

Second International Conference
on
Archaeological Prospection



1997

Ise, Japan

Second International Conference
on
Archaeological Prospection

1997
September 9 - September 12
Ise, Japan

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Tokyo Institute of Technology
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Center for Archaeological Research, Mie Prefecture
Ise City
University of Mie
Saiku Historical Museum
Toba National College of Maritime Technology

Cosponsorship

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The Society of Exploration Geophysicists of Japan
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Details for Participants

1. Registration

Registration will be held on Tuesday, September 9, at the Ise City Hotel from 6 pm to 8 pm. Drinks will be available during registration.

2. Information about the Conference Hall

The name and address of the conference hall are:

Sun Arena, 4383-4 Kamodani, Asama cho, Ise shi

Tel. +81-596-22-7700, FAX. +81-596-22-7710

Since Sun Arena is located outside of Ise City, a shuttle bus will leave the Ise City Hotel Annex to the conference hall in the morning, and return to the Hotel Annex in the evening. It takes half an hour.

On Wednesday, September 10, the bus will not return until after the welcome party, to be held at the conference site. There will be no chance to return to the Ise City Hotel Annex until the party ends, at 8 pm. For personal access to the Hall, taxi is also available from the hotels. The fare costs approximately 3,000 yen.

3. Oral Presentations

Speaking time is 15 minutes, plus 5 minutes for discussion. To notify speakers of the end of their time, a bell will ring once at 13 minutes, twice at 15 minutes, and three times at 19 minutes.

One OHP machine and two slide projectors are available for use with oral presentations.

On Tuesday, September 9, from 16:00-20:00 at the Ise City Hotel, interpreters would like to meet the speakers for a preview of their presentations in order to familiarize themselves with the subject matter.

4. Poster sessions

Poster presenters will have an opportunity to introduce their posters orally during a Poster Preview Session on Wednesday, September 10, from 11:50-12:10 and Thursday, September 11, from 12:00 - 12:20. Presenters are asked to bring a single transparency (OHP printout) for the introduction. Each poster presenter will be given a 60 second time slot for this brief oral introduction.

The board size for each poster is 90 cm wide by 110 cm high. Please note that the board has a hard surface, and will not take pins or thumb tacks. Poster material must be fixed in place with tape. Very large items may be hung from fixtures at the top of the board.

POSTERS WILL BE DIVIDED INTO TWO GROUPS.

The Poster Session for odd numbered posters will be held on Wednesday, September 10, from 14:20 - 15:40, and for even numbered posters on Thursday, September 11, from 12:20 - 14:20. Please follow the numbers given in the Abstracts.

The organizing committee requests to set up all posters by Wednesday 10:10, and display them until Thursday 16:30.

5. Welcome party

A modest welcome party will be given, through the courtesy of Mie Prefecture, on Wednesday, September 10, in the same building where the conference is held.

6. Lunch

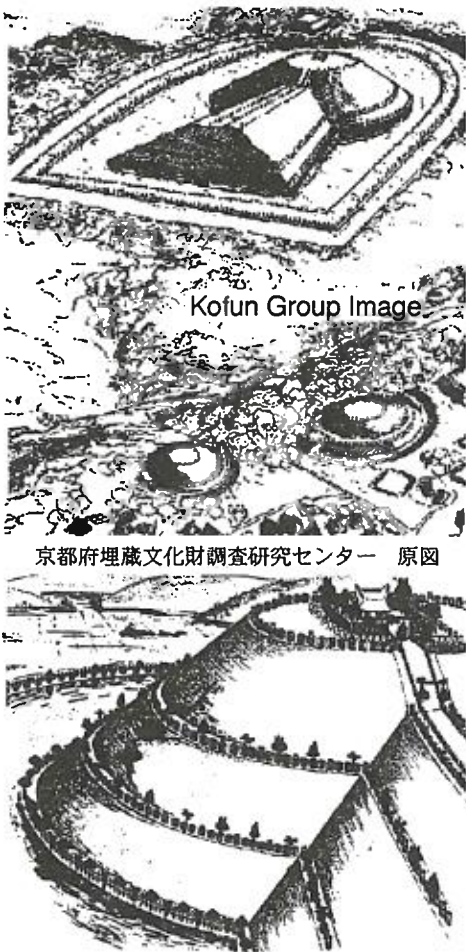
Since the Sun Arena conference hall is located away from the city center, we will provide several kinds of foods for free lunch (but donations to help cover the cost of the food are very much welcome). The conference hall also has a small restaurant, which provides some choice for those who prefer to make their own arrangements for lunch.

7. Tea & Coffee

Tea and coffee will be available free of charge during the conference at all times.

8. Tour (Excursion)

Each participant should have received a circular from Kinki Nippon Tourist Co., regarding the optional excursion. The course will take in the Ise Shrine, Mikimoto Pearl Island, and the Saiku Archaeological Museum.



Haniwa is a type of clay figure which was fired at a relatively low temperature. They are commonly recovered from mounded tombs dated to the Kofun Period (ca. A.D. 4-6 C.) in Japan. These figures were typically placed close together in a circular or rectangular plan around the perimeter of individual burial mounds. These arrangements consisted of single, double or triple *haniwa* lines. The *haniwa* illustrated in the cover logo was excavated from Jokobadani Mound No.4 in Mie Prefecture. Most archaeologists believe that this *haniwa* represents a female shaman or a servant to the gods.

**Second International Conference
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Ise, JAPAN**



1997

Tuesday (September 9)

(18:00 ~ 20:00)

Registration: Ise City Hotel

Wednesday (September 10)

(9:00 ~ 9:20)

Opening Session

(9:20 ~ 10:10)

Plenary Session

Archaeological Prospection in Perspective

Mark Pollard and Arnold Aspinall, Department of Archaeological Sciences, University of Bradford, U.K.

Break and Souvenir Picture (10:10 ~ 10:30)

(10:30 ~ 11:50)

1 Shallow Depth Determination

Chair : Gregory Tsokas, Geophysical Lab., Aristotelian University of Thessaloniki, Greece

(10:30 ~ 10:50)

1 . Quantitative Integration of Geophysical Methods in Archaeological Prospections

Cammarano Fabio, Patella Domenico and Salvatore Piro, Istituto per le Tecnologie Applicate ai Beni Culturali, C.N.R., Italy

Mauriello Paolo and Patella Domenico, Dipartimento di Geofisica e Vulcanologia, Univ. Federico II, Italy

(10:50 ~ 11:10)

**2 . Investigating the True Resolution of GPR Data in Archaeological Surveys:
Measurements in a Sandbox**

Jüerg Leckebusch, Institute of Geophysics, Swiss Federal Institute of Technology, Switzerland

- (11:10 ~ 11:30)
3. Archaeological Survey Using Pulse Compression Subsurface Radar
- Yoshiyuki Tomizawa**, Gunma National College of Technology, Japan
Masanobu Hirose and **Ikuo Arai**, The University of Electro-communications, Japan
Tsutomu Suzuki, Nippon Institute of Technology, Japan
Takeichiro Ohhashi, OYO Corporation, Japan

- (11:30 ~ 11:50)
4. Underground Tomogram from In-Situ Data Measured in the Cross-Borehole Configuration
- Jung-Woong Ra** and **Seong-Kil Park**, Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Korea

**Poster Preview (11:50 ~ 12:10)
(Odd Number Posters)**

Chair : Kazunari Adachi, Faculty of Engineering, Yamagata University, Japan

Noon Break (12:10 ~ 13:20)

- (13:20 ~ 14:40)
- # 1 **Shallow Depth Determination (Continued)**
- Chair : Jüerg Leckebusch**, Institute of Geophysics, Swiss Federal Institute of Technology, Switzerland

- (13:20 ~ 13:40)
5. The Geophysical Prospection of Medieval Iron-Smelting Sites in North-East Yorkshire and Their Interpretation
- Robert W. Vernon**, **J. G. McDonnell** and **A. Schmidt**, Department of Archaeological Sciences, University of Bradford, U.K.

- (13:40 ~ 14:00)
6. 3D Imaging of Monumental Tombs buried in Keyhole-shaped Tumuli by Electrical Prospecting
- Keisuke Ushijima**, **Hideki Mizunaga** and **Chika Sakamoto**, Exploration Geophysics, Faculty of Engineering, Kyushu University 36, Japan

- (14:00 ~ 14:20)
7. Application of Geophysical Exploration Methods to Archaeological Investigation of Japanese Castles
- Megumi Kobayashi** and **Fumio Karube**, Archaeological Geophysics Department, OYO Corporation, Japan

- (14:20 ~ 14:40)
8. Transformation of the Resistivity and Magnetic Anomaly Patterns by Inversion Filtering
- Gregory N. Tsokas** and **Panagiotis Tsourlos**, Geophysical Laboratory, Aristotelian University of Thessaloniki, Greece
Constantinos Papazachos, Institute of Engineering Seismology and Earthquake Engineering, Greece

32. **Between Pulse Radar and FM-CW Radar**
Masatsugu Shimizu and Hiroyuki Kamei, Department of Computer Science, Tokyo Institute of Technology, Japan
33. **Excavation of 6th-7th century A.D. Cemeteries in Miyazaki, Kyushu, Japan**
Masaaki Okita, Walter Edwards and Hisao Kuwabara, Department of Archaeology, Tenri University, Japan
Dean Goodman, Geophysical Archaeometry Lab., Univ. of Miami Japan Division, Japan
34. **Soil Permittivity Measurement Using Wire Antennas for Underground Radar**
Koichi Ito, Lira Hamada and Kazuyuki Saito, Department of Electrical & Electronics Engineering, Faculty of Engineering, Chiba University, Japan
Hiroyuki Kamei, Dept. of Computer Science, Tokyo Institute of Technology, Japan
35. **Signal Processing of Subsurface Radar Characteristics Using FDTD Method**
Yasumitsu Miyazaki and Koichi Takahashi, Department of Information and Computer Sciences, Toyohashi University of Technology, Japan
36. **Characteristics of Waveform Obtained by Pulse Type Subsurface Radar**
Kihachiro Taketomi, Gifu National College of Technology, Japan
Yasumitsu Miyazaki, Toyohashi University of Technology, Japan
37. **Underground Imaging Using Shear Waves**
Tsuneyoshi Sugimoto, Hiroki Saitou and Motoyoshi Okujima, Faculty of Engineering, Toin University of Yokohama, Japan
38. **Combined Study with Electromagnetic Prospecting and Rockmagnetic Analysis on Archaeological Sites**
Takao Uno and Kaname Maekawa, Department of Archaeology, Toyama University, Japan
Hideo Sakai and Kimio Hirooka, Department of Earth Sciences, Toyama University, Japan
39. **Study of Remote Sensing Infrared Method of Underground Object by Means of Thermal Image Method**
Yoshizo Okamoto, Faculty of Engineering, Towa University, Japan
Chunliung Liu, Faculty of Engineering, Ibaraki University, Japan
40. **A New Automatic Resistivity Measurement System and Correction of Ground Surface Concavity**
Hideo Akabane and Masahiro Agu, Department of Media and Telecommunication Engineering, Ibaraki University, Japan
Yasuaki Teramachi, Department of Computer and Information Science, University of Industrial Technology, Japan
Koji Noguchi, Department of Mineral Resources Engineering, School of Science & Engineering, Waseda University, Japan
Yoshiwo Okamoto, Dept. of Electric Engineering, Chiba Institute of Technology, Japan

41. High-Resolution Magnetic Data Acquisition, Processing and Inversion
Joerg Herwanger, Jüerg Leckebusch, Hansruedi Maurer, Heinrich Horstmeyer and Alan Green, Institute of Geophysics, Swiss Federal Institute of Technology, Switzerland
42. The Characteristic Fatty Acid, DHA, discovered on the Pottery at the Ancient Tomb of Saitobaru in Japan
Shun Wada and Takaki Abe, Food Science and Technology, Tokyo University of Fisheries, Japan
43. Prospection of Burnt Soil by Electron Spin Resonance (ESR)
Atsushi Tani, Jens Bartoll and Motoji Ikeya, Department of Earth and Space Science, Graduate School of Science, Osaka University, Japan
Takashi Inada, Department of Archaeology, Faculty of Letters, Okayama University, Japan
44. Thermal History and Dating Study of the 600,000-Year-Old Stone Tool by ESR
Atsushi Tani, Jens Bartoll and Motoji Ikeya, Department of Earth and Space Science, Graduate School of Science, Osaka University, Japan
K. Komura, Low Level Radioactivity Lab., Faculty of Science, Kanazawa University, Japan,
H. Kajiwara, Tohoku Fukushi University, Japan
S. Fujimura, T. Kamada and Y. Yokoyama, Tohoku Paleolithic Institute, Japan
45. Chemical Approach for Magnetic Prospection of the Burned Soil in Remains: Concentration Changes of Ironoxides in Burned Soils Studied by Magnetic Susceptibility, ESCA, ESR and ICPMS Measurements
Tokuko Watanabe, Department of Food Science and Technology, Tokyo University of Fisheries, Japan
Kazuya Takahashi, Nuclear Chemistry Laboratory, The Institute of Physical and Chemical Research, Japan
Riichirô Chûjô, Department of Materials Engineering, Teikyo University of Science and Technology, Japan

Break and Poster Session (14:40 ~ 15:40)
(Odd Number Posters)

(15:40 ~ 16:40)

2 The Interplay Between Display and Interpretation

Chair : Dean Goodman, Geophysical Archaeometry Laboratory, University of Miami Japan
Division, Japan

(15:40 ~ 16:00)

9. **Characteristics of a Shape Estimation Algorithm for Small Subsurface Objects**

Toru Sato, Kazuhisa Takemura and Pan Huimin, Department of Electronics and
Communication, Kyoto University, Japan

(16:00 ~ 16:20)

10. **Non-Linear Inversion Algorithm in Archaeological Prospection**

Rocco Pierri and Giovanni Leone, Seconda Università di Napoli, Dipartimento di
Ingegneria dell' Informazione, Italy

Tommaso Isernia, Università di Napoli 'Federico II', Dipartimento di Ingegneria
Electronica, Italy

(16:20 ~ 16:40)

11. **Application of Geophysical Methods and Graphic Representation Techniques
to Investigation of Ancient Temples**

Miho Tohge, Fumio Karube, Megumi Kobayashi and Akio Tanaka, Archaeological
Geophysics Department, OYO Corporation, Japan

Welcome Party (17:00 ~ 20:00)

Thursday (September 11)

(9:00 ~ 10:00)

3 Aspects of Remote Sensing in Archaeology

Chair : Jorg Fassbinder, Bayer. Landesamt f. Denkmalpflege Ref. Archaeological
Prospection and Aerial Archaeology, Germany

(9:00 ~ 9:20)

12. **Remote Sensing in Desert Archaeology in China**

Jianguo Liu, Institute of Archaeology, Chinese Academy of Social Sciences, China

(9:20 ~ 9:40)

13. **The Roman Town of Vieil-Evreux : an Integrated Approach (multi-scale and
multi-method)**

Michel Dabas and Bertrand Chazaly, Centre National de la Recherche Scientifique
(CNRS) , France

Laurent Guyard, Conseil Général de l'Eure, Mission à l'action culturelle, France

(9:40 ~ 10:00)

14. Remote Sensing and Archeological Prospection of the Camino Real from Taos, New Mexico, to Parral and Chihuahua, Mexico

John Peterson, Department of Sociology and Anthropology, The University of Texas at El Paso, U.S.A.

R. B. Brown, Department of Geological Sciences, The University of Texas at El Paso, U.S.A.

Nicholas Pingitore, Instituto Nacional de Antropologia e Historia, Mexico

Break (10:00 ~ 10:20)

(10:20 ~ 12:00)

4 Soil Science in Prospection

Chair : Armin Schmidt, Department of Archaeological Sciences, University of Bradford, U.K.

(10:20 ~ 10:40)

15. Soil Magnetism and Magnetic Prospection

Jorg Fassbinder, Bayer. Landesamt f. Denkmalpflege Ref. Archaeological Prospection and Aerial Archaeology, Germany

(10:40 ~ 11:00)

16. Molecular Species Detected in Magnetic Prospection with the Aid of Electron Spectroscopy (ESCA)

Riichirô Chûjô, Department of Materials Engineering, Teikyo University of Science and Technology, Japan

(11:00 ~ 11:20)

17. Magnetic Moments in Prehistory

Catherine Batt and **Steve Dockrill**, Department of Archaeological Sciences, University of Bradford, U.K.

(11:20 ~ 11:40)

18. Measurement Results on Electromagnetic Characteristics of Soil using the Dipole Antenna

Yoshiyuki Wakita, **Yoshio Yamaguchi** and **Hiroyoshi Yamada**, Department of Information Engineering, Faculty of Engineering, Niigata University, Japan

(11:40 ~ 12:00)

19. Electron Spin Resonance (ESR) as a Method of Dating and Assessment of Environment

Motoji Ikeya and **Atsushi Tani**, Department of Earth and Space Science, Graduate School of Science, Osaka University, Japan

Poster Preview (12:00 ~ 12:20)
(Even Number Posters)

Chair : Hiroyuki Kamei, Dept. of Computer Science, Tokyo Institute of Technology, Japan

Noon Break and Poster Session (12:20 ~ 14:30)
(Even Number Posters)

(14:30 ~ 15:30)

5 Archaeological Propection in Action

Chair : Michel Dabas, Centre National de la Recherche Scientifique (CNRS) , France

(14:30 ~ 14:50)

20. Comparative Study of Magnetometer Results from a Kiln Site Near Ooto, Japan

Armin Schmidt, Department of Archaeological Sciences, University of Bradford, U.K.

Hiroyuki Kamei, Department of Computer Science, Tokyo Institute of Technology, Japan

Yasushi Nishimura, Nara National Cultural Properties Research Institute, Japan

(14:50 ~ 15:10)

21. Geophysical Survey of Hirui-Otsuka Mounded Tomb in Ogaki, Japan

Hiroyuki Kamei and **Yuzo Marukawa**, Department of Computer Science, Tokyo Institute of Technology, Japan

Hiroshi Kudo, Sakurakoji Electric Corporation, Japan

Yasushi Nishimura, Nara National Cultural Properties Research Institute, Japan

Masayuki Nakai, The Board of Education of Ogaki-city, Japan

(15:10 ~ 15:30)

22. Geoelectrical Investigations of Groundwater Resources and Their Effects on Saqqara Archaeological Area, Giza, Egypt

Gad M. El-Qady, **Hassaneen, A Gh.** and **Osman, S.Sh.**, National Research Institute of Astronomy & Geophysics, Egypt

Keisuke Ushijima, Exploration Geophysics, Kyushu University 36, Japan

Break (15:30 ~ 15:50)

(15:50 ~ 16:30)

5 Archaeological Propection in Action (Continued)

Chair : Salvatore Piro, Istituto per le Tecnologie Applicate ai Beni Culturali, CNR, Italy

(15:50 ~ 16:10)

23. Development of Ultrasonic Time-of-Flight CT System for Archaeological Propection

Kazunari Adachi and **Yasutaka Tamura**, Faculty of Engineering, Yamagata University, Japan

(16:10 ~ 16:30)

24. Archaeological Prospecting with GPR Approach: Case Studies at Xian and Shangqiu, China

Libing Gao, Institute of Archaeology, Chinese Academy of Social Sciences, China

Poster Session

25. **Magnetic Property of Soil and Rock at Paleolithic Site**
Hiroo Inokuchi, Kobe University Research Center for Inland Seas, Japan
Hayao Morinaga, Department of Geology, Faculty of Science, Himeji Institute of Technology, Japan
Hideki Yamashita, The Museum of Kyoto, Japan
Akira Ono, Archaeology Laboratory, Tokyo Metropolitan University, Japan
Takashi Inada, Archaeology Laboratory, Faculty of Literature, Okayama University, Japan
26. **3-D Amplitude Rendering of GPR Data from Saitobaru Tunnel Burials**
Dean Goodman, Geophysical Archaeometry Laboratory, University of Miami Japan Division, Japan
Yasumichi Hongo, Department of Archaeology, Miyazaki Prefectural Office, Japan
Masaaki Okita, Department of Anthropology, University of Tenri, Japan
Yasushi Nishimura, Nara National Cultural Properties Research Institute, Japan
27. **Pulse Electromagnetic Scanning Technology in Studying Shallow Subsurface in the Depth Range from 0 to 20 Meters with an « Impulse-Auto »**
Georgi M. Trigubovich, Siberian Research Institute of Geology, Geophysics and Mineral Resources, Russia
Zahar Slepak, Kazan University, Russia
28. **An Application of Polarization Anisotropy Coefficient to Subsurface FM-CW Radar**
Toshifumi Moriyama, Yoshio Yamaguchi and Hiroyoshi Yamada, Department of Information Engineering, Faculty of Engineering, Niigata University, Japan
29. **GPR Application to Archaeology by the Use of Boreholes**
Motoyuki Sato and Zhou Hui, Center for Northeast Asian Studies, Tohoku University, Japan
30. **Investigation of the Underground Structure of Kofun using VLF-MT Method**
Tadashi Nishitani, Institute Applied Earth Sciences, Mining College, Akita University, Japan
31. **Implementation of Automomatic Resistivity Surveying System and Evaluation of Data Analysis**
Masato Mori and Hiroyuki Kamei, Department of Computer Science, Tokyo Institute of Technology, Japan
Takeshi Murakami, Hitoshi Yoshida and Mamoru Miura, Department of Computer and Information Sciences, Iwate University, Japan
Hiroshi Kudo, Sakurakoji Electric Corporation, Japan

Second International Conference
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Archaeological Prospection

Abstracts



Archaeological Prospection in Perspective.

A. Aspinall and A.M. Pollard

Department of Archaeological Sciences,
University of Bradford,
Bradford BD7 1DP, UK

It is now nearly thirty years since the 'pioneers' began to apply the techniques of geophysics to the detection of buried archaeological features. Since then, rapid progress has been made in both instrumentation and data processing, allowing a much wider range of techniques to be applied, and a much higher level of interpretative sophistication. It is timely to ask the extent to which these developments enhance the location and interpretation of buried features.

There has also been a significant widening of the scope of remote sensing in general over this period. Airborne and satellite-based imagery has developed remarkably, and 'chemical prospection', once limited largely to soil phosphorus surveys, now includes a growing range of biochemical markers. Perhaps more significantly, however, there has been a growing realisation of the convergence of the needs of environmental and archaeological remote sensing, and this may point the way towards the future of what might be collectively called 'shallow remote sensing'.

Quantitative Integration of Geophysical Methods in Archaeological Prospections

Cammarano Fabio, Patella Domenico and Piro Salvatore

Istituto per le Tecnologie Applicate ai Beni Culturali, CNR, P.O.Box 10 - 00016 Monterotondo Sc. (Roma, Italy)

Mauriello Paolo and Patella Domenico

Dipartimento di Geofisica e Vulcanologia, Univ. Federico II, Napoli (Italy).

Non-destructive geophysical prospecting methods are increasingly used for the investigation of archaeological sites, where a detailed physical and geometrical reconstruction of structures is required prior to any excavation work. Generally it is difficult to apply geophysical methods to detect small subsurface bodies, especially when the structures are made with the same materials of the ground. In this case we obtain a very low value of the S/N ratio.

The probability of a successful investigation rapidly raises if a consistent multi-methodological approach is adopted, according to the logic of objective complementary of information and global convergence toward a high quality multiparametric imaging of the buried structures. To construct and integrate as complete as possible maps of subsurface targets, it is necessary to develop a method to combine the results of different, absolutely non-invasive techniques, based on the high-resolution three-dimensional tomography mode. The integrated approach must of course operate according to the principle of potential correlation among all those methods that have demonstrated the highest efficacy in investigating inhomogeneous media.

In this work the results of some multi-methodological surveys have been employed with the aim of detecting either sharp discontinuities (boundary of the cavity, fractures in the medium, etc) or volumetric variations (bodies with different physical properties). For the survey a combination of passive and active methods (magnetic, GPR, self-potential and dipole-dipole geoelectric) has been employed.

With all methods a high resolution data acquisition method has been adopted with the aim to reconstruct a global vision of the investigated area. Signal processing and tomographic techniques have been used for the data elaboration and interpretation. Imaging processing has been used for the data representation.

Investigating the True Resolution of GPR Data in Archaeological Surveys: Measurements in a Sandbox.

Juerg Leckebusch

Institute of Geophysics, Swiss Federal Institute of Technology, ETH - Hoenggerberg, 8093
Zurich, Switzerland

The resolution capabilities of ground-penetrating radar (GPR) in archaeological applications are not well established. To address this problem, measurements have been made across artificial walls and other objects buried in a sandbox. To limit the extent of the sandbox, all targets were scaled to 50% of expected true sizes. Accordingly, the antenna frequency was changed from 500 MHz, which is normally used in archaeological investigations, to 900 MHz. Measurements were made across: (i) "homogeneous" sand (i.e. without buried targets), (ii) one buried wall, (iii) two buried walls, one above the other, and (iv) two buried boulders. The simulated walls comprised blocks of concrete with no metal rebar. For each sequence of measurements the data were recorded with an inline spacing of 0.025 m and a crossline spacing of 0.05 m. Such fine sampling was necessary to allow for the full 3D migration of the data, a procedure that proved to be necessary for extracting accurate geometries. Relative permittivities of the concrete and the sand were determined independent of the GPR measurements using a network analyser and a time domain reflectometry (TDR) system. Upper surfaces of the single wall and of the upper wall of the two-wall experiment were well resolved in the GPR data. In contrast, the lower wall appeared as a "point" on the GPR data, probably because, at the deeper location its dimensions were of the same order as the Fresnel zone. Furthermore, the upper and lower walls were separated by only one half the wavelength of the dominant radar signal. A single reflection/diffraction pattern represented the two large boulders, which were buried close together. It should be noted that the effects of shallow strong reflectors may mask or significantly distort the images due to deeper features.

Archaeological Survey Using Pulse Compression Subsurface Radar

Yoshiyuki Tomizawa

Gunma National College of Technology, 580, Toriba-machi, Maebashi-shi, Gunma 371, Japan.

Masanobu Hirose and Ikuo Arai

The University of Electro-communications, 1-5-1 Chofu-gaoka, Chofu-shi, Tokyo 182, Japan.

Tsutomu Suzuki

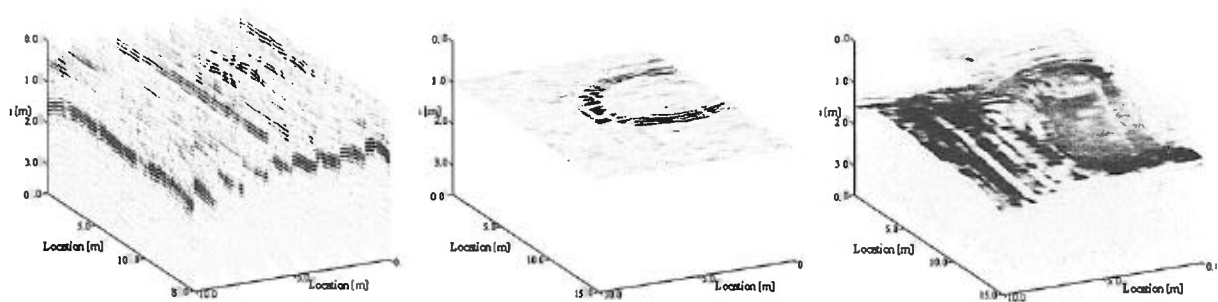
Nippon Institute of Technology, 4-1 Gakuendai Miyashiro-machi, Saitama 345, Japan.

Takeichiro Ohhashi

OYO Corporation, 2-6 Kudan-Kita 4-chome, Chiyoda-ku, Tokyo 102, Japan.

A new pulse compression subsurface radar to detect effectively archaeological objects have been developed by using a chirp signal. Several types of subsurface radar are available mainly for probing buried pipes or cables. However, it was very difficult to use subsurface radar for archaeological survey because there was no practical signal processing technique to pick up the weak signal from the targets such as tomb, ruins and old mounds.

Pulse compression radar using a chirp signal is well known to have high detectability of a weak signal buried in noise with very high resolution. We have assembled a pulse compression radar with the delay correlator for chirp signal. The radar was used to survey archaeological ruins named the remains of Tajiri (Komochi, Gunma, Pref.). The experimental survey have been done successfully. The dwelling vestige and the old tomb covered with the pozzuolana were detected clearly.



Cross-sectional view.

Time slice image.

3D image.

3D images of old mound at the ruins of Tajiri.

Underground Tomogram from In-Situ Data Measured in the Cross-Borehole Configuration

Jung-Woong Ra and Seong-Kil Park

Department of Electrical Eng., Korea Advanced Institute of Sci. and Tech.

371-1, Kusong-Dong, Yusong Gu, Taejon, Korea

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Detection of isolated target such as deep underground tunnel may be possible by the cross-borehole measurements. In-situ permittivities(ϵ) and conductivities(σ) of the underground medium may be obtained by three borehole measurements; one for the transmitting(source) antenna and the others for the receiving antenna picking up the scattered fields at two different distances. By taking the division of these two fields, one may obtain the permittivity and the conductivity from the ratio of the amplitudes and the difference of the phases.

Multi-frequency averaging of these permittivities and conductivities smooths out not only the dispersive characteristics but also the rapid fluctuations across the planar discontinuities such as cracks and faults. It is shown by the two-dimensional simulations that cracks and faults may be identified by the back projection of the multi-frequency averaged ϵ and σ . The isolated targets such as the air tunnel, however, produces highly fluctuating interference fringes of ϵ and σ at the target, even with the multi-frequency averaging. After identifying the isolated target from the interference fringes and by defining the region of reconstruction, one may reconstruct the isolated target by using the iterative inversion method. The two-dimensional numerical simulation shows that the successful reconstruction of the air tunnel is possible.

The tomogram of ϵ and σ distribution are obtained from the in-situ data measured by Ra-Geovis, the continuous electromagnetic wave underground radar, by using the multi-frequency averaging and the backprojection. Identification of an isolated target such as air tunnel is still different from this tomogram obtained from the in-situ measured data. Incoherent tomogram obtained from the in-situ data, however, shows the isolated target as well as the distribution of the background medium very well but qualitatively.

The Geophysical Prospection of Medieval Iron-Smelting Sites in North-East Yorkshire and Their Interpretation.

Robert W. Vernon, J.G. McDonnell and A. Schmidt.

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Geophysical techniques have been used for archaeological site assessment for nearly 40 years. They have however, only been used by a few researchers to evaluate iron-working activity. The Proton Magnetometer was used for most of the early surveys but this instrument has now been superseded by the Fluxgate Gradiometer and magnetic susceptibility methods. Resistivity techniques however, are widely regarded as having little application on iron-working sites. In most instances geophysical surveys have identified a magnetic anomaly associated with a furnace or large concentrations of iron slag. Geophysical techniques in these circumstances have worked well. However, large quantities of iron slag can mask responses from ancillary structures associated with iron production, and may result in the incomplete or erroneous interpretation of geophysical data.

The geophysical survey work in North-East Yorkshire has examined a range of iron-working sites covering a period from about 1000AD to 1650AD. The iron-working activity ranges from a simple bloomery, through to a blast furnace and associated finery/chafery complex. Initially, three sites were surveyed in 1995 and a further five prospected in 1996. The surveys employed a variety of techniques including the fluxgate gradiometer, magnetic susceptibility, pulse induction and resistivity (including pseudo sectioning). During 1997 several of the sites were resurveyed to a higher accuracy and one will be excavated.

The purpose of the work has been to identify which techniques or combination of techniques produce interpretable results and what surveying methodology to employ. Initial findings have indicated that a general fluxgate gradiometer (1.0 m sampling) reconnaissance survey will delineate the area of slag and peripheral pre-slag features. Specific structures are then re-surveyed at 0.5m sampling interval by both gradiometer and resistivity methods.

All the surveys have produced clear identifiable evidence of iron-smelting features including furnace sites, buildings, leats and slag tips. In many instances the features can be matched precisely to topographic changes. The slag produces a variety of geophysical responses which can be associated with changes in iron-content, depth of burial and thickness of the slag deposit.

The geophysical interpretations are then compared with the historical evidence. Several of the surveyed sites were operated by the Cistercian order of monks located at Rievaulx Abbey in North Yorkshire. By comparing the evidence with similar Cistercian operations elsewhere in Britain it has been possible to appreciate how one particular surveyed site may have functioned. After the dissolution of Rievaulx Abbey in the 1530s iron production continued at Rievaulx with the construction of a charcoal fired blast furnace. The probable site of this furnace has been surveyed together with the associated finery/chafery complex. The geophysical evidence has led to a re-assessment of the use of water-power in the Rievaulx area and has indicated that resistivity methods can identify charcoal rich deposits.

Although the geophysical research work on iron-working sites in North-East Yorkshire is still in its infancy, it has shown that clear interpretable data can be obtained from such investigations which can add considerable information to the archaeological and historical record. The paper will give an overview of the work undertaken to date.

3D Imaging of Monumental Tombs buried in Keyhole-shaped Tumuli by Electrical Prospecting

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Abstract:

Various geophysical methods have been applied to image archaeological monuments buried in shallower depth and to allow selective excavation without destroying the valuable monuments. However, these geophysical methods developed in the mining industry have some limitations such as reflection coefficients, depth penetration and resolutions. Therefore, we have to select the most suitable band of electromagnetic waves used for archaeological prospecting considering physical properties and the geological scale of subsurface targets in an inhomogeneous formation. The most powerful technique may be a ground-penetrating radar method but less attainable depth up to 2 m in a conductive formation. Then, we had to develop a new archaeological resistivity meter called ARM for a quick mapping of deep buried targets in a wide area. According to the on site processing of ARM survey data, detailed vertical electric soundings were conducted to determine the formation resistivity with depth over the Iwatoyama keyhole shaped tumulus. Observed VES curves were interpreted based on a multiple layered earth and 2D models by an automatic data fitting method with a personal computer. From 2D inversion results of VES data, 3D shape of the target was visualized by the computer graphic techniques. The detected target is evaluated to be the stone cavity surrounded by conductive materials such as clay minerals from the joint interpretation of horizontal mapping and vertical sounding data on the monumetal circular mound.

Application of geophysical exploration methods to archaeological investigation of Japanese castles

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In recent years, archaeological excavations have been proceeded at many Japanese castle sites for the purpose of maintenance of the historical sites due to urbanization near the castles. In these excavations, archaeological features of the Japanese castle like moats 'HORI', entrance and exit 'KOGUCHI', building remains and marks of reclamation in KURUWA are usually targets to be found.

However, it is often difficult to find these targets effectively in the wide castle site, we have proposed to use the geophysical exploration methods for archeological investigation of Japanese castles. Geophysical exploration methods have great advantage that non-destructive, quick and economical investigation can be carried out in the wide area. Among the many geophysical exploration methods, we have mostly applied ground probing radar (GPR) and Resistivity Image Profiling (RIP) in the archaeological investigation above.

The investigation of the buried moats, the excavation surveys with the geophysical exploration methods have revealed that these two methods can be effectively used especially. The GPR can detect small moats and the RIP is effective to detect large ones and low resistivity ones.

For the case of investigation of KURUWA, we tried to apply the GPR and showed its effectiveness. However there are not so many examples of excavation surveys for KURUWA. We will have to study the feasibility of geophysical exploration methods for the investigation of KURUWA.

For the future, we are going to establish more efficient archaeological investigation methods of the Japanese castles using the geophysical exploration techniques.

Transformation of the Resistivity and Magnetic Anomaly Patterns by Inversion Filtering

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The resistivity profiling anomalies which are produced using various arrays, as well as the magnetic ones encountered in areal mapping, are deconvolved by the use of inversion filters. The filters are computed by inverting the effect produced by a simple basic model. For the resistivity case, the forward computations of the effect of the basic model and all other models used are performed by means of a finite element modeling scheme. The respective computations for the magnetic case are based on the analytical expressions of the finite prism. The filters are designed in such a way that the output is a spike centered over the buried body. Tests with synthetic and real data are presented, which justify the use of the scheme. The scheme is particularly useful because it transforms the anomalies in a easy readable form by non experts, and also suitable for presentation as image. I.e., the measured fields are in a form which resembles the result which we would have obtained if an excavation had taken place.

Characteristics of a Shape Estimation Algorithm for Small Subsurface Objects

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Most of techniques used in subsurface radar applications, such as the aperture synthesis or the pulse compression, are developed originally for conventional radars which use the air as the propagation medium. Among the features that specialize subsurface radar, the loss and dispersion of the medium together with the existence of strong clutters strictly limit the usefulness of these techniques. For an accurate imaging of subsurface objects, it is thus essential to develop an algorithm which can handle these features. While it is very hard to include the effect of loss and dispersion in inverse scattering problems, various numerical procedures have already been developed for the forward scattering case. Our approach has been to model the target with a limited number of parameters, and to recursively modify it so that the observed signal waveforms fit the estimated ones computed for the model. In order to save the machine time, we compute the estimated scattered wave by using a modified ray tracing method which include the effect of diffraction. In this paper, we deal with the problem of target imaging in a two-dimensional homogeneous lossy and dispersive medium. The attenuation and dispersion of the transmitted waveform is taken care of by applying proper filter functions which are synthesized in the frequency domain. The model parameters to be determined are the permittivity and conductivity of the medium, their frequency derivatives, and the location of several points that characterize the outer contour of the object. The performance of the developed algorithm is quantitatively examined by numerical simulations. The simulated data are generated using the Frequency-Dependent FDTD method. Target shapes assumed are conductive cylinders and plates whose size is a few wavelengths at the center frequency of the pulse. In order to examine the tolerance of the algorithm against clutters, 200 point targets with various permittivity are randomly embedded in the simulated medium. It is found that the algorithm can accurately reconstruct the target shape for the signal-to-clutter ratio of larger than 10dB, and the size can be correctly estimated even with S/C of 4dB.

Non-Linear Inversion Algorithm In Archaeological Prospection

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The key point of the confidence of non-linear inversion have been addressed and two algorithms have been analyzed. The first one is based on a quadratic approximation of the mathematical relationship between the data and the unknowns [1]. The second one is called bilinear method [2]. Both have been applied to the inverse scattering problem by pointing out the relevance of the 'information content' of the data in the non-linear case and essentially amount to minimizing a non-quadratic functional. Therefore deep attention has been devoted to considering the presence of local minima where the solution algorithm could converge to starting from an arbitrary point. The theoretical results and the numerical experiences [3] have confirmed the crucial role of the number of the available equations with respect to the number of the unknowns. This conclusion is applicable at all frequencies, from DC to microwaves, and for all kind of different signals (electric, magnetic, seismic, acoustic, elastic). Results will be shown at the Conference.

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Application of geophysical methods and graphic representation techniques to investigation of ancient temples.

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Japanese ancient buildings have been mostly made of wood unlike European and Americans. Abandoned and rotten buildings therefore leave no traces of them on the present earth's surface. Those which were burned out a long time ago are also the case. In Japan, archeological findings of the ancient buildings are the traces of their pillars.

In the investigation of ancient temples, it is also very important to detect the traces of buried pillars. The traces of buried pillars are roughly classified into two types. One is a pillar hole. There are some cases that the base of the pillar remains in a pillar hole. The other is a pillar base stone, which is a much clearer trace than a pillar hole. Most of major buildings had the pillar base stones under their pillars for preventing subsidence and corrosion of them. However the pillar base stone had been often taken away from the building because of construction of a new building or some other reasons. The use and scale of the building can be inferred from the arrangement of the pillar detected. The arrangements of the cloisters of the ancient temples are classified into some typical patterns. We can infer from the pattern when and by whom the building was constructed. An ancient temple was ditched. The arrangement of the ditch can also provide the information about the territory which the temple had governed and its influence.

We have applied geophysical methods to archeological investigations of the ancient temples. In many cases of the investigations, we have conducted geophysical surveys for detecting entire part of buried ditches a part of which was already excavated. Because to define the area occupied by the temple is very important to design the excavation area. In some investigations, we have used geophysical methods to detect the traces of the building in the central part of the temple for inferring its cloister arrangement. In the site where the part of the great foundation stone of the central pillar of pagoda was discovered, we had conducted geophysical surveys to estimate the size of the stone for understanding how to set the stone.

In this paper, we will demonstrate the effectiveness of application of geophysical methods to investigation of the ancient temples through the examples of the surveys of ditch arrangement and the size of the foundation stone of the central pillar of pagoda.

Remote Sensing in Desert Archaeology in China

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Abstract - In west-northern China, the world famous ancient Silk Road passed through the grand desert. Since the end of last century, Archaeologists have done lots of field works on some important ancient cities in desert. But many archaeological phenomena are still unclear, most of ancient cities need to be done deeper research by new method.

I have done the remote sensing archaeology in ancient cities for several years. and now, I would like to introduce two projects I have studied to everyone:

Firstly, the remote sensing archaeology in Beiting ancient city. Beiting ancient city is located in northern Xinjiang (E89° 12' , N44° 06'). It had been an important city on the silk road in the period of 8th-12th century. Before 1980, archaeologists worked there and found it has two circles of curtain walls (outer curtain wall and inner curtain wall) and moats, on the curtain walls, there are some buttress' remains. From the interpretation of the black-and-white and color infrared aerial photography, I found the third circle of curtain wall (palace wall) and some streets in the ancient city besides the former findings.

2ndly, the remote sensing archaeology in ancient cities from Kuerle to Luntai in Xinjiang, which was the important area on the silk road since the early Han dynasty (2nd BC.) to the end of Tang dynasty (8th century). There are many ancient cities in this area. Because the natural condition isn't so good to do field work, archaeologists hardly find out the ancient cities by traditional method. After interpreting the black-and-white aerial photography (the scales is 1:60 000 to 1:70 000) in this area, I found 22 ancient cities. According to analyzing the topographic maps (the scales is 1:50 000 or 1:100 000), I determined the positions, sizes, shapes, structures etc. and mapping the plans of these cities.

The Roman Town of Vieil-Evreux : an Integrated Approach (multi-scale and multi-method)

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Despite many excavations since more than a century and numerous aerial surveys over the roman buried town of Vieil Evreux (West of France), important discoveries can still happen. Electrical surveying in the nearby of the known roman thermal area over more than 2ha (ploughed fields) has brought a new insight about the spatial organisation and the functioning of the thermal bath complex : accurate positioning of a fanum (temple), its internal building (cella) with even its entrance (door) facing East direction, and the discovery of aqueducts for water supply and sewage. The buried portico limiting the thermal area was made also clear. Excavations, which rely on the results of the geophysical survey, has confirmed these structures.

The information brought by aerial photos has also to be taken into account when trying to integrate the former results over a wider area : geophysical investigations cannot be systematised because they are time-consuming and in practice when the area exceeds several hectares, aerial anomalies, if they exist should be used. But to be of value for archaeologists, the results obtained from aerial photos must have a positional accuracy compatible with the accuracy of archaeological geophysical surveying and to the future diggings, that is at least better than 1 meter. Rectification of oblique aerial photos is something now usual (orthophotos, rectification) but the accuracy of the orthophotos is seldom mentioned. In the case of Vieil-Evreux, we have access to outstanding photos taken during the big drought of 1986. Rectification of these photos has proved that the overall error can exceed 8 meters. This error is partly due to the mathematical model used for the projection of course but mostly to the quality and scarceness of the control points used for computing the projection parameters and the defaults of the optics of camera. In Europe, most of the photos are taken by amateurs with ordinary 24x36 cameras. They constitute a huge fund which has not been used since now except pioneering works like the one from Scollar. Moreover, when archaeologists take the pictures, they seldom have in mind the possibility of rectification and consequently few control points can be used. Finally, one should notice that the 'best' aerial anomalies are observed in crop fields areas (open-field) where control points are scarce and where fields limits are changing nearly every year.

In the case of Vieil-Evreux, a new protocol was developed and tested : control points were added using the following assumption : on the area surveyed by the geophysical team, some individual electrical anomalies can be delimited and assumed to be in concordance with the phytologic patterns (difference in colour and/or retarded or advanced growth of crops) observed on the aerial photos. Since the geophysical anomalies are referred to a national grid system (Conical Lambert projection), they can be used as control points for the rectification. Dozen of points were extracted and added to the original set. When rectification was finished, we were able to compute a root mean square error of 0.8m. Adding the 'geophysical' control points proved to be feasible and has reduced the overall error to a minimum acceptable by the archaeologist. With the transcription of the numerous anomalies observed on the orthophotos, it was then possible to expand our archaeological knowledge to an area of more than 25 ha around the thermal baths. Several photos were then separately rectified in order to get a mosaic of pictures to cover the whole site. Accuracy can also be checked at this point when looking at the overlapping features at the borders of each photographs. Finally, the use of other technics like magnetometry scanning and surface gathering can be integrated to the data already acquired and will constitute what we call a 'non-destructive data base' which has preserved the archaeological site for the future generations.

Remote Sensing and Archaeological Prospection of the Camino Real from Taos, New Mexico, to Parral and Chihuahua, Mexico

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The Camino Real from Chihuahua to Taos was the major thoroughfare for Spanish exploration and settlement of the region of Northern New Spain. Missions, presidios, and haciendas, the three vital links in the Spanish Colonial system are all still to be found in the region dating from as early as the late 17th century. Human settlement for over 10,000 years in the region has been contingent on water resources in this arid region. The correlation of known prehistoric and historical archaeological sites has never been evaluated. This project utilizes remote sensing data, ground penetrating radar studies of specific sites, and archival and archaeological survey to determine optimal locales for human settlement through a combination of geohydrological as well as archaeological studies. The predictive model derived from these studies is applied to contemporary settlement patterns as well as the potential for sustainability of hydrological resources and settlement systems in the region.

SOIL MAGNETISM AND MAGNETIC PROSPECTION

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Magnetic surveys of archaeological sites with cesium magnetometers (resolution +/- 10 pico Tesla) allow a precise detection and description of the buried heritage. Digital image processing of aerial photographs and magnetic data enables us to make detailed plans of the archaeological sites thus found.

In an attempt to produce a good overview of the potential of the cesium CS2 magnetometer, archaeological sites of different periods and geologies were chosen. The results of the magnetometry in different soils are explained by their soil magnetic properties. The detection of unburned mud brick structures in the surrounding mud at Qantir Piramesse in the Nile Delta (Egypt) shows that in this case the remanent magnetization and not the susceptibility is responsible for the magnetic anomaly.

Mineral magnetic analysis of the soil samples mainly reveals that the ferrimagnetic minerals maghemite, magnetite and greigite are responsible for the formation of magnetic anomalies.

Molecular Species Detected in Magnetic Prospection with the Aid of Electron Spectroscopy (ESCA)

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Some of archaeologists state magnetic prospection is powerful for the survey of fired places such as kilns, hearths, and so on, while the others do not. The present author believes this is not due to the difference of sensitivity of the researchers, but due to that of soil. He means some soil is sensitive to the change of chemical species by heating, while the other is not. For the proof of this belief the detection of chemical species of soil in site was done. ESCA (Electron Spectroscopy for Chemical Analysis) is promising for this proof. Samples were collected from Ombara Site, Okayama with an interval of each 15cm along both NS and EW directions. This site is of a palaeolithic age. A series of samples was soil after burning experiment as a reference. In the region of Fe (iron) 2p two peaks were observed; one from FeOOH and the other is the coalescence from Fe₂O₃ and Fe₃O₄. The observation of volume susceptibility tells us the majority in the latter is Fe₂O₃ in the latter. On the other hand, the change of magnetization owes to Fe₃O₄. In the fired area the latter is more intense, while the former is in the unfired area. In this site the magnetic prospection is, therefore, the observation of the magnetic moment due to the change from FeOOH to Fe₃O₄ accompanied by the change to Fe₂O₃. For actual archaeological site a lot of useful information was obtained such as the distinguishment between fired site and the disposal place of charcoal, the effect of present iron-pole used as a road-sign.

Magnetic Moments in Prehistory

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Many types of human activity affect the magnetic properties of the geological materials on which they occur. By integrating measurements of these magnetic properties; such as susceptibility, viscosity, gradiometry and archaeomagnetic data; with other archaeological data, it is possible to answer detailed archaeological questions about such activities.

The potential of the close integration of magnetic measurements with ongoing archaeological excavation is illustrated in this paper by discussion of studies during the 1995-7 excavation of a multiperiod settlement mound at Scatness, Shetland. This site is ideal for an investigation of this nature, as it contains over four meters of stratified archaeological deposits. These represent an occupational sequence spanning several millennia, from Bronze Age cultivated soils; through the Iron Age, represented by a broch and later wheelhouse complex; to the Pictish and Viking period. Contexts from the historical period (16th century to early 20th century) additionally provide an opportunity to integrate the archaeological record with historical and ethnographic data.

This paper focuses on three specific types of context:

- *Hearths and burnt areas*- using magnetic remanence, viscosity and susceptibility to determine date and function
- *Midden deposits*- using susceptibility, in combination with chemical and environmental evidence, to determine source material and formation processes
- *Soils*- using susceptibility, in combination with environmental and soil micromorphological evidence, to detect and characterise anthropogenic enhancement of soils

These examples demonstrate that, when combined with other archaeological information, the evidence of human activity retained in magnetic properties can prove a valuable tool for archaeological interpretation.

Measurement Results on Electromagnetic Characteristics of Soil using the Dipole Antenna

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Recently, a signal processing technique gives the enhanced ability of archaeology prospection to a subsurface radar. Synthetic Aperture Radar (SAR) technique, which is one of the most powerful techniques, has an ability to improve the resolution of the radar image. Since the theory of SAR technique is based on the Fresnel scattering problem, the improvement of a radar image requires accurate velocity of an electromagnetic wave in a soil. Since permittivity of soil determines the wave velocity in the medium, it is necessary to measure the soil's electromagnetic characteristics (permittivity, conductivity, etc.) for effective SAR processing.

However, most of the present measurements using network analyzer does not provide accurate soil's characteristics. There are two reasons as follows; (1) When the sample soil is picked up, the microscopic structure of the soil (bulk density, porosity, water content ratio, etc.) is destroyed. (2) These instruments measure only a partial sample of soil. Particularly, the latter reason is serious problem for subsurface radar SAR processing. Consequently, a measurement using a dipole antenna attached on the soil surface is proposed in this report. Since the antenna frequency characteristics are related to the medium properties, this method is appropriate to measure the soil's characteristics.

The soil's permittivity and conductivity are obtained by following 4 steps; (1) Calculate the resonant frequency and resonant resistance of the dipole antenna for certain range of soil's permittivity and conductivity. (2) Plot the calculated results on the permittivity-conductivity 2-dimensional plane, and draw the contour of these data. (3) Measure the resonant frequency and resonant resistance of the dipole antenna on the ground. (4) Plot the measured data on the monograph which is obtained in 2nd step. The permittivity and conductivity of the soil are then given by the intersection on the resonant frequency contour and the resonant resistance contour.

The measurement results show that the sufficient accuracy for SAR processing is obtained by this method. This measurement will provide important information and useful procedure for the improvement of SAR imaging.

Electron Spin Resonance (ESR) as a Method of Dating and Assessment of Environment

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Electron spin resonance (ESR) or sometimes called electron paramagnetic resonance (EPR) has long been a method to analyze electronic states of paramagnetic ions and radical species based on quantum physics. Two decades ago, new applications to determine the age of archaeological and geological materials with ESR started as demonstrated for stalactite cave deposits (Ikeya 1975). The principle is based on the determination of the accumulated natural radiation dose in geological archaeological materials. The absolute signal intensity or relative to some standard, or that calibrated by additive radiation dose gives the radiation dose or the age in all these works.

ESR dating of fossil bones and teeth in paleo-anthropology was developed (Ikeya and Miki, 1980) and extended to shells and corals as reviewed in the textbook (Ikeya 1993). Mineral deposits such as gypsum were used to determine the age of excavation site in desert. Future ESR dating of outer planet world in space science is a main subject.

Assessments of heated soil and burnt stone tools proved that ESR is a useful tool in addition to a method of dating. ESR dating has a vast field of applications open to young generation from archeology to space survey.

In this review talk, the state of the art of ESR dating is presented together with recent applications done in my laboratory after publication of the textbook in late 1993.

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Comparative Study of Magnetometer Results from a Kiln Site Near Ooto, Japan

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The measurement of magnetic anomalies, caused by buried features, is a common investigation method in archaeological prospection. Various sensor types and configurations can be employed in the field (total field sensors, vector sensors, single sensors, gradiometers,...) but due to the magnetostatic nature of anomalies all results should be mathematically equivalent. This paper will examine the theoretical relationship of three datasets that were recorded at an ancient kiln site near Ooto, Japan. Measurements were made with a proton magnetometer (using a fixed base station), a fluxgate vertical component gradiometer and a three axis (vector) fluxgate gradiometer. Data were converted to a common reference representation and compared with each other. While the general trend of computed data compares well with directly measured results, the better spatial definition of measured data justifies the effort of their acquisition.

Geophysical Survey of Hirui-Otsuka Mounded Tomb in Ogaki, Japan

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The Hirui-Otsuka mounded tomb located in Ogaki-city, Gifu Prefecture, Japan, is one of the biggest keyhole shape mounded tombs in the Tokai region. The length of the mound is 144m, the diameter of the round part is 94m, and the height is 10m. Archaeological investigations of this tomb have been carried out continuously since 1994. A "haniwa" (a terra-cotta figure for decorating a burial mound) found in 1995 indicated that this mound dated back to the late 4th century AD.

Some geophysical methods were adopted in these investigations. In this paper, we present the results of the geophysical surveys; some of them have been verified by the excavation.

Firstly, ground penetrating radar (GPR) survey and resistivity survey were applied in 1994 in order to find the missing moat and to determined the area of this tomb. The GPR used in this survey was the Kodex KSD-3AM pulse radar whose antenna had the center frequency of 166MHz. The Geoscan RM15 was employed for resistivity survey and the Wenner configuration with 1m electrode spacing was adopted. The GPR plan images (time slices) showed clearly the outline of the missing moat which was consistent with the excavation results, but the apparent resistivity map showed a different result.

In 1996, the radar and magnetic surveys were carried out on the top of the mound in order to acquire the information about its central burial. In this time, the newly developed FM-CW radar was used besides the conventional KSD-3AM pulse radar, and the three-component fluxgate gradiometer for the magnetic survey. A 10m by 10m rectangular burial pit in the middle of which a pit-style stone chamber about 8m long by 2m wide was settled was discovered on the top of the round part of this mound by the radar survey. The stone chamber appeared more clearly in the FM-CW radar profiles than in the pulse radar ones, and a pit dug by thieves could be found by the FM-CW radar. Some magnetic anomalies were detected on the top of the round part. Many of them might be produced by iron artefacts, but it has not been verified whether they are modern or ancient. The excavation on the mound will be carried out from this autumn.

Geoelectrical Investigations of Groundwater Resources and Their Effects on Saqqara Archaeological Area, Giza, Egypt.

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Abstract:

Geoelectrical resistivity (GER) and Transient electromagnetic (TEM) surveys were carried out for investigating groundwater potentials and mapping aquifers at Saqqara archaeological area. The purpose of the present study is to derive the simple and effective solutions to protect the valuable archaeological site from the contamination of the groundwater. According to the integrated evaluation of both GER and TEM data, the formation of the Saqqara area is constituted from three to six layers. The resistivity structure of the formation is the AAHA($\rho_1 > \rho_2 > \rho_3 > \rho_4 < \rho_5 < \rho_6$) type. Their lithologies with depth consist of gravel, marly sand, sandy clay, clay, saturated sand and limestone respectively. From the results of the integrated interpretation of GER and TEM data, it reveals that there are two groundwater aquifers, shallower and deeper. The shallower aquifer is present under the cultivated lands in the eastern part of the surveyed area. It is concluded that the present aquifer has main effects on the archaeological monuments at the Saqqara area and is fed from the seepage water from irrigations of the cultivated lands.

Development of Ultrasonic Time-of-Flight CT System for Archaeological Propection

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The authors have been striving to develop a practical ultrasonic time-of-flight (TOF) computed tomography (CT) system for non-invasive inspection of large wooden or stone structures with archaeological interest since 1992. All the trial-manufactured systems have similar set-ups. They are composed of a ultrasound source for emitting ultrasonic short pulses, a single or multiple ultrasonic receivers, a power amplifier for exciting the ultrasound source, a signal processing unit and a lap-top computer for controlling and imaging. Those systems have actually been used for inspection of wooden and reinforced-concrete pillars of some buildings with cultural values in Japan. The CT images of those pillars reconstructed from TOF data obtained in the field works are presented in this paper. The main points of progress concerning the reserch are as follows:

- (1) Mechanically robust transducers which can emit high-intensity ultrasonic pulses into various objects have been developed. For safe and easy handling, the transducers are contained in probe handsets specially designed for this purpose.
- (2) A high performance head amplifier contained in the probe handset for receiving minute ultrasonic pulse signals has been developed.
- (3) The authors have devised an image-processing method for the CT with reasonable treatment of ultrasonic transmission paths for which the TOF data cannot be taken owing to excessive attenuation of ultrasonic puises.
- (4) Ultrasonic signal receivers made of PVDF film have also been developed. Since the receivers can be easily made at low cost, they are suitable for constructing a multi-channel signal receiving system.

Archaeological Prospecting with GPR Approach: Case Studies at Xian and Shangqiu, China

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Abstract - During 1996 and 1997, several ground-penetrating radar surveys have been carried out in conjunction with field archaeological investigations in China. The typical cases are cooperative projects at Xi'an and Shangqiu.

The first survey was a detailed, high-resolution radar survey at the site of a ninth century palatial architecture Hall of Hanyuan, Daming Palace in Xi'an, Shanxi province. The reconstruction of the Hall of Hanyuan is a cooperative project by the Institute of Archaeology in Beijing and Nara National Cultural Properties Research Institute. The radar here was used as non-destructive technique to locate the building structures beneath the ground surface. The GPR system was pulseEKKO 1000 with 225 MHz antennas and was helpful in identifying and locating anomalies caused by stone and brick structures.

The latter two radar surveys were rapid, low-resolution reconnaissance surveys undertaken with magnetic method, resistivity survey and RS images as part of a collaborative project "Archaeological Investigation of Early Shang Civilization in China" between the Institute of Archaeology in Beijing and Harvard University's Peabody Museum at Shangqiu area, Henan province. With the joint work of geoarchaeological and geophysical team during spring and fall 1996 season, spring season of 1997, We have a most important find of a Eastern Zhou city (770-450BC) with rammed earth walls. The GPR was pulseEKKO IV with 100 MHz antennas and output voltages of 1000v. Radar was moderately successful in detecting the Hangtu or rammed earth walls, in a matrix of sandy loess deposited by alluvial processes, several meters under the ground surface .

This paper will show several radar profiles with different pattern of anomalies and geological interpretation by comparing with the core profiles. Radar profiles will compare with the resistivity profiles acquired by McOHM-21. the survey design, data processing and interpretation are also discussed.

Ongoing work involves comparing our radar surveys taken at different sites with rchaeological excavation results to increase the understanding of how radar can be applied to archaeology and to improve interpretation of radar responses to artifacts.

Magnetic Property of Soil and Rock at Paleolithic Site

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Ancient artificial heating, such as a campfire, leave some traces on the site surface. We have been tried to detect a place of ancient heated soils by magnetic techniques. Susceptibility measurement in situ and/or in laboratory, and remanent magnetization measurement are supposed to be useful for finding the traces of heating. The details of change in magnetic features of soils by progressive heating in laboratory are examined to make clear the relation between degree of heating and change in magnetic properties. Silty soil (SS), weathered volcanic ash (WVA) and non-weathered volcanic ash(VA) are used in our experiments. Intensity of remanent magnetization of all specimens becomes strong during thermal treatment below 250 °C. This increase of the intensity of remanent magnetization may correspond to acquisition of thermal remanent magnetization. Increase of susceptibility and intensity of remanent-magnetization for SS and WVA is recognized on heating above 250 °C to 600 °C. This increase reflects chemical change of magnetic minerals (from goethite to magnetite through hematite). The sample of SS shows the most remarkable change, but the sample of VA shows no significant change in susceptibility during thermal treatment.

The remanent magnetization intensity survey is the most effective for detection of the trace of heating, however it takes a great deal of time. Susceptibility measurement in situ is the most easiest method and is useful for the silty soils. Combined method, susceptibility and remanent intensity, is useful for almost cases. Susceptibility method can detect the heated soils in most case, but the only small anomaly in susceptibility is identified in some cases such as weathered volcanic ash. Remanent intensity survey is useful to confirm the trace of heating in such case.

In addition to the laboratory experiment, campfire experiment in the field and some examples of detection of fire evidence in archeological sites will be presented.

3-D Amplitude Rendering of GPR Data from Saitobaru Tunnel Burials

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Subsurface images showing the general location, depth and shape of tunnel burials at the Saitobaru National Burial Mound Park in Miyazaki Prefecture, Kyushu, are developed from ground penetration radar (GPR) datasets. The pseudo 3-D datasets are generated using parallel radar profiles spaced 0.5m across a tunnel burial site at Saitobaru. The tunnel burials built in the Kofun Period (300-700 AD) are imaged by showing surface renders of the strongest reflection amplitudes which are illuminated using a computer generated light source. The results indicate that 2 tunnel burials are connected via a joint corridor which is also verified from direct excavation. The surface render of lower reflection anomalies can also be used to illuminate structures associated with the V-shaped corridor that connects the entrances of the tunnel burials.

The results are quite promising for 3-D rendering displays in archaeological prospection, particularly at sites where the target structures are the strongest recorded reflections and are well defined structures much larger than the size of the radar antenna.

Pulse Electromagnetic Scanning Technology in Studying Shallow Subsurface in the Depth Range from 0 to 20 Meters with an «Impulse-Auto»

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Electromagnetic scanning is a young high-resolution technology to study a near-surface layer down to depths of a few tens of meters using a controlled source of electromagnetic radiation in the frequency range to 2 MHz. This range corresponds to a transitional diffusion-wave zone and, as practice shows, is a highly promising one to settle a lot of different problems. The technology is meant for continuous recording of spatial-temporal pictures of diffusion-wave processes in the medium space under investigation. Using a basic spectrum frequency lower than that used in GPR, the proposed technology is less dependent on the increased medium conductivity. A high density of field recording makes it possible to get high-resolution temporal projections representing electrophysical properties and positions of objects.

As a rule, successful solution of many problems follows rather reliable electrophysical prerequisites. The principal severity is in adequate formalization of experimental data, together with process problems of recording fast processes occurring in a near-surface layer.

Important factual evidence in using electromagnetic scanning to solve different problems of great economic importance has been gained by now. These are detection of underground works with engineering specifications lost, monitoring of utility systems, localization of flooding zones, determination of ground water and industrial sewage, geology, ecology and archaeology as well. In many cases the investigation of a cultural layer has reinforced high reliability in determining its thickness in spite of its non-uniform structure. Advances in searching for local inhomogeneities inside the cultural layer depend on the occurrence depth and dimensions of a target. Hyperdense spatial-temporal recording of an electromagnetic field has allowed one to reveal in time sections «quasi-wave processes» at frequencies of order 1 MHz. Wave moires on the diffusion component of the process appear above exploration targets and are additional indications which remain to be explained. As an example they refer to time sections which have been obtained in Kazan Kremlin.

An Application of Polarization Anisotropy Coefficient to Subsurface FM-CW Radar

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The subsurface radar has been received considerable attention in diverse areas such as archeological exploration, detection of pipes, gas cables and cavities. The subsurface radar receives various echoes including clutter in addition to target echo, because the underground is inhomogeneous. It is desirable to have the ability to distinguish these echoes. Therefore, the classification of target is one of the important problems in the subsurface radar. This paper discusses the classification of target buried in the underground by radar polarimetry.

Radar polarimetry, i.e., the full utilization of the vector nature of electromagnetic wave information, is useful to solve this problem. If a polarimetric measurement is conducted, a scattering matrix is obtained. The scattering matrix which represents polarimetric scattering characteristics contains useful information for classification and recognition of target. In order to retrieve specific information from scattering matrix, there are some methods proposed based on polarization anisotropy coefficient, or three-component decomposition technique, etc.

In this paper, we used three methods for classification of target buried in the underground. First, we applied the polarization anisotropy coefficient to classify the echo into isotropic target (sphere, plate) and anisotropic target (wire, pipe). Since the scattering matrix has two invariants regardless of polarization basis, the polarization anisotropy coefficient is useful to find the man-made target buried in the underground by this coefficient. Second, we used a three-component decomposition technique for scattering matrix. It is possible to decompose the scattering matrix into three components, as if the target consists of sphere or plate, diplane, right or left helix. The decomposition contributes the classification. Third, we tried to classify targets by power polarization signature approach. The shape of signature helps us to identify targets. Therefore, these values contribute the classification of the target buried in the underground.

In order to show the validity of these techniques, we carried out a field experiment using the FM-CW radar. The FM-CW radar is suited for short range sensing and is useful to detect target buried at a depth of a few meters in the underground. Radar polarimetry has been applied to subsurface FM-CW radar, and it has been shown that polarimetric filtering is useful for reduction of surface clutter. In this experiments, targets were a metallic plate (polarimetric insensitive) and a metallic pipe (high polarimetric sensitive). Several detection and classification results are shown in this paper. The power polarization anisotropy coefficient varied significantly with target types (isotropic and anisotropic target). Three-component decomposition was found to be useful to detect the plate target. The orientation angle of buried wire target corresponded to the tilt angle of Co-pol maximum polarization state according to the power polarimetric signature. Therefore, these techniques improves the radar ability to distinguish target buried in the underground.

GPR Application to Archaeology by the Use of Boreholes

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Ground penetrating radar (GPR) is an emerging technology for shallow geophysics and is quite suitable also for archaeology. Many applications have been reported in archaeology and we can find many successful survey results. However, in the practical applications, we are always suffered from the problems of penetration depth and resolution. These two factors are governed by the radar system, however, they are most significantly controlled by its frequency and material of soil which should be surveyed.

If we can set a radar system in deeper region by the use of borehole, we can expand its penetrating depth without the loss of resolution, because we can use higher frequencies. There are following arrangements of GPR survey in archaeology which utilizes boreholes.

(1) Reflection measurement : This is the most common way, and is most powerful technique if the survey objects are volumetric. For instance, this is suitable for investigation of buried wall and Kofun burials.

(2) Cross-hole measurement : If more than two boreholes with separation of less than 10m are available, cross-hole wave propagation can be used for tomography. However, resolution achieved by this technique is less than most reflection measurement.

(3) VRP: Vertical Radar Profiling : Setting a transmitter in a borehole and a receiver on the ground surface, we can measure transmitted signal through the target material. The signal contains information about the geological boundary and also contains reflection in deeper region.

We propose the use of radar polarimetry in these borehole radar measurement arrangements. This technique enhances small disturbance of wave propagation and accordingly we can detect very small anomaly in the soil.

In this presentation, we will show some examples of the application of borehole radar including the survey at Komoti village, Gunma, Japan. The archaeological site at Komoti village is an ancient village covered by volcanic pumice stone. We applied the VRP survey in this site and tried to detect the ancient ground surface. The borehole was 6m in depth. Conventional GPR survey from the ground surface can clearly detect this old ground surface which is lying about 2m in depth. However, most radar cannot detect any information below the old ground surface, because the most energy is reflected from this surface. On the contrary, our VRP survey could determine the old ground surface and also some deeper layers until about 5m. We applied migration technique for imaging the vertical structure. We believe this technique enhances the possibility of the use of GPR especially in the deeper region.

Investigation of the underground structure of Kofun using VLF-MT method

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VLF-MT method is a kind of magneto telluric method, which is widely used techniques for inquiring underground structure. MT method utilizes a natural electromagnetic field. It uses wide range of frequencies and makes clear the resistivity structure from a shallow part to a deeper part. VLF-MT method utilizes artificial electromagnetic field of very low frequency range for the purpose of investigating the underground resistivity structure. The frequency, 22.2 kHz, is available in Japan. On the site, we measure an electric field in the direction of the sending office and magnetic field perpendicular to the electric field. We can obtain an apparent resistivity and phase difference between the electric and the magnetic field. The measurement is simple and easy, and can get electric field intensity, magnetic field intensity, apparent resistivity, and phase difference promptly on the spot. VLF-MT method is commonly used for inquiring around 100 m until now, and it can find subsurface water, geological structure, and active fault. It was used to grasp a general trend of a structure and the measurement interval was coarse. Accomplishments are reported in active fault such as the Senya and the Hanaore dislocation. In this study I took the short measurement interval and inspected the effectiveness of the VLF-MT method to the archeological prospecting. I applied its method to Kofun, the mounded tomb, to know the position of the stone chamber. I did VLF-MT survey for the mounded tomb which was ascertained a position of a stone chamber or a layer of clay. Mesh interval for the survey was set to one meter and measurements was done two-dimensionally. Nishizuka Kofun in Fukui prefecture has the round portion of the mound of a keyhole tomb. The underground structure of it was almost settled and we were able to watch the reaction of chamber in the apparent resistivity and phase differences. Almost the same tendency was observed in Tonozuka and Kasaya Kofun in Ibaraki prefecture. The position of chambers were able to estimate in both mounded tombs. By the measurement, good relationship was obtained between the position of chamber and the four parameters, intensity of electric and magnetic field, apparent resistivity and phase difference. It is clear from these investigation that VLF-MT measurement are able to reveal the position of a chamber in the mounded tomb. VLF-MT survey is an effective method to know the plane view of the position of a chamber. I applied this method to the unexcavated mounded tomb to know the position of a chamber. Torazuka-5 and Kasaya Kofun in Ibaraki prefecture are not investigated. I applied VLF-MT technique in these mounded tombs and estimated the position of stone chamber based on the resistivity and phase differences. Nishi Norikura Kofun located in Tenri city. This mounded tomb was explored by a radar before, but it did not show the position of a stone chamber. I applied VLF-MT method to this site in mesh interval from 0.5m to 1m. This method reveals the position of stone chamber clearly and it suggests a corridor-style stone chamber. It is obvious that VLF-MT method is an effective tool to detect the position of stone chamber in the mounded tomb. However, It has a weak point in the estimation of depth. Response from a shallow part shows a sharp peak and that from a deeper part shows a wide peak generally. But it is difficult at the present stage to estimate the exact depth and scale of the chamber. I think this weak point can overcome if we calculate the response from the chamber using an appropriate model. We will be able to get depth information from the measurement values in the near future.

Implementation of Automatic Resistivity Surveying System and Evaluation of Data Analysis

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An automatic resistivity surveying system has been developed to improve the efficiency. This system consists of a resistance meter(RM-4; Geoscan Research), a linear array of electrodes, an electrode selector, an A/D converter and a personal computer. RM-4 is easily replaceable by RM-15, MacOhm, and other resistance meters. The electrode selector is controlled by the personal computer via a 16bit parallel I/O interface. It can select arbitrary four electrodes from a linear array of electrodes, and connect them to current and potential terminals of the resistance meter. This system is capable of control up to 512 electrodes, but we use 48 electrodes now, because of the size of connector and the weight of cables and electrodes. Twin probe, Wenner array and Schlumberger array are now installed in this system. RM-4 is easily replaceable by RM-15, MacOhm, and other resistance meters.

Resistivity data from the resistance meter are sent to the personal computer via the A/D converter and stored; of course, they are simultaneously displayed in line graphs on the monitor. The personal computer processes the stored data and produces a series of resistivity sections; plan maps at the chosen depths can also be produced.

For example, it takes only ten minutes for this system to make a pseudo section of the depth of 4m along a 23.5m line with the electrode spacing of 0.5m.

At present, a program that guesses the depth of the interface of two horizontal beds, has been installed in this system, more complication and sophistication progress are prepared.

Between Pulse Radar and FM-CW Radar

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Ground Penetrating Radar survey has been carried out in many archaeological sites in the world. Pulse radar is mainly used because of the simpleness of its configuration, but it is very difficult to interpret its images and sometimes we have been led to misjudgement. One of the reasons is that ghost images due to "ringing" appear. The ringing is an oscillating waveform with two or three cycles and it arises due to the narrower bandwidth of the antenna than that of a pulse signal transmitted.

We have been developing a FM-CW(Frequency-Modulated Continuous Wave) radar. In the FM-CW radar, linearly frequency-modulated continuous waves are transmitted. The FM-CW radar has no ringing, because we can choose frequencies of the transmitted signal inside the bandwidth of antenna. So, the image of FM-CW radar is very clear. FM-CW radar has another advantages: S/N-ratio of FM-CW radar is higher than that of pulse radar; and the resolution of range depends not on the frequency band, but on the rate of frequency change.

In the developed FM-CW radar, the triangular frequency modulation is used between 100MHz to 500MHz, and its period of the triangle waveform is 50msec.

We have carried out many experiments to evaluate the ability of the FM-CW radar in some archaeological sites in Japan: Harunotsuji village site, (1c BC to 3c AD), Iki Island, Hirui O-tsuka mounded tomb, (4c AD), O-gaki City, Zo-bisan No.1 mounded tomb, (3c AD), Yo-rou, tunnel tombs in Saitobaru site, (5c AD to 6c AD?), Saitobaru City, Kumeda-Kaibukiyama mounded tomb, (4c AD), Kishiwada City, etc.. We show the results of the experiments comparing the FM-CW radar images with pulse radar ones.

Excavation of 6th-7th Century A.D. Cemeteries in Miyazaki, Kyushu

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Tombs with horizontally opening burial chambers cut directly into natural strata were built in Japan from the 5th to 8th centuries A.D. Two types are widely recognized: those dug into a slope and approached by a level or upward inclining pathway, and subterranean chambers approached by a shaft cut vertically into the ground. A third type, also subterranean but approached by a path cut on a downward incline, has been recently discovered in Miyazaki; two examples investigated with GPR and conventional excavation are reported here. For both, the approach path had completely filled in, leaving no surface indication of the tombs' existence.

Saitobaru Tomb Cluster Site. A site discovered through conventional excavation to contain subterranean tombs was chosen for tests of prospection techniques. In July-August 1995, radar and electric resistivity surveys were conducted on the area previously excavated, with good radar results obtained. An adjacent area was then investigated with GPR, yielding abnormalities judged to represent two subterranean chambers leading from a single approach path (Tomb No. 7).

In December 1995, one quarter of the approach to Tomb No. 7 was excavated, revealing entrances to two burial chambers (X-1, X-2). A 10 cm hole was bored through the fill of each entrance, and a miniature video camera inserted. Skeletal remains, and late 6th century Sue and Haji pottery, were visible in X-1. Temperature and humidity measured markedly higher inside than at the surface.

X-1 was excavated in September 1996. Judging from skeletal remains and grave goods, it appears that three or more individuals were buried in the 2.55 x 1.91 m chamber. In addition to conventional recording and recovery of remains, samples were taken for analysis of fatty acids, plant opal, pollen, and intestinal parasites. Among the results obtained thus far, residues of DHA (docosahexaenoic acid) and EHA (icosapentaenoic acid) in the pottery suggest that fish or shellfish was included among the funerary offerings. Plant opal of bamboo and other grasses indicate that stalks of such plants were perhaps used to line the floor of the chamber.

Airabaru Tomb Cluster Site. Subterranean features were clearly revealed through a GPR survey conducted by Dean Goodman; subsequent excavation by the local Board of Education indicated the presence of seven tombs, approached by paths cut on a downward incline.

A conventional excavation of the burial chamber of Tomb No. 6 was conducted by our team in July 1996. Prior to opening the lone sealed chamber, a miniature video camera and fiberscope were inserted for visual observation. These revealed that the chamber walls and ceiling were covered with red pigment, subsequently analyzed as an iron oxide. The floor was also seen to be divided by low balks into two roughly symmetrical areas serving as alcoves for burials, running along the left and right side walls of the chamber, and separated by a narrow central corridor. In subsequent investigation, the chamber measured 2.39 x 2.12 m. In addition to skeletal remains, more than 1,000 glass beads were recovered among the funerary goods. Samples were also taken for the same types of analysis as mentioned above for Saitobaru. Results received to date show plant opal remains similar to Saitobaru, with minute rice traces perhaps due to the use of straw rope in transporting materials to the site.

(Abstract prepared by Edwards)

Soil Permittivity Measurement Using Wire Antennas for Underground Radar

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For underground prospectations of non-destructive imaging of the historical site, various types of microwave electromagnetic radars are now proposed and utilized. For such type devices which utilize electromagnetic wave propagation to sensing underground, it is essentially important to know the electrical property of the soil on the site, or the permittivity of the soil to estimate how the electromagnetic wave propagates in the soil. However, the permittivity strongly depends on the conditions of the site such as the humidity or composition of the soil, therefore it is important to measure its permittivity on site.

Here, a method of *in-situ* measurement is proposed by using several types of wire antennas as the probe; for example, the wire antenna with a ground plane, the coaxial dipole antenna and the coaxial-slot antenna.

The method is as follows; First, the scattering parameters of the antenna employed are calculated by applying the moment method in the media of various complex permittivities. Next, the relationships between the real and the imaginary parts of the scattering parameters and the permittivity are plotted in the chart. Inserting the antenna directly to the soil and measuring the scattering parameters with a network analyzer, the permittivity averaged along the inserted direction is obtained. Comparing the measured data with the chart, the permittivity of the soil on site is obtained.

In this presentation, the structures of these antennas are described. Then the procedure of estimation including the calculation model and method are explained. Finally, some examples of the estimation of the permittivity of the actual soil are demonstrated.

Signal Processing of Subsurface Radar Characteristics Using FDTD Method

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Ground penetrating radar finds many applications that include detection of invisible underground objects. Recently, it has also been used for the detection of archaeological evidences such as, ancient buildings, tombs, monuments, etc. It is advantageous that the use of subsurface radar is non-destructive. In the present study, since the field of sensing is often rough, we studied the wave scattering from buried objects including rough surfaces and random media. Electromagnetic wave reflection and scattering of impulse generated by ground penetrating radar are statistically studied for target objects buried under the random ground surface, using FD-TD method. Numerical analysis, by FD-TD method is used to derive important reflection and scattering characteristics of electromagnetic pulses by target objects on and under the randomly perturbed ground surfaces.

By using FDTD method, numerical simulations are accomplished for main reflection and multiple scattering. In this paper, several kinds of perturbation effects of rough surfaces are studied by using stochastic function with correlation.

Spatial and temporal properties of current concerned with radiation fields at radar antenna are assumed to have beam and broadband frequency characteristics. Rough surface characteristics are given by random surface functions with spatial properties of large and short correlation. Spatial and temporal response field characteristics are shown by computer simulation based on Maxwell's equations and absorption boundary condition for nanosecond pulses. In our simulation, Size of the FDTD analysis region is 2.56m along horizontal direction, 0.44m above the ground and 2.56m below the ground. For FDTD analysis the region is divided into sub-regions with 0.01m width and the time axis is divided into 0.02ns intervals. The target is a rectangular air-gap at 0.5m depth and two reflected waves generated by upper bound and lower bound of air-gap are received by receive antenna. The time response of electromagnetic wave scattering is calculated in the total region and signal response at the observation point is shown.

Statistical relationship between the received signal and random surface is established. Interference effects due to random surface on reflection field by target objects are investigated for short distance between the antenna and rough surfaces that generate complicated reflection waves are studied for multiple scattering between rough surfaces that generate complicated multiple scattering with target objects. This computer simulations may yield useful data for the optimum system design of ground penetrating radar.

Characteristics of Waveform Obtained by Pulse Type Subsurface Radar

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In this paper, we describe the characteristics of waveform obtained by pulse type subsurface radar. The considered pulse is monocycle type usually having nanosecond pulse width. When incident pulse reflected at the target, and received, generally, the waveform becomes to complicate. Major complicated reasons are because of dispersive and random property of underground medium. However, we have to extract of the target information from these complex waveforms. We are going to mention the following items: about pulse propagation effected dispersive media, transient waveform at multi-layered ground model, theoretical and experimental consideration of cepstrum analysis, and finally statistical property and processing useful information of target from subsurface radar echoes. Especially, the results obtained by statistical processing have relatively disappeared more clearly the presence of target.

Underground Imaging Using Shear Waves

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To detect buried relics, though electrical and electromagnetic methods are thought to be valid for many places, sound waves method is valid rather in a place including water. Therefore we proposed an underground imaging method using shear waves and a method based on stacking of reflected scattered waves in which point reflection is assumed. To confirm the validity of our proposed method, exploration experiments were carried out at a site in the Nara National Cultural Properties Research Institute and the east ditch in the Heijyokyo Palace. Figure 1 shows an example of an underground image. In this Figure, a concrete pipe is buried (depth: approximately 0.77 m, diameter: 0.47 m). Assumed sound speed is 190 m/s. The experimental results confirm the feasibility of our proposed method.

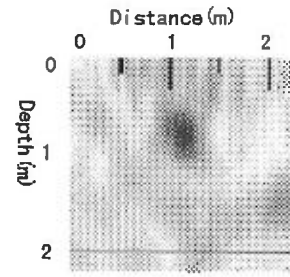


Fig.1. An example of an underground image.

Combined Study with Electromagnetic Prospecting and Rockmagnetic
Analysis on Archaeological Sites

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We have made the electromagnetic prospecting at the archaeological sites proceeding the excavation investigation. In this study, we will report the magnetic survey at the ancient kiln and the electric survey at the settlement site.

(1)Magnetic prospecting at the kiln

The study was made at the area where the kiln called "Suzu-ware kiln" was buried. Magnetic anomaly was investigated on four kilns. The archaeological date is the 14th century. Survey by the proton precession magnetometer and the fluxgate magnetometer showed the clear magnetic anomaly. The excavated kiln with the size over 10 m length is consistent with the magnetic anomaly. The detailed magnetic survey showed the strongly magnetized area corresponding to the firebox of kiln and combustion chamber in the kiln, which was baked to the high temperature. The appearance of anomaly depends on the axis of the kiln.

At the wall of the kiln, we collected the baked earth as the oriented block sample. The block sample was then cut into the small specimens in the laboratory for the paleomagnetic study. The measurement of remanent magnetization showed that the magnetic intensity is relatively strong at the area of 30 cm from the wall. This magnetized area may largely contribute to the magnetic anomaly of the kiln.

(2)Prospecting of electric resistivity

Distribution of electric apparent resistivity was studied at the archaeological medieval castle site called "Emashi-yakata". The prospecting was extensively done on the field after that the surface soil was removed. Anomaly of resistivity appeared corresponding to the firmly fisted area at the settlement site. They are the area such as moat, dirt floor part.

Study of Remote Sensing Infrared Method of Underground Object by Means of Thermal Image Method

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A remote sensing device using the infrared radiometer was developed to detect the internal flaw of the material and structure in many field. The thermal image system using the infrared radiometer was carried out to analyze the location and its dimension of the flaw numerically. The method was applied to detect obscured and underground structural elements, like piping, vessel, slab and ancient tomb using solar and artificial radiation heater.

Several proven exploration methods, like radar, electric resistance and magnetic flux, had been used to detect their location of the buried objects. But those methods are not remote sensing and limited in a small area. It is needed to develop a new kind of the scientific detecting method feasible to conduct by the speedy, automatic and remote sensing system.

In this paper, the infrared radiometer using solar and radiation heaters was used to detect an invisible underground test piece and their detection characteristics are estimated numerically by modeling the underground structure. The detection limit and heat transfer mechanism pertaining to the detection process were evaluated and discussed simultaneously. It was clarified that our proposed method was useful to detect the buried object and carried out the verification of heat transfer analysis.

As application tests, we examined the field test of the buried ancient tombs, like Komochi-mura and Saitobara remains in Japan. We verified the existence of invisible buried remains under the ground by observing the non-uniform temperature distribution as in case of the test results using radar and electric resistance methods.

Finally, the infrared thermal image method using the infrared radiometer is the remote sensing diagnosis to detect the buried remains. And it is quite useful to a wide variety of engineering applications by measuring an abnormal temperature distribution on the comprehensive surface nondestructively and simultaneously.

A New Automatic Resistivity Measurement System and Correction of Ground Surface Concavity

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One of the most familiar methods for archaeological prospect is to measure the resistivity of the ground. It is easy to measure the resistivity, however, it is difficult to prospect the anomaly of the 3 dimensional resistivity profile from line scanning measurement on the surface. In order to get 2 dimensional data in good quality, the number of the data become huge and it takes much time for the measurement. Recently we have developed a new resistivity measurement system for archaeological prospect which is composed of the two-phase lock-in amplifier, current supply amplifier, electrodes selectors and a hand held personal computer for automatic data acquisition. The new system has the advantage compared with the traditional measurement system in noise rejection and data acquisition time. This system enables the signal detection having the same frequency and the same phase with those of the injection current. Here one data averaging over 250 times is obtained in 0.5 second. Further we can choose any pair of current electrodes and any pair of potential electrodes in 256 electrodes. This electrode-controlling system is also applicable to traditional measurement system i.e., the traditional measurement system can be graded up by the supplement of a part of this newly developed system.

In the archaeological prospect of the underground, ruggedness of the surface becomes serious problem. We had already developed a new resistivity calculation software for the surface having arbitrary shape. It is possible to measure the detail of the ground surface and perform the calculation using this new software, however, it takes long time and is not practical for general archaeological prospect. For this reason, we used a simple correction method for concave ground surface. The concave ground surface is approximated by half-sphere. It is not so difficult to consider the half sphere in resistivity calculation, and also easy to measure the center position and the radius of the sphere. Because of this simplicity, our new method becomes very useful for general archaeological prospect.

The archaeological prospect of Ohyasuba ancient tomb in Fukushima prefecture has successfully been performed using this new system and new correction method. Ohyasuba ancient tomb is a keyhole tomb with quadrangular rear mound and the details of inner part have been unknown since the discovery in 1994. In the rear positions of the tomb where we performed the prospect, there are many concavity. In our prospect, resistivity anomaly is inferred in the center of rear part along to main axis of the tomb. After two month from our prospect, wooden coffin which is surrounded by clay is found at the place where we have inferred. In our presentation, the new prospecting system, new correction method and the results of the measurement of Ohyasuba tomb will be reported.

High-Resolution Magnetic Data Acquisition, Processing and Inversion

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Extensive tests with a new low-cost Caesium magnetic gradiometer system have demonstrated the importance of maintaining constant sensor height and constant distance between the sensors and console during surveying. In order to help ensure high data quality and to speed up data acquisition, a non-magnetic cart has been constructed. For archaeological purposes, theoretical studies have demonstrated that a spatial sampling interval of 0.5 m may lead to aliasing of important short-wavelength information. After careful selection of magnetic sensor heights, vertical magnetic gradient data were recorded across the site of a buried medieval settlement. After applying a suite of appropriate corrections, a number of medieval pithouses and ditches were imaged on the magnetic data. To improve resolution, we reduced the magnetic data to the pole; such a reduction resulted in significant movements of the imaged features.

For many archaeological problems it is possible to apply constraints on the modelling/inversion of the magnetic data. For example, in our study area all significant magnetic features are expected to lie beneath the so-called "ploughing depth", and the susceptibility contrast between archaeological features and the surrounding soils should be more or less constant. We have derived a modelling/inversion procedure that inverts the magnetic gradient data for the lengths of vertical magnetic prisms whose upper surface lies at a constant level beneath the ploughing depth. To test the robustness of our scheme, we have explored extensively the influences that different susceptibility contrasts and smoothing parameters have on the inversions. Our preferred inversion model is entirely consistent with other information about the pithouses, especially that gained from ground-penetrating radar surveys conducted across the same region.

The Characteristic Fatty Acid, DHA, discovered on the Pottery at the Ancient Tomb of Saitobaru in Japan

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Saitobaru ancient tomb of underground corridor style burial chamber is located in Miyazaki prefecture in Kyusyu island of Japan. The age of the ancient mound is estimated as the late of 6th centuries. In 1996, the tomb was excavated and the surface lipids from several potteries discovered in the main burial chamber were examined on the fatty acid composition.

After the careful extraction of the lipid using the solvent of chloroform-methanol mixture, the fatty acid of the lipid was analyzed by the methods of gas liquid chromatography(GC), GC-mass spectrometry, and nuclear magnetic resonance. Polyunsaturated fatty acids such as docosahexaenoic acid (DHA) were identified. DHA is the characteristic fatty acid as the functional lipid needed for mammals and we usually obtained it from the food of fish and marine products.

The reason why DHA founded on the pottery in the chamber is considered that the burial chamber has an outstanding preventive environmental condition for the lipid oxidation with the constant moisture of 100% at dark and no interaction with the outside air. As a result, it was proved that fish or marine product existed on the pottery in the Saitobaru ancient tomb.

Prospection of Burnt Soil by Electron Spin Resonance (ESR)

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One of our interests in archaeological study is whether and how ancient man used fire at specific places. If all organic materials decomposed and no artifact (stone tool or pottery) is present, only color of the soil can tell details about ancient life at historical places. However, it is not easy to decide whether a reddish or black colored soil is burnt or not, only by contemplation of the color.

Electron spin resonance (ESR) is a powerful tool for investigation of paramagnetic centers in solids and have been applied to dating in archaeology, anthropology and earth science using fossil bone, tooth, coral, quartz and so on. In this study, ESR signals of iron ions (Fe^{3+}), radiation-induced centers and pyrolytically formed radicals in soil were used to determine between burnt and unburnt soil. As the soil was heated in a furnace, the radiation-induced centers were annealed and pyrolytically formed radicals appeared. The spectral pattern of iron ions changed during the heating process. We could estimate temperature and atmosphere at the heating event using these signals. Chemithermoluminescence (CTL) of the soil was also studied. Soil samples taken on a test fire and in Onbara site, Japan were investigated.

M. Ikeya: New applications of electron spin resonance - Dating, dosimetry and microscopy. Singapore, World Scientific 1993.

J. Bartoll et al.: ESR investigation of burnt soil. *Appl. Magn. Reson.* 11,577-586 (1996).

Thermal History and Dating Study of the 600,000-Year-Old Stone Tool by ESR

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Electron spin resonance (ESR) dating of chert, fault gouge, tephra and so on has been studied using radiation-induced centers like E' and Al centers in SiO₂. The thermal stability and dose response of those centers have been investigated. The heating temperature of the burnt stone should be studied to ensure that all defects used for dating were annealed completely by heating. It can be estimated by ESR with signals of Fe³⁺ ions or radiation-induced centers, which was applied to soil investigation to distinguish between burnt and unburnt soil (see the other poster). Thermoluminescence (TL) dating was frequently applied to burnt stones, heated chert and burnt flint. ESR dating of heated chert and burnt flint, mainly composed of SiO₂, was reported, while a burnt stone tool has not been studied with ESR.

The stone tool (7 cm x 4 cm x 1 cm) was discovered at the Kamitakamori site, northern Japan, which Japanese archeologists consider to be possibly the oldest paleolithic site in Japan. The yellow stone tool is made of silicified tuff and has a red belt at the edge. It was collected under a tephra layer called Ks-1 which was dated by paleomagnetism as 560 ka. The other scientific methods of ESR and TL gave the age of a tephra layer called Tm-1 above the Ks-1 layer as 430 - 610 ka and 406 - 484 ka, respectively. In the present work, we revealed the thermal history of the stone tool and dated the stone tool directly to be 600,000 years old using signals of Fe³⁺ ions and radiation-induced centers in SiO₂ by ESR, respectively. This suggests the presence of ancient man in Japan at the age of Choukoutien, China (Peking man).

M. Ikeya: New applications of electron spin resonance - Dating, dosimetry and microscopy. Singapore, World Scientific 1993.

Takamori Site II & III. ed. the Tohoku Historical Museum 1993 & 1995.

Chemical Approach for Magnetic Prospection of the Burned Soil in Remains:
Concentration Changes of Ironoxides in Burned Soils Studied by Magnetic
Susceptibility, ESCA, ESR and ICPMS Measurements.

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In situ magnetic susceptibility measurement and the palaeomagnetical measurement of the residual magnetization have been developed as nondestructive, convenient physics-oriented methods for the magnetic prospection of burned soil remains in ancient age. In this paper, we will propose a chemical approach for the prospection of burned soils on the basis of a total analysis of quantitative data obtained by measurements of magnetic susceptibility, electron spectroscopy for chemical analysis (ESCA), electron spin resonance (ESR) and inductively coupled plasma mass spectroscopy (ICPMS). Experimental fire was made in open-air on the two types of soil, volcanic ash and soil including clays. Relative concentration of iron oxides, such as FeO, Fe₃O₄, Fe₂O₃, and FeOOH, was estimated for every individual soil pre- and post-sampled in the area where the fire was made. According to the results, mappings of the magnetic susceptibility and of each chemical species of ironoxides were depicted.

Specimens from the area where soil was heated to higher temperature showed relatively higher concentration of Fe₂O₃ and lower concentration of Fe₃O₄. The amount of FeOOH decreased in the heated region as against in the non-heated region. The proposed chemical method for the magnetic prospection will be evaluated from the view point of dependence on soil type and temperature of fire and of the methodology itself.

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