the presence or absence of robbing from GPR data. Nevertheless, these shapes do correspond with stone coffins on the basis of their exact positions and reflection depth.

Because GPR survey of this mound tomb was carried out across the whole surface as well as in parts of the excavation trenches, we were able to assess the advantages and disadvantages of both methods. The

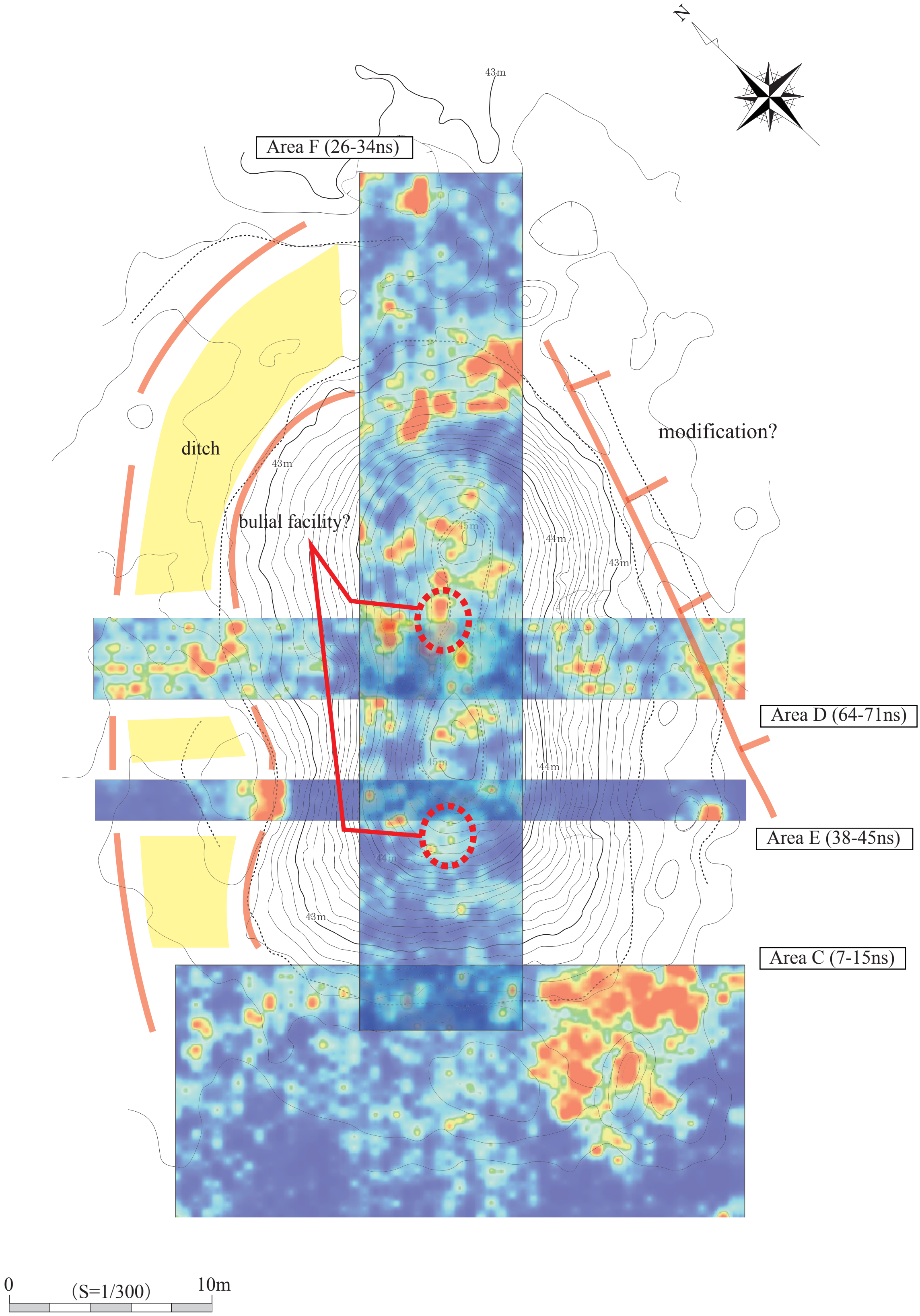

Fig. 4 The results of GPR survey at the Yamadahouma 3 go-fun

advantages of use of the whole surface are that there are no reaction omissions from underground structures and it is easy to capture features if reflections comprise shapes. However, if a strong reaction is recovered from an artificial structure such as a hole dug to bury refuse within the same exploration area this will lead to a relatively weak overall reaction. In contrast, if the GPR approach is used to investigate an area such as a trench, then this encapsulates the disadvantage that information from outside this area cannot be determined with the same resolution as that of the excavation. Nevertheless, one advantage is that the reaction revealed is clear and the range of the area is limited. GPR should be carried out to supplement and understand the advantages and disadvantages of both methods when areas are determined.

Results show that it is necessary to choose a method that is appropriate for the site in question, and that it is also essential to understand and observe the site while conducting the survey to ensure accuracy.

Overall, data show that it is possible use measurements and GPR to grasp both the form of the mound and the range of the ditch that comprise Yamadahouma 3 go-fun. GPR results have also revealed the position of burial facilities at this site.

5. The Ohtsutsumi gongenzuka Kofun

Site name: Ohtsutsumi gongenzuka tumulus
Address: Sammu Country, Chiba Prefecture
Date: September 2014
Survey body: Waseda University
Site characteristics: Keyhole-shaped mound tomb
GPR equipment: MALA X3M System (500MHz Antenna)

The Ohtsutsumi gongenzuka Kofun belongs to the Ohtsutsumi complex, which includes two keyhole-shaped mounds and seven round mounds. This mound tombs is the largest one in Sammu Country and is located at the contact between the Kujukuri plain and the plateau of the Kido river basin.

The Otsutsumi gongenzuka Kofun is 115m in length and was excavated in 1951 by Nihon University, Japan. As a result of this excavation, swords, blades, a large number of iron arrowheads, earrings made of gilt bronze, and a large number of beads were collected. The burial facility in this mound comprises a unique type of horizontal stone chamber that has two rooms, the rearward of which contains a stone coffin. This mound was built on the southeast side of the mound group along the back circular part. The total length of the burial facility which opens towards the south is about 9m, and the back wall of the rearward room had been painted with vermilion. We know that the Ohtsutsumi gongenzuka Kofun was built in the final stage of the Kofun period because it does not contain any Haniwa figures in spite of its large size. At present, the stone chamber contained within this mound tomb has collapsed and thus its structure can be observed from outside. On the basis of excavations in 1991 and 1992, shield-shaped triple ditches were reported as part of this mound (Sammugun City Cultural Property Center 1992).

A GPR analysis was carried out as part of this survey to confirm the scale of this mound and the shape of the ditch. Settings for this analysis were based on the results of past excavations as well as observations of the terrain at the time of GPR deployment. The equipment used was a 500MHz antenna X3M system produced by MALA Geoscience. We defined areas perpendicular to prospected remains and GPR surveys were carried out at 0.5m intervals. However, because experience has shown that it is difficult to survey the entire surface stationary from the mound, this work was carried out using GPR in partial areas. Areas A and B were defined for the purpose of detection at the foot of the mound and neck at the side of the mound, while areas C, D, and E were set for confirmation purposes at the foot of the mound and on the terrace at the back of the circular part. We also surveyed areas F and G in order to understand the foot of the mound and the terrace present in the front square part.

Results were able to confirm reflections of the foot of the mound in each area. Reactions in the shape of the mound neck were clearly detected in areas A and B, over a particularly wide range. The reaction of the ditch can also be confirmed to a depth of 15-45ns based on profile data, and reactions were observed along the foot of the mound in areas C to G.

GPR results show that arrow feather-shaped terrain to the side of the front square part of this mound reflects the original shape of the mound. This refraction has also been confirmed in the case of the Tonozuka Kofun, and whether, or not, these shapes are a reason for construction or part of the original design

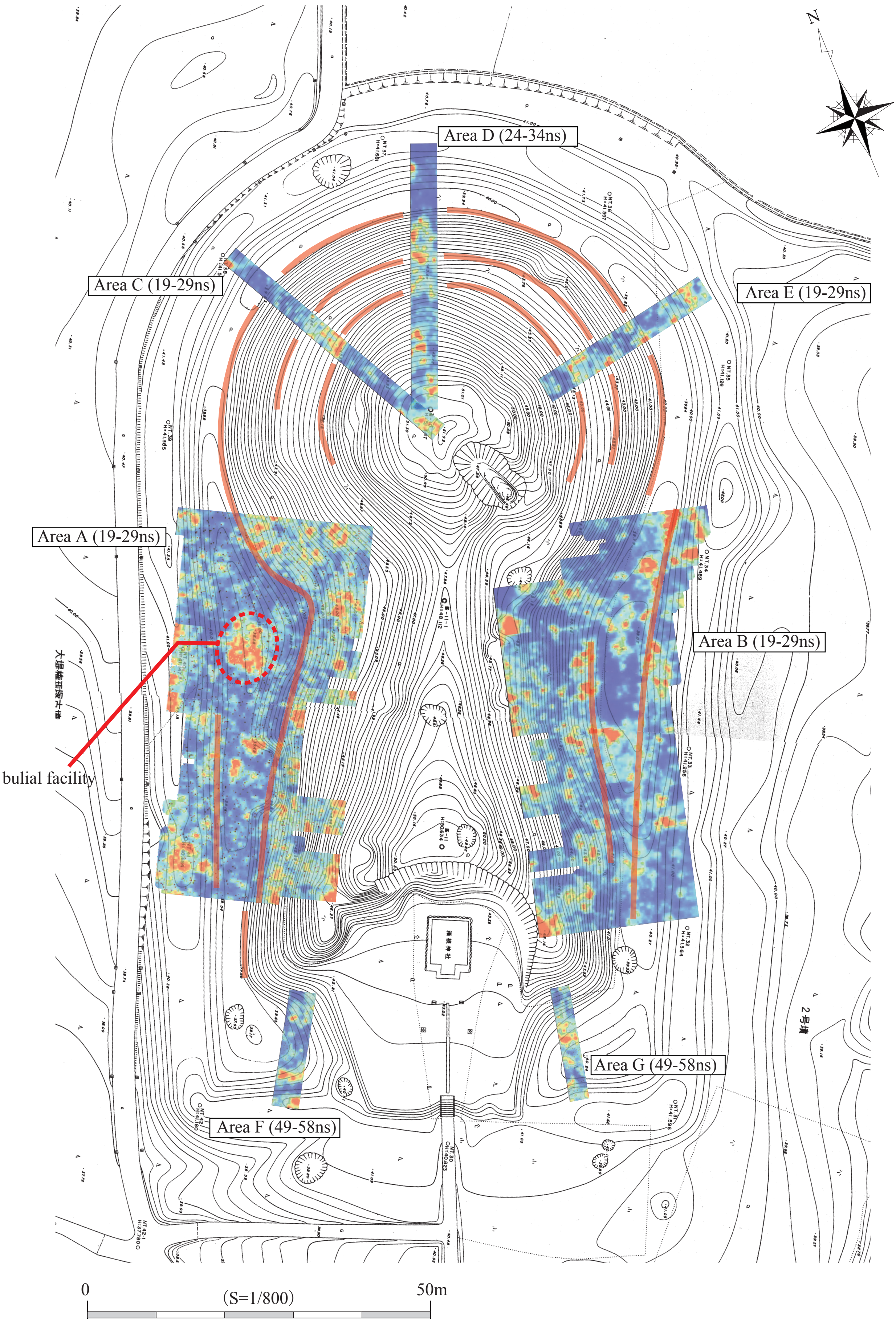

Fig. 5　The results of GPR survey at the Ohtsutsumi gongenzuka Kofun

will be a subject for future investigation. Results also reveal the presence of a ditch in area A that can be assumed to be the burial coffin.

On the basis of GPR data, reflections of the ditch and burial facility have been obtained for this mound tomb, and the shape of the mound, unknown until now, has been reconstructed using measurement results, this survey as well as observations from previous ones.

The current research situation demands accurate restoration of mounds as part of studies of the Kofun period. Thus, it is necessary to enhance accuracy of mound tomb restoration using GPR alongside more conventional approaches.

6. The Yamamurohimezuka Kofun

Site name: Yamamurohimezuka tumulus
Address: Sammu City, Chiba Prefecture
Date: February to March 2016
Survey body: Waseda University
Site characteristic: Circular mound
GPR equipment: MALA ProEx System (250MHz and 500MHz Antenna)

The Yamamurohimezuka Kofun is the largest circular mound in Chiba Prefecture. This mound was made at the same time as the Danozuka Kofun, a characteristic square mound tomb from the end of this period. The Yamamurohimezuka Kofun is important because it has not been excavated until now, although a survey map was presented by the cultural section of the education bureau in Chiba Prefecture in 1991. The use of GPR was determined as a valid approach as the position and structure of burial facilities within this mound tomb are unknown.

We set the exploration areas as trenches in excavations on the basis of restrictions set by the terms of the survey and obstacles such as trees. However, in order to set these areas effectively, the survey was carried out by scanning in all directions in advance. Thus we set the survey areas so as they overlap with points grasped by specific reactions. As the underground situation can be confirmed on the monitor in real time, a point where a strong reaction can be confirmed is grasped on site.

We used the 250MHz antenna in areas A to E and the 500MHz antenna just in area F. Time-slices and profiles were output including terrain adjustment processing for areas C to E which have the large difference in elevation.

The range and purpose of each area and our interpretation of reflections are described below, with GPR results presented in Figure 6. We set six areas in this survey for the purpose of detecting burial facilities and understanding the reactions of ditches, terraces, and the foot of the mound.

One GPR slice was set in area A on the south side of the mound in order to determine the reflection of the stone chamber. Results show a U-shaped reaction which opens to the south at a depth of about 30ns. Thus, this area is considered to be part of a horizontal stone chamber, based on the intensity of reflected waves and their position, although the reactions of ceiling stones could not be confirmed. This result might be due to the collapse of ceiling stones or wave attenuation by a clay covering on the ceiling stones.

Results show a somewhat strong reaction (from 20ns to 90ns) in area B. However, these results cannot be used to confirm that this was a funeral facility as points from the reflection are weak compared to those detected in area A and the reaction extends to the lower slopes beyond the range of the terrace.

Results show a strong reflection in the x16-20m range in area C. On the basis of this reaction it can be estimated that a possible reflection of the boundary surface between the embankment and the sediment is present. In addition, a strong reflection can be seen even from deeper parts of the profile, acting to sandwich the reaction from the embankment. This reactions are likely to be the boundaries between high water content soil deposited in the ditch and the upper layer, although the beginning of this reaction is quite deep (60ns). Therefore, the possibility remains that double ditches were present on the west side of the mound based on the intensity and position of this reaction. It is necessary to interpret these anomalies in combination with survey results because it is difficult to interpret the characteristics of this GPR survey given restrictions of the range of the area.

Results show a slight reflection in two locations in area E that can both be attributed to reflected waves from sediment in ditches. The reaction of these ditches can be estimated on the basis of the points of these reflections, along the contour of the terrain.

A reaction with a clear shape on a large scale was not observed anywhere in the survey area, although

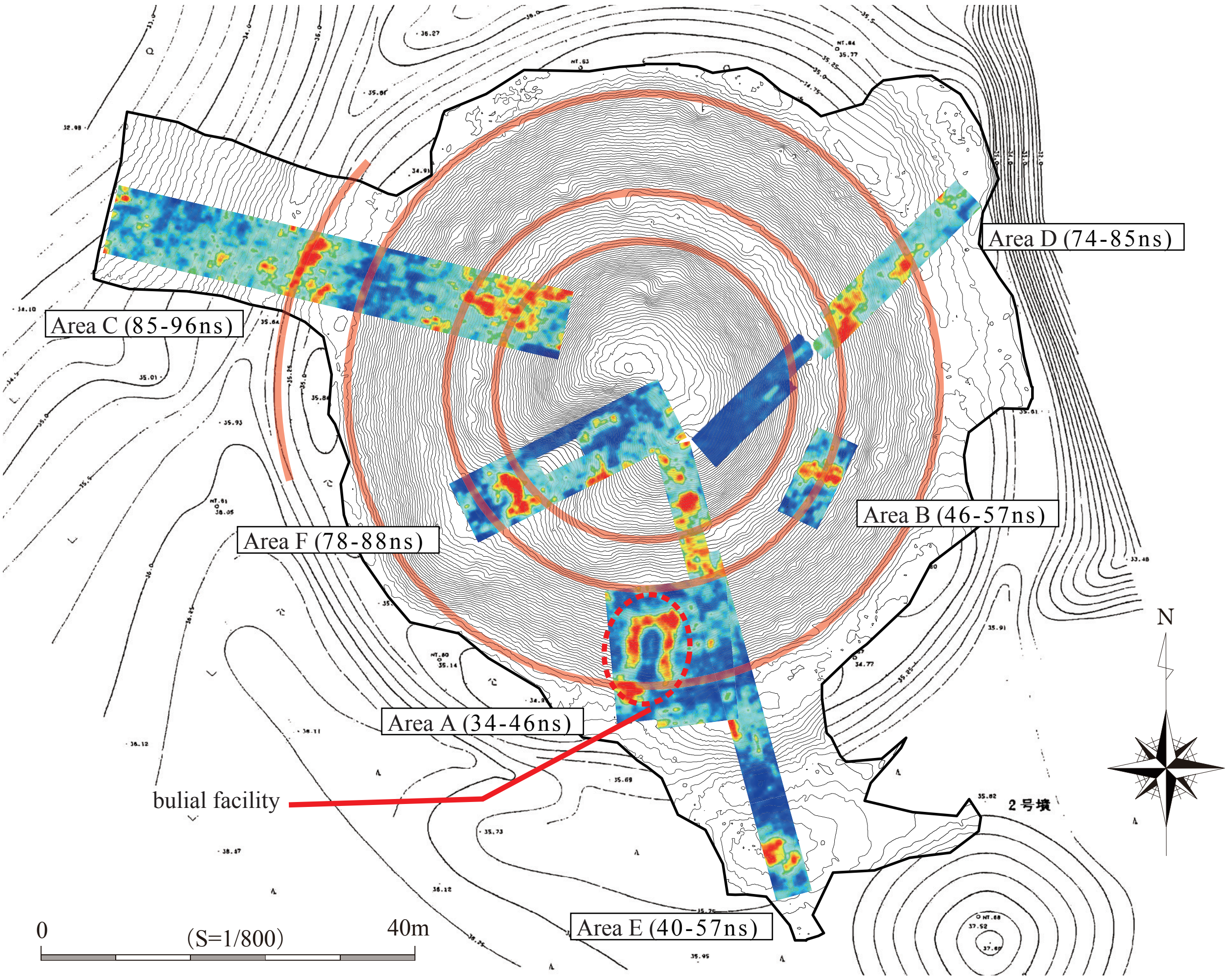

Fig. 6　The results of GPR survey at the Yamamurohimezuka Kofun

Fig. 7　The scene of GPR survey at the Yamamurohimezuka Kofun

strong reactions were scattered in area F. Information that this shape corresponds to a large depression that was used in the past as an approach to the top of the mound was obtained by talking to local residents.

7. The Ryukakuji 50 go-fun

Site name: Ryukakuji tumulus No.50
Address: Sakae Town, Inba Country, Chiba Prefecture
Date: February to March 2014
Survey body: Waseda University
Site type: Keyhole-shaped mound tomb
GPR equipment: MALA X3M System (250MHz and 500MHz Antenna)

The Ryukakuji 50 go-fun is located on the western edge of the plateau of the Ryukakuji complex. This mound tomb is located on a slope that trends downwards to the northwest, southwest, and southeast. The shape of the mound is spread from the northwest corner of the front square part until the neck of the south side because on the west side soil from the mound flows out in this direction. The Ryukakuji 50 go-fun is the third largest keyhole-shaped mound tomb after Sengenyama Kofun and the Ryukakuji 57 go-fun in this association.

Indeed, in one study of the the Ryukakuji complex, the Sengenyama Kofun has been accorded a very important meaning and academic placement. Thus, in this study it was necessary to compare this mound precisely with the Ryukakuji 50 go-fun and 57 go-fun, which have been shown to be very similar shapes to the Sengenyama Kofun. In the first place, it was therefore necessary to perform a basic survey using non-destructive methods because the most recent survey map of this area was made in 1982 (by the cultural section of Chiba Prefecture education bureau). A precise survey of the Ryukakuji 50 go-fun was carried out because this site has a good residual situation. Results of a boring survey have confirmed the presence of a burial facility, indicated by the presence of a horizontal stone chamber on the south side of the terrace around the neck of the mound tomb (Hagiwara and Harada 1985). Careful survey work in this area was required because the burial facilities of the Ryukakuji complex show strong regional characteristics, including the fact that the Ryukakuji 24 go-fun has two burial facilities while 101 go-fun has four. These characteristics were highlighted by excavation results from 1982 to 1986 carried out on the Ryukakuji complex (Board of Education in Chiba Prefecture 1982, 1984, 1988). It is also important to note that because the positions of these burial facilities have already been estimated by previous surveys, it was necessary to perform a basic survey from a new perspective because little work has been done on the smaller mounds of the the Ryukakuji complex in recent years. Thus, the purposes of this survey were:

1. To obtain objective and accurate information about the Ryukakuji 50 go-fun using a three-dimensional survey and GPR, and;
2. To determine the structure of the mound and the location of the burial facility on the basis of GPR results.

To complete this survey, GPR was carried out over both the entire area as well as smaller area subsets. We set areas in order to get information from the site by taking into account the results of our earlier measurement survey.

In this first place, a survey was performed across the entire area of the site in order to detect burial facilities. This was done because there are many examples of mound tombs that have been referred to as 'atypical' and that contain more than one burial facility between the late and the end of the Kofun period in this region. As a result, significant reflection was not observed from the top of the back circular region of this mound and the front square region while there was a strong reflection in the neck of the south terrace that was reported in a previous survey. These results suggest that it is less likely there was more than one burial facility in this mound tomb.

Next, GPR was used to confirm the position of the terrace, the foot of the mound, and the presence of a ditch in the R1-R10 areas. Reaction results confirm the positions of the terrace and the foot of the mound, while in area R1 a reaction was detected that is considered to represent the corner of the front square region of the mound. Band reactions in areas R3 and R9 are considered to represent the foot of mound; these regions in R10 were probed using a 250MHz antenna because the presence of a burial facility was expected and, indeed, strong reflection was observed in the range of the terrace that is considered to be a stone structure based on the strength and shape of the reflection. These results strongly suggest the presence of a stone coffin, as the scale of the reflection is small.

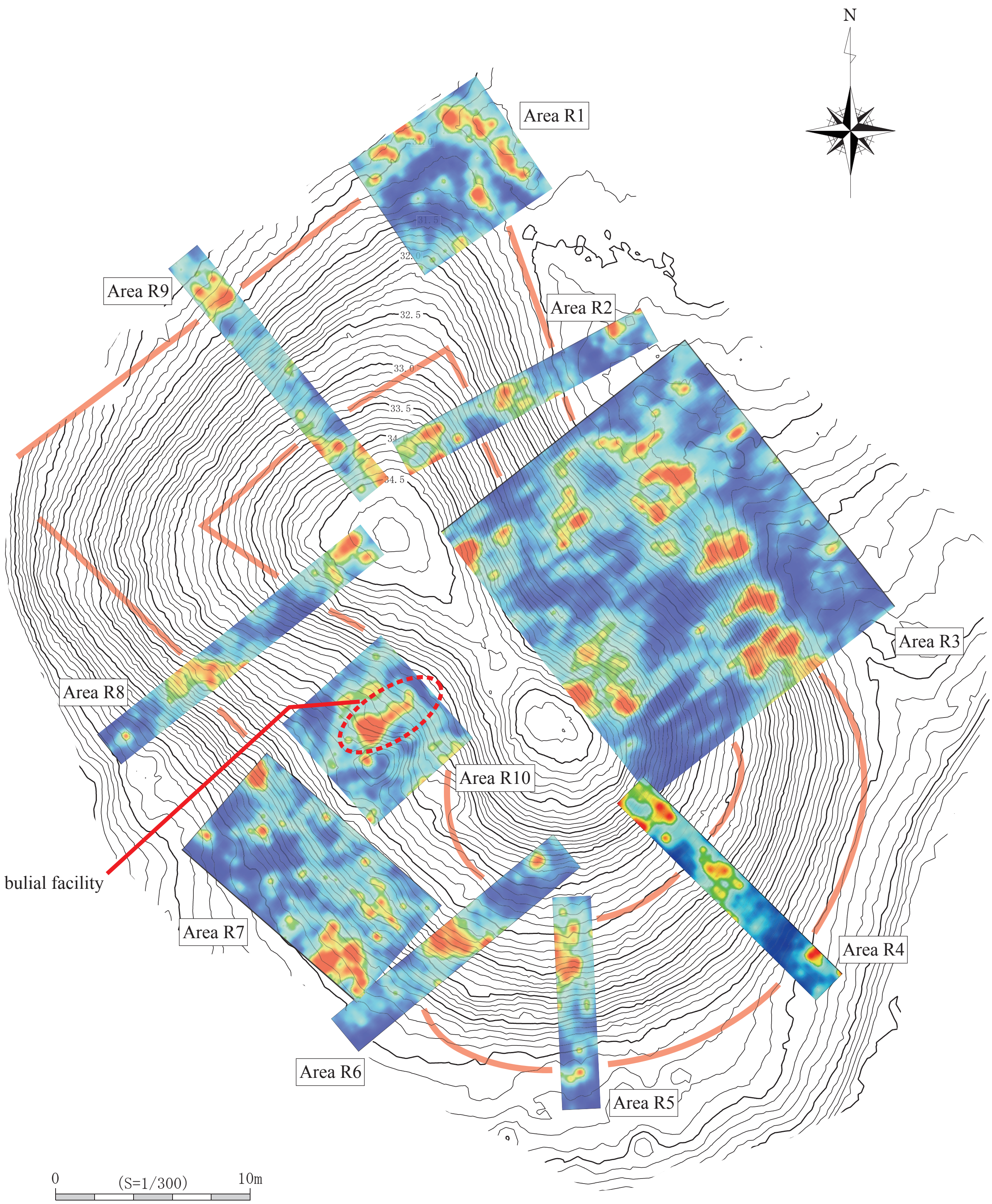

Fig. 8 The results of GPR survey at the Ryukakuji 50 go-fun

A stone coffin has been revealed on the basis of this survey in the neck of the south terrace, within the range of the mound.

8. The Shimousa Ryukakuji

Site name: Ryukakuji
Address: Sakae Town, Inba Country, Chiba Prefecture
Date: February to March 2013
Survey body: Waseda University
Site characteristics: Buddhist temple ruin from the Asuka Hakuhoh period
GPR equipment: MALA RAMAC/X3M System (500MHz Antenna)

The Ryukakuji is the oldest ancient period temple in the eastern part of Japan. The head of the Bhaisajyaguru (Yakushi Nyorai) statue, the main statue from Ryukakuji, has a similar style to that from the Yamada-dera, and as such has been designated as nationally important cultural property. In addition, because of the similarity between a tile excavated at Ryukakuji and another from Yamada-dera, a deep relationship at this location has been revealed with the power of Asuka. However, although this temple has been under investigation since the 1940s, many issues remain unclear.

This survey was conducted to clarify the placement of the founding period temple and to reveal the evolution of the ruins from ancient to modern times. In order to accomplish these tasks, we performed both topographical and a GPR surveys.

We adopted a direct method for our topographical work and created a survey map of 10cm contours using levels and total stations. Results of this survey rendered the north side of the terrain clearly visible. In addition to the foundations of the main hall and tower, we revealed the possibility that the northwest corner of this temple preserves the position of a corridor retained from the founding period.

For our GPR survey, we set the survey areas in a form perpendicular to the remains like excavation trenches, with the exception of Area F on the main hall. The total number of survey areas is 17 (areas A to Q), and the purposes of the GPR survey were as follows:

1. To understand the reaction of the corridor;
2. To detect the reaction of the foundations of the building including the main hall and tower; and
3. To confirm the existence of foundations of the Nioh-mon (gate).

In area F (the main hall), a strong reflection was observed in the range of the current foundations, considered to reflect the foundation embankment of the main hall. In addition, a clear reaction from the foundations of the tower was confirmed, as reported from an excavation that took place in 1971. The point to be noted is that the belt-shaped reactions of a width of about 8m are found in the region estimated to represent the northwest corner of a corridor from current terrain (areas I, L, M, and P). This reaction can also be confirmed based on profile data that show that the reactions of area L and M have almost the same scale and depth, possibly reflecting the northwest corner of the corridor foundations. The eastern part of area L could not be revealed by using GPR because of the presence of stoneworks, a similar reaction detected in areas L, M, and N. However, results show that the reaction in area N takes a wider form than in areas L and M.

In contrast, as we could not confirm a reaction at the existing Nioh-mon site, this was found to be a gate built some time after the early modern period. Although the possibility remains that this gate has been cut off, it is nevertheless the case that Nioh-mon was built after the early modern period given topographical conditions.

The GPR results presented above are consistent with the outcome of our topographical survey, and therefore it is possible to estimate the original placement of the temple.

Based on the overall results of this survey, we assume a different placement for the temple building than that based on previous research. In addition, we are able to understand the transformation process of the axis of the precincts of the ruins. Based on these results, we conclude that it is necessary to re-organize the results of past research, promote new excavations, and discuss the placement and subsequent transition of the temple buildings of Ryukakuji.

The GPR results presented here were collected over the course of the excavations conducted in 2015.

9. Conclusions

In this study, GPR survey results for seven ancient mound tombs and one ancient temple have been presented.

We have compared sections from excavation

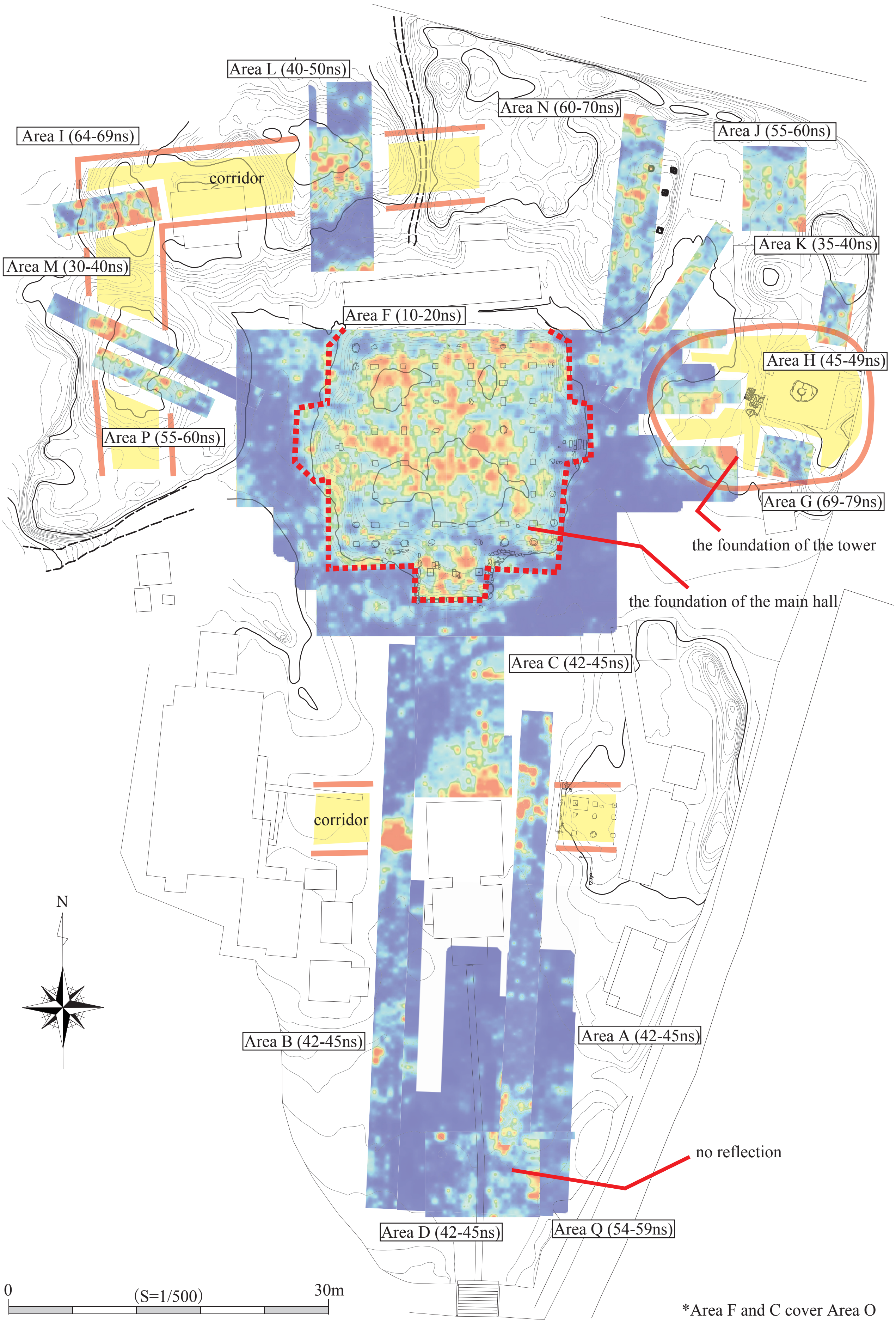

Fig. 9　The results of GPR survey at the Ryukakuji

trenches with GPR results performed before excavations. The data presented here mean that it is possible to improve the accuracy of GPR survey results by comparison as well as providing a better understanding of what produces underground reflections (Figure 10).

As a result of the data presented here, we are able to understand the origins of generated reflections by comparing visible sections at sites with GPR profiles. Three conclusions can be drawn as a result of these comparisons. First, data verify GPR results, in particular differences between pits dug by robbers and their surrounding layers. Second, data show that it is possible to determine reflections that do not result from excavations on the basis of comparisons. Third, by combining GPR exploration with excavation, site information can be further increased, again leading to an improvement in GPR accuracy.

Thus, as discussed previously, GPR exploration minimizes the necessity for site excavations and the amount of underground information will increase as visible excavation sections are compared with profiles. However, because the sites in this study tend to have very complex stratigraphy, it proved difficult to understand all of them using GPR. One reason that there are small differences between the RDPs (relative dielectric permittivity) recorded in this area is because the sites considered here experience extremely low precipitation. Nevertheless, even in this environment, it is necessary to devise approaches to enhance the effectiveness of GPR. Methods considered effective when exploring or interpreting data are:

<Exploration>

1. Combining data with that collected via other exploration methods. For example, the electric exploration resistivity method can be employed if

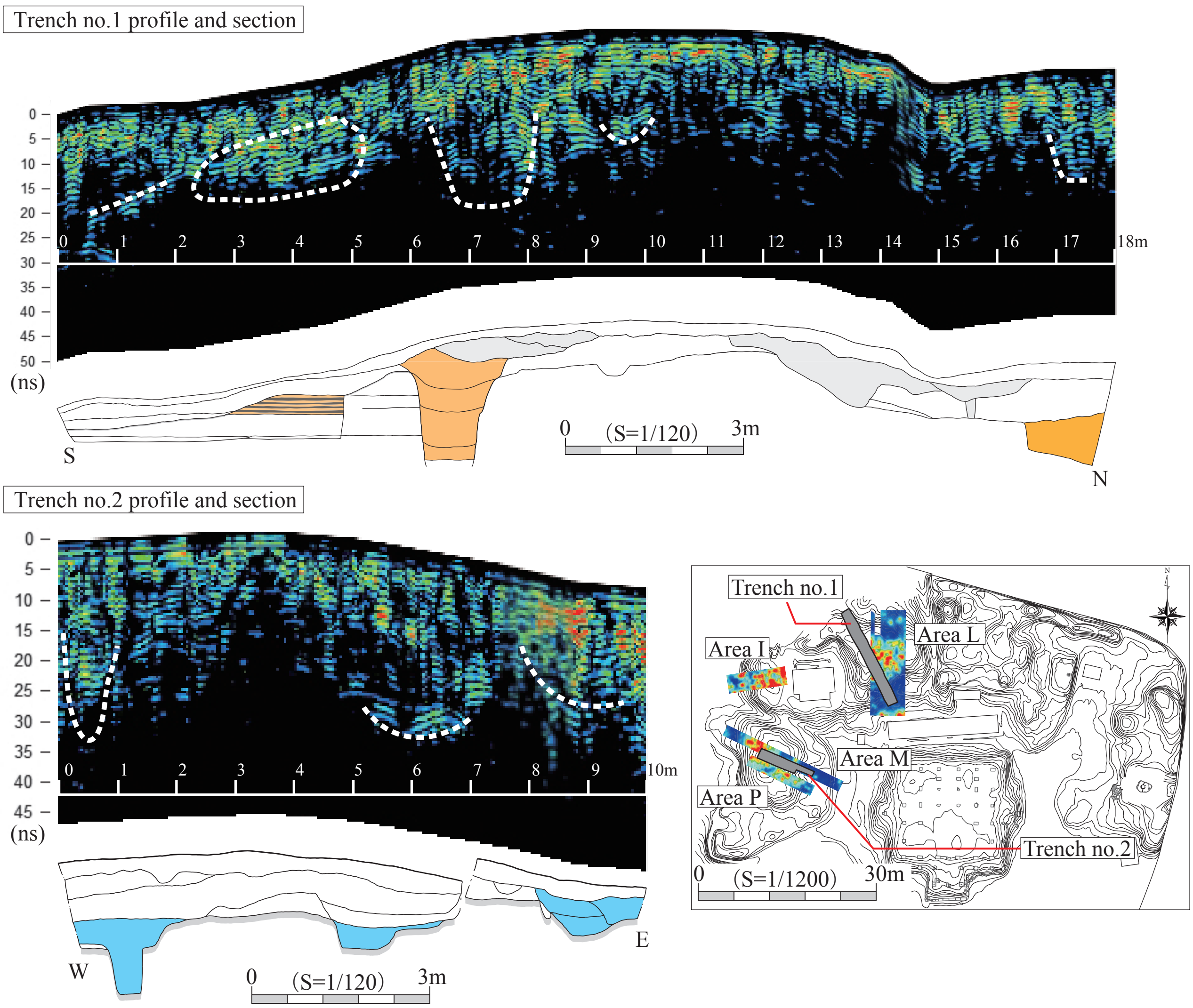

Fig. 10 The comparisons of plofiles and sections at the Ryukakuji

a target is deeply buried, or if the presence of metals or previously heated remains are suspected, then magnetic exploration can be used. Information loss can be compensated by the combination of these methods.

2. Undertaking explorations within a narrow interval. The surveys reported here were carried out at 1m intervals, enabling the collection of more specific data and the production of high quality time-slices.
3. Scanning in both X and Y directions. Experience shows that it is possible to produce a time-slice with less noise if profiles are collected from both directions and if reflections from different directions are referred to when making comparisons.

<Analysis>

4. The use of appropriate processing filter to generate profiles. Less noisy profiles should be used if possible as these contain visible reflected sheer reflected from underground. With this in mind, it is preferable to process not just the migration and background data but also to use a filter to regain information in some cases. Indeed, in some cases a profile should be referred to that has only been subject to resample processing.
5. Applying terrain correction to profiles. In order to determine which aspects of reflected waves are more realistic, it is also important to apply terrain corrections to profiles.
6. Outputting analyzed profiles at high resolution. Experience shows that it is desirable to output profiles which have as high a resolution as possible, and that comparisons should be made using images that are as clear as possible. The same rule applies to section photos that are to be used for comparisons.

In summary, comprehensive surveys should be carried out that combine measurements from excavations as well as GPR.

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Fig. 1-10: Correcting and producing by the author