Report of a three-dimensional survey and GPR research on the Sakitama-Futagoyama Tumulus in Saitama Prefecture, Japan

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Abstract

This is a preliminary report of non-destructive research combining three-dimensional measurement and ground penetrating radar (GPR) on the Sakitama-Futagoyama Tumulus, the largest keyhole-shaped Kofun tomb in Saitama Prefecture. The research aimed to obtain point cloud and GPR data in order to understand an accurate three-dimensional structure of the tumulus. The results revealed the original structure, which does not show similarities with the Daisen Tumulus, the largest kofun tomb in Japan, as previous studies suggest. This research was also part of the workshop for Syrian experts organized by the Archaeological Institute of Kashihara, Nara Prefecture and the United Nations Development Program (UNDP). Therefore, this report is the result of a collaboration between Japan and Syria.

Introduction

A three-dimensional survey and ground penetrating radar (GPR) research were carried out on a mound tomb of the Kofun period by the Waseda Institute for Advanced Study in association with the Department of Archaeology, Waseda University in December 2018. The non-destructive research aimed to obtain data to understand an accurate three-dimensional structure of the Sakitama-Futagoyama Tumulus built in the late Kofun period (Mid-6th century AD), the largest keyhole-shaped tomb in Saitama Prefecture. This research was part of a workshop in the *Silk Road Friendship Project: Saving Syrian Cultural Heritage for the Next Generation* implemented by the Archaeological Institute of Kashihara, Nara Prefecture, with funds provided by the United Nations Development Program (UNDP). Taking the practical training on the site, Syrian experts acquired new digitalized technologies for their tasks of documentation and conservation of archaeological heritage. Therefore, this report is the result the result of collaborative work between Japan and Syria.

1. Organization and progress of the research

The research organization in 2018 was as follows.

Site Name: Futagoyama Tumulus in Sakitama Kofun group (designated as a National Historic Site)

Site Location: 5170 Sakitama, Gyoda City, Saitama Prefecture, Japan

Research Period: 15 to 28 December, 2018

Leading Institute: Waseda Institute for Advanced Study

Supporting Institute: Department of Archaeology, Waseda University and Institute of East Asia Archaeology for Walled City and Silk Road, Waseda University

Field Directors: Masahiro BABA (Associate Professor, Waseda Institute for Advanced Study) and Masayoshi JOKURA (Associate Professor, Department of Archaeology, Waseda University)

Supervisors: Jiro KONDO, Ryuzaburo TAKAHASHI and Shuichiro TERASAKI (Professors, Department of Archaeology, Waseda University); and Yukitsugu TABATA (Associate Professor, Department of Archaeology,

Waseda University)
Syrian experts: Jihad ABU KAHLA, Saad YOUSSEF and Daed NEMAH (Directorate General of Antiquities and Museums of Syria); Khozama AL BAHLOUL (Department of Antiquities of Latakia, Syria)
Participants: Yama NAWABI (Assistant, AIZU Museum, Waseda University); Ikuo DENDA, Yuna ISHII, Ahmed ABDELAAL and Hirokazu SUZUKI (Graduate students, Department of Archaeology, Waseda University); Aya KANAI (Graduate student, Department of Art and Design, Joshibi University); Shiori KAWABE, Wataru TAKAHASHI, Youtarou TAKAHASHI, Yuichiro SEKINE and Aya KISHIDA (Undergraduate students, Department of Archaeology, Waseda University); Muhamed Asem AlMANSOUR (Graduate School of Medicine, the University of Tokyo Hospital); Thuka KUOKA (Research student, SOKA University); and Baraa ENEZAN (Graduate student, Department of Human Science, Tokyo Metropolitan University)
Collaborators: Akito MURATA, Kenichi OKAMOTO, Kotoko YAMADA, Ayumi NAKAI, Motofumi AOSASA and Motohiro KAKIAGE (Museum of the Sakitama Ancient Burial Mounds); SHINODA Taisuke (Education Board at Gyoda City); Eiji FUJITA, Kiyoshi FUKUDA, Tetsu OOTANI and Hiroshi AOKI (Saitama Cultural Deposits Research Corporation); Masanori OKISHIO (Co., Ltd. Reakkusu); Ichiro KATO (Archives and Mausolea Department, Imperial Household Agency); Harumitsu AKIMOTO (Society for Haniwa study); Kazuo MIGISHIMA (Gunma Prefectural Museum of History); and Takashi IMAI (Kofun-tei restaurant)

Prior to the research, a *current status change* application was submitted to the Education Board at Gyoda City, which was approved on 8 November, 2018. On the site, Syrian experts mainly operated the GPR, while the Japanese participants took charge of the three-dimensional measurement using five Layout Navigators (LN) and an Unmanned Aerial Vehicle (UAV).

The research progress in 2018 was as follows.

15 Dec: Transferring the equipment by car from Waseda University to the site and meeting at the Museum of the Sakitama Ancient Burial Mounds. In the afternoon, work began with the traverse and leveling survey as well as the posting to announce the UAV schedule for the neighborhood.
16 Dec: Measurement of the traverse and leveling was completed, and the UAV survey began.
17 Dec: Three-dimensional survey with LN on the tumulus surface and GPR (using 450 MHz) in the Area FT-N began.
18 Dec: LN and UAV surveys and GPR in the Area FT-P continued.
19 Dec: LN and UAV surveys and GPR in the Area FT-J continued.
20 Dec: LN and UAV surveys and GPR (using both 160 MHz and 450 MHz) in the Area FT-K continued.
21 Dec: LN and UAV surveys and GPR in the Area FT-L continued.
22 Dec: LN survey and GPR in the Areas FT-Q, R and S continued.
23 Dec: LN survey and GPR in the Areas FT-T, U, V, W and X continued.
24 Dec: LN survey and GPR (using 160 MHz) in the Area FT-C continued.
25 Dec: LN and UAV surveys continued. GPR workshop was held at the Museum.
26 Dec: LN and UAV surveys and GPR in the Areas FT-b, K, Y and Z continued.
27 Dec: LN and UAV surveys and GPR in the Areas FT-a and I continued. In the afternoon, all members visited the nearby Kofun tombs and the Institute of Saitama Cultural Deposits Research Corporation.
28 Dec: The original condition of the site was restored by pulling out all measuring stakes and meeting at the Museum in the morning. Thereafter, the equipment was transported to the University, and all work was completed in the evening.

2. Purpose and method of the research

The Department of Archeology, Waseda University and Institute of East Asia Archaeology for Walled City and Silk Road, Waseda University have been conducting non-destructive research combining three-dimensional digital measurement and a GPR survey in Japan and abroad. In particular, they have ample research experience and achievements regarding the Kofun tombs (Jokura 2015, 2018; Jokura and Aoki 2016; Jokura et al. 2017). As part of

this program, a GPR survey on the Futagoyama Tumulus was carried out by Baba and Jokura in collaboration with the Education Boards at Saitama Prefecture and Gyoda City in 2017 (Jokura et al. 2018). This research revealed important aspects such as the location and shape of the burial chamber, the plan of the surrounding moats and three-dimensional structure of the mound. To obtain further information, integrated research was conducted in 2018 led by the Waseda Institute for Advanced Study, who contracted with the Archaeological Institute of Kashihara, Nara Prefecture to host Syrian experts. The research objectives, therefore, were to fully understand the three-dimensional structure through the most advanced digital technology and provide the opportunity for Syrians and Japanese students to study the technology at the site.

The research comprised three operations: 1) three-dimensional measurement of the Futagoyama Tumulus with LN, 2) GPR of the Futagoyama Tumulus, and 3) topographical survey of the Sakitama Kofun group using UAV. Plates 1-11 show scenes of work.

1) Although a digitalized map of the Futagoyama Tumulus created by a three-dimensional scanner has recently been published by the Education Board at Saitama Prefecture (2018), it is not sufficient to be used for archaeological studies. This is because the data were acquired when the surrounding moats were filled with water, and small undulations such as robbery holes at the top of the mound could not be accurately represented. Therefore, we re-surveyed using our original methodology. First, the reference points (W1-18) were set in an open traverse using the standard points (No.4 and No.5) and 501 as the backsight. Then, based on No.4 (altitude of 17.410 m) and No.5 (altitude of 18.200 m) as the benchmark, the leveling traverse gave altitude values to the reference points (Fig. 1 and Table 1). After the survey area on the tumulus was divided into eight subareas (A to H), the three-dimensional measurements with five LNs were conducted for a point cloud data analysis. In total, 279,809 points were acquired (Fig. 2). The data were imported into ArcGIS software in which geo-referencing was processed with a map provided by the Education Board at Saitama Prefecture using No.4, No.5 and 501 as the ground control points. A Triangulated Irregular Network (TIN) and Digital Elevation Model (DEM) were created, based on which a 0.1 m contour was described. The contour lines were combined with a slope map created with Natural Neighbor interpolation (0.2 cell size), making the final three-dimensional digital map (Fig. 3).

2) GPR research conducted in 2017 located a horizontal stone chamber dug into the east side of the round mound (Fig. 4). Therefore, the work this season concentrated on the whole mound, surrounding moats and bank. To enhance the accuracy of data and efficiency of the operation, the surface of the mound was divided into 28 small survey areas (Fig. 1). Using Total Stations, each area was created as a rectangular shape. The GPR operation was carried out on 0.5-meter interval lines in the area. A MALA GX system with a 450 MHz antenna was employed to collect all data. The data were processed using GPR Slice software in which the Time Slices were created after only filter processing. In each area, several Time Slices were selected and synthesized through overlay processing, providing comprehensive subsurface maps. The final map was superimposed on the digital map (Fig. 4).

3) Topographic modeling using UAV has recently been popularized. In August 2018, the Institute of East Asia Archaeology for Walled City and Silk Road, Waseda University carried out an aerial survey of the Futagoyama Tumulus using Phantom 4 pro, which was manufactured by DJI, providing high-quality data. Therefore, we conducted the UAV aerial survey over the entire area of the Sakitama Kofun group with Phantom 4 pro flying at an altitude of around 30 meters. The acquired images were processed using AgiSoft Metashape. All ground control points were measured and converted into the world coordinate system, from which the DEM was created and analyzed with ArcGIS. The results will be published in another journal.

3. Results of the research

The results of the three-dimensional measurement and GPR research are summarized here. As shown in Fig. 3, our survey provides a highly accurate and detailed topographical map. Previous comprehensive studies suggested that the shape of the mound is similar for the Futagoyama Tumulus and Daisen Tumulus of the mid-Kofun period in Osaka Prefecture, which is the largest Kofun in Japan (e.g. Ueda 1996; Tsukada 2002). However, our digitalized survey is not consistent with this suggestion. The map shows that a raised floor at the entire fringe of the mound was

reconstructed. Furthermore, the edges were modified with piling soils during the site maintenance project in the last century, as water in the surrounding moat was drawn off by the Education Board at Saitama Prefecture. Moreover, it can be observed that the mound itself was constructed with a two-stage structure producing a terrace in the middle. The terrace is clearly seen in the round mound and partially in the rectangular mound. The map indicates other features of the tumulus: the round mound is smaller, the rectangular mound is larger, and the mid part is narrower than previously thought. These features indicate that the Futagoyama Tumulus is not related to the Daisen Tumulus, but originated from another route such as the Imashirozuka Tumulus in Osaka Prefecture.

The GPR research shown in Fig. 4 clarifies the original structure of the mound. Reacting to the higher amount of moisture in the soil, the map clearly shows the two-stage structure of the mound and terrace around it. It also discriminates between the reconstructed floor at the bottom and original fringe of the mound. On the front side of the rectangular mound are observed destruction traces, which may be due to the construction of medieval tombs and a World War II bomb shelter. While the surrounding moats and bank with a platform were modified in the last century, their original plans and structures can be recognized on the GPR map.

Final Remarks

This paper reported the preliminary results of non-destructive research on the Futagoyama Tumulus conducted in 2018 as part of the workshop for Syrian experts. The research provided point cloud and GPR data, which were adequate to analyze the three-dimensional structure of the tumulus. Further research results from UAV survey and ongoing excavation by the Education Board at Saitama Prefecture will be reported in Japanese to present a comparative analysis of the design principles of Kofun tumuli.

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Source of illustrations

Figures 1-4 were created with ArcGIS software using measurement data. The Education Board at Saitama Prefecture provided the base map.

Tables 1-2 were produced from measurement data.

Photographs of Plates 1-11 were taken by the Department of Archaeology, Waseda University.

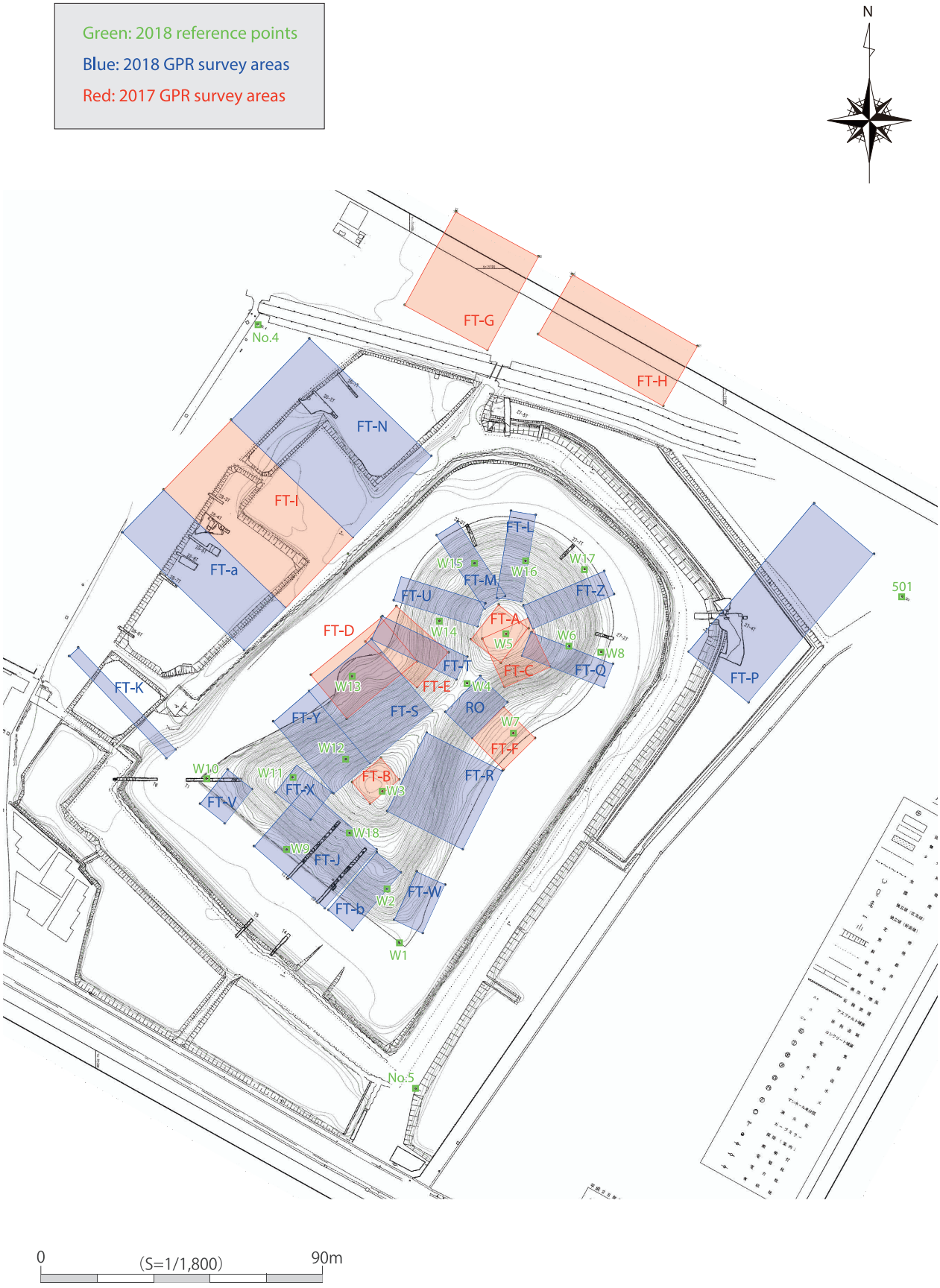

Fig 1 Location of reference points and GPR survey areas at Futagoyama Tumulus

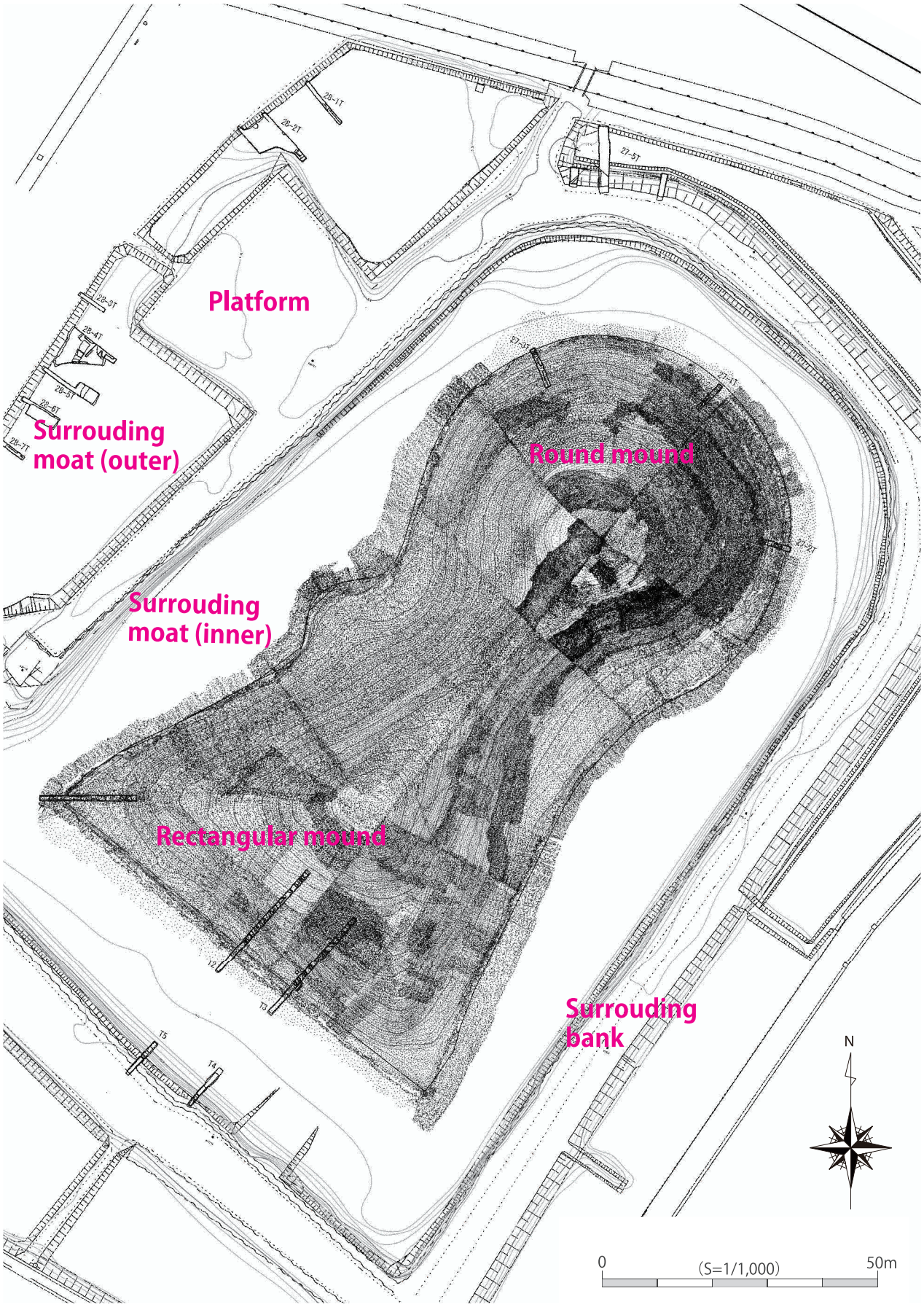

Fig 2 Topographical map of Futagoyama Tumulus createrd by three-dimensional point cloud data (279,809 points)

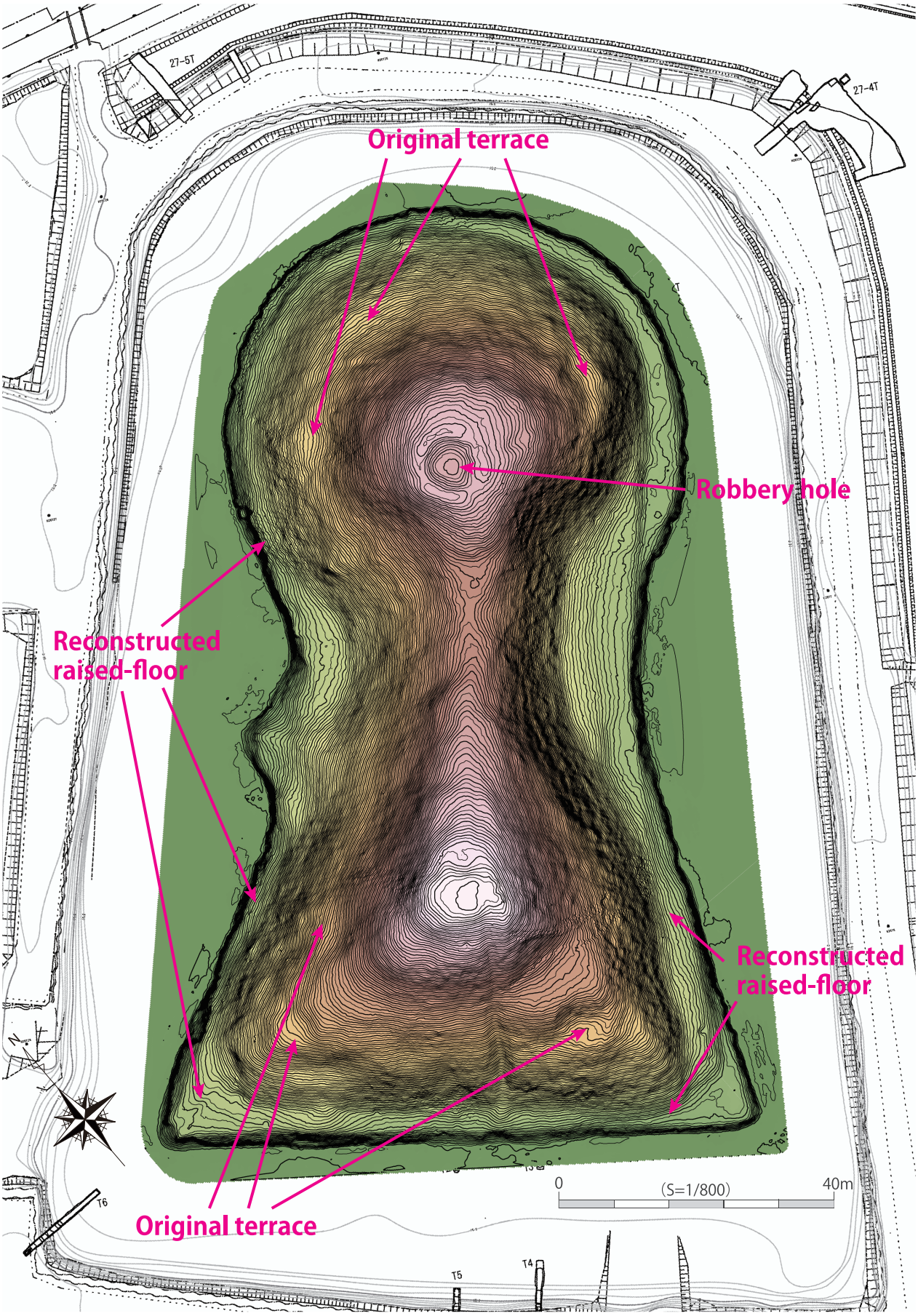

Fig 3 Results of three-dimentional digital measurment on Futagoyama Tumulus (10 cm contour + 20 cm slope)

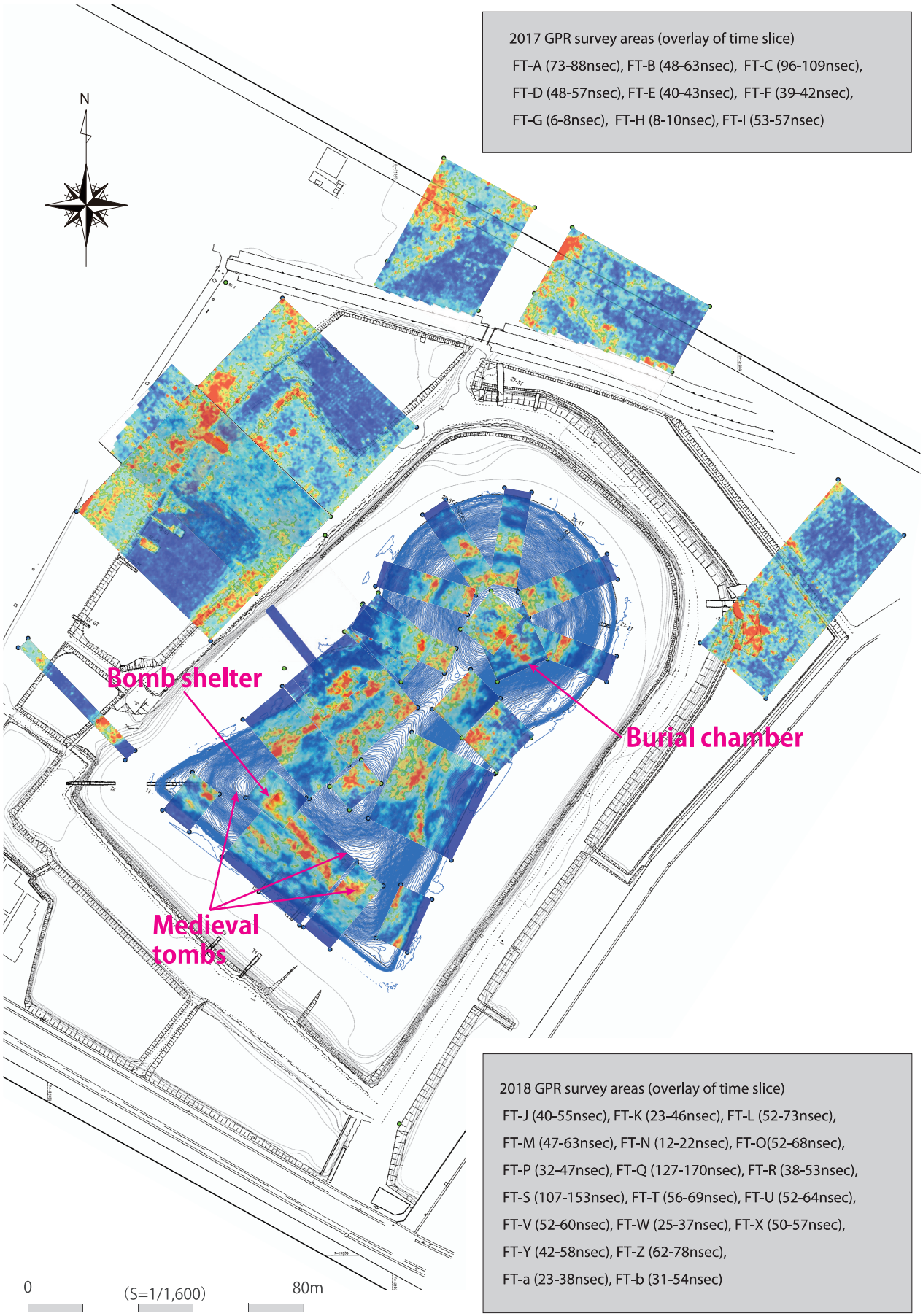

Fig 4 Results of measurement and GPR survey on Futagoyama Tumulus

Table 1 Reference points for measurement at Futagoyama Tumulus

Point	X	Y	Z
No.2	13695.985	-31975.774	18.309
No.3	13786.805	-31891.616	18.219
No.4	14182.044	-31948.424	17.41
No.5	13938.183	-31898.135	18.2
501	14095.155	-31742.9	17.981
※JGD2000. 9 sysytem.			
W1	13984.634	-31903.283	18.583
W2	14001.826	-31907.244	23.473
W3	14033.084	-31908.79	31.864
W4	14067.487	-31881.667	27.528
W5	14083.306	-31869.229	29.689
W6	14079.346	-31849.087	24.152

Point	X	Y	Z
W7	14051.607	-31866.877	19.194
W8	14077.454	-31838.894	18.908
W9	14014.492	-31939.283	19.182
W10	14037.076	-31964.806	19.21
W11	14037.447	-31937.294	25.731
W12	14043.327	-31920.446	27.894
W13	14069.785	-31918.316	19.182
W14	14087.406	-31890.479	24.151
W15	14105.913	-31879.293	23.021
W16	14106.688	-31863.007	23.052
W17	14103.907	-31844.215	19.009
W18	14019.733	-31919.292	26.274

Table 2 Survey points for GPR at Futagoyama Tumulus ①

Point	X	Y	Z
A1	14081.487	-31880.434	—
A2	14074.121	-31870.919	—
A3	14085.076	-31862.168	—
A4	14092.584	-31871.552	—
B1	14035.93	-31918.333	—
B2	14029.058	-31912.581	—
B3	14036.776	-31903.372	—
B4	14043.648	-31909.137	—
C1	14081.818	-31876.731	—
C2	14066.293	-31869.715	—
C3	14072.89	-31855.15	—
C4	14088.395	-31862.119	—
D1	14070.198	-31931.471	—
D2	14056.267	-31920.06	—
D3	14074.631	-31897.605	—
D4	14088.523	-31909.012	—
E1	14080.819	-31914.125	—
E2	14066.266	-31897.611	—
E3	14077.485	-31887.696	—
E4	14092.08	-31904.201	—

Point	X	Y	Z
29-14	14060	-31870	—
29-16	14050	-31880	—
29-17	14050	-31860	—
29-18	14040	-31870	—
G1	14188.235	-31901.53	—
G2	14173.861	-31875.212	—
G3	14203.715	-31858.894	—
G4	14218.094	-31885.221	—
H1	14175.072	-31808.16	—
H2	14197.964	-31848.045	—
H3	14178.887	-31858.995	—
H4	14156.003	-31819.111	—
I1	14091.822	-31939.587	—
I2	14114.134	-31918.048	—
I3	14151.597	-31956.925	—
I4	14129.325	-31978.427	—

Table 2 Survey points for GPR at Futagoyama Tumulus ②

Point	X	Y	Z
J1	14015.509	-31949.591	17.496
J2	13995.707	-31927.03	17.494
J3	14014.465	-31910.561	26.511
J4	14034.255	-31933.102	26.563
K1	14076.172	-32008.549	17.809
K2	14043.58	-31977.542	17.429
K3	14046.353	-31974.651	17.438
K4	14078.917	-32005.668	17.766
L1	14094.965	-31872.277	28.475
L2	14093.6	-31864.407	28.49
L3	14121.215	-31859.771	17.422
L4	14122.543	-31867.654	17.465
M1	14114.721	-31891.368	17.403
M2	14091.309	-31875.997	28.986
M3	14095.614	-31869.419	28.303
M4	14119.083	-31884.678	17.472
N1	14151.585	-31956.928	17.768
N2	14114.115	-31918.077	18.223
N3	14140.062	-31893.102	18.075
N4	14177.509	-31931.967	17.667
O1	14058.353	-31888.58	27.695
O2	14049.997	-31879.993	20.723
O3	14061.455	-31868.833	20.739
O4	14069.802	-31877.434	27.628
P1	14077.544	-31811.003	18.564
P2	14061.41	-31791.906	17.229
P3	14108.78	-31751.891	17.728
P4	14124.912	-31770.99	17.673
Q1	14076.374	-31864.167	28.513
Q2	14066.231	-31838.064	17.472
Q3	14073.672	-31835.169	17.564
Q4	14083.839	-31861.267	29.505
R1	14026.682	-31907.122	30.283
R2	14014.545	-31883.033	17.482
R3	14039.535	-31870.435	17.402
R4	14051.673	-31894.517	28.587
S1	14058.761	-31892.793	27.803
S2	14042.019	-31912.723	30.626

Point	X	Y	Z
S3	14065.002	-31932.014	17.456
S4	14081.715	-31912.12	17.477
T1	14081.712	-31912.113	17.476
T2	14068.731	-31885.079	27.077
T3	14075.96	-31881.619	27.732
T4	14088.911	-31908.663	17.478
U1	14093.97	-31905.045	17.479
U2	14085.674	-31878.318	29.473
U3	14093.301	-31875.934	28.47
U4	14093.97	-31905.045	17.479
V1	14029.049	-31966.787	17.497
V2	14022.794	-31958.954	17.515
V3	14033.711	-31950.246	22.24
V4	14039.981	-31958.048	19.74
W1	13991.99	-31904.893	19.178
W2	13987.796	-31895.815	17.404
W3	14003.217	-31888.646	17.474
W4	14007.426	-31897.685	20.684
X1	14032.684	-31942.698	24.372
X2	14024.044	-31931.695	24.933
X3	14032.676	-31924.901	29.169
Y1	14055.342	-31943.493	17.482
Y2	14032.377	-31924.224	29.265
Z1	14092.314	-31863.708	28.664
Z2	14084.961	-31860.564	28.872
Z3	14095.946	-31834.821	17.45
Z4	14103.292	-31837.956	17.353
a1	14115.654	-31991.645	17.79
a2	14078.126	-31952.781	18.309
b1	13995.134	-31925.839	17.503
b2	13988.719	-31918.19	17.597
b3	14007.114	-31902.771	23.705
b4	14013.546	-31910.47	26.352

Plate 1 Measuring reference points with TS

Plate 2 Setting up GPR area

Plate 3 Operating GPR on Tumulus

Plate 4 Operating GPR on surrounding moat (inner)

Plate 5 Aerial view of Sakitama Kofun group (left: Inariyama, mid: Shogunyama, right: Futagoyama)

Plate 6 UAV measuring

Plate 7 Controlling GPR

Plate 8 Measuring tumulus

Plate 9 Research team 2018

Plate 10 Visiting and discussing at “Saimaibun”

Plate 11 Aerial view of Futagoyama Tumulus