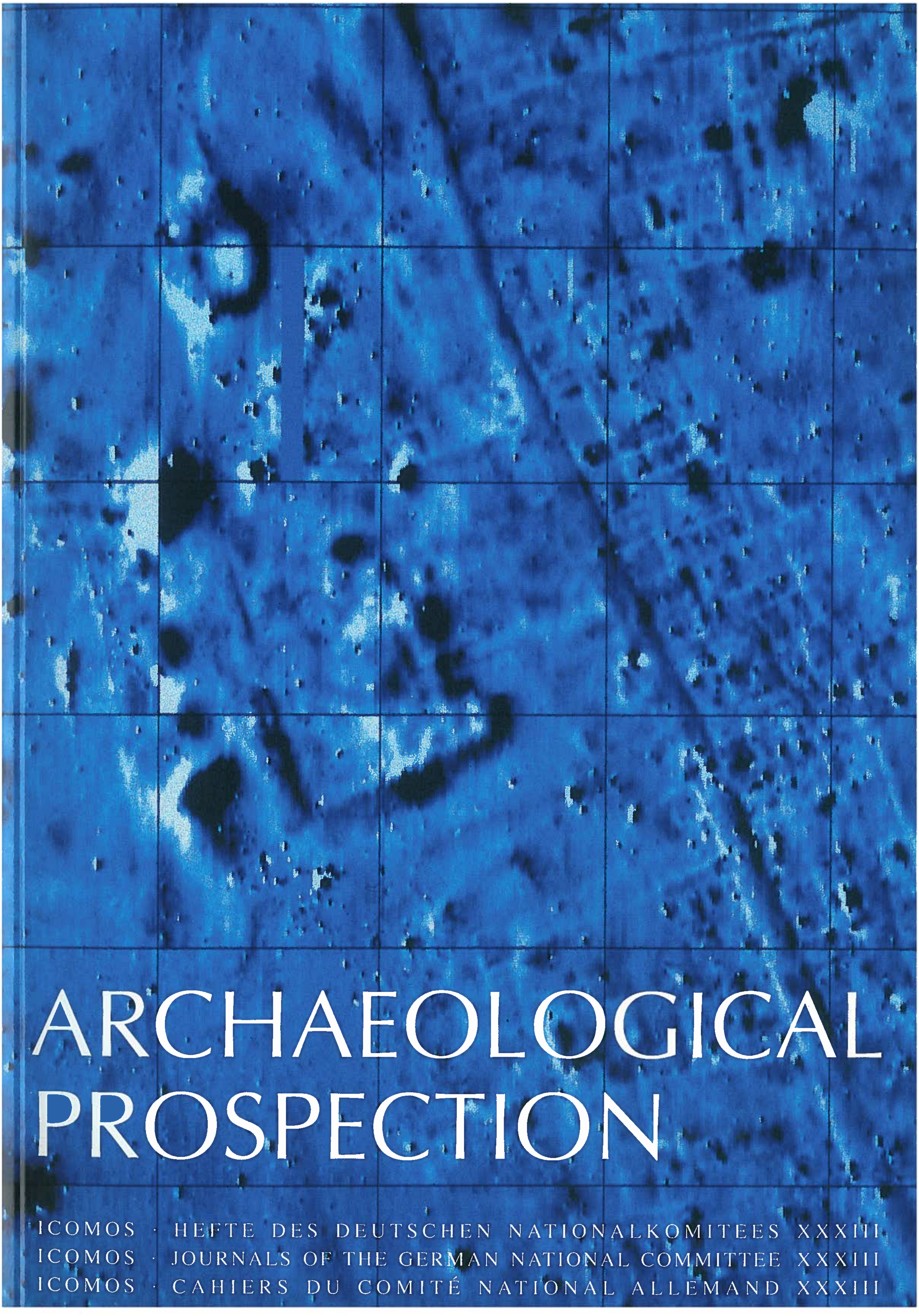

ARCHAEOLOGICAL PROSPECTION

ICOMOS · HEFTE DES DEUTSCHEN NATIONALKOMITEES XXXIII
ICOMOS · JOURNALS OF THE GERMAN NATIONAL COMMITTEE XXXIII
ICOMOS · CAHIERS DU COMITÉ NATIONAL ALLEMAND XXXIII

INTERNATIONAL COUNCIL ON MONUMENTS AND SITES
CONSEIL INTERNATIONAL DES MONUMENTS ET DES SITES
CONSEJO INTERNACIONAL DE MONUMENTOS Y SITIOS
МЕЖДУНАРОДНЫЙ СОВЕТ ПО ВОПРОСАМ ПАМЯТНИКОВ И ДОСТОПРИМЕЧАТЕЛЬНЫХ МЕСТ

Jörg W. E. Fassbinder, Walter E. Irlinger (Editors)

Archaeological Prospection

Third International Conference on Archaeological Prospection

Organized by the Bavarian State Conservation Office
and the European Geophysical Society EGS
in Cooperation with ICOMOS Germany
Munich 9.–11. September 1999

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Umschlagabbildungen/Cover

Vorne/Front cover: Palmyra, Syria. Cutting of the city map of the hellenistic Palmyra. Magnetometry with the caesium magnetometer (Smartmag). Dynamics ±7.5 Nanotesla white/black, 256 grayscales, 40 wave meter grid. The blue colour is due to the short light of the wazzu gray computer screen
(Photo: J. W. E. Fassbinder)

Hinten/Back cover: Chicha, Siberia. Magnetometry of a first Scythian "city" at South Siberia, showing a fortified settlement enclosure with more than one hundred Grubenhauser. Caesium magnetometer (Smartmag). Dynamics ±4.0 Nanotesla white/black, 256 grayscales, 40 meter grid
(Photo: J. W. E. Fassbinder)

Vorsatz/Endpapers, front: Aerial view of downtown Munich
(Photo: Bayerisches Landesamt fur Denkmalpflege Lufbildarchäologie, Archivnr. 7934/061,
Photograph: Otto Braasch)

Nachsatz/Endpapers, back: Two Celtic Viereckschanzen (square enclosures) near Steinlach, Bavaria. They are visible as soil marks and show the typical inner wall and ditch in front of it (Photo: Bayerisches Landesamt fur Denkmalpflege Lufbildarchäologie, Archivnr. 7932/020,
Photograph: Otto Braasch)

Seite 6/Page 6: Magnetometer cart from 1990, equiped with the Scintrex caesium magnetometer in gradiometer configuration
(Photo: Deutsches Museum, München, by courtesy of Deutsches Museum, Bonn)

Vorwort/Foreword: Translated from the German into English by Michaela Nierhaus

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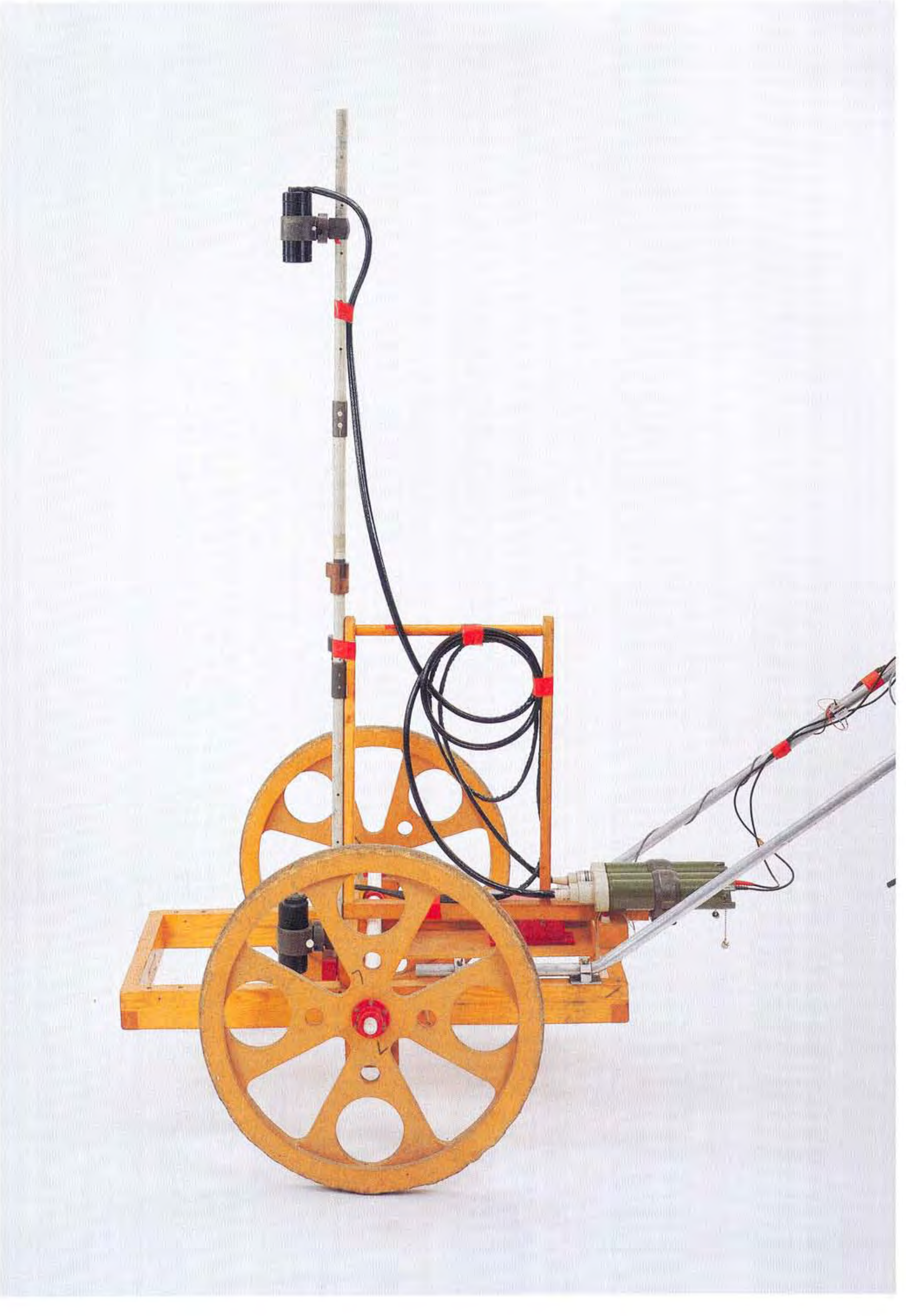


Foreword

From September 9th to 11th, 1999, the Bavarian Conservation Office and the European Geophysical Society (EGS) are jointly holding the international conference "Archaeologische Prospektion" in Munich. More than 150 scholars and scientists from all over the world are attending this conference to discuss archaeological prospecting and new approaches – their significance for scientific evaluation and archaeological conservation practice.

Particularly the last few years have seen tremendous technological progress in archaeological prospecting. New devices, geophysical methods and evaluation possibilities have rendered field work much faster and more sophisticated. New ways of presenting results to the public have also become available, among them modern computer software to demonstrate the whole wide range of research being done aided by field models and 3D animation, which make even tiniest traces invisible to the naked eye visible.

Prospecting archaeological sites looks back on a proud tradition of more than 100 years. Air photography, geophysical methods and remote sensing have proven to be most successful. The conference will therefore center mainly around them.

Air photography has been employed widely in archaeology for quite some time and is now finding intensive use in the former East Block countries. Magnetometry, first successfully applied by Martin Aitken in 1957, has established itself as the most effective geophysical method. Measuring methods have improved substantially since Erwin Scollar first introduced computers in field work and in the evaluation of measured data in the 1960s and 1970s. Especially, the use of caesium magnetometers in archaeological prospecting has made great strides.

Fundamental research in different applications of caesium magnetometers was conducted at the Bavarian State Conservation Office, noteably, by Helmut Becker and Jörg Fassbinder who, i.a, using other device configurations to make numerous reference measurements at home and abroad, kept improving measuring procedures. Continuous study of the theoretical principles contributed enormously to furthering the understanding of the methods. The examination of the magnetic properties of archeological sites and the discovery of magnetic soil bacteria, in particular, drew worldwide attention and can be regarded as the essential pioneer work in magnetometer prospecting. The first measuring car bearing a caesium magnetometer developed at the Bavarian State Conservation Office is now already on exhibition in the Bonn branch of the "Deutsche Museum für Forschung und Technik in Deutschland nach 1945" (see Fig.).

The development of accelerated data processing in the field opened new dimensions for its application. Today even quite large archaeological sites can be measured within a reasonable amount of time; for instance Cicah in Siberia, Troy, Hellenic Palmyra and the Ramsessidean city of Qantir in Egypt, where the geophysicists of the Bavarian State Conservation Office, who are frequently invited to participate in excavations, have worked to great all round satisfaction, show how precise images of ancient settlement structures can be obtained. Moreover, successful prospecting forms an ideal basis for archaeological research, because it reduces to a minimum the time-consuming search for the important centers of excavations. Accurate maps permit exact calculation, pinpoint plotting of sections and sieving out areas in which important results may be anticipated.

Thus at the end of the 20th century, a time when so many archaeological sites all over the world are threatened with destruction, improved prospecting methods in conjunction with scientific scholarship offer archaeological conservation new perspectives.

Michael Petzet

Abstracts of the "Third International Conference on Archaeological Prospection" in Munich

(in alphabetical order arranged)

F. Almeida, R. Moura, A. Rocha, A. Silva, C. Martins

Geophysical Techniques and GIS Applied to Archaeological Prospecting in Porto Old Town Center (Portugal)

Ground Probing Radar techniques can be used to analyse projects at shallow depths of investigation. At the University of Aveiro, Portugal, GPR techniques have been widely used in Archaeology, Geotechnics, Hydrogeology and Environmental problems. However, these techniques should be always used in conjunction with other geophysical methods so that a better overall interpretation is proposed.

Archaeological application of GPR in conjunction with seismic refraction and electrical resistivity measures from Infante Square, Porto (North Portugal) are discussed. GPR was used to delineate bedrock topography as well as local diffraction from buried structures. GPR interpretation is supported by seismic refraction interpreted using the Generalised Reciprocal Method. The overall geophysical model was tested and adjusted using local mechanical soundings. The information was integrated using a GIS for geophysical and geological interpretation and for further utilisation by archaeologists and architects.

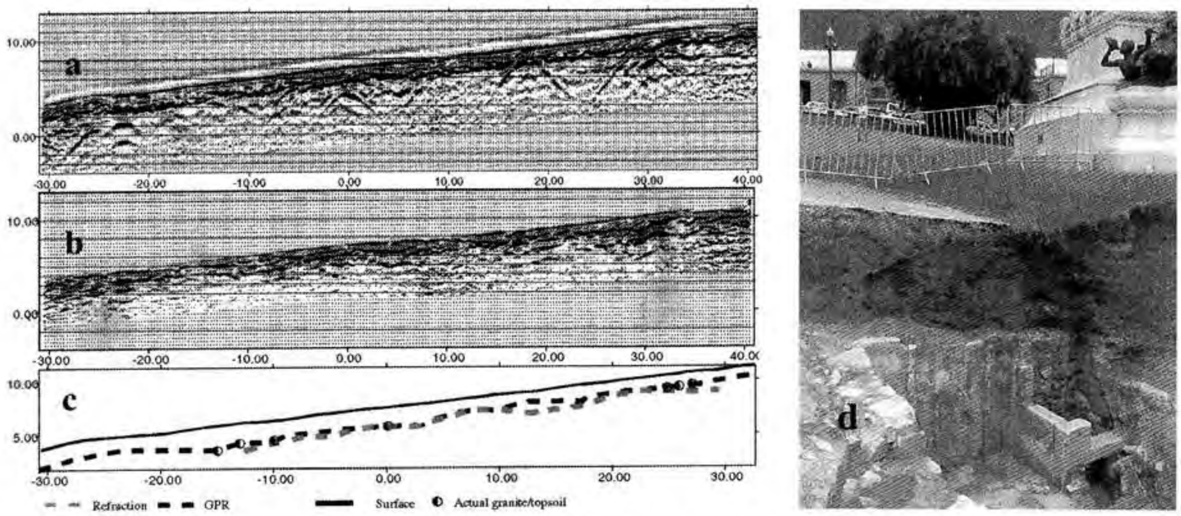


Fig. (a) GPR unmigrated section (AGC plot). (b) GPR migrated section (exponential/spherical gain). (c) Interpreted GPR bedrock (dashed black lines); mechanical soundings (symbol); GRM refraction interpretation (dashed grey lines). (d) Local picture of excavations and top soil at hiperbole nearby position 0 in (a)

C. Batt

The Use of in situ Magnetic Susceptibility Measurements to Interpret Archaeological Deposits

The value of magnetic susceptibility as a tool for the location of archaeological sites has been demonstrated on many occasions. However, recent studies have shown that magnetic susceptibility also has the potential to aid the identification and interpretation of deposits during excavation.

This paper examines the information that can be provided by *in situ* measurements of magnetic susceptibility on archaeological deposits such as hearths, cultivated soils, middens and industrial residues. The discussion is illustrated by case study examples using deposits encountered during the excavation of a multiperiod settlement mound at Scatness, Shetland. Significant variations in magnetic susceptibility were found in both excavated deposits and exposed sections, allowing distinctions to be made between features resulting from different anthropogenic activities, including heating, cultivation, domestic residue disposal and iron smithing. It also appeared possible to detect changes in the use of fuel sources over time.

The relative merits of the Exploranium GS meter and the Bartington field coil for studies of this nature are presented and *in situ* magnetic susceptibility measurements are compared with laboratory measurements of the same contexts. In addition, mineral magnetic measurements, soil micromorphology, soil chemical analysis and archaeological evidence from artefact and ecofact assemblages, are used to confirm the interpretation of the deposits examined.

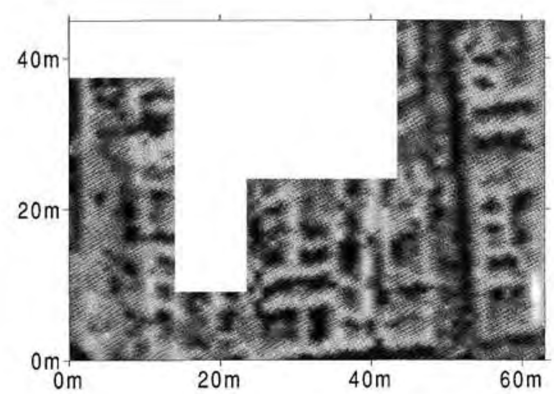
It is demonstrated that *in situ* measurements of magnetic susceptibility can provide the archaeologist with a rapid, simple and cheap measurement, which can be used during excavation to indicate the origin of deposits and any subsequent anthropogenic modification.

C. Benech, N. Florsch, J. Gaborit, G. Thebaut

Integration of Geophysical Survey into Archaeological Prospecting Strategy : the Case of Apamée upon Euphrat

For three years, the archaeological site of Apamée upon Euphrat was investigated by electric and magnetic methods in relation with the excavations and the topographic study. These geophysical surveys have greatly contributed to the global understanding of this site, which will disappear in December 1999 by the formation of a lake due to the building of a dam. This mission of rescue organised on this Hellenistic City required fast and efficient methods. Thanks to a greater and greater efficiency and the edition of maps more and more detailed, the geophysical methods are confirmed today very adapted to this context. The use of the Cesium gradiometer (G-858, Geometrics) for the magnetic method allowed maps of a rare quality revealing the urban system (streets, walls of defence, stocks of habitations). They constitute a real archaeological document, which permitted one to make a pertinent choice of the locations of the excavations. These excavations have completed the geophysical information, studying sectors in an out of the way place with the magnetic method, but localised in the urban scheme from the geophysical maps. Twelve hectares have been surveyed among the thirty-five hectares of the site. Different sectors occupied by thick orchards can't be prospected with the Cesium gradiometer but they should be razed before the filling in of the lake. We hope thus to complete the map of Apamée before its disappearance under the waters.

Fig. 1. Magnetic survey of local area (houses and streets)



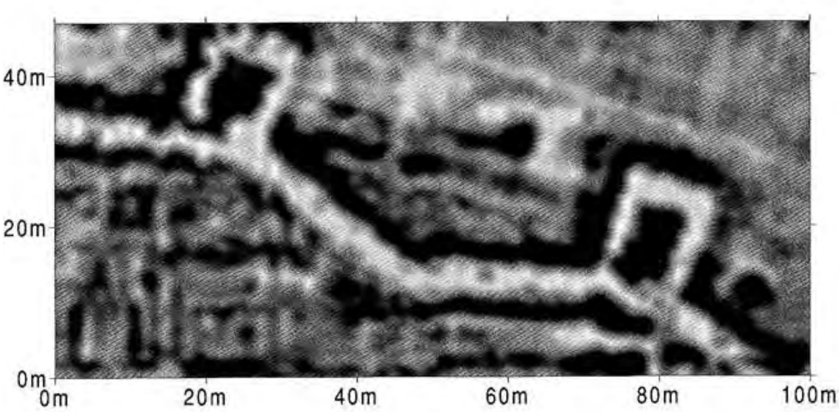


Fig. 2. Magnetic survey on the northern rampart of the city

C. Benech, G. Desivgnes, A. Tabbagh

Simultaneous Interpretation of Electromagnetic and Magnetic Data Using Linear Filtering

Magnetic (M hereafter) and electromagnetic (EM hereafter) methods are two different but complementary ways to study soil magnetic properties which intervene in pedogenis and anthropogenic processes by measuring respectively any types of magnetisation and magnetic susceptibility (in frequency domain).

Recent studies established a linear relation in Fourier domain between M and EM data. This method allows one to deduce induced magnetisation from EM data by using linear filter. The Fourier transformation of the induced magnetisation is obtained by the direct product of the Fourier transformation of magnetic susceptibility by the ratio of the Fourier transformation of the impulse M response on the Fourier transformation of the impulse EM response generated by a magnetic dipole. The tests realised on synthetic data allowed one to prove the efficiency of this filter and to evaluate the influence of the different parameters. It has been established that the depth of the dipole has a very limited influence on the filter and can be approximated by a single magnetic dipole.

The linear filter has been thus tested on field data from different archaeological sites: a pottery workshop from Iron Age (Verdun sur le Doubs, France) and a metallurgic workshop from medieval period (Melles, France). The results show a good correlation between filtered EM data and magnetic data. The result will essentially depend of the estimation of the depth of the magnetic source. The filter must thus be tested with a single dipole at different depth to be sure to obtain the best result.

G. Bossuet, P. Barral, C. Petit, C. Camerlynck, M. Dabas

Diachronic Interpretation in Magnetic Prospection. The archaeological Sites of Ribemont-sur-Ancre (Somme, France) and Authumes (Saône-et-Loire, France)

Over two archaeological sites, magnetic prospections were carried out with gradiometer equipment. For each site, several geophysical responses corresponding to different historical time scales are superimposed. The need for a diachronic interpretation arises to separate the different structures and replace them into the proper time window. This can be achieved by the confrontation with all available historical sources and archaeological features.

The archaeological site of Ribemont-sur-Ancre (Somme) has an extension of 70 hectares. Studied for 30 years, this major site known as a reference for Celtic civilisation, is nowadays reinterpreted as a Celtic trophy from the second half of the 3rd c B.C., superposed with a pre-augustean sanctuary. Since its discovery in 1960, a lot of missions of aerial prospecting (Agache 1960, 1964, 1970, 1978) and archaeological excavations have taken place. If the spatial distribution of remains is well known – a large temple, a worship enclosure, baths, a theatre and insulae-, many questions are still unsolved :

- some structures identified on aerial photographs are very faint and not yet controlled by archaeological soundings,
- over large areas well documented by an extended aerial data cover, no marks are visible despite many artefacts on the ground surface,
- the opportunity of using the magnetic method in a magnetically polluted environment (presence of numerous iron objects and other related structures dating from the first world war).

However, magnetic prospection has enabled the detection of new structures: Celtic ditches, a craftwork area, etc. Confrontation of magnetic data to old field boundaries and vertical aerial photographs taken by the Royal Air Force during the first world war allows us to interpret the origin of the different anomalies in terms of historical periods over 2,000 years.

The archaeological site of Authumes (Saône et Loire) is located on a mound over the Doubs valley. Surface findings span over an area of approximately 700 x 300 m. They extend from the 3rd c B.C. until 4th c. A.D. Concentrations of artefacts from one period seem to be well concentrated over different areas. However, no marks appears on the available aerial photographs. In order to gain information in a very short time to convince political authorities, the magnetic prospection was required: a surface of 3 ha was surveyed within two days. The map shows a palimpsest of superimposed structures probably associated with the different states of occupation of this site. Further excavations and geophysical surveys should confirm the time superposition of the discordant structures and the possible relationships between them.

M. Brown

Macro- and Micro-Land Division in the Later Prehistoric Period: Aerial Survey, Pit-Alignments and GIS in South-east Scotland

South-east Scotland, an area some 80 km by 80 km in extent, is characterised by its low rounded hills up to 600 m in height, heather-covered on the higher slopes, cut by narrow valleys, and bounded on the north by the broad estuary of the Firth of Forth and a wide coastal plain, on the east by the North Sea, on the west by higher hills of similar form, while to the south the border with England is formed, in part, by the River Tweed, but, for the most part, by hedges and stone walls in farm land, cultivated similarly on both sides of the line. The Royal Commission on the Ancient and Historical Monuments of Scotland has been carrying out consistent aerial reconnaissance in south-east Scotland for over twenty years. While the presence of pitted features had been recorded in earlier years in antiquarian accounts, as well as by aerial and field survey, it was in 1978 that an association was noted between pit-alignments and settlements appearing in cropmark and earthwork form and attributed conventionally to the Iron Age.

There are two main forms of linear boundary in the cropmark record, linear ditches and pit-alignments or interrupted ditches. They are paralleled as upstanding monuments by linear earthworks, which usually appear as a bank and a slight, presumably quarry, ditch and, in a very few examples, as a series of small,

Fig. 1. Transcription of Fort, Warlawbank, Horseley Hill, Scottish Borders

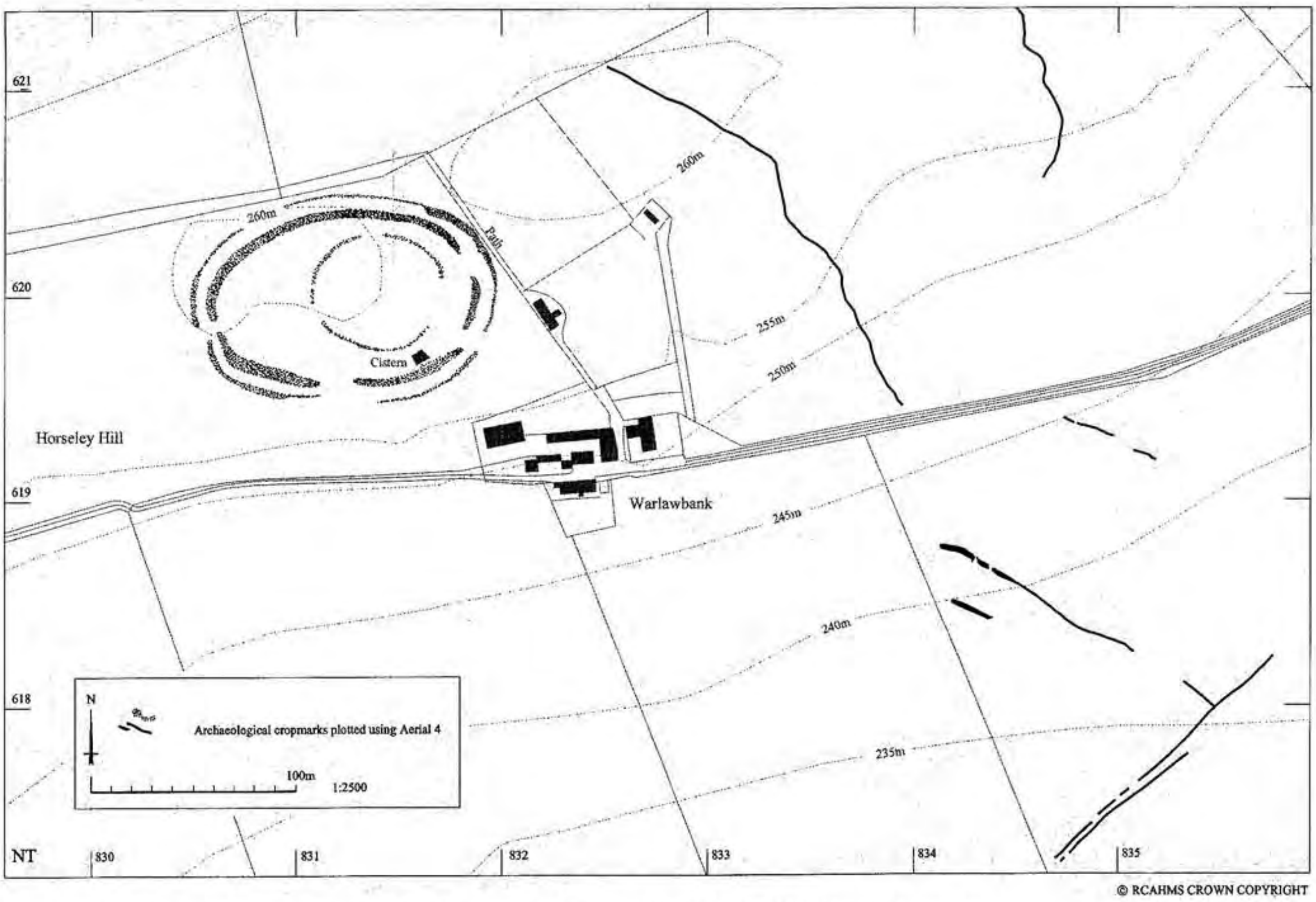


Fig. 2. Pit-alignments and settlements, East Field, Inveresk, Midlothian C26868 RCAHMS Crown Copyright

regular depressions, accompanied by a low bank, which match the pit-alignments. The pits are usually quite small, between 2 m and 3 m in diameter and often poorly defined. *Pit-alignment* is a convenient morphological term, which may be applied to monuments of different periods and cultures. Examination of the distribution patterns in GIS show a clear concentration in south-east Scotland, and in certain areas within it.

With the 1990s came a survey break-through, allowing the relationship between pit-alignments and linear cropmarks to be clearly established, and, with the advent of GIS in the Royal Commission, came the ability to view these very small individual features both in isolation and as part of larger grouping, which can, in the most extreme example, be seen to run for at least eight km. The digitised transcription and rectification of pit-alignments, linear cropmarks, the settlements with which they may be associated and earlier monuments, which may have had significance in the laying out of boundaries, and the incorporation of information into the GIS is time-consuming work, of which perhaps 20 % has been completed. Examples were recorded running uphill into the currently uncultivated moorland and even to the cliff edge above the North Sea, implying a completeness of control of the land, that required detailed physical boundaries defining small areas, which might be compared in scale to the modern field pattern, the product of enclosure between the late seventeenth century and the early nineteenth century. The results of a series of recent pollen analyses across southern Scotland and northern England would suggest that from about 350 cal. B.C., there was not a very considerable expansion in the intensity with which agriculture was practised across the area, and this dating would not conflict with field survey. The evidence for an ordered and complex system of land division in south-east Scotland is considerable, and necessarily raises questions about the social organisation of the inhabitants of the area before the advent of the Romans.

T. C. Brunet, A. U. González, V. M. Herrera, J. M. V. García, A. L. R. Alcalde, S. O. Villajos

Remote Sensing Analysis and the Design of Archaeological Prospections: a Regional Study of Settlement Patterns at Eastern Andalucia (Spain).

This paper is intended to show the advantages of new techniques as Remote Sensing, Global Positioning Systems and Geographic Information Systems on the design of research projects directed towards the aims of Landscape Archaeology. Centered on an area of contact among a variety of geographical environments, this project tries to recognise and understand the differences on settlement patterns on a diachronic perspective, employing the new technical implements and generating databases linked with archaeological prospection.

The chosen area is organized along the corridor defined by the river Guadiana Menor, establishing a link between the coastal ports of south-eastern Spain with the important mining area of the upper Guadalquivir. The first stage of the analysis of settlement patterns should be guided to the detection of archaeological sites, as well as to determine the physical characteristics of the environment. Apart from other indispensable tasks, as the revision of the previous archaeological and historical information, there are two essential topics to be accomplished: archaeological prospection and the stock of any relevant geographic information. With this aim, we can benefit of new tools, as Remote Sensing Analysis (RSA), Global Positioning System (GPS) and Geographic Informations Systems (GIS). All of them involve a considerable advance on the capacity of analysis of any research regionally oriented.

However, the novelty of these techniques in their archaeological application, and the specific character of each topic and of this particular area, compel us to generate concrete methodological instruments in order to adapt those resources to the research, during fieldwork and on the laboratoy analysis. In this paper, we will try to present how the integration of the three systems leads to obtaining meaningful advantages in the attainment of the research objectives.

From a technical point of view, the combination of RSA and GPS allows us to connect directly observations made during fieldwork within the information system. The result is what we could "archaeological prospection satellite-assisted". From the point of view of theory, a central premise is the systematic integration of the archaeological aims of fieldwork, basically the location and documentation of archaeological sites on a regional area with those specifically geographic in character, within a single system of information, planning and evaluation.

Conventional programs of archaeological prospection at a regional level are scarcely efficient in relation with these approaches. This ineffectiveness comes usually from the application of criteria that are exclusively archaeological on the selection of survey areas, sampling patterns and prospection models. This implies in many cases a remarkable difficulty to establish generalizations from – by example – data about site distribution, and, in any case, a deficient assignment of economic resources. The introduction of geographic criteria proves to be essential in this context

Within this methodology, the documentation system includes the conventional archaeological information as an element of landscape, different enough to require specific criteria of classification, but in any case, articulated with other factors and variables of geographic or biological character.

Fig. 1. Iberian Peninsula and Study Area

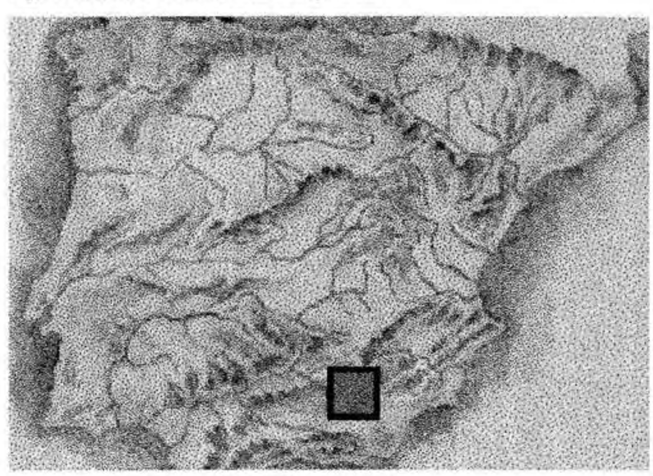


Fig. 2. Relation between water sources, rivers and archaeological sites

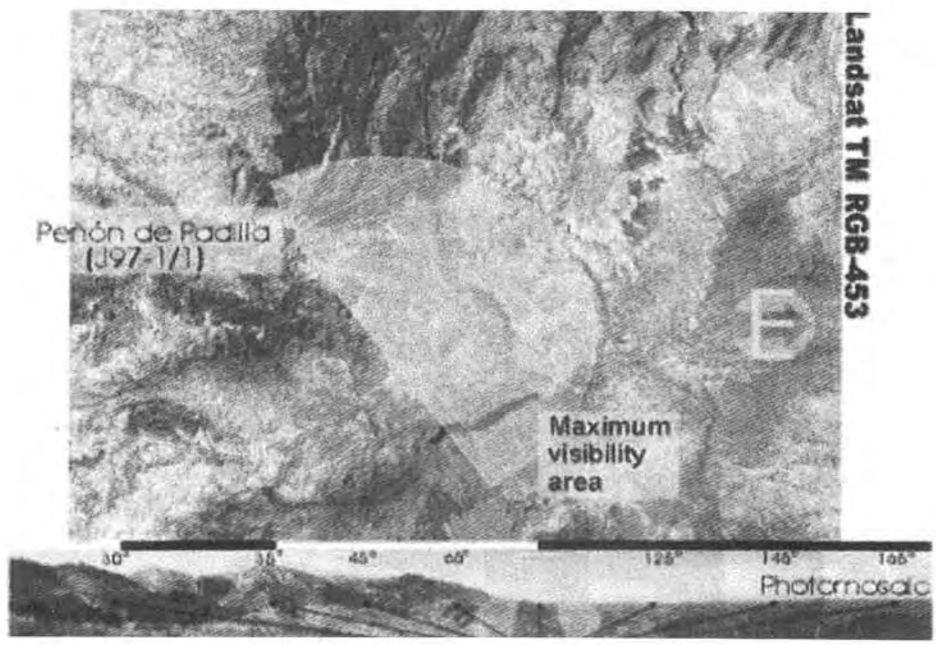


Fig. 3. Establishing visibility areas from an archaeological site

Fig. 4. Definition of Landscape units based on information provided by the Landsat image

S. Buteux, Ch. Gaffney, J. Gater, S. Ovenden-Wilson

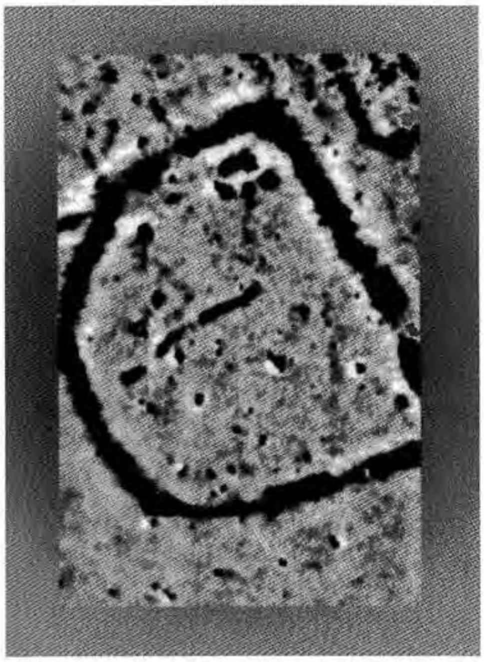
Fluxgate, Caesium Vapour and Excavation: Establishing the Validity of High Sensitivity and High Sample Density Magnetic Measurements

An extensive fluxgate gradiometer survey was undertaken on a large housing development at Northampton, England. The results, based on a 1.0 x 0.5 sample density, were unambiguous, with evidence for clear settlement foci. However, it was felt that some of the detail, especially for individual dwellings was missing. A research design was formulated to see if the missing elements could be located. In particular the strategy was aimed at establishing the differences, if any, between two magnetic instruments (fluxgate gradiometer and caesium vapour gradiometer) of different sensitivity on "typical" British soils and to establish what variation an increased sample density achieves.

Firstly, two enclosures and a "ring" ditch were re-surveyed using the Geoscan FM 36 and data collected on a 0.5 x 0.125 m grid. The area was then surveyed using a Scintrex Smartmag SM-4G on the same nominal sample intensity. The results were analysed to highlight:

1) The differences between the two fluxgate gradiometer surveys.
2) The interpretable differences between the fluxgate and caesium vapour data.

This study benefits from two further factors. Firstly, a "blank" area was surveyed to analyse soil noise in an effort to understand true levels of identifiable anomalies. Secondly, all areas were then stripped and archaeologically excavated. As a result, direct comparison has been made between the instruments and the physical reality of the buried evidence and not simply a qualitative "analysis" between greyscales. This work has far reaching implications about how we go about survey, both in terms of strategy and instrumentation.



F. Cammarano, B. Di Fiore, P. Mauriello, D. Patella

Application of a 3D Probabilistic Multimethodological Tomography to Cultural Heritage

We present the results of a new 3D tomographic multimethodological procedure using a probability function, which allows the inference of the presence of anomalous sources in an optimum way without a priori constrainsts. In particular, we use Self Potential and Geoelectrical data, showing that the 3D tomographic reconstruction of sources, generated by both a natural electric field and an artificial one, can improve the information about prospected targets. As a matter of fact, the 3D Self Potential tomography aims at defining the charge distribution across electric discontinuities and the 3D Geoelectric tomography aims at contouring the volumetric distribution of the resistivity. Therefore, the two tomographic procedures complement each other giving a more complete and reliable interpretation. We discuss the results from the study of the state of preservation of the Axum Stele (Rome, Italy). The 3D tomographic procedure allowed us to identify missing materials, microfaults and linking bronze dowels implanted inside the Stele between the overlayed blocks.

A. C. De Lima Canto

Spatial, Geoarchaeological and Paleoenviromental Analysis of the Archaeological Site "Furna do Estrago" – Brazil

The archaeological site "Furna a do Estrago", situated in the municipality of Brejo da Madre de Deus, Pernambuco State, represents an important parameter in the reconstitution of the prehistoric landscape in the semi-arid environment of Northeast Brazil during last the 11,000 years BP.

Based on the systematic study of this site, analysing the cut 7A of the "Furna do Estrago" – constituted of seven archaeological layers –, a reasonable contexture of past occupations resident in the Furna was possible, evidenced respectively between 11,060 ± 90 BP (layer seven); 9,150 ± 90 (layer six); 8,495 ± 70 BP (layer five) and 1.040 ± 50 years BP (layer two).

Starting from general ideas about the Quaternary, situating the "Furna do Estrago" in this period, specific methodologies have been applied that come for other areas of the scientific knowledge (grain-size analyses, morphoscopy and X-ray diffraction), palinology, zoo and the phytoarchaeology graphic resources met in informatics, for the space reconstitution of the site and areas of bigger human activity in the resulting archaeological layers.

The ordination of the related aspects in the analysed stratigraphic section, differentiated well by the resultant layers, with a depth reaching 1.40 m in an area of 7 sqm, allowed a direct correlation between the expressive amount of identified archaeological records, associating them with the responsible sedimentary dynamics for the formative process of the stratigraphic profile.

In this relation it was observed, from the grain-size analysis, homogeneous sedimentary process in the stratigraphic sequence between the milleniums, where the degree of selection and the proper grain-size are characterized by a small difference between the layers, with the predominance of an average sandy material in a sedimentary regime of low energy.

Such assertion, associated to the mineralogical results (X-ray diffraction), especially represented for the clay minerals: kaolinite and illite; and to the zoo and phytoarchaeological aspects, allowed to indicate for the datings mentioned above, a warm period with high temperature in the Pleistocene/Holocene limit (11,060 ± 90 years BP), following by a warm and dry period for 9,150 ± 90 years BP, again a dry period at 8,495 ± 90 years BP, suffering later a climatic mild, probably between 6,500 and 4,000 years BP (layer four – without dating, but with intense zooarchaeological and palynological indicators characterizing humid periods – probably the "Optimum Climatic One"), reaching contemporary climatic trends to the semi-arid of Northeast Brazil, only near 1,040 ± 50 years BP.

The zoo and phytoarchaeological characterizations confirm the sedimentological and mineralogical perspectives for the prehistoric environment in the Furna, by the expressive or scarce features in confrontation with the already argued parameters.

From the botanical point of view, all identified species with characters of typical Caatinga plants, have their bigger concentrations in the form of archaeological material dispersed among the layers.

From the faunistic point of view, the expressive presence of the categories Mammalia, Reptilia, Amphibia and Molusca, predominantly between layers 5, 4 and 3, permit to infer that the best phase of adaptability to the environment, for the past groups, is given between 8,495 ± 70 BP and 2,000 years BP, attributing for the previous periods not so favourable environmental conditions, responsible for the scarcity of the food resources.

This information, coherently organized in the stratigraphic section and reconstituted by operation of computer science, made possible the indivudualization of strategic considerations about the prehistoric occupations, classifying, from the distribution of the archaeological records in the profile, the areas of bigger anthropic activities and availability of the resources.

At last, as presented in this work, a sequence of the environmental periods which would have crossed the prehistoric groups of the Agreste of Pernambuco, characterizing the landscape of the last 11,000 years BP and indicating the most favorable periods for the development of the occupations situated in this time span are shown.

B. Cech, G. Walach

The Importance of Integrated Prospection Techniques for Archaeological Investigations on Mining Sites in Rugged Alpine Topography

The investigation of mining archaeological sites in the Alps requires a special approach to investigation due to the difficulties of the terrain conditions (topography, vegetation). Using a gold mining region from the 15th and 16th century in the Gasteinertal (High Tauern) as a testbed, a method of prospection was developed and tested which is being called the integrative model of prospection. The main characteristic is a partition of the process into a number of phases, thus archieving a significant degree of improvement of the cost-result ratio. Through the specific use of research, non-invasive and invasive methods, the prospected area is being successively reduced from phase to phase by a ratio of about 1000:100:10:1, while the density of information increases at the same time. The area of prospection is indicated by research (phase 1). The location of finds is determined by systematic archaeological and geomagnetic profiling (phase 2). In phase 3 the boundaries of the site areas are determined through geophysical methods (geomagnetics and electromagnetics). Finally in phase 4 the detailed scenario of the site is investigated through the use of archaeological, geodetic, geophysical and geochemical methods and the area to be dug is determined. During the excavation, geophysical methods are used for detailed investigation of difficult digging areas, archaeologically not accessible areas (steep inclines, rock fall areas, snow fields) and for the resolution of problems of the geology of the deposit (SP method) and of mining technical problems. Also petrophysical methods (rock density, susceptibility) are being used as well, both in situ and on finds (ores, slags, soil discolorations).

In the area of the mining field Bockharttal and the precious metal smelter Angertal mining, processing and smelting installations were prospected and archaeologically excavated in the years 1994 to 1998. The method of prospection, its significance for planning and execution of the excavation and the archaeological results for this application will be presented.

H. Chapman

The Prospection of Archaeological Features in Wetland Landscapes: an Approach Using Cell-based GIS Modelling of High Resolution GPS Data

The value of wetlands lies in their extraordinary potential for the preservation of archaeological remains. This value has been reflected by the number of projects which have been centred around finding and assessing sites within wetland landscapes. Despite this, however, there has been very little development in the methods of prospection which have centred around field-walking and ditch surveys. This paper outlines a new method of prospection within wetland landscapes using GIS to model three dimensional surfaces from high resolution, high accuracy surveys of micro-topography. This method has been able to identify the locations and nature of buried archaeological deposits due to differential shrinkage of biogenic deposits relative to clastic sediments which is reflected in the surface.

Two sites were surveyed using high accuracy differential Global Positioning System (GPS) equipment at a standard deviation of 0.02 m. They were surveyed in transects aligned upon ranging rods at a surface resolution of between approximately 8.0 m and < 1.0 m in areas of greater archaeological potential. The data from these surveys was processed using ARC/INFO© Geographical Information System (GIS) software to generate an interpolated cell-based surface. This surface was generalised in a number of ways including basic contour banding and light-source allocation to provide hill-shading in order to highlight natural and archaeological features represented through elevation, aspect and slope. The results from this modelling were later assessed through ground-truthing.

The first site was at Sutton Common (South Yorkshire) in the Humber wetlands. Here a pair of Iron Age lowland enclosures exist within a wetland landscape, positioned on "islands" on opposing sides of an infilled palaeochannel. Enclosure B remains as an upstanding earthwork monument while enclosure A was bulldozed in 1980 and was under intensive arable agriculture until 1997. Despite seventeen years of ploughing, the outline of enclosure A was clearly visible along with a number of further features such as the presence of a ditch on its western side. Also the position of a causeway between the enclosures, crossing the palaeochannel, was indicated.

Ground-truthing at this site was assisted through a programme of excavations, commissioned by English Heritage, which were positioned on the basis of the model. This work revealed a direct correlation between features identified from the modelling and those identified in the excavation trenches.

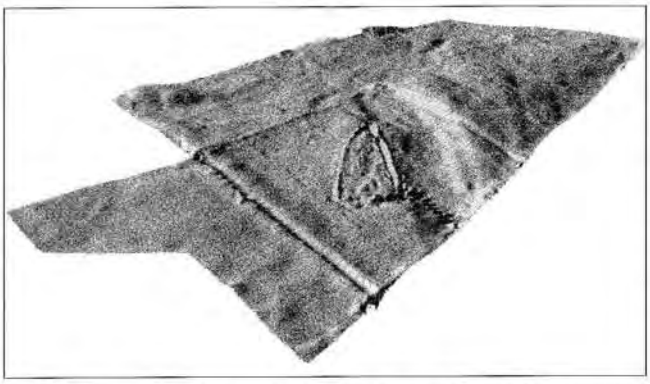


Fig. Sutton Common GIS model showing the positions of the upstanding and bulldozed enclosures – the full landscape measures 880 x 580 m

The second site was Meare Village East (Somerset) in the Somerset Levels. Here an Iron Age site had been identified on a raised peat mound within a peat-filled hollow. The settlement was characterised by clay spreads and mounds which were occupied by industrial remains and hearths. The results from the GIS model of this site reflected the positions of many of the known clay mounds which cover the site as very slight rises, most of which were imperceptible on the ground. Further it identified a number of other mounds which had been located through a magnetometry survey. Other mounds were indicated outside of the known area of the site. The results were checked by excavating a number of borehole transects. These identified correlations with some of these new mounds, but also a lack of correlation with others which appear to have been influenced by later activity.

In each of these cases the identification of archaeological features has been possible due to the increased shrinkage of biogenic sediments relative to clastic sediments within the framework of the current drainage regimes at each site. At Sutton Common, this increased shrinkage was identified in the peat-filled palaeochannel and the archaeological ditches. At Meare Village East, the scenario was reversed with the increased shrinkage lying in those areas not covered by the clay mounds. Overall the method has proven to identify archaeological features within wetland landscapes which cannot otherwise be seen on the ground.

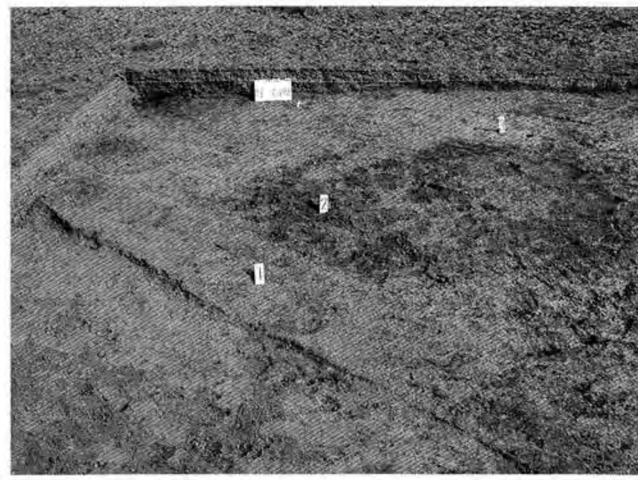
M. Chlodnicki, T. Herbich

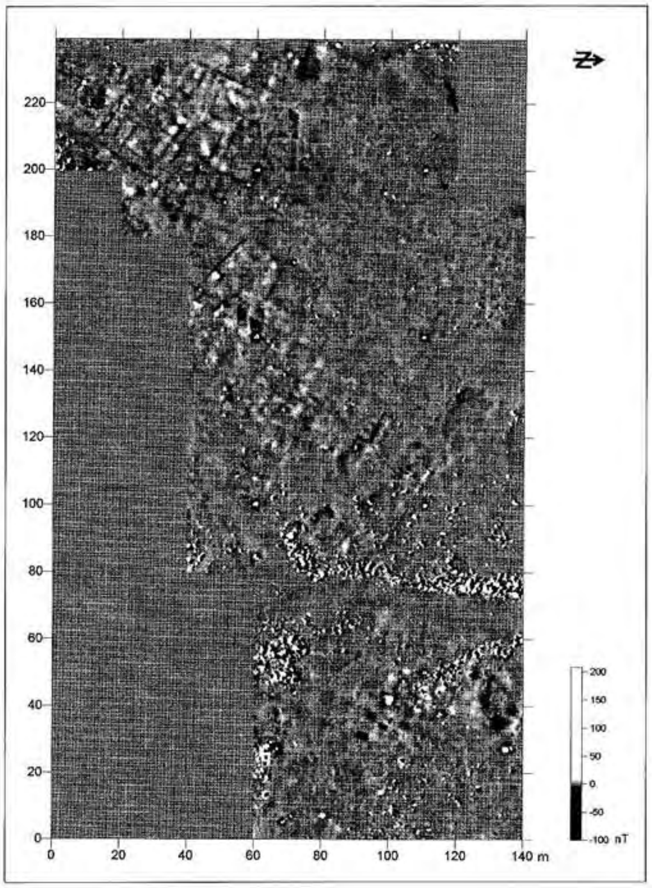
The Magnetic Survey at Tell el Farkha, Egypt

The site of Tell el Farkha is located immediately to the north of the modern village of Ghazala (14 km east of Simbillawein), in the Sharqiya province, Eastern Nile Delta, Egypt. The site was identified by the Italian Archaeological Mission (led by R. Fattovich) in 1987, the excavations were carried out between 1987 and 1990. From 1998, the excavation has been continued by the Polish Archaeological Mission, led by M. Chlodnicki (as a joint project of the Poznan Prehistoric Society, the Jagiellonian University and the Polish Centre of Mediterranean Archaeology in Cairo).

The site is located on the top of a sand gezira and extends over an area of ca. 400 x 110 m, with a maximum height of about 4.5 m over the level of the cultivated plain. It is marked by three mounds along the northern edge of gezira and a gentle slope delimited by the village houses in the south (fig. 1). The maximum thickness of an anthropogenic deposit, above the water table, can be evaluated at 5–6 m.

So far, the excavations have shown three main occupational phases of the site, the earliest one going back to the Predynastic period (4th millennium B.C.), and the later ones to the Late Predynastic/Early Dynastic period and the Old Kingdom (3rd millennium B.C.). The last two occupational phases are characterized by occurrence of mudbrick buildings. The Predynastic phase exhibits only pits and light clay installations.





Most of the site is covered with a thick mantle of halfa grass, and a powdery earth stratum built up by collapsed mudbricks and aeolic redeposition. This stratum contained appreciable amounts of pottery, flints and stones. Below this deposit (10–40 cm below the surface) some fire installations, pits and first evidence of architectural remains occurs. In deeper layers many rectangular and semicircular constructions made of mudbrick were found, some of them paved with mudbrick floor. - Total area of excavation before 1990 was 192 sqm In 1998–99 the excavated area was 282 sqm large.

In 1998, a geophysical test was carried out in the western part of the site, in the area of 4,000 sqm The survey revealed distinctive settlement traces. In 1999, the whole site was surveyed, i.e. the area of 27,000 sqm A number of obstacles were caused by the fact that the survey was carried out in the area exploited by a densely inhabited village (huge amount of metal objects on the surface, traffic, driving of cattle etc.).

The fluxgate gradiometer FM36 (by Geoscan Research) was used. The test survey was in the grid of 0.5 x 0.5 m, the final survey in the grid of 0.25 x 0.5 m. Apparent traces of buildings from the latest settlement phases – the ones closest to the surface (Early Dynastic/Old Kingdom) are well visible on the magnetic map (fig. 2). The traces were registered on the middle mound (between Y=100 and 240) and the eastern mound (Y above 240, outside the area presented on the map enclosed). The survey revealed the general disposition of buildings. Traces of the buildings start disappearing towards the north, resulting from the increasing thickness of the deposits covering the remains of the settlement.

The survey shows that the settlement stretches southwards below the contemporary houses.

The survey has already been primarily verified by excavations, e. g. a distinctive, negative linear NW-SE anomaly (between Y=170 and 180, X=40 and 60) turned out to correspond to a mudbrick wall located immediately under the surface (fig. 3). The wall was accompanied by a concentration of ashes (a positive anomaly at the NE side of the wall).

The nature of a number of rectangular anomalies (between X=90 and 120, Y=30 and 50) on the eastern mound is not clear. They may correspond to a cemetery (?); but that will be clarified during the next campaign.

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F. Chouker

Archaeological Site Investigation by Means of Geoelectric Measurements in Tel-Halawi (Northern Syria)

About 100 Vertical Electrical Soundings (VES-Points) were measured at the site of Tel-Halawi, located on the left side of the Euphrates just before flowing into the Assad Lake in northern Syria. The VES-Stations, of only 2 m spacing, were distributed along 9 profiles (5 meters apart from each other), covering the southern part of the site (s. maps in Fig. 1). The electrode array, adopted for doing geoelectrical survey, was a modified Schlumberger configuration (pole-dipole array with the B-electrode placed far enough to be of negligable effect), which was suitable to be run with the following steps: OA = 1; 1.5; 2; 3; 4; 5; 7; 10 m, while the separation of potential electrodes (MN = 0.5 m) was constant all over the soundings.

The resistivity data measured in the field were then treated and plotted as resistivity cross sections of different pseudo-depths, showing the specific influence of the different targets laying at the corresponding depths. The procedure, even though more time consuming, looks as a very promising technique for discovering near-surface targets through resistivity survey, reflecting successively the resistivity variations with depth, and separating anomalies in regard to their depth situation below the surface within the first ten meters. It offers also higher reliability of results, due to confirmed response of the subsurface targets noticed as multiple anomaly on several cross sections with gradually growing depths. Many of these anomalies measured along the resistivity profiles were verified through excavation work.

R. Chujo

Assignment of Mummies in Chusonji Temple to Fujiwara Chieftains with the Aid of NMR for Silks in These Coffins

Chusonji is the buddhist temple constructed in the 12th century at Hiraizumi city, Northeast Japan. In this temple three mummies are still preserved: they are

Kiyohira Fujiwara (died in 1128)
Motohira Fujiwara (died in 1157)
Hidehira Fujiwara (died in 1187)

All of them were Fujiwara chieftains. In the coffins of these mummies many silk materials were used.

The amino acid composition may be determined from ^{13}C NMR (Nuclear Magnetic Resonance) for these silk materials. Due to the degumming of the materials they are not dissolved into any solvent. Only solid state NMR can be applicable. Solid state one is insufficient in the resolution compared with solution one. In Figure 1 are shown typical spectra. Chemical shift splittings are observed in C=0 region between Gly and Ala. The mole fraction of these two amino acids are different with each other.

Possible candidate of the origin of such difference in the fraction is climate (especially temperature) when silkworm was reared. Actually, from the comparison with dendrochlonological data good correlation was obtained. However, the number of samples is confined to only three. In order to overcome the insufficiency of number of the samples we have to introduce an alternative strategy. It is NMR observation of modern silk reared in definite temperatures. In this case we can use solution state NMR to silk gland extracted from silkworms. Chemical splittings were observed in C a region due to good resolution and the mole fraction was able to determine for Gly, Ala, Ser and Val. Three species were used as follows:

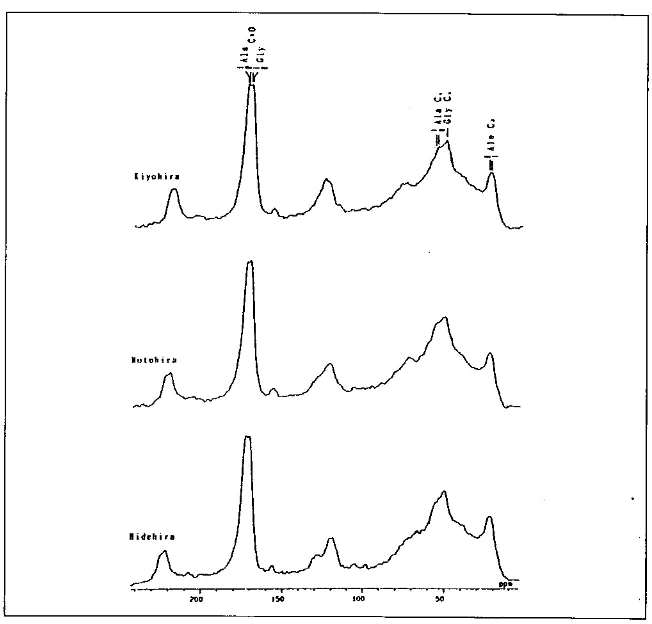
Shunrei No. 1 x Shogetsu No. 1: the most popular since Mendel's law.
Habataki: special species which can feed on apple as well as mulberry.
Koishimaru: the oldes species existing at present.

Temperature dependance was clearly observed for all species. Qualitative coincidence can be confirmed between the fraction of above and this NMR data. Only the numerical values for Habataki cover those for silks in the coffins. From the comparison between them temperature was estimated as follows:

1128: 27.1 °C
1157: 26.2 °C
1187: 27.5 °C

According to the document (established in the 14th century) of the sutra stock house of Chusonji, in the central, the left and the right coffins Kiyohira (the first), Motohira (second) and Hidehira (third) were preserved, respectively. This document is thought to be reliable. However, there is still one unsolved problem. There are two ways on the definition between left and right. In Japan the definition was usually done from the respected persons side. The respected person means buddha image in this case. This is a completely opposite definition from that of prayers side. From the NMR investigation in this study the definition from the respected person side is supported. The definition has to go back to the former one at least from this study. This conclusion is reasonable from the standpoint of Japanese traditional definition between left and right.

Fig. 1. Solid state 13C NMR spectra of silk materials preserved in the coffins in Chusonji temple



M. Cole, A. David, J. W. E. Fassbinder, N. Linford, P. Linford, A. Payne

Comparative High Resolution Caesium Vapour and Fluxgate Gradiometer Survey at a Range of Archaeological Sites in England

Magnetometer surveys continue to be used over a wide range of archaeological sites throughout the UK and have met with a high degree of success given the generally favourable geological and soil conditions found throughout the country (Clark 1990). The majority of these surveys have been conducted with fluxgate gradiometers which offer the advantage of both affordability and rapid data acquisition in the field, constrained only by a modest sensitivity compared to high resolution caesium vapour sensors. Whilst primarily designed for aeromagnetic applications the suitability of optically pumped magnetometers for archaeological survey has long been recognised (Ralph 1964) deterred only by the cost of the equipment and difficulties with field operation. To this end, German and Austrian geophysicists have extensively developed caesium instrumentation for archaeological applications which currently allow high resolution magnetic data to be collected at a much higher rate than the fluxgate surveys (Becker 1995).

Despite the obvious advantage of higher sensitivity that caesium magnetometers provide relatively few surveys have been conducted with caesium magnetometers in the UK compared to the continent. This is due, perhaps, to both the historical development of fluxgate instrumentation in the UK (Alldred 1964) and the abundance of magnetically enhanced soils found throughout the majority of the country (Dearing et al 1997). Numerous geophysical surveys, supported by subsequent excavation, attest to the suitability of fluxgate instruments to a provide a more than adequate sensitivity over the resultant well magnetised archaeological features that these sites produce. However, the scarcity of direct comparisons with caesium data has limited the assessment of high resolution magnetic survey and the benefits this may offer over conventional fluxgate gradiometers.

The aim of this study is to present results from a series of comparative surveys conducted over a range of sites in England through an ongoing collaboration between the Bayerisches Landesamt für Denkmalpflege, Munich, and the Archaeometry Branch, Ancient Monuments Laboratory, English Heritage. A range of monument types and geological substrates have been investigated encompassing sites both favourable to magnetic

Fig. 1. Stonehenge

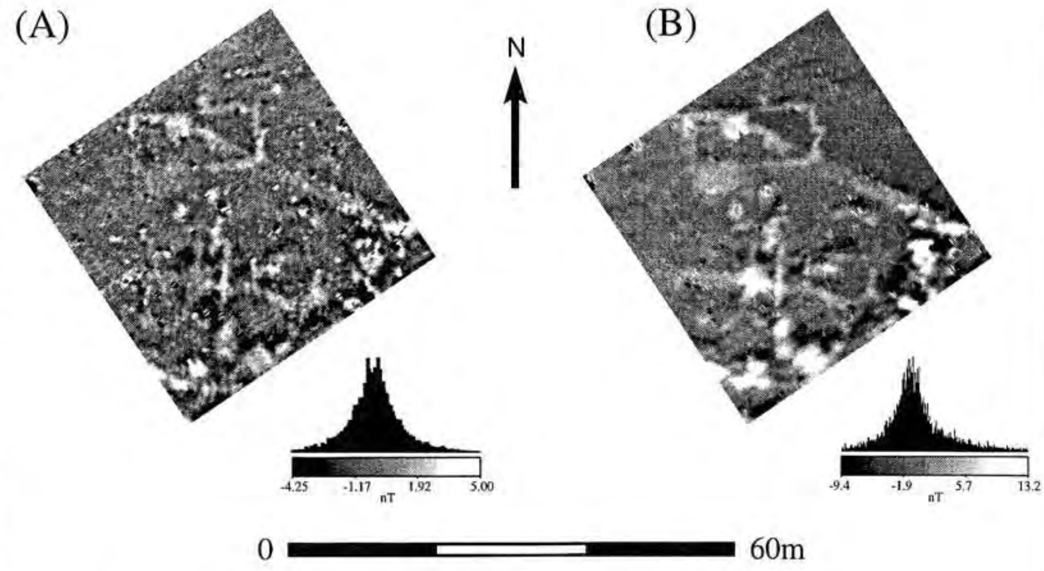


Fig. 2. Fluxgate gradiometer (A) and Scintrex CS2 Caesium total field survey (B) of an Anglo-Saxon timber building at Yarnton, Oxfordshire

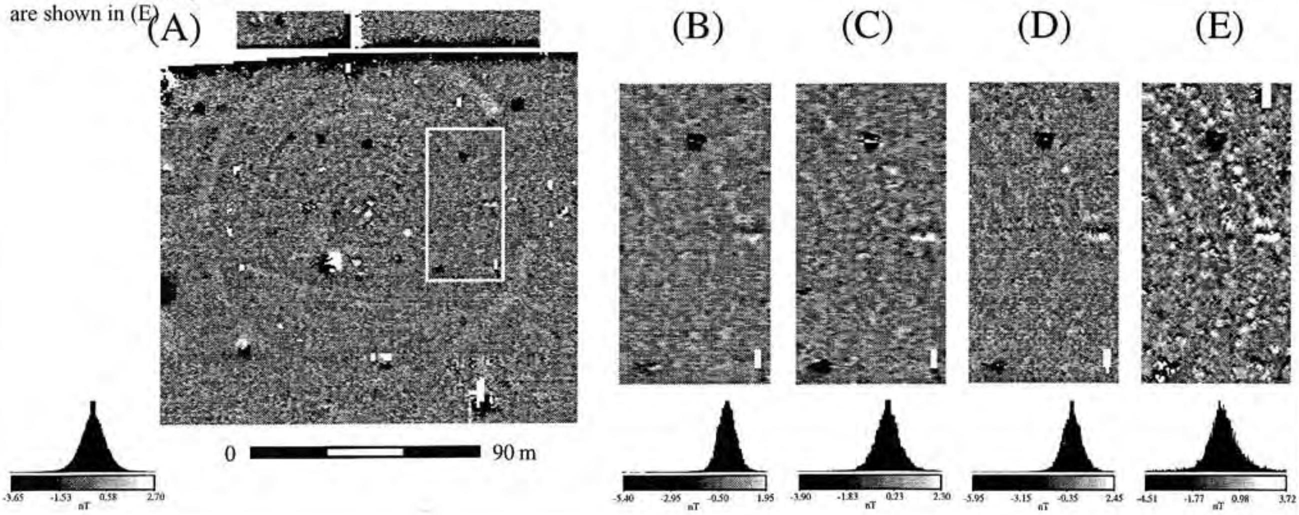


Fig. 3. Fluxgate gradiometer data from the Stanton Drew henge (A) together with comparitive survey of a trial area by fluxgate gradiometer at a standard sensor height (0.25 m x 1.0 m) (B), at a lowered sensor height (0.25 m x 1.0 m) (C) and with both lowered sensor height and reduced sample interval (0.25 m x 0.5 m) (D); caesium gradiometer results collected with a Scintrex SmartMag 4 are shown in (E)

survey and those where fluxgate gradiometers have met with difficulty discerning weakly magnetic anomalies. The study includes comparative magnetic data sets collected with a pair of adapted Scintrex CS2 caesium vapour total field sensors and Geoscan FM36 fluxgate gradiometers at similar sample intervals (0.25 m x 0.5 m). For further comparison, additional fluxgate data was collected at more typical reconnaissance sample intervals (0.25 m x 1.0 m) and also with a reduced sensor height, closer to the operational height of the CS2 sensors, to maximise the response from weakly magnetised features.

Figure 2 illustrates the results of a comparative survey of an Anglo-Saxon timber building at Yarnton, Oxfordshire, where both fluxgate and caesium instruments have detected a rectangular anomaly due to the building and other associated activity. It is of interest to note the discrepancies arising in the interpretation dericved from the two magnetometer plots which, no doubt, reflect a combination of instrument sensitivity and differing levels of confidence applied by the two research groups during the analysis of the data. This issue is explored further at sites, including Yarnton, where excavation following the geophysical survey has allowed a direct comparsion between significant magnetic anomalies and the underlying causative features.

Results are also presented from a similar comparsion between fluxgate instruments and the commercially available Scintrex SmartMag 4 caesium vapour gradiometer conducted over the site of a suspected timber temple revealed wthin the Stanton drew stone circle, W England (Fig. 3). Whilst the SmartMag has a much lower sensitivity than bespoke systems derived sensitivity over fluxgate gradiometers.

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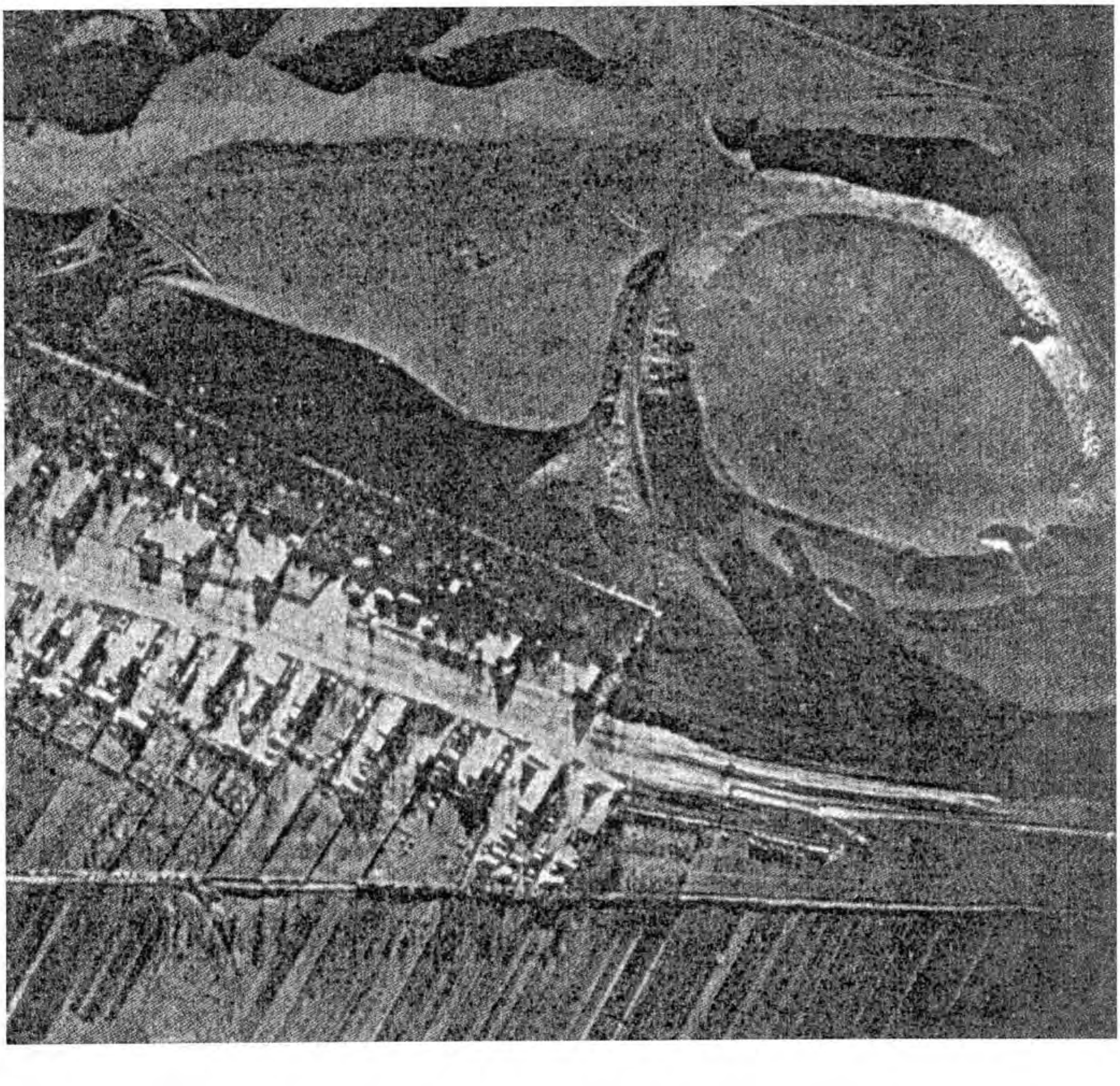
Z. Czajlik

Archaeological Aerial Prospection in Hungary: a Landscape Vanishes ...

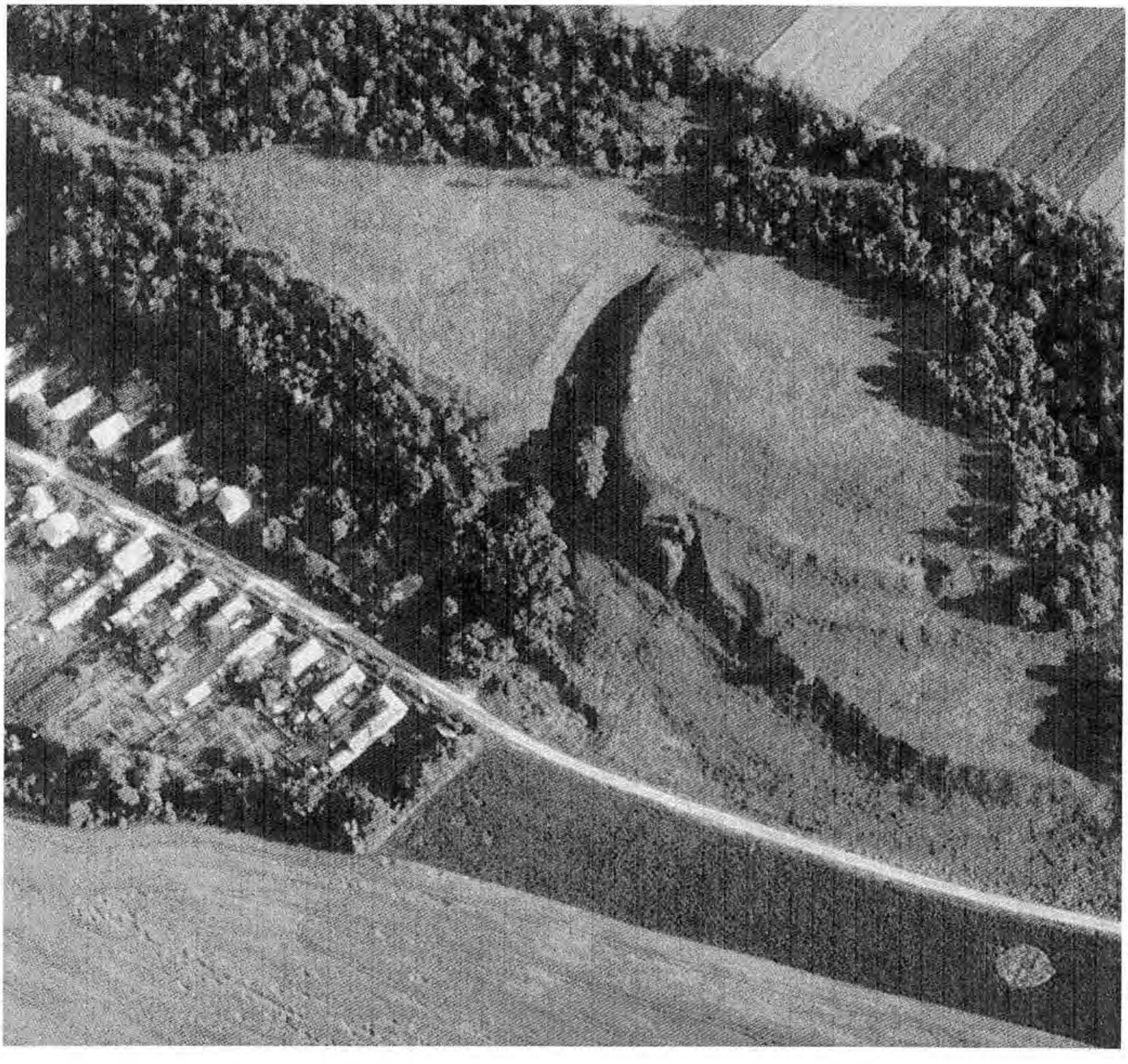
Thanks to a seven-year lasting cooperation between France and Hungary, I had the opportunity to fly approximately 80 hours over Hungary. These aerial prospections were mainly directed by Mr. René Goguey, who is a pilot as well as aerial archaeologist, of the Aerial Archaeology in Burgundy, France. The material is now archived in the Laboratory for Rauminformatik at the Archaeological Institute in Budapest, which was established because of emergency diggings on the highway M3. The collection includes not only images from René Goguey, but also from us and several foreign scientists as well as old copies from other Hungarian institutions.

Fig. 1. Vál-Pogányvár prehistoric fortification (Photo was taken By S. Neogrády, April 1934)



We recognized in the beginning that the possibilies of aerial archaeological photography do differ very much depending on the geographical and agricultural situation nowadays. Hungary has very many habitats for aerial photography, especially at landscapes which were not affected too much by agriculture. The images can be interpreted not only from an archaeological point of view, but also from a standpoint of Holocene geology. While flying above Hungary, one gets a very good impression not only of the landscape but also of the landscape´s transformation. The results are alarming. Changes which are obvious from 80 hours in the air are strengthened by the impression we get while comparing aerial images from this time.The documents prove, that aerial habitats vanish and more important, a dramatic transformation of the landscape takes place. We have to take leave not only from the habitants but the whole landscape.

Fig. 2. The same fortification in June, 1998 (Photo was taken by the author); is it possible to protect the site and its environment for the next 64 years?



M. Dabas, C. Camerlynck, G. Bossuet

Detection of Neolithic Cultural Layers by GPR in a Lacustrine Area: the Case of Chalain (Jura, France)

More than 29 archaeological sites are found in the area of the lake of Chalain (Jura) in France. The stratigraphy from these sites span from the 32nd to the 24th century B.C. Two settlements have grown during Neolithic times between the west and the east shore of the lake. The first one has shown a stratigraphy between the Horgen culture (32nd century B.C.) and the Chalain culture (24th century B.C.). To the east, the second one, was investigated mainly by augering. The geophysical survey took place on this side with a Pulse Ekko 1,000 radar.

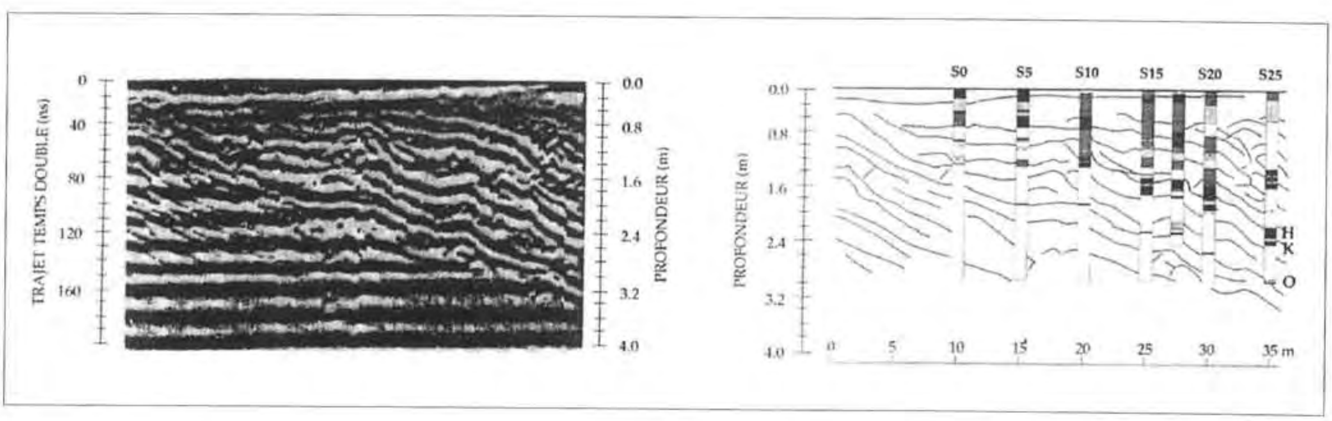
The stratigraphy of the sites is made principally of dark organic matter deposits within a white lacustrine chalk. In order to study these deposits, the archaeologist can either make ordinary digging, necessarily limited to a small area, or use auger-borings but with a dense sampling strategy. In the latter case, he will have to face the problem of interpolation between the borings.

Despite the fact that GPR was used for other archaeological sites, the case of Chalain is specific: i) the vertical extent of some of the deposits is very thin (a few centimetres at a depth of two meters or more) and makes this kind of target a challenge for a geophysicist; ii) due to water level changes during historical time, some of the deposits are partly under the present level of the lake or in the transition zone.

Three GPR profiles were done along the shore and six perpendicularly to the shore. Information is available down to a depth of 3.4 m. Reflectors show clear patterns such as on-lap and off-lines figures. Several strong reflectors with a North-East dip are also visible and one specially at a depth of 3.2 m. Horizontal reflectors are due to ringing. Six auger-borings were performed along one profile and have shown the presence of reduction material (charcoal) and also organic matter. In particular, three levels named as H, K and O can be correlated from one drilling to the other. They can be associated with settlings from the late Neolithic.

The superposition between the stratigraphic log obtained from drillings and the radar reflectors has enabled a good correlation between them. In particular, the oldest level named O (Horgen culture) corresponds to the strongest and the deepest radar reflector. This demonstrates that it is possible to detect and map the O strata and the more recent levels without destruction. Moreover, a trial radargram was done above the lake level and proved the feasibility of a non-destructive detection of archaeological layers under 6 meters.

In summary, this case study shows that, with a sufficient low frequency antenna, it is possible to detect anthropic levels within chalk deposits in a lake and to precise their depth and lateral extension. It would be then possible by making a high resolution GPR survey with a dense sampling scheme, to map the extension in three dimension of the archaeological deposits since 6,000 years without destruction.



M. Doneus, C. Gugl

Interpretation and Mapping of Aerial Photographs Using Digital Photogrammetry and GIS

Fig 1. Aerial photograph from June 1986 showing crop-marked walls in one ▷ of the fields (Photo: S. Tichy; released by Austrian ministery of defence No: 13088/3-1.4/99)

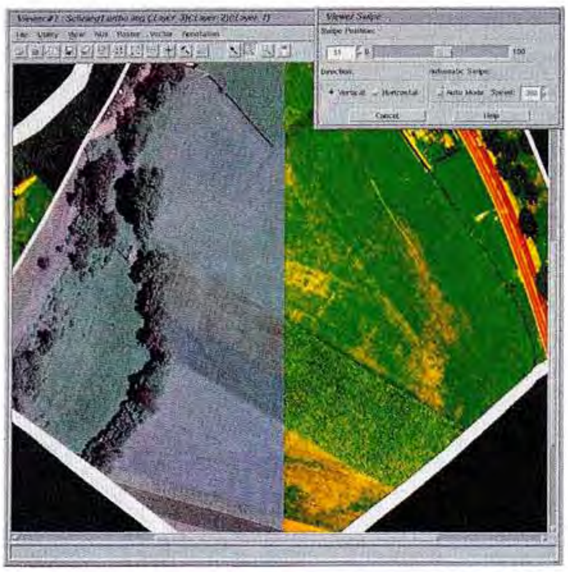


Fig. 2. Screenshot during an ERDAS® session: two orthophotographs from the same area are overlaying each other. To be able to estimate the geometrical correctness, the above orthophotograph is partly swiped away

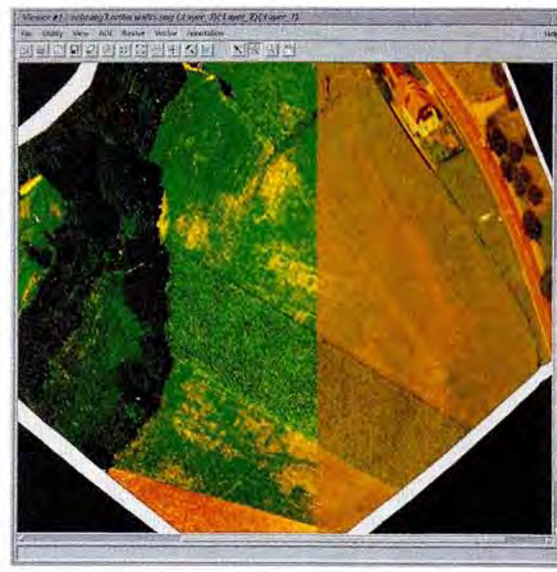


Fig. 3. Orthophotograph and its variation: the left part is treated with a Wallis filter

Fig. 4. Combination of aerial archaeological interpretation (red) and excavation results (blue) on orthophotograph

The Roman town Teurnia is located in the area of the "Holzerberg" in todays St. Peter im Holz (Carinthia), covering approximately 17 hectares. Since 1845, excavations have been going on, which revealed parts of the towns wall, the forum, residential terraces and several early christian churches. Among them also the episcopal church dating from the 5th and 6th century A.D on top of the Holzerberg. A part of the town at the eastern bottom of the Holzerberg was photographed several times from the air by S. Tichy, a member of Carinthia´s building surveyor´s office between 1978 and 1992. These oblique photographs show the crop-marked town map of an area of 23,000 sqm To be able to integrate the information of these photographs into a complete town map, the aerial archive at the institut for Prehistory in Vienna was consulted.

The area of interest expands over several narrow fields with different crops, each responding differently to the underlying archaeology. This results in a patchwork, where photographs show cropmarks only in single fields. Fortunately, since the photographs were taken over several years, cropmarks could be recorded on each field. Therefore, all of the photographs had to be used for interpretation. Additionally a vertical stereopair (1:10,000) was available, produced by the Austrian air force during summer 1980. It covers the whole area of Teurnia. The oblique photographs were taken using a non-calibrated small format camera with unknown focal length. Unfortunately, some photographs showed a bad distribution of possible control points.

To be able to deal with these problems, we decided to use a bundle adjustment, where control points (= points with ground control) and tie points (= points visible in two or more photographs, but without ground control) are measured on all photographs and all measurements are adjusted to the ground control values in a single solution. The whole procedure was done digitally using the software Softplotter^{TM} on a Silicon Graphics O2 workstation with 256MB RAM. The vertical photographs and the slides were scanned with 2,000 DPI. Ground control was measured using a total station. After the orientation, topographical data (3D-points and breaklines) were measured and a digital terrain model calculated. Consequently, this was used to rectify all of the photographs which were oriented by the bundle adjustment. The resulting orthophotographs have a pixelsize of 0.2 m. The accuracy depends on the quality of the distribution of the control points and lies between 0.5 m in the central part (which contains most of the archaeology) and up to 3 m in the more distant parts.

The interpretation was done using the geographic information system ERDAS Imagine®. Using the provided image enhancment techniques, the orthophotographs were treated with contrast stretch, Wallis filter or crispening. All of the georeferenced orthophotographs and their filtered variations were interpreted on screen. The interpretation drawing was combined with digitized results from the previous excavations which had been done between 1971 and 1978. The combined analysis of the results from the excavation and from aerial interpretation provided archaeologists with new clues to the extent of the settlement area during the 1st to 3rd century A.D. It will also function as basis for future archaeological activities as geophysical prospection.

M. Doneus, W. Neubauer, A. Eder-Hinterleitner

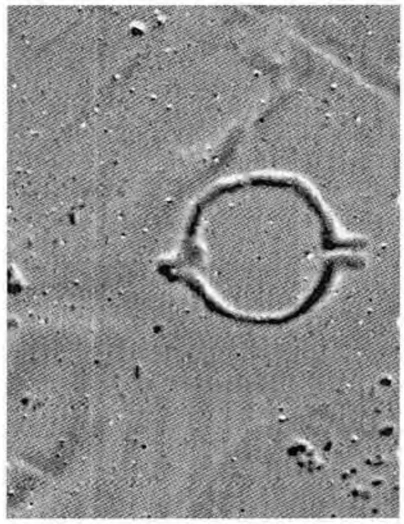
3D Reconstruction of Archaeological Sites Based on Prospection Data

The Middle Neolithic circular ditch at Schletz is located in the hilly landscape of northeastern part of Lower Austria and was detected by aerial archaeology in 1981. The interpretation of the aerial photographs was done using analytical photogrammetry. For the whole procedure, an analytical plotter device with a PC 386 was used. This device has a high precision in measuring picture coordinates (at about two mycrons) and therefore produces highly accurate 3D maps of the relevant archaeological information. In that way, the outline of the circular ditch could be drawn which was used later on for setting out the grid used by the geophysical prospection. Additionally, a raster of 3D-points and 3D-breaklines were measured and consequently, the digital terrain model of this site was calculated.

In 1995, a magnetic survey of the site using a high resolution caesium gradiometer was carried out. An area of two hectares was measured in a raster of 0.5 x 0.25 m. The data were visualised as digital images and georeferenced for interpretation. The archaeological interpretation shows a highly eroded single circular ditch with two interruptions, which were used as entrances. Each entrance feature is flanked by two short ditches, which meet the main ditch at a right angle. Using GIS, all the different prospection data were digitally combined to create additional images for subsequent archaeological interpretation.

To derive 3D reconstructions of the archaeological features a magnetic model was constructed. This was done by 3D modelling of the subsurface using dipole spheres of equal size and ho-

Fig. 1. Magnetogram of the circular ditch at Schletz, Lower Austria; caesium gradiometer 0.5 – 2.0 m, raster 0.5 x 0.25 m, area 19,200 sqm, dynamic range [-5,7] nT



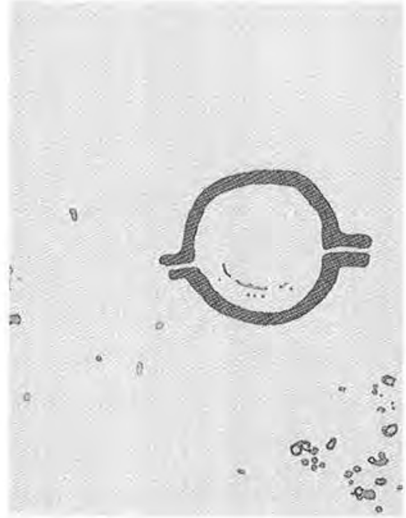


Fig. 2. Archaeological interpretation of the combined prospction data

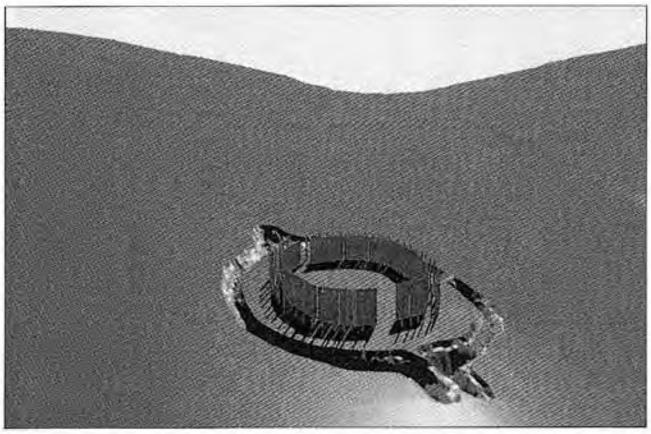


Fig. 3 and 4. 3D view of the reconstructed monument Schletz

mogenous susceptibilities. A primary distribution of the spheres in the 3D space was produced and the anomaly was calculated. The calculated image was then compared to the measured data and changed until the measured data were accounted for within a minimum error by simulated annealing. In Schletz, the susceptibilities of the ditch fill could be measured during the excavation in 1995, when a trench was laid out through the V-shaped ditch. During the stratigraphic excavation, each layer of the ditch-filling was registered by a tachymeter and magnetically analysed, which lead to a precise understanding of their size and magnetic influence. The consequence of these results for the 3D modelling were an improvement of the magnetic model of the filled ditch which lead to more accurate reconstruction results. The result of the 3D magnetic modelling was intersected with the digital terrain model and in that way visualized within its landscape. Aerial photographs were then mapped on the terrain, which can then be looked at from any direction and animated to produce virtual flights. Other details, as the single posts of the palisade could be taken from the 2-year's excavation. The postholes were digitised and thus, the whole palisade could be reconstructed.

Images as magnetograms, digital aerial photographs, reconstructions of the ancient environments or photographs from excavated parts of the monuments can hierarchically be mapped on the digital terrain model. Integration of reconstructed archaeological features based on additional excavation data produces a virtual model of monuments that had been covered by soil over thousands of years, bringing them back to (virtual) life.

D. Donoghue, C. Brooke

Airborne Thermal Prospection in the 8–12 µm Wavelength Range

The use of thermal infrared imaging for archaeological prospection has received relatively little attention compared with other geophysical techniques. However, it appears to have potential for identifying archaeology under permanent pasture which is a land use that covers an extensive part of the UK rural landscape and which rarely yields crop marks in conventional vertical or oblique photography. An experiment was carried out to test the ability of airborne thermal imagery to detect shallow ground disturbance at the site of the Battle of Bosworth (1484) in Leicestershire, UK. The relatively uniform temperature of the ground surface normally hides information contained in daytime thermal imagery. Instead, we invert the heat flow equation using pre-dawn and mid-day image pairs acquired from an airborne thermal line-scanner to compute a measure of diurnal heat capacity (apparent thermal inertia). In theory, we would expect structures that lie buried beneath the ground to have a diurnal heat capacity distinctive from the surrounding soil.

First, we present a methodology for deriving diurnal heat capacity (apparent thermal inertia) from airborne thermal imagery. Secondly, we interpret the raw and processed imagery for the presence of buried structures and shallow ground disturbance. Finally, we assess some of the interpreted structures by comparing their location and morphology with independently acquired, ground based, magnetic and resistivity surveys.

Bosworth battlefield in Leicestershire provides an excellent test site partly because there is controversy over its precise location and disturbed ground features may help to reconstruct the geography of the battle. Also, there is known to be a deserted medieval village lying unexcavated within the study area. The modern landscape around Bosworth differs markedly in appearance from that of the fifteenth century. Straight hedges have enclosed the former open fields and the marshlands, known to have existed, have been drained and improved. Today the land around Bosworth is predominantly under permanent pasture and does not yield good crop mark evidence from traditional vertical or oblique photography.

M. G. Drahor, E. Sengül

Large Scale Geophysical Investigations in Ulucak Höyük Archaeological Site

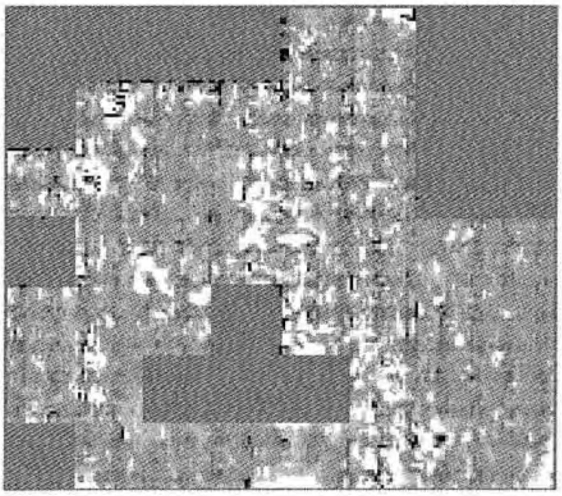


Fig. 1. The magnetic map of the Ulucak Höyük

Ulucak Höyük archaeological site is located 10 km away from Izmir. The artificial hill includes different settlements from Early Bronze Age to Late Roman Period. In this area, the archaeological excavation has been carried out since 1995. This excavation showed that the Ulucak archaeological site is very important for the history of Izmir city and environs in Early Bronze Age and later on. The geophysical surveys have continued to map all artificial hills by different geophysical exploration tecniques such as magnetic, resistivity, self potential and EM-VLF since 1998. The magnetic gradiometer studies were carried out by Geoscan FM-36 fluxgate gradiometer in 3,900 square meter area, approximately. In this study, the measurement intervals were chosen as 0.5 m on the profiles approximately 1 m apart. Furthermore, the data were collected in 39 area by 10 m x 10 m. In the processing, the data were firstly united in an appropriate co-ordinate system for all survey areas. Then, the arranged data were processed with different signal processing techniques and the enhancement map of the magnetic survey was obtained, (Fig. 1). Gradiometer measurements show that magnetic anomalies are generally condensed in the southern and eastern part of the artificial hill. Moreover, the magnetic anomalies are directed in two different directions. First anomaly group is N-S and E-W, and seem to similar the Late Roman foundations found by the archaeological excavations in the southern part of Höyük. The second anomaly group was near the Early Bronze age settlements in the eastern part of Höyük.

Resistivity studies have been carried out by twin array with 0.5 x 1 m grid interval in the Höyük. The aim of this study is to measure all this area by the resistivity method by the end of 1999. The preliminary results are quite interesting and the buried archaeological settlements were clearly defined in resistivity maps which are similar to each other. Especially, the resistivity and magnetic are in accordance in the southern part of the Höyük. In addition, the self-potential method was applied in the some anomalous area which high magnetic and resistivity values were obtained. The data were collected by two different measurement arrays, gradient and total area systems. As can be seen from the gradient map, the self-potential anomalies are low in amplitude. However, it is directed to N-S and E-W direction as magnetic and resistivity maps are (Fig. 2). This result is important to support the usefulness of self-potential methods in archaeological prospection. Furthermore, a new correction technique was tested to develop the self-potential method. The data showed that the new correction technique is very useful in archaeological prospection, and data quality was rather increased compares to the classical correction techniques in self-potential method.

In addition to these geophysical surveys, the EM-VLF method was used along some test profiles and areas. The results were interesting and previously identified anomalies observed clearly in magnetic, resistivity and self-potential maps, were again obtained.

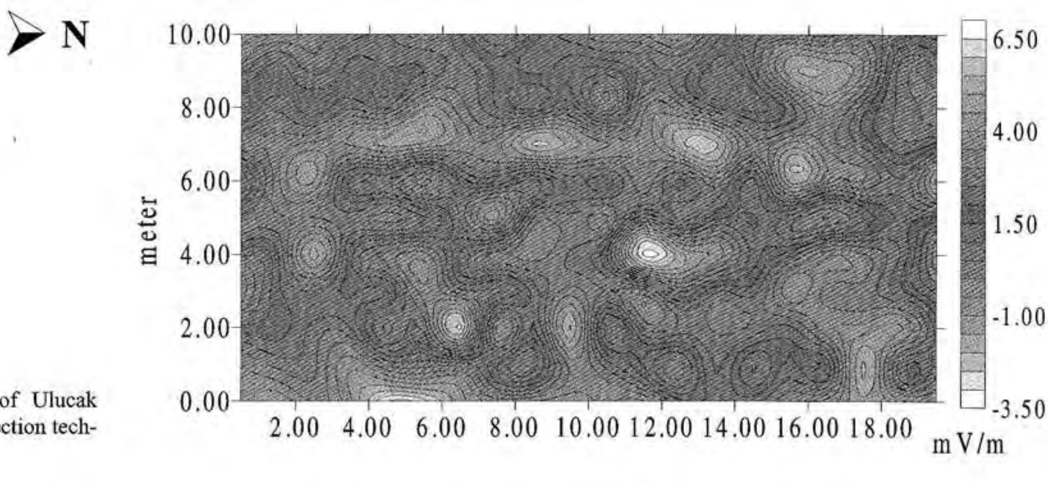


Fig. 2. The gradient map of Ulucak Höyük by using the new correction technique

A. Eder-Hinterleitner, W. Neubauer, P. Melichar

Magnetic Modelling for the 3D Reconstruction of the Neolithic Circular Ditch System of Steinabrunn/Austria

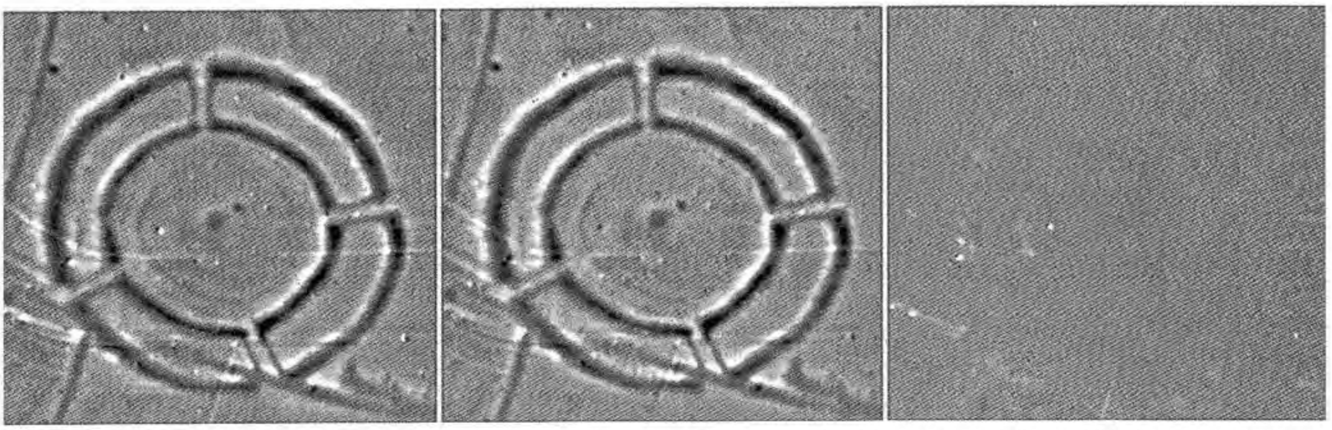
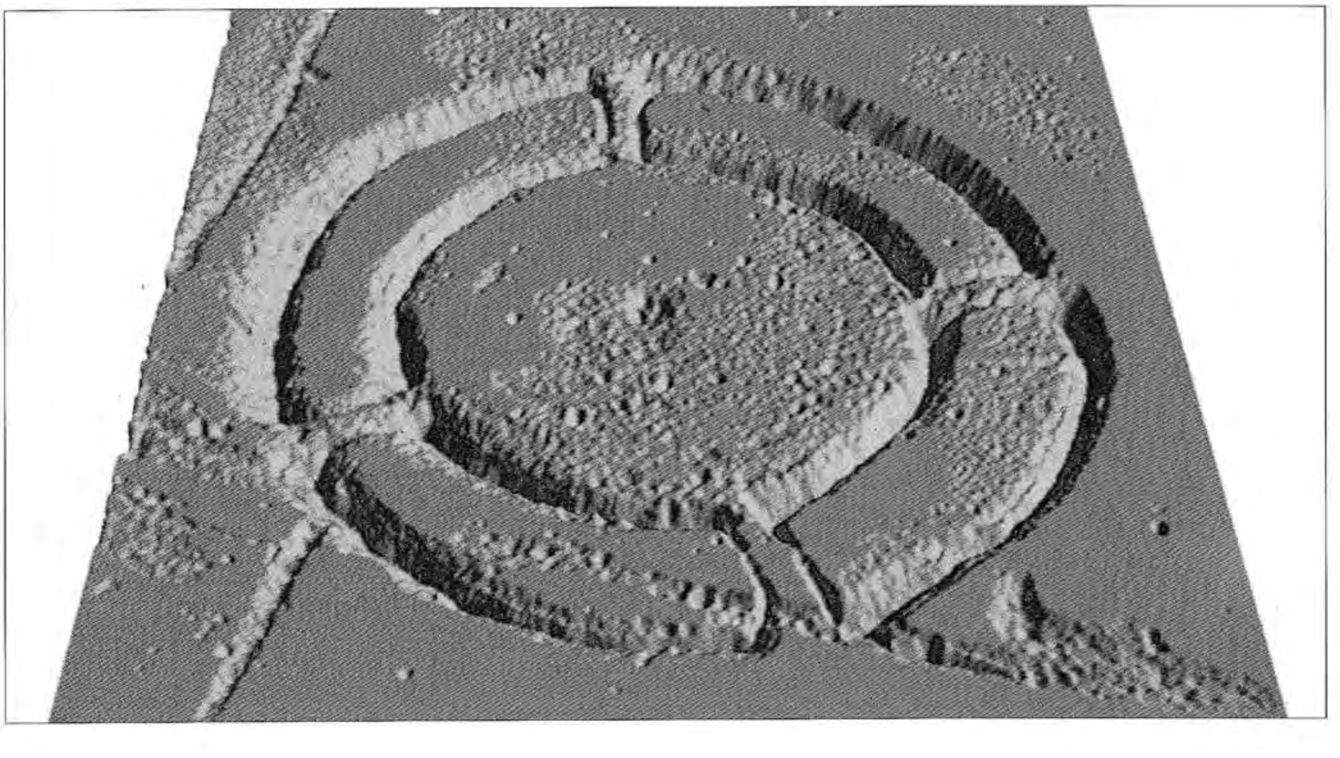


Fig. 1. The comparison of the measured and reconstructed anomalies shows the equally good reconstruction of all parts of the monument; caesium gradiometer 0.5 m – 2.0 m; raster 0.5 m x 0.25 m; area 110 x 105 m; visualised anomalous range [-6,15] nT

The most efficient method for investigating circular ditch systems from the Middle Neolithic (Lengyel culture) situated in homogenous loess is high resolution magnetic prospection. Their shape, the number of ditches and entrances and the state of preservation become obvious. By using caesiumgradiometers in a raster of 0.5 x 0.25 m even the remains of inner wooden palisades become visible in the magnetogram. This high resolution and high precision data forms an excellent input for 3D magnetic modelling to reconstruct the depth, width and shape of the ditches.

The reconstruction of the ditches of such a large monument is achieved by simulating the measured data using a simplified magnetic subsurface model of the filled ditches. The subsurface model is realised by single dipole sources with specific magnetisation arranged in a 3D array. The distribution of the dipole

Fig. 2. Three-dimensional visualisation of the reconstructed ditch of the rondel at Steinabrunn; the ditches have diameters of 81 m to 87 m and 52 to 57 m and a reconstructed depth up to 3.2 m



sources is determined by an iterative optimisation algorithm similar to simulated annealing. This iterative algorithm has to minimise two measures: the absolute difference between the measured data and the modelled magnetic anomalies and a regularisation term to produce a smooth ditch interface, which may include pre-information about the ditch section. The specially developed optimisation algorithm is called leaped annealing and is able to optimise various magnetic models. The reconstruction problem is therefore converted into an optimisation problem with plenty of parameters. For the monument Steinabrunn 184,800 parameters have to be determined.

The particular magnetic model was developed based on archaeological-geophysical excavation results and uses two independent magnetic horizons to represent the complicate stratification of the fill of the ditch. The first horizon models the upper parts of the filled ditch, which show high magnetic susceptibility contrast. The other models the lower parts of the ditch with lower magnetic susceptibility contrast. The application of the developed model is able to successfully reconstruct all parts of the monument due to its ability to adapt to different fill and varying state of preservation. The magnetic modeling of Steinabrunn uses an array of dipole sources with 0.25 x 0.25 m spatial and 0.1 m depth resolution.

The fully automatic reconstruction takes a few hours on an up to date computer and is divided into the following steps. In a preprocessing step the corrected data are classified to eliminate strong anomalies of modern source from the reconstruction. Then a first reconstruction is computed using an regularisation term which smoothes the ditch interface. The result of that first reconstruction is used to detect the shape of the ditches. This information is necessary to be able to integrate the known shape of the ditch section into the regularisation term within the final reconstruction step. The mean difference between the measured and the modelled magnetic anomalies of the rondel Steinabrunn is 0.085 nT ± 0.53 nT, the ditches have a reconstructed depth up to 3.2 m.

The reconstructed ditch can be intersected with the digital terrain model and mapped with additional information and reconstructed features from excavation results, like the palisade. New sights of such a Middle Neolithic monument can be achieved by animation of the scene to help understanding the purpose of these oldest Middle European monuments.

W. Edwards, M. Okita

Application of GPR to the Study of Subterranean Chamber Graves in Kyushu, Japan

The utility of GPR in the study of subterranean chamber graves was tested in an experimental program combining prospection and other forms of non-destructive investigation with limited excavation at a sixth-century cemetery site in southern Kyushu.

The existence of subterranean chamber graves at the Himori Site in Takaharu Village, Miyazaki Prefecture, was first revealed when part of a natural knoll was leveled for agricultural purposes in 1969. Investigations of the tombs, conducted from that time on by the Board of Education of Miyazaki Prefecture, show the basic shape of these features to consist of a vertical shaft no more than 2 m deep, from which a narrow horizontal passageway and burial chamber 2 m x 2 m or smaller are tunneled in one direction only (Fig. 1). The entrance to the passageway was typically sealed with a pile of stone slabs, preserving the chamber as a hollow cavity, while the shafts had been filled in completely. The Prefecture also conducted a shallow excavation over a 440 sqm area at the top of the knoll in 1981, locating ten pits, rectangular in horizontal plan, believed to represent the upper portions of vertical shafts corresponding to an identical number of chambers.

In September 1997, GPR was conducted over the area of the Prefecture's investigation at the knoll's crest. Anomalies suggesting the presence of chambers were readily detected in pro-

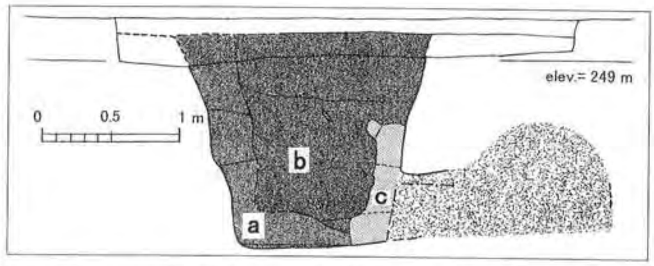


Fig. 1. Cross-section of Feature 3, showing relation of vertical shaft, passageway, and chamber; a: fill from the initial construction of the grave; b: fill from a subsequent burial; c: shadow of thick wooden boards used to seal entrance

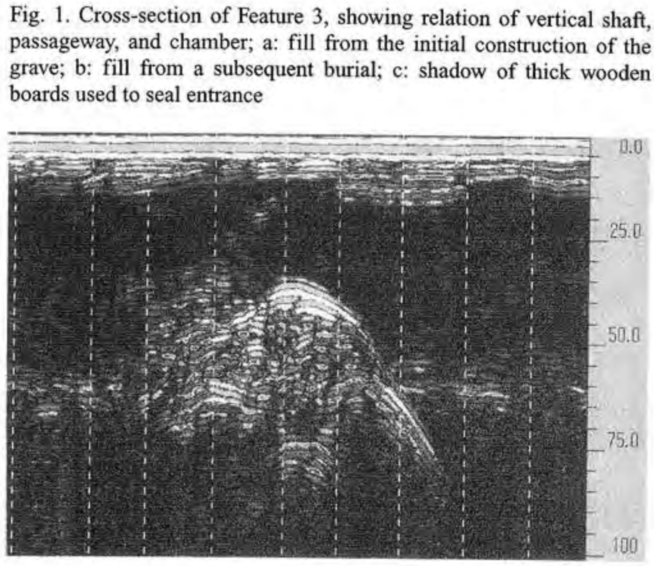


Fig. 2. GPR profile of Feature 3, showing parabolic anomaly indicating the chamber; disturbance to the left is the shaft

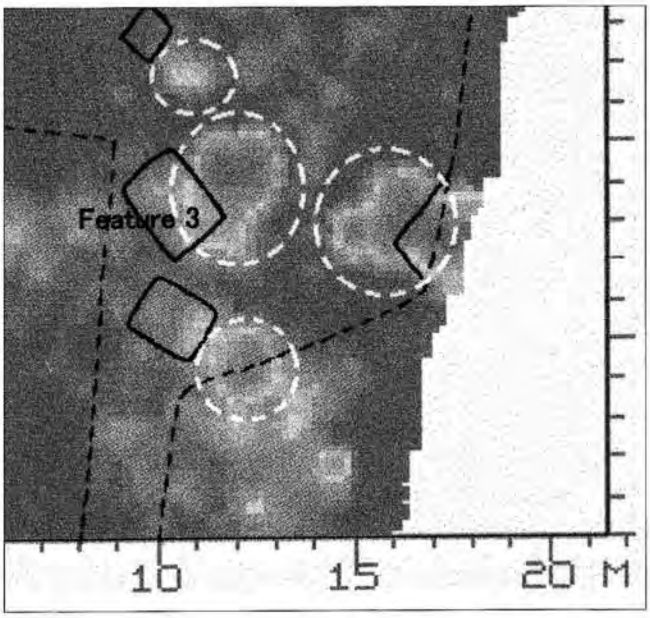


Fig. 3. Portion of time-slice image, showing strong anomalies (circled) indicating locations of chambers in relation to the corresponding shafts (rectangles)

file (Fig. 2), and horizontal time-slice analysis (developed by D. Goodman) showed these correlated closely with the shafts previously located by the Prefecture, presumably indicating the directions in which the chambers lie (Fig. 3). As no such anomaly was seen in association with Feature 8, however, it was provisionally concluded from the GPR results that the identification of this feature through conventional excavation as a grave shaft was mistaken.

The conclusions derived from the GPR survey were subsequently tested through limited excavation in December 1998. Feature 8 was sectioned east-west, with the southern half excavated, showing it to be a shallow pit ending shortly below the modern surface, and not leading to a chamber. Similar sectioning of Feature 3 (Fig. 1, 4) confirmed the existence of a passageway entrance on the northeast side of the shaft, as suggested by the time-slice images. Careful examination of the section showed that the chamber had been reopened after its initial construction, presumably for the purpose of a subsequent burial, and that the entrance had been sealed with a thick wooden board, rather than stone slabs (Fig. 1). Observations such as the latter are beyond the current capabilities of research by prospection alone.

Finally, a hole was opened through the dirt filling the entrance to the chamber of Feature 3, and first a miniature video camera, then a digital still camera were inserted, both attached to the ends of long poles, to obtain visual images of the chamber's interior. The digital camera in particular provided useful images showing the skeletal remains of two or more individuals, at least one of whom was an adult female, which had been arranged after decomposition of the flesh along the back wall of the chamber.

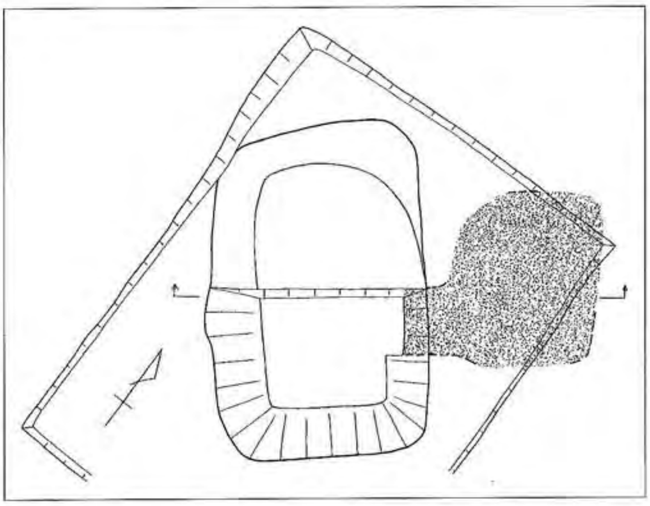


Fig. 4. Plan of Feature 3, sectioned, with outline of associated chamber (shaded, drawing based upon visual inspection)

G. Fuchs, I. Kainz

Archaeological Prospection for the Koralmbahn in Austria

A new high capacity railway line, the socalled Koralmbahn, is planned to connect the cities of Graz and Klagenfurt in South-eastern Austria. In the East of the Koralm range, which will be passed by a long tunnel, it runs through the Laßnitz Valley, where numerous archaeological sites from the Neolithic to the Roman periods were expected, but only a part was known.

For the evaluation of possible impacts to the archaeological heritage existing data were not suitable, so a systematic archaeological survey was carried out to cover the whole valley floor completely for a length of ca. 20 km. Different methods were applied in combination to check reliability of observations and to facilitate interpretation. In addition to the ground survey, aerial prospection was carried out. The detailed mapping of morphology made it possible to detect some regularities in site distribution and to define important parameters for the positioning of settlements. As the valley is still flooded today, the deposition of alluvial sediments and the possible occurence of sites below younger sediments had to be investigated by a number of boreholes at selected cross profiles.

The project was carried out, including preparatory work, fieldwork, interpretation of data, generating of digital maps and preparation of the final report within six months from March to August 1997. The archaeological digital data (Arc/Info files) were introduced to the Styrian land information system (GIS Steiermark) to be used for other planning purposes also.

The 41 unquestionable sites belong to 47 findspots of nearly all periods from the Aeneolithic to the Modern Periods, 38% of them are Roman. 86 areas were defined as possible archaeological zones (Fundhoffnungsgebiete). Due to the low density of prehistoric or Roman finds or ambiguous evidence; here more detailed prospection measures must be applied to interprete the occurence of finds.

As an unexpected result it could be shown that Roman sites situated even on the lowest part of the valley floor are not covered by alluvial sediments, indicating that floods did not affect them. A complete Roman landscape with *villae rusticae* and settlements or single buildings of different types was investigated. The distances between them are 1.5 to 2.2 km for the large ones and several cases 0.5 to 0.7 km only. Parts of the Roman road, levelled burial mounds and settlement sites were observed by aerial prospection as well.

All sites detected were graded according to their cultural and scientific significance providing basic data for decision making in the planning process. It has to be stressed that the sites were already known in the *earliest stage* of planning. This provides the key to introduce archaeological sites like other environmental data with the goal to minimize impacts, so the chance for the preservation of important sites is improved considerably. Measures for the further stages of the project, which are necessary from the archaeological point of view, were proposed as a guideline. For example, intensified prospection including geophysics, soil probing, the archaeological involvement during the construction works and excavations, where necessary.

The excellent cooperation between the planning authority (Eisenbahn-Hochleistungsstrecken AG, Projektleitung Koralmbahn), the Sites and Monuments Office (Bundesdenkmalamt), the direction of public works of the Styrian Government and the firm carrying out the archaeological prospection and evaluation (ARGIS) may be considered as a model for future large scale construction works in Austria.

C. F. Gaffney, J. A. Gater

Popularising Archaeological Geophysics: The "Time Team" Experience on British Television

A three day time constraint, minimal information on the expected archaeology, even less details about the site conditions and a director with three camera crews and a script demanding instant results. These are the challenging conditions faced by archaeological geophysicists working on the popular Channel 4 *Time Team* series in the UK. Yet experience gained in the day-to-day world of archaeological evaluation work in Britain is ideal training for such a challenge.

Nearly 60 programmes have been made, viewing figures are regularly over 3 million people and the series has been sold worldwide to the Discovery Channel. Using results from the first seven series, including those not transmitted, this paper will demonstrate how the problems and constraints are overcome. Discussion will also consider the two transmissions that have been broadcast "live" over holiday weekends. The ethics of "simplifying" often very complex science will be considered, as will the problem of making geophysics exciting without being professionally challenged. The integrity of the programme will be contrasted with experiences on other archaeological television programmes.

A. Gibson, H. Becker

Archaeological Prospection at the Hindwell Neolithic Enclosure in the Walton Basin, Wales, UK

The Hindwell Neolithic enclosure was discovered from aerial photographs taken in 1994. Some further parts were found in 1995 and 1996 so that some 75% of the perimeter is now known. Excavations in 1995 and 1996 revealed the site to have dated to 2,700 B.C. (late Neolithic) and to have been delimited by a wooden palisade of posts some 8 m long and weighing 4 tonnes. Approximately 1,400 posts had been used and the enclosure covered 34 hectare.

Little was known of the interior of the site as it was covered with pasture fields. Caesium-vapour magnetomery was undertaken over these "blank" areas to try and identify internal features and/or areas of activity, the position and nature of the entrance and whether or not the line of the enclosure could be detected beneath a Roman fort which overlies the eastern perimeter.

Prior to the geophysical survey a full physical survey was undertaken at the site to try and detect microcontours and to place the site into real space. Geophysical survey was undertaken over the same grid. The results indicated that the enclosure appears to have been empty or else the internal features were of such an ephemoral nature that subsequent agriculture has removed all traces. Some large pits were located, however, as well as some interesting anomalies on the perimeter. The survey of the Roman fort produced important information regarding the phasing and internal arrangements of the monument and detected the palisade running below the fort. This also, unexpectedly, survived as a slight earthwork in this area.

Fig. 1. "Magneto-Scanner" in Hindwell 1998; four caesium magnetometers Scintrex SMARTMAG SM4G-Special with quadro-sensor configuration, two gradiometer consoles-data loggers, power supply (4 batteries 12 V/6 Ah) and automatic distance trigger mounted on a nonmagnetic chariot, total weight about 60 kg), type I 1/1996

The project was funded by the European Commission, The Cambrian Archaeological Association, Cadw: Welsh Historic Monuments, The Discovery Programme and The City Archaeology Service, Zwolle.

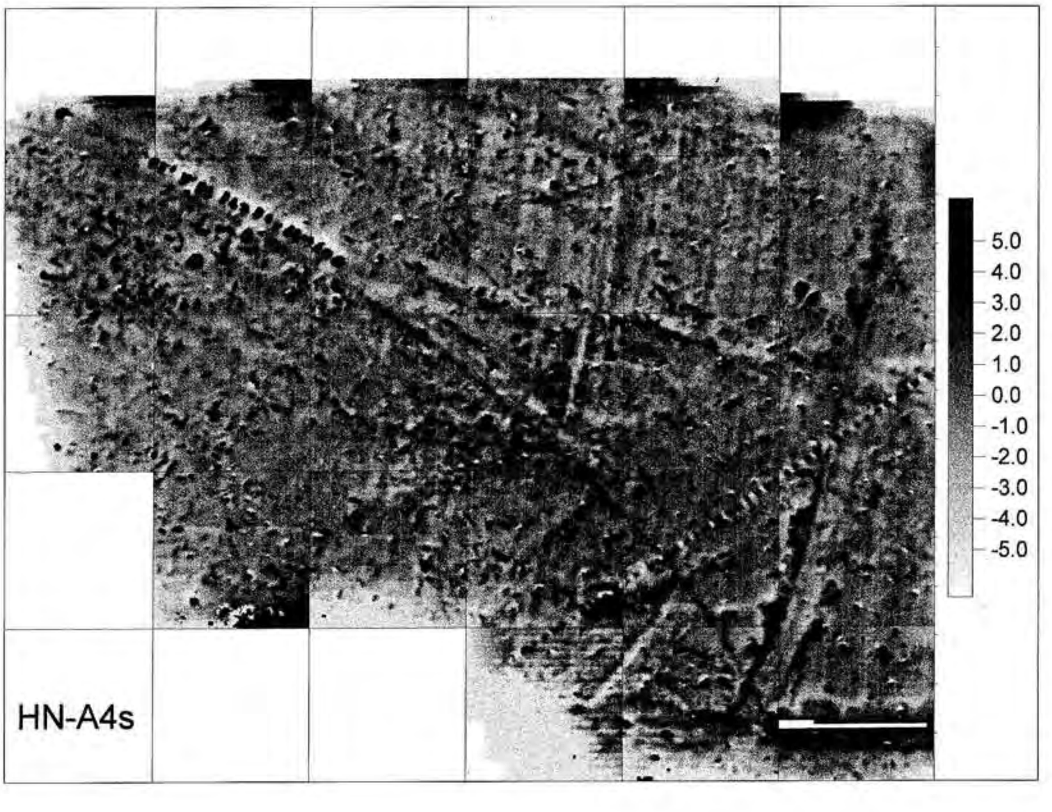


Fig. 2. Hindwell 1998; trace of the northwestern arch of the palisade of the Neolithic enclosure with a series of burnt pits; part of the magnetogram (about 4 ha) of the caesium magnetometry with quadro-sensor system Scintrex SMARTMAG SM4G-Special, sensitivity 10 pT (± 0.01 nT Nanotesla), dynamics – 0.5/+ 5.0 nT in 256 grayscales (white/black), interpolated raster 0.25/0.25 m, 1 Hz bandpass filter, reduction of the diurnal geomagnetic variation by line-mean value, 40 m grid

V. V. Glazounov

Archaeomagnetic Object Dating at Conditions of Shape Magnetic Anisotrophy

Classical archaeomagnetic investigations based on laboratory analysis of oriented samples are under discussion now (Abrahamsen, 1986). The focus of discussion is shape magnetic anisotropy effect. The shape anisotropy causes magnetisation vectors refraction of homogeneous object. Archaeomagnetic refraction is mainly formed by TRM vectors. Refraction of TRM probably causes the significant error of archaeomagnetic investigation results. Development of methods for refraction error correction is actual (Abrahamsen, Koppelt, Voss, 1997).

Evaluation of archaeomagnetic errors due to the refraction was done on mathematical models of a pottery kiln. The kiln was found during magnetic prospecting done in Crimea (Ukraine) in 1988. Magnetic structure of the kiln was has been worked out on the base of an algorithm which includes two parts. The first part of the magnetic structure, determined by the TRM vectors is modeling. This magnetic structure is formed by an ancient geomagnetic field when the temperature of the object is near to blocking temperature (Radhakrishnamurty, Likhite, 1969). At the second part, final magnetic structure of the object due to by modern geomagnetic condition is calculated. Calculations were done by a computer. Programme, "DEGMAG" (Ermokhine, Glazounov, 1989). Mathematical modeling results allow one to conclude that the scattering of the TRM vector directions of kilns is connected not only with well known reasons, but also with demagnetisation effect of these objects. That conclusion has practical interest as it allows for contributed corrections to the procedure of the archaeomagnetic research. The places of selection of the oriented samples of kilns should be chosen taking into account the results of the object magnetic structure modeling.

Additional investigations of the model show that the vector of the total magnetic moment of the object is practically parallel to the ancient geomagnetic field vector. This fact is reasonable to use for archaeomagnetic object dating at the condition of shape magnetic anisotropy. Methods of the magnetic moment vector determination are well known in theory of inverse magnetic problems. Algorithms based on methods of approximation and spectral analysis for the inverse problems solution were done. For the algorithms realization information about geometry of the object, distribution of magnetic susceptibility and factor Q of kiln has to be known. This information is available after archaeological excavations of the kiln. Examples of a practical test of the spectral method for medieval isometric pottery kiln dating is presented (Glazounov, 1985).

D. Goodman, Y. Nishimura, S. Piro

High-Resolution GPR Surveys for Archaeological Prospections Data Acquisition and Elaboration Techniques

Recent developments in 3D high-resolution multi-image processing and contouring as opposite to destructive testing have greatly contributed to improve the quality of geophysical information in archaeological reconnaissance surveying.

Ground Penetrating Radar (GPR) offers very high-resolution sounding capability with detection of features of the order of a few tens of millimetres thickness at ranges of several metres.

In this work, the results of high-resolution GPR surveys carried out in two archaeological sites characterised by different geological environmental conditions are presented. The two archaeological sites are: Roman Villa – Cazzanello (Tarquinia, Viterbo – Italy), and Forum Novum – Vescovio (Stimigliano, Rieti – Italy).

The Ground Penetrating Radar profiles were carried out using an SIR System 10 A^+ (GSSI), equipped with different antennas, operating at 300 and 500 MHz. For the first site, GPR profiles were collected in an area with dimensions 140 m x 60 m; in the second site two different area with dimensions 60 m x 80 m and 40 m x 80 m were investigated. In all areas the interval between adjacent profiles was 0.5 m.

To enhance the interpretation of the GPR data, radar signal processing and time-slice representation are worked out. The results obtained on shallowly buried structures indicate that the floor plans of the buildings can be clearly identified from time slice analysis.

H. J. Greenfield

Surveying early agricultural sites in Southern Africa: the Application of the Geonics EM-38 Conductivity Meter to the Early Iron Age Site of Ndondondwane, South Africa

The objective of the geophysical survey of the Early Iron Age site of Ndondondwane (ca. 750 A.D.) was to identify potential subsurface features in order to target areas with high probability for excavation. The problem with the use of most geophysical surveying techniques on EIA sites in southern Africa is the lack of comparative studies. Also, few sites have yielded the kind of high ceramic concentrations, burnt clay floors and other features that would be easily identifiable by most geophysical instruments. Most structures in such sites are of an ephemeral nature – unburnt dung floors and thatch roofs. As a result, a Geonics EM38 conductivity instrument was used in the survey. It measured differences in soil moisture which allowed identification of even relatively ephemeral structures on the site. The results of the survey and implications for its use on other sites will be discussed.

S. Groh, W. Neubauer, A. Eder-Hinterleitner

A Resistivity Survey to Locate the Forum of the Roman Town Flavia Solva (Austria)

In the year 1998 in the area of the Roman town Flavia Solva, Province Noricum (Styria, Austria), a primary resistivity survey was carried out during field practice with students in archaeology in two days. Target of this prospection campaign was the localisation of the *municipium's* forum which had been searched for in vain for over 125 years. The towns rectangular street system, known from partial excavation and aerial evidence, is also known from a series of Claudian (41–54 A.D.) towns in the Northern provinces (Trier, Cologne, Avenches, Virunum). Common to all of them is a predominant main street which implies the importance of the surrounding buildings (*insulae*). Due to considerations on the towns map known so far the area of Insulae XXIII and XXVI has been identified as a possible location of the forum.

To verify this hypothesis we carried out a resistivity survey using two RM15 resisitivity meters with multiplexers MPX5 (Twin Array) covering 7,000 sqm on parcels owned by the Federal Authorities. The street system is evident on the digital image representation of the resisitivity data measured with 0.5 m electrode separation in 0.5 x 0.5 m raster and with 1 m electrode separation in 0.5 x 1.0 m raster. The georeferenced images of the 0.5 m, 1.0 m and a "pseudogradient" constructed by division of the two data sets were archaeological interpreted using the GIS ArcView. Parts of the Insulae XXIII, XXVI and XXX were covered by the survey which confirmed the main features of the existing town map.

The archaeological interpretation of the resisitivity survey testify a multi phase building activity for the Insula XXIII. The western part of this *insula* seems to be free of buildings. In the North along street L equally big rectangular rooms seem to follow the street, reminding of *horrea* or *tabernae*. South of these rooms four nearly equally big rectangular house complexes seem to be adjacent, built over in antiquity in the West. The recognisable apses and the compact building modus as well as the big free place oriented to the North-South directing main street could point to a more monumental building. The neighbouring Insula XXVI with a width of approximately 60 m belongs to the largest building complexes of Flavia Solva. The length of approx. 75 m, typically for this *insula*, derives from the reconstruction of the excavation results in Insula XXX and V.

The prospection testifies an obvious division of the examined area in a western part mainly closed by buildings and a less closed eastern part. There is a clear structure of the buildings in a middle room which is divided in two parts, resembling a hall accompanied by smaller rooms. Adjacent in the East is a big free place surrounded by two parallel halls. The exterior hall seems to encircle the whole building complex. The inner hall terminates a place whose eastern part is build over by the Federal Highway. The interpretation of the buildings of this *insula* is still difficult at present. The big free place surrounded by halls could be interpreted as the forum of Flavia Solva searched for a long time. Also the buildings in the south-western part of the *insula* may be easily compared to the prospected findings of the civil town of Carnuntum in 1996 which were interpreted as the forum. The solution of the evolved archaeological questions to locate the forum of Flavia Solva will only be verified by surveying the area east of the Federal Highway. For higher resolution and to include depth information a radar survey also covering the fields east of the Highway is planned for 1999.

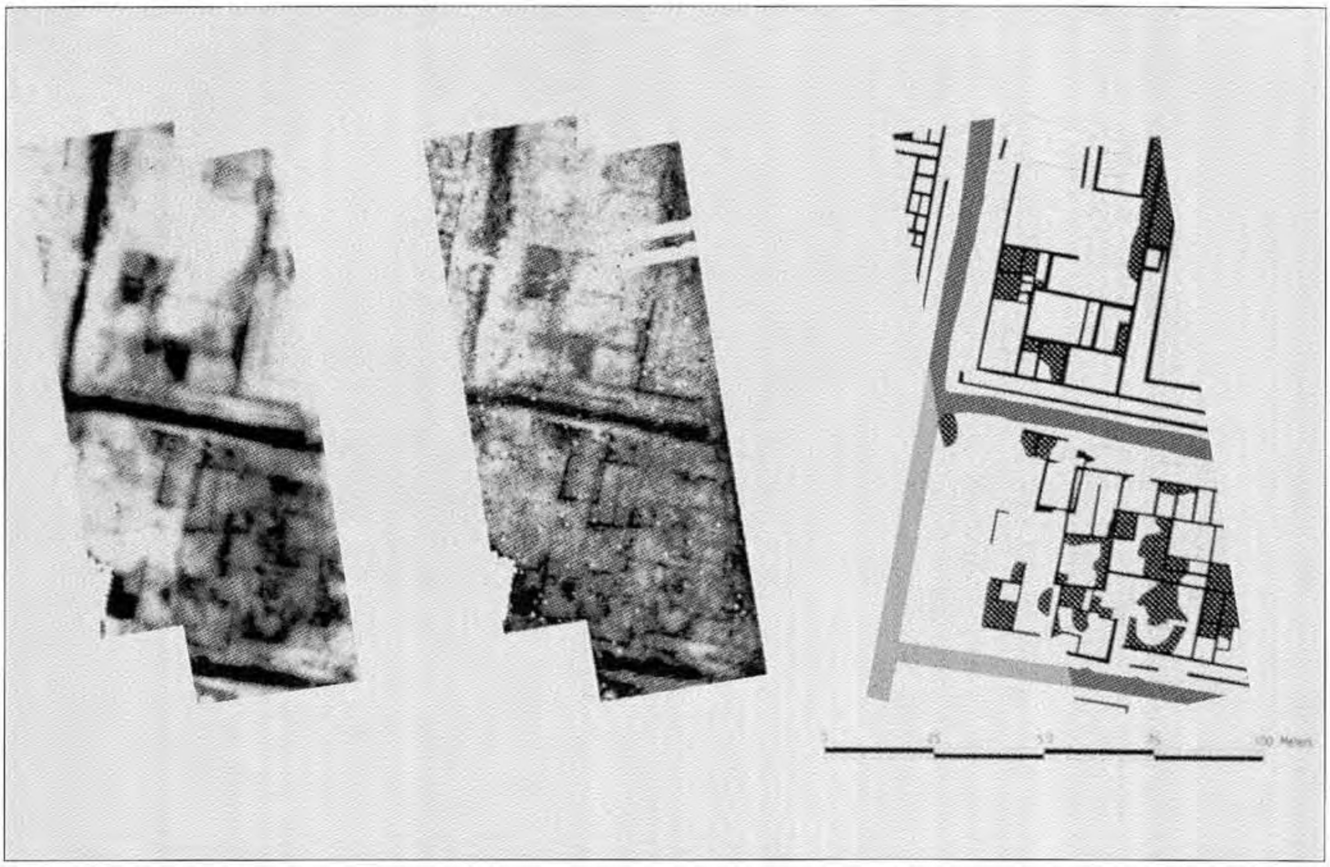
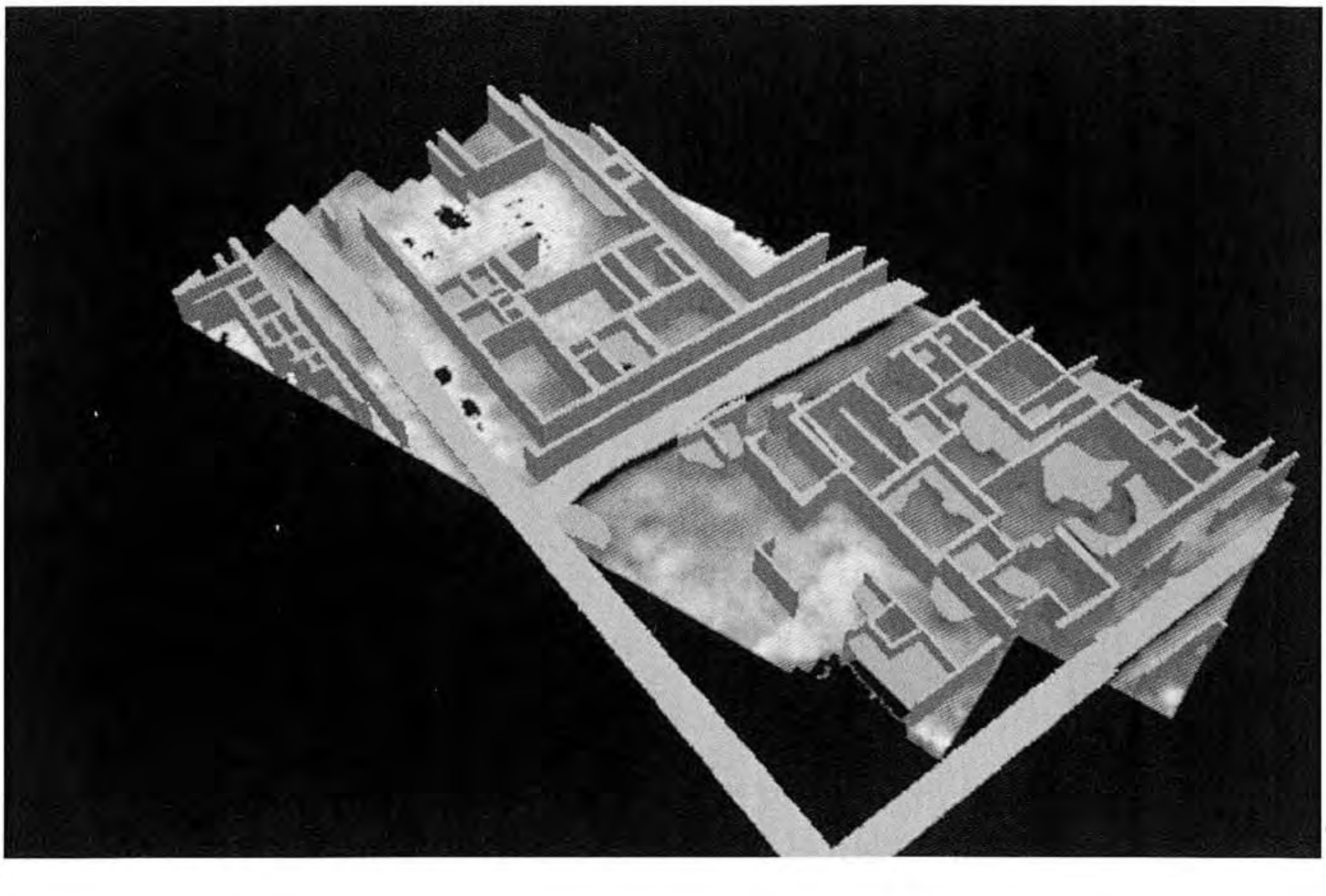


Fig. 1. Resistivity survey of a part of the Roman town Flavia Solva, Styria; RM15 twin array 0.5 m, raster 0.5 x 0.5 m, area 7,700 sqm. Right: Corrected raw data electrode spacing 0.5 m. Middle: "Pseudogradient" calculated by divison of data from the survey with 0.5 m electrode spacing and the survey with 1 m electrode spacing after Wallis filter. Left: Archaeological interpretation map

Fig. 2. 3D view of the archaeological interpretation model



K. Hamilton, J. G. McDonnell, A. Schmidt

Assessment of Early Lead Working Sites in the Yorkshire Dales by Archaeological Prospection

Although lead was a major source of economic wealth in antiquity, there have been few studies of lead smelting sites in Britain. This study presents a geophysical characterisation of Medieval lead smelting sites (bales) in Swaledale. Sites were surveyed using aerial photography, fluxgate gradiometer surveys, earth resistance surveys, TM808 metal detector surveys and both volume and mass specific magnetic susceptibility surveys. The surveys demonstrated that sites were characterised by an area of magnetic noise, usually situated uphill from an area of bare ground, with scatters of lead slag on the surface. The results showed that bale sites appear to have consisted of several small areas of burning, often with associated fuel stores. While some of the bales were stone lined, some consisted of a small burnt area. The results suggest that the difference between bale and blackwork oven is less clear than was previously thought.

A. Hesse

The Ten Commandments of the Genuine Surveyor in Archaeology

1. Do not believe that geophysics either is able to answer all the questions or is the only way to answer them (Hesse and Renimel, 1978).
2. Never undertake so called "experiments" which are not really such things or have already been done (see 3).
3. Read the literature in order to avoid doing again stupid things that have already been described (too many to mention them!)
4. Never use one single method before checking (according to previous results or preliminary tests) that it will definitely answer the question (Hesse, 1980, fig. 6; Hesse and Doger, 1993).
5. You may use several methods together if you want, but use your brains first (Hesse, 1997 and 1999).
6. Better draw large maps than separate profiles, in order to locate *subsequent* soundings (Hesse, 1994).
7. Gather all your data, whatever the method used, on synthetic maps, juxtaposed or superimposed, with a common scale (you may call it a G.I.S. if it amuses you) (Hesse *et al.*, 1978 and in press).
8. Do not believe everything the archaeologist says (especially when he asks the wrong questions) Your answer cannot be other than wrong.
9. If you cannot answer a question, ask yourself whether you are not able to answer another question they forgot to ask you (Hesse, 1970 and 1982).
10. Forget everything I have just told you and keep your eyes open.

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P. Hirschegger-Ramser, P. Ferschin, M. Kandler, W. Neubauer

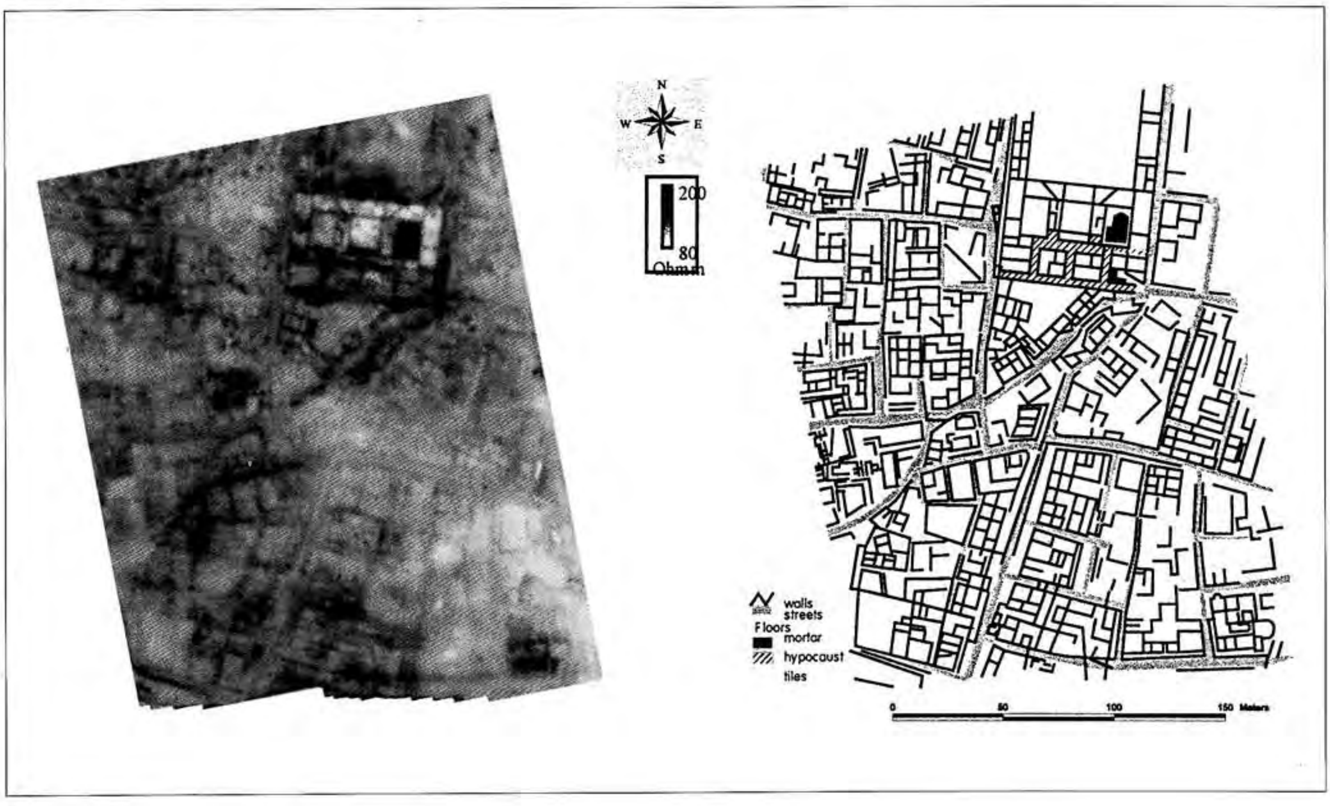
Computer Aided Virtual Reality Reconstruction Based on Prospection Data An Example from the Roman Town Carnuntum/Austria

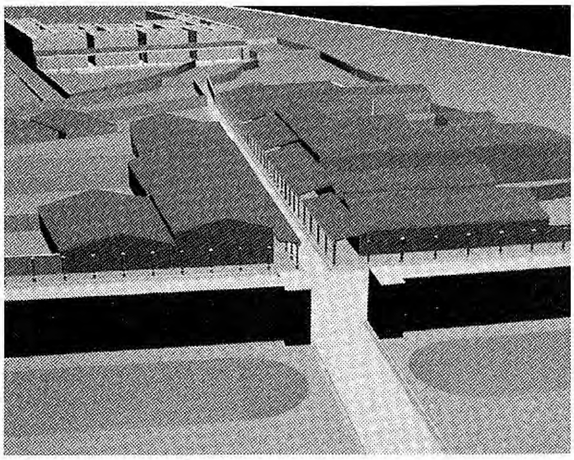
To demonstrate the potential of archaeological prospection data, computer aided reconstruction is used to illustrate the archaeological interpretation of a part of the Roman civil town Carnuntum east of Vienna. This part is mainly known from data collected during the last three years by an integrated prospection approach combining aerial archaeology, geomagnetics, resisitivity mapping and GPR. By combining archaeological knowledge with architectural construction techniques from the Roman period we try to derive virtual reality scenes that can be shown to a wider audience to illustrate a reconstructed scenario of archaeological sites not yet excavated. By using software for architectural modelling as well as desktop virtual reality techniques we create virtual walkthroughs of the Roman civil town of Carnuntum/Austria.

The computer aided reconstruction has been performed with modern architectural software as well as some general purpose modelling tools that are especially suited to generate complex forms like in the Roman period. Furthermore existing three dimensional libraries of Roman architectural art helped to create realistic virtual scenes inside the computer. To manage the data complexity of a realistic visualisation for a part of an entire town several methods for data reduction and data abstraction have been used to produce visual appealing results, although the amount of data had to be reduced drastically. The computer based reconstruction is a combination of threedimensional architectural models as well as plausibel definition of materials from the roman time. The base for the reconstructed buildings have been derived from the evaluated geophysical prospection by archaeological interpretation carried out by archaeologists. The heigth of the buildings have been estimated with archaeological aid from the prospected floor plan and the measured wall thickness. The shapes of the buildings have been reconstructed using the floor plan again and additional knowledge from already excavated buildings at the same site.

The archaelogical reconstruction visualizes a large area of about 8 ha. The virtual walkthrough starts from outside the town from the necropolis situated aside the main road leading into town from the south. By passing the town wall with the fortification ditch in front we enter the town still on the main road. We pass several houses (shops, housing areas, workshops), a temple and enter a large public building at the southern end of the forum. After crossing the forum the walk leads through a basilica to a monumental public bath.

Fig. 1. Resistivity survey of a part of the Roman civil town of Carnuntum with archaeological interpretation map; RM15 twin array 0.5 m, raster 0.5 x 0.5 m, area 5 ha





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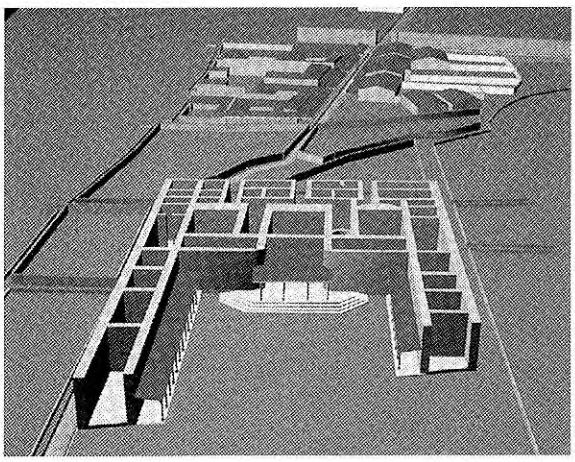

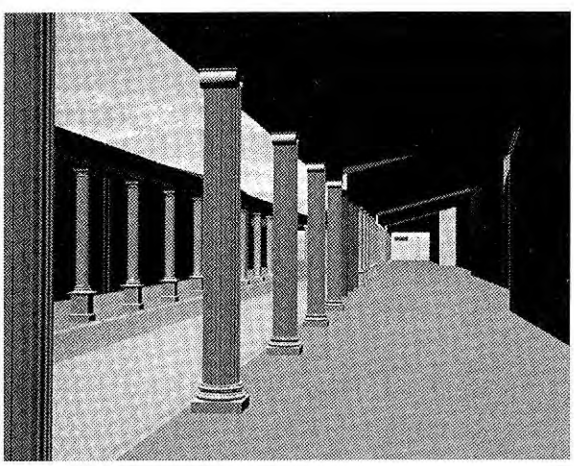

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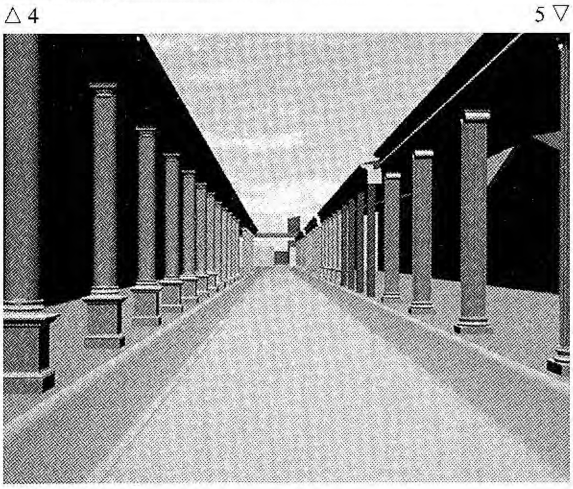


The computer aided reconstruction is a fast and cost effective way to present the archaeological interpretation model derived from prospection data to a wider audience. Computer aided reconstruction of archaeological sites provides a wide base for discussion in archaeology still giving the chance of dynamic development of the scene which is a major advantage compared to conventional reconstruction.

Fig. 2. View from outside the town on the main road leading towards the forum

Fig. 3. View from north (above the forum) towards a selected part of the town along the main road

Fig. 4. View from inside a portikus along the main road

Fig. 5. View from the main road towards the forum

B. Hoffmann, A. Neville, F. Teichner, D. Wooliscroft

The First Geophysical Survey at the Roman Villa of Milreu (Algarve/Portugal)

Situated in the hinterland of the Phoenician-Roman city of Ossonoba, the modern Faro, with its important port on the Atlantic coast, the Roman villa of Milreu is one of the best preserved ancient monuments in Portugal. In 1877, Estácio da Veiga excavated large areas of these ruins, such as an extensive peristyle with rich coloured fish-mosaics, bath-buildings and a late Roman sanctuary *(nymphaeum?)*. From the 1970's to the mid-nineties, the German Archaeological Institute in Lisbon concentrated its investigations on the sanctuary. In March 1999 a new phase of the evaluation of the ancient site was initiated and, with the support of the IMPULS foundation of the VDMA (Frankfurt am Main) and the Friedrich-Schiller-University at Jena, it was possible for the first time to carry out a resistivity survey of a Roman rural monument in the Algarve.

A Martin-Clark five-probe and a Geoscan RM4 meter were used to allow the site to be prospected at different depths. The aim of the survey was to explore the possibility of further buildings in this already extensively excavated villa complex. In all, five areas of the site were surveyed:

Area 1 (fig. 1) was a 30 x 28 m grid to check for constructions lining the road which leads west from the entrance to the villa towards the river, Rio Seco. Earlier excavations immediately to the north had provided evidence of structures on a different alignment from the villa and presumably of an earlier date. The area towards the western end of the site, was very badly obscured by the spoil heaps from past excavations and no unambiguous archaeology was detected. There were, however, a number of very localised high spots in the north-east quarter of the grid, and although these might only represent natural boulders, they could also be interpreted as post pads or stone-choked post holes. Faint traces of linear structures on a similar alignment to the excavated structures could also be identified.

Area 2 was a 35 x 25 m grid situated behind the still well preserved late Roman sanctuary. The ground was partly impeded by dumped material as well as modern rubbish deposits which tended to mask any archaeology in the area. Nevertheless, the survey did reveal a slightly curved band of high readings leading off to the south-west behind the villa proper which has tentatively been identified as a path or road.

Area 3 (fig. 2, 30 x 23 m) lay in an orange grove to the east of the visible ruins. The trees were planted in rows, each of which was served by an irrigation system, and the survey results reflect this by displaying heavy banding. This can, however, be at least partly filtered out making it possible to identify underlying structures, some of which might represent remains shown in the antiquarian plan of Estácio da Veiga. There is, for example, a series of square shapes towards the southern end of the grid that may form an extension of the barrack-like buildings already known closer to the sanctuary (*pars rustica*). To the north of these there appear to be two more rectangular structures that do not appear on the old plan and which raise the possibility that more buildings may exist than has been assumed hitherto.

Fig. 1. The Roman villa of Milreu (Portugal); survey grid 1

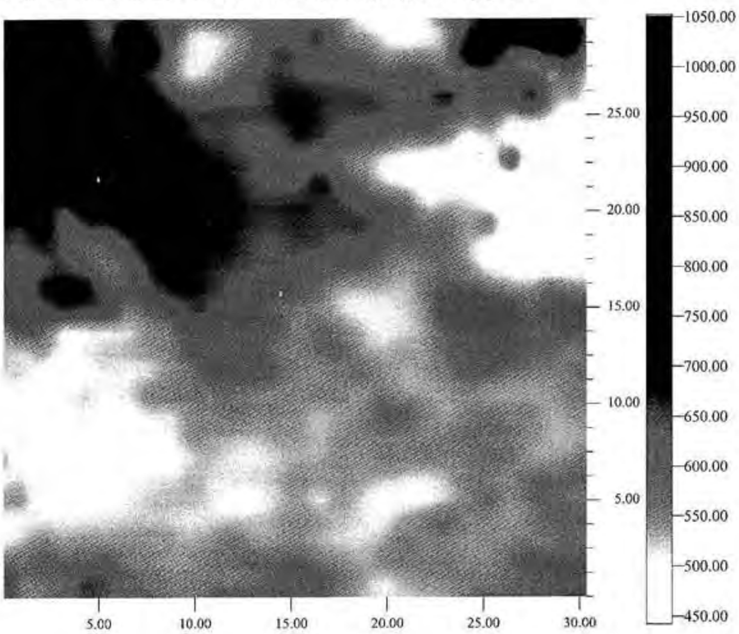
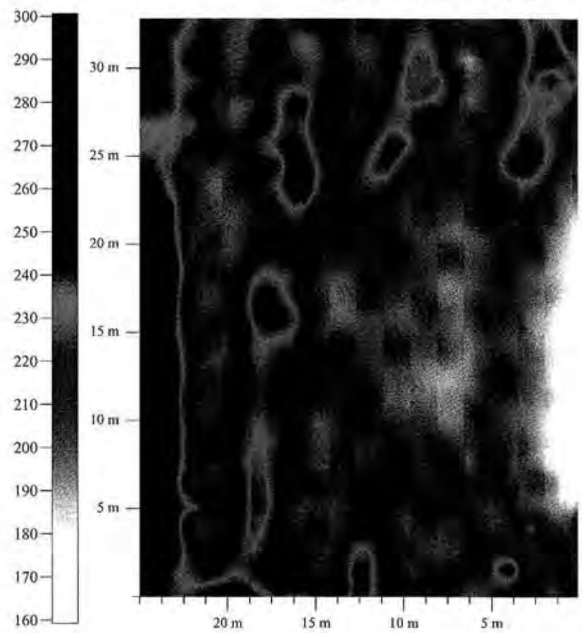


Fig. 2. Milreu; survey grid 3



Area 4 lay just to the east of a sixteeth-century farmstead and was designed to see if the Roman period walls found under this building could be traced outside it. There was only room for an 8 m wide (x 30 m long) grid between the building and the site's boundary fence but, despite its small scale, the survey proved successful in identifying structures connecting a mosaic-paved room under the farmstead and an atrium with a fountain to the south.

Area 5 lay just inside the modern entrance to the site, between grids 1 and 2. It consisted of very dry, compacted earth topped by a thin layer of pea gravel. No new structures were detected, but the survey was able to pinpoint structures that had been excavated previously but then backfilled.

In summary, although the presence of significant deposits of excavation spoil had meant that no great faith had been put in the ability of resistivity survey to produce useful data at Milreu, good results were obtained which have contributed to our understanding of this remarkable Roman site. The present work was merely a test survey and it is planned to carry out more extensive prospection in the coming year.

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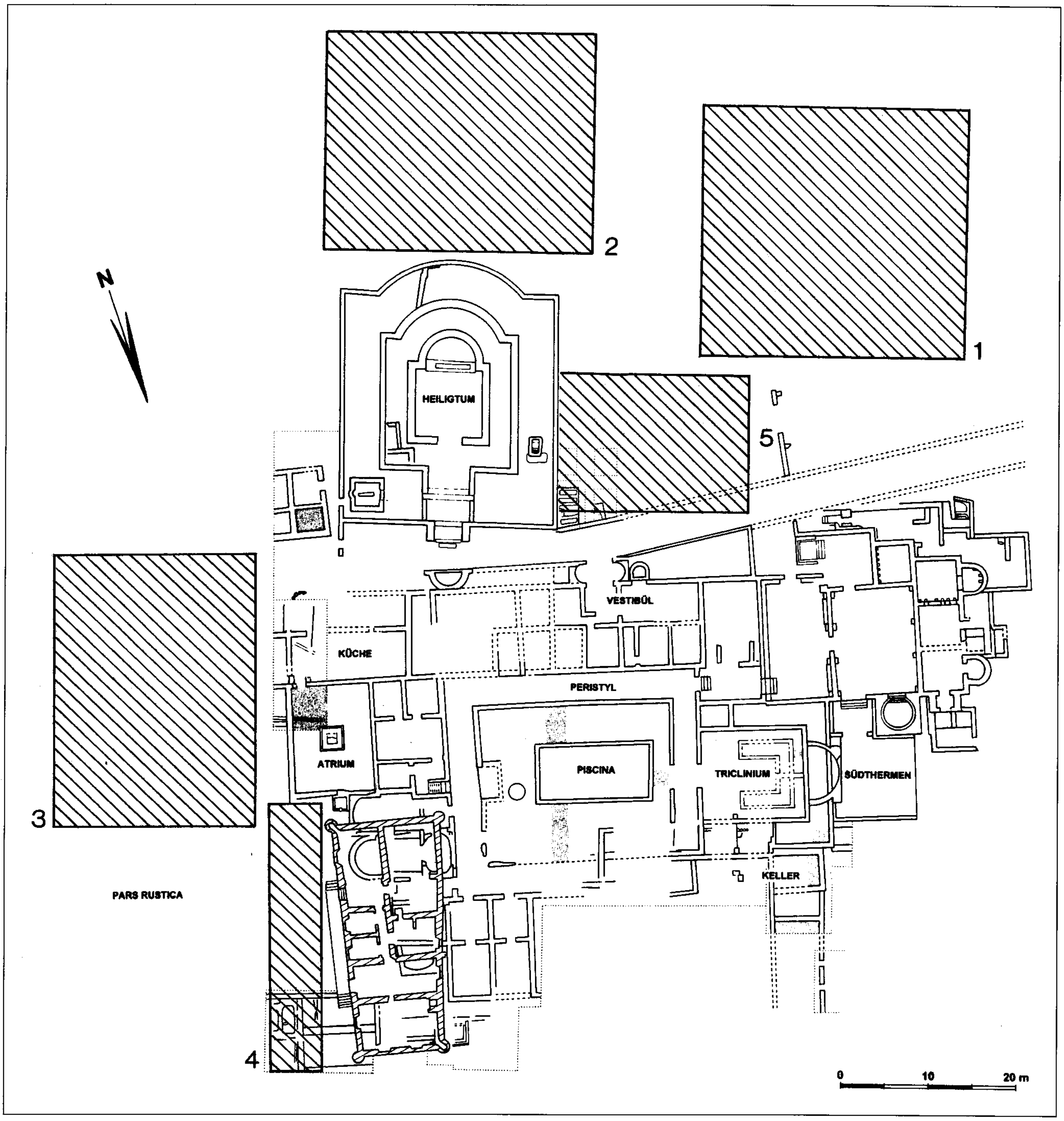
Fig. 3. The Roman villa of Milreu (Portugal) and the survey grids 1999 (area 1–5)



G. Indruszewski

Geophysical Prospection in the Oder Mouth Area – Contributions to Archaeological Target Verification

During the 1998 season spent in the Oder mouth area, the National Museums team has completed a lengthy seismic survey of all three channels through which the Oder discharges its waters into the Baltic Sea. The instrumentation used was a combination of high-tech and general acoustic devices which permitted the registration of bottom and sub-bottom anomalies. Few of these targets were inspected by divers afterwards, but the experience gained in this kind of environment enables a better understanding of the application of Chirp-type sub-bottom profiler to underwater archaelogical prospection, and in general to the application of seismic prospection to underwater targets. The present knowledge of geophysical prospection in underwater environments is encreasing. The focus favours clearly geological applications, while archaelogical applications are still in the incipient phase of experimentation. The material presented here tries to increase the understanding and interpretation of bottom and subbottom anomalies in the light of the expirience gained in the field.

G. Indruszewski, W. Karrasch

Aerial Reconnaissance as an Aid to Reconstruct Coastal Geomorphological Processes

The need to cover large areas of coastal zones for the broader understanding of active geomorphological processes has led to some expiriments with aerial photography in the Roskilde fjord. Part of the "Wendish Seafaring" project which deals with the reconstruction of past landscapes in the Oder mouth area, and the expiriments carried out over the Roskilde fjord area were directed toward optimization of flying ceiling, selection of film type, photographic technique and camera type, and finding the best flying daylight time. The results were processed in the facilities offered by both institutions in Roskilde and they are presented here in the light gained by the authors during the flights. The results permitted the observation of several new features regarding the geomorphology of the area, and they constituted the basis for a renewed effort in dealing with deltaic formations and morphodynamics in the coastal zone.

H. Kamei, H. Igarashi, Y. Ueda

FM-CW GPR and its Signal Processing

Pulse GPR (Ground Penetrating Radar) has been widely used in the field of archaeological prospecting recently; however, we have often encountered the limit of its applicability. So, the authors have developed another type ground penetrating radar, a FM-CW (Frequency-Modulated Continuous Wave) radar (Kamei *et al.* 1996). In the FM-CW radar, the transmitter frequency increases or decreases linearly with time. As the frequency cannot be continuously changed in one direction in practice, the transmitter frequency is triangularly modulated between 100 MHz and 500 MHz. The period of the triangle waveform is 50 m/sec. If there is a reflecting object at a distance R, the echo signal will return after a time $T=2R/v$ (where v is a velocity of electromagnetic wave in soil). If this echo signal is heterodyned with the transmitted signal, a beat signal will be produced. This beat frequency f_b is proportional to the delay time T; $f_b = aT$, where "a" is a rate of change of the transmitter frequency and a=16Hz/nsec in this case. Because the FM-CW radar is on the basis of detecting frequencies, the vertical axis of FM-CW radar profile becomes a frequency axis; furthermore, higher S/N-ratio is expected than pulse radar. And the FM-CW radar image is not affected so much by the "ringing", because the transmitted signal whose frequency spectrum is limited inside the bandwidth of antenna. Signal processing techniques play an important role in detecting frequencies from the beat signal and in making images in the FM-CW radar. In this paper, such techniques are discussed.

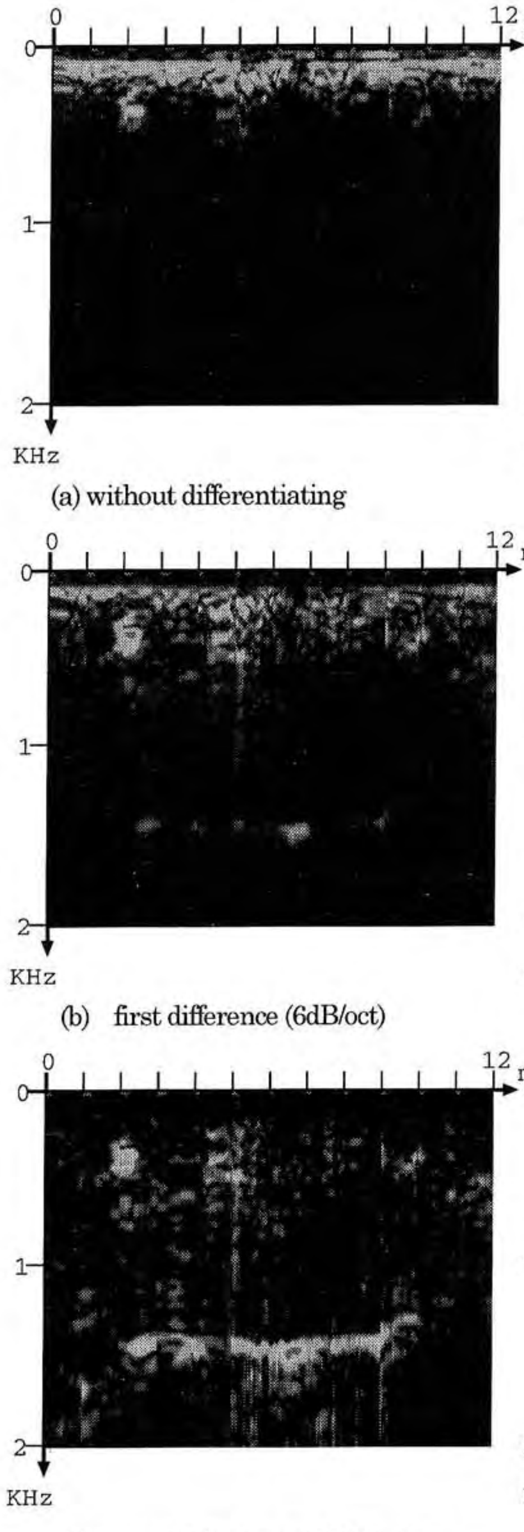
As a pre-processing, a technique of emphasizing higher frequencies is introduced. In a pulse GPR, a time-varying gain (STC) is applied in order to compensate for propagation loss, but this technique is not applicable to a continuous-wave GPR. In the FM-CW GPR, a signal from a deeper target appears in higher frequency domain. It is well known that differentiating a time-varying signal results in emphasizing the higher frequency part of its power spectrum at the slope of 6dB/oct. By differentiating a beat signal of the FM-CW GPR, deeply buried targets appears more clearly in the GPR image.

Many spectral-estimation methods such as FFT, MEM (Maximum Entropy Method), filter bank, *etc.*, are applicable for detecting the beat frequencies. They have both advantages and limitations, respectively; so, a proper method should be chosen for the purpose, multiple methods may be also available.

In this FM-CW GPR, the transmitter frequency changes from 100 MHz to 500 MHz in a half period of the modulating triangular waveform. By setting the length of the time window for spectrum analysis shorter than a half of the modulation period, we can select the frequency band used for imaging; the higher frequency, the shorter wavelength, then the higher resolving power, physically.

A delay time T is detected as a peak at a frequency of f_b (= aT) in the power (amplitude) spectrum of the beat signal in the FM-CW radar; furthermore, the delay time T also appears in the phase term of the spectrum. So, we can make another image using phase spectra. In a phase spectrum by FFT, a step-like change of phase appears at a frequency corresponding to the delay time T. Since there are some cases where detection of step-like change is easier and/or more accurate than peak detection, a FFT phase spectrum image of the FM-CW GPR is available.

Kamei, H. et al. (1996), "A 100–500 MHz Band FM-CW Ground Penetrating Radar for Archaeological Prospecting", Abstracts of Archaeometry 96, *Urbana,* USA, May 20–24, p. 57



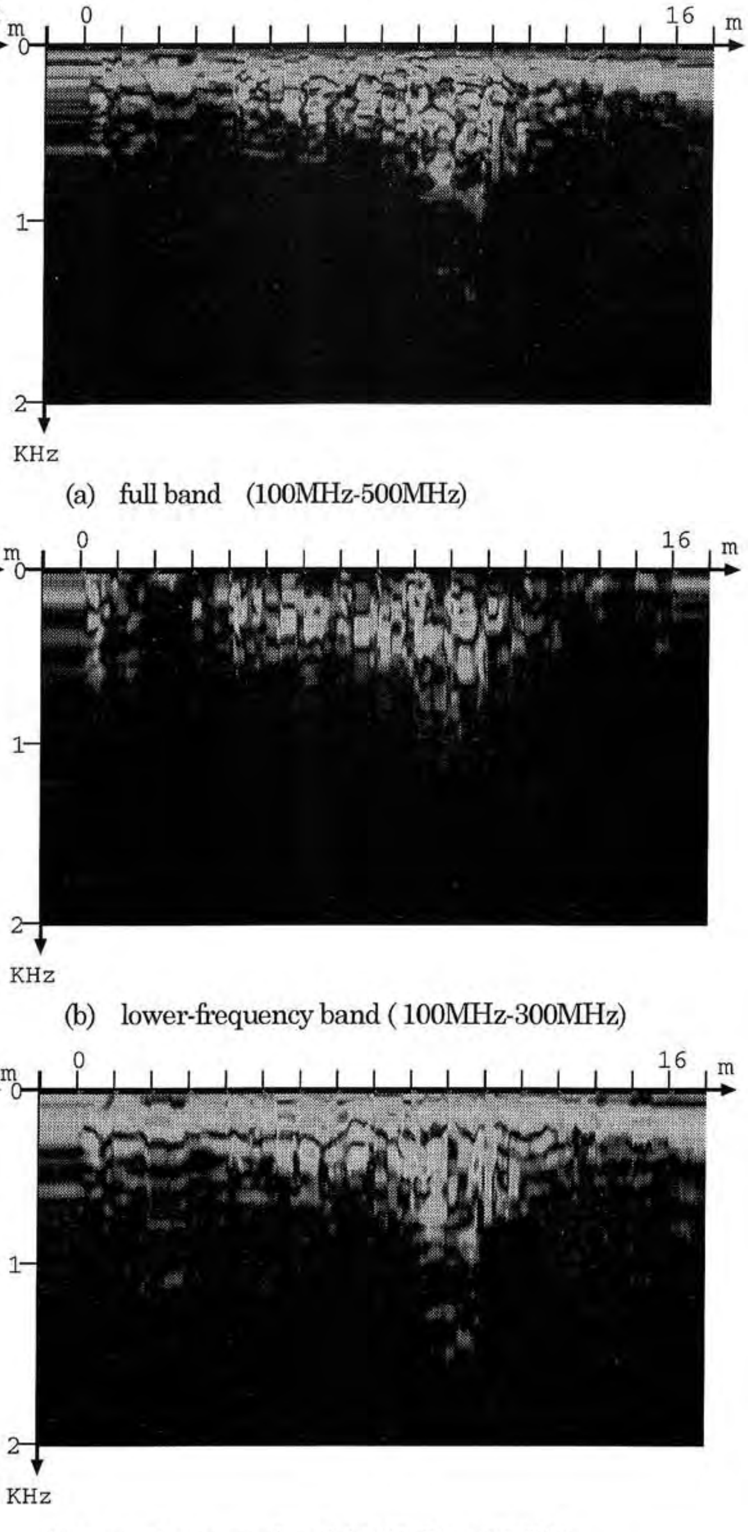


Fig. 1. Emphasizing higher frequency by differentiating a beat signal of the FM-CW GPR (Sakurai mounded tomb, Fukushima pref., Japan, AD 4C).

(a) without differentiating
(b) first diffenrence (6dB/oct)
(c) second difference (12dB/oct)

Fig. 2. Effect of frequency band on profiles of the FM-CW GPR (the brick floor of Shimotsuke brick kiln built in 1889, one of the oldest brick kilns in Japan, Gunnma pref.)

(a) full band (100 MHz-500 MHz)
(b) lower-frequency band (100 MHz-300 MHz)
(c) upper-frequency band (300 MHz-500 MHz

M. Kandler, M. Doneus, A. Eder-Hinterleitner, P. Melichar, W. Neubauer, S. S. Seren

Carnuntum – The Largest Archaeological Landscape in Austria and the Impact of Archaeological Prospection

A total area of about 300 hectares within the modern communities of Petronell and Bad Deutsch Altenburg can be classified as an archaeological area, which only partly has been archaeologically explored up to now. A complete inventory of all available aerial photographs will soon be compiled. A new general view of known archaeological structures may now be obtained by using photogrammetry for the interpretation of aerial photographs.

So far parts of the area have been successfully prospected applying geomagnetic and/or geoelectrical methods and GPR. Both aerial photography and existing geophysical data indicate that the archaeological heritage has suffered severe damage by deep ploughing. As constant excavation and reconstruction work is done at the "Archäologischer Park Carnuntum", rescue excavations have to be initiated quite often because of modern construction projects. Those excavations tend to become long term projects. Scientific interests frequently are in conflict with the economic and housing development of the today's villages Petronell and Bad Deutsch Altenburg which are situated right in the archaeological zone. Thus establishing an appropriate prospection strategy applying non-intrusive methods for Carnuntum, the largest archaeological landscape in Austria, seems to be an important step towards further archaeological research and monument protection as well as regional planning.

The presented case studies may be regarded as prime examples of combined archaeological-geophysical prospection. The available aerial photographs are complemented by non-destructive geomagnetic and geoelectric measurements with a reading distance of 0.5 m or less. The resulting images can be combined with supplementary information. Thus quickly and inexpensively further knowledge of the archaeological monuments may be gained by means of digital image combination. After choosing suitable instrument set-up and measuring parameters accuracy may be enhanced by adding data of GPR measurements and depth information. The presented interpretation methods allows us to incorporate GPR into the standardized interpretation process of archaeological – geophysical prospection. GPR and other available geophysical data being the basis, a detailed 3D interpretation model of monuments is created. The thus gained information is an extremely important and efficient tool for any further archaeological research. Empiric data resulting from special case studies and developed evaluation – and interpretation methods enable projecting of a specific strategy for overall prospection of Carnuntum. Such a prospection seems to be urgently necessary from the scientific as well as from the development-planning point of view and could give enormous input to economic strategies by bundled and focused actions for the largest archaeological zone in Austria.

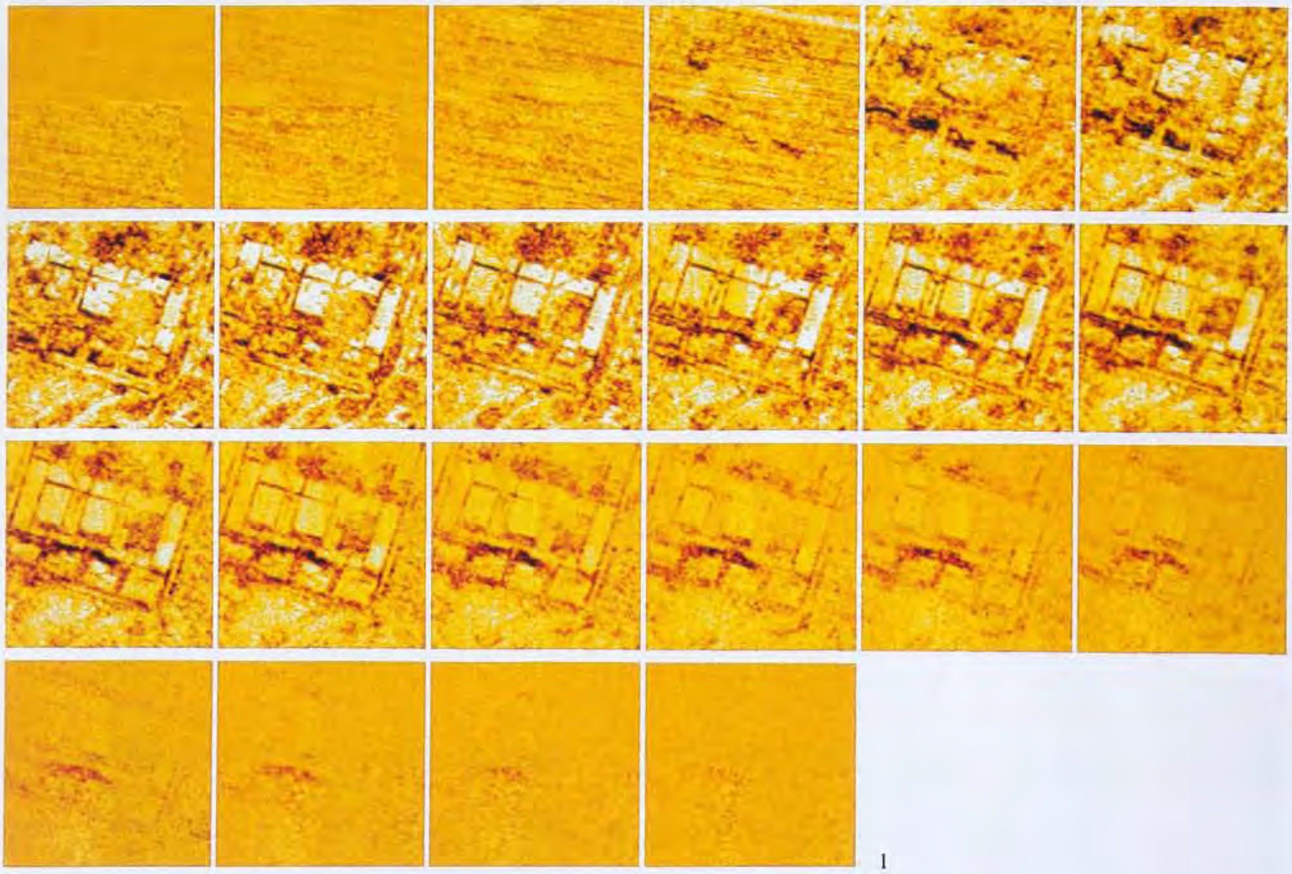
Fig. 1. Time-slices of GPR-data from Carnutum; visualised are the absolute amplitude of the refelction waves in 15 cm slices (Pulse Ekko 1000, 450 MHz antenna, area 80 x 80 m, measured raster 0,5 x 0,1 m)

Fig. 2. The integrated archaeological interpretation model: based on the GPR-prospection, the geoelectric prospection and the geomagnetic prospection

Fig. 3. Geoelectric prospection (RM15, twin-array 0,5 m, raster 0,5 x 0,5 m, dynamic range [80-180] Ohm meter)

Fig. 4. Geomagnetic prospection (Caesium gradiometer 0,5–2,0 m, area 80 x 80 m, raster 0,5 x 0,25 m, dynamic range [-10,10] nT)

Fig. 5. 3D visualisation of the archaeological interpretation model; view from the south-west



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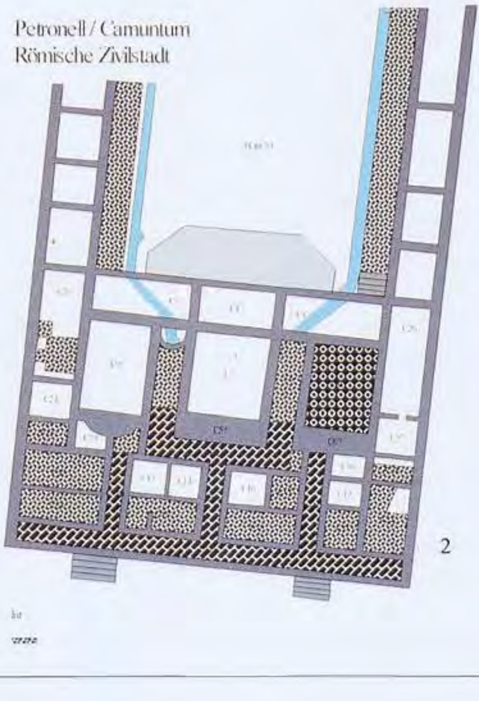

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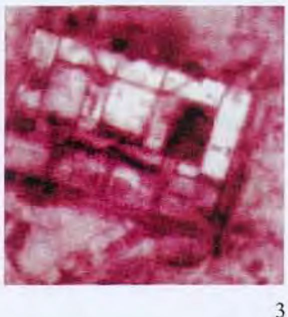

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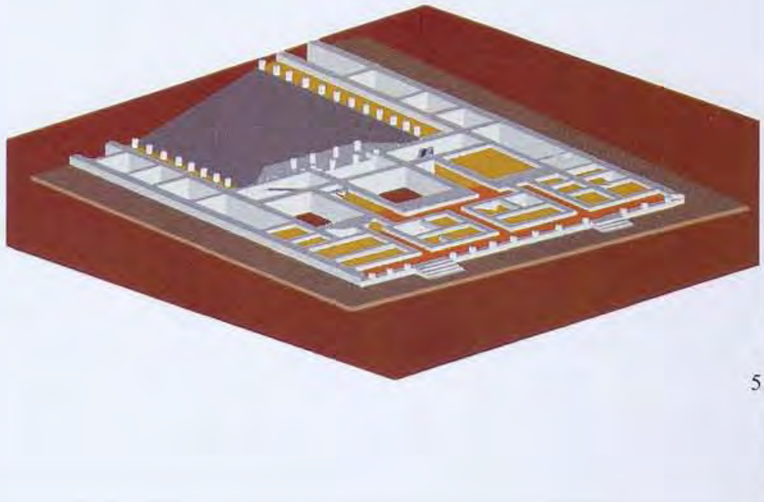

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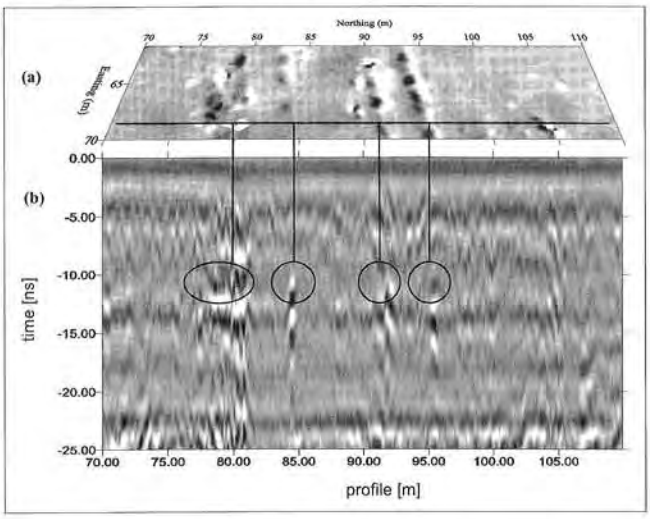
U. Koppelt, N. Abrahamsen, G. Dittrich., J. Frandsen,Y. Hofmann, C. Kroner

Interpretation Enhancement of Archaeometric Investigations due to Joint Interpretation of Geophysical Fields

Because of different limitations, e. g. time, instrumental or economic limitations, only single-method geophysical investigations are carried out in many cases. However, a single method is often limited by the capability of the utilized physical principles to display certain archaeological patterns. Therefore, an integrated geophysical investigation technique should be applied to overcome this problem. At Kalø peninsula (Jutland, DK) an integrated geophysical prospecting was carried out to detect different subsurface targets related to the old medieval castle and its surroundings. To locate houses and the position of different defense structures, four different areas were investigated using geomagnetic prospecting, ground penetrating radar (GPR), geoelectrical profiling and surveying. By means of combined geomagnetic and GPR measurements the situation at the first entrance to the peninsula was investigated. To correct the GPR data for topographic effects, the topographic map was refined by dense surveying. Because geoeletrical profiling has generally a lower resolution than the other two methods, it was applied as a first prospecting method to find the continuation of the ancient road outside the forecourt. Afterwards, anomaly regions found by this method were studied in detail using GPR and geomagnetic prospecting. The data revealed the distribution of old farm houses in the forecourt and the position of the ancient road leading from the entrance of the forecourt up to the castle. A 3D-image of the urban plan of the area under study is finally presented.

Fig. 1. Joint interpretation of total magnetic field data (a) and GPR data (b) on a profile crossing the remains of an ancient building. From the GPR time section a depth to the top of the remaining foundation of about 50 cm was estimated. Depth estimates of 45–50 cm, obtained by means of inverse modelling and from logarithmic power spectra of geomagnetic data, were in good coincidence with the former results



N. Kozhevnikov

Barun-Kahl : History of Purely Geophysical Discovery of the Oldest Iron Age Site at the Western Shore of Lake Baikal

Some years ago, very slowly decaying transient signals were measured during TEM survey over metamorphic crystalline rocks in the mouth of the Barun-Khal valley which is situated in the vicinity of village Chernorud, at the western shore of Lake Baikal. Being converted to apparent resistivity, these transients resulted in values of about 2–5 Ohm meter. Since both in-field and laboratory DC resistivity measurements didn't indicate any conductive rocks evidence within the TEM anomaly area, the TEM results seemed to be confusing.

To elucidate the cause of the slowly decaying transients, parent rock and soil samples were studied in the laboratory using: 1) microscopic examination; 2) small coil TEM measurements; 3) hysteresis and thermomagnetic analyses. It turned out that anomalous in-field measured transients were caused by the relaxation of magnetization of extremely fine ferri -and/or ferromagnetic particles concentrated in the near-surface layer. The origin of these particles for a long time remained a mystery.

In 1996, the third-year students of the Irkutsk Technical University that had in the vicinity of Chernorud their training in field geophysics, found a gopher's burrow. Among the soil thrown out of the burrow, many slags and charcoal fragments were found, which suggested an ancient metallurgical activity. The slags were electrically nonconductive. Examination of slags with chemical, X-ray diffraction and SEM analyses has revealed that they consist predominately of a silica matrix and dispersed within it ultrafine particles of metallic iron, magnetite, phayalite, and wuestite. Being placed into a small coil, the slags produced slowly decaying transients caused by magnetic viscosity effects. By chemical and mineral composition the Chernorud site's slags proved to be identical to those which are known to have been formed during yielding iron in ancient bloomery furnaces.

The total magnetic field measurements carried out along two lines intersecting at the above gopher's burrow have indicated a positive magnetic field anomaly with amplitude of 50 nT, and 25–30 m in diameter. A reconnaissance excavation carried out to a depth of 0.8 m over the 1 m by 2 m area centred at the gopher's burrow resulted in discovery of slags, charcoal, porous iron, and baked clays. In 1997, the excavation area and depth were increased up to 3 m by 4 m, and 1 m, respectively. This time, remains of a bloomery furnace, some pottery sherds and other artefacts were found.

In 1998, magnetometry data were collected over a rectangular, 200 m by 150 m area centred at the excavation. Magnetic field measurements were taken at 2 m intervals along parallel profiles spaced by 4 m. The magnetic field contour and surface maps exhibited two positive isometrically-shaped anomalies connected via a narrow "cross connection". Unfortunately, the gopher's burrow and excavation fell just within the "cross connection" rather than within one of the main anomalies. The following excavations are planned to be taken in central parts of the above anomalies.

Radiocarbon dating of three charcoal fragments sampled during the excavation from different depth intervals has given ages of 1915 ± 35, 2050 ± 35, and 2180 ± 30. These results make it apparent that the Iron Age at the western shore of Lake Baikal started about 700–900 years earlier is generally appreciated. Note that anomalous transients were measured over an area of no less than 15 ha. This suggests that iron yielding in the Barun-Kal valley was performed on a large scale.

R. Krivánek

Contribution of Caesium Magnetometer Prospection to Archaeological Projects in Bohemia

The first pioneer magnetometric measuring on archaeological sites in Czechoslovakia were realized in the late 60's. The various kinds of proton magnetometers and also methodologies of archaeomagnetic prospection were applied on different types of Czech, Moravian and Slovakian archaeological sites and in particular features for more than 25 years. By present eyes of archaeogeophysicists it has been the time of many very good results of small magnetic surveys which were mostly aimed at the individual interest of archaeologists and their archaeological excavations. Geophysics in archaeology has been often observed and also used during that time only as a service prospection method of archaeology. Another more intensive application of geophysics before rescue archaeological activities and excavations started in this country in the beginning of 90's. Since that time it has been more real to start also another aimed cooperation of geophysics within other methods of archaeological prospection and also archaeological research. Archaeomagnetic methods were than more systematicaly connected, for example into the project of aerial prospection and its verification, project of surveys of abandoned medieval glass-working sites or into the landscape reconstruction project within application of intensive field walking methods. ... Due to this intensive individual cooperation and putting geophysics into the Department of Landscape Archaeology of Institute of Archaeology in Prague then could Bohemia start the new era of more systematic archaeological and also archaeogeophysical projects based on the use of proton magnetometers and fluxgate gradiometers. The new archaeological project "Settlement areas of prehistoric Bohemia" (Gojda et al. 1997-2002, Institute of Archaeology Prague) offers new ways of wide and intensive cooperation of non-destructive archaeological methods (aerial prospection, geophysical prospection, landscape reconstruction, systematic field walking survey all together with GPS, GIS) for the systematic study and prospection of chosen intensively settled and used prehistoric areas/landscapes. The results on the poster demonstrate the new scales of use of modern caesium magnetometers for the study of the whole archaeological sites (atypicaly fortified prehistoric settlement sites, ploughed burial-mound areas) and connection of results with other archaeological methods. Another new archaeogeophysical project under the Ministry of Culture "The identification of destroyed fortifications and inner structure of settlement of hillforts" (Krivánek 1999–2000, Institute of Archaeology Prague) documents another application of caesium magnetometrs for the detailed prospection of larger areas of abandoned hillforts which could bring new archaeological view on site, but also could help for better and more precice protection of whole archaeological monuments. Only the first year of experience with caesium magnetometer prospection has shown that for the Bohemian archaeogeophysics a new era of unexpected and many times impossible applications of method on large areas of sites as in detailed scale of individual types of features. Other cooperations of various archaeological and geophysical methods are also planned in Bohemia in some future interdisciplinary projects.

J. Leckebusch, R. Peikert

Automated Extraction of 3-D Features from Georadar Data for Interpretation and Visualisation

Georadar is now an established method for archaeological prospection and the advantages and limitations are known. If properly processed and migrated, 3D georadar data can very accurately estimate the depth and size of structures in the underground. The potential of this 3D mapping technique has not yet been fully exploited. The data are normally represented in the form of profiles (vertical slices), time- or depth-slices or a combination of these. Unfortunately these procedures allow only limited insight into the true 3D structures. Attempts to overcome this problem by manual or semi-automatic interpretation are very time-consuming. The proposed solution to reveal the full 3D structure is the automatic calculation of isosurfaces. This new method is robust and efficient and reduces the amount of data substantially, which makes it suitable for surveys of large areas. The information contained in the isosurfaces can be readily exported to GIS-, CAD- or virtual reality systems for further analyses and/or display. With these tools the results can be viewed from any angle to aid the imaging and interpretation, the dimensions of the structures can be extracted directly, and the results can be rendered to make them understandable even for non-specialists.

S. Lemke, L. Mankowski, D. Hayes, S. Martin

Geophysical Characterization of a Sugar Mill on St. Croix, U. S. Virgin Islands

Whim Plantation on St. Croix in the U. S. Virgin Islands was the site of a sugar mill operation from the early 17th to the late 19th centuries, and now houses the St. Croix Histrical Society. In the spring of 1999 a multidisciplinary group from Michigan Technological University conducted geophysical surveys over the site of the sugar mill complex to highlight promising areas for a planned archeological dig to be conducted in the summer of 1999. Ground penetrating radar, total field magnetics and earth resistivity were used. This area contains both subtle anomalies of buried foundations and small metallic objects as well as massive anomalies caused by very large buried and surface metallic objects. Interest lies not only in the easily identifiable anomalies but also in smaller anomalies hidden within the data. The complexity of the data required advanced processing and interpretation. The site was not only well suited to multiple geophysical methods, but required them. Each geophysical method could pick out large anomalies well, but confidence with subtle anomalies could only be gained through comparison with all three geophysical methods.

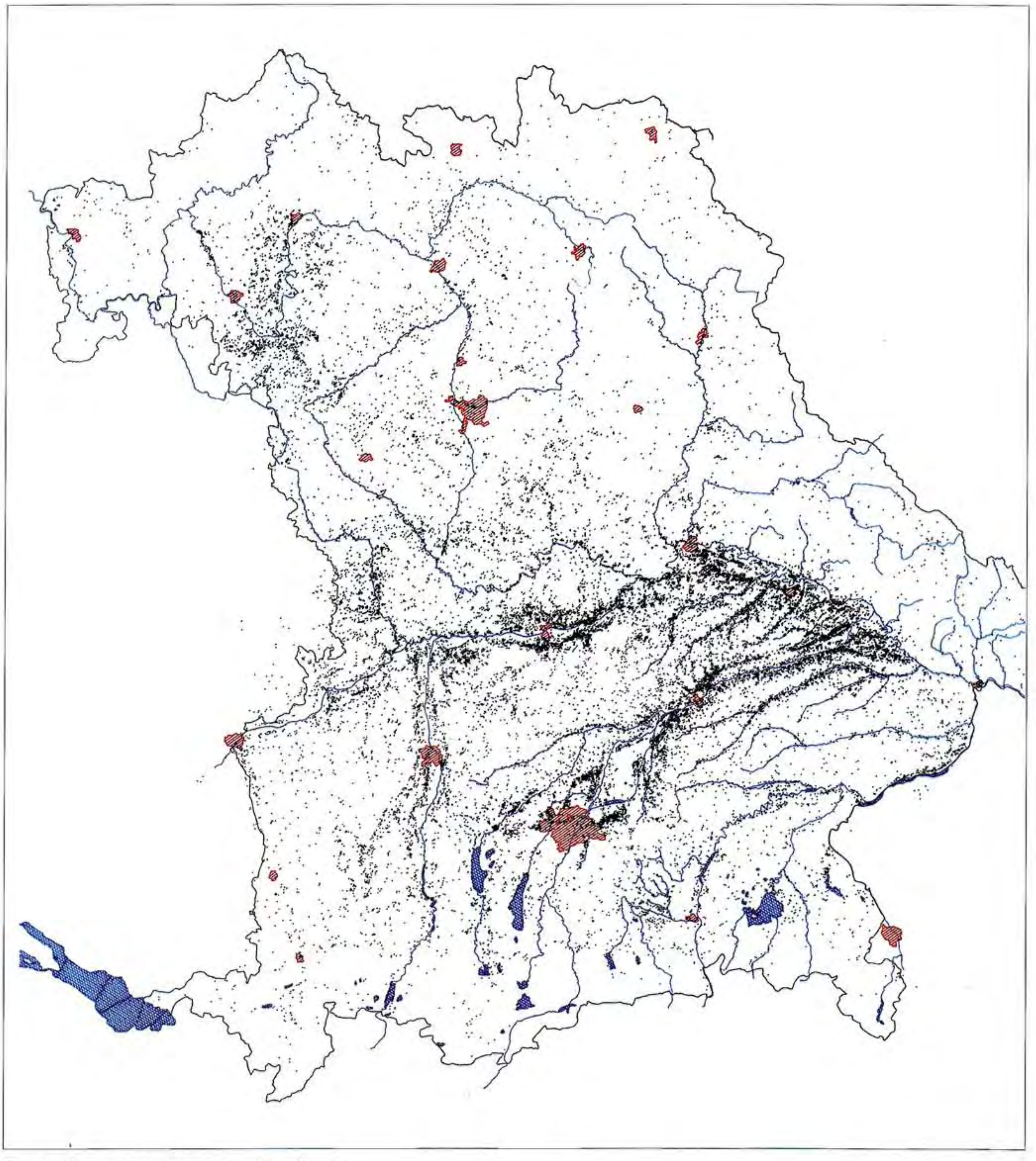
K. Leidorf

Aerial Archaeology in Bavaria

Bavaria is the largest state in Germany. In the last twenty years aerial archaeology has been practiced. For reasons of costs, the pilot has to also act as navigator, archaeologist and photographer. This method has proven to be the most successful and at the same time the least expensive. The beginning years were, for an eager pioneer visionary, very busy and with little time devoted to systematic research and the detailed processing of the aerial photographic material received. At that time flying activities were concentrated on regions which were suspected to yield many new finds. So much photograhs were taken that large amounts of the pictures lay unattended for a long time in nonfunctional archieves.

In the meantime, without losing the effectivness of detail, many improvements were instituted. It was realized that the amount of aerial photographs alone were no criterion for the quality of aerial photograph prospection methods. Only when a usable amount of photographs were made available to the archaeologists in a short time was one able to speak of effective aerial archaeological photography. For that a well supplied archieve with properly trained personnel and necessary equipment is most important. Qualified personnel are extremely necessary in order to have an error-free and properly functioning archieve. Wrong archiving often leads to the temporary loss of photographs which often are found suddenly after a long period of time. Continuous communication between the archaeologists on the ground and the aerial archaeologist is very important in order to fulfill a concrete need for aerial photography in a very short time. The advance preparations for the prospection flight have been very much improved in recent years. Meanwhile some of the flight projects have been mapped from known archaelogical sites seldom flown over where many new sites have been located. This tiresome project over not so promising regions does not indicate a large amount of new findings like those that appeared in the beginnig years, but do give a large amount of scientific and other important information.

In addition to the project intense flying always indicates enough possibilities to control already known finds and document any changes in their condition. Even with all of the preparatory work on the ground, a little luck is always needed in aerial photographic prospection due to different factors like weather, flying route, time of day, viewing direction, shape and changes in growth of land characteristics. Many of these factors must correspond with each other for new finds to be of value to all concerned.



The distribution of Aerial Photographs at Bavaria

G. Leroux

Aerial Prospection at Low Altitude in Brittany and Pays de la Loire Region, Results and Synthesis of 1989–1999 Researchs

Since 1989, a vast geographic sector centred on the eastern part of the Armorique area which lies both in Brittany aud the Pays de la Loire region, is subject to systematic aerial prospections at low altitude. The conditions of detection, although fairly varied, do not constitute real obstacles to the discovery of vestiges. Due to the real regrouping of lands that began in the 1960's, the traditional bocage of western France has gradually been replaced by semi-open landscapes which are turning out to be the favorite haunt of aerial archeology.

Among the thousands of discovered sites, an overwhelming majority belongs to the category of enclosures bordered by sets of embankments and ditches,that have now been levelled and filled in. As a matter of fact, the vestiges kept above the grownd are few and belong most of the time to the medieval period. Concerning the Gallo-Roman monuments built on fundations that were lined with stones, there are hardly any. The chronological range is wide because all the major periods from Neolithic to the Middle Ages are represented. The nature of the sites covers the whole range of human manifestations pertaining to the conquest and the development of "local territories". The habitats, necropolises, roads and the patterns of fields are engineered to the extent of making up a rural fabric which is truly coherent, especially during the Iron Age and Antiquity. This has been particularly brought to light in the bassins of river Seiche and Oudon, which are respectively situated in the eastern fringe of the departement of Ille-et-Vilaine and in the south-west of departement of Mayenne. The third international conference on archeological prospection will give us the opportunity of presenting a serie of discoveries that, without being original, remain nonetheless fundamental for the knowledge of the stages of the ancient settlement in the western extremity of the European continent. In the recent years, the computerized dataprocessing has been applied to the rectifying of oblique aerial photographs and to the making up of cumulative cartography.

Finally the aerial campaigns are succeeded by ground verifications, excavations and boring which bring fundamental chronological data.

E. Lück, M. Meyer

Geophysical Preparation of an Archaeological Excavation in the Highlands (Mardorf, Hessen)

From 1993 up to 1998 archaeologists excavated a settlement near Mardorf. The investigated settlement Mardorf 23 is situated in the eastern part of the "Amöneburger Becken", an about 120 km^2 extended basin in the middle part of Hessen in Germany. Because of the soil conditions (loess developed on clay) this region belongs to the uppermost fertile parts of Hessen. Mardorf 23 seems to be one of the oldest German settlements in that region. Excavations showed that this settlement had its origin in the Iron Age- and Emperor Age (about 50 B.C. up to 300 A.D.)

In addition to the archaeological studies, also geological and geophysical prospections were done. To optimise the excavations, geomagnetic prospections were carried out. In 1995 B.Zickgraf and M.Posselt started these investigations. They covered an area of about 16,000 sqm Because of the good results, in 1997 and 1998 we continued these measurements. Up to now an area of about 60,000 sqm was mapped with geomagnetic methods. We worked with a Fluxgate-gradiometer FM-18 from GEOSCAN research (Bradford, UK). All the field work was done in the same manner. The distance between two points was 0.5 m and also the increment between the profiles was 0.5 m. The resolution of the gradiometer was not better than 0.1 nT/m.

Because of a temperature drift, the data had to been corrected by a smoothing algorithm. This was done on the base of statistical calculations.

We can find out objects from different time scales. There are not only visible archaeologicaly but also are geological and modern structures.

Especially in the south-eastern part we can see some linear structures which can be composed to polygons. Excavations have confirmed the assumption that we have found geological structures which were formed during the glacial period. These former ditches are now covered by a layer of about 1 m thickness.

Younger geological elements can be seen in the north. From geological and archaeological studies we know, that the landscape has been changed in the past. The curved former border of meadow can be seen from west to east. In the north the covering layer consists of alluvial sand with variable thickness. That is why it seems to be unlikely that archaeological structures in this

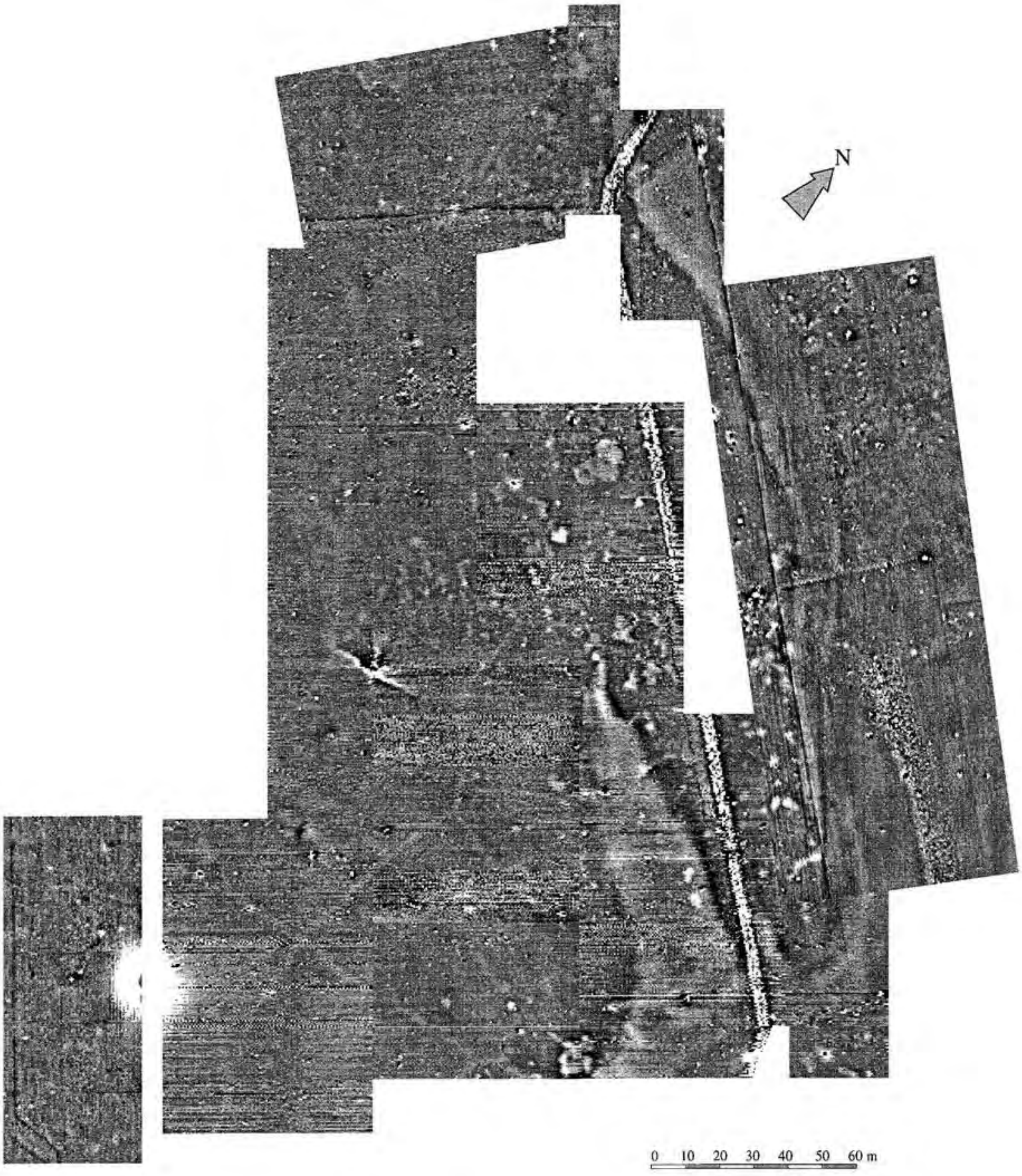


Fig. Results of all measurements done in this region within a scale of ± 5nT/m

area can be detected by geomagnetics. South of this border we see a lot of narrow restricted positive anomalies. They are caused by pits, holes and vestiges of states. The excavation has shown that these anomalies belong to different time periods. Not only old German but also Neolithic marks are visible.

The sharp linear elements are caused by old field boundaries. Additionally we see younger and modern structure. The more or less linear anomaly in the northern part of the investigated area is due to a modern field-path covered with basalt. Some metal causes the large anomaly in the south-east.

Acknowledgement

We thank the colleagues B. Zickgraf, M. Posselt, U. Spangenberg, N. Lieske and M. Eisenreich for their support during the field measurements.

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M. Martinaud, F. Madani

Resistivity Vertical Filtering for Horizontal Prospecting Physical Basis and Archaeological Case Histories

An important question in archaeological geophysical prospection is the separation between anthropic and natural geological features. Generally the archaeological features are near the surface so that it is possible to distinguish them from the natural ones through suited investigation depths.

It is well known that electrical resistivity prospecting is a good method for the adjustment of the investigation depth owing to the electrode spacing. But the investigation depth and the electrical image are strongly dependent on the electrodes arrangements. The "archaeological" arrays are the twin electrode, the pole-pole, the square and the Wenner. In this paper it is shown that the pole-pole yields a very good discrimination between shallow and deep buried features. The pole-pole array is an improvement of the twin electrode (1) in the sense that remote electrodes are far from each other so that the readings provide the true apparent resistivities without any problem of continuity between adjacent grids.

The physical basis of the behaviour of the pole-pole array can be deduced from synthetic results about the anomaly created by a small body on a pseudo-section. Indeed, when comparing the anomalies of a small body imbedded in homogeneous ground obtained with several archaeological arrays, one sees that the pole-pole anomaly has a better resolution in the horizontal direction and also in pseudo-depth (2). This advantage of the pole-pole over the other arrays for depth discrimination is reinforced by two other properties: its technical simplicity (only two mobile probes) and its largest investigation depth (3). Thus, for a given investigation depth, the pole-pole array has the smallest dimensions of all arrays.

We show that multi-spacing pole-pole maps allow an efficient vertical filtering of anomalies in cases which would be otherwise hard geophysical problems. Case histories are the search for ditches in karstic geology, the detection of stony burial structures on very shallow resistive substratum, the separation of superimposed structures in a Roman town (4) or, on the country, the proof of the absence of any buried anthropic structures.

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Y. Marukawa, Y. Lu, H. Kamei

Reconstructing the 3-D Distribution of the Magnetic Field Data and its Application

In geomagnetic survey, we usually measure the magnetic field only on one 2-D plane. In this study, the authors will propose the method of reconstructing the 3-D distribution of the magnetic field data from the 2-D magnetic field data and its application to estimate of the shape and the depth of the magnetic bodies. For example, in the case that two magnetic bodies are buried and one magnetic body is just above another one, only one magnetic anomaly is observed on a horizontal plane over these bodies. However, if we could assume a vertical observation plane in the ground and obtain the magnetic field data on the plane, we would find two magnetic anomalies on this virtual plane.

The magnetic field distribution on z = z1 plane can be calculated from the magnetic field on $z = z_0$ plane using 2-D Fourier transform as

$$F\,[\mathbf{B}_{Z_1}] = F\,[\mathbf{B}_{Z_0}]\exp\left(-\,|\,\mathbf{k}\,|\,(z_0 - z_1)\right),$$

where $\mathbf{B}_{z0}$ and $\mathbf{B}_{z1}$ are magnetic field on $z = z_0$ and $z = z_1$ plane, F[•] is the 2-D Fourier transform, $\mathbf{k} = (k_x, k_y)$ is the 2-D wavenumber vector and $z_0 > z_1$. Applying this equation repeatedly to the 2-D magnetic field data on 2-D planes with various inclinations, the 3-D distribution of the magnetic field data in regular region can be reconstructed.

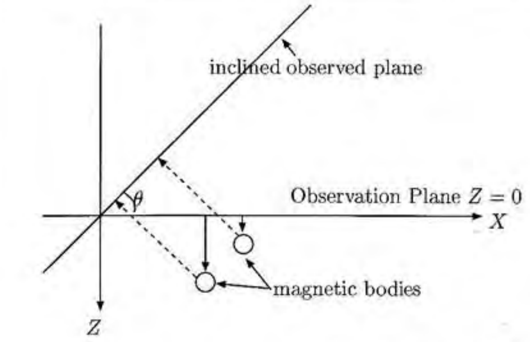
Assuming an appropriate plane in the 3-D space and applying the reduction to the pole technique to the reconstructed magnetic field data on the plane, we can estimate more accurately the shape of the magnetic bodies.

The Fourier spectrum of the magnetic field data produced by one magnetic body in logarithmic scale is presented as

$$\log | F [\mathbf{B}_{Z0}] | = - | \mathbf{k} | (z' - z_0) + Constant,$$

where z' is a depth of the magnetic body, z_0 is a vertical coordinate of the observation plane. Thus, we can estimate the depth of the magnetic body from the inclination of the logarithmic spectrum of the magnetic field data. However, if there are many magnetic bodies, it indicates only the depth of the shallowest body. In this study, the authors will propose the method to determine the depth of these magnetic bodies even if more than one magnetic bodies are buried in different depth. In a simple case that two magnetic bodies are buried in different depth, as the observation plane is inclined with angle θ, each distance between the observation plane and the magnetic bodies changes. At a particular angle θ', these distances are equal to each other. So, the depth of both magnetic bodies can easily calculate from the angle θ' geometrically.

For example, two magnetic dipoles are buried shown in Figure 1. The Fourier spectrum of the magnetic field data on $z = 0$ plane is shown in Figure 2. Figure 3 shows that the inclination of the logarithmic spectrum of the magnetic field data on the virtual observation plane varies as the inclination angle of the plane is changed every 1° between 40° and 50°. We can easily find a bending point at θ' = 45° in figure 3; then, we can estimate the depth of each body.



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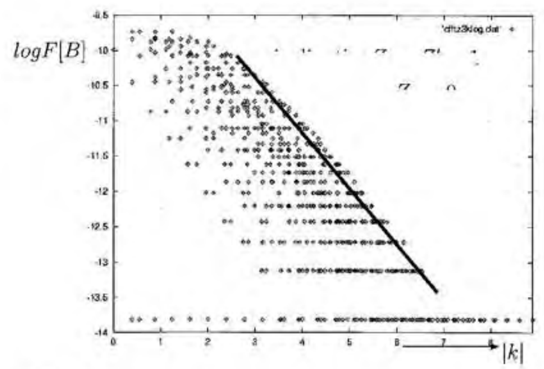

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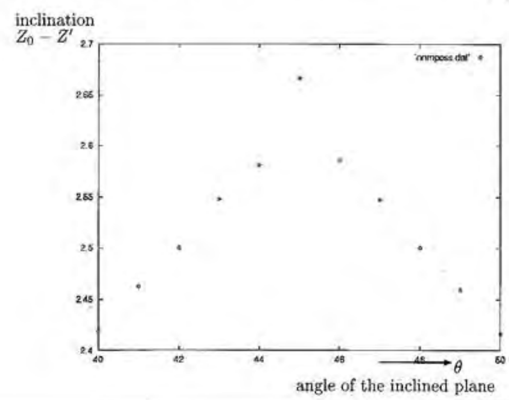

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Fig. 1. Simulated model for buried magnetic bodies

Fig. 2. Fourier spectrum of magnetic field data observed on z = 0 plane.

Fig. 3. Inclination of logarithmic Fourier spectrum of magnetic field data vs. angle θ of the observation plane

P. Mauriello, D. Monna, I. Bruner

Development of a System of Geoelectrical Data Acquisition and Elaboration

The aim of the paper is to illustrate a system of acquisition, elaboration and interpretation of data obtained by geoelectrical prospecting in the upper level of the ground for archaeological research. The energising equipment furnishes an A.C. sinusoidal current with frequencies between 40–380 Hz. The generator has been set with two tension outputs to utilise two different energising dipoles during the survey. In this way it is possible to elaborate data in a tensorial form to obtain apparent resistivity maps in conformity with the actual anomalies distributions. Measurements are taken over rectangular areas using two dipoles of different sizes which are fixed perpendicularly on a mobile frame. In this way, for each measurement point, it is possible to evaluate two different components of the induced field. (The current probes are kept in the same place while all the voltage measurements are taken in the chosen area). The method proposed allows the measurement to be taken quickly. No induction effects are shown in the cables at the above mentioned frequencies interval. The acquisition system is based on a PC with a 16 bits card, a filter-amplifier provides elimination of natural and artificial disturbances. Without filtering it is possible to acquire four temporal series obtaining SP and geoelectrical measurements. For each measured area a software was developed under the PC environment to perform the invariants map of the apparent resistivity tensor, directly in the field.

C. Meyer, E. Danckwardt

DC Tensor Geoelectrics – Now Applicable to Archaeological Prospection!

The combination of geoelectrical mapping and sounding using modern multi-electrode resistivity meters can give dense information about underground structures and layers. Usually axial electrode arrays – e. g. Wenner or dipole-dipole – are applied. A crucial disadvantage of an axial configuration is the bad resolution of complex 3D structures. Improvement may be achieved by application of square arrays. But geophysicists shouldn't stop halfway.

Only considering specific resistivity r as a tensor (r_{ij}) results in a real improvement of the resolution of square array measurements. Tensor measurements and 3D inversion allow a determination of boundaries of complex 3D structures – resistive bodies like air-filled cavities or foundations as well as conductive ones like fillings of pits, cellars or water-filled cavities.

Examples for model estimations by FD algorithms and tomographic inversion of the specific resistivity tensor show the large possibilities of DC tensor geoelectrics compared with conventional electrode arrays. A field example – the investigation of a gallery digged into a loess layer – is given.

W. Neubauer, A. Eder-Hinterleitner, P. Melichar

Large Scale Geomagnetic Survey of an Early Neolithic Settlement in Lower Austria (5,250–4,950 B.C.)

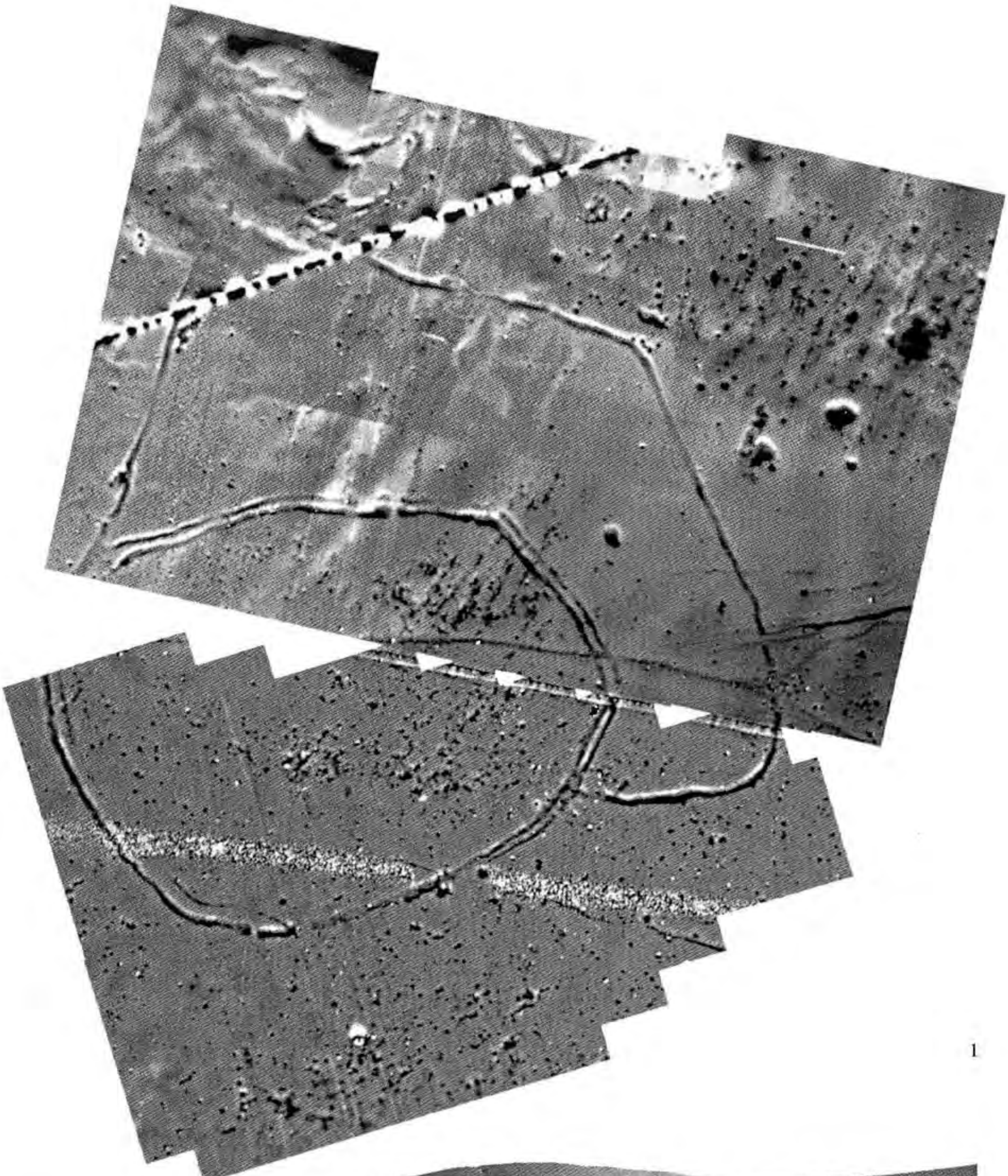
Asparn a. d. Zaya 50 km north of Vienna is a well known settlement from the Early Neolithic culture of Linearbandkeramik situated in loess soil with low susceptibility. The site was recovered by aerial archaeology and is already partly excavated by annual campaigns since over 15 years. The site covering 25 ha was magnetically prospected during the last years using cesiumgradiometers with 0.1 and 0.005 nT resolution. The latest surveys carried out with a multisensor caesium gradiometer in 0.5 x 0.125 m raster recovered typical remains of the Neolithic longhouses. Even the traces of single posts were resolved by the magnetics. The magnetic data (over 1.5 million readings) is visualised as digital image. For archaeological interpretation the data is resampled on 0.125 x 0.125 m raster and georeferenced using GIS software. The archaeological interpretation is done by thematic mapping and attributable description using the GIS ArcView.

The archaeological analysis of the geomagnetic evidence shows at least three main periods of occupation. Two of them were fortified by ditches 4–6 m width and up to 3 m deep. Several entrances inside the fortification are visible in the magnetogramm. The ditches form an oval central ditch system with an outer and an inner ditch which partly run in parallel and a trapezoidal enclosure appended in the north. Due to the high resolution of the magnetic data it was possible to interpret several typical longhouses of the Early Neolithic inside the plenty of pits of various size. The analysis of the orientation of the houses found by magnetics confirmed at least two periods. The settlement slightly moved from the bottom to the top of the hill. The excavation results showed the fortified settlements are the youngest. The occupation of the site dramatically finished 4,950 B.C. by a massacre as the remains of the killed inhabitants were found at the bottom of the ditches.

Occasionally an earlier settlement from the germanic period (200 – 400 A.D.) was detected at the lowest terrace of the river Zaya. The magnetic pattern of that settlement is clearly different from the Neolithic one. Several typical grubenhouses could be detected. The site of Asparn a.d. Zaya is already heavily eroded due to modern agricultural use as could be shown by aerial photographs, susceptibility profiles, the magnetic evidence and the excavation results. For the documentation of the rapid erosion process a partial remeasurement is planned after ten years.

Fig. 1. Magnetogram of the Early Neolithic settlement of Asparn a. d. Zaya; caesium gradiometer, area approx. 25 ha, raster 0.5 x 0.25 m and 0.5 x 0.125 m, dynamic range [-5.0,5.0] nT

Fig. 2. 3D visualisation of the digital terrain model of Asparn a. d. Zaya combined with the archaeological interpretation of the magnetic prospection data



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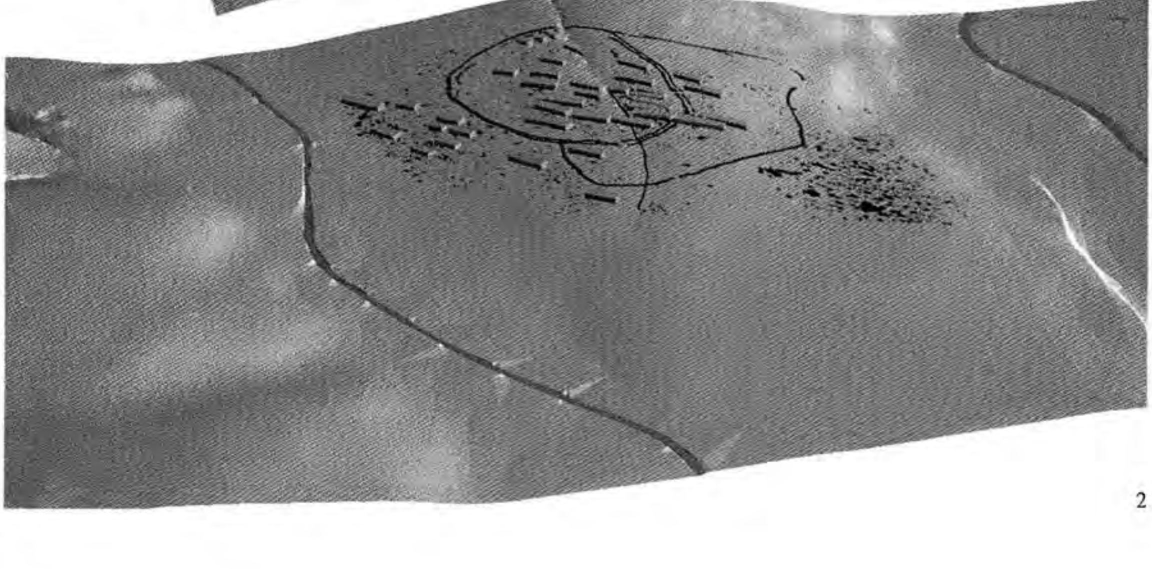

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W. Neubauer, A. Eder-Hinterleitner, M. Doneus, P. Melichar

Archaeological Prospection of the Middle Neolithic site Puch/Kleedorf, Lower Austria

The site of Puch/Kleedorf near Hollabrunn north of Vienna is known from aerial archaeology. It is situated on gravel and sand overlain by loess and covers 25 ha. The aerial evidence shows a lot of pits and two circular ditch systems. These circular ditch systems may be dated to the Middle Neolithic (4,800–4,500 B.C.). The archaeological remains show impressive polychrome painted pottery of the Lengyel culture. The most striking expression of the high cultural level of this farmer society are the monumental circular ditch systems situated inside large settlements. These oldest monumental buildings in Middle Europe are formed by up to three concentric circular ditches 40 to 180 m in diameter. The ditches are 4 to 8 m wide and always show a typical V-shape 3 to 6 m deep. They normaly have regulary situated interruptions, the entrance inside the monuments. The centre is enclosed by one to five rings of palisades but lack of any other archaeological remains which could help to understand their purpose.

The circular ditch systems Puch and Kleedorf are situated in closest neighbourhood. The distance of the centre of the double circular ditch system of Puch to the single one of Kleedorf is 260 m. They were magnetically prospected using high resolution caesium gradiometers. The site was archeologically interpreted based on GIS combining aerial photos and geomagnetics. The digital terrain model measured from the aerial photos was combined with 3D magnetic modelling results to produce a comprehensive reconstruction of the site using prospection results.

The magnetogram of Puch shows two concentric ditches with 83 m and 60 m in diameter, two entrances and the trace of an inner palisade enclosing a central area of 1,750 sqm. The southern part of the monument is already seriously destructed. The northern ditches are up to 4.5 m wide. The magnetogram of Kleedorf shows a single circular ditch 100 m in diameter formed by single segments of varying length. Again the centre is enclosed by a concentric palisade too. The central area of this monument measures 5,550 sqm exactly the overall size of the monument Puch. The segments of the ditch are up to 40 m in length and partly up to 6 m wide. All around the two monuments many pits could be detected by the magnetic survey as well as by aerial archaeology.

The site of Puch was selected as reference site for testing new magnetic equipment and processing methods. It could be taken out of agricultural use. The site was already prospected using various grids from 0.5 x 0.5 to 0.125 x 0.125 m, different gradients from 1.5 to 2.85 m, resolutions of 0.1 and 0.005 nT producing digital image representations for easy comparison of the various results. Further comparative work is planned including electromagnetic methods and GPR as well as further magnetic surveys carried out with other magnetometers by various prospection teams.

Fig. 1. Caesium gradiometer Picodas MEP750 at Puch/Kleedorf (Lower Austria); 3 sensors in 0.35 m and one sensor in 2.85 m above ground are mounted on a non-magnetic handcart measuring a 2.5 m gradient of the earth magnetic field with a resolution of 0.005 nT in a 0.125 x 0.5 m raster

Fig. 2. Magnetogram of the Middle Neolithic circular ditch systems Kleedorf and Puch and the surrounding areas; total area: 100,400 sqm; raster: 0.125 m x 0.5 m; dynamic range [-5,5] nT

Fig. 3. Archaeological interpretation of the double circular ditch system Puch.

Fig. 4. Archaeological Interpretation of the single circular ditch system Kleedorf

Fig. 5. Photorealistic visualisation of the reconstructed circular ditch system Puch; the depth of the ditches are modelled by the magnetically prospected data and intersected with the digital terrain model; the aerial photograph is draped on it

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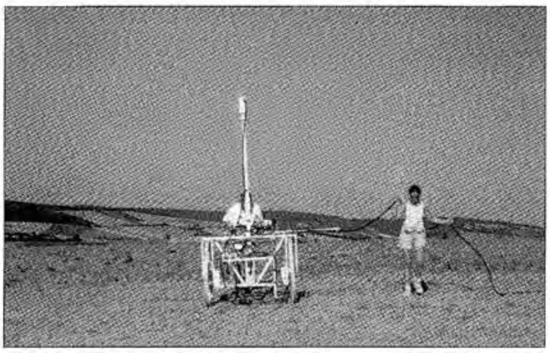

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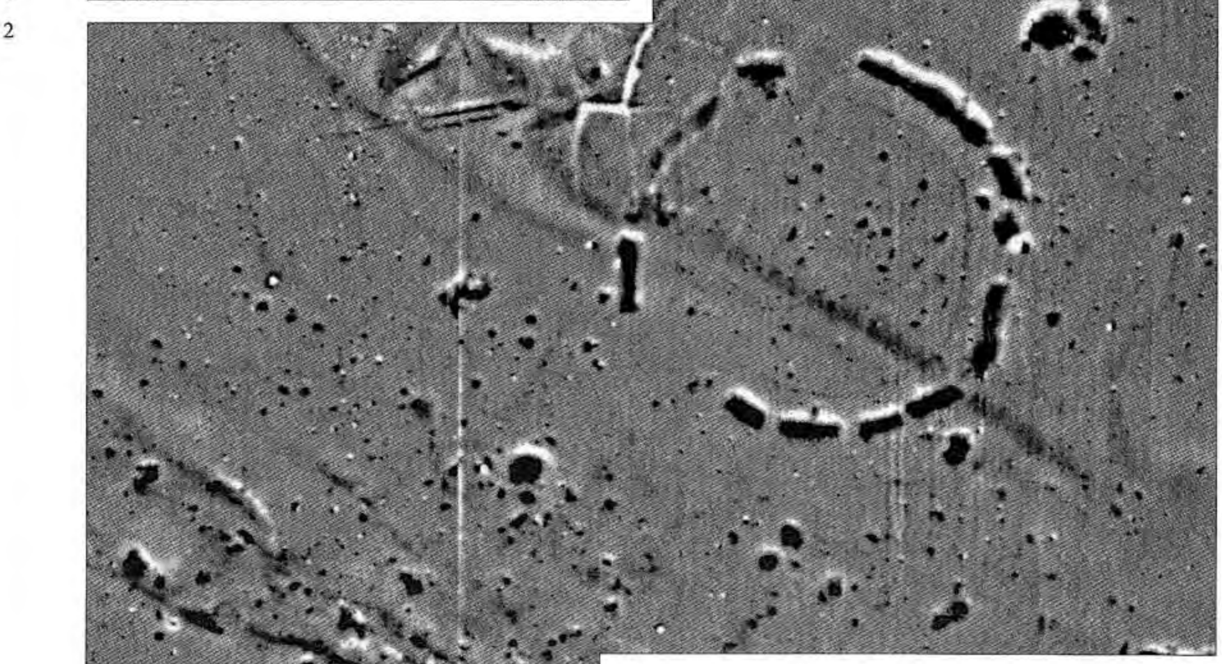

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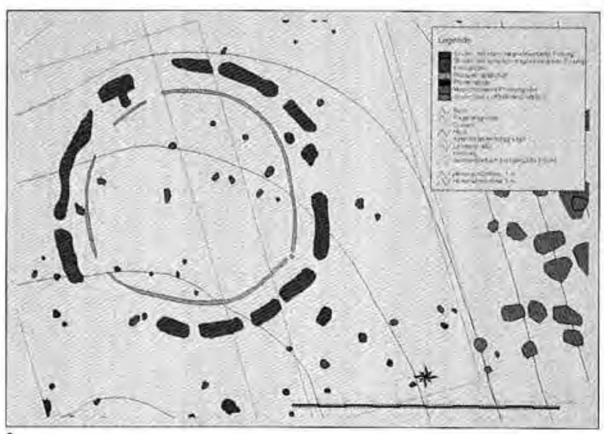

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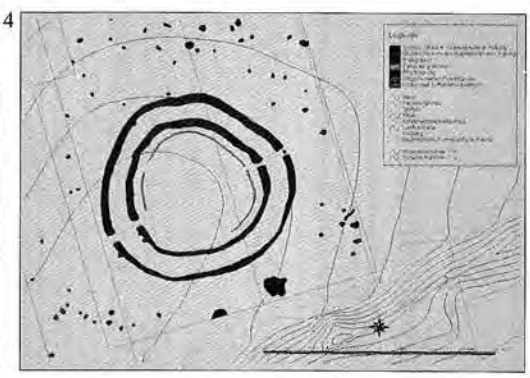

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W. Neubauer, A. Eder-Hinterleitner, S. S. Seren, P. Melichar

Integrated Geophysical Prospection of Roman Villas in Austria

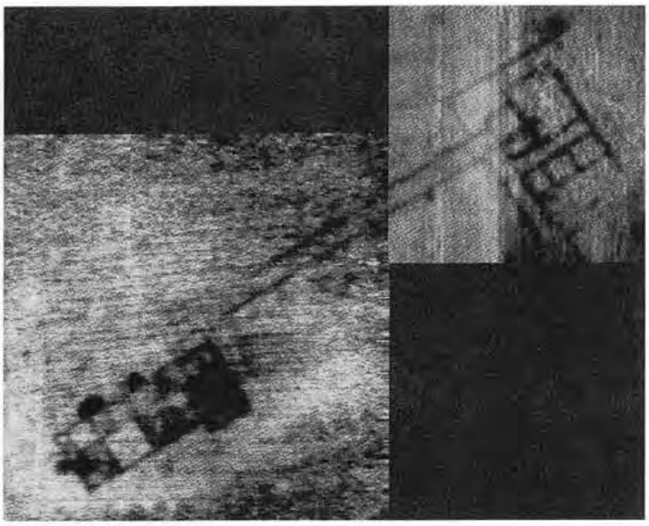
Geophysical prospection of Roman villas is one of the major interests of archaeologists working in the former Roman provinces Pannonia, Noricum and Raetia. We present various sites situated all over Austria in different geological context. All of them cover at least 3 ha and might be situated in grass land as well as ploughed fields.

The villas were prospected by an integrated approach using high resolution caesium gradiometers (0.1 to 0.005 nT / 0.5 x 0.125 m grid), multiplexed RM15 resisitivity meters (0.5 x 0.5 m grid, a = 0.5; 0.1 m) and PulseEKKO 1000 ground penetrating radar (GPR) (0.5 x 0.05 m. grid). Magnetics is mainly used to produce a large scale (> 5 ha) overview of the sites overall structure combining main buildings, economical buildings, roads, field system and the very often nearby cemetery. Selected parts of the magnetically prospected area indicating walls are additionally surveyed using resistivity mapping and/or high resolution GPR. As the resisitivity contrasts of walls are much higher than their magnetic contrasts they show up very clearly. GPR adds important 3D information on the detected buildings. GPR is adequately applied to this type of Roman monuments i.e. data is measured in 0.5 x 0.05 or 0.5 x 0.1 m raster using 450 MHz or 900 MHz anntennas and with digital recording of the data. While magnetic and geoelectrical methods are standardly applied and widely accepted, the archaeological application of GPR still suffers from insuitable survey logistics, data processing, visualisation and interpretation techniques. The theoretically high archaeological potential of the method so far could not be presented to the archaeologists convincingly. GPR produces large amount of data with high information density. Visualisation of data mainly is done in B&W or colour coded representations of received amplitudes by time and distance in single sections known as "radargram". These representations of single sections show typical diffraction and reflexion patterns and are not easily understandable. One even could assume that it is nearly impossible for lay-men or unexperienced archaeologists to interpret anything in such a radargram. To use the high archaeological potential of this method new techniques of processing are necessary for producing objective and reproducible results. One of this techniques is the use of horizontal time slices as regular GPR data representations. Such a time slice is created by summarizing (or averaging) the reflected energy of the radar waves over a time window at any discrete reading of the regular or irregular measurement grid. We consequently propose here the use of a 3D data block of summarized amplitudes. This block might be cut through in any horizontal or vertical direction. The pile of horizontal time slices from GPR data might be animated for exploring the data. Magnetic, resisitivity and GPR data are visualised accordingly as digital images and combined in a GIS for archaeological interpretation by thematic mapping and attributal description. Based on the archaeological evidence derived from the combined interpretation of the geophysical results we produce a 3D archaeological reconstruction of the roman villas, presenting a comprehensive archaeological interpretation model. These models based on geophysical prospection data might also be animated producing understandable presentations of our heritage concealed beneath the surface for archaeologists as well as lay-men.

Fig. 1. Resisitivity map of a Roman villa rustica at Altheim-Weirading showing the main building and the nearby bath

Fig. 2. GPR time slices of a Roman villa suburbana near Oviavum/ Wels

Fig. 3. 3D visualisation of the villa rustica at Altheim-Weirading based on prospection results



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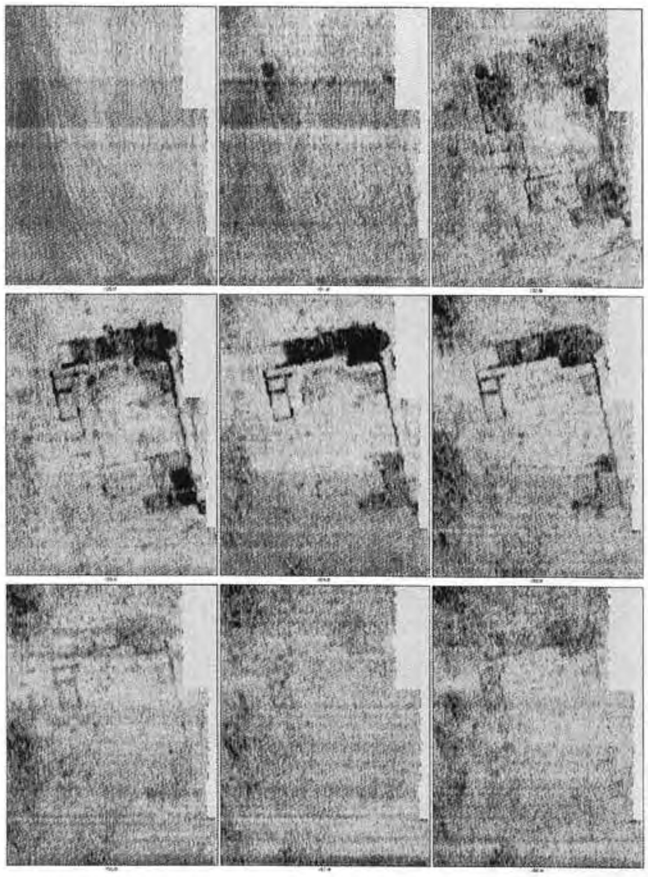

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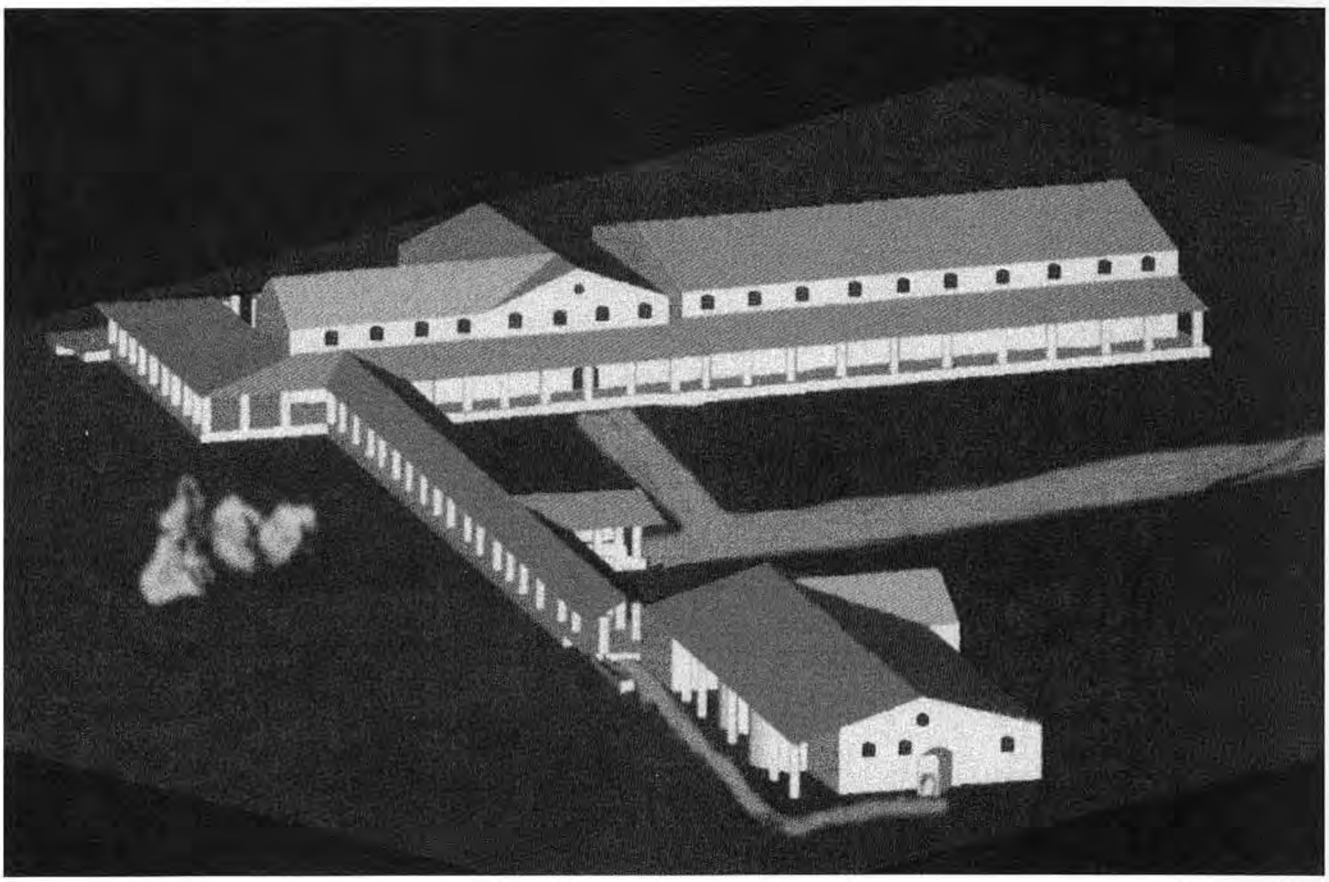

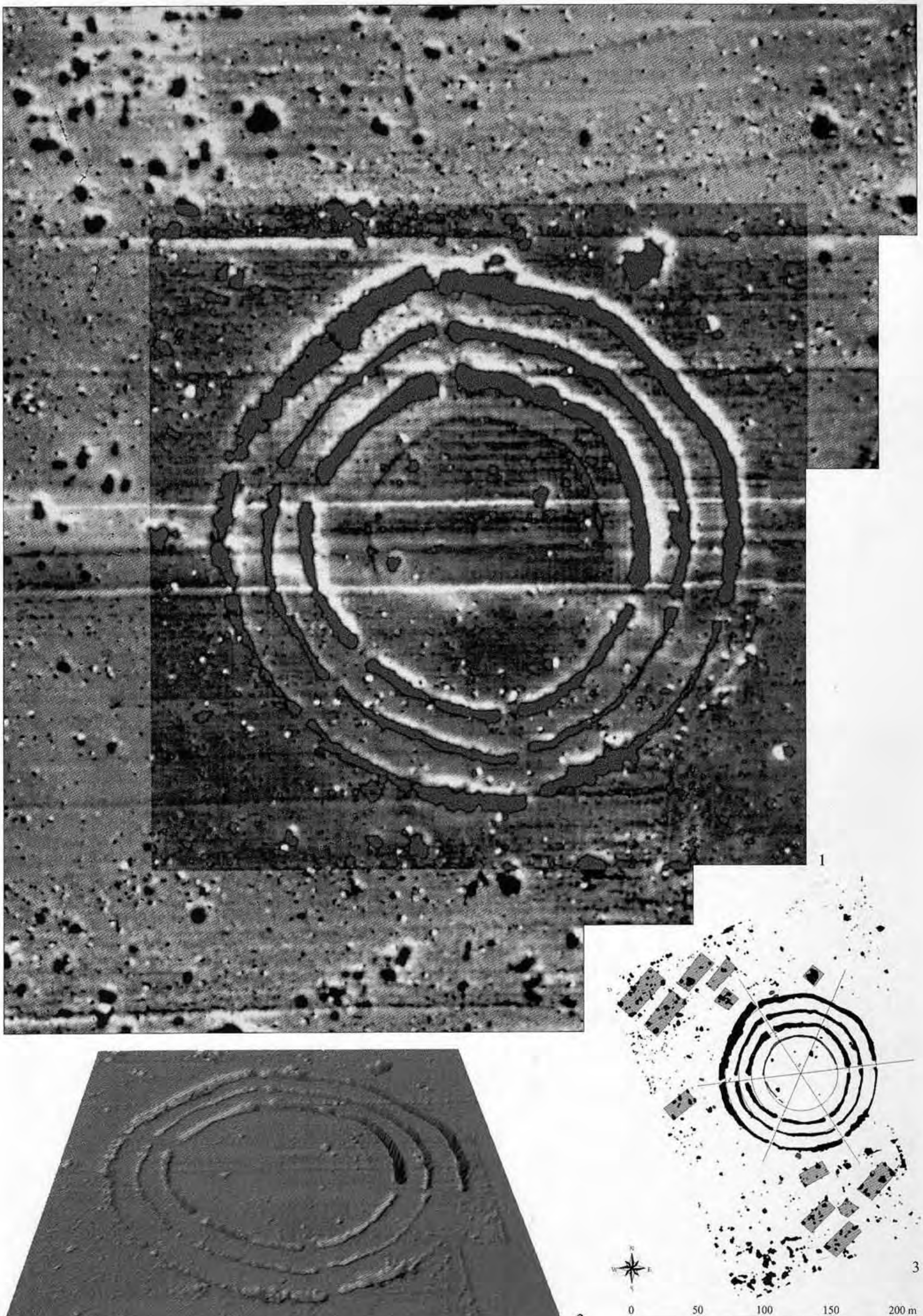
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W. Neubauer, A. Eder-Hinterleitner, P. Melichar

Geomagnetic Survey of the Middle Neolithic Circular Ditch System Glaubendorf II, Lower Austria

The circular ditch system of Glaubendorf II was detected by aerial archaeology and is situated north of Vienna in Lower Austria. The monument lies on a slightly sloping terrace of the river Schmida. The site situated in loess soil is already heavily eroded. A first interpretation of the aerial evidence showed three concentric ditches and six regular entrances were suggested. A first archaeological excavation in 1986 opening a small 70 m trench proved the triple ditch monument with a single inner palisade as to date to the Middle Neolithic (4,800–4,500 B.C.).

Fig. 1. Magnetogram of the Middle Neolithic circular ditch system Glaubendorf II and the surrounding area; caesium gradiometer 0.35–2.85 m, area: 42,800 sqm; measuring grid: 0.125 m x 0.5 m; dynamic range [-3,6] nT

Fig. 2. 3D Visualization of the reconstruction of the Middle Neolithic circular ditch system Glaubendorf II. The reconstruction is based on an archaeological model of the filled ditch with four differently magnetised layers. The resolution of the reconstruction is 0.25 x 0.25 m and 10 cm in depth

Fig. 3. Archaeological interpretation with hypothetical houses (shaded grey). The ditches have diameters of 71 m, 90 m and 109 m and are between 3.5 m and 4.5 m wide. Inside the ditch system there are the remains of a palisade that has a diameter of 53 m.

The site was magnetically prospected in spring 1998. The magnetic survey covered 4.28 ha and was measured in a 0.5 x 0.125 m raster using a PICODAS MEP750 multisensor cesium-gradiometer with 0.005 nT resolution. The magnetic data was visualised as digital image and georeferenced for archaeological interpretation. The digital image representation shows a triple circular ditch system surrounded by various pits indicating the last remains of the former settlement. The circular ditches with diameters of 71.90 and 109 m are 3.5 to 4.5 m wide. They are interrupted by five entrances. The monument was actually constructed on a regular hexagon, but the sixth entrance was only built on the inner ditch and was dug through later. This could be shown by 3D modelling of the ditches and the according 3D reconstruction of the monument. In the centre a 2,000 sqm free area was surrounded by a palisade 53 m in diameter with only two entrances in the east and in the west. The palisade is only partly visible in the magnetogram due to erosion. In magnetics the area already excavated in 1986 no longer shows the traces of the palisade. Looking at the excavation results we have take in account a mass of at least 40 cm eroded during the last 12 years. Due to this rapid erosive processes geomagnetics is the only way for the documentation of these oldest monuments in Middle Europe. More then 30 of them are situated in the Eastern part of Austria and half of them still awaiting geomagnetic prospection.

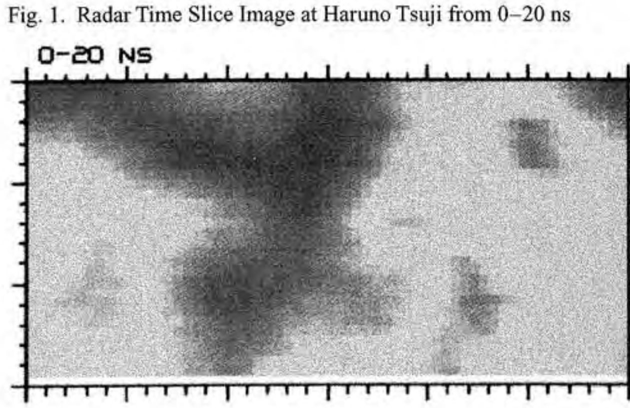
Y. Nishimura, D. Goodman

A trial GPR Survey for Accomplishment of Deeper Penetration in Wet Soil Conditions

In the GPR method, the penetration of microwaves strongly depends on the soil conditions, and especially on the soil wetness. Soil wetness increases conductivity and thereby attenuates propagating radar waves. For accomplishing deeper penetration, an experimental survey has been carried out on Iki-Island, Japan, at a site where a channel was constructed 2,000 years ago for connecting a small port to a river. The channel is currently buried in a highly water saturated paddy field by up to 3 meters of soil. The soils currently within the buried channel and those buried below the channel floor are both primarily clayey wet soils.

A GPR survey using a 400 MHz antenna and a recording window of 200 ns was conducted on the site. The effective depth of relatively noise free reflections was down to about 100 ns or 3 meter depth. Special gain settings for the recorded signals and post-processing filtering of the radargrams was performed on the data prior to applying time slice analysis.

Fig. 1. Radar Time Slice Image at Haruno Tsuji from 0–20 ns



For helping to corroborate the GPR results, EM methods were used as a comparative study. The results using EM31 instrument with a 3.6 meter coil spacing show very similar results recorded on GPR time slices between 80–100 ns.

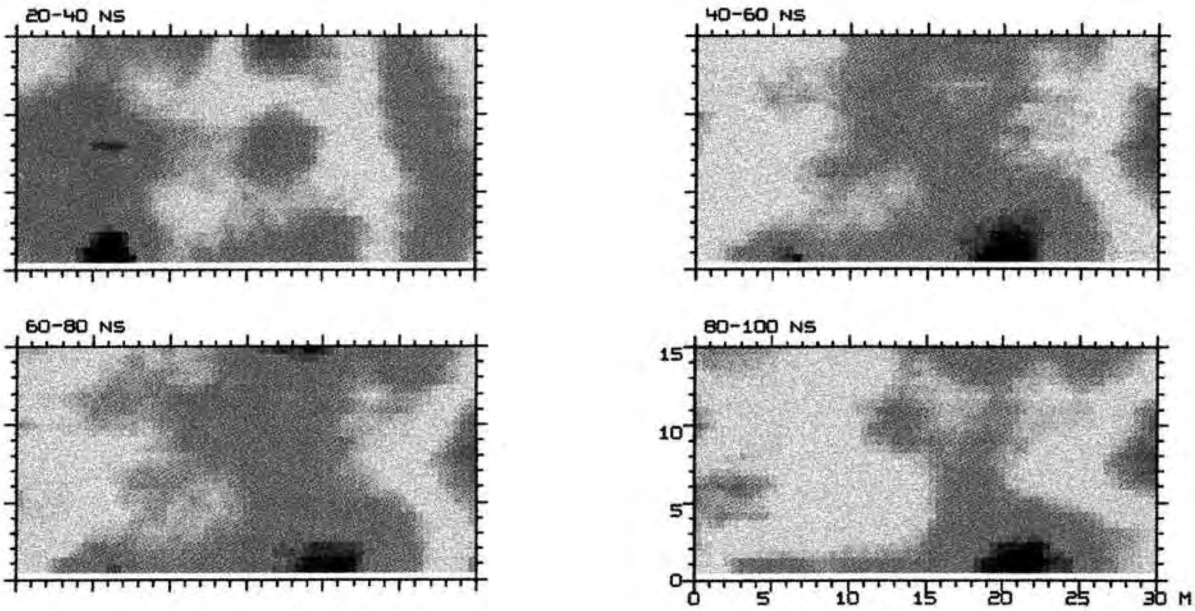


Fig. 2–5. Radar Time Slice Images at Harunotsuji from 20 to 100 ns

J. Orbons

Prospecting Roman pottery industries in the Argonne, France

The Argonne is a region in the north-east of France that is very well known for two reasons. First of all, it was an industry of Roman-age terra sigillata slipware, secondly the region was ravaged in the First World War. The area covers about 700 square kilometres and has several valleys running roughly north-south that cut through a chalk bedding. The French government has plans to develop the region. Prior to the development a large scale archaeological prospection took place. It was coordinated by Sander van der Leeuw from the University of Paris. The work started in the summer of 1996 and was finished in the autumn of 1998 covering 6 field-campaigns of one month each.

The work was carried out at 4 levels.

- Desktop analyses by importing a wide range of information into a GIS system. Geological maps, height-models, hydrological information, previous finds etc, etc, were all analysed.
- Field-walking was carried out at sites selected by the desktop analyses, producing many potentially new locations of Roman-age pottery ovens, but also locations of Roman settlements and road-structures.
- Geophysical surveys were carried out at sites discovered in the field-walking that looked promising for a close inspection.
- Pottery analyses produced additional information like dates and technical information on the pottery industry.

The results from the field-walking, the geophysical surveys and the pottery analyses were then imported back into the GIS, so a new analyses could be carried out. These new analyses were then used to guide the following field walkings and geophysical surveys. This iterative process made sure that a full representative sample of the region was prospected taking geology, hydrology and height into account.

A total of 7.5% of the 700 square kilometres were field walked, 32 sites were surveyed with geo-electrical and magnetic measurements covering a total of 47 hectares. With the help of students from the University of Utrecht, Department of Geophysics and the University of Patras in Greece, some geophysical experiments took place at several sites, trying to extract as much archaeological information from the discovered sites as possible. Many of the measured sites were also augered and the combination of the multiple measurements and the augering resulted in some remarkable archaeological information on the oven-sites.

Due to the integrated techniques and zooming in from large-scale surveys into close detailed inspections, a result was obtained that offers a good insight in the archaeology of the complete region.

J. Orbons

Archaeological Pioneering Prospection in Rumania

The Roman province of Dacia was occupied by the Romans for about 150 years. During these years the province was the northern frontier and therefor very well guarded with Castella and wall-ditch systems.

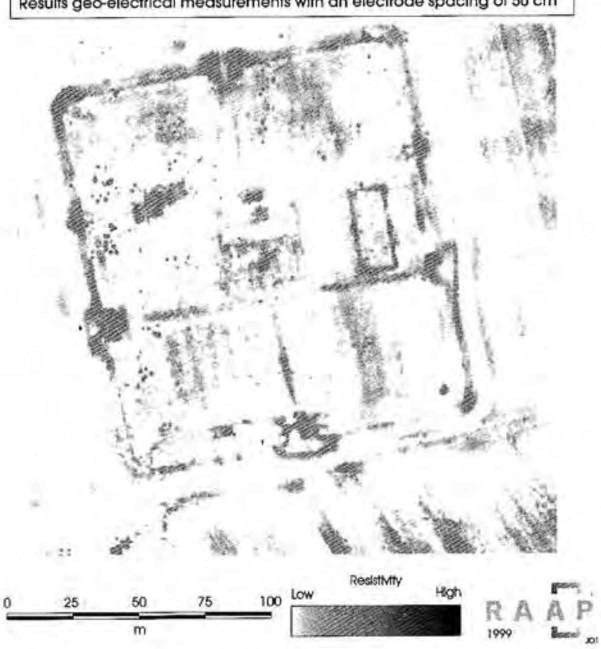
The University of Nijmegen in the Netherlands was invited by the Museum of Art and History in Zalau, Rumania to carry out a pioneering archaeological prospection. Two sites were selected for the fieldwork: the Castellum of Tihau and the Roman city of Porolissum.

The Castellum was selected because previously some roof-tiles were found at the site carrying the markings of the "Cohors I Cananefatium", Dutch tribal auxiliary forces in the Roman army, therefor linking the Roman history of this Castellum to todays Dutch University of Nijmegen. Furthermore, previous trial-excavations proved that the site was relatively undisturbed and offered good opportunities for an extensive prospection.

The city of Porolissum was selected because it has a vast fort and a civil Vicus of unknown size. Small trial-trenches covering a wide area prove that it must have been a very large city, but so far the full extent is still unknown.

The work consisted of height measurements, field prospection, augering, trial trenches and geophysical measurements. Geophysical measurements were carried out by RAAP-archaeological consultancy with the assistance of two students from the University of Utrecht, Department of Geophysics. The methods used were geo-electrical and magnetic measurements using Geoscan equipment.

Roman Castellum Tihau, Rumania
Results geo-electrical measurements with an electrode spacing of 50 cm



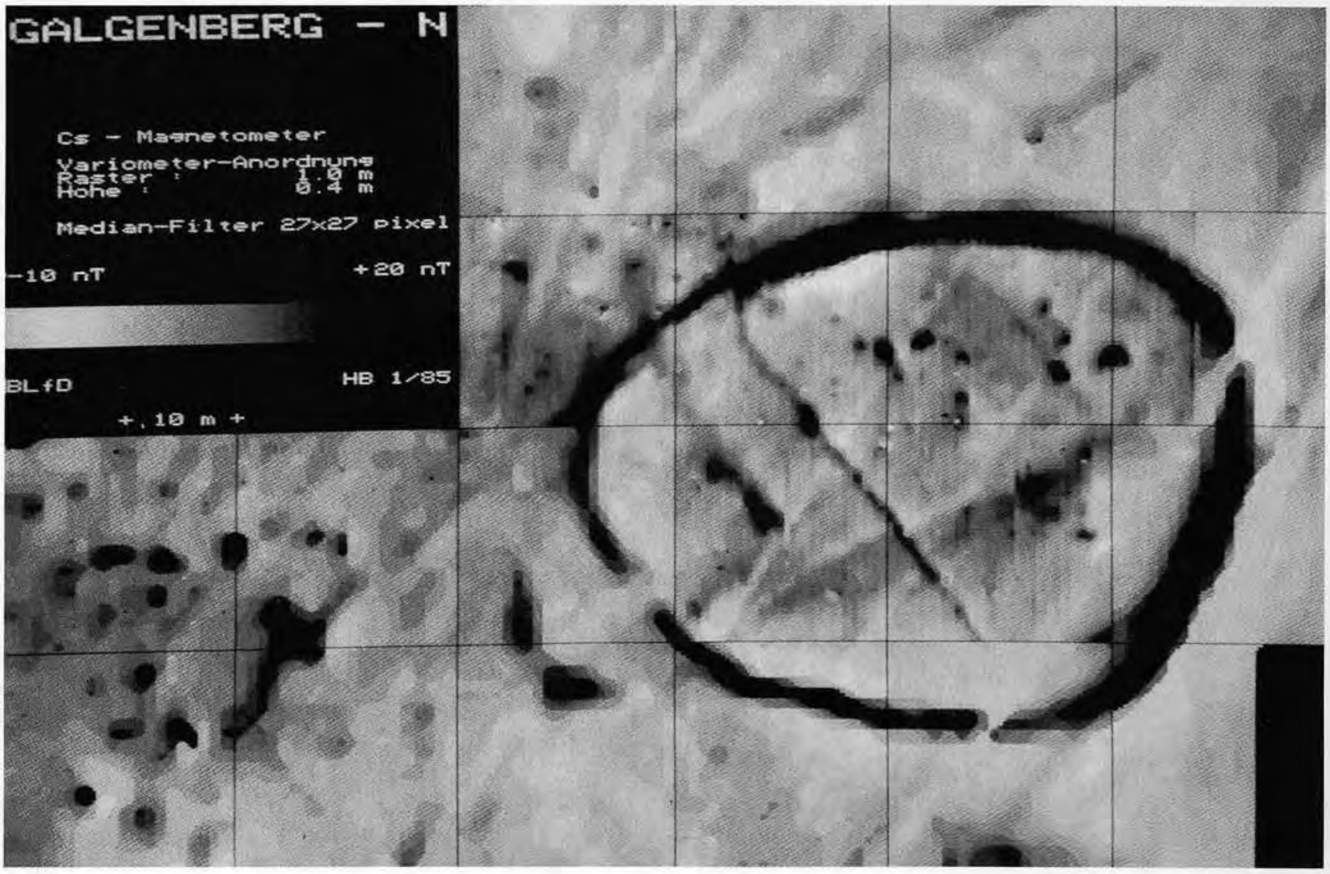
At the Castellum of Tihau the prospection resulted in a clear image of the construction of the castellum and the building within the castellum itself. The geo-electrical measurements show nicely the rectangular stone constructions of the wall with rounded corners, the gates and defensive towers, the roads, the horreum, the principia and the praetorium. Remarkable information was obtained from the difference between the geo-electrical measurements with an electrode spacing of 50 cm and the geo-electrical measurement with an electrode spacing of 100 cm. Some structures like the praetorium only show up at the 50 cm level, but the gates and the food-storage show up in both. The magnetic measurements show clearly the wooden barracks structures and some ovens lying outside the castellum. Due to the usage of multiple techniques, additional archaeological information was obtained and this fortress can be considered as one of the best studied Castella in Dacia.

The figure shows the result of the geo-electrical measurement with an electrode spacing of 50 cm.

The results in the city of Porolissum were not as clear as expected. Some linear structures could be interpreted as roads, some structures might be related to houses. The very steep slope of the hill is certainly to blame for the blurry images.

Fig. 1. Galgenberg-Kopfham; aerialphoto of soilmarks of a ditch system after first ploughing at the Galgenberg near Kopfham, Lower Bavaria (Photograph O. Braasch from 04.01.81, Archivnr. 7538/040; SW229-16)

Fig. 2. Galgenberg-Kopfham; magnetogram as digital image of the first use of caesium.magnetometry in Bavaria in 1981; caesium-magnetometer Varian V101 in variomater mode, sensitivity 0.1 nT, raster 1.0 to 1.0 m (interior area with 0.5 to 0.5 m), dynamics -10.0/+20.0 nT in 256 grayscale (white/black), 10 m grid, north to the right, Mag-nr. 7538/40-85B



B. S. Ottaway

Archaeological Relevance of Cs-Magnetometry

Aerial survey and field walking of a freshly ploughed field lead to the discovery of a new site in 1981: the Galgenberg near Kopfham in Lower Bavaria. To find out more about the size and extent of the site a survey was carried out by Dr. Helmut Becker of the Bayerisches Landesamt für Denkmalpflege, Munich, using for the first time in Europe the highly sensitive caesium magnetometer. The measurements, taken manually at 1m intervals, indicated complex ditch systems with several features inside and outside the enclosures. The main, oval enclosure seemed to have one entrance with foreworks lying directly in front of it. It was this plan that guided our subsequent excavations at the Galgenberg for the next nine years.

A subsequent caesium magnetometer survey, taken semi-automatically at 0.5 m intervals with digital graphic evaluation, gave a much more detailed picture of the main enclosure. Constant comparison of excavation and caesium magnetometer results led to improved, fully automated data collection and digital evaluation now widely used by Becker and his team. This method was used to produce a survey covering a large area on the Galgenberg, indicating the presence of at least six enclosures, which might otherwise have remained undetected.

Although the magnetometer survey had provided the 'blue print' for the excavation it was only by excavation that the full extent of the complexity of the prehistoric remains and their relationship to one another became clear (Ottaway, 1999). For instance, the forework to the entrance, suggested by the caesium magnetometer survey to be a relatively simple structure, had undergone at least three major structural changes. These had transformed the entrance from one surrounded by a cluster of square features to an entrance which was most probably embellished and strengthened by two forework buildings which were arranged in such a fashion that entry into the enclosure was by two or three relatively narrow gaps left between the forework structures and the ditch. Entry into the enclosure was much more controlled than before and could, if necessary, be defended easily and effectively. The forework and some of the structures around the terminals of the ditch had been whitewashed, which must have given additional visual impact. The result must have been imposing, restricting vision and movement into the enclosure. It was more of a statement of control, protection and defence than it had been for previous generations.

Deposits in many of the other features inside and outside the enclosure speak of phases of decommissioning and deliberate deposition of artefacts, followed by destruction horizons and a shift in the nature of deposits.

To conclude, only through the complementation of prospection and excavation can the full picture of the prehistoric landscape and the sites contained therein be explored.

Reference

B. S. Ottaway 1999. "A Changing Place. The Galgenberg in Lower Bavaria from the fifth to the first millennium B.C.", *BAR International Series* 752

A. E. Patzelt, M. Waldhör, B. Greiner

Resistivity and GPR Survey of two Early Mediaeval Grave Yards in Southern Germany

Introduction

The routine application of geophysical prospection for archaeological subsurface structures have been established during the last decades. Major benefits arise from the *fast and non-destructive* documentation of archaeological objects even on large areas. Most common, magnetometer surveys with hand held fluxgate magnetometers are carried out. Beside this, resistivity, electromagnetic and ground penetrating radar (GPR) measurements are used, when investigation sites are not suitable for a magnetic survey.

Here we want to present the results of two surveys on Early Middle Aged yards in the cities of Weinstadt and Kirchheim/Teck (Baden-Württemberg, Southern Germany). Both sites have been investigated with resistivity meters and GPR, respectively. In general the survey of single graves is relatively difficult, as the objects are quite small and the physical contrast to the surrounding subsoil is often very low.

Survey in Weinstadt – stone-lined Merowingian graves

A field of about 5,000 sqm was investigated for stone-lined graves, which were suspected due to some earlier archaeological investigations. Resistivity and GPR measurements have been carried out, as both methods seemed to be suitable to detect single graves, lined or covered with limestone rocks, in loess ground. An earlier magnetic prospection with a fluxgate magnetometer (FM36, Geoscan) yielded no results on archaeological structures due to the local soil conditions.

The GPR survey with a 400 MHz bistatic antenna (Ramac GPR, Mala) on part of the area yielded no clear results. Hence, the total area was measured with a resistivity meter (RM15, Geoscan). We used the standard Twin Probe configuration with a mobile probe spacing of 0.5 m. According to the small scale of the archaeological objects a narrow sampling interval of 0.5 x 0.5 m was chosen. It was expected that limestone rocks (marking single graves) in conductive loess soil corresponded with relatively high resistivity values. Figure 1a shows the result of the resistivity survey, together with the location of later excavated stone-lined graves. The data quality of the survey is less good in the eastern part of the investigated area due to the rough terrain there. Several small areas with local high resistivity values (Fig. 2) occur in the middle and the east. Most of these areas correspond with a stone-lined grave, as the later excavation has shown. However, the graves without a stone frame were not detectable by the resistivity measurements. Although the resistivity survey was not able to resolve all stone-lined graves, the approximate position and extension of the grave yard was recognizable from the resistivity survey. Hence, the geophysical prospection has been a helpful tool in planning and execution of the archaeological excavation. An excavated Early Middle Aged stone-lined grave is shown in Figure 2.

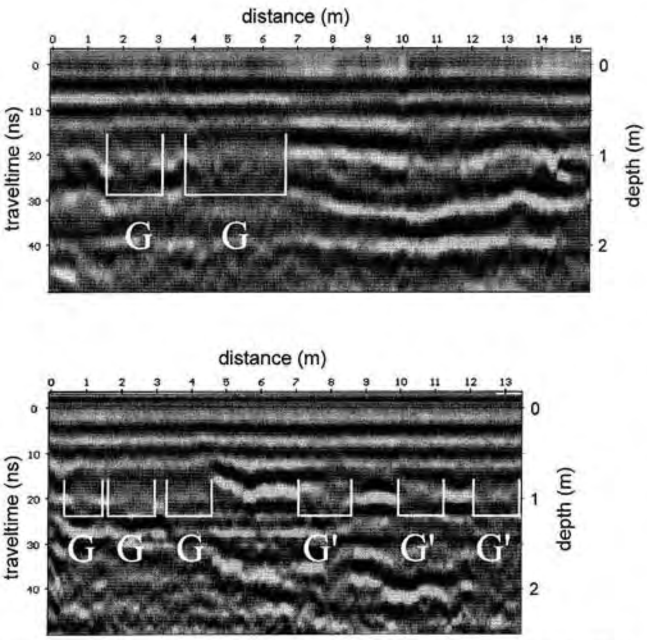


Fig. 1. GPR profiles (400 MHz) at the location of Kirchheim/Teck. Upper profile: Two known graves are located at profile coordinates of about 1.5 m to 7 m. Depth of the graves is approximately 1m. To the right undisturbed sedimentary layering is recognizable. Lower profile: At profile coordinates 0.3 m to 4.5 m three graves are located. Indications for the position of three additional graves are given at a distance of 7.2 m–8.5 m, 9.8 m–11.2 m and 12.0 m–13.5 m, respectively. G: known grave, G': grave suspected according to the radar data and confirmed by later excavation.

Fig. 2. Processed resistivity values and location of subsequent excavated stone-lined graves at the location of Weinstadt. Relatively high resistivity values often correlate with limestone-lined graves in the loessy ground. Hence, the center of the Early Middle Aged grave yard could be detected by the geophysical measurements. However, the single stone-lined grave in the west could not be recognized from the resistivity measurements ▷

Survey in Kirchheim/Teck – Alemanian graves

The investigation area, a meadow of approximately 1,400 sqm, is located in the inner city of Kirchheim/Teck. The area is part of a large Early Middle Aged grave yard, and over 100 single graves have been found at building sites in the vicinity. Magnetic measurements could not be carried out, as the area was partly lined with a several meter high metal fence. Hence, a resistivity survey (RM15, Geoscan) of the area in Twin Probe configuration with a sampling interval of 0.5 x 0.5 m was carried out. According to the expected depth of the graves (0.7 m–1.0 m) a spacing of 1.0 m for the mobile probes was chosen. However, from the resistivity survey only gross geologic features (changes in thickness of the alluvium) could be recognized. No indication on archaeological objects could be obtained, while the subsequent following excavation yield several graves at the investigated area. While the archaeological excavation was in progress, GPR measurements with a 400 MHz bistatic antenna (Ramac GPR, Mala) was performed over partly excavated graves. A radar profile over two known graves is shown in Figure 1 (upper profile). At the right half of the GPR profile undisturbed, continuous sedimentary layering is visible. The graves clearly show up as zones of weak reflection with the sedimetary layering being interrupted. This pattern was assumed to be typical for graves at the local geologic conditions and further GPR measurements have been performed in the nearest vicinity of the excavation. Indications for additional graves were found at several locations, an example is given in Figure 1 (lower GPR profile).

Summary

In principle, resistivity and GPR surveys are suitable for the detection of graveyards or even single graves. However, graves without a stone frame or stone cover might not be visible in resistivity measurements. Surveys have be carried out with a high sampling interval and test measurements over already known graves are helpful. Nevertheless, the success of a survey still strongly depends on the local geologic conditions.

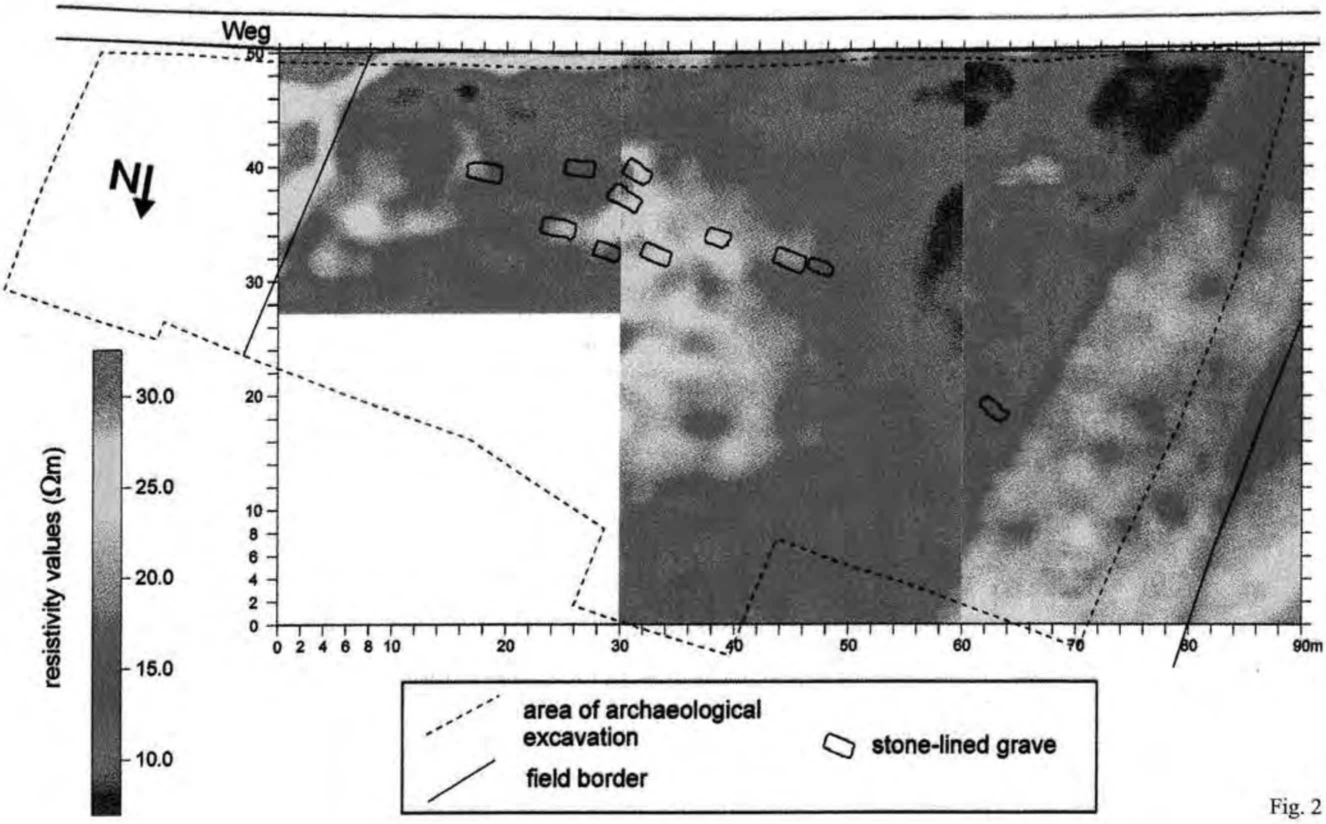
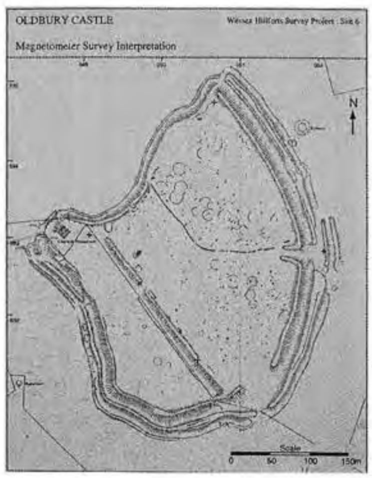


Fig. 2

A. Payne

Functional Variability in Wessex Hillforts : New Evidence from Geophysical Survey

Hillforts have attracted archaeological interest for much of this century, and debate on their function and significance continues to be central to the academic study of the Iron Age. The term hillfort covers a multitude of different types of site and their varying sizes, morphologies and situations strongly suggest a range of different functions. Reliable interpretation of the role of hillforts in Iron Age society continues to be hampered by the small number that have been extensively examined archaeologically. Despite major investment in excavation of hillfort sites in Central Southern England, even here the majority of sites still remain a poorly understood resource.



Two years ago a major programme of archaeological geophysics was started by English Heritage in partnership with Oxford University to investigate a wideranging sample of hillforts (20 sites in total) in the dense hillfort zone of Wessex. The project was

designed to build on the potential of rapid magnetometer survey for investigating hillfort interiors on chalkland geology shown by earlier surveys at sites such as Maiden Castle and in the Danebury Environs.

The project aims were to:

i) better define and assess the archaeological resource preserved inside hillforts in order to help guide future management and conservation initiatives and
ii) expand the presently limited extent of our understanding of hillfort interiors across a single region.

The project has revealed a wealth of new evidence for the nature of the internal utilisation of Wessex hillforts. While supporting some of the existing models of hillfort development, the surveys also show that the pattern is considerably more complex and varied than previously realised. A complete set of results from the project will be presented publicly for the first time and their interpretation discussed (discussion of significance of the results among participants will be very welcome as their interpretation is currently only at a preliminary stage)

If time permits, Wessex hillforts will be contrasted with geophysical results just obtained from the concentration of hillforts around the foothills of the Cheviots in the Northumberland National Park. The different geophysical approaches required to optimise the information recovered from these sites (of intrinsically different character to their Wessex counterparts) by nondestructive means will briefly be discussed.

C. Peters, M. Church, C. Mitchell

Investigation of Hearth Fuel Sources on Lewis Using Mineral Magnetism

As part of a wider research progamme of experimental archaeology at Callanish Farm, Isle of Lewis, Scotland, a number of experimental hearths were constructed, based on excavated evidence from the Late Iron Age houses at Bosta. Controlled and repeated burning of different fuel sources, for example well-humified peat, fibrous-upper peat, peat turf and wood was carried out over a number of burning episodes of three day durations.

A range of mineral magnetic measurements, including remanences and the variation of susceptibility with high temperature, were taken from the resulting ash samples. The high temperature susceptibility measurements show that the fibrous upper peat and peat turf have a single magnetic component, with loss of susceptibility between 570 and 600 °C. In comparison the well-humified peat and the wood display a loss in susceptibility at significantly lower temperatures, with many samples having two distinct magnetic components. Stepwise discriminant analysis was performed on the room temperature magnetic data. A biplot of the resulting two main variables distinguishes between the four different sources.

Magnetic measurements were also carried out on hearth samples from two archaeological sites, Galson and Guinnerso, on Lewis. Comparison was made to the ash samples in order to determine if the fuel sources could be identified. Both the high temperature susceptibility curves and the discriminant analysis suggest that for the two selected sites the predominant fuel source was well-humified peat.

C. Peters, C. Batt, R. Thompson, I. Dewar, G. Wilmot

Mineral Magnetic Study of Enhanced Soils from Old Scatness Broch, Shetland

Measurements of in-situ and laboratory-based magnetic susceptibilities on material from the multi-period Old Scatness Broch site on Shetland, Scotland have indicated greatly enhanced soils. The enhancement in susceptibility is associated with midden deposits and is over one hundred times the susceptibility of surrounding deposits. In order to understand the origin of the enhancement and suggest causes for it, investigations were made to determine the nature and extent of the magnetic grains within the soils. A range of laboratory-induced remanences and susceptibilities, including the variation of susceptibility with high temperature, were measured on samples from three different areas within the site: 1) 67 samples were taken from two horizontal profiles through midden deposits within a circular post-broch structure.

Discrete layers of deposition were visible within the midden. These midden deposits gave exceptionally high in-situ magnetic susceptibility values. 2) Five samples were collected from midden material deposited within a Pictish structure. 3) 88 samples were collected from a continuously sampled (at 2 cm intervals) profile within a pit dug on the outskirts of the main settlement area. The profile extends through layers of midden, soil and sand material.

In addition to determining the magnetic mineralogy and domain state of the magnetic grains, the magnetic data is also being used to compare between the different groups of material to gain an insight into changes in anthropogenic activity through time. For example, differences between the midden material collected from the circular structure and the midden material from within the Pictish structure are being investigated, which could give information on variations of fuel sources, industrial activities or burning processes between different periods.

C. W. Pierce, C. A. Shell

Three Dimensional Geophysics and Visualisation

Ground penetrating radar (GPR) and resistivity profiling provide potential routes to the generation of full three-dimensional geophysical models of buried archaeological sites. This paper reports on the development of field methodology for these two techniques in southern England, with the investigation of appropriate data processing procedures and the visualisation needs for presentation of the results in a form comprehensible to the archaeologist. These three interdependent aspects will be discussed with data examples drawn from a set of sites selected to give a broad range of site and sediment characteristics, including buried sarsen (quartzite) stones in the West Kennett Avenue, Avebury, a sarsen-chambered neolithic long barrow with chalk mound, and the brick foundations of a late 15th Century Hall. The importance of appropriate procedures for topographic correction is emphasised, particularly where simple correction algorithms available in commercial software are limited in their applicability. Animation has a potentially significant role in the visualisation of multi-dimensional data, especially where data are available from complementary resistivity and GPR surveys.

M. Posselt, B. Zickgraf

Geophysical Prospection of Linearbandkeramik Sites in the Landscape Archaeology of the Western Wetterau and the Usinger Becken, Hesse, Germany

The Linearbandkeramik is the culture of the earliest farmers in Central Europe (5,500–4,900 B.C.).The project "Bandkeramik Settlement History in the Mörlener Bucht"of the Johann Wolfgang Goethe-Universität Frankfurt/M. has the objective to learn to know more about the settlement-system of this culture and its history starting from the beginning of the using of the landscape for settlements, gardens and fields up to the collapse of its cultural system.

With this aim the project investigates the Bandkeramik settlement of a 60 km^2 area of the settlement area called Mörlener Bucht between the cities Butzbach and Bad Nauheim in Hesse, Germany. The results of different archaeological field methods should be linked to the knowledge of the physical features of the landscape. The field work has a main stress on large-scale and non-destructive methods like intensive fieldwalking, in some cases providing the coordinates for each object, and surface plots of the topography linked with geophysical prospection. Only few excavations should be done to prove the character of selected features. It is the task of the geophysical prospection to investigate settlements in large scale. It should help to show their extension and structure.

Up to now several large fluxgate-gradiometer surveys with more than 30 hectares at six different areas of investigation have been carried out.

Settlements, which are situated off the well investigated fertile landscapes or which seem to have a distinct function are of special interest. At the site of Wehrheim-Friedrichsthal, situated in a settlement area recently revealed, a first small magnetometer survey showed a typical ground plan of a Bandkeramik house with respect to its form. Several of such ground plans have been detected at the site of Butzbach-Fauerbach. One outstanding specimen is an almost completly preserved ground plan with a horseshoe-shaped ditch of the northwestern walls and several postholes, measuring about 40 m in length. Furthermore features have become visible, which might be linked with the supposed exploitation of hematite in Bandkeramik times at this site.

Fig. Wehrheim-Friedrichsthal, Hochtaunus District, Hesse; Linearbandkeramik settlement. 256-gray-scale plot of the fluxgate-gradiometer survey in comparison with the ground plans of Bandkeramik houses at the site of Friedberg-Bruchenbrücken, Wetterau District (J. Lüning, Die Anfänge der Landwirtschaft vor 7000 Jahren: Ausgrabungen in Friedberg-Bruchenbrücken, in: V. Rupp (ed.), Archäologie der Wetterau [Friedberg 1991] 100). Order from the Seminar für Vor- und Frühgeschichte, Johann Wolfgang Goethe-Universität Frankfurt/M.

M. Posselt, B. Zickgraf

Magnetometer Survey at the Early Latène Barrow at Glauberg, Germany and Izs Environs

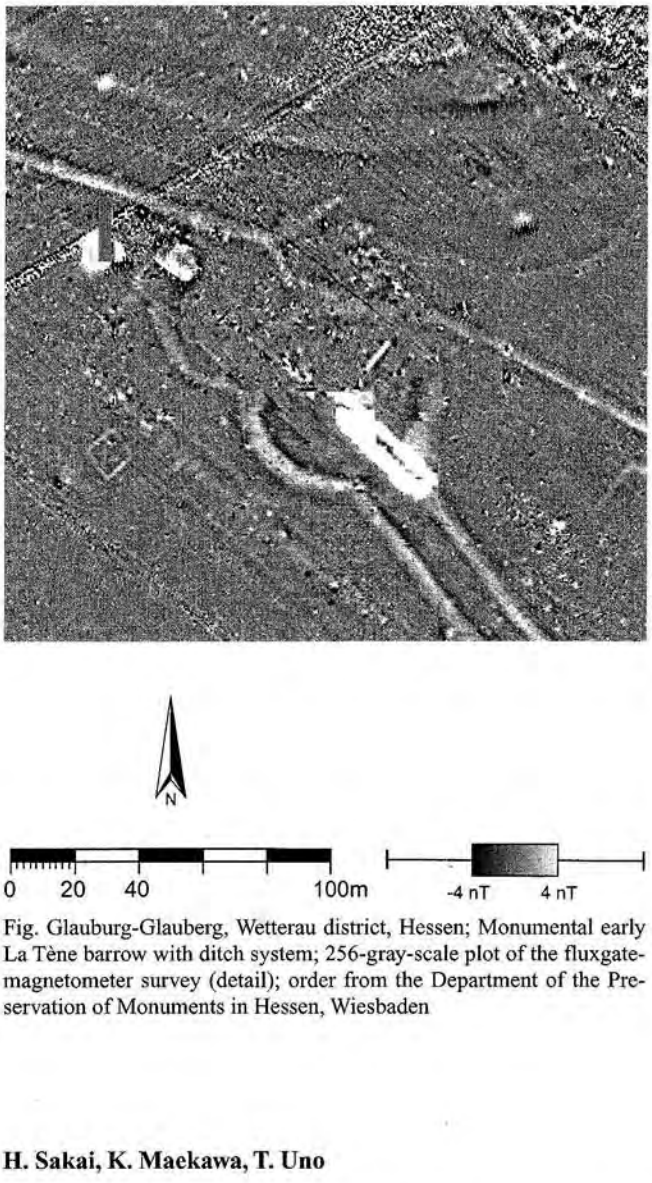


Fig. Glauburg-Glauberg, Wetterau district, Hessen; Monumental early La Tène barrow with ditch system; 256-gray-scale plot of the fluxgate-magnetometer survey (detail); order from the Department of the Preservation of Monuments in Hessen, Wiesbaden

In 1994 the Hesse Department for the Preservation of Monuments excavated a rich grave of the Early Latène period at the southern slope of the prehistoric hillfort of Glauberg in Hesse, Germany.

The grave goods (gold torque, bronze wine-flagon etc.) lead to the assumption that it was the grave of an important personality. In the course of further excavations, an almost completly preserved statue of an idealized celtic ruler or hero and fragments of three more statues were brought to light. These findings and excavations at the hillfort of the Glauberg proved that this site was an important place on the northern rim of the Celtic world, similar to the princely residences of southwestern Germany, northern Switzerland and eastern France.

In the first place aerial photography found hints for a barrow measuring about 50 m in diameter being surrounded by a ditch. The excavation in 1994 confirmed this idea. Further weak traces of features were visible in the near environs of the barrow.

A first magnetometer and resistance survey following the excavation and covering an area of 1.5 hectares with the barrow in its centre showed very soon that it was included into a large system of ditches that enclosed the area in the Iron Age period.

Until now an area of about 110 hectares was covered by an even 0,5 m grid system using a fluxgate-gradiometer. The ditch-system localized up to now has an extension of more than 1,2 km from east to west. Also visible are further ditch-sytems of different age. Scattered over the whole area of investigation are several settlements of neolithic to Iron age context inside and outside the large Iron age ditch-system.

The magnetometer survey at the Glauberg makes the special operation of geophysical methods among archaeological field methods clear (excavation, aerial photography, field walking etc.). Its potentiality and increasing importance in archaeology once again becomes visible.

H. Sakai, K. Maekawa, T. Uno

A Comparative Study of Electromagnetic Survey and Excavation Results at Archaeological Sites Containing Kilns and Buildings

Electromagnetic probing was conducted before excavation on baked areas and trampled areas at a number of archaeological sites. The studies undertaken were as follows:

(1) Magnetic surveys at a Suzu-ware kiln Site (14^{th} century);
(2) Magnetic investigation at the Paleolithic Ohara B site;
(3) Electric resistivity surveys on trampled areas of the sites of buildings at the Murodo site (18th century) and Emashi castle site (15^{th} century).

Results

(1) Magnetic surveys of a kiln site (13–14^{th} century).
Both a proton precession magnetometer and a fluxgate gradiometer were used and clear magnetic anomalies appeared in four areas. Excavation revealed that the appearance of these anomalies is related to the direction of the major axis of the kilns. Kilns with their major axis aligned north-south show quite a good cor-

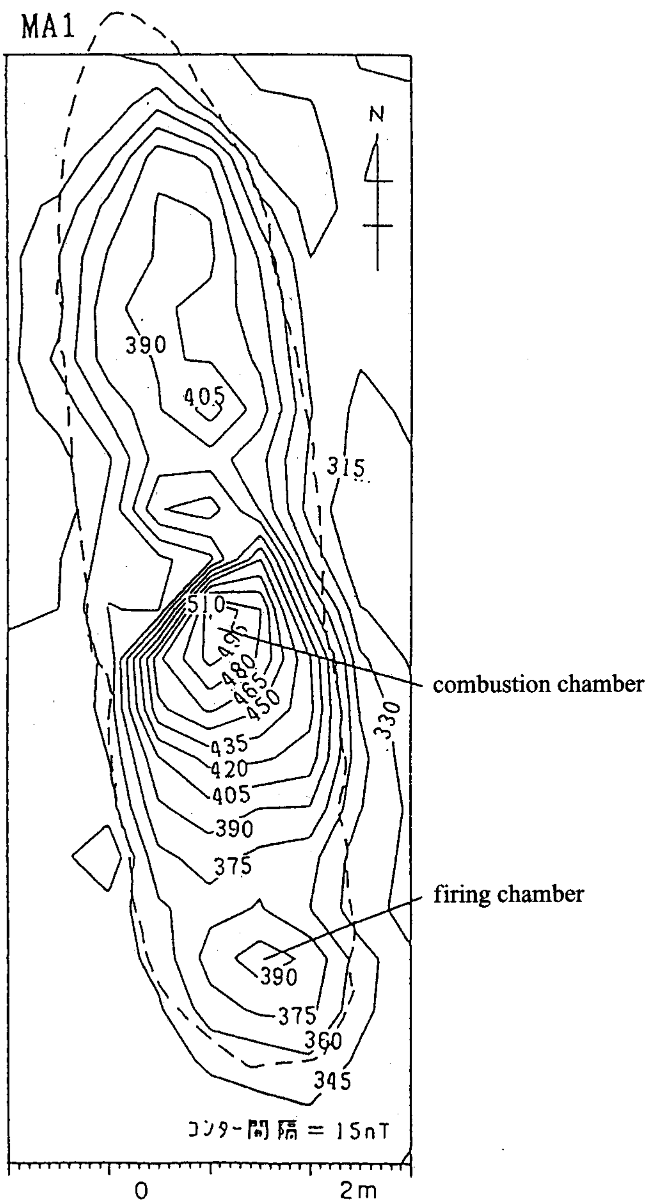


Fig. 1. Case 2: Distribution of the total magnetic force at a kiln surveyed by proton magnetometer at Kurobatake site. Excavation confirmed that intense high anomaly areas were the combustion chamber and the firing chamber of the kiln

relation with magnetic anomalies, whereas kilns with an east-west alignment show a southward deflection of their anomaly patterns.

When a proton magnetometer survey was done with low sensor height (less than 5cm from the ground surface) quite clear anomalies were detectable on the kiln sites. Excavation showed that these anomalies correspond to the combustion chamber and the firing chamber of the kiln. As a result of being heated to a high firing temperature, these regions had acquired intense magnetization (thermo-remanence) not only on the surface but at a deeper level as the magnetic properties of the baked soil confirm.

(2) Magnetic investigation at the Paleolithic Ohara B site.

Finding a hearth is important evidence for the existence of a dwelling from the Paleolithic period onwards. We attempted a magnetic survey in combination with a rock-magnetic study for this purpose. At an artificially baked area by an open-air fire, both a magnetic survey and a test of the remanent magnetization of the soil proved effective as methods of locating the slightly baked area. The Paleolithic Ohara B site was studied using these magnetic methods, and a magnetically anormalous area was found suggesting the site of a fireplace. Another magnetized area was found by analysing the distribution of magnetization in the buried soil. The remanent magnetization in the soil showed a circular directional pattern, which could have been caused by a strong electric current flowing from the air into the ground. Such a pattern would be consistent with the spot having been struck by lightning. Thus, the soil retains evidence of lightning striking it in the Paleolithic period. This suggests that the effects of lightning can be recognised using archaeological techniques.

(3) Electric resistivity surveys on trampled areas of the sites of buildings at the Murodo site (18th century) and Emashi-castle Site (15th century).

Trampled areas such as the earth floors of house sites were identified as areas of high resistivity. By contrast, areas beneath the raised timber floors of buildings registered low resistivity. Such a clear difference may be caused by the degree of compaction and water content of the soil constituting the remains. Thus resistivity surveys are useful for studying the character of former buildings.

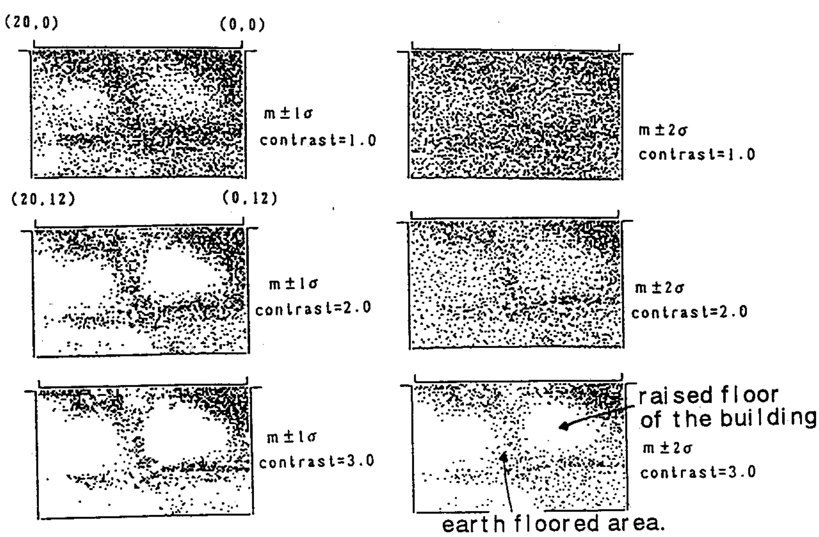


Fig. 2. Case 1: Distribution of resistivity surveyed using an RM-15 meter at the Murodo site. The low resistivity zone corresponds to the area under the raised floor of the building and the high resistivity zone to the earth floored area

N. Schleifer, J. Bigalke, M. Koetter, A. Junge

Geophysical Application of the Induced-Polarization(IP)-Effect for the Detection of Medieval Wells.

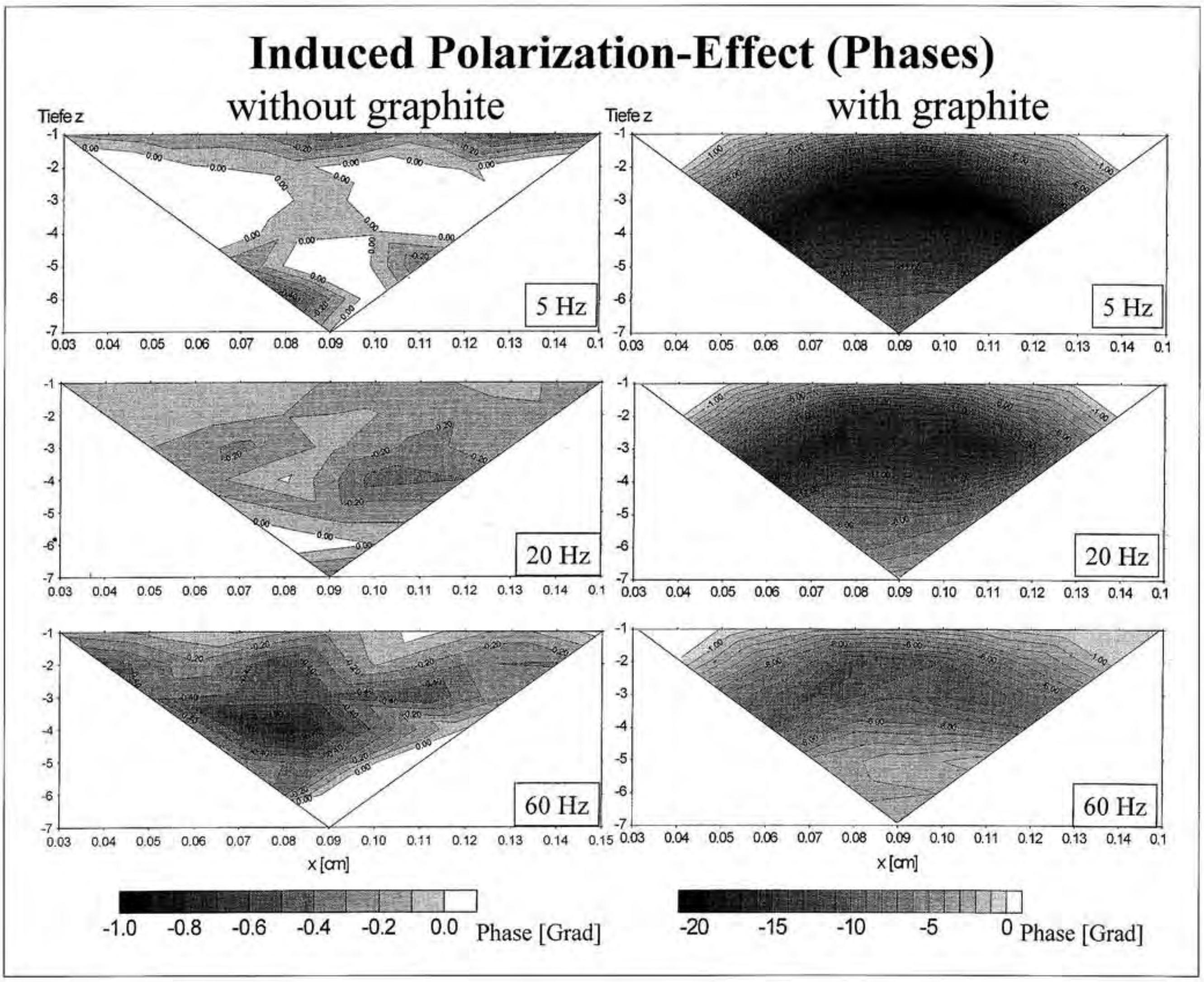
Besides the well-established groundspecific parameters, magnetic susceptibility and apparent resistivity, the polarizability of the soil is another possible parameter for archaeological problems.

The induced polarization (IP) bases on electrochemical processes in the subsoil that take place while an electrical current is injected into the ground. Consequently the resulting potential field at the surface is frequency dependent and reflects additional electrical properties of the soil. So far the method has been successfully applied for the monitoring of groundwater contamination and the distinction between clay and water-bearing rocks.

An application within the archaeological environment could be the detection of medieval wells containing wooden remains for subsequent dendrochronological investigations.

Within the "Graduiertenkolleg Archäologische Analytik" supported by the DFG (German Research Foundation) our institute is developing a multichannel geoelectrics-instrument (SIP-256) that is able to measure both the apparent resistivity and the induced polarization-effect. By using an "intelligent" remote unit at each electrode the speed of the measurement has been increased tremendeously. Thus the instrument enables fast mapping and sounding and a real-time visualization of three-dimensional structures.

Fig. 1. Pseudosections of the parallel performed IP-measurements



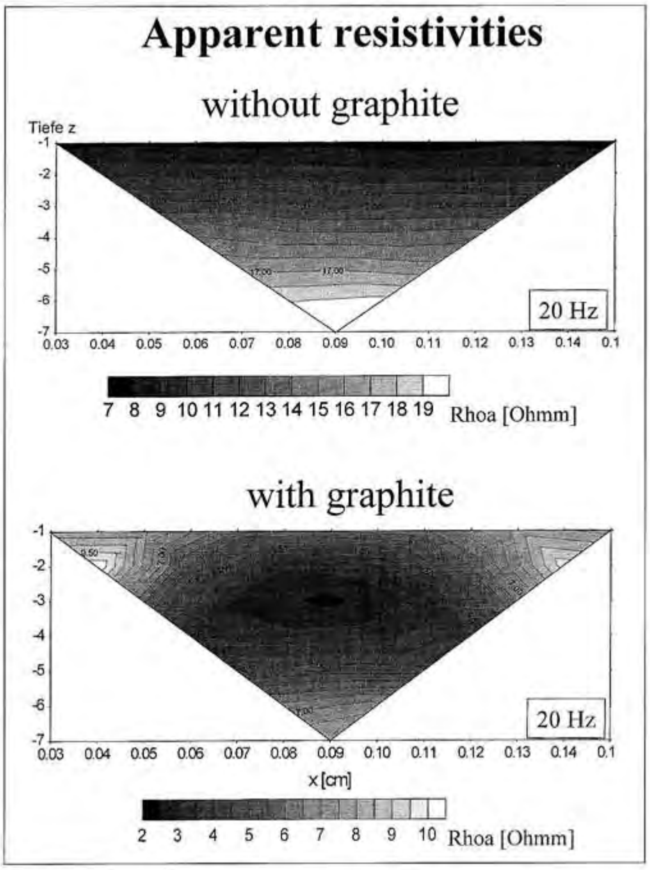


Fig. 2. Pseudosections of the apparent resistivity measurements in the laboratory

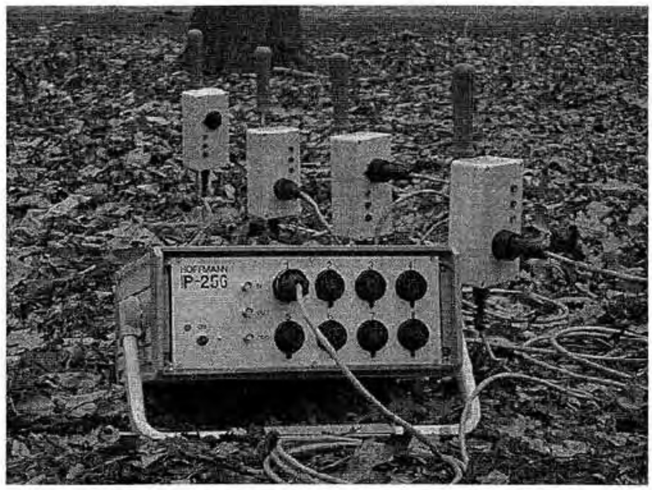


Fig. 3. SIP-256 Multichannel Geoelectrics-Instrument

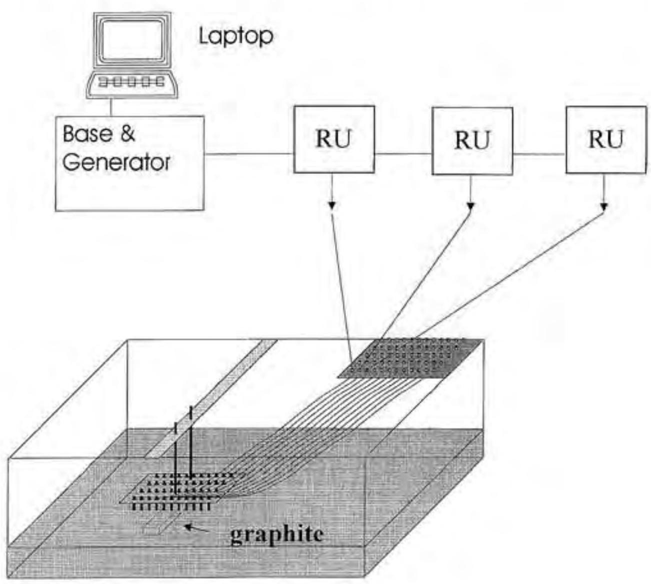


Fig. 4. Simplified picture of the experimental setup in the laboratory; RU = Remote Units

A. Schmidt

Recent Work on Pseudosections for Archaeology

Standard earth resistance surveys for archaeology normally use fixed electrode arrays to cover large areas. The features detected depend on the penetration depth of the probe arrangement and by combining surveys undertaken with various electrode spacings it is possible to investigate anomalies at different depths. Such data can be subjected to complex algorithms to calculate the actual resistivity distribution of the ground (tomography) or converted without further processing into values of apparent resistivity (pseudosections).

This paper investigates how the simple use of pseudosections can provide images of the subsurface to aid the archaeological interpretation of sites. Efficient field techniques for cheap data acquisition will be reviewed and the responses to various electrode arrangements (twin-probe, Wenner, Wenner-broadside) illustrated. Data collection, manipulation and display are important issues when dealing with such data sets and case studies for the use of pseudosections, pseudoslices and volume visualisations will be provided. A major advantage of pseudosections is their minimal requirement for processing and basic data treatment tools (e. g. topographic adjustments, depth scaling) will be assessed.

Pseudosections are an efficient tool for an initial evaluation of the third dimension (i. e. depth) and survey examples will be provided to show the validity of this approach despite limitations of the simplistic data treatment.

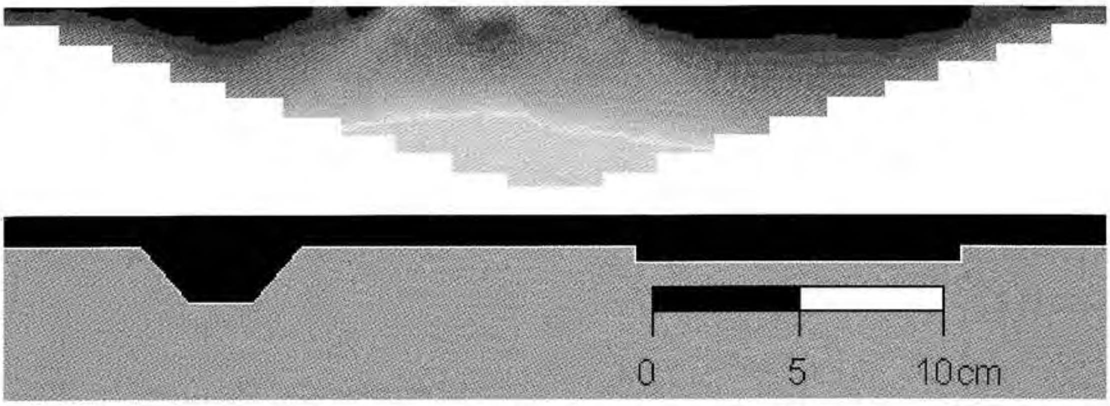


Fig. Wenner pseudosection of a test tank with sketch of the actual profile; Range: 2 ... 20 Ωm (dark to light, linear)

A. Schmidt, R. Coningham

Archaeological Geophysics in South Asia

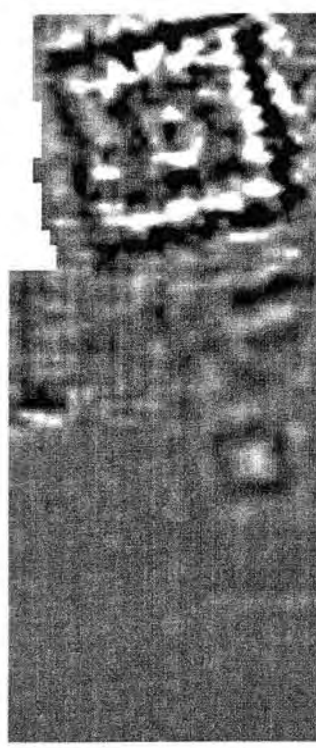
According to its mission of protecting and preserving the cultural heritage world-wide, UNESCO has provided funding for the geophysical investigation of buried archaeological remains related to World Heritage Sites in South Asia. During two pilot studies the response of buried features to standard geophysical prospection methods was investigated on selected sites in Bangladesh and Nepal in 1997.

The use of fluxgate gradiometers and earth resistance meters is well established in the developed world and the interpretation of geophysical anomalies as archaeological features is fairly well understood. However, very few geophysical surveys were undertaken on archaeological sites in South Asia and due to the climatic, environmental and geological conditions the geophysical signature of subsoil archaeological structures is markedly different. The specific problems encountered in the subcontinent will be exemplified with geophysical survey results from Bangladesh and Nepal (FM36 fluxgate gradiometer and RM15 earth resistance meter with twin-probe array).

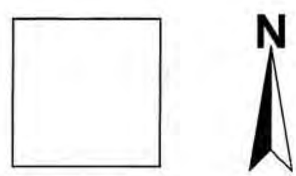
Bangladesh is dominated by the alluvial floodplain of the Ganges with heavy Monsoon rain in the summer. As a consequence the non-perished architecture is dominated by solid brick structures with ornamental terracotta tiles which, as a ruin, manifest themselves as brick walls within brick tumble. Accordingly, magnetometer results are difficult to interpret. It was, nevertheless, possible to enhance the monument records of the World Heritage Sites of Bagherat and Paharpur considerably.

The survey of the sites of Tilaurakot and Ramagrama in Nepal showed much clearer evidence of buried brick foundations and provided insight into the layout of the ancient citadel and the stupa site, respectively.

Fig. Fluxgate gradiometer survey over remains of an ancient monastery



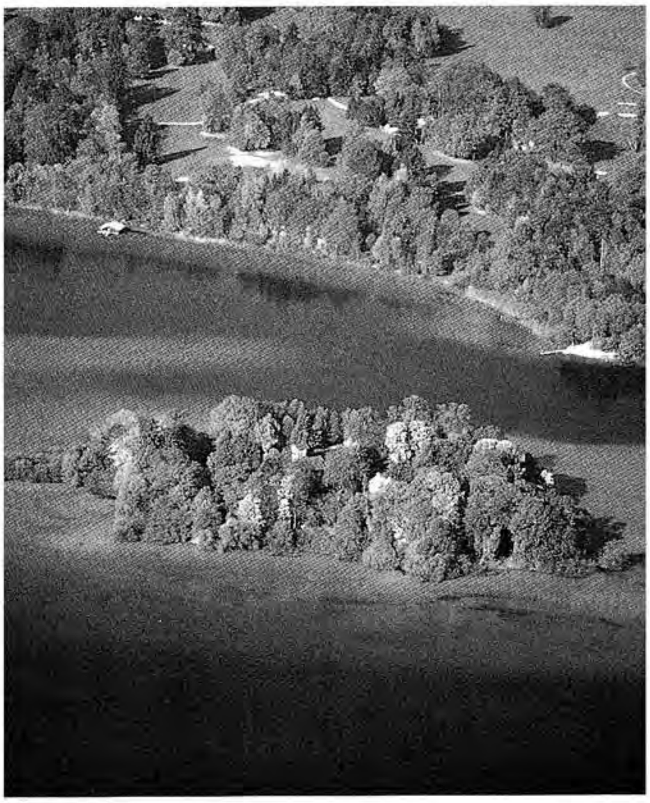
Range: -9 ... +9 nT
(light to dark, linear)

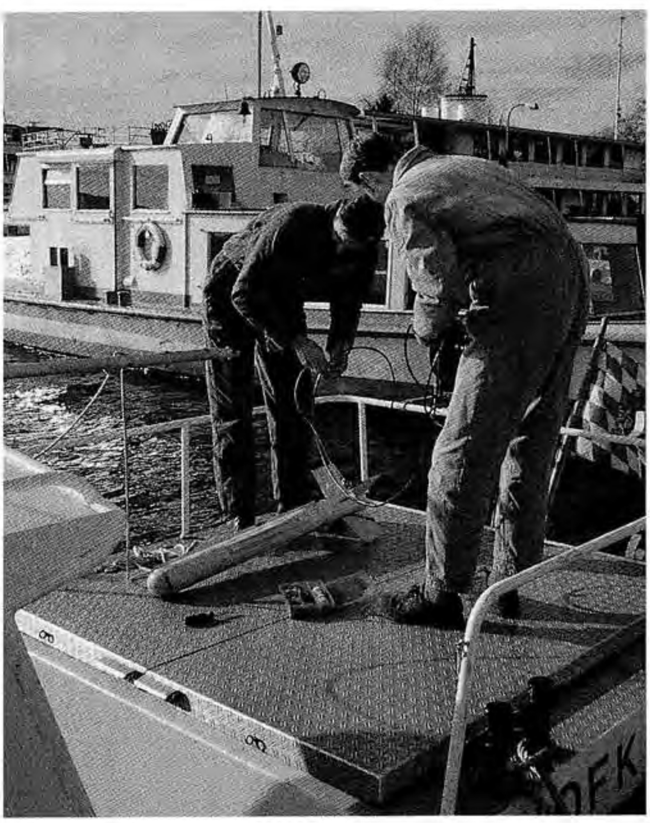


10 m x 10 m
Resolution 0.5 m x 0.5 m

G. Schönfeld

Wetland-Archaeology in Lake Starnberg , Bavaria





Southern Bavaria, embedded in a prealpine hilly landscape, possesses a lot of rivers, lakes, and swamps in the hinterland of the lakes. In similar situations of neighbour-regions, especially in Switzerland, Baden-Württemberg and in Austria in the Salzkammergut, has been detected a great number of prehistoric wetland sites. In Bavaria only a few sites are known until now. Nevertheless hundreds of hints are recorded. So it is an additional task of our team, to discover wetland sites and to examine them. We organize our work in projects.

A good example happened in 1997 and 1998, when the famous summerhouse of the bavarian kings on the small island, called Roseninsel, in the Lake Starnberg has been restored. A trench for electrics, phone and water was dug from the shore to the 500 m distant island. We decided to control earth-work on and nearby the island, which is well known for prehistoric finds and for a large number of wooden posts, some of them dated in Urnenfelderkultur and to try reconnaissance of further sites on the shore of lake Starnberg.

Documentation of the trench revealed the existence of a LBA-settlement, which was built on the shore of that time on pebbles and sand. On the island itself we discovered a small medieval castle. But the main purpose, to find out exact positions and dates of prehistoric settlements on the island, until then only known from sherds, could not be fulfilled successfully. The glacial dump has formed the island as a cone with steep sides running quickly under the sea-level. Prehistoric strata on the upper side of the cone were dried out and have been destroyed during earth work for summerhouse and park. However, preserved strata could not be reached in the trench. Drilling under the water-level revealed prehistoric strata until 3.80 m under the sea-bottom. With these data we have got for the first time ideas about postglacial sea-level changes in the lake Starnberg. As a result we could now define prehistoric water-levels, which depend from the level of known prehistoric sites, i. e. between 484 m ü. NN. (recent level) and ca. 379,50 (level of late neolithic)

As a next step we surveyed the recent shore until the water-level of 379 m with a side-scan-sonar. We recorded a lot of posts. Most of them are of recent age. Others seem to be older. They may be identified by GPS-position. In a few weeks we shall send divers to cut the posts. Then they will be dated in our dendrolab or, if not possible, by C-14-analysis.

In my eyes, we have found an attractive not expensive way, to survey lake-settlements.

Fig. 1. The Roseninsel in Lake Starnberg; aerial view from the east (Bayerisches Landesamt für Denkmalpflege, Luftbildarchäologie, Photograph Klaus Leidorf, Aufn. Datum 26.10.1989, Archivnr. 8132/001)

Fig. 2. "The Fish", a side-scan-sonar ready for survey in Lake Starnberg

B. Song

Aerial Archaeology in China: Possibilities, Perspectives and Results

This is a provisional report of the research project entitled "Introduction to Aerial Archaeology in the Peoples Republic of China" at the Department of Pre- and Proto-History of the Ruhr University, Bochum in Germany. The project was started in 1995 with the aim of integrating aerial archaeology as an innovative method in the archaeology and the protection of monuments in China. It is financially sponsored by the "Stiftung Volkswagenwerk" and is based on close cooperation with the Chinese culture authorities and institutions on various different levels.

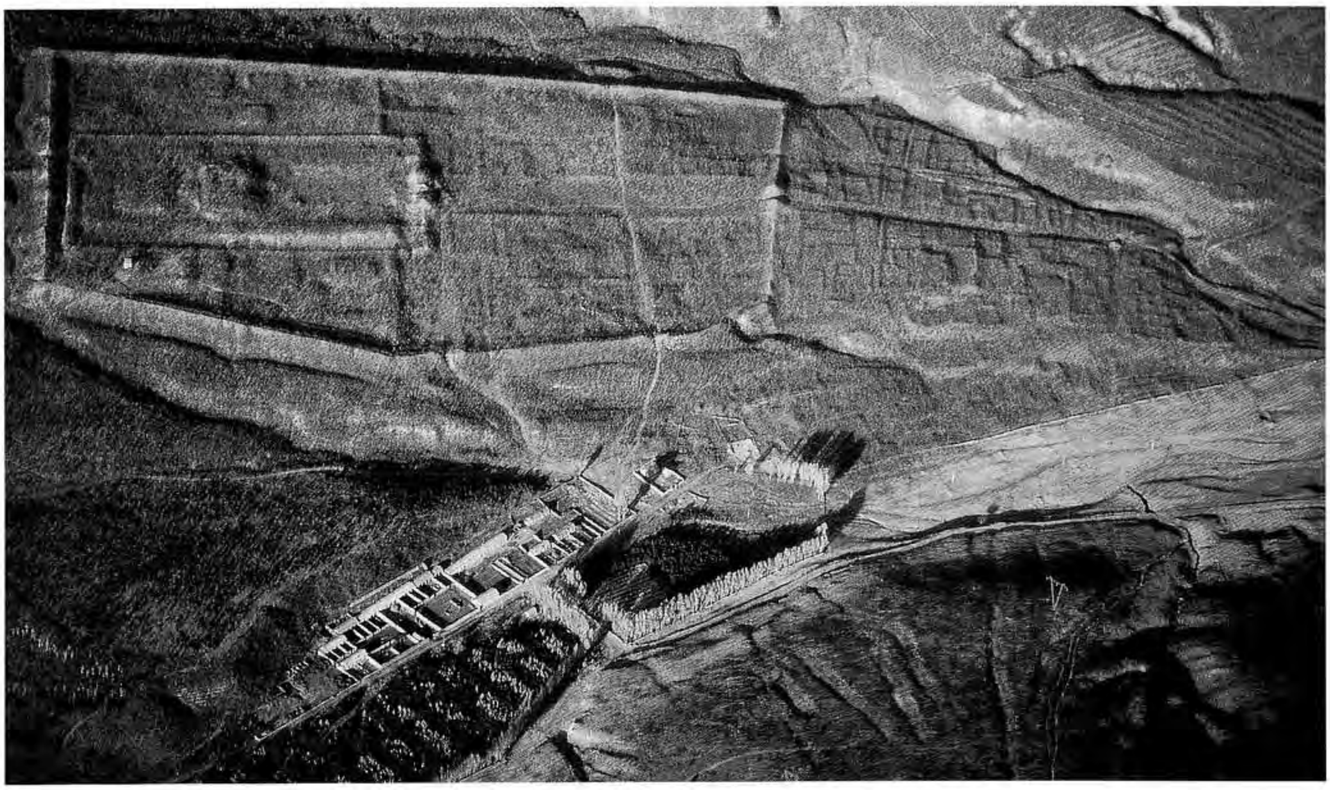
A research center for remote sensing and aerial archaeology was founded 1997 in China at the National Museum for Chinese History (NMCH) in Beijing. This center has now rooms and equipment for the interpretation of aerial photography, cartography, archives for aerial photography and maps. The fundamental tasks of this center are: 1) to develop and research aerial archaeological methods and technologies; 2) to carry out over-regional projects in cooperation with archaeological institutes and institutions concerned with the preservation of historic buildings and monuments; 3) to support and look after the application of aerial-archaeological methods in certain regions: For example, the placing of work data such as maps an aerial photos, technical support, the training of professionals, etc. into the proper hands.

Parallel to these efforts to institutionalize aerial archaeology, from 1996 to 1997 many ground site projects were done in certain Chinese provinces to test and to prove exemplary aerial archaeology in actual practice. It was planned by means of this to collect methodical experience in different regions of China with differing climate, soil, vegetative and topographical aspects and not least the archaeological circumstances relating to these sites. This project was planned, prepared and carried out by the Department of Pre- and Proto-History at the Ruhr University, Bochum, in cooperation with the Chinese Ministry for Cultural Assets, the National Museum for Chinese History and relevant provinces.

The first result of these projects showed that the methods of aerial archaeology which have already been proved successful in Europe in carrying out aerial archaeology (with special focus on the discovery of underground archaeological sites), function just as well in China. The results, however provisional, are good for archaeological research and the maintenance of subterranean archaeological sites and especially to help persuade the archaeologists and the authorities for the preservation of monuments in China to use these new and effective methods.

Three selected projects are introduced under their relevant archaeological, methodical and technical aspects. They took place respectively in Linzi, Shandong Province (East China), in Gongyi, Henan Province (Central China) and in Chifeng, Inner Mongolia (North China).

Fig. The City of Zuzhou near Lindong, Inner Mongolia



I. Trinks, H. Stümpel, S. Lorra

Integrated Geophysical Surveys for Archaeological Prospecting – New Results

The working group for archaeological prospecting at the department for geophysics at Kiel University (Germany) has undertaken several geophysical surveys on archaeological sites in northern Germany, Luxembourg, Italy and Turkey during the last years. Magnetic, electric, ground penetrating radar (GPR) measurements and shallow shear wave seismic were used for the investigation of Hittite, Greek, Roman and Viking age settlements, fortifications and temple constructions.

Primarily magnetic prospecting was applied for fast data acquisition in order to get a general idea of the subsurface remains of the archaeological site. Five Fluxgate gradiometer probes (Förster; dz = 40 cm), mounted on a portable rack, are carried by two persons along 50 meter survey profiles with a sampling interval of 5 centimetres inline and 20 or 40 centimetres crossline. The datasets were processed with the software Mar Plot and presented as grayscale images. Striking anomalies are further investigated with geoelectric and GPR measurements. Therefore a multielectrode array and different GPR antennas (120, 200, 500 and 900 MHz) are available. Subsequent processing algorithms perform a 3 D view of the subsurface structures.

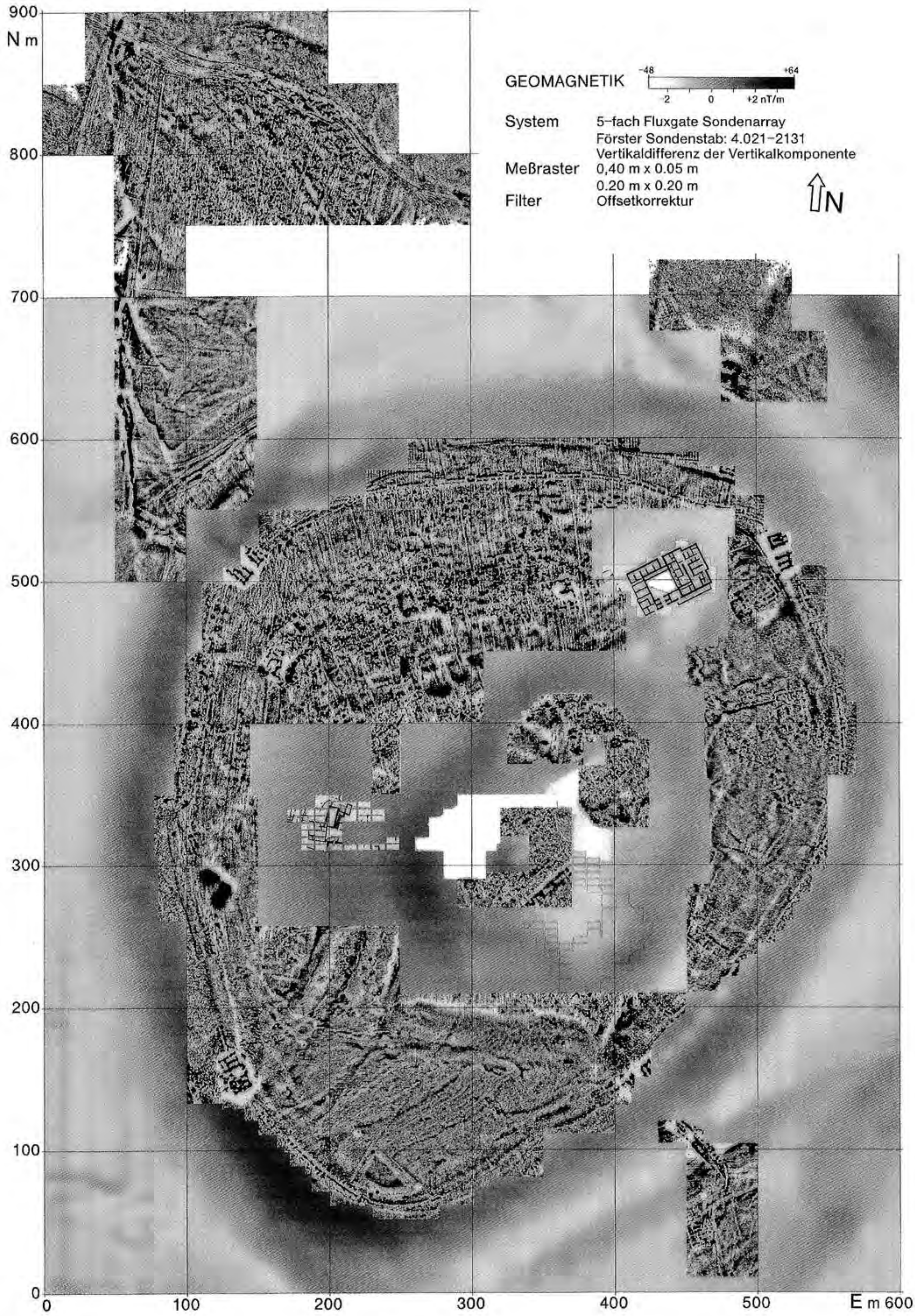
Prominent magnetic anomalies were found at the site of the Hittite town Sarissa in Central Anatolia, Turkey. Here 3,000 year old ruins, located on a remarkable mound, were excavated. With the exception of few steep slopes the entire acropolis (150,000 sqm) was investigated in the course of several survey campaigns (Fig. 1). The foundation of the 1.5 km long interior town wall surrounding the town centre was discovered and a distinct symmetric conception of the four ancient city gates was prospected. High uniform magnetic anomalies of the gate buildings insinuate a destruction by conflagration. The geomagnetic measurements were compared with geoelectric and GPR investigations at several locations. Our results show that the extension of the residential area is much larger than previously thought. The surveying of a sanctuary, found on a nearby mountain skid, revealed northward aligned buildings and the enclosure of an adjoining lake.

Magnetic and seismic measurements were applied for the investigation of the archaic fortification wall of Milet, located on a former peninsula at the west coast of Turkey. Nowadays the archaeological site is situated in the alluvium of the Menderes river. Milet's urban area included several ports and was enclosed by a town wall. Early settlements were found on a hill, called Kalabak tepe, in the south of the peninsula. We investigated the extent of the archaic city wall with geomagnetic measurements in order to examine the connection between Kalabak tepe and the lower part of the town. The rectangular street system, adopted by the Milesian Hippodamus, was detected and its orientation and size were proved to correspond with the excavated structures. The western coastline representing the border of the settlement was determined by the results of the magnetic survey. Some magnetic anomalies close to the ancient shoreline can possibly be identified as fortification or harbour constructions. Shear wave seismic was used to explore the structure of a harbour basin while magnetic investigations revealed the layout of the quay walls.

A recent feasibility study in the archaeological park of Selinunte, Italy, showed weak structures of buildings, street systems and the town wall, due to a low contrast between the used building materials and the surrounding subsoil. Further examples of the Viking age settlement Rerik at the Baltic coast and the Gallo-Roman settlement Wallendorf, close to the border to Luxembourg, will be presented in order to discuss the limits of geophysical prospection methods.

Future improvements may be possible with quick and precise positioning systems. Differential GPS promises an accuracy in the order of centimetres and is suited for the presented sites.

Fig. 1. Result of the magnetic prospecting using the Fluxgate array on the archaeological site of the Hittite town Sarissa ▷


GEOMAGNETIK
-48
+64
-2
0
+2 nT/m
System
5-fach Fluxgate Sondenarray
Förster Sondenstab: 4.021-2131
Vertikaldifferenz der Vertikalkomponente
Meßraster
0,40 m x 0.05 m
0.20 m x 0.20 m
Filter
Offsetkorrektur
N
900
N m
800
700
600
500
400
300
200
100
0
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100
200
300
400
500
E m 600

G. N. Tsokas, R. O. Hansen

The use of Complex Attributes in Interpreting Magnetic data from Archaeological Sites.

The present paper deals with the exploitation of the complex attributes of the magnetic signal in order to extract properties of the sources of the anomalous fields. Of course, the analytic signal comprises the most well known among them. The "local phase" and the "instantaneous wavenumber" comprise the other two quantities which lead also to source parameters mapping.

The analytic signal amplitude (Nabighian, 1972; 1974) poses some attractive features for any sort of magnetic prospecting. Its advantageous "geophysical" property is that is peaks exactly over the edge of the buried dipping contact that causes the magnetic anomaly. Also, its amplitude is independent of inclination, declination, remanent magnetization and dip if the sources are 2-D. With respect to archaeological Geophysics, the only disadvantage is that the analytic signal anomalies are relatively much broader than the lateral extent of the buried target.

The aim is to delineate the edges of the buried bodies, to estimate their susceptibility contrasts, to assess strike angles and produce burial depth estimates all at once. The complex attributes analysis offers the means to carry this out. It is exactly their applicability and effectiveness in exploring the subsurface for buried antiquities which is investigated in these pages.

The analytic signal amplitude for the simple contact model which produces the magnetic total field, T, is

$$|A| = \sqrt{\left(\frac{\partial T}{\partial z}\right)^2 + \left(\frac{\partial T}{\partial x}\right)^2} \tag{1}$$

and the local phase, i.e. the phase of the analytic signal for any particular location is

$$\vartheta = \tan^{-1}\left[\frac{\partial T}{\partial x} / \frac{\partial T}{\partial z}\right] \tag{2}$$

The local frequency is defined as the rate of change of the local phase, but customarily the local wavenumber is used

$$k = \frac{1}{|A|^2}\left(\frac{\partial^2 T}{\partial x \partial z}\frac{\partial T}{\partial z} - \frac{\partial^2 T}{\partial x^2}\frac{\partial T}{\partial z}\right) \tag{3}$$

If we substitute the expressions for the vertical and horizontal gradients of the anomaly produced by a sloping contact Nabighian (1972) into the local wavenumber formula (3) yields

$$k = \frac{h}{h^2 + x^2} \tag{4}$$

where h is the burial depth (Thurston and Smith, 1997; Smith et al. 1998). If we define the coordinate system such that x = 0 directly over the edge, the maximum occurs at the same point and offers a means for burial depth estimation since at x = 0, then $h = \frac{1}{k}$

Thurston and Smith (1997) devised a technique to estimate the local dip and local susceptibility contrast as well by means of equation (3). That is $\delta = \theta + 2I - 90^0$ again at x = 0. The local susceptibility is obtained by

$$k = \frac{|A|}{2kFc\sin d} \tag{6}$$

A useful model in various geophysical applications is the slab which also serves in archaeological Geophysics. For instance, a mesh of ruins which the archaeologists call "destruction phase" can be modeled as a magnetic slab. The same applies in some cases for structures like kilns, pits, tombs. The slab used here is buried at 1 m depth, its thickness is 0.5 m and its susceptibility contrast is 0.0005 (emu).Figure (1) shows the recovered local strike esimates of this source. The plane view of a slab is also shown in the same figure. The edges are completely delineated and strike angles recovered give a clear idea of the shape of the target.

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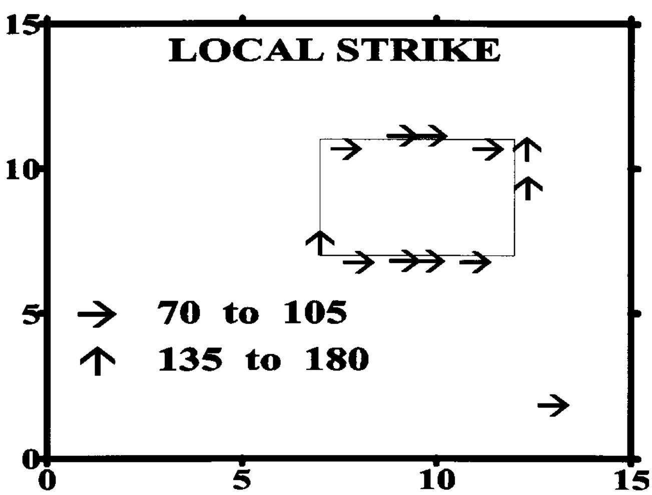
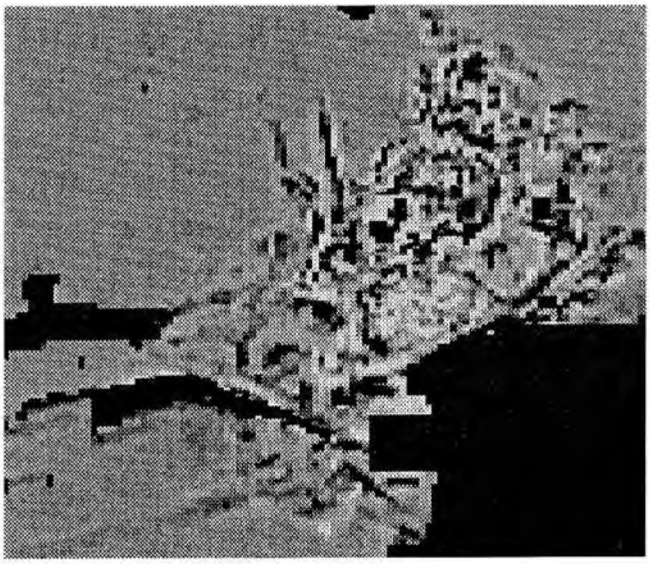
Fig.1. The local strike estimates inferred from the complex attributes of the anomaly which the slab model produces. The plane view of the model is represented by the solid line. Strike estimates are grouped in two categories



R. W. Vernon, G. McDonnell, A. Schmidt, M. Fletcher

Geophysical Surveys on two Yorkshire Blast Furnace Sites, England



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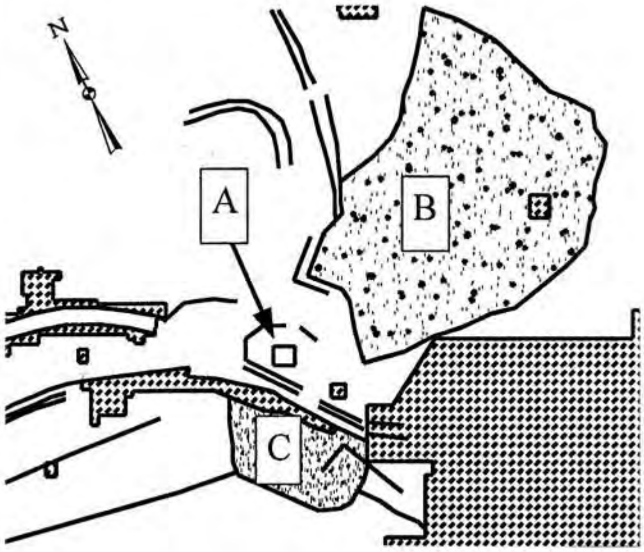


2

Fig. 1,2. The fluxgate gradiometer data of the Bretton site (Fig. 1) is clipped between -100 nT (white) and 80 nT (black); the interpretation (Fig. 2) locates the furnace (A), ore burning area (B) and the slag dump (C); note the difference in response between B (hight iron content) and C (low iron content); surveyed area: h = 120 m, l = 140 m

Blast furnaces were introduced into England towards the end of the Medieval period. This paper investigates the use of geophysical surveys for the interpretation of two prominent blast furnace sites in Yorkshire.

A predecessor of such blast furnace, a high bloomery, was revealed by geophysical surveys in Bilsdale to the north of Rievaulx Abbey, North Yorkshire, operated by the Cistercian monks. When the abbey was dissolved in 1538, the new landowner is known to have established a blast furnace in Rievaulx village. Geophysical survey work identified the finery / chafery complex, where the cast iron was processed, with slag tips, charcoal stores and leat systems. Combined with topographical survey work, limited excavations and documentary evidence the approximate location of the blast furnace in Rievaulx village was identified. The geophysical work is limited to open spaces between post-furnace housing and other physical constraints. However, it has been possible to identify the ore-roasting area and the likely source of water for operating bellows.

A second blast furnace site, in the Bretton Sculpture Park, near Wakefield, West Yorkshire occupies a green field site. A leat entering and leaving the site and a slag dump are the only pronounced earthwork features. Slag, burnt ore and charcoal are present in the soil. The blast furnace was operated in the 18th century by the same Yorkshire partnership who were also associated with a second furnace at Rockley, located 10 km south of Bretton. During the 1980s, the Rockley furnace, which is upstanding, and adjacent casting floors were investigated. By applying information from the Rockley excavation and the geophysical results from Rievaulx it has been possible to produce a very accurate interpretation of the Bretton furnace survey.

A. R. Volker

Geophysical Mapping of Archaeological Structures in Sachsen-Anhalt/Germany

In August 1993 the section "Geophysics" was established at the Landesamt für Archäologie (LfA) as part of the section "Naturwissenschaften" (Sciences). Legal basis for the protection of archaeological monuments in Sachsen-Anhalt is the "Denkmalschutzgesetz" (the law for protection and preservation of ancient monuments).

The geophysicist at the LfA supports the archaeologists before and during exvacations with detailled mapping of archaeological structures indicated by archaeological aerial photographs. Main objective of geophysical mapping is to locate and document monuments with high precision in order to support their protection

Geomagnetic and resistivity mappings are carried out with a fluxgate-gradiomenter FM 36 and a resistance meter RM 15 (Geoscan Research, Bradford, England). Since 1993 nearly 20 monuments have been mapped.

Following projects will be presented in detail:

Geomagnetic plots reveal a circular enclosure with three entrances and two interior palisades at Goseck, Landkreis Weißenfels. The circular monument has a diameter of approximately 36 meters and is probably of Early Neolithic Age (Trace Plot).

A curvilinear double ditched enclosure (Late Bronze Age?) was discovered beside the River Bode near Wegeleben, Landkreis Halberstadt and geomagnetically documented (Shade plot).

The site of the totally vanished castle "Gottau" in the Elbe river plain at Ranies near Magdeburg, perhaps 12^{th}–15^{th} century A. C., was geoelectrically mapped with a method 1m-twin with a raster of 1 meter (Special Shade Plot).

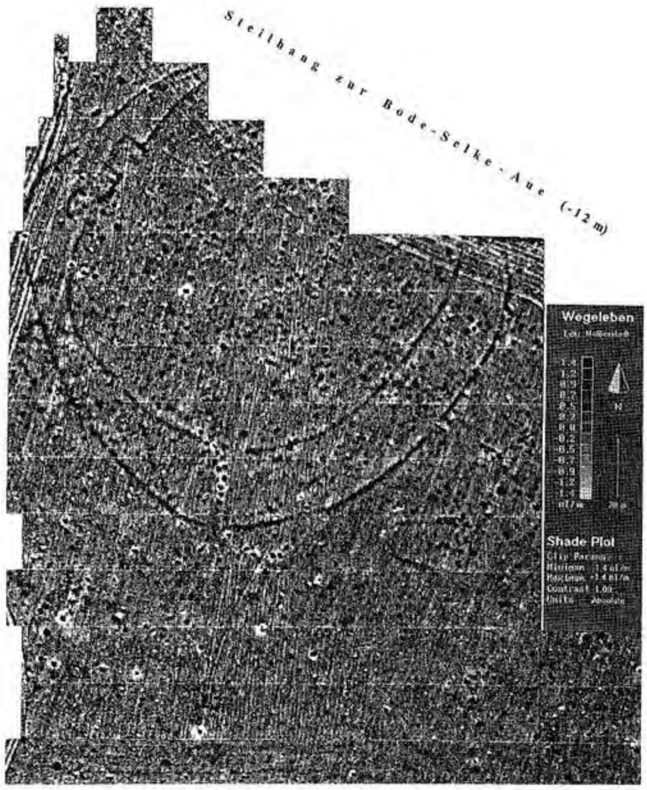
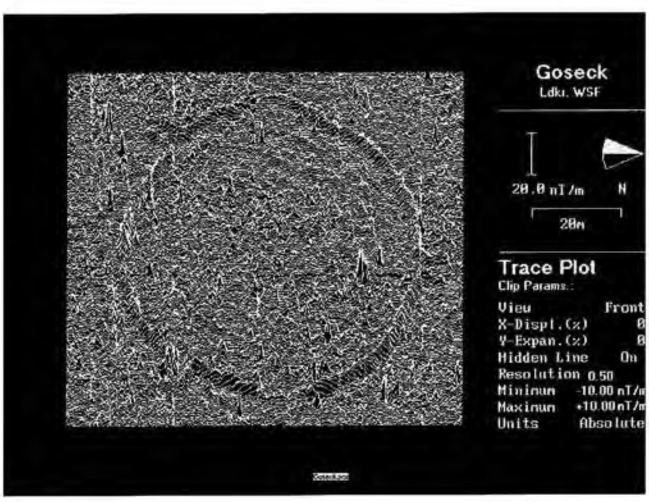
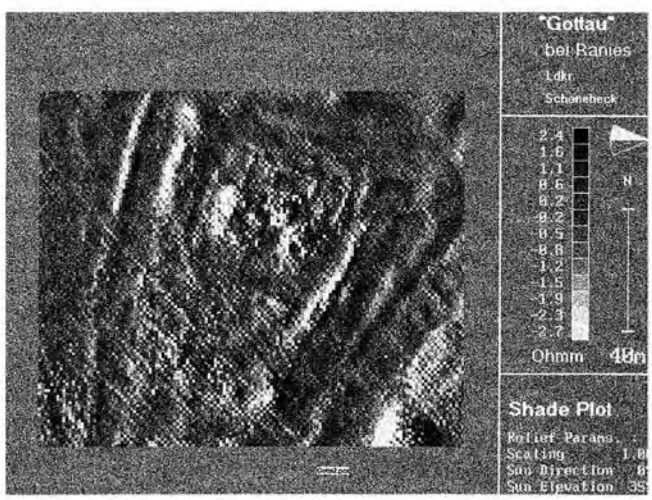


Fig. above. The curvilinear double ditch enclosure beside the river Bode near Wegeleben, Landkreis Halberstadt, probably Bronze Age; shade plot of the geomagnetic mapping

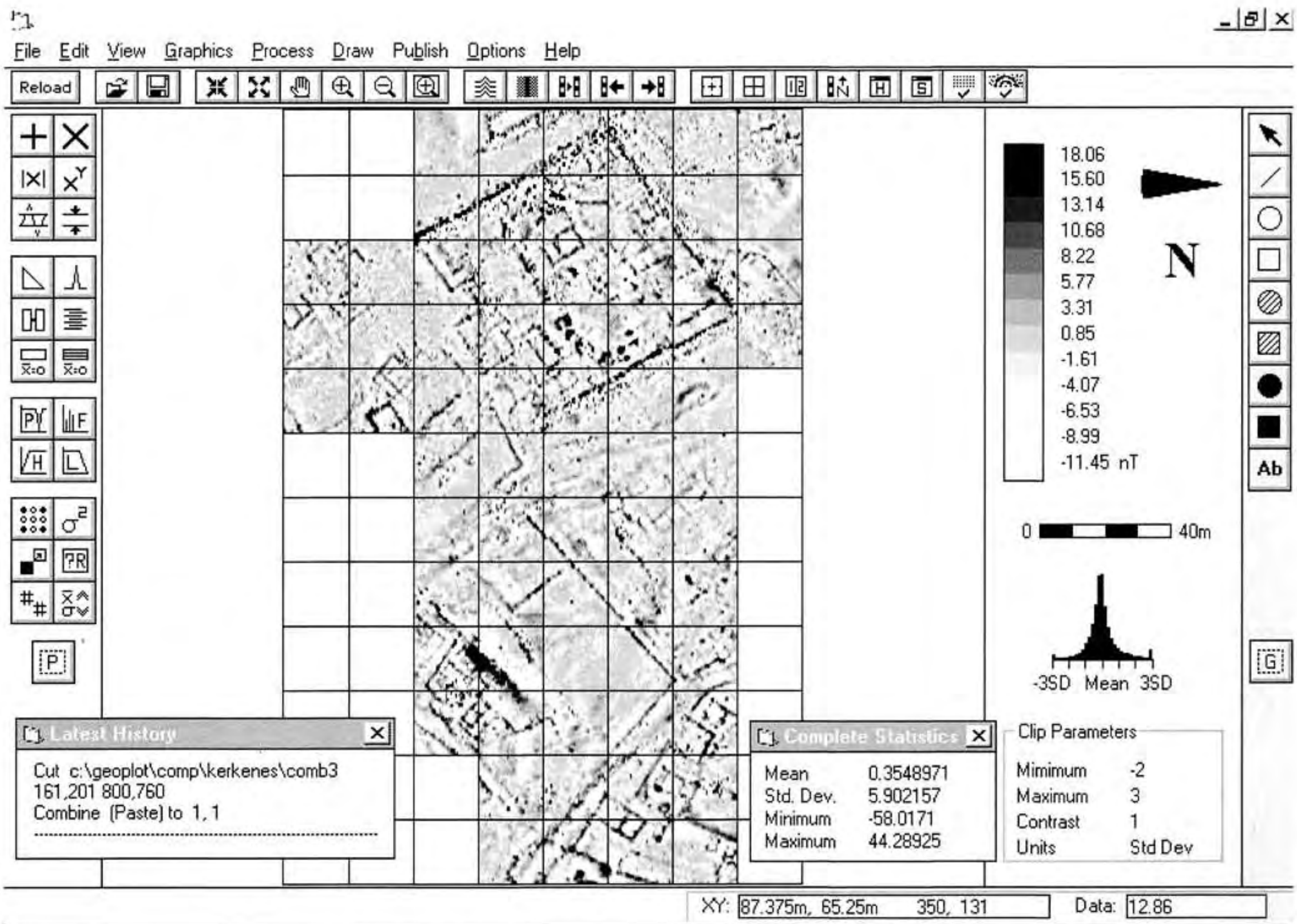




R. Walker, L. Somers, C. Adam

Processing and Presentation of Geophysical Data

A discussion of the processing and presentation of geophysical data from a range of sites (UK, USA and the Middle East) is made using a new release of the program package Geoplot 3.0 for Windows from Geoscan Research. This package can process and present data from a variety of instruments including : resistance meters, gradiometers, magnetometers, EM instruments, and magnetic susceptibility instruments. Processing facilities include: high pass, low pass and periodic filters, spectrum and variance analysis, despiking, interpolation, edge matching, zero mean traverse correction, destagger correction, general purpose numeric functions (add, multiply, absolute, power, clip, compress, search and replace, randomise) and a powerful cut and combine function for combining data sets mathematically. Graphics may be presented as shade plots (grey scale or colour), trace plots (stacked profiles or 3D), dot-density or pattern plots and plotting parameters can be entered in standard, clip, compress or relief (artificial sun) mode. Appropriate combination of data processing and graphical display (eg specific tailoring of colour palette) may be used to enhance specific features.



T. Weski

The Value of Prospection from an Users Point of View

Archaeological prospection is not done for scientific reasons alone, but it has also practical use for the creation of the record of archaeological sites. The first attempt for such a record was started in Bayern as early as 1880 covering the whole country. It was soon outdated and a second one was completed for one Regierungsbezirk (administration district) in 1909. For these and later attempts only visible monuments, e.g. barrows, hill forts etc. and stray finds were available. Therefore certain areas, for example the surroundings of Munich, where due to the geological situation stray finds are lacking, were regarded as being practically without any prehistoric settlements. This picture was completely changed with the introduction of aerial photography in the late 1970s. Suddenly it became obvious that in this previous archaeological desert there were hundreds of settlements, graveyards and former barrows. Thanks to these informations it was possible to conduct excavations before the sites were destroyed by building activities.

All local communities and other administrations are obliged to create land use and development control plans in which archaeological sites are included. Thanks to the results of aerial photography realistic informations can now be given to the planning authorities. Still aerial photography has a big drawback: the absence of evidence on photos does not necessarily mean that there are no archaeological remains buried in the ground; a fact, which is often difficult to explain to investors and other people. It happens again and again that in places where aerial photography gives hardly any results, e.g. in the green land areas close to the Alps, that archaeological sites are discovered unexpectedly during construction activities.

Other prospection methods, e.g. magnetometer or georadar are seldom used before excavations, because it is cheaper to remove the top soil in the endangered area and see what has to be done, particularly if these services are conducted by contract archaeologists. But for the protection of sites under the *Archäologische Reservate* and the *Grabungsschutzzonen* scheme various prospection methods are used to gain knowledge about the character and extent of the monument. Phosphate analysises are seldom made, but in one case it was possible to link these results to different parts of Early Medieval houses.

To sum up: the management of cultural heritage would only be able to fulfil about one fifth of its tasks without any archaeological prospection.

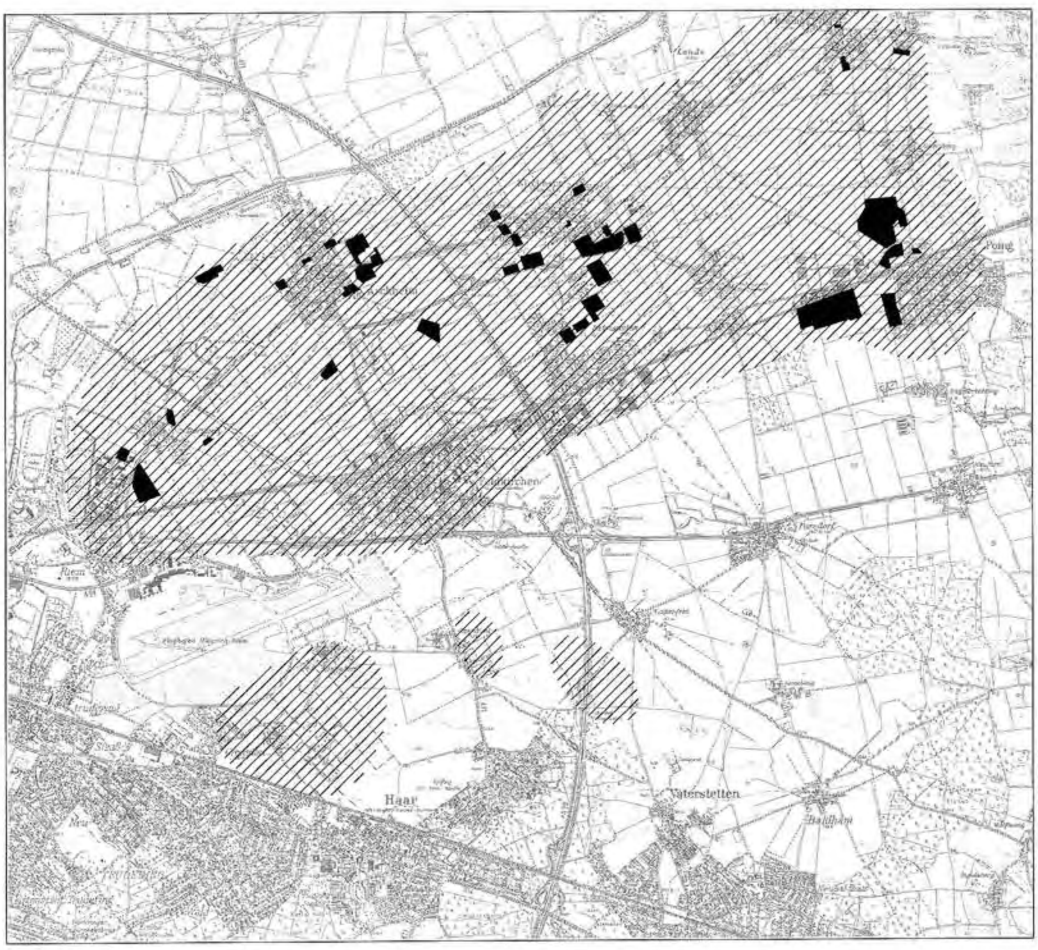


Fig. Distribution of archaeological sites discovered by aerial photography (shaded) and areas excavated prior to construction activities (black) east of Munich; Scale: 1:75 000 (Drawing: M. Vaeßen, Bayerisches Landesamt für Denkmalpflege, Abt. Bodendenkmalpflege, by courtesy of Bayerisches Landesvermessungsamt München, 1920/97)

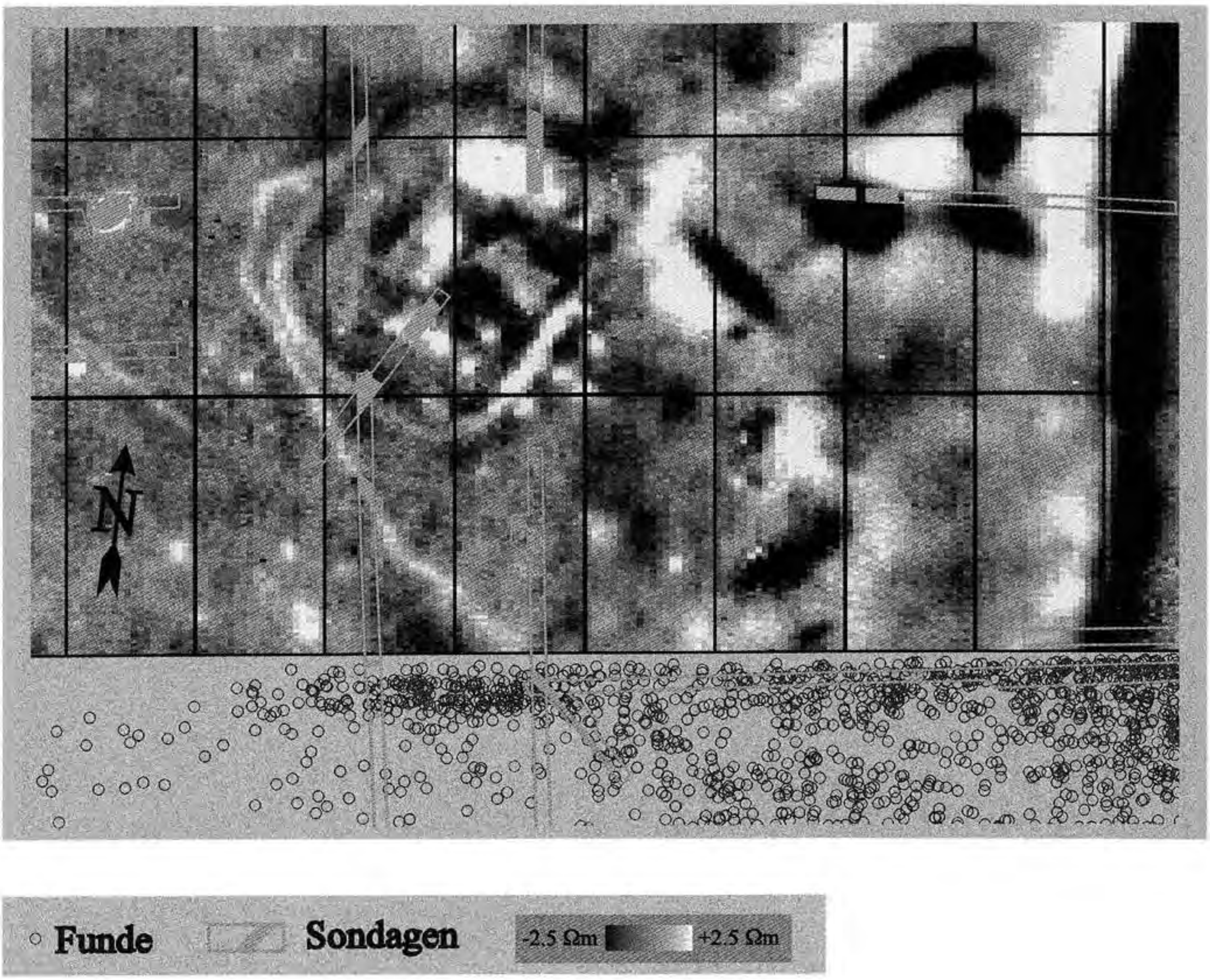


Fig. 1. A *Roman Burgus* near Pulheim/Rheinland
Combined results of fieldwalking on a harrowed field (K. Frank et al.), a geoelectric survey on a meadow (1.0 m-Twin-configuration; samplingrate 0.5 m x 1.0 m; gridsize 40 m x 20 m filtert; J. Wippern, G. Mosebach & J. Zechner) and trial trenches (K. Frank, Ch. Wohlfarth et al.)

J. J. M. Wippern

Integrated Archaeological Prospection: Some Case Studies

The "Rheinisches Amt für Bodendenkmalpflege/Landschaftsverband Rheinland" (Bonn) often carries out archaeological prospections e.g. in the preliminary stages of development plans or ahead of road construction. The first step is the analysis of the archive data like historical maps or the information about chance finds. The next step is systematic fieldwalking including single-find plotting. This method enables us to date the site and to define its extent approximately. Fieldwalking is not applicable to meadows and does not yield reliable information about the preservation of the features. By means of a subsequent geophysical survey using magnetic and/or electric prospection on selected areas it is possible to locate different archaeological objects very precisely. Based on the results of the geophysical survey well-aimed bore probes are carried out in order to prove the preservation. In difficult situations instead of bore probes you most likely use trial trenches.

R. Zantopp

Archaeological Prospection from the Air in the District around the Open Mining of the Cologne Basin in Northrheinwestfalia/Germany

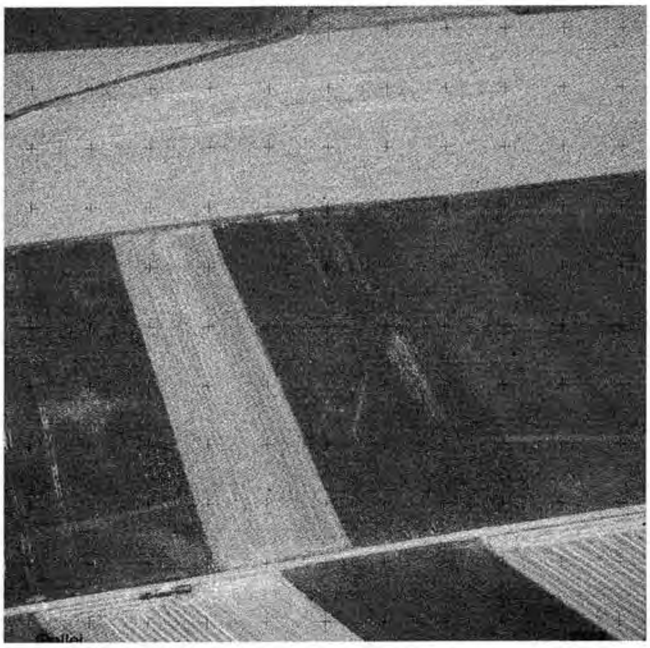


Fig. 1. Crop marks of Roman villa and way from 18th century in July near Inden (A03286/MSBD848 LVR/RAB/Zantopp, R.)

To work successfully in archaeology in the open mining district of Cologne Basin it is necessary to get knowledge as far as possible of what you will see under the surface when digging into the ground.

This knowledge comes by archaeological prospection with the special science disciplines of geophysical measurements, geochemical proofs, geoarchaelogical drillings, surface scans and last but not least aerial archaeology.

This remote sensing method since 1960 systematically at work in the 14,400 km^2 wide Rhineland area of Germany.

To focus this method specially in the three open-mine areas of the Cologne Basin a special project was set up running for over one year, financed by the Foundation "Stiftung Archäologie im Rheinischen Braunkohlenrevier".

A main focus of this project was to test the abilities of vertical and oblique photos in connection with colour-infrared film material.

This paper describes the project-aims, work and results illustrated with a few aerial photographs, plots and digital orthophotos of findings and brings out what changes in aerial archaeology in the whole Rhineland area are initiated by this project.

The following figures will illustrate the workflow from aerial archaeology findings to excavation of an Roman villa in the "Inden" mining district.

Fig. 2. Orthophotomap from the site to prepare further research

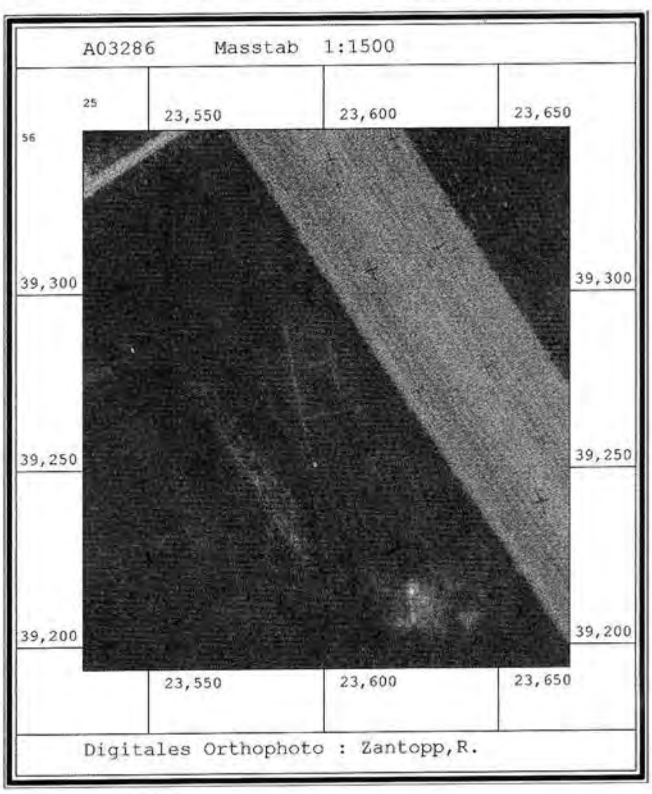
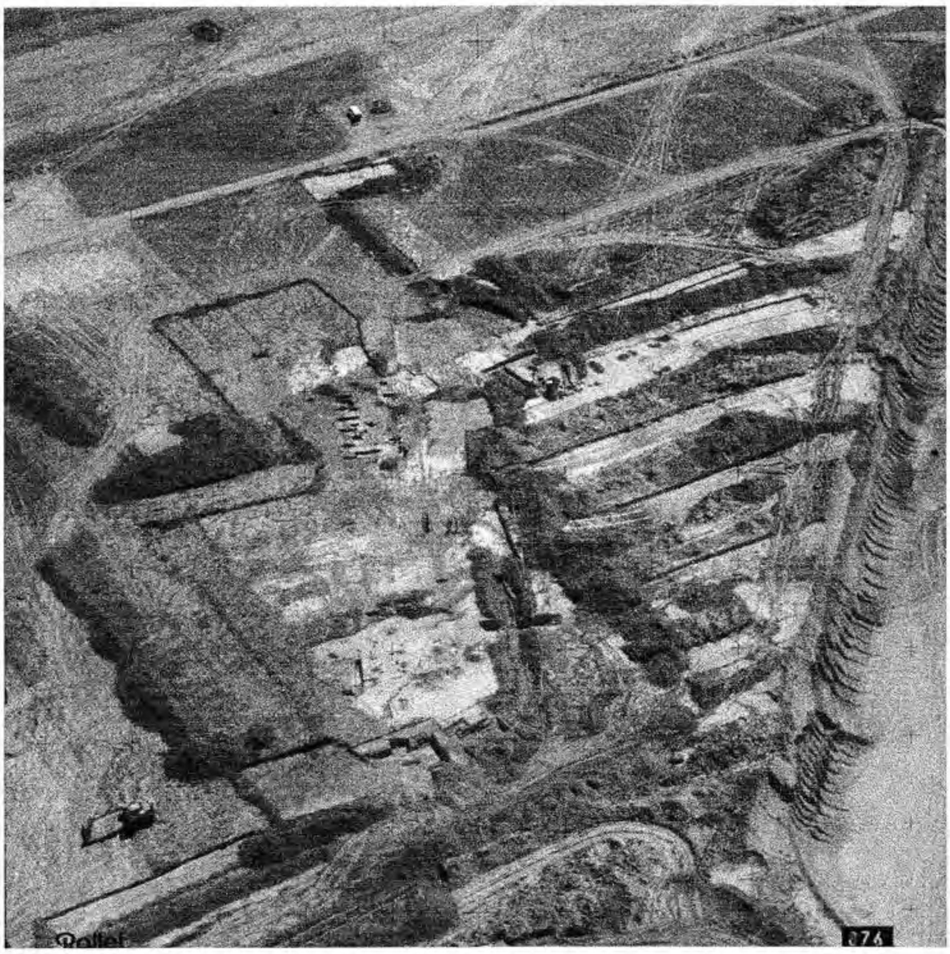


Fig. 3. Excavation on the site short before cole-mining comes (A03286/ MSBE95 LVR/RAB/Zantopp, R.)



M. Zupancic, D. Najdovski

Decoding an Invisible Late Roman Inscription using GPR imaging and EM modeling

In a late Roman city wall of Celje in Slovenia there is, among other secondarily used stone material, a block with a Roman inscription. A part of an inscription is visible. The other part is hidden.

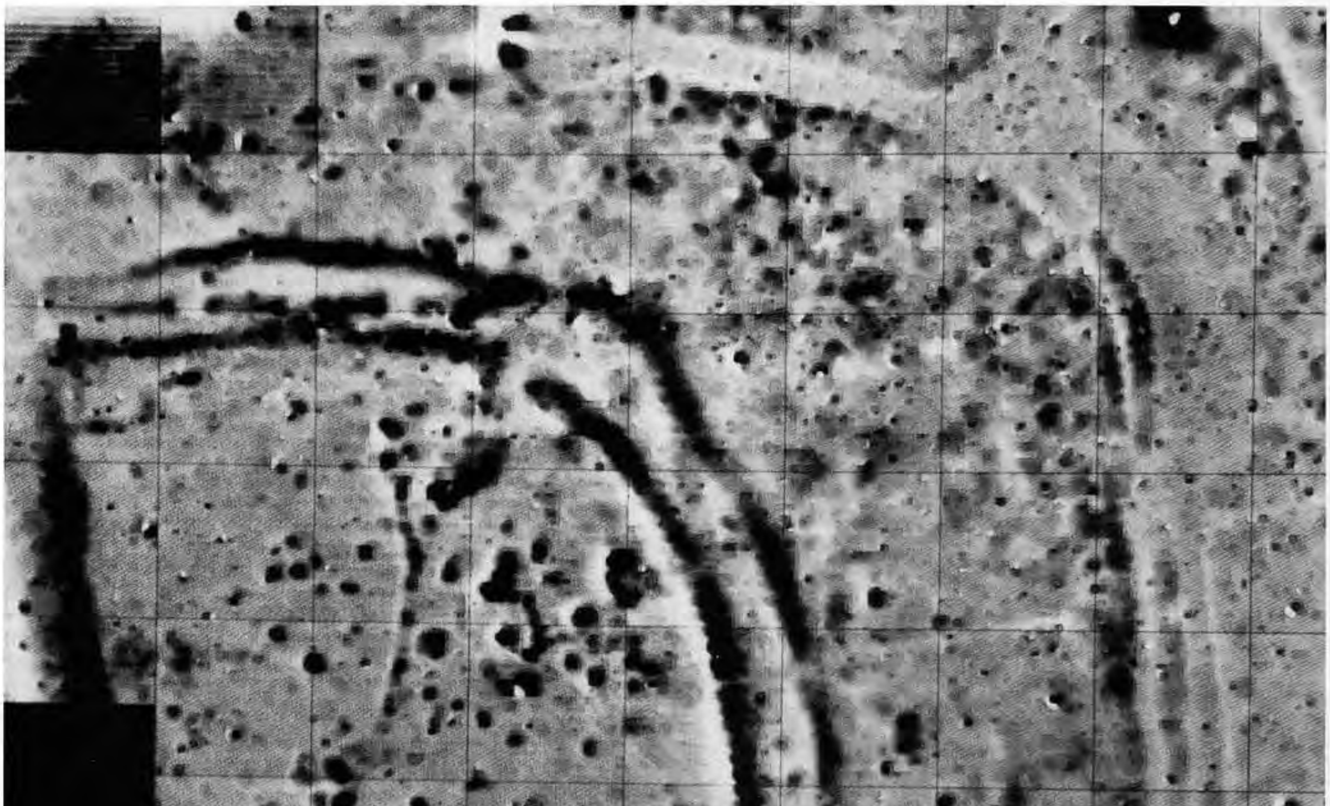
A preservation ethics indicates a nondestructive approach, used by the authors.

To read a hidden part of an inscription we used electromagnetic (EM) modeling for Ground Penetrating Radar (GPR) imaging with a Finite Difference Time Domain modeling (FDTD).

The purpose of our experimental and modeling efforts is to achieve a pre-processed data base for 3D image reconstruction algorithm.

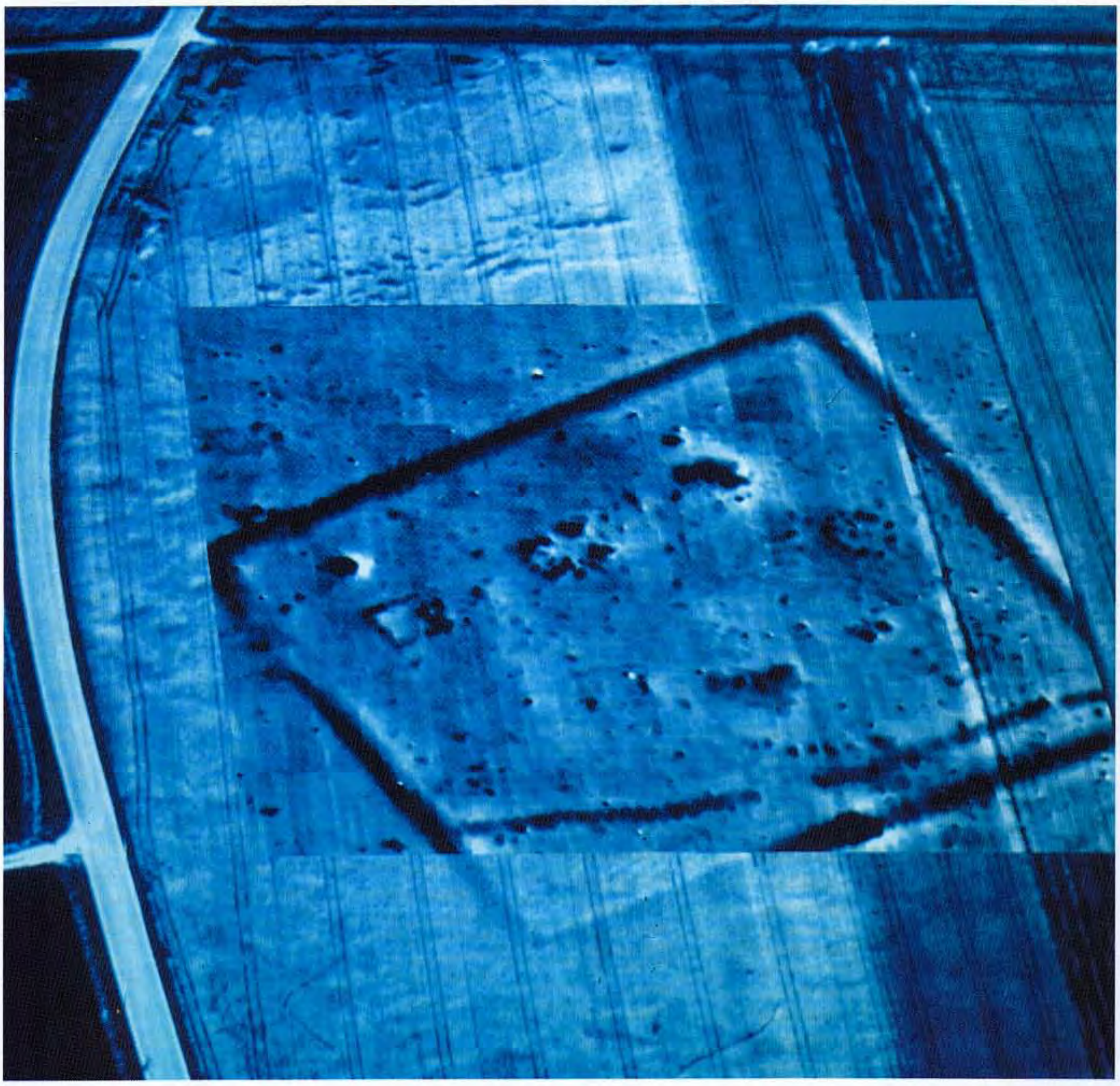
We present a rendering in three-dimensions with high resulution detail visualization.

Keywords: 3D FDTD EM modeling, GPR, 3D radar imaging, visualization.



Methods and Equipment used by the Department Archaeological Prospection and Aerial Archaeology at the Bavarian State Conservation Office, Munich

◁ Fig. above: Aerial view of a neolithic enclosure nearby Riekofen, Bavaria; ditches as positive crop marks.
Below: Magnetometry of the site. The example showing both: enrichment and depletion of magnetic minerals in archaeological soils. On the same site the ditches showing up as a positive magnetic anomaly – enrichment – and as negative anomaly – depletion and dissolution of magnetic minerals



J. W. E. Fassbinder, W. E. Irlinger

Combining Magnetometry and Archaeological Interpretation: A Square Enclosure in Bavaria

Here we present the results obtained by high-resolution caesium magnetometry on a square enclosure of the Celtic period (300–100 B. C.) in Southern Bavaria.

Integration of the geophysical data with archaeological knowledge delivers the crucial information for a detailed plan, for classification and for a description of the archaeological finding.

Introduction

Magnetometry has been used for achaeological prospection for more then 40 years (Belshé 1957; Aitken 1958). However, most results obtained by proton and fluxgate magnetometers reveal only magnetic anomalies greater than 0.1 Nanotesla. Progress in this prospection technique was made by the introduction of digital image processing of the data (Scollar & Lander 1972). The modification of the cesium magnetometer for archaeological prospection (Becker 1982) and the availability of an instrument with a magnetic sensitivity of ± 0.01 Nanotesla (Becker 1995) was a major step in the development (Aveling 1997). We measured the apparent magnetic anomalies of the total earth magnetic field 0.3 meter above the ground in a sampling point density of 0.5 x 0.25 meter. Digital image processing and its representation as a 256 grayscale picture enables a detailed view beneath the soil.

Soil magnetism

Enrichment of ferrimagnetic minerals in topsoil (Le Borgne 1955; Tite & Mullins 1971; Mullins 1977) is frequently observed. The enhancement is due to the formation of maghemite or magnetite by different processes (Mullins 1977; Lovley et al. 1987; Maher & Taylor 1989; Fassbinder et al. 1990). Any intervention in soil produces a magnetic anomaly which can be measured above ground. The contrast in magnetic susceptibilty and remanent magnetization between the structure and the adjacent undisturbed soil enables the detection of single posts and palisades, stone structures, ditches, pits, killns and fireplaces. Depending on the type of soil, the enrichment of magnetic minerals in a trace of a post or palisade may enhance the magnetic susceptibility by 2–50 times and increase the magnetic remanence by 5–20 times (Fassbinder & Stanjek 1993). Man made fire or natural fire may produce a much higher increase.

The cesium magnetometer enables the detection of anomalies caused by each single post in the adjacent loess soil. But the detectability of an archaeological anomaly is a rather complicated function of the sensitivity of the instrument, sampling density, and a function of soil noise which surrounds it (Graham & Scollar 1976). Therefore the magnetic prospection was done on bare soil before planting. The ploughing and the harrowing of topsoil is equal to a mechanical demagnetization and provides ideal conditions for magnetometry.

◁ Fig. 1. Egweil from the air. The magnetic map of the site has been cut in to the oblique aerial photograph of the site

Magnetometry

The principle of the magnetic prospection technique with the cesium magnetometer is based on the measurement of the total magnetic field. For magnetometry we used a high resolution total field cesium magnetometer (Scintrex CS2) with a sensitivity of ± 0.01 Nanotesla (the intensity of the total earth magnetic field in Europe ranges from about 45,000 to 49,000 Nanotesla, the diurnal variations are in the range of 10–30 Nanotesla, and is furthermore depending upon the sun activity). For the field survey we chose the so-called "duo-sensor" configuration in order to have a maximum speed of prospection combined with a high possible sensivity (Becker 1997). A wheel-devised equipment provides a constant distance between magnetometer and topsoil (Fig. 2). In this configuration two sensors are moved in a zigzag-mode 0.3 meter above ground. The sampling speed of the magnetometer (10 readings a second) allows us to measure a 20 meter profile of the grid (20 x 20 meter) in less than 15 seconds. A bandpass filter in the hardware of the magnetometer processor is used to cancel the natural micro-pulsations of the magnetic field. The slower changes in the daily variation of the geomag-

Fig. 2. Magnetic prospection with a Scintrex CS2 caesium magnetometer with the duo sensor configuration

netic field is reduced to the mean value of the 20 meter sampling profile and alternatively to the mean value of all data of a 20 meter grid. This compares to a difference between the measurement of both magnetometer probes and the calculated value of the earths magnetic field. This difference, the apparent magnetic anomaly, is then influenced by the archaeological structure respectivly by the magnetic properties of the soil and the geology.

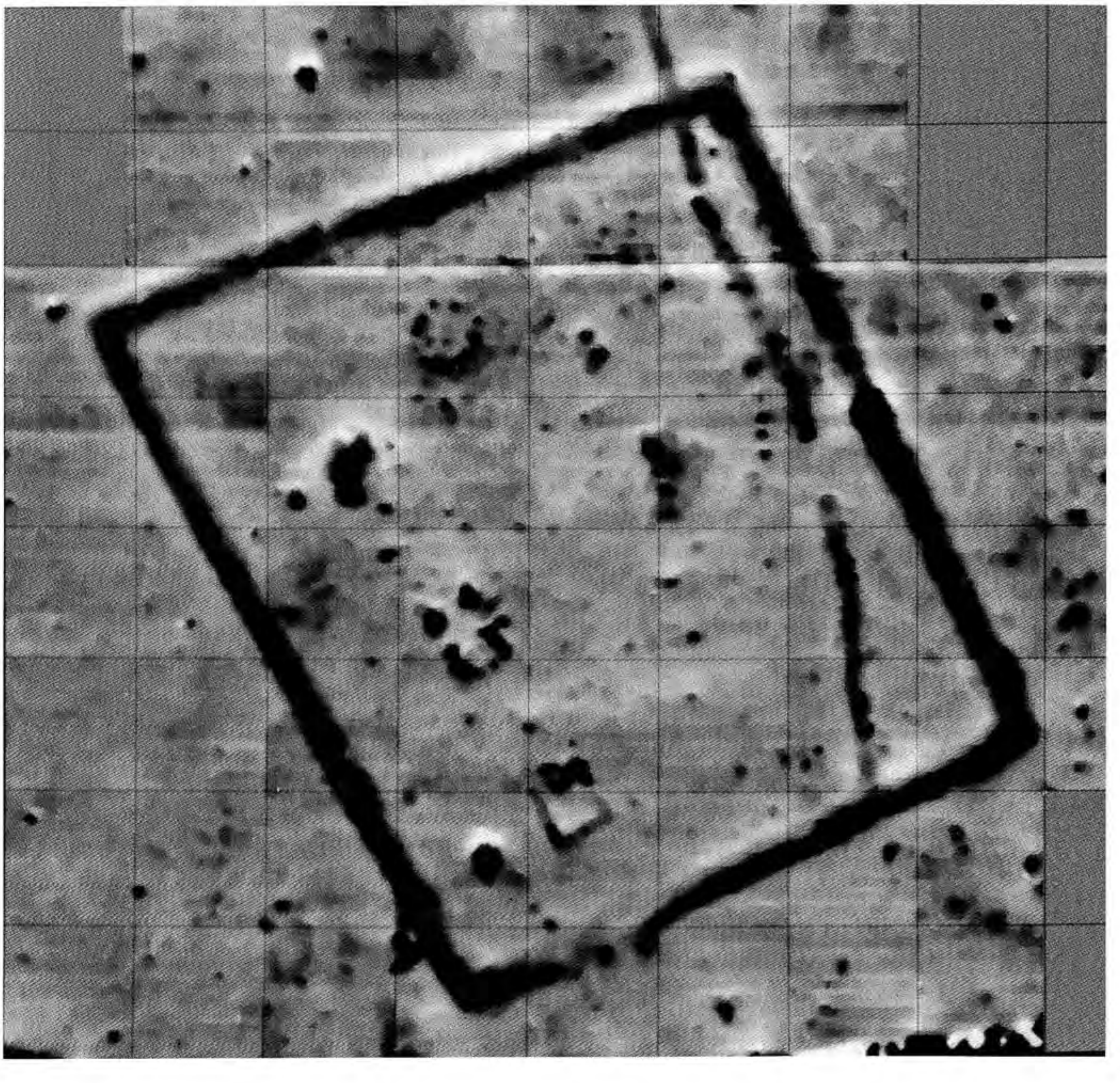
Ninety seven percent of the magnetometer data in a 20 m grid varies in the range of -4.5 to +4.5 Nanotesla from the mean value of the earths magnetic field. All of the stronger anomalies can be ascribed to burned structures or to pieces of iron rubbish. In situ burning is easily distinguishable from iron pieces by the direction of their erratic dipole directions. For image processing the magnetometer readings were converted into gray values ranging from 0 = white to 255 = black. Therefore each gray value compares to a magnetometer value of 0.035 Nanotesla.

Archaeological background

Iron age enclosures are widespread earthworks and occur mostly in Southern Germany (Bavaria, Baden-Württemberg), France, England and the Czech Republic (Bittel et al. 1990; Decker & Scollar 1962). These earthworks are characterized by earthen walls with uninterrupted steep side ditches and a single narrow entry mostly at the east side (Schwarz 1959; Murray 1995).

The square enclosure of Egweil, located at Southern Bavaria, was discovered in 1982 by the aerial archaeologist Otto Braasch. However the photographs show only the ditches as crop marks. The typical form with the uninterupted ditch and the size of the enclosure as it was shown by the aerial picture allows a rough interpretation as a Celtic site (Braasch 1990; Irlinger 1994, 1996a).

Fig. 3. Egweil. Magnetic plan of the iron age Viereckschanze at Egweil. Magnetogram in the digital image processing technique, CS-2 caesium magnetometer (Scintrex) and read out unit (Picodas), sensitivity (0.01 Nanotestla, duo sensor configuration, dynamics – 4.5 to +4.5 Nanotesla in 256 grayscales, sampling rate 0.5 x 0.25 meter, grid 20 x 20 meter



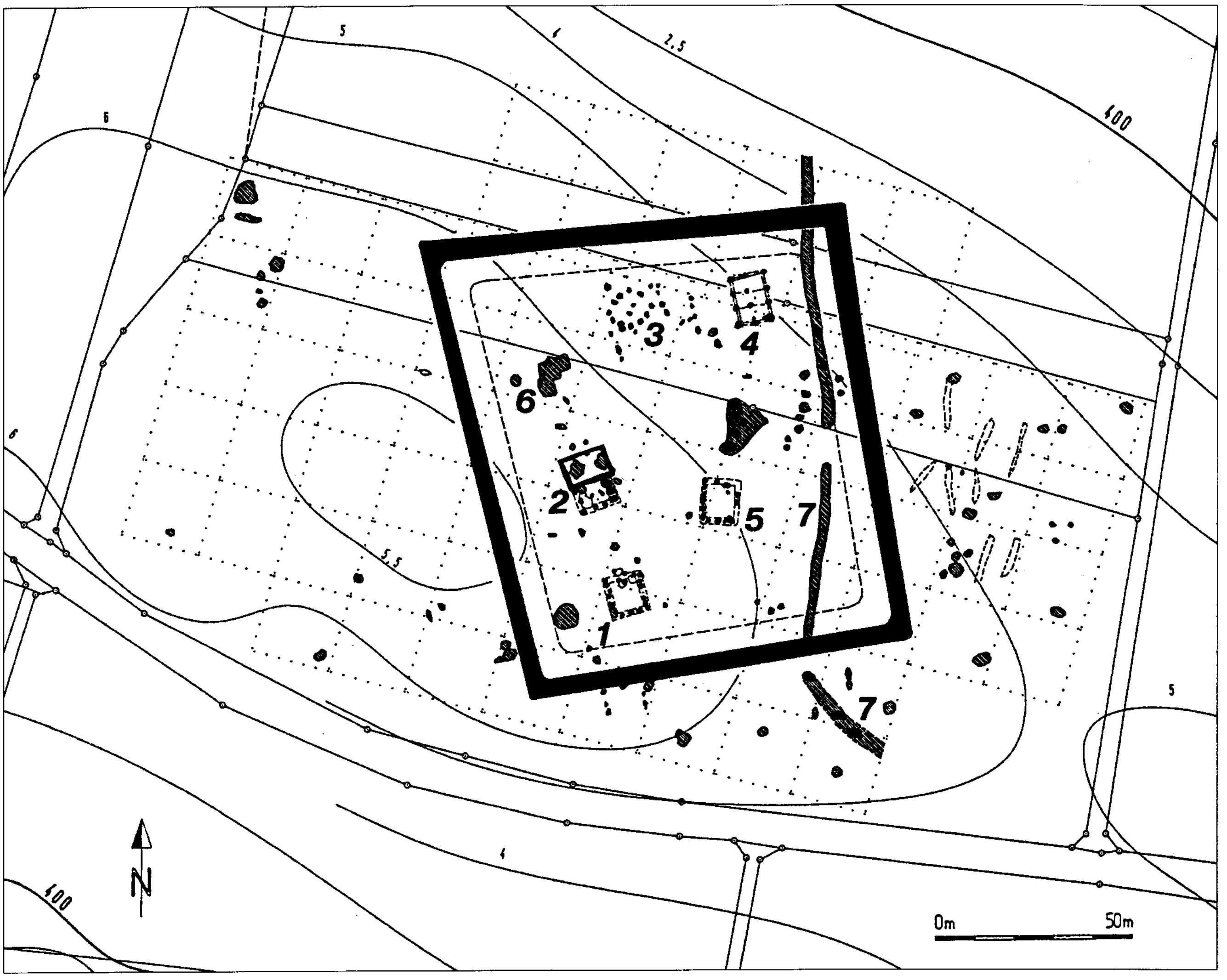


Fig. 4. Egweil. Graphic plan on the basis of the digital image processing of the magnetic picture. Drawn as an overlay from the computer and plotted together with the geographical card

Most of them are rarely visible from the air except when occurring for some days as a crop mark, soil mark or for some hours as snow mark. Although in Bavaria there are 162 enclosures visible above ground by their upstanding earthwalls and ditches, some additional 120 were discovered by aerial archaeology during the last 20 years (Irlinger 1996b).

Information from the inner structure of the monument are known fọr only 24 enclosures in Southern Germany. The function of these enclosures can actually only be discussed controversially. The lack of information on square enclosures yields to contradictory explanations, such as the use of these monuments as animal enclosures or for religious purpose.

Combining archaeological knowledge with geophysical interpretation of the data

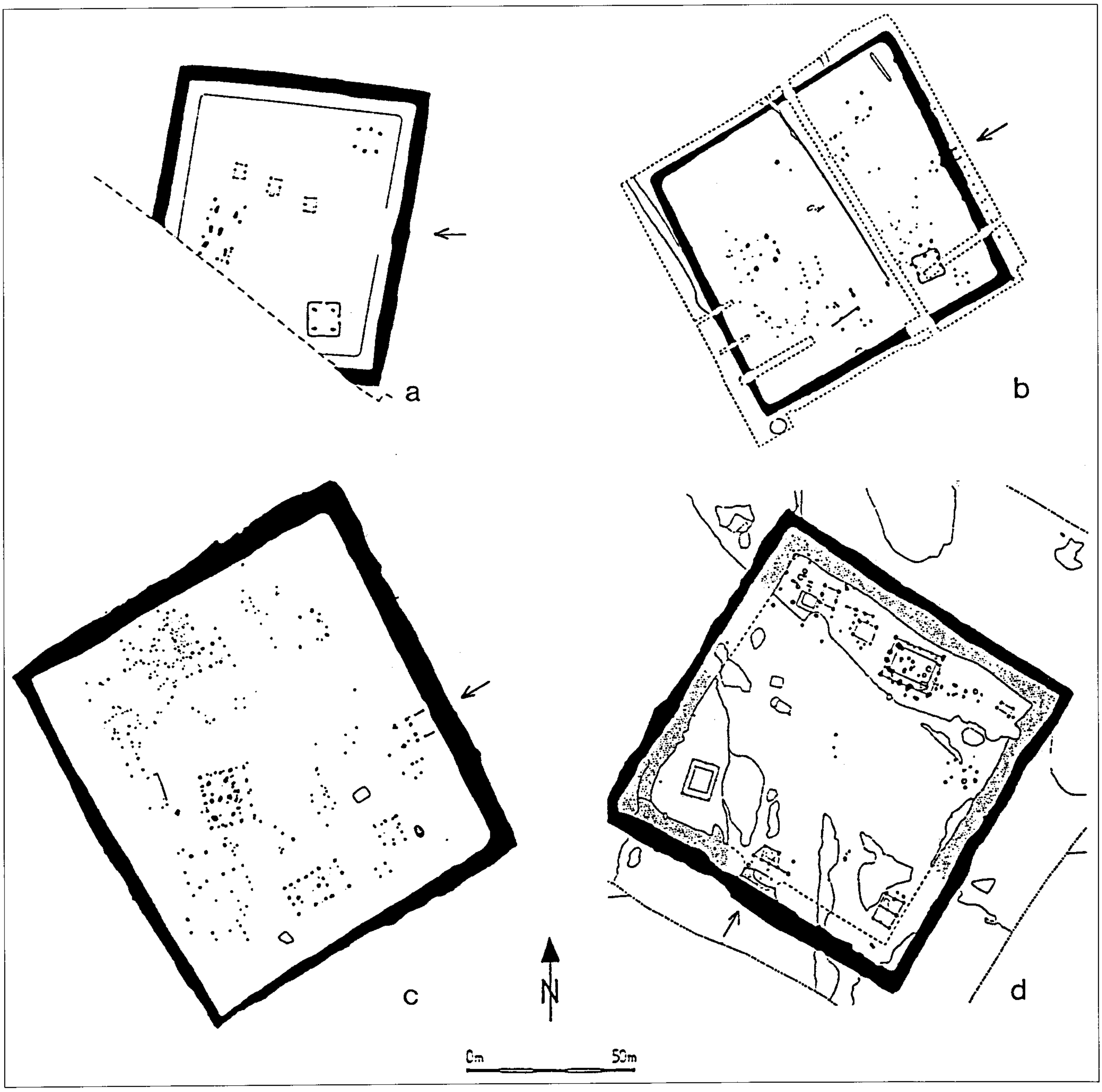
The magnetic measurement reveals all the typical elements of a Viereckschanze (Fig. 3). The inner side of the ditch measures 90 meters in the south, 112 meters in the west, 97 meters in the north and 105 meters in the east respectivly. Characteristic is the difference in the length of the sides as well as in the angles of the corners. The two sides of the south-eastern corner make a rectangle. The others show deviations from the rectangular with 96° in the south-west, 83° in the noth-west and 85° in the north-eastern angle. This finding is one of the peculiarities of Celtic Viereckschanzen. The totally destroyed rampart inside the ditch is indicated by slightly lighter grayshade with a broadness of 6 to 7 meters. Therefore the enclosed area covers estimatly 0.8 hectares, and compares to an average size for a Viereckschanze (Fig. 4), (Bittel et al. 1990; Schwarz 1959). The entry to the enclosure is vague, but is indicated by single posts of a former bridge inside and outside the ditch nearly in the middle of the east ditch. This bridge is broken into the ditch and makes it slightly smaller. Further indication for the entry is the configuration of the buildings inside. This can be compared to excavated examples (e. g. Fig. 5b–d). The location of the entry to the eastern (and to the north-east, see Fig. 5a–c) has been found on many square enclosures. Nearby and parallel to the eastern part of the enclosure, a ditch runs from the north to the south, but belongs to a Neolithic earthwork (Kaufmann 1997) (see Fig. 4,7).

Inside the enclosure we detected clearly the structures of five buildings. These buildings are visible by traces of posts and small ditches (see Fig. 4,1–5). One of them (Fig. 4, 2) seems to have a stone base. Two buildings are located close and parallel to the western ditch having a size of 10 x 12 meters (Fig. 4,1) and 10 x 14 meters respectivly (Fig. 4,2). The latter one additionaly shows stone structures by its negative magnetic anomaly. Building 4,3 is located in the central or in front direction to the entrance. To the north of this building is a large positive anomaly which is due to a pit (Fig. 4,6) similar to the one which has been excavated at Holzhausen (Schwarz 1975). Two buildings are found in a parallel line to the northern ditch by their traces of massive postholes (Fig. 4,3–4). Some anomalies shows clearly the trace of the post inside the posthole. One of them, a single-phase building located in the corner of the northern and eastern ditch, consist of 12 posts (Fig. 4,4). Without any orientation to the ditches and a few meters south-east from the center we found traces of another building (Fig. 4,5).

Conclusion

The complete magnetic map of the square enclosure in its result can be compared to the plans of excavated sites. It contains all the specific structures, the ditch, location of the entrances and the structure and size of the buildings which are typical for square enclosures of the Celtic period (see Fig. 5a–d).

We propose magnetometer prospection rather than excavation as a tool for the mapping of archaeological sites. Excavation and magnetic prospection are both a matter of discovery. While the results of an excavation is the total destruction of the monument, magnetic prospection yields similar results without this destruction. The magnetometry delivers the precise plan, archaeological knowledge the classification and a detailed description of the finding. Apart from the fact, that magnetometry does not lead to archaeological artefacts, it can serve as a substitute for excavation.



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◁ Fig. 5. Examples of four excavated square enclosures at Southern Germany, comparable in their extensions and structures to the result of magnetometry. The arrow marks the entry.
a) from Bopfingen-Flochberg (Krause & Wieland 1993) at Baden-Württemberg (Germany).
b) from Ehingen (Bittel at al. 1990) at Baden-Württemberg (Germany);
c) from Riedlingen (Klein 1996) Baden-Württemberg (Germany);
d) from Pocking-Hartkirchen (Schaich 1997) Bavaria (Germany)

H. Becker

Duo- and Quadro-sensor Configuration for High Speed/High Resolution Magnetic Prospecting with Caesium Magnetometer

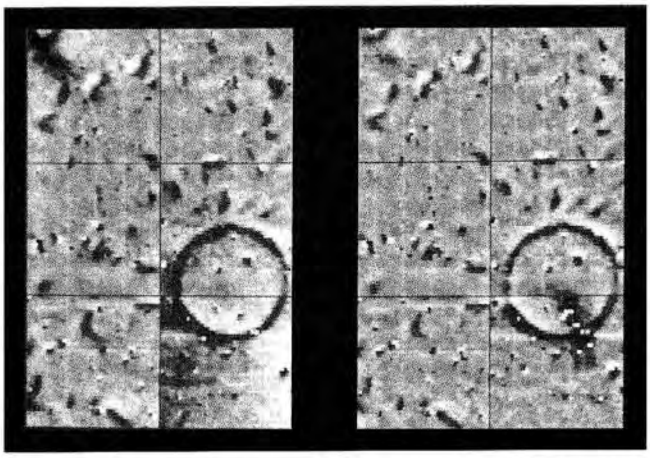

Fig. 1. Wolfertschwenden, Roman burial or mausoleum directly under a power line, duo-sensor configuration of CS2/MEP720 system, digital image of the magnetogram of six 20 m grids, raster 0.25/0.5 m, dynamics -6.4/+6.4 nT in 256 greyscale (white/black). a) reduction of the diurnal variation by the line mean, speed dependent shift correction, no grid edge matching. b) linear reduction of the static field of the high voltage pole in 25 m distance by highpass filtering and desloping, same technical data as a)

The caesium magnetometry with the so-called duo-sensor configuration became the most successful method for magnetic prospection used by the Munich team (H. Becker and J. W. E. Fassbinder). Available since 1996 when the Scintrex SMARTMAG SM4G-Special came on the market, this magnetometer system was nearly exclusively used for our international cooperation work in many countries under most variable climatic and geologic conditions. This paper describes the development of the multi-sensor technique in caesium magnetometry and points out that speed is as important as special resolution and sensitivity for magnetic prospecting in archaeology.

For geophysical prospecting in archaeology the three 's' are required: sensitivity, speed and spacial resolution. These principles for magnetic prospecting are followed in Vienna (Melichar 1990, Neubauer 1990, Eder-Hinterleitner et al. 1996) and Munich (Becker 1990, 1995, 1996, 1997, 1998) by high resolution caesium magnetometry, but other groups are following. The developments in the Munich laboratory with caesium magnetometers V101 (Varian, Scintrex) and CS2/MEP720 (Picodas/Scintrex) met most of the three 's' requirements, but could be still improved in speed (Becker 1997). Fluxgate gradiometers which are widely used in the UK are limited in sensitivity especially applied at most of the low susceptibility contrast sites in Europe (Becker, Jansen 1996). There exists also a five sensor fluxgate gradiometer system (delta Z) developed in Kiel (Stümpel 1995), but this may be also insufficient regarding sensitivity at low susceptibility soils. The V101- and CS2/MEP720 caesium magnetometer systems have been developed for one track gradio- or variometer configuration of the sensors, which ideally compensates the outer geomagnetic variations. It took the author almost two years realizing, that the two sensors of the gradiometer CS2/MEP720 could also be moved parallel in fieldwork covering two tracks for total field measurement at same hight above ground. This simple "trick" doubles the sampling-speed. Every sensor added to the system multiplies the survey speed and opens a wide range for magnetic prospecting over large areas with limited time.

Fig. 2a, b. Duo-sensor on wheels with CS2/MEP720 system (application at Seehof, Photo J. W. E. Fassbinder) and one man carried SMARTMAG SM4G-Special (H. Becker in Resafa 1999, first use by H. Becker at Monte da Ponte in 1995)

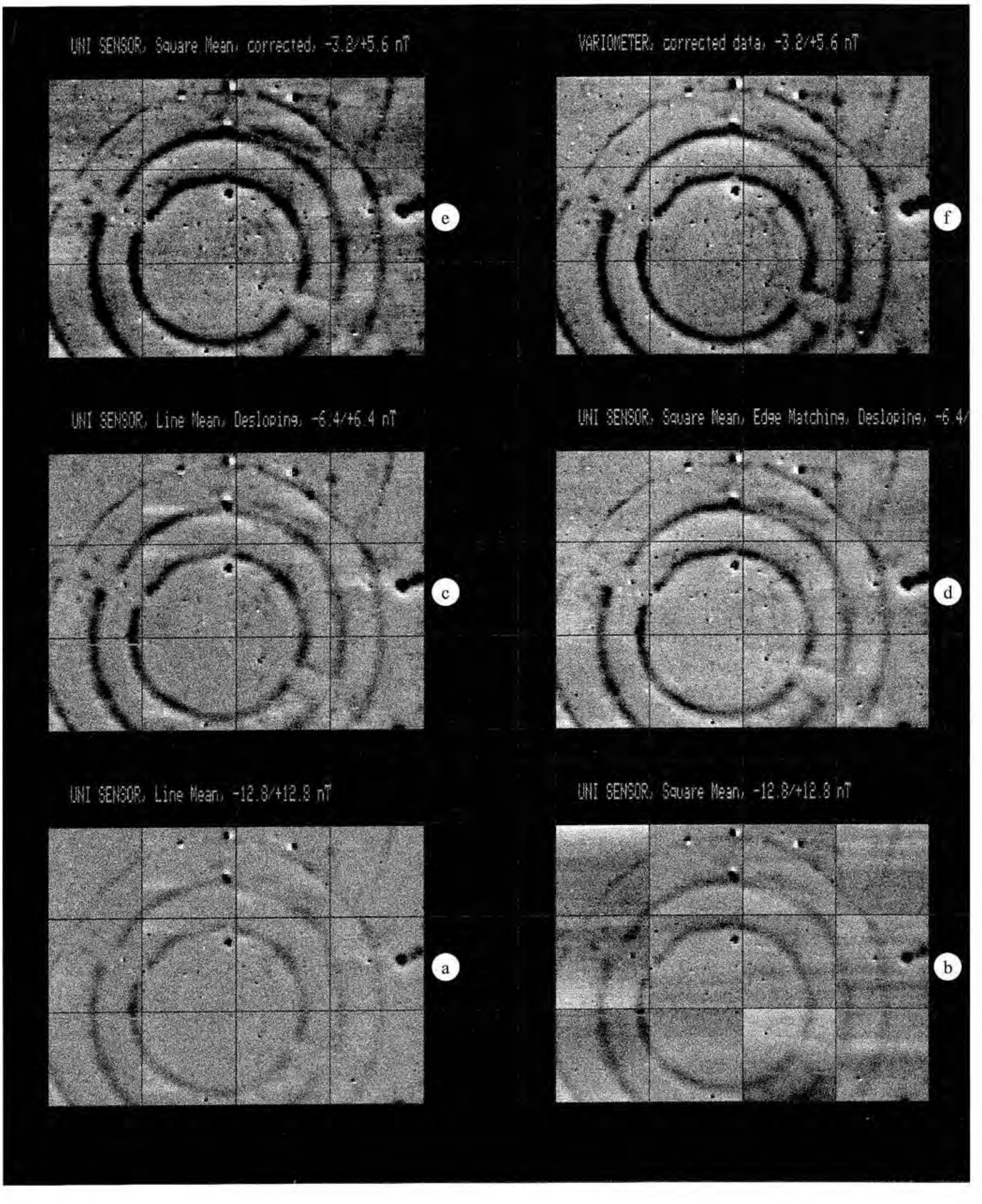

Fig. 3a–f. Reprocessing uni-sensor Schmiedorf-Osterhofen 1986. Caesium magnetometer Scintrex/Picodas CS2/MEP720, sensitivity 0.001 nT, raster 0.5/0.25 m, 20 m grid. a) uni-sensor, line mean reduction, dynamics -12.8/+12.8 nT. b) uni-sensor, square mean reduction, dynamics -12.8/+12.8 nT. c) uni-sensor, line mean reduction, edge matching and desloping, dynamics -6.4/+6.4 nT. d) uni-sensor, square mean reduction, edge matching and desloping, dynamics -6.4/+6.4 nT. e) final result, uni-sensor, square mean reduction, corrected, dynamics -3.2/+5.6 nT to be compared with f) variometer mode, corrected data, same dynamics -3.2/+5.6 nT

Duo-Sensor configuration for caesium magnetometer CS2/MEP720

Every student in geophysics was trained that the base for high sensitive magnetic prospecting is the complete reduction of the natural and technical temporal geomagnetic variations (micropulsations, diurnal variation, powerlines, etc.) by measuring the difference between two sensors in vertical gradio- or variometer mode. However first tests with the CS2/MEP720 Picotesla sys-

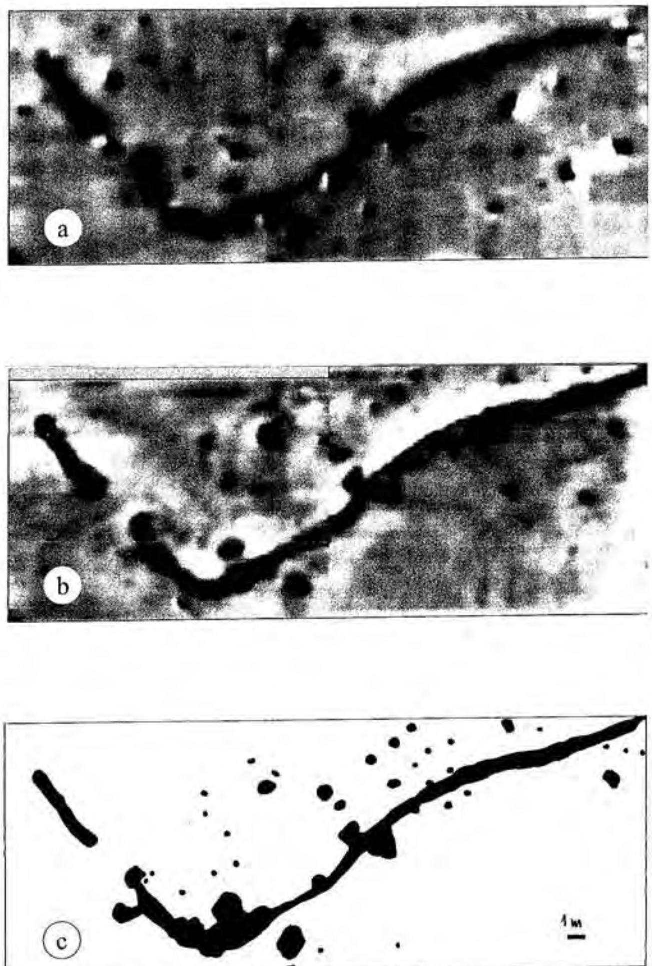

Fig. 4a–c. Murr 1995–1996. Example for surface- and open trench prospecting with duo-sensor on wheels (CS2/MEP720) and man carried application (Smartmag SM4G-Special). (a) Sureface measurement with CS2/MEP720 on wheels; raster 0.5/0.25 m; dynamics -3.2/+3.2 nT. (b) Open trench measurement with hand carried SMARTMAG SM4G-Special, raster 0.25/0.125 m, dynamics -3.2/+3.2 nT. (c) Archaeological findings in the excavation

tem in July 1995 have shown, that the two sensors can be arranged horizontally measuring the total intensity of the geomagnetic field at two parallel tracks at same hight above ground (typically 0.3 m) (Fig. 2a). The survey time in the field is reduced to half. A 20 m grid in 0.5/0.1 m raster can be measured in less than 10 min, an hectar in the same raster (200,000 samples) in 4 to 6 hours.

The key to this new technique is given by the magnetometer processor MEP720 (Picodas, Canada) with electronic bandpass filters selectable for 0.7, 1 and 2 Hz for cancellation of high frequency magnetic disturbances. Similar filters are used with Smartmag SM4G-Special (Scintrex). This offers also the opportunity for magnetic prospecting with Picotesla sensitivity directly underneath powerlines (Fig. 1) or beside electric railways. Also the natural temporal high frequency geomagnetic variations (micropulsations) are cancelled by the same method of electronic bandpass filtering. Only the diurnal geomagnetic variation is reduced by the calculation and differentiation of the line means in a 20 (40) m grid, which follow the main course of the geomagnetic field (Fig. 3a–d). At the moment the diurnal geomagnetic variation shows a extremely smooth curvature because of the minimum of sunspot activity in 1996. For control one has to calculate also the square mean over a 20(40) m square because the line mean would cancel a magnetic alignment in line direction. The square mean reduction might be also important for the detection of deeply buried features. Only temporal variations with a wavelength compatible to the measuring time for a 20 m line (15–20 sec) can not be cancelled by this method. But for the identification of archaeologically relevant anomalies there may be no problem, because these long wavelength disturbances will not show up in the next line and can be identified easily (e. g. Fig. 4).

The first example for a duo-sensor measurement with CS2/MEP720 system shows the magnetic prospecting in July 1995 for a Roman villa near Wolfertschwenden/Bavaria. The area containing a ring ditch possibly of a Roman burial or mausoleum is situated directly under a 500 kV powerline. The high frequency noise had been completely cancelled by electronic filtering with 1 Hz bandwidth, and the diurnal geomagnetic variation by numerical reduction on the line means in the 20 m grids. Only the strong static magnetic anomaly of a huge steel carrier in 25 m distance had been removed by highpass filtering (10 x 10 points) and desloping. Today this archaeological monument is partly covered by a cement paved road which can be identified in the magnetogram by its low noise signature (Fig. 1).

Fig. 5. Ostia Antica 1996. "Magnetoscanner" on its first run, magnetic prospecting with two SMARTMAG SM4G-Special in quadro-sensor configuration on a non magnetic cart (total weight = 48 kg)

In order to show the validity of the used software for the line mean and square mean reduction of the temporal geomagnetic variations a reprocessing of the magnetic prospecting of the Neolithic ring ditch site of Schmiedorf-Osterhofen in Lower Bavaria was made for a uni-sensor configuration. This site had been measured in 1994 with the CS2/MEP720 system in variometer mode (one sensor fixed as base station) in 0.5/0.25 m raster and had been published for demonstrating the magnetic anomalies of palisades in the Picotesla range (Becker 1995). Despite this rather disadvantageous case of a uni-sensor reprocessing with temporal geomagnetic variation up to 20 Nanotesla over the measuring time of a 20 m grid, the result after line mean reduction of the moving uni-sensor is almost compatible with the magnetogram in variometer mode (= difference of the moving sensor and the base station) (Fig. 3a–d).

In the meantime the duo-sensor configuration is applied as the standard method for magnetic prospecting carried out by the Munich team. The limits of this powerful method for large coverage in archaeological prospection are found on areas with nearby moving strong magnetic sources like trucks, caterpillars or tank lorries. But for "normal" applications in agricultural areas the duo-sensor configuration for caesium magnetometers with selectable bandpass filters may be used for double speed or double spacial resolution.

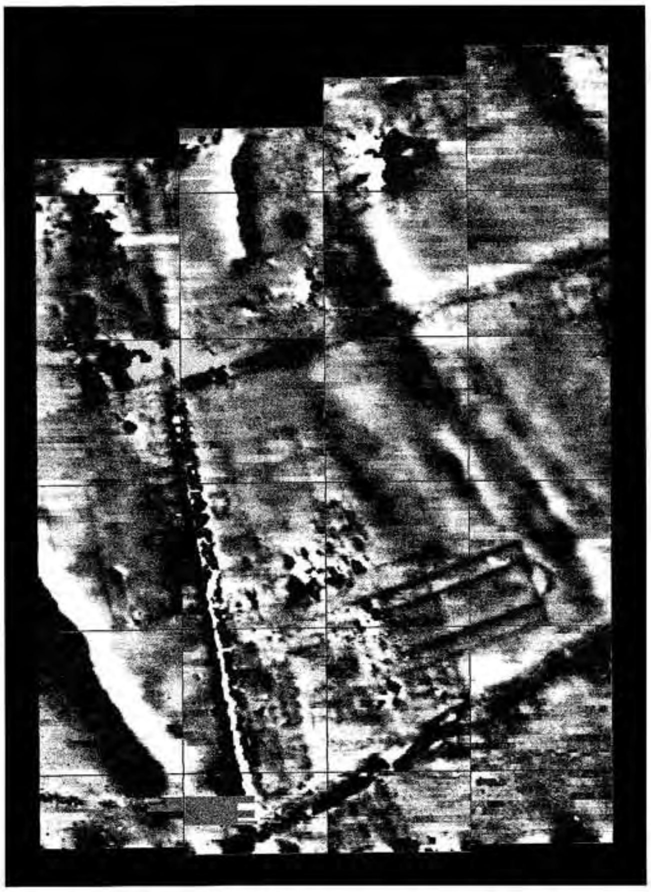

Fig. 6. Ostia Antica 1996 Magnetogram (detail with the basilica of Constantinus I.) in greyshading, dynamics -50.00/+50.00 nT in 256 greyscale (white/black), sensitivity ± 10 pT, raster after resampling 0.5/0.25 m, 1 Hz bandpass-filtering, reduction on 40 m line means, 40 m grid, Mag Nr. OS96-A

Duo-sensor configuration for Caesium magnetometer Scintrex SMARTMAG SM4G-Special

Since 1996 there are two new caesium magnetometers as gradiometer (or variometer) systems available: SMARTMAG SM4G (Scintrex, Canada) with 10 pico Tesla (0.01 nT) sensitivity at 0.1 sec cycle and G586 (Geometrix, Canada) with 0.5 nT at same speed. On request Scintrex made some modifications for archaeological prospecting and a SMARTMAG SM4G-Special caesium gradiometer was extensivly and successfully tested in the duo-sensor configuration on the Copper Age site of Monte da Ponte (Portugal) in March 1996 covering about 7 ha. The same site was already used as a test area for CS2/MEP720 system in variometer mode in 1994 and 1995, which covered about 4 ha (Becker 1997). Because of the rough topography of the site the instruments were used only in a carried application with a manual distance triggering at 5 m intervals. The quality of the data was found to be better with the SMARTMAG than CS2/MEP720 because of improvements of the resampling program with a perfect speed dependent shift correction. Due to the rather strong magnetisation contrast of the site the difference of the sensitivity by a order of 10 between the two systems was not significant.

Another direct comparison of duo-sensor configurations of CS2/MEP720 and SMARTMAG was carried out in the Neolithic settlement near Murr, Bavaria in July 1996 (Becker 1996). The whole site and the vicinity (about 10 ha) was surveyed in July/August 1995 with CS2/MEP720 system in duo-sensor configuration on wheels with 0.5/0.25 m raster. A small area was remeasured with SMARTMAG in a man carried duo-sensor version with 0.25/0.125 m resolution over the open trench of the excavation, after the top soil had been removed by a caterpillar tractor. The comparison between the high resolution magnetograms with the excavation illustrates the main problems of such prospecting work especially of detecting the detailed structure of prehistoric houses (postholes) (Fig. 4a–c). The correspondence of the high resolution SMARTMAG magnetogram over the open trench with the archaeological features in the ground is almost perfect. Even the magnetic anomalies of the postholes of a Neolithic house show up clearly. These anomalies are also visible in the magnetogram of the closed surface, but they are badly disturbed by magnetic features in the top soil. Therefore it may be rare detecting a single posthole from the surface because of the noise of the surface and the top layer. Only typical houses are identifiable in high resolution magnetograms over big areas, when the whole layout of houses become visible.

The main advantage of the SMARTMAG system compared with CS2/MEP720 is the fact that it can be operated as a one man carried application due to less battery weight and miniaturisation of the electronics and data storage which is kept in a small console (Fig. 2b). For the CS2/MEP720 system two persons were necessary because of the separation of the sensor unit and the magnetometer-processor/data storage/battery unit. The long cables between these 2 units caused lots of problems espe-

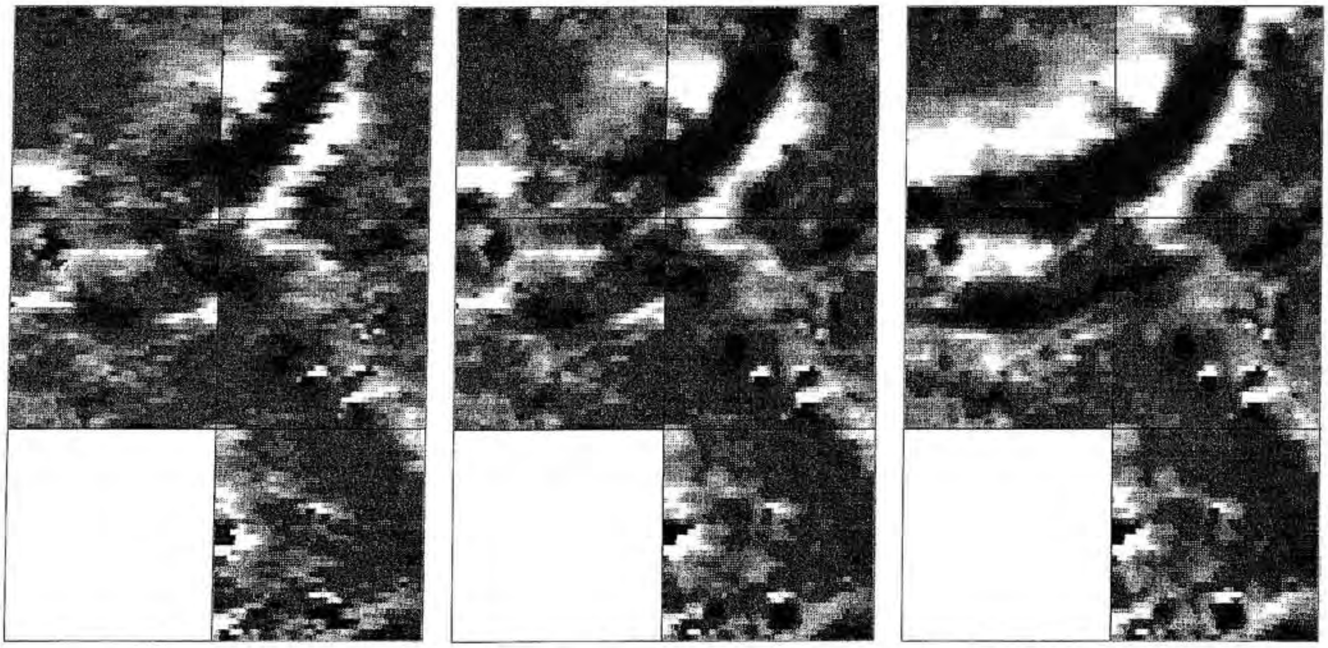

Fig. 7. Monte da Ponte. Speed dependant shift correction and influence of the line mean and square mean reduction of the temporal geomagnetic variation. Magnetogram of five 20 m grids at the second wall (see Fig. 4), raw data (left), speed dependant shift correction with reduction on the line mean (middle), same with reduction on square mean (right), which shows the complete trace of the second wall

cially under rough surface conditions, where a third person was needed only for clearing the cables. With SMARTMAG even as one man carried application with duo-sensor configuration 1.5 ha per day at 0.5/0.1 m spacial resolution (200,000 samples) can be covered easily. On large areas 40 m grids are used instead of 20 m which again improves the survey speed. Some modifications of the data acquisition program of SMARTMAG with automatic increment of line number and reset of station number after stop still could speed up field operation. The limits of ground coverage for high sensitivity/high speed/high spacial resolution caesium magnetometry are no more set by the instrument but only by the walking persistence of the operator.

Quadro-sensor configuration for caesium magnetometer SMARTMAG SM4G-Special

The experiments with the duo-sensor configuration may have demonstrated that modern caesium magnetometers like SMARTMAG offer the opportunity also for a quadro-sensor configuration simply by arranging the four sensors of two gradiometer systems horizontally. The whole setup of such a system consisting of the four sensors A, B, C, D with four magnetometer/sensor electronics, two consoles AB and CD and four batteries have been mounted on a non magnetic cart. The quadro-sensor system on wheels reach a total weight of 48 kg (non magnetic cart = 18 kg, batteries = 14 kg and 4 magnetometer systems = 16 kg) and can still be operated in the field by one person (Fig. 5).

A first test of a quadro-sensor system was carried out in August 1996 at Ostia Antica, the ancient harbour of Rome. An test area of 15 ha was measured in the regio V of Ostia during seven days of field-work. In the meantime under smooth surface conditions the prospection of 1 ha with 0.1/0.5 m spacial resolution may be done with the quadro-sensor chariot in 2 hours. The project in Ostia resulted in the discovery of the basilica of Constantinus I. (Fig. 6, for details refer to Becker 1999 later in this volume).

A compensated quadro-sensor configuration was also tested 1996 in the prospection for a Roman road station near Oberdrauburg/Austria, where the fifth magnetometer was successfully used as base station in variometer mode for monitoring the temporal geomagnetic variations. No difference was found between this compensated (4 + 1 sensor) configuration and the double duo-sensor processing.

Resampling procedure and data processing

Fast moving sensor systems need special procedures for sampling and data processing. The major advance for fast field measurements with high spacial resolution is the time mode sampling instead of the event triggered sampling at distinct sample intervals at 0.5 m. Modern magnetometers allow ten measurements per second with picotesla (pT) sensitivity (MEP720/-CS2, Picodas/Scintrex), 10 pT sensitivity (SMARTMAG SM4G, Scintrex) and 50 pT sensitivity (G586, Geometrix). The high frequency geomagnetic time variations are canceled by bandpass filtering 0.7, 1, 2 Hz for Picodas MEP720 or 1,2,8 Hz for Smartmag SM4G. As mentioned above the diurnal variation is reduced to the mean value of a 40 m line and also to the mean value of a 40 m square to be sure not canceling anomalies directly in the line. The cycle of Picodas MEP720 and Scintrex SMARTMAG SM4G can be set to 0.1 sec (10 measurements per second) which means a spacial resolution of 10 – 15 cm at normal to fast walking speed. With rather fast sensor moving systems the problem of a data shift must be solved, this means in zig zag mode a displacement of the sensor's position even after exact distance triggering. The measuring time of the magnetometer should be known for exact distance triggering, which is also dependent to the walking speed. This shift correction must be calculated with a time constant, which is typical for specific magnetometer types (0.25 for MEP720/CS2 and 0.75 for SMARTMAG). Only a speed dependent shift correction results in a 'sharp' image for the magnetogram (Fig. 7a–d).

Conclusion and future aspects

In 1996 an area of about 80 ha, but in 1997 an area of 140 ha with 0.5/0.1 m spatial resolution (70 Million readings) had been measured with CS2/MEP720 and two SMARTMAG SM4G-Special systems. The prospecting program in Bavaria was handicapped by restrictions for transportation of the equipment on site for the two survey teams. The development of the basic instrumentation for high speed/high resolution magnetic prospecting even for routine application in the archaeological monument conservation programmes has been finished now. Possibly a compensated multi-sensors configuration (4+1 sensor) will get more importance in the future after the sunspot minimum in 1996. Automatic positioning systems consisting of GPS for beginning and end of a line combined with wheel-triggers for exact distances on the line may speed up field procedure even more. The two MEP720 systems with four CS2-sensors and five SMARTMAG SM4G-Special caesium magnetometers with three consoles which can be operated as 2 complete compensated quadro-sensors systems, which will attribute a important part in archaeological research and archaeological monument conservation.

Acknowledgement

Bayerische Motorenwerke AG BMW sponsored the compensated SMARTMAG quadro-sensor system by adding 3 to the existing 2 sensors. Jörg Faßbinder designed the electronic interfaces for the positioning systems of MEP720. Thomas Becker built two prototypes of nonmagnetic carts for the duo-/quadro-sensor configurations. Rainer Appel wrote the resampling software RESAM2 for the duo-sensor and JOIN4 for the quadro-sensor application. The archaeologists Philine Kalb (German Archaeological Institute Lisbon) and Martin Höck (Universidade da Beira Interior, Covilha, Portugal) supported the extensive test-measurements in 1994 to 1996 at Monte da Ponte, Portugal. Michael Heinzelmann (German Archaeological Institute Rome) organised the project at Ostia Antica. Robert Hetu (Munich Department) checked the manuscript for proper English.

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Prospection in Cooperation with Foreign Authorities (1991–1999) selected examples

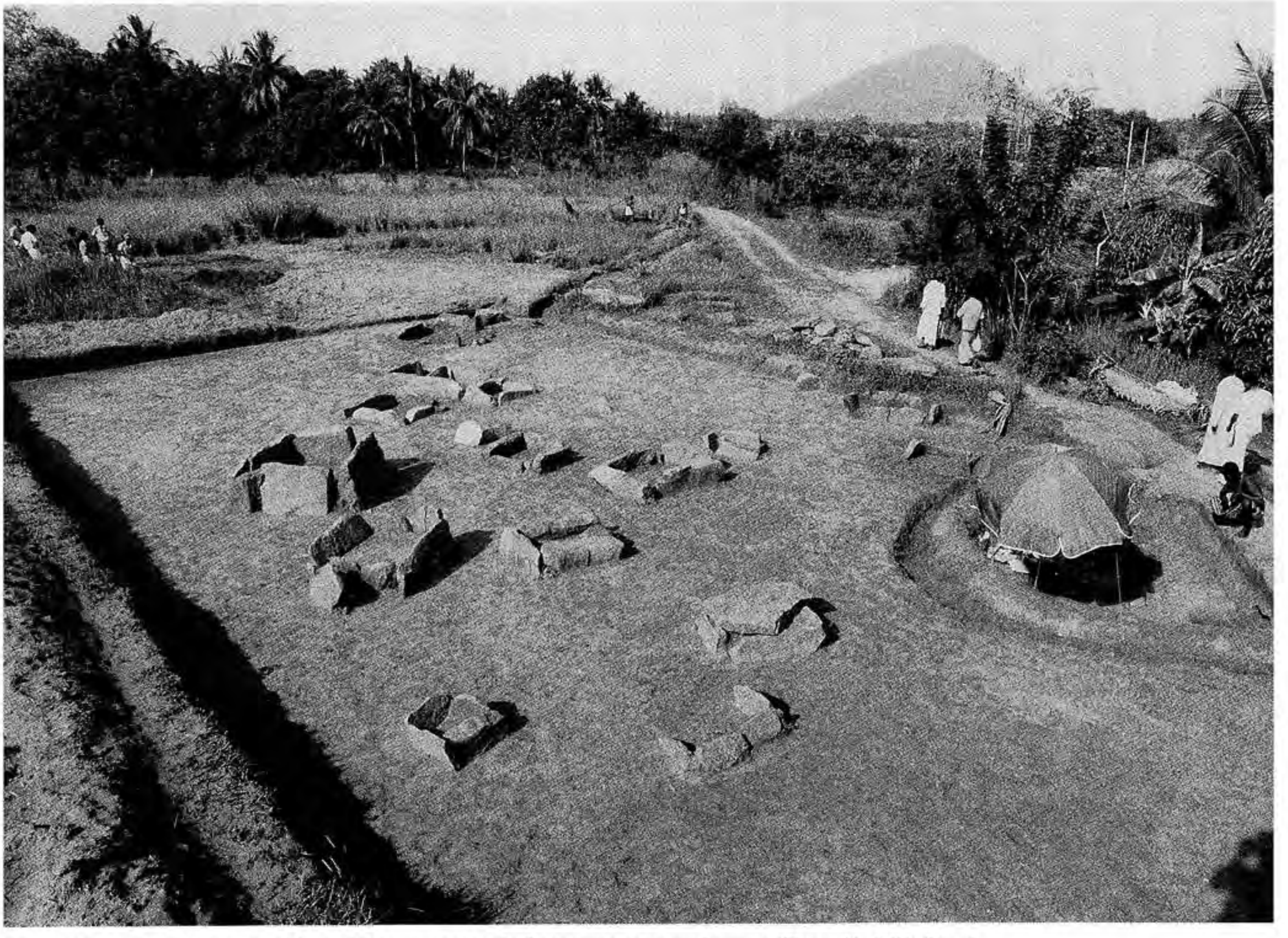

Fig. 1. Ibbankatuwa, Sri Lanka. View of the survey area. In front some excavated graves (Photo. H.-J. Weißhaar)

J. W. E. Fassbinder, H. Becker

Magnetic Prospection of a Megalithic Necropolis at Ibbankatuwa (Sri Lanka)

In a cooperation with the Bavarian State Conservation Office, an international research project of the Kommission für Allgemeine und Vergleichende Archäologie (KAVA) and of the Unesco (Sri Lanka Cultural Triangle Dambulla Project, and the "Archaeology and Research University of Kelaniya Archaeological Team" a geophysical prospection was carried out at a protohistoric megalithic necropolis at Ibbankatuwa (Sri Lanka).

Introduction

The granite stones of the megalithic graves at Ibbankatuwa (Ibbankatuwa = translated from the language of the people of Sri Lanka: field of the turtles), are distributed over an area of 300 x 250 meters. Some of them were visible above the ground but it was believed that many others were covered by soil. Between

1988 and 1991 21 graves of the necropolis were excavated by the KAVA. It was suggested that the graves formed clusters belonging to different settlements or periods. The aim of the prospection (in the year 1991) was therefore first to find all graves, to make a detailed plan of the necropolis to avoid further excavation and to find out whether there is a clustering among the graves or do we have a random distribution. From the excavation we know that the undisturbed graves consisted of four site shapes (0.7–1.6 meter) and a coverstone. Some graves, one of which was extremly long, were divided into three parts. In the undisturbed graves were found one or two urns. Some urns were also found outside the graves.

Instruments

For the survey we used the cesium magnetometer system from Varian/Scintrex (V101, Canada). This consists of two magnetometer probes with an automatic data log on a handheld computer, the sensitivity ± of 0.1 Nanotesla and gives 10 readings per second. The intensity of the total earth magnetic field at Ibbankatuwa ranges from 36,000 by ± 1,000 Nanotesla. For the survey we used the instrument in a gradiometer configuration (Fig. 1). The reason was by using the variometer configuration we measured local disturbences of the magnetic field intensity of > 200 Nanotesla caused by the underlying granite rocks. The limitedness of the computer equipment however alowed only the dynamics of the original field data ± 99.9 Nanotesla. Readings were taken with a density of 0.5 x 0.5 meter in a 20 x 20 meter grid at a sensor hight of 0.3 meter and 1.3 meter respectivly.

The use of the portable computers or Laptops offers the opportunity of rough data processing right in the field. There are programs for prints of the 20 x 20 meter-block data and a graphic display as a symbol density plot, both on a battery driven printer. By this method, the main archaeological features can be made already visible in the field. For final data processing in the laboratory, the field computer is interfaced to the digital image computer. It is possible to present the magnetic data a digital image however (Fig. 3). The measured point in the field is considered as a picture point (a pixel) and the magnetic intensity values are transformed to gray values ranging from 0 (black) to 255 (white). After statistical analysis and depending on the intensity of the magnetic anomaly, we chose a window (normally from −10.0 to +15.5 Nanotesla) for a linear transformation of the magnetic intensity value into the gray value of the digital image to preserve the highest sensivity (± 0.1 Nanotesla) of the survey. All data corrections and enhancements were done in the interactive digital image processing technique. Filtering procedures, contrast enhancement and false color transformation allow easy identification of the archaeological features in the magnetic image.

The archaeological relevant structures are marked by hand on a transparency over the hardcopy (photograph of the screen) and are transformed as vectorial data to the graphic computer or directly on the screen. The result which is given to the archaeologists is the plan drawn by a plotter with china ink (Fig. 4).

Fig. 2. Ibbankatuwa. Caesium magnetometer system employed in Sri Lanka. The probes are covered by banana leaves to give them a shelter upon the sun. The caesium magnetometer with vertical gradient configuration of the sensors; difficult to see: the tilting of the probes by proximately 45° to the north direction

Magnetic properties of the soil

The use of magnetic prospecting techniques (Aitken, 1974; Becker, 1990) for the mapping of buried features, such as pits, ditches, posts and palisades as well as walls and tombs is possible when there is a magnetic contrast between the archaeological structures and the underlying sediment.

The magnetic properties of the soils differ from those of the underlying sediments or rocks and are therefore of great importance for the interpretation of magnetometer readings. Enhancement of the ferrimagnetic minerals magnetite and maghemite is frequently observed in the top layer of soil horizons (Mullins 1977). While the formation of maghemite in soils is due to natural or man made fires (Le Borgne 1955), pedogenic e.g. in situ formed magnetite may be ascribed to the magnetofossils of magnetic soil bacteria (Fassbinder et al. 1990)

The concentration of ferrimagnetic iron oxide was measured in terms of the susceptibility of soil samples, the susceptibility of the pottery and the susceptibility of the granite rocks of the gravestones. The granite rock showed an unexpected high susceptibility of 30 x 10^{-3} SI units. Table (1) shows the mean volume susceptibility (SI-units) of the A, B and C-horizons, the susceptibility of the pottery and of the underlying granitic rocks. The side shapes and coverstones of the graves consists of the same rocks.

Sample mean volume susceptibility (10^{-6} SI)	
A-horizon	370 ± 10
B-horizon	280 ± 10
C-horizon	235 ± 10
Pottery	1,700 ± 20
Granite rock	33,000 ± 100

Table 1.

Results

Magnetic prospection has been carried out in an area of 100 x 180 meters. Parts of the area cannot be measured because of the thick underbrush and the cobras hanging from the trees. The magnetic picture of the ground reveal some quadru or multipole

Fig. 3. Ibbankatuwa. Digital image of the magnetometer data of the surveyed area at Ibbankatuwa. Magnetogram in the digital image processing technique. Ceaesium magnetometer system from Varian/Scintrex, V101, Canada, sensitivity ± 0.1 Nanotesla, gradiometer configuration, dynamics -10.0 to + 15.0 Nanotesla in 256 grayscales, sampling rate 0.5 meter, grid 20 x 20 meter

anomalies resulting from the extraordinary remanent magnetization of the granite rocks. The graves consists of four site shapes (0.7–1.6 meter) and a sometimes big coverstone, each forming a magnetic dipole. This configuration forms sometimes a rather complicated magnetic anomaly pattern, which causes problems for a valid interpretation.

The natives of Sri Lanka use every, and even the smallest piece of metal as well as the caps of our soft drink bottles to make some tools for themselves. This is the reason why we had absolutly no noise due to modern scrap or waste in the magnetic survey. The magnetic picture reveal groups of graves. Most features in the prospection plan describe rather the whole grave than single stones. Beside some graves we found single anomalies which may be ascribed to the occurrence of pithoi as they where found by the excavation but these anomalies may also be caused by single granite rocks.

Conclusion

The magnetic survey at the megalithic necropolis Ibbankatuwa results in the identification and recording of several clusters of site shapes and cover stones of the necropolis. The results demonstrate that magnetic contrast between the granite rocks and the underlying soil is strong enough to detect all stone features. Together with the results of the excavation, it was possible to complete a detailed plan of the whole necropolis.

Acknowledgements

In memoriam Prof. H. Kilian. We thank Prof. S. Banderanayake and Dr. R. Silva for his continual encouragement and support during our work at Sri Lanka; K. Brianda a student of the Kelaniya Archaeological Team, Sri Lanka for his field assistance. The lively discussions with Dr. J. Weißhaar are greatly appreciated. Thanks to Robert H. Hetu for reviewing the manuscript.

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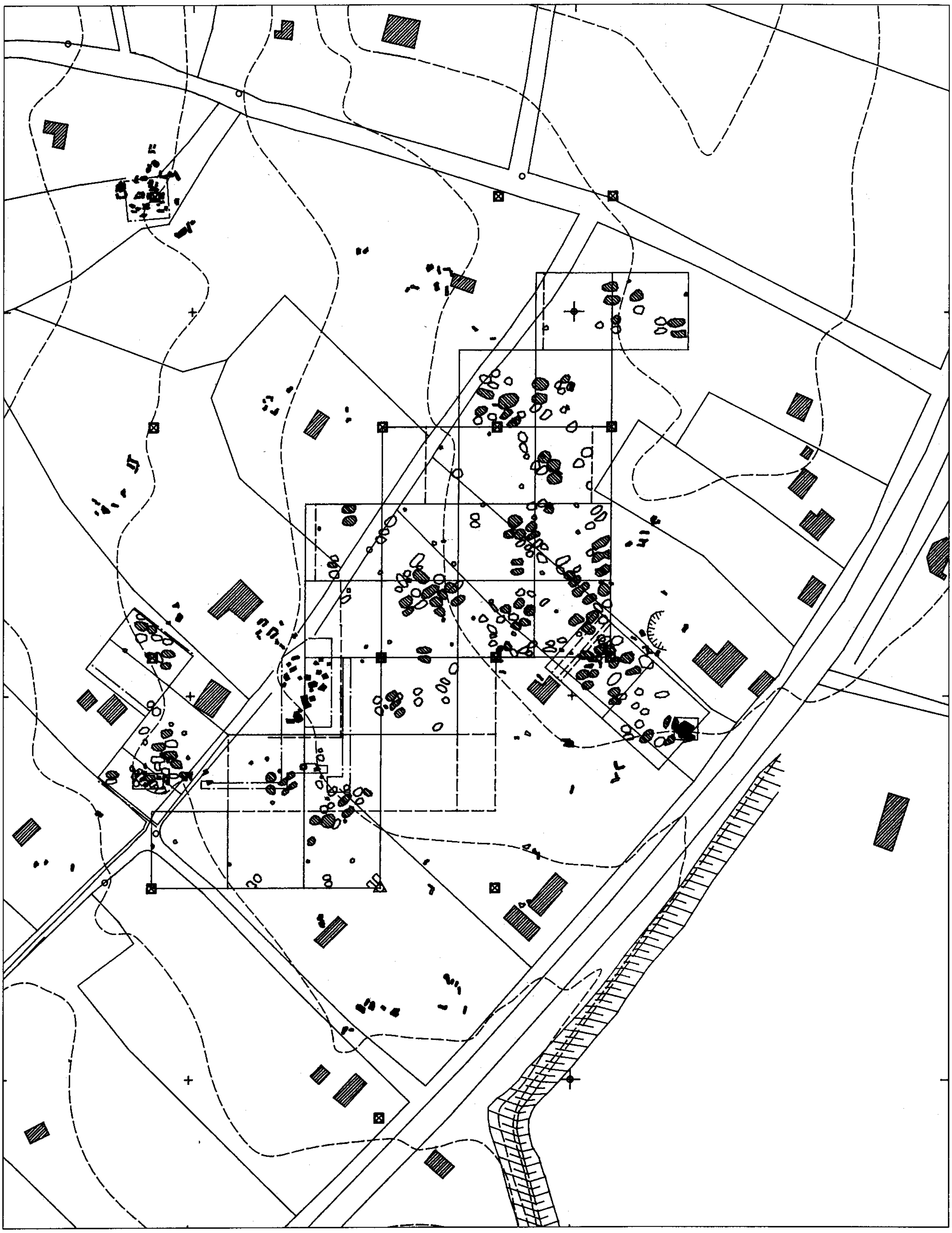


Fig. 4. Ibbankatuwa. Plan of the whole necropolis at Ibbankatuwa based on the interpretation of the magnetic prospecting data and on the excavation plan

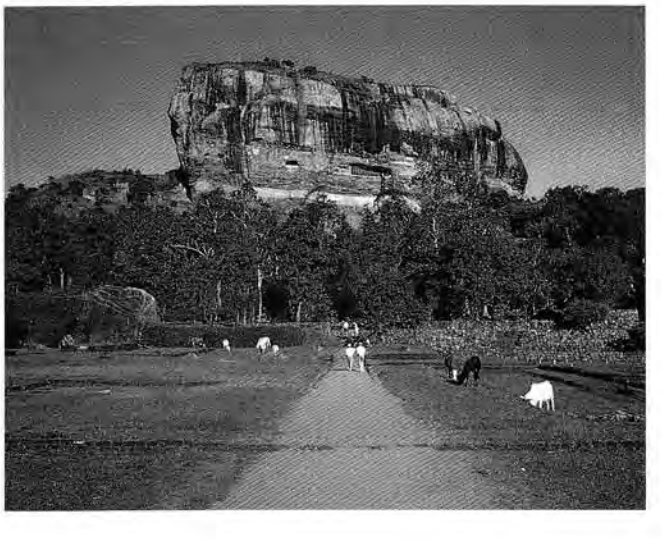
Fig. 1. Sigiriya. Excavated garden architecture

J. W. E. Fassbinder, H. Becker

Magnetometry in the Garden of the Sigiriya Rock Fortification (Sri Lanka)

In a cooperation between the Bavarian State Conservation Office, the Kommission für Allgemeine und Vergleichende Archäologie (KAVA), the Unesco (Sri Lanka cultural Triangle Sigiriya Project, and the Archaeology and Research University of Kelaniya Archaeological Team.

Fig. 2. Sigiriya rock from the west



Introduction

The old rock fortification Sigiriya consists of a large gneiss-rock 200 meters high which is surrounded by a fortification from the 4th to 5th century (Fig. 2). The name Sigiriya is probably a composition of the word "giri" (rock) and "sinha" (lion). Another explanation would be "mouth of the lion". This could be because of the entrance which forms an huge lion. The rock forms the middle of a park landscape with artificial lakes which is surrounded by an 2,400 meter long wall on both sides with an water filled ditch. The area west to the rock is composed by three complexes which are separated by brickwalls. The outer part was used as a garden measuring 500 x 120 meters. From the garden there is broad avenue 240 meters towards the rock and to the former city which is located in front of the rock. To the right and left of the avenue there are little lakes. The survey area was located in the north-west quarter of the garden (Fig. 3, 7). The south-west and southeastern quarter are completely excavated, as well as parts of the northeastern quarter. However, these results are not yet published.

Instrumentation and Results

For the survey we used the cesium-magnetometer system from Varian/Scintrex (V101, Canada) in a gradiometer configuration. This instrument consists of two magnetometer probes with an automatic data log on a handheld computer (Epson HX20), the sensitivity of ± 0.1 Nanotesla and give 10 readings per second. The intensity of the total earth magnetic field at Sigiriya varied from 36,000 by ± 1,000 Nanotesla. We used the gradiometer configuration for the same reason as at the site Ibbankatuwa. The underlying granite/gneiss rock caused magnetic anomalies of a soft shape (some of them where 40 x 40 meters) but with a field intensity of > 200 Nanotelsla. By using the ± 0.1 Nanotesla sensitivity, the limitedness of the software however allowed only anomalies of ± 99.9 Nanotesla to be measured.

Readings were taken on a 0.5 meter traverse and a 0.5 meter sampling interval at a sensor hight of 0.3 meter and 1.3 meter respectivly. The grid size was 20 x 20 meter blocks. The magnetic

Fig. 4. Sigiriya rock art: fresco of the cloud girl

Fig. 3. Sigiriya rock fortification: 1 enclosure wall, 2 water basin, 3 small hill, 4 water pond, 5 old monastery, 6 the Sigiriya Rock with Cobra Hood Cave, Asang Cave, Audience Hall, Cistern Rock and the frescos with the Cloud Girls, 7 survey area

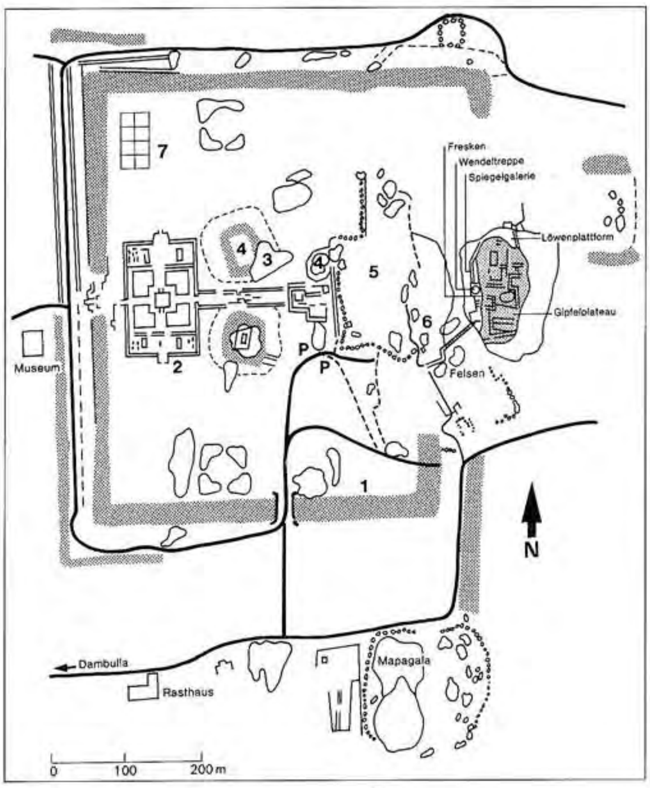
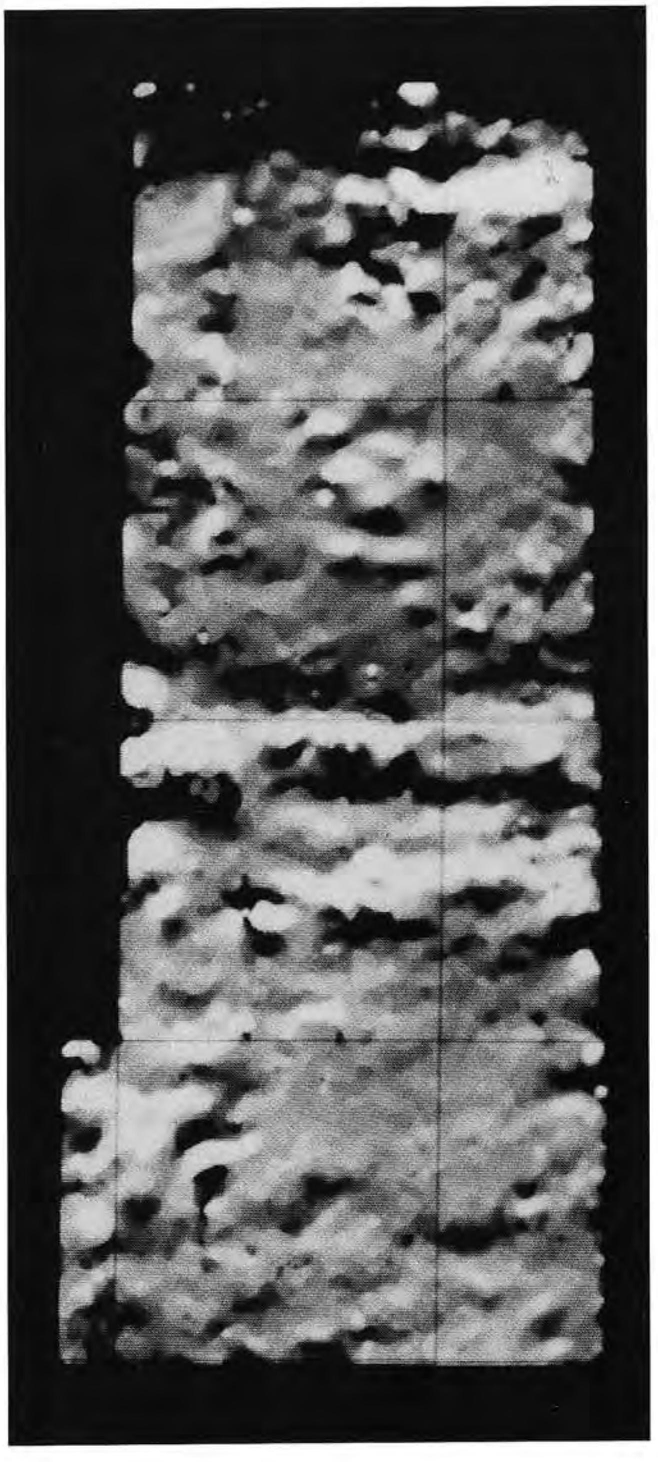


Fig. 5. "Aerial view" of the Sigiriya garden



intensity values are transformed to gray values ranging from 0 (black) to 255 (white). The dynamics of the original field data is in the range of ± 99.9 Nanotesla. After statistical analysis and depending on the intensity of the magnetic anomaly, we choose a window from -10.0 to +15.5 Nanotesla for a linear transformation of the magnetic intensity value into the gray value of the digital image to preserve the high sensivity (± 0.1 Nanotesla) of the survey. All data corrections and enhancements were done in the interactive digital image processing technique. Filtering procedures, contrast enhancement and false color transformation allow easy identification of the archaeological features in the magnetic image.

Because of the low geographical altitude a tilt correction of the probes of about 45° to the north was necessary. Finally the magnetic data are presented as a digital image (Fig. 6). The result of of the image is the clear anomalies caused by the burned brick construction of the garden architecture. The anomalies can be compared to the excavated garden architecture as it is visible on the other side of the garden.

The archaeologicaly relevant structures are marked by hand on a transparency over the hardcopy (photograph of the screen) and are transformed as vectorial data to the graphic computer.

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Fig. 6. Sigiriya. Digital image of the magnetometer data of the surveyed area at Sigiriya. Magnetogram in the digital image processing technique. Cesium magnetometer system from Varian/Scintrex, V101, Canada, sensitivity ± 0.1 Nanotesla, gradiometer configuration, dynamics –10.0 to +15.0 Nanotesla in 256 grayscales, sampling rate 0.5 meter, grid 20 x 20 meter

Fig. 1. Troy 1894. Excavation of the fortification wall of the citadel of Troy VI by Wilhelm Dörpfeld in 1894

H. Becker

In Search for the City Wall of Homers Troy – Development of High Resolution Caesium Magnetometry 1992–1994

Collaboration of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. W. E. Fassbinder) and the Troy Project, University of Tübingen and University of Cincinatti (M. Korfmann, B. Rose, H. G. Jansen)

Since 1868 when Heinrich Schliemann came to Troy trying to verify the story of the Trojan war the site remains a focus for archaeological research. Schliemann worked very hard searching the lower city of Troy as described in the Iliad. After the excavation of numerous "wells" (today we would say deep trenches) and finding only pottery of the Roman and Greek period, but none of older types which would be expected for the remains of Troy of the Iliad – he states rather disappointed and being absolutely sure that Troy consists only of the citadel, the so-called Pergamos, but no lower city. He also says that Homer must have exagerated in this point in the Iliad.

More than 100 years later the modern excavations in the ruins of Hisarlik-Troy undertaken since 1988 by M. Korfmann (University of Tübingen for the pre-Roman periodes) and C. Rose (University of Cincinatti for the Hellenistic and Roman periods) unearthed also some settlement patterns outside of the fortification wall of the 6^{th} "city" Troy VI of the citadel which gave evidence for a "lower settlement" but there was still the city wall missing which should surround the "lower city" of Late Bronze AgeTroy VI.

Troy became a test field for the development of high resolution caesium magnetometry and marks the enormous step from Nanotesla- to Picotesla systems 1992/1993 and 1994. First tests for magnetic prospection by Hans-Günter Jansen 1990 and 1991 using a fluxgate gradiometer Geoscan FM18 results in a very impressive picture of the Roman city Troy X but showed not the slightest sign for structures of Troy VI (Jansen, 1992). In 1992,

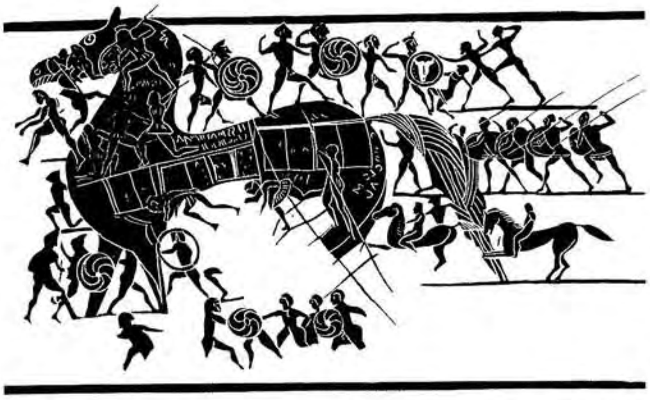


Fig. 2. The Trojan Horse. Figure on a Korinthian aryballos, around 560 B.C., Paris, Cabinet des Médailles

we (the author and Jörg Faßbinder) made a first test for high resolution caesium magnetometry in an area far South of the citadel, where one should expect the fortification wall of Troy VI, but which was not visible in the previous fluxgate-magnetometry. We used the Varian/Scintrex V101 caesium magnetometer which gave a sensitivity of 0.1 nT (Nanotesla) at 0.1 sec. cycle in the variometer mode at halfmeter spacial resolution. The discrete measurements at 0.5 m interval were triggered by an automised distance meter which was fixed at the box containing the readout unit for the magnetometer, an Epson handheld computer for data logging, the interface electronics and the power supply (12 V car battery) (Fig. 3).

The magnetogram of the 1992 measurement shows clearly the setup of the Roman city Ilium by straight streets and rectangular insulae measuring 106.60 to 53.30 m, which correspond to 360 to 180 Roman foot. Obviously the city planers of Troy IX combined two 180 foot squares to one insula-rectangle. A second measure may be deduced by a rectangular structure, which is rotated by 10 degrees to the west of the Roman orientation. These rectangles measure 180 to 150 Milesian yards and may be the measure of the Hellenistic city Troy VIII. But only few buildings are completely visible in the magnetogram. The superposition of several cities – here at least the three Hellentistic, Roman and

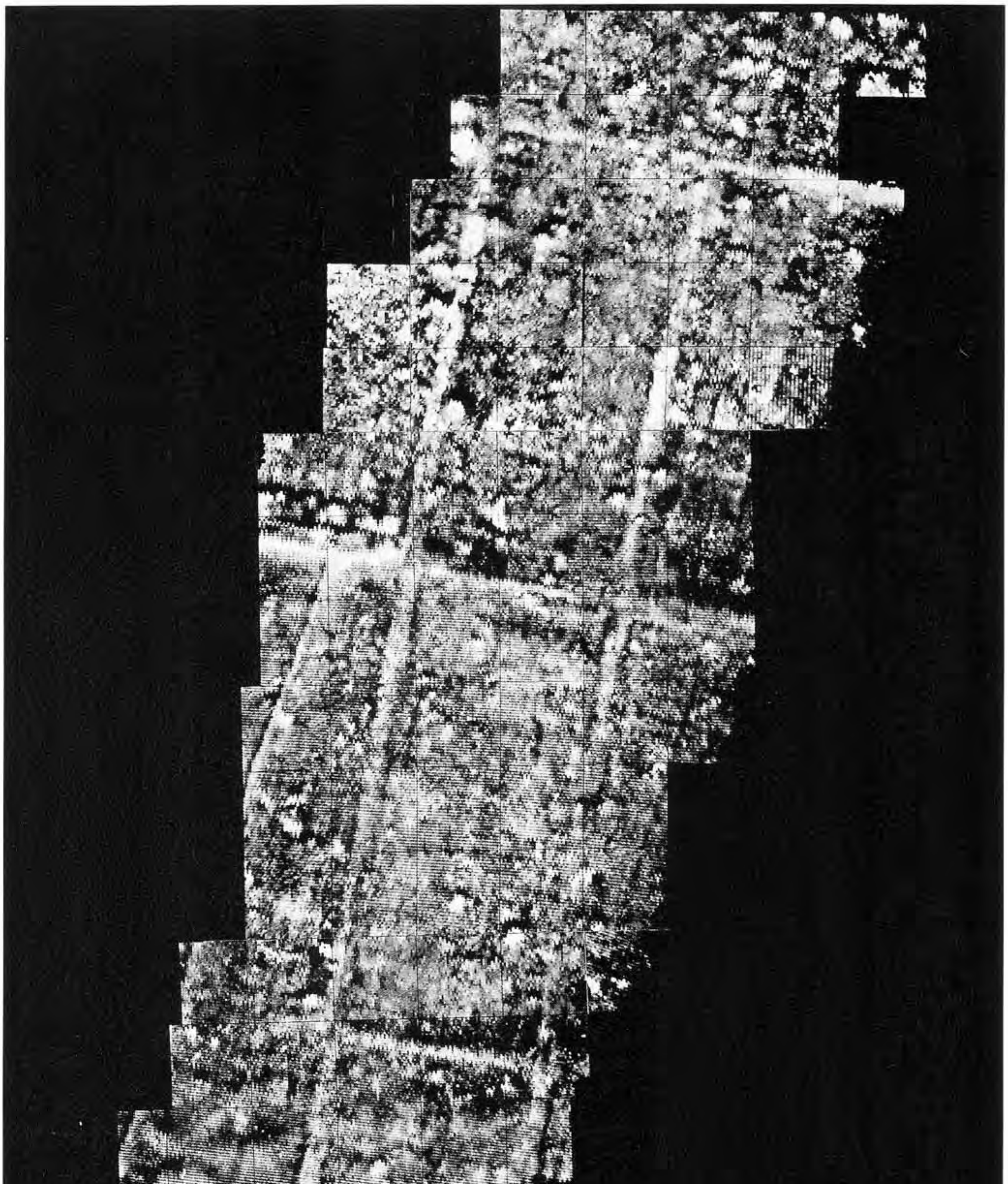
Fig. 3. Troy 1992. Magnetic prospecting in the lower city of Troy in 1992 using the caesium magnetometer Scintrex V101 in the variometer mode; the base sensor is fixed to the middle tree in the background

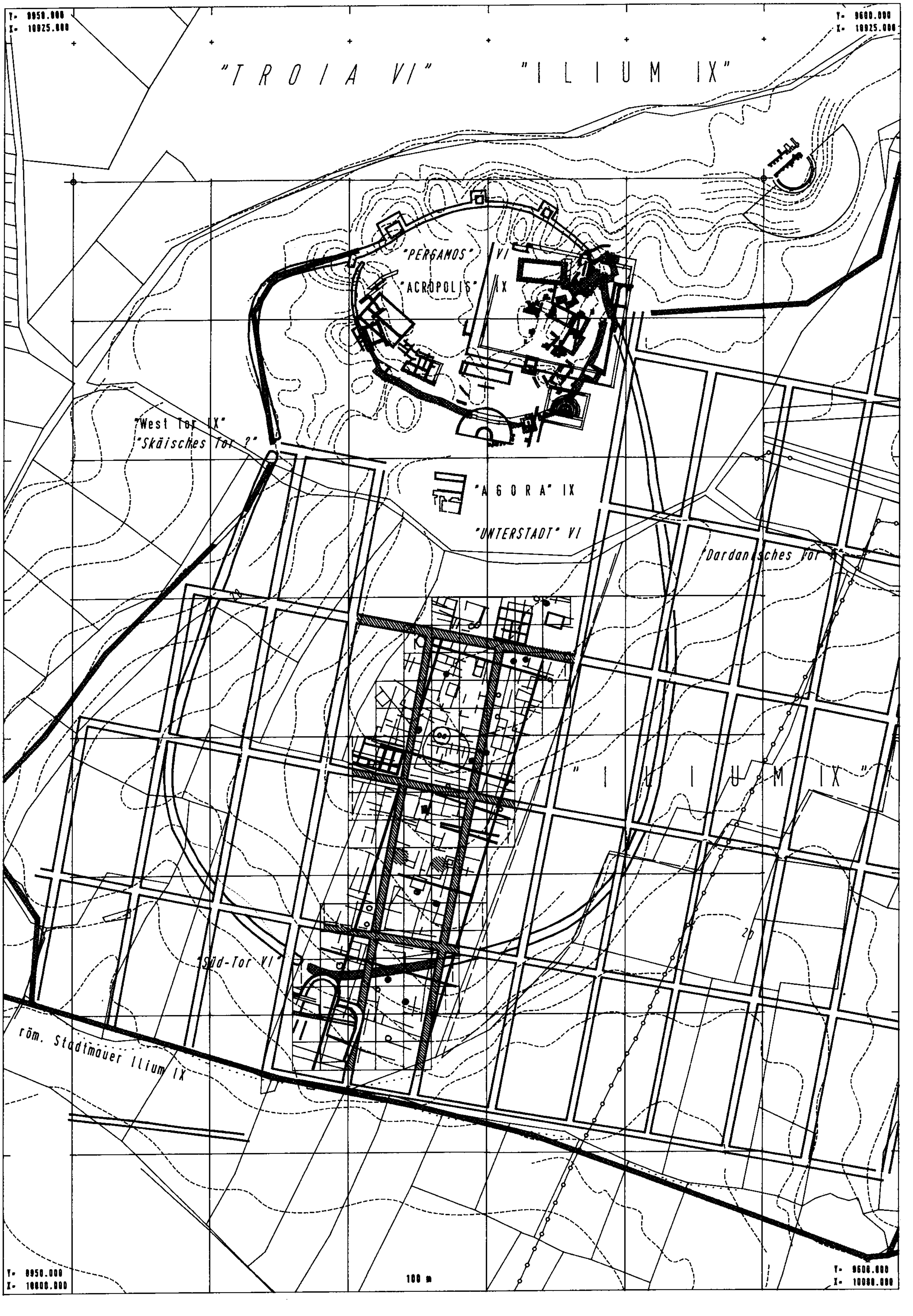
Byzantine city – results in a very confusing image of the archaeological structures monitored by the magnetic anomalies 30 cm above ground. Strangely enough the discovery of the searched Late Bronze Age city fortification of Troy VI caused only little problems. This positive magnetic anomaly was detected by its completely different orientation and signature in the southern part of the prospected area in 400 m distance from the citadel. First it was thought that this was the burnt wall of Troy as described in the Iliad. But the excavation in summer 1993 unearthed a ditch cut into the rock. This misinterpretation was caused by the result of a drilling program in the area of the lower city of Troy, which gave a depth of the bedrock in 2 to 3 m. We only had to turn the calculated model of the burnt wall upside down to get the filled in ditch of the fortification of Troy VI. A first reconstruction of the lower city of Late Bronze Age Troy VI on the base of the magnetic prospection revealed a minimum size of about 18 ha, which would give space for 6,000 inhabitants. Troy became a real city as described in Homer's Iliad (Fig. 4 and 5).

Unfortunately the new Picotesla magnetometer system was not ready by the summer campain 1993, so we had to rely again on the old V101 caesium magnetometer. Following the fortification ditch to the west Troy VI grows bigger and bigger covering an area of at least 22 to 25 hectare, which would be enough for 10,000 to 20,000 people. The relicts of the foundations of a huge stonebox wall of the type "Alisar" (Anatolia) could be identified in the magnetogram, but this was never verfied by the excavation. There are also two gates (interruptions of the ditch) in the south and the southwest, and one could think about the Scaeian Gate mentioned in the Iliad where Hector was killed by Achilleus.

After the news went round the world, that the burnt wall of Homers Troy was discovered, I was asked early in 1993 by Robert Pavlik from Picodas (Canada), if a high resolution caesium magnetometer with Picotesla sensitivity should be designed for archaeological prospection on the ground. In a very fruitful collaboration the hard- and software of recently developed airborne magnetometer systems were modified for the archaeological application on the ground, which resulted in the MEP720/CS2 system with MAGRAD software. The main advances of this system compared with the previous V101 was the ultra high sensitivity of 1 Picotesla, time mode – rather than distance triggered – sampling, which opens the possibilty of bandpass-filtering (1 or 2 sec) set in the hardware of the magnetometer-processor for cancelling the high frequency time variations. MAGRAD software and data logging were installed on an subnotebook computer Olivetti XX, which could be powered also by a 12 V battery. Before using this new magnetometer in Troy in August 1994, it was already tested extensivly in spring 1994 at the chalcolithic fortified settlement of Monte da Ponte in Portugal (Becker, 1995, see below).

Fig. 4. Troy 1992. Discovery of the fortification ditch of the "Homeric" city of Troy VI in the magnetogram. Caesium magnetometer Scintrex V101, sensitivity 0.1 nT, variometer mode, raster 0.5/0.5 m, dynamics –20.0/+31.2 nT in 256 grayscales (black/white), 20 m grid, North upwards ▷




Y- 9950.000
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"TROIA VI"
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"PERGAMOS" VI
"ACROPOLIS" IX
"West Tor IX"
"Skäisches Tor ?"
"AGORA" IX
"UNTERSTADT" VI
"Dardanisches Tor"
"ILIUM IX"
"Süd-Tor VI"
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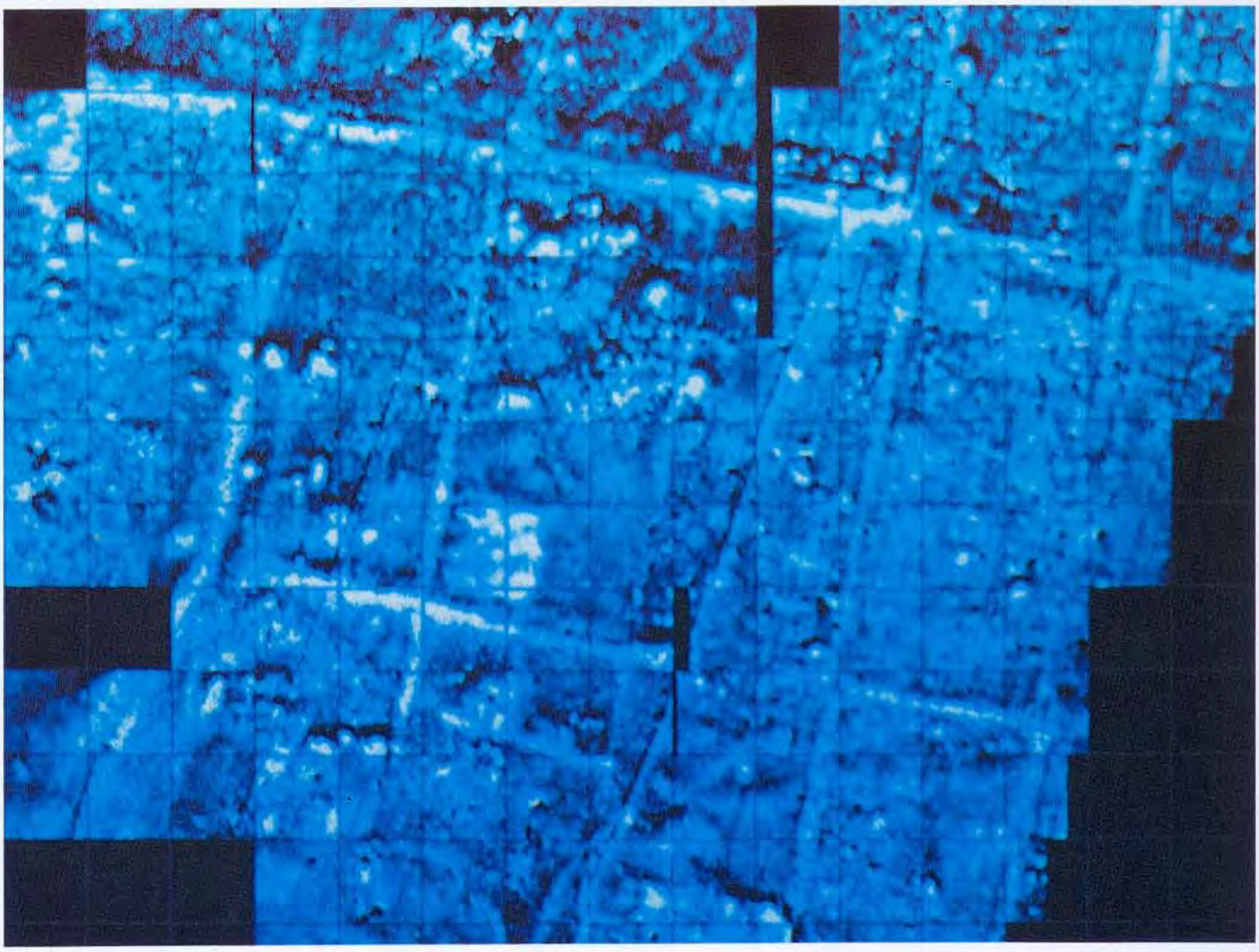

◁◁ Fig. 5. Troy 1992. Plan and reconstruction on the base of the magnetogram in Fig. 4 with the insulae of Roman Ilium (Troy IX), Hellenistic Ilion (Troy VIII) and the trace of the "Homeric" fortification of the lower city (Troy VI); the Late Bronze Age buildings of the citadel (Troy VI), the Hellenistic and Roman sanctuary (Troy VIII/IX) after the plan of Wilhelm Dörpfeld, Troja und Ilion (1902)

◁ Fig. 6. Troy 1992–1994. a) Aerial photo with the citadel of Troy and the traces of archaeological activities since H. Schliemann 1868 (Photograph H. G. Jansen, 1989). The area for magnetic prospection is adjacent to the south (downwards)
b) Magnetogram for the area south of the citadel of Troy. Clearly visible is the system of streets and insulae of the Roman Ilion Troy IX, but there can be also detected the trace of the Late Bronze Age fortification ditch of the "Homeric" Troy VI (see plan Fig. 6 for orientation); for technical details see Fig. 4

In Troy the ultra high sensitivity of the CS2-MEP720 system is not needed because of the extraordinarily high content of geological magnetite in the cultural debris, but the new instrument was even faster in the field than the previous V101 system. Another 6 ha area could be prospected by the new system over ten days in 1994 at a even higher spacial resolution of 0.2 to 0.5 m with time mode sampling, which still is 1.5 times faster than the previous V101 system with 0.5 to 0.5 m spacial resolution with discrete point sampling. With the picotesla system there seems to be hardly any non-linear phase shift in the zigzag-mode sampled data. The walking speed dependent resampling procedure results in an almost sharp image, even after fast sampling in the field.

The magnetogram from 1994 adds again some important information about the urban structure of ancient Troy. Following the setup of the Roman city Troy IX we could control the extrapolation of the insula-system another 300 m to the east simply by testing the location of the crossing of the streets. The most important result was found in the outmost corner the very last 20 m grid to the West, where another ditch appeared. Its magnetic signature, size and location on the last rock bank above the Skamander plain gave enough evidence that we have found another Troy VI ditch – some 50 m outside the Hellenistic/Roman city wall. Homer's Troy might have been even bigger than the later city of Roman Ilium. The area of Troy VI would grow to at least

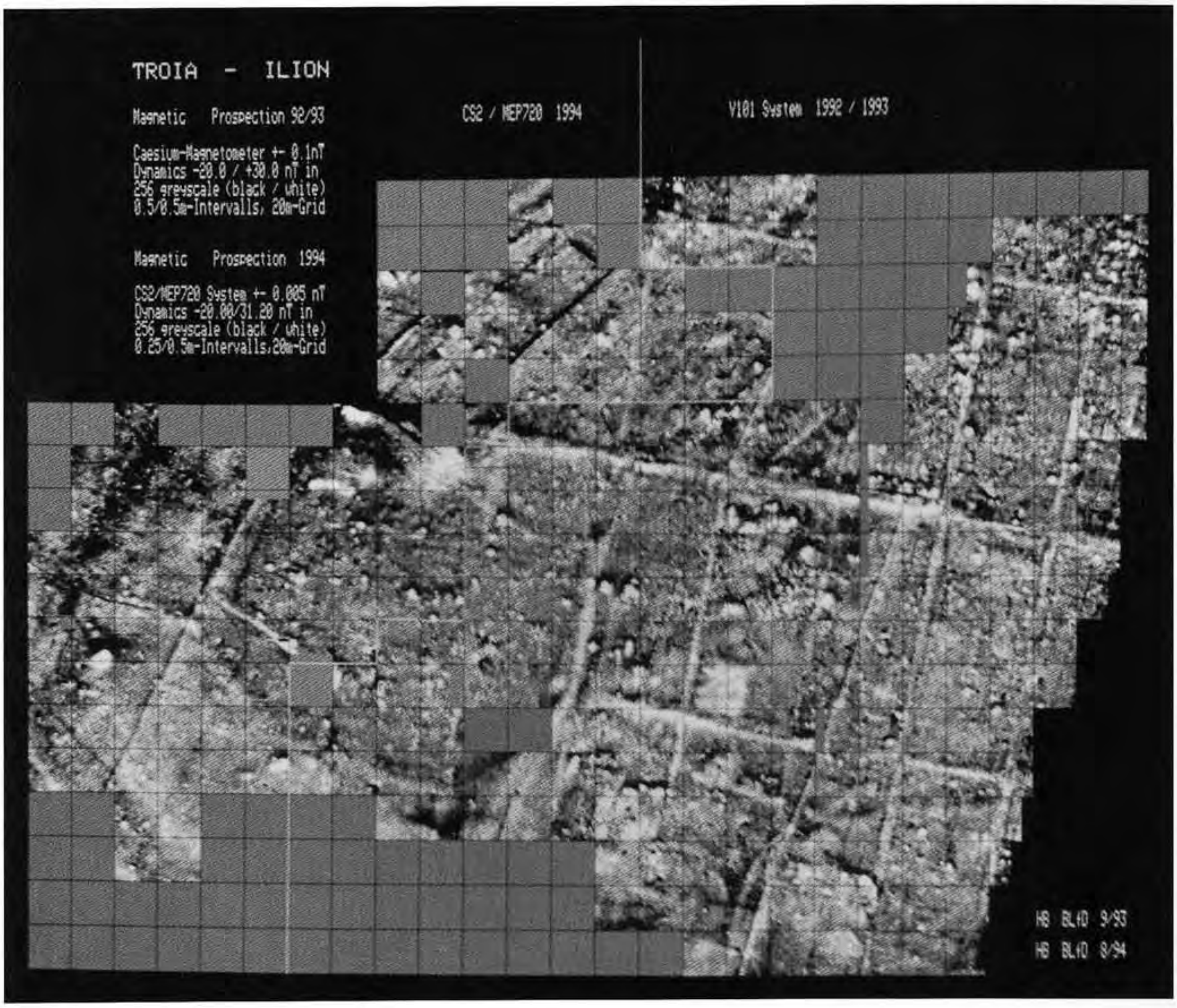

Fig. 7. Troy 1992–1994. Magnetic prospection in Troy with caesium magnetometers V101 (0.1 nT) at 0.5 by 0.5 intervals (9 ha on the right-hand side) and CS2-MEP720 system (0.005 nT) with 0.5 by 0.25 m intervals (5 ha 1994 on the left-hand side); both in variometer mode; sensor hight above ground 0.3 m; magnetogram in digital image processing technique; dynamics -10.0 to +15.5 nT in 256 greyscale (black to white); 20 m grid

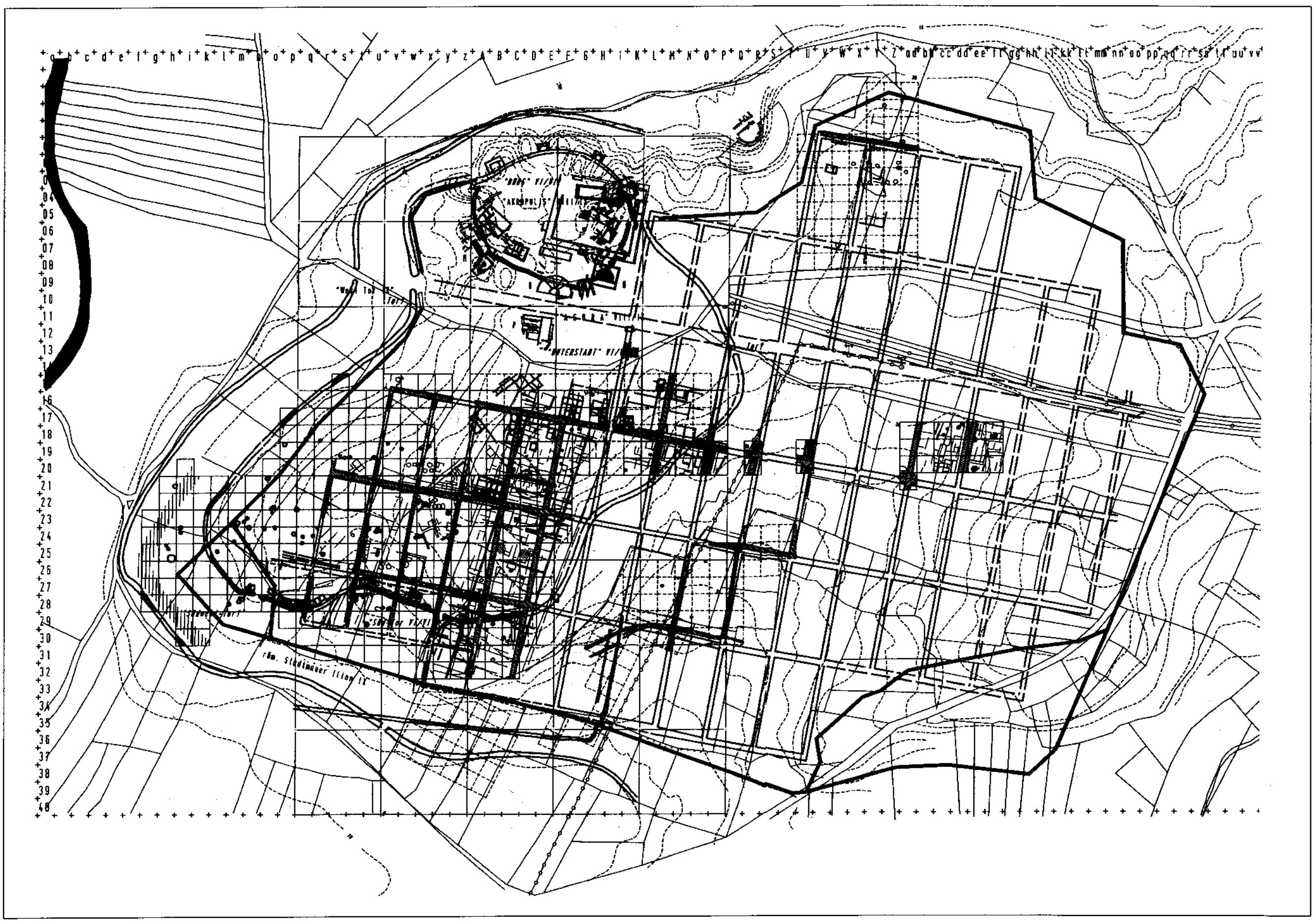

Fig. 8. Troy 1992–1994. Plan and reconstruction on the base of the magnetogram in Fig. 7 with the insulae of Roman Ilium (Troy IX), Hellenistic Ilion (Troy VIII) and the trace of the "Homeric" fortification of the lower city (Troy VI); the Late Bronze Age buildings of the citadel (Troy VI), the Hellenistic and Roman sanctuary (Troy VIII/IX) after the plan of Wilhelm Dörpfeld, Troja und Ilion (1902)

300,000 square metre (30 hectare) with a periphery of more than 2 km. Still one should keep in mind that the eastern border and fortification of Troy VI is not being prospected at all.

Therefore it would be very important continuing the most successful prospection of the cities of Troy by caesium magnetometry. Hard to believe that all further plans for finishing the magnetic prospecting of Troy were blocked by the project director. Obviously even modern archaeologists have problems accepting scientific generated data and information about areas, which could never be investigated by digging. The ready to use modern magnetometer systems with multi-sensor technic could do the job of prospecting all the remaining areas of Troy/Ilion/Ilium within 14 days. Interesting to consider how Heinrich Schliemann would have accepted these modern technologies for producing archaeological city maps in short times.

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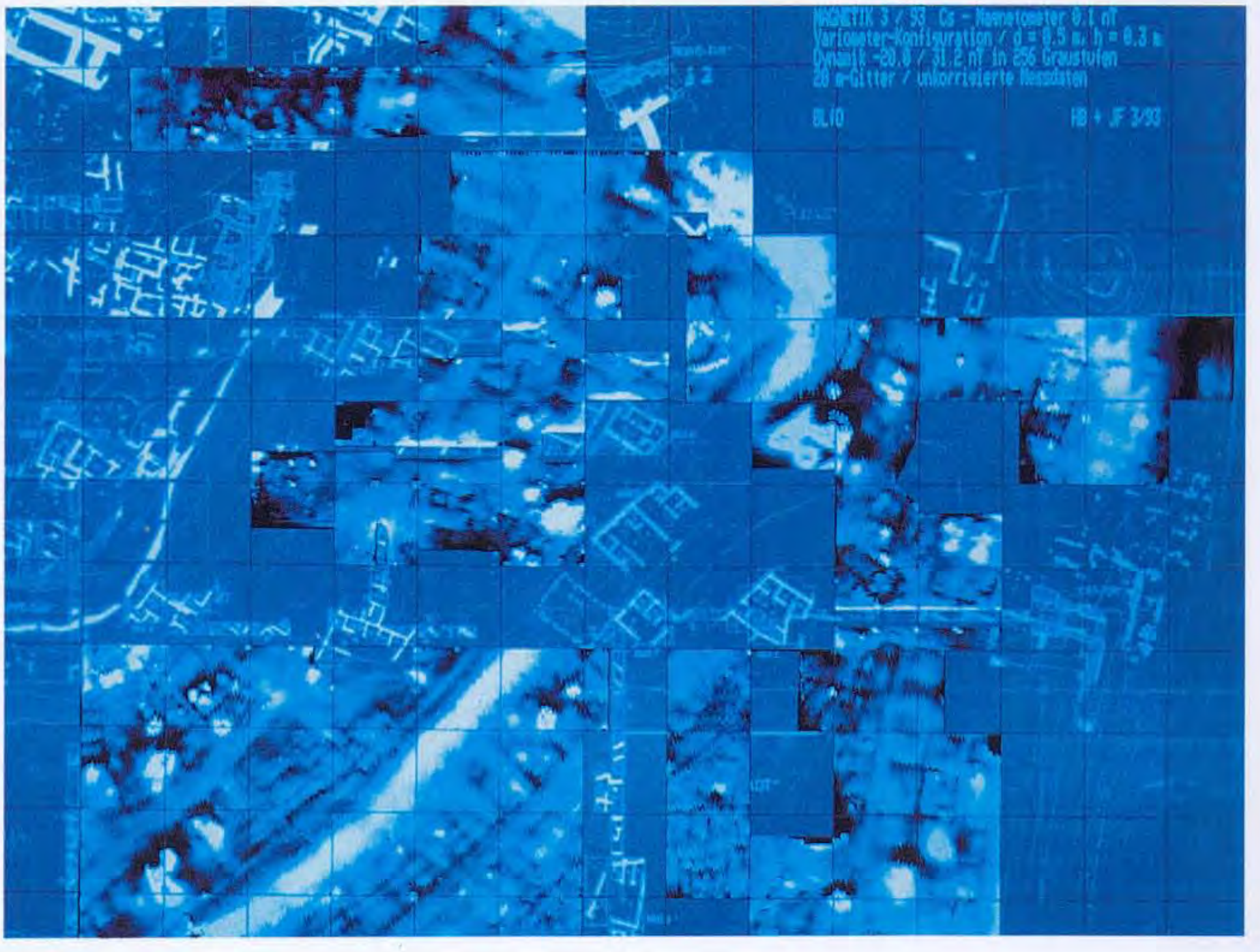
MAGNETIK 3 / 93 Cs - Magnetometer 0.1 nT
Variometer-Konfiguration / d = 0.5 m, h = 0.3 m
Dynamik -20.0 / 31.2 nT in 256 Graustufen
20 m-Gitter / unkorrigierte Messdaten
BL10
HB + JF 3/93

H. Becker, J. W. E. Fassbinder, F. Chouker

Magnetic and Resistivity Prospection in Munbaqa-Ekalte (Syria) 1993

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. W. E. Fassbinder), Institute for General and Applied Geophysics Munich University (H.C. Soffel), Technical University of Hamburg-Harburg (D. Machule), German Archaeological Institute Damascus (T. Ulbert), Department for Geophysics of Damascus University (Faris Chouker, Nazih Jaramani).

In March 1993 geophysical methods were tested in the Middle Bronze Age site Ekalte near Munbaqa for archaeological prospecting. It should be tried establishing a city map of Ekalte for the areas, which were not excavated. For this purpose the caesium magnetometer Varian/Scintrex V101 was applied by the Bayerisches Landesamt für Denkmalpflege and a resistivity apparatus by the Department for Geophysics of the University of Damascus. The magnetic prospection covered the whole area of the hilltop of the tell and the so-called Interior City and the Exterior City – in total about 4 hectare with 0.5/0.5 m raster (40,000 sqm = 160,000 measurements). The test area of the resistivity survey was 40 to 50 m in the northern Interior City (ca. 0.2 hectare = 2,000 measurements in meter intervals).

◁ Fig. 1. Munbaqa-Ekalte 1993. Above: Survey. Below: Compilation of the magnetogram and the excavation plan in digital image processing, caesium magnetometer Varian V101, sensitivity 0.1 nT, variometer configuration, raster 0.5/0.5 m, sensor hight 0.3 m, dynamics -20.0/+31.2 nT in 256 greyscales, 20 m grid, north upwards

The magnetic prospection in Munbaqa showed in comparison with previous surveys in Assur 1989 (Becker 1991) and Troia 1992 (Becker et al. 1993) the most successful results on an oriental tell. Also the resistivity measurement gave a similar good result, but the instrument and the sampling technique must be changed to become much faster. The prospection in Munbaqa was the first trial with caesium magnetometry and a first combination of magnetics and resistivity in Syria.

The whole nonexcavated area of Munbaqa with the Interior – and the Exterior City were prospected with the caesium magnetometer V101 in variometer mode and 0.5/0.5 m raster. The magnetometer has a sensitivity of ± 0.05 nT at a cycle of 0.1 sec. (10 measurements per second). The dynamic range of the measurement was -99.9 to +99.9 nT in 2000 units. The sensor-unit had to be carried by the operator – a second person had to control the readout unit of the magnetometer and the data logging on a handheld computer Epson HX20, which also made possible a first graphical output of the data as a symbol-density plot. The positioning was made by an optoelectronic distance-meter on the 20 m line.

The final evaluation of the data was made by digital image processing at the computer lab of the Bayerisches Landesamt für Denkmalpflege in München. The dynamics of the data was transfered in a window -20.0 to +31.2 nT in 256 greyscales (0.2 nT per grayvalue). The data were corrected by destaggering and shifting of the zig-zag pattern. It was tried tracing the magnetic

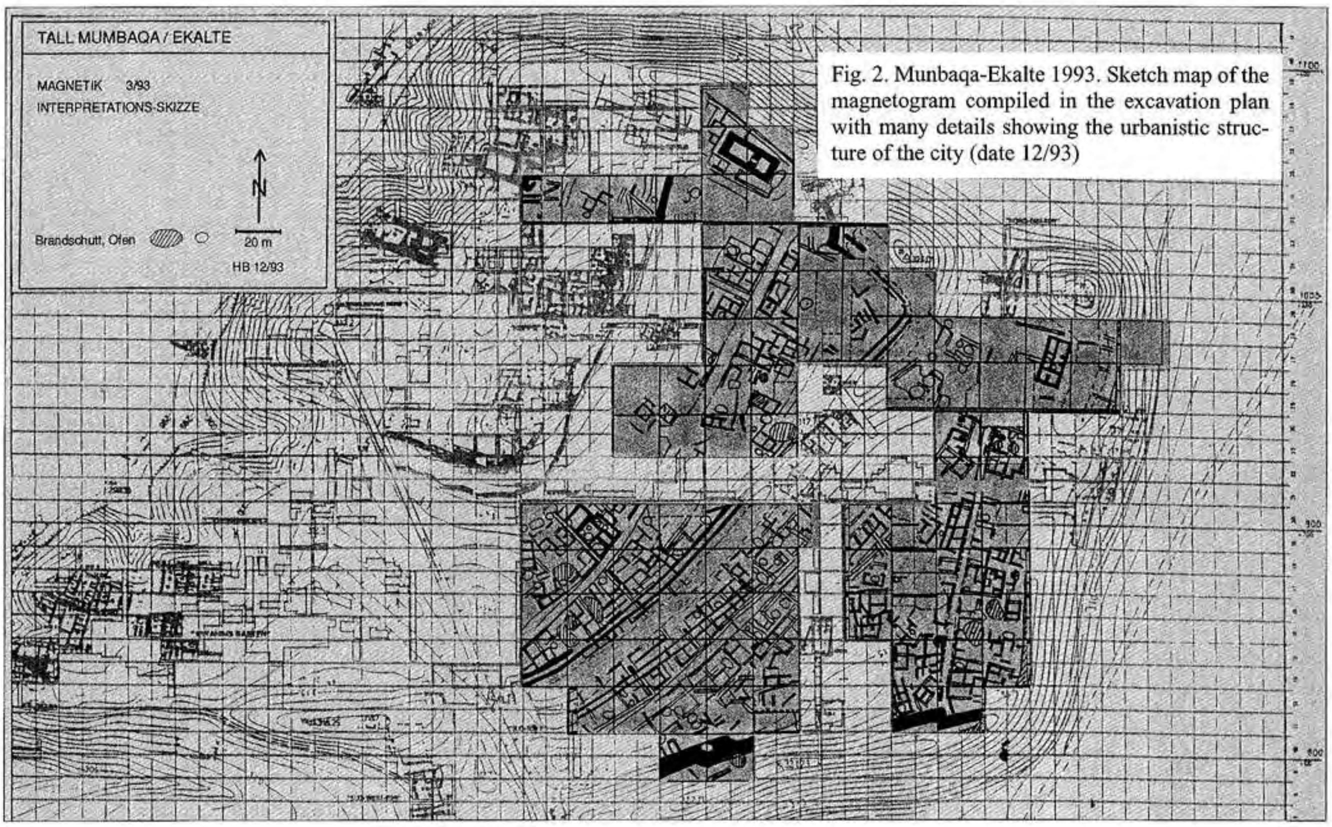

Fig. 2. Munbaqa-Ekalte 1993. Sketch map of the magnetogram compiled in the excavation plan with many details showing the urbanistic structure of the city (date 12/93)

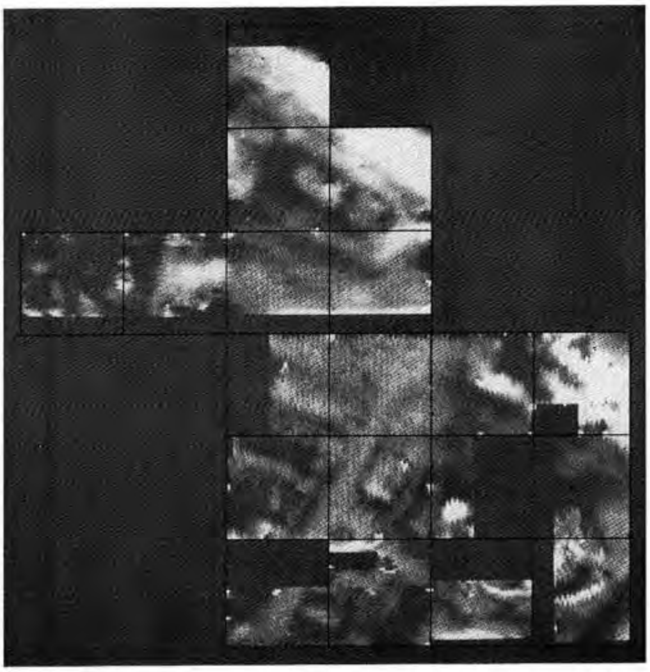

Fig. 3a. Munbaqa-Ekalte 1993. Magnetogram (detail) of the area behind the north gate with the big stone-building and the test site for resistivity surveying. Same technical data for magnetics than Fig. 1 (below)

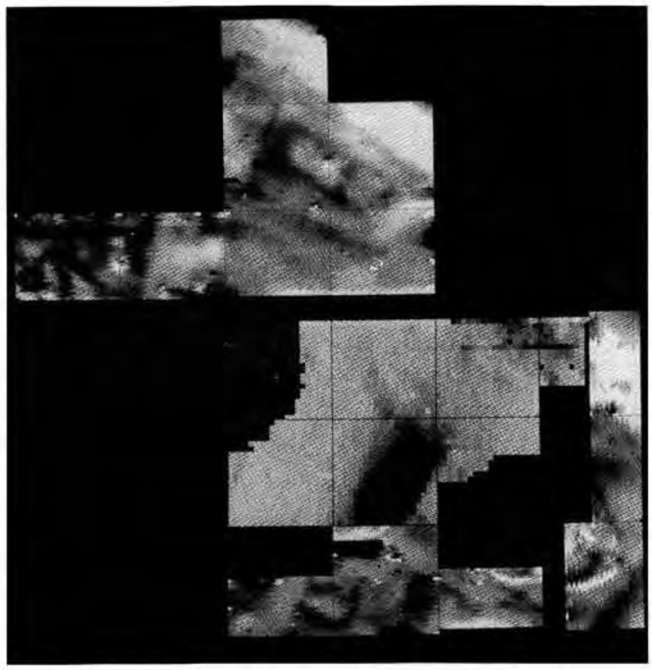

Fig. 3b. Munbaqa-Ekalte 1993. Compilation of magnetics and resistivity in digital image processing

anomalies underneath the high ramparts made from gravel by different windowing of the data. But a reprocessing should be undertaken with highpass filtering, which should show the archaeological structures much clearer.

The conditions for magnetic prospecting in Munbaqa were ideal, because of a big fire catastrophy, which must have destroyed the Late Bronze Age city. But the burnt ruins show a somehow unclear image. Very sharp on the other hand are the foundations made from stone imaged in the magnetogram shown by their negative magnetization contrast.

The magnetogram makes the interpretation almost of the complete city map of Late Bronze Age Ekalte with several streets possible. Extraordinarily clear is the net of streets visible with two mainstreets, public places, secondary streets and narrow lanes over the whole city. Near the northern gate a big stone building is located, which is rather similar in architecture like the other stone buildings (temple 1 and temple 2) on the Akropolis. The layout of many houses including their complete devision into rooms are show clearly in the magnetogram, that it may be possible to distinguish between several house types. It seems from the magnetogram that the big gravel rampart deviding the Interior and Exterior City was thrown up upon the buildings in this area. The strong anomaly of the rampart may be distinghishable for the underlaying architecture by highpass filtering.

The test for resistivity surveying was undertaken with a commercial instrument normally used for geological investigations. After measuring two 50 m long test profiles with various electrode configurations and electrode separations, the modified Schlumberger configuration (A 6.5, M 1.0, N -> oo, B) was chosen with optimal contrast for the archaeological structures. With this configuration a 40 to 50 m test area was measured with 1.0/1.0 m raster. The data were written into a working sheet and interpreted as isoline diagram which showed very little of the archaeologically relevant structures. The final data processing was made at the image computer in Munich which resulted in a good correspondance between magnetics and resistivity (Fig. 3a, b). Certainly a more modern technology like the Geoscan RM15-Advanced resistivitymeter with multiplexed electrode configurations would result in a better resolution for archaeological details. Unfortunately the site of Ekalte-Munbaqa is now vanished in the huge storage Lake Assad.

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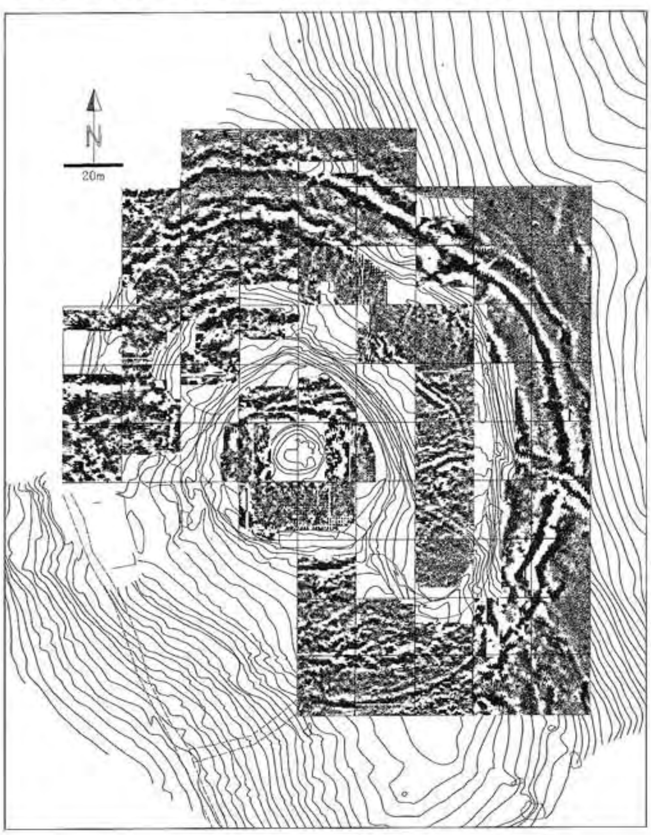
H. Becker

Ultra High Resolution Caesium Magnetometry at Monte da Ponte, Concelho Evora, Portugal 1994–1996

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker), Institute for General and Applied Geophysics Munich University (H.C. Soffel), German Archaeological Institute Madrid (H. Schubart, T. Ulbert), German Archaeological Institute Lisbon (Ph. Kalb), Centro de Estudo e Proteccao do Patrimonio, Universidade da Beira Interior, Covilha (M. Höck), Rupprecht and Michaela Steinman, Evora.

During a prospection flight with O. Braasch in May 1989 the archaeologists team of the project Vale de Rodrigo (Ph. Kalb and M. Höck) realized that the site of Monte da Ponte must be something special. The place was used for centuries as canada for locking the sheep during night when driving them over long distances. But only for keeping sheep this building would be overconstructed consisting of several rings of high stone ramparts with a central tower and radial divisions. But until 1996 no characteristic ceramics could be found, when some Copper Age pottery came to light by the activity of rabbits. With the beginning of the topographical survey of this complex site by Martin Höck in 1994 a 20 m grid was layed out for geophysical prospection. The site became a test area for the prototypes of the Picotesla-caesium magnetometer-system CS2/MEP720 and the duo-sensor configuration with SM4G-Special. It became evident that a very important archaeological site had been discovered. A test excavation started in 1996.

Fig. 1. Monte da Ponte 1994/1995. Magnetogram as dot density plot on the base of the topographical map by M. Höck. Caesium magnetometer CS2/MEP720, sensitivity 1 Picotesla (0.001 nT), variometer mode, raster after resampling 0.5/0.25 m, highpass filtering 5 x 5 pixel, dynamics -2.5/+2.5 nT in 17 grayscales (white/black), 20 m grid, north upwards



Based on the experience from the prospection of Megalithic sites in the Vale de Rodrigo project (Becker 1994) for prospecting the stone structures at Monte da Ponte resistivity survey was applied first. This became also a test for the new resistance meter RM15-Advanced (Geoscan, Bradford) with twin electrode. But it was clear from the beginning of the prospection project, that it would take to long time to undertake a resistivity survey alone. For magnetic prospection the prototype of the ultra high sensitive CS2/MEP720 caesium magnetometer (Scintrex/Picodas, Canada) was used the first time. This instrument being still the most sensitive magnetometer used on the ground marks the step from Nanotesla- to Picotesla-systems (Becker 1995). The measurement was done in variometer mode (one sensor fixed as base station for cancelling the geomagnetic time variations). The instrument was switched to 10 measurements per second, which gave a spacial resolution of about 10 cm on the line. Traverse inverval was choosen with 0.5 m. Distance triggering was made manually every meter using a switch. The whole process was controled by the subnotebook computer Olivetti Quaderno, which was used for data logging too. A 12 V car battery was sufficient for running the system one day. Also a sun collector was added to the power supply, so there were no problems with energy in the field. However at this first test many problems mainly concerning the distance trigger and data logging had to be solved. The main problem under difficult surface conditions remained due to the separation of the sensor-unit and the (magnetometer, power supply, computer)-unit connected by a long cable which got stuck very often and had to be handled by a third person. The ideal magnetometer for rough surface conditions became the Scintrex SMARTMAG SM4G-Special, which can be operated by one person carrying the whole system, and which was used the first time in March 1996 at Monte da Ponte.

The comparison of resistivity and magnetic prospection at the main east plateau of Monte da Ponte showed, that the magnetometer survey is the most suitable method for prospecting this site, because magnetics is about 5 times faster than resistivity. Also the archaeological structures are better shown in the magnetograms, because at Monte da Ponte a high magnetic contrast was found due to a huge conflagration of the site. The ramparts and walls of the monument were identified in the magnetogram both as positive and negative magnetic anomalies, depending on their magnetic contrast (Fig. 1 and 5). There must have been a wooden construction with sun dried mudbricks on the stone foundations of the fortification wall, which have been burnt down. The walls of the fortification and also the filling of the bastions in the forth wall must have gained a strong positive

△ 2

△ 3

4 ▽

magnetization, which certainly is due to the burnt mudbrick materials. The magnetic anomaly pattern seems to be rather complicated, because these positive anomalies have their magnetic "shadow" as a negative anomaly in the north. The structures with negative magnetization contrast (stone foundations in burnt surroundings) show as negative anomalies with a positive "shadow". Sometimes it's difficult to decide which anomaly is due to the structure itself and which is only the "magnetic shadow" phenomenon.

The site of Monte da Ponte shows a geometric construction of a huge oval fortification with 5 ring walls including the central tower, which measures 190 to 170 m. The plateau area between the second and the forth wall, which may have been the main habitation area, is divided into several sectors by radial walls with negative magnetization contrast, which indicates stone walls. The well preserved forth wall shows at their northern front a series of bastions, which are no more visible at the surface. But they could be also be seen in the drying vegetation during some days in late spring 1996. The main gate may be identified on the east side in the fifth wall and the earth rampart extended in front of it, with the trace of the gateway leading to the interior plateau between tower and the second wall. Only the tower could not be surveyed, because is was impossible walking over it due to a big

Fig. 2 and 3. Monte da Ponte 1994. Caesium magnetometer Picotesla-system CS2/MEP720 (Scintrex/Picodas) at first application in March 1994

Fig. 4. Monte da Ponte 1996. Caesium magnetometer SMARTMAG SM4G-Special (Scintrex) with duo-sensor configuration, sensitivity 10 pT (0.01 nT) at 0.1 sec cycle (10 measurements per second)

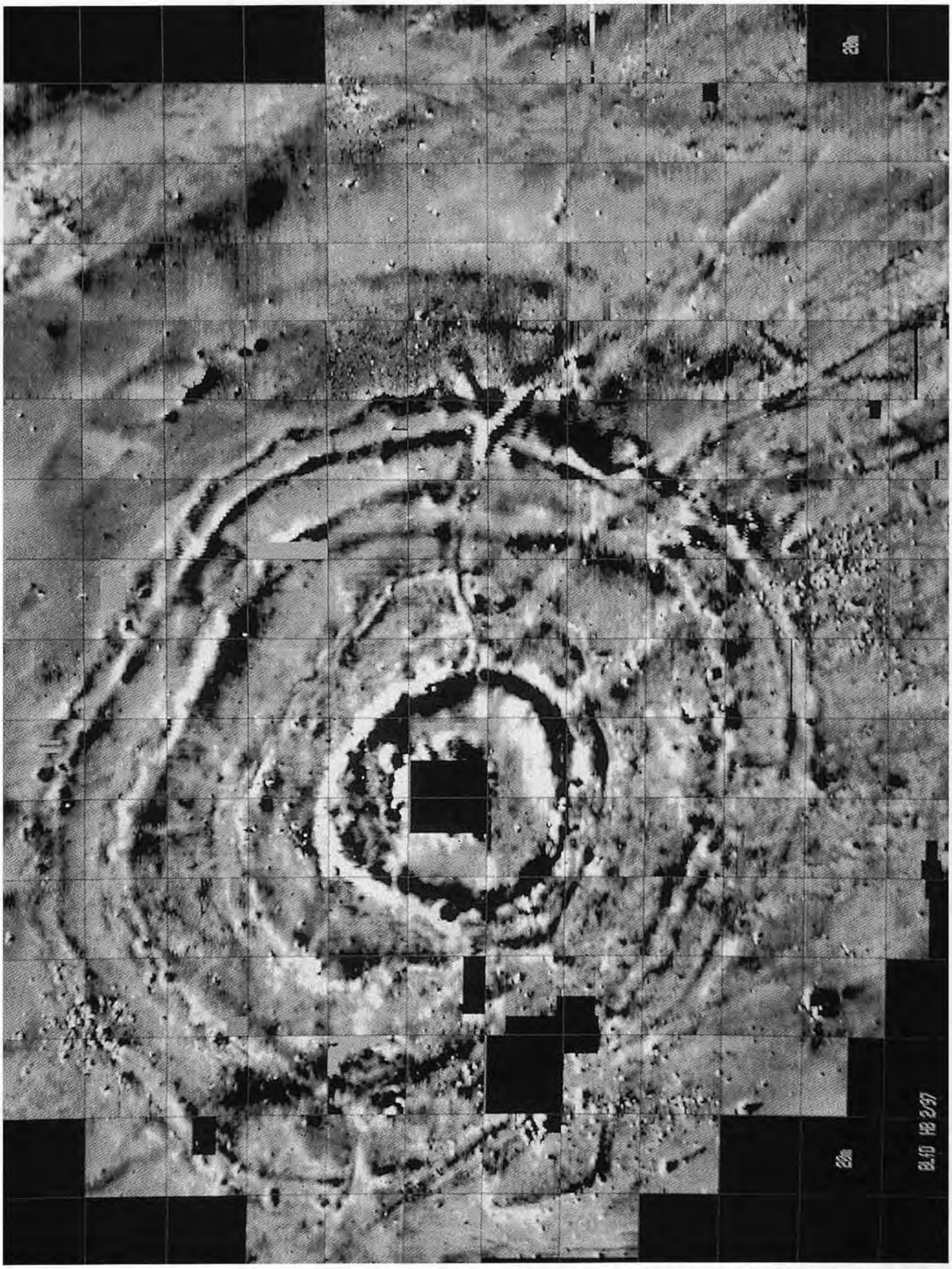


Fig. 5. Monte da Ponte 1994–1997. Magnetogram as digital image. Caesium magnetometer CS2/MEP720 (technical details see above) and SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster after resampling 0.5/0.25 m, dynamics -6.4/+6.4 nT to -3.2/+3.2 nT (outer area) in 256 greyscales (white/black), 20 m grid

Fig. 6. Monte da Ponte 1997. Aerial view of the Copper Age fortified settlement with signaled control points (20 m grid) on the ground by Ruprecht and Michaela Steinman as base for an photogrametric evaluation for a plan of all stones

heap of stones and many bushes. In front of the fifth wall there is another curved structure, which could be an earth-work. Another 20 and 30 m outside of this structure there can be partly identified the trace of a palisade and an outmost ditch mainly on the northeast quarter of the fortification (Fig. 5). The third ring wall is only preserved in the northern part, but has vanished from the surface in the remaining area. The fifth wall can not be seen above surface any more, but is clearly visible in the magnetogram.

Early in 1996, when the SMARTMAG magnetometer was to be tested, all stone ramparts (walls) were cleaned from their blackberry bushes, which resulted in an almost complete plan of the whole fortification (Fig. 5), but still missing the central tower. With the use of the duo-sensor configuration the SMARTMAG magnetometer allowed also the prospection of huge areas in the surroundings, where the above mentioned palisade and ditch system was found. The idea of finding more external seperate fortifications far outside the site was not confirmed by the prospection.

Besides the terrestrial topographic work by M. Höck, 1997 also some flights for aerial photos were undertaken by Ruprecht and Michaela Steinman, which also show the 20 m grid as ground control for photogrametric work. The 20 m stacks of the grid were signaled for this purpose by white plastic dishes. The photogrametric evaluation of these oblique aerial photographs by digital image processing will result in a scaled plan of all stones visible on the photos. There will be also a chance for an stereoscopic analysis of the aerial photos with sufficient overlap.

The combination of several prospection und survey methods like aerial photography, field walking, topographic surveying, digital terrain modeling and geophysical prospecting resulted in an idea and plan of the important archaeological monument of a Copper Age fortified settlement at Monte da Ponte. In addition to these nondestructive methods archaeological test excavation can be concentrated on specific areas for answering questions, which should give optimal additional information about this site. Thanks the open and extremely helpful cooperation between many scientists named above, the development of new instruments and techniques for geophysical prospection in archaeology became a real progress.

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H. Becker, J. W. E. Fassbinder, U. Brunner

The Discovery of the Royal Capital of Awsan at Hagar Yahirr, Wadi Markha, Yemen by Satellite Images, Aerial Photography, Field Walking and Magnetic Prospecting

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. Fassbinder), German Archaeological Institute Sanaa (B. Vogt), Museum for Ethnology Munich (W. Raunig), Institute for Geography of University of Zürich (U. Brunner)

The site of Hagar Yahirr in the Wadi Markha was first investigated about 10 years ago by satellite images (taken during shuttle mission in February 1984 by MOMS, Brunner/ Haeffner, 1990). In 1991 the place had been visited by an Swiss German Yemenitic expedition (U. Brunner, W. Daum, B. Hrouda, W. Raunig, Y. Abdalla) and a first cartographic sketch was drawn, but it was completely out of scale. Early in 1994, just before the civil war, a series of vertical aerial photographs were taken by MAPSXX in 1:30,000 scale covering the whole of Wadi Markha, which is situated along the borderline of the former two Yemens (Fig. 6).

Hagar Yahirr may have been the Royal capital of the kingdom of Awsan (Pirenne 1980). The site is surrounded by a well preserved city wall. Some parts of the southern fortification and the complete western half was destroyed, presumably by activities of an enormous sail (water flood) in Wadi Markha. Ashes and burnt soil in the whole area of the ancient city seems to confirm the tradition found as an inscription in Sabwa, that the Sabaean king Karib il Watar captured in the year 695 B.C. the Royal capital of Awsan, killed 16,000 people, pressing 40,000 people to slavery, destroyed the irrigation systems and burnt down the whole city. Nowadays we see still this situation (a huge field of burnt ruins (leveled by the wind and erosion and covered with yellow sand. A radio-carbon sample of a burnt beam taken in January 1995 confirmed the date of this catastrophical conflagration in 695 B. C.

Fig. 1. Hagar Yahirr 11/1995. Caesium magnetometer CS2/MEP720 with duo-sensor configuration operated by J. Fassbinder

After a first visit to Hagar Yahirr on the ground in 1991 it became evident, that this site should be investigated by geophysical prospection in advance of any further archaeological activities. Hagar Yahirr gave the chance for remote sensing of a large archaeological site at different hights and with different methods. The range consists of satellite images from hights of 700 km (Landsat Earth Mapper, see Fig. 3), 300 km above ground (MOMS-1), followed by aerial pictures from about 4,600 m above ground and finally magnetic prospection at 30 cm hight above ground. Obviously there is still one step missing with low altitude aerial/kite/baloon photography with signaled control points on the ground for mapping archaeological or architectural structures visible above surface.

In January 1995, during the first archaeo-geographic research project in Wadi Markha, a test for magnetic prospecting was undertaken at Hagar Yahirr. Aim of the measurement was to decide whether magnetic prospecting would be a suitable method for surveying archaeological structures under the surface in preparation of planned archaeological excavations. There were already some experiences in magnetic prospecting of buried cities under similar conditions such as Assur in Iraq (Becker, 1991), Munbaqa in Syria (Becker et al. 1994) or Troy in Turkey (Becker et al. 1993). A resistivity survey, which would be rather ideal for prospecting stonewalls, may not be applicable because of contact problems of the electrodes in the dry sand. This limited test for magnetic prospection was only for the preparation of another longer campaign for surveying with fast caesium magnetometry, the whole site of Hagar Yahirr, which extends over an area of 600 x 320 m (about 16 hectare).

After an extensive field walk over the site, the southeastern part was chosen for this experiment for magnetic prospection, because the city wall vanishes here under sand. This part also includes the singular area with some fragments of well masoned square limestone and highly burnt debris of mudbricks, which could have been a major building of the city destroyed in a conflagration. A 20 m grid was orientated to magnetic north by compass and marked by wooden sticks. A fixed base station for zero point reduction and calibration was choosen in an magnetically quiet area in the centre.

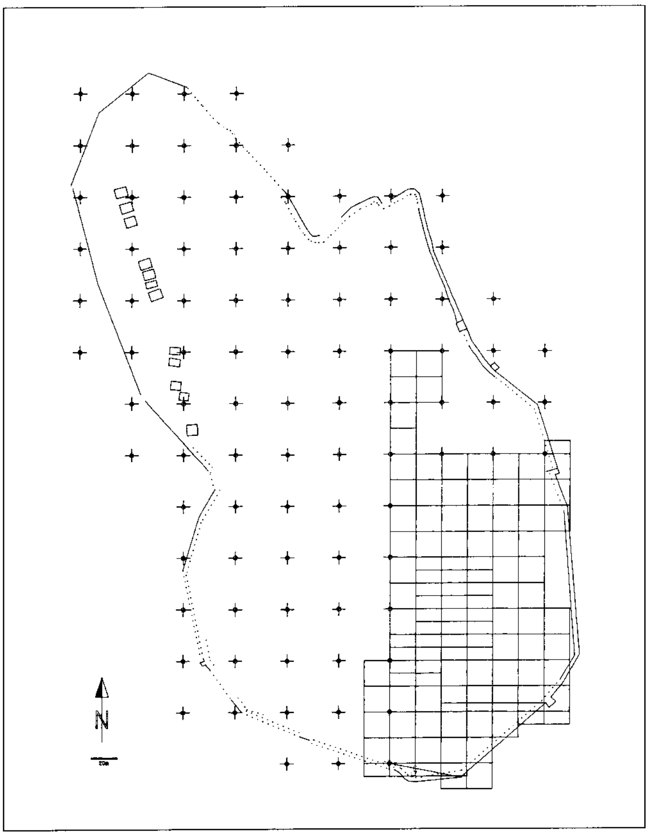


Fig. 2. Hagar Yahirr 1995. Plan of the site with 20 m grid of the magnetic survey. Plan after Breton 1994, Archäologische Berichte Jemen VIII, page 181; north orientation corrected to magnetic North 1/1995

The whole southern and eastern front of the city wall, made out of stone, is very well preserved. Gate constructions and bastions are still visible. In some parts a mud wall was detected following inside the city wall. In the southern part of the city a 120 x 200 m "Temenos" or "Akropolis" was seperated by a 2.5 m thick wall consisting of stone mantle filled in with clay. In many parts of the ancient city especially at the southwestern border complete foundation walls of stone houses are well preserved. Some huge stone structures up to 5 m hight in the eastern area of the Akropolis may have formed the base of towers. The biggest consists of two rooms and is situated outside the city wall some 150 m southeast.

In the distance of about 300 to 400 m northeast in the plain of Wadi Markha another field of ruins was detected. The pottery found on the surface seemed to be similar and contemporaneous to Hagar Yahirr. There may be some evidence that here an open trade centre or an industrial area outside of the main city was found. Until now no surface signs for an necropolis could be detected.

Magnetic prospecting with fluxgate gradiometer Geoscan FM36

The instrument used for this first test for magnetic prospecting in Yemen was a fluxgate gradiometer FM36 (Geoscan, Bradford), which is easier to transport and to handle in the field than the high sensitive caesium magnetometer CS2/MEP720 (Scintrex/Picodas, Canada), which needs at least 2 persons for operation. The fluxgate gradiometer has a sensitivity of 0.1 Nanotesla (nT) for delta Z, which is reproducable in the range of ± 0.3–0.5 nT at 10 Hz cycles. The sample trigger ST1 (Geoscan, Bradford) was used for speeding up the magnetic survey, which was carried out in a zig-zag mode. Sample interval and profile spacing was set to 0.5 m. For detailled description of FM36 see Clark (1990).

Light weight and an inbuilt data logger for 16,000 readings are the main advantages of FM36, which can be operated by one person. The help of local people and the teacher of the habitation of Hagar Yahirr today, is gratefully acknowledged.

Comparing the sensitivity of FM36 with caesium magnetometer CS2/MEP720 one should realize, that a picotesla system operates at a 1000 fold sensitivity (Becker 1995). This is a fact especially at low geomagnetic latitudes such as Yemen showing an inclination of the earth's magnetic field in the range of 10°. This means that the vertical component measured by the fluxgate gradiometer amounts only to less than a fifth of the total field value of caesium magnetometry. Another problem is given by thermal, mechanical and electronic drift of the FM36, which causes severe faults especially in plain sun. Some of these problems (e.g. tilt error) could be avoided by a field procedure in parallel mode rather than zig-zag mode, but this means a double reduction in speed, which would be never tolerable. On the other hand a duo-sensor configuraton of the caesium magnetometer CS2/MEP720 would allow the survey of 1 hectare with 0.5/0.1 m line/sample intervals (200,000 measurements) in about 5 hours.

Nevertheless an total area of 0.8 hectare (32,000 measurements) was surveyed in less than 3 days with the fluxgate gradiometer FM36.

The fluxgate gradiometer FM36 may be interfaced to any notebook computer for transformation of the field data under the GEOPLOT software package (Geoscan, Bradford). GEOPLOT also opens the possibility for advanced data processing and graphic display as dot density or shading plot with 17 grey levels. After destaggering and highpass filtering the archaeological structures show up rather clearly (Fig. 5) All data processing under GEOPLOT software can be made directly in the field. For final data processing with digital image techniques in the laboratory an ASCII-output composite file is written.

Final processing on the digital image computer in combination of aerial photographs and ground magnetics was made in the computer laboratory of the Bavarian State Conservation Office. This computer system allows the recification by a central projection, the finite transformation and scaling of oblique and vertical aerial photographs and the processing of geophysical data as a digital image with high resolution (1024x1024 pixel with 256 gray levels). The result of the data or image processing is viewed on a high resolution screen. The definition of an graphic overlay allows the interpretation of the archaeological structures directly on the image computer. The so-called vector protocol is transfered to a graphic computer and the plan of an archaeological site can be plotted in several colours representing several layers of information (Becker 1990, 1991).

Fig. 3. Satellite image from Wadi Markha at a hight of 700 km (Landsat Earth Mapper, processed by R. Blom, Passadena) ▷

Fig. 6. Aerial photo plan of Hagar Yahirr after digital image processing (contrast enhancement), scaling on the base of Fig. 3, magnification of the aerial photo by MAPSXX 1:30,000 with makro system HR CCD-Camera (1024x1024 pixel in 256 gray levels) ▷

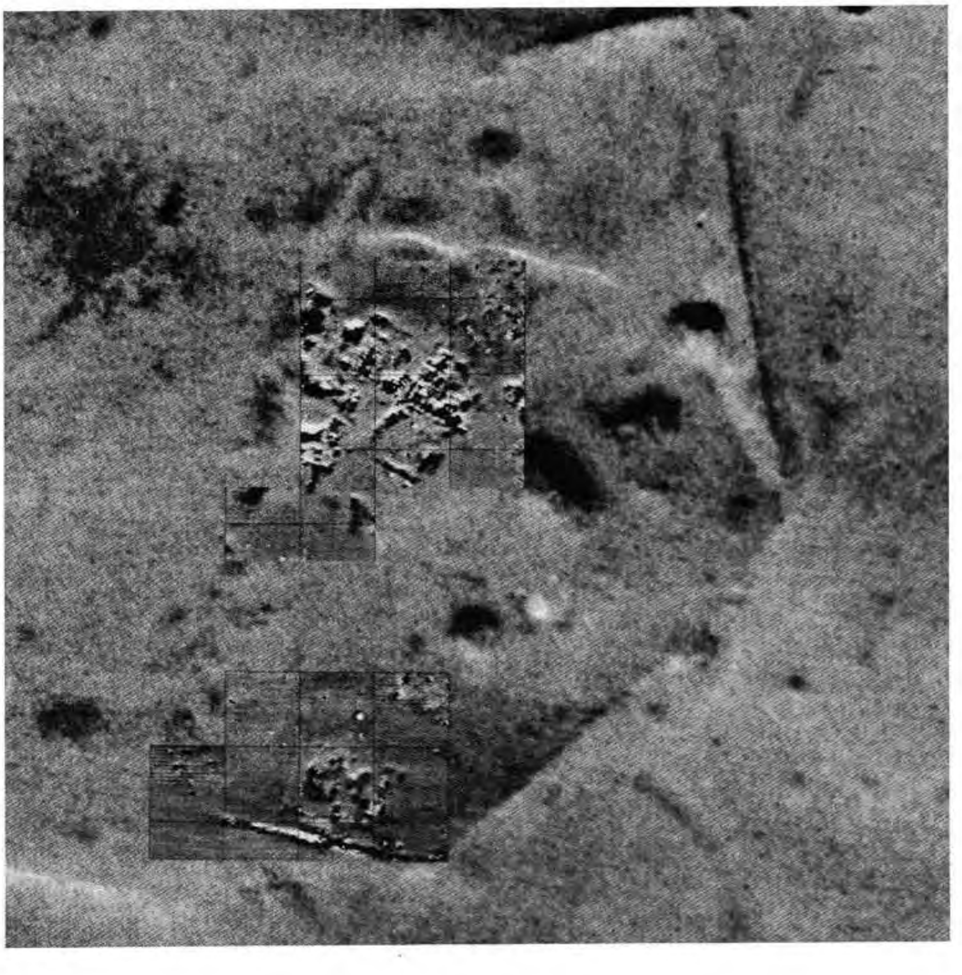
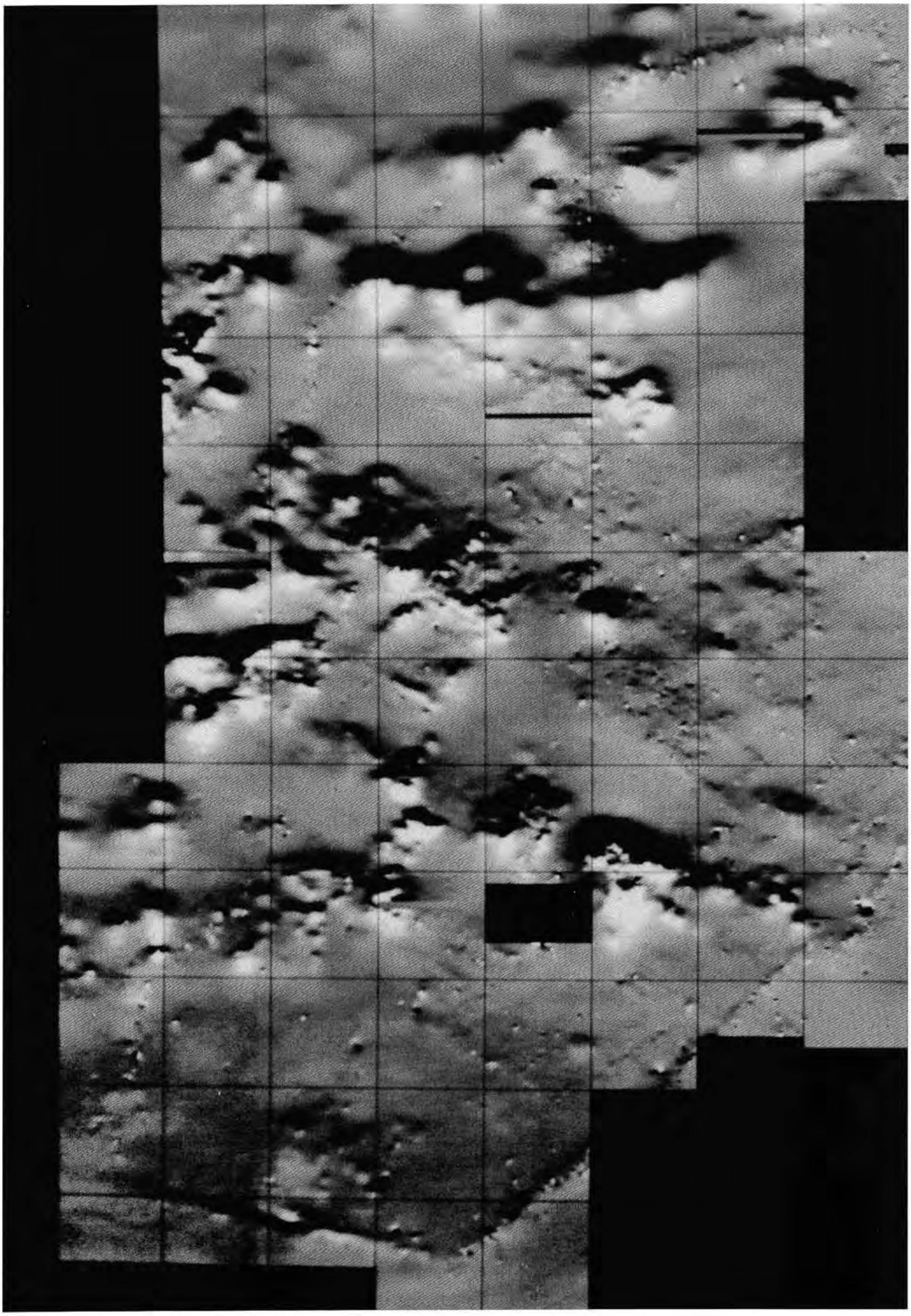
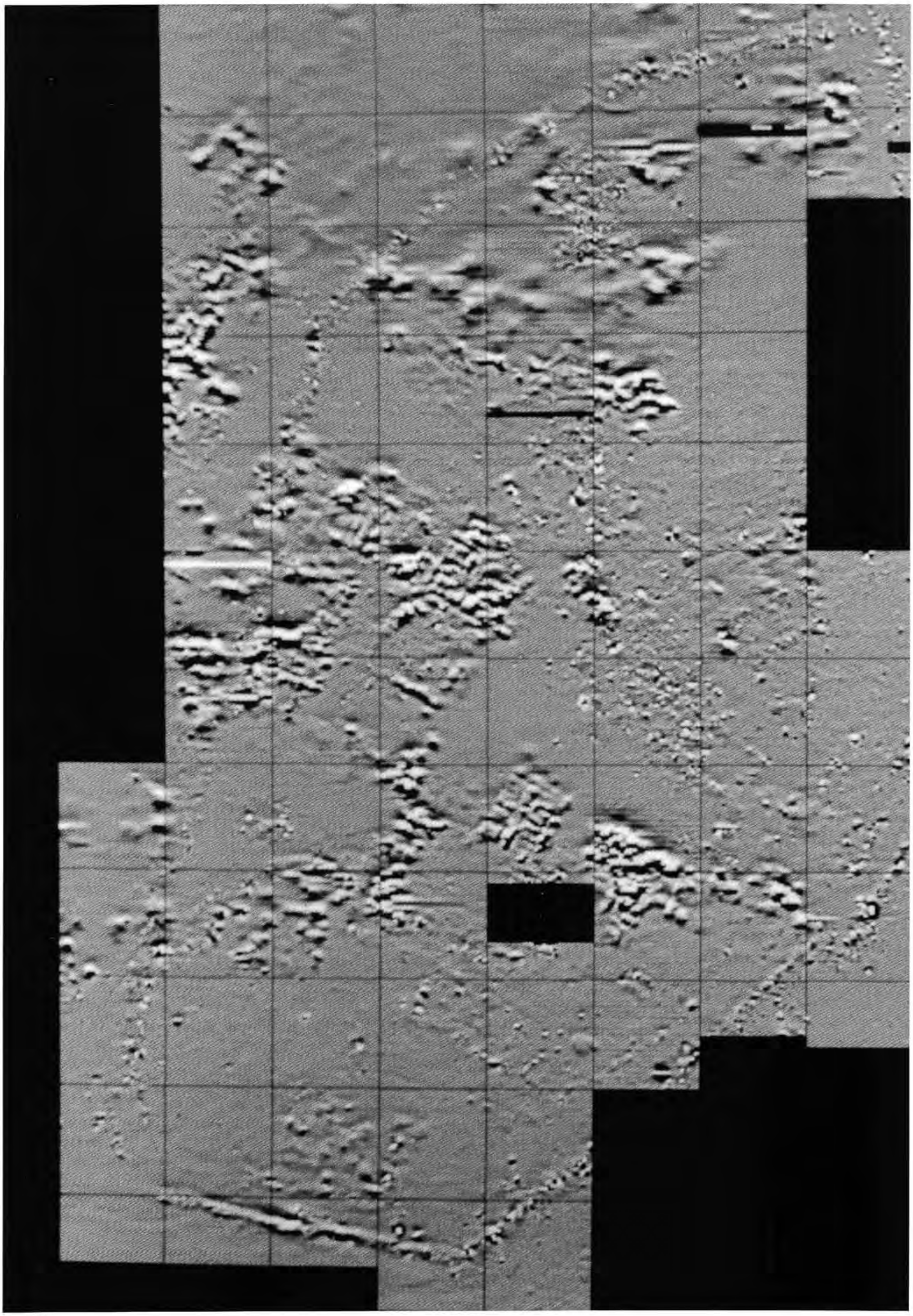


Fig. 4. Digital image (section of Fig. 6) of the Southeastern area of Hagar Yahirr, which may have been the Temenos or Akropolis of Awsan

Fig. 5. Same as Fig. 4, but compilation with the magnetogram as digital image, fluxgate gradiometer FM36, sensitivity ± 0.3 (0.5 nT delta Z), raster 0.5/0.5 m, dynamics delta Z -3.5/+3.5 nT in 256 gray levels (white/black), 20 m grid





The input image of the vertical aerial photograph series in scale 1:30,000 was an photographically magnified image of Hagar Yahirr from 1:30,000 to 1:5,000 scale. A test to see if one could identify house structures in the northwestern area, which are quite clearly visible at the surface, by digital image and contrast enhancement was not successful. But digital image processing made possible the scaling of the vertical photograph on the base of the terrestrial plan of Breton (1994). There were no problems even in finding enough control points for the compilation of the magnetic survey in the aerial photograph (Fig. 5). On the other hand there may be some possibilities of image enhancement, if one starts from the original film negatives.

The interpretaton of the magnetic prospecting is quite evident: In the southern area the city wall is clearly visible as a positive magnetic anomaly, which is caused by the high susceptibility of the stones. There may be a gate with a pronounced gateway on the southwestern wall of the Akropolis. The city wall seems to vanish completely to the west which is possibly caused by a heavy sail (water flood) in Wadi Markha. But data enhancements by zero line mean procedure, high pass filtering and destaggering show up a very faint anomaly in the continuation of the city wall buried by sand (Fig. 6). High sensitive magnetometry would be needed to clarify this question and to follow the wall at the western boundary of te city.

Just behind the wall a building was identified about 30 x 20 m wide with limestone walls (negative alignments) and burnt mud- or schist/metamorphic-walls (positive alignments). Another very big building (40 x 60 m) with many rooms, doorways and courtyards is situated in the northern part of the test area. The remains of this building were highly burnt in a conflagration. The whole area at the surface has a red colour caused by the burnt mud; there are also many burnt fragments of carved limestone found at the surface. Probably this area represents a "temple" or "palace" site inside the "Temenos/Akropolis".

The result of the test for magnetic prospecting is very evident: By means of this method it would be possible to derive the complete and detailed city plan of Hagar Yahirr. But the results would be much better by using the high sensitive caesium magnetometer, which could cover a large area in short time. Many house structures at the surface could be mapped in combination by low altitude-, balloon- or kite-borne photography with signaled control points on the ground for rectification and scaling of oblique views.

◁◁ Fig. 7a. Hagar Yahirr 11/1995. Section of the magnetogram as digital image with caesium magnetometer CS2/MEP720, sensitivity 0.001 nT, duo-sensor configuration, raster 0.5/0.25 m, dynamics -10.0/+10.0 nT in 256 graylevels (black/white), 20 m grid, North upwards

◁ Fig. 7b. Hagar Yahirr 11/1995. Same as Fig. 7a, but highpass filtering 5 x 5 pixel, dynamics -3.5/+3.5 nT

Magnetic prospecting with caesium magnetometer CS2/MEP720 with duo-sensors

In November 1995 the planned magnetic prospecting with CS2/MEP720 caesium magnetometer system was made in Hagar Yahirr with the assistance of J. Fassbinder in continuation and in the same grid of a first test with fluxgate magnetometer FM36 in January 1995 (Fig. 1). An area of 4 hectare (40,000 sqm = 320,000 measurements) was measured in the standard technique, but the sensors had to be tilted to 45°. This area covers the whole of the so-called upper city of Hagar Yahirr and some parts of the lower city (Fig. 7a, 7b). The results of magnetic prospecting are excellent and show an almost complete plan of the architecture of the city. The good results are due to the ideal magnetization process in Hagar Yahirr by the conflagration of the whole city.

Further magnetic prospection of the whole area inside the city wall of Hagar Yahirr is highly recommended before first archaeological excavation will be start. There is strong evidence, that the complete plan of the burnt city can be derived only by magnetic prospection in 1 or 2 campaigns of 10–14 days together. By field walking in the direct vicinity of Hagar Yahirr a large outer city possibly of the same age was found which was not burnt down.

Unfortunately in 1997 an archaeological excavation started at Hagar Yahirr before the next prospection campaign. It was only after the second day that this excavation was stopped by the Bedouins with guns. Any further attemps to reach Hagar Yahirr again for the continuation of the prospection in 1997 and 1998 were not successful because of the Bedouins. The last trial for reaching the site for finishing the survey in February 1998 was defeated by arms.

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H. Becker

Discovery of a first Neolithic settlement in the Meseta of Central Spain near Ambrona (Soria) by caesium magnetometry in 1996

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker), Institute for General and Applied Geophysics Munich University (H.C. Soffel), German Archaeological Institute Madrid (M. Kunst, H. Schubart, T. Ulbert) and University of Valladolid (M. Rojo)

The archaeological excavation of the Early Bronze Age barrow La Pena de la Abuela near Ambrona (Soria) by Manuel Rojo, University of Valladolid, brought some Early Neolithic pottery fragments from the deeper strata to light, which gave the idea searching for an Neolithic settlement somewhere in the vicinity. An extensive program for fieldwalking by a team of the University of Valladolid surveyed about 12 localities with Neolithic and later ceramics in the wider surroundings of Ambrona, which were completely unknown before.

In September 1996 a magnetic prospection by caesium magnetometry was undertaken in the sites Ambrona-La Lampara containing also the Pena de la Abuela, and Ambrona-La Revilla del Campo trying to get more information about these supposed Neolithic settlements. In August 1997 first test excavations in both sites started on the base of this magnetic prospection. In 1997 the Neolithic settlement of La Cumbre and another barrow Ambrona-Atalayuela, followed 1998 by Ambrona-Dolmen de la Sima and Ambrona-El Pozuelo, were also prospected by magnetometry and resistivity.

For magnetic prospecting a Scintrex SMARTMAG SM4G-Special was used with the duo-sensor configuration for saving time (for details of the instrument and data processing see Becker, 1999, 2000). This instrument and the special duo-sensor technique was tested first only in spring 1996 for the prospection of the Copper Age site of Monte da Ponte in Portugal. The magnetometry at the site La Lampara was applied with 0.5 m distance between the sensors and with 0.2 second cycle (5 measurements per second), which corresponds to 0.2 m spacial resolution. Only the open area of the barrow Pena de la Abuela, which still was under excavation, was measured with 0.25 m and 0.1 sec cycle

Fig. 1a. Ambrona-La Lampara 1996. Caesium magnetometry using Scintrex SMARTMAG SM4G-Special with duo-sensor configuration

Fig. 1b. Ambrona-Dolmen de la Sima 1998. Resistivity survey using Geoscan RM15-Advanced Resistance meter with twin electrode

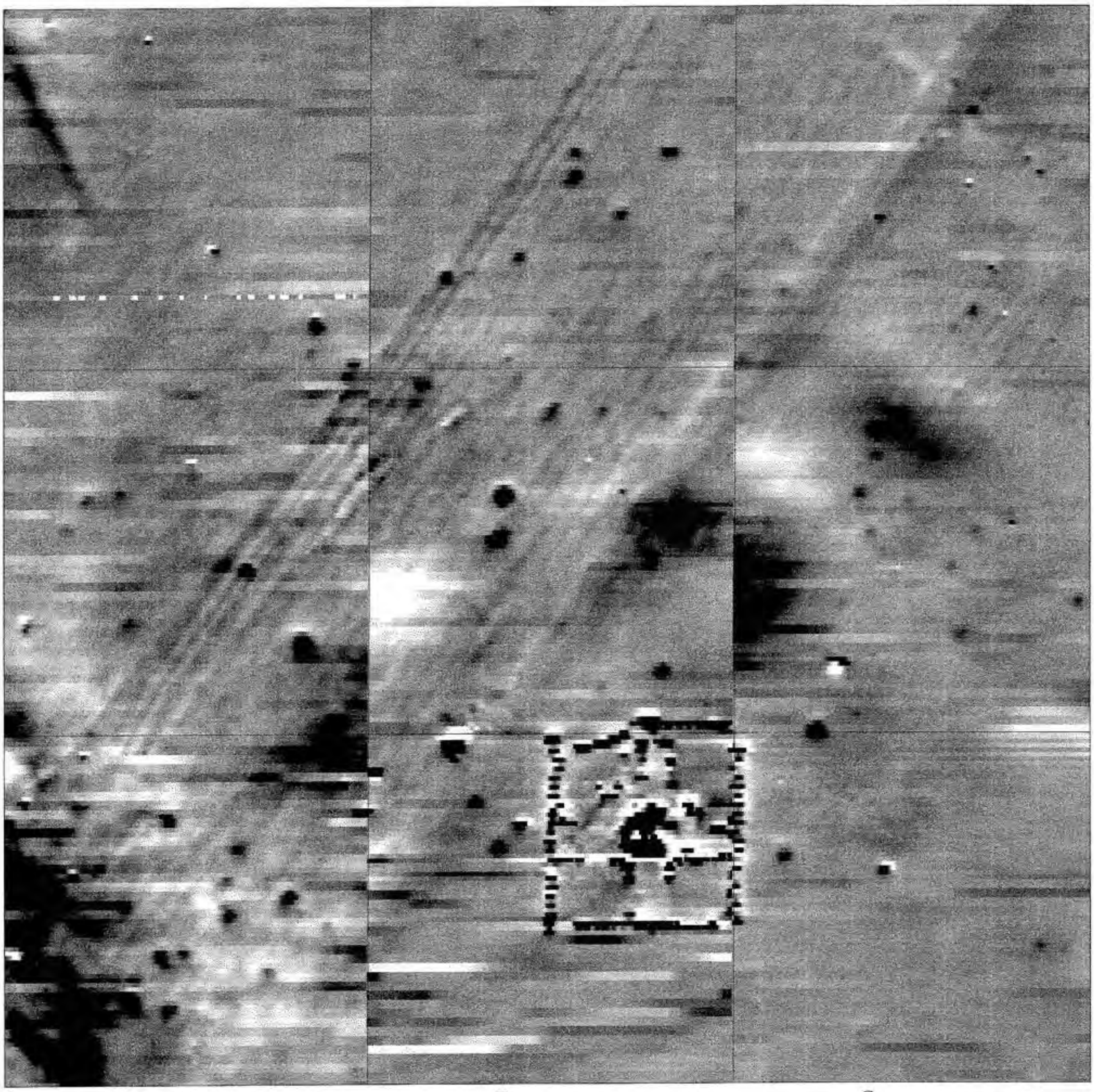

Fig. 2. Ambrona-La Lampara 1996. Magnetogram after digital image processing. The distinct anomaly in B2 marks the pit with an Early Neolithic burial. Caesium magnetometry Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster 0.5/0.25 m, dynamics -3.2/+3.2 nT in 256 grayscales, 40 m grid, North upwards

resulting in a raster 0.25/0.125 m after resampling. Bandpass filters were switched to 1 Hz for canceling the high frequency time geomagnetic variations. The slower diurnal variation was reduced by the mean of all line values, which follows ideally the daily variation. The reduction to the square mean value was also calculated, to be shure for not cancelling anomalies in the direction of the line. The duo-sensor configuration was carried by the operator and the distance control was switched manually every 5.0 m. After dumping the data to a notebook computer complete data processing was undertaken during the night controlling the quality of the data and the archaeological relevance of the measurement. GEOPLOT V2.2 software (Geoscan, Bradford) was used for first visualization as grey shading plot. These plots showed that unsufficient control of sensor hight above ground resulted in some stripes, which could not be corrected any more. But these are easy to differentiate from archaeologically relevant anomalies.

Due to the topographical conditions around the barrow Pena de la Abuela in the field La Lampara one would suppose the extension of a possible settlement only in northwestern direction. An area of 120 to 120 m consisting of nine 40 m grids were measured (about 300,000 measurements) in two days. In the

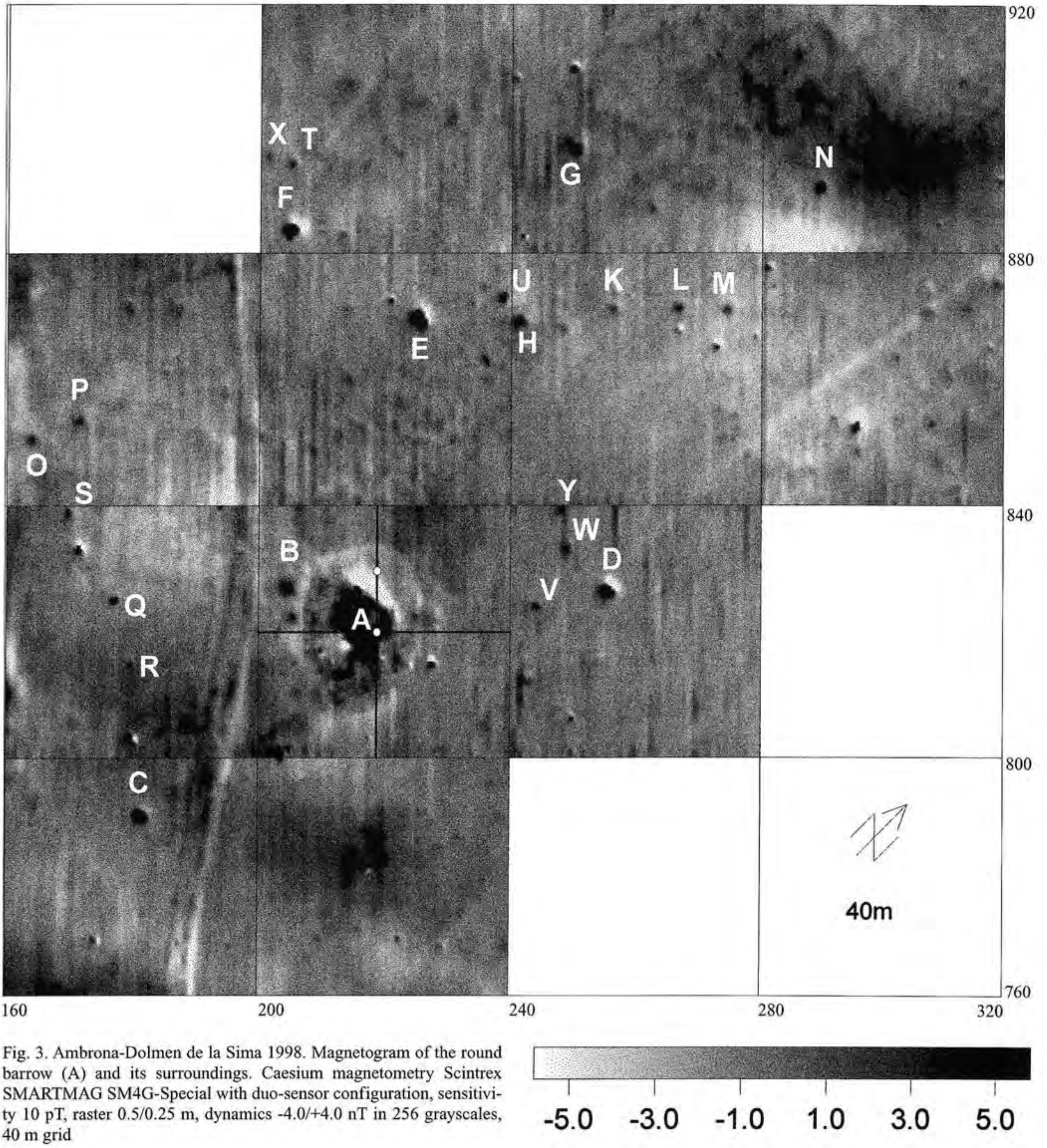

Fig. 3. Ambrona-Dolmen de la Sima 1998. Magnetogram of the round barrow (A) and its surroundings. Caesium magnetometry Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster 0.5/0.25 m, dynamics -4.0/+4.0 nT in 256 grayscales, 40 m grid

magnetogram about 30 pits (settlement or burials) with various sizes in a wide distribution were identified clearly (Fig. 2). The distribution of all these pits was covered completely by the magnetic survey, therefore one would suppose, that the settlement had an extension of 110 to 80 m. Most of these settlement traces lie in the socalled canada, an old track for driving herds of sheeps over long distances. The trace of this canada also is clearly visible in the magnetogram possibly due to the compression of the ground in several trails over centuries. This area of the canada has never been ploughed, and the archaeological structures in the ground should be well preserved even near to the surface. But there were no traces of poste holes, which would mark prehistoric houses. Some of these magnetic anomalies are in such a manner strong and wide (e.g. A2 in Fig. 2, diameter about 2.6 m), that one would suppose rather an burnt place than a settlement pit.

For the barrow under excavation only little details are visible in the magnetogram (B3 in Fig. 2) because of the extremly strong disturbances due to a great many iron nails used in the excavation for taking the measurements. Nevertheless some archaeological features are still visible in the magnetogram like the burnt chamber, which causes quite a strong magnetic anom-

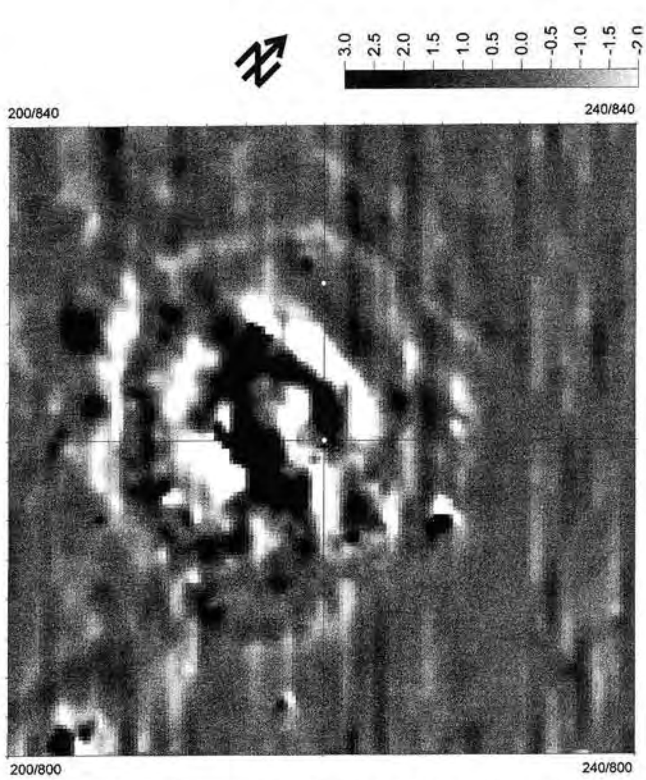

Fig. 4a. Ambrona-Dolmen de la Sima 1998. Magnetogram (detail) of the round barrow with a rectangular chamber. Caesium magnetometry Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster 0.5/0.25 m, highpass filtering 10 x 10 pixel, dynamics -2.0/+2.0 nT in 256 grayscales, 20 m grid

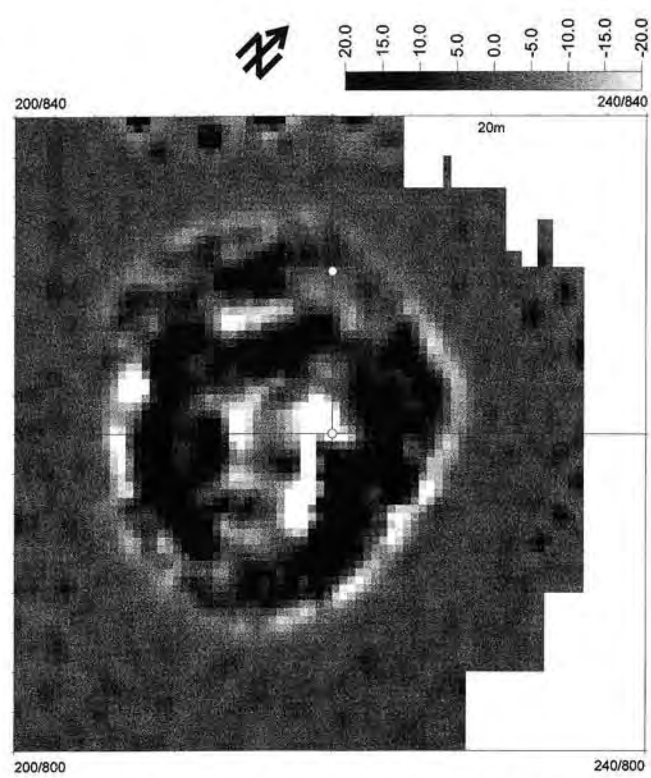

Fig. 4b. Ambrona-Dolmen de la Sima 1998. Resistivity diagram of the round barrow. Geoscan RM15-Advanced resistance meter with twin electrode, raster 0.5/0.5 m, dynamics -20.0/+20.0 units (original data 40.0/240.0 Ohm m), 20 m grid

aly. The trace of a circle of some burnt postes, which may have marked the border of the mound, may be seen in the western half of the barrow.

Also in 1996 the neolithic site La Revilla was prospected over an area of 120 to 160 m. The magnetic anomalies were quite different to La Lampara, therefore one would suppose rather an settlement than an burial site, but the structures were not clearly to be seen and difficult to interpret. Another possibly fortified neolithic settlement (La Cumbre) situated at an rocky plateau some kilometers apart was test measured in 1997. The magnetogram shows a wide range of magnetic anomalies of various amplitudes and widths, which would be typical for a settlement. Some of the minor anomalies might be post holes cut into the rock (lime stone). The pits of the settlement are mainly distributed on the upper plateau only. The northern border of the settlement was possibly a burnt rampart or a burnt wall, which still forms a steep edge.

In 1997 another tumulus was detected by Manuel Rojo, who saw the site from the nearby road. His name Dolmen de la Sima means that this is an megalithic monument, which should contain a burial chamber made from huge stones. Like in La Lampara the magnetic prospection covered also a wide surrounding area. The magnetogram was found to be also rather similar to La Lampara with many pit anomalies of various types in the surroundings (Fig. 3). Possibly another burial site was detected in the vicinity of the round barrow. The Dolmen de la Sima shows a very distinct rectangular positive anomaly over the centre of the mound, which may be the burial chamber. There is some evidence, that the chamber is made from wood, but outside packed with stones, because of its geometric shape with absolutely straight edges, which might be constructed by wooden beams (Fig. 4a). The higher magnetization of the chamber may be explained either by a burnt chamber or by a biogenic magnetization process due to magnetic bacteria, but there are no investigations about this process until now.

It was tried to learn more about the interior structure of Dolmen de la Sima by a resistivity survey in August 1998. But this was rather problematical because of a extremly dry soil which gave no electrical contact to the gound at all. After putting some 10,000 liter of water over the site the resistivity measurement could be started. Also in resistance the chamber is marked by a wide anomaly in the centre of the mound with good conductivity. The stone package around the chamber is well visible in the electrical diagram too (Fig. 4b). But there are also some anomalies of high resistance upon the chamber shown in the magnetic prospection, which gives some evidence to the earlier idea about a stone chamber in the Dolmen de la Sima. We will know more about this complex site by the end of the sommer, because an excavation will start in August this year. Both archaeologists and geophysicists have to learn more about the possibilities interpretating geophysical prospection with archaeological evidence.

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H. Becker

Prospecting in Ostia Antica (Italy) and the Discovery of the Basilica of Constantinus I. in 1996

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker), German Archaeological Institute Rome (P. Zanker, M. Heinzelmann), Institute for Photogrametry and Remote Sensing Technical University Munich (M. Stephani, K. Eder, R. Brandt), Bayerische Akademie der Wissenschaften (Kommission zur Erforschung des antiken Städtewesens) München, Soprintendenza Archaeologica di Ostia (A. Galina Zevi).

After the huge excavations in 1938 to 1942 in Ostia Antica, the ancient habour of Rome for the World Exhibition 1942 in Rome, there remained about 40 hectare of the area of the ancient city untouched. This is about 50 to 60% of the original built up area. On one hand the untouched area would be a chance for future research work in Ostia, at the other hand this was always a handicap for urbanistic research. The ideas about the building structure in some quarters of the city (regiones) as well as about the distribution and type of various buildings will be almost hypothetical. Even the location of some important buildings like the amphitheatre and the temple of Volcano are still unknown. Therefore the department Rome of the German Archaeological Institute began to organize a experimental project testing modern methods for archaeological prospecting for urbanistic research. The combination of aerial photo interpretation of several sources, digital terrain modelling and geophysical prospecting (caesium magnetometry and resistivity surveying) were applied on the base of the same coordinate system.

An area of about 15 ha, the biggest untouched area, in regio V in the southeast of the ancient city was selected for a first test for geophysical prospecting in August 1996. The limits of this test area were chosen very close to the excavated parts of this regio, to the south and east it was spread far beyond the ancient city wall reaching the modern fence of the archaeological area. Hopefully in this area used as ploughed field for agriculture the archaeological structures should remained untouched and buried not very deeply.

Considering the time of ten days only for this first test in August 1996 caesium magnetometry was applied only, because resistivity surveying seemed to slow for vast areas. The summer in 1996 was also very dry with temperatures sometimes above 36° Celsius (in the non-existing shadow), which would have caused severe electrical contact problems to the ground. After a very limited test for resistivity surveying in area where the basilica was found in 1997 there was a bigger area surveyed by resistivity methods in June 1998, which gave almost no additional information about the archaeology in the ground that could be seen already in the magnetograms.

This was also the first test for a quadro-sensor caesium magnetometer system mounted on a non magnetic chariot (the so-called "Magneto-Scanner"(Fig. 1). This new system consists of 4 caesium magnetometers Scintrex SMARTMAG SM4G-Special with quadro-sensor configuration, 2 gradiometer consoles, data loggers, power supply (4 batteries 12V/6Ah), interface electronics and automatic distance trigger mounted on a nonmagnetic chariot, total weight about 50 kg. A fifth magnetometer can be used for compensating the daily magnetic variation synchronised in a variometer mode. The whole system (5 magnetometers and the chariot) can be packed into any normal personal car (there is no van necessary). The "Magneto-Scanner" had to be built up rather quickly to be ready for the test in Ostia within some weeks. Several persons and companies helped for this fast construction: The main part of this system was sponsered by the Bayerische Motorenwerke AG BMW, the nonmagnetic chariot was built by my brother Dr. Thomas Becker – the construction was made during manufacturing – and Scintrex (Canada) succeeded in fast delivery even for the modified sensor-systems SM4G-Special. Jörg Fassbinder helped solving many problems due to the interface electronics and the distance triggering and Rainer Appel succeeded finishing a software

Fig. 1. "Magneto-Scanner" of the Bavarian State Authorities for Monument Conservation at its first test in Ostia Antica 1996, consisting of four caesium magnetometers Scintrex SMARTMAG SM4G-Special with quadro-sensor configuration, two gradiometer consoles-data loggers, power supply (4 batteries 12V/6Ah) and automatic distance trigger mounted on a nonmagnetic chariot, total weight about 50 kg), proto-type 1996

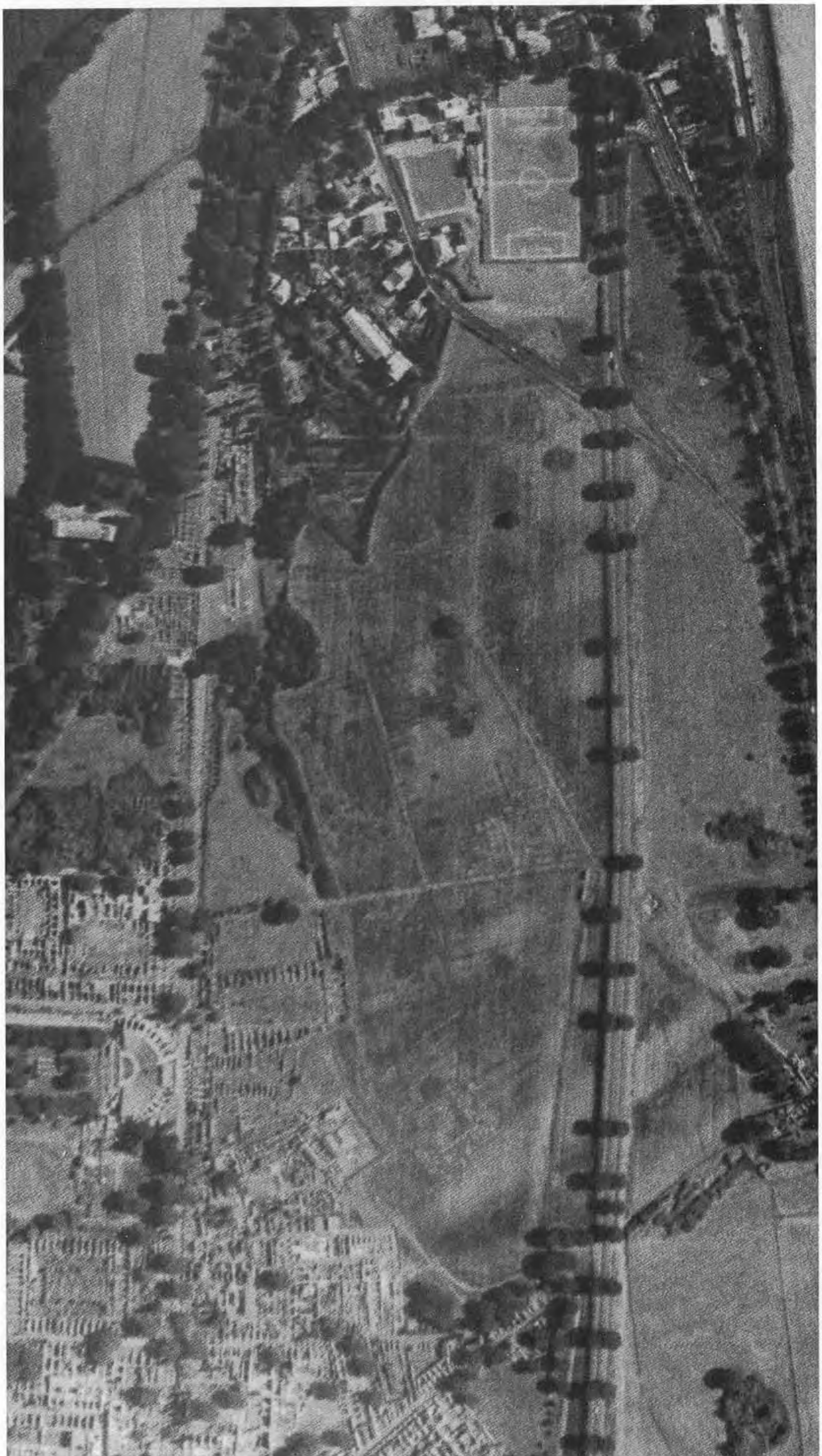
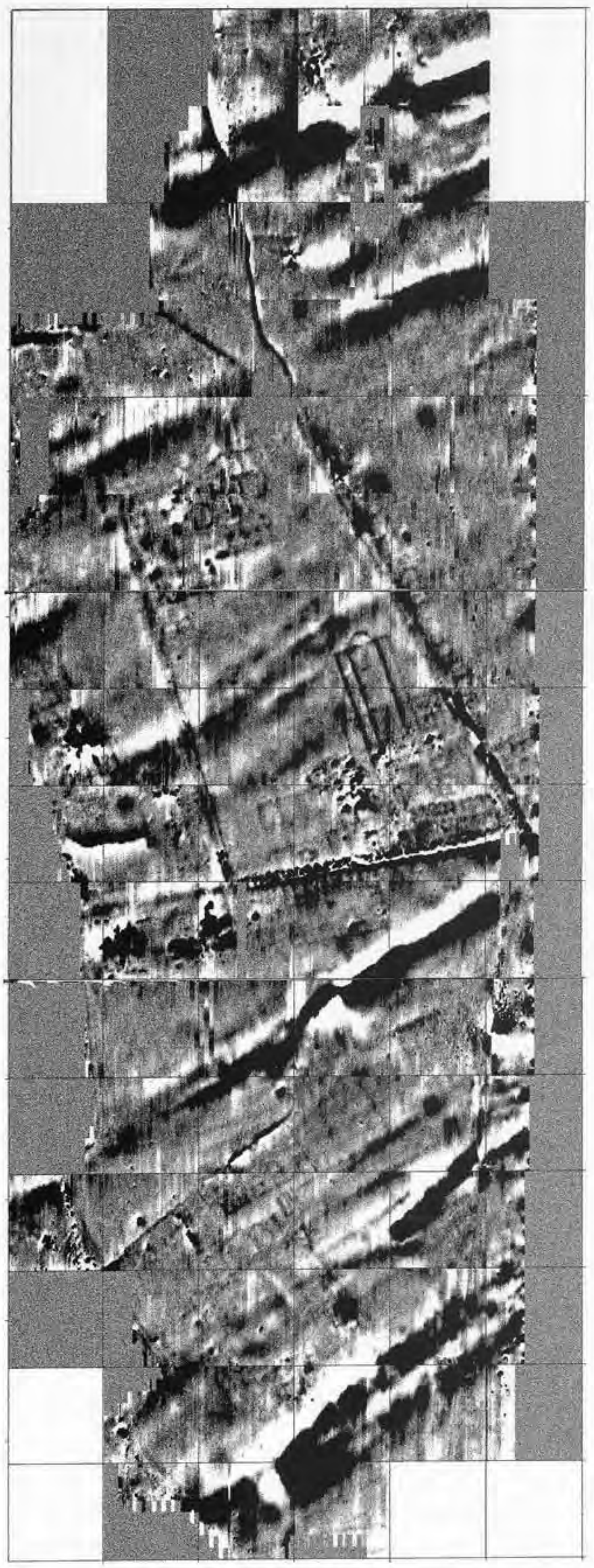


Fig. 2. Ostia-Antica. Aerial photo of unknown source (after world war II.) of the regio V with the so-called Via del Sabazeo, the Porta Secondaria in the South and parts of the Republican city wall as crop marks. This field showing the crop marks is covered almost completely by the first test for magnetic prospecting in 1996



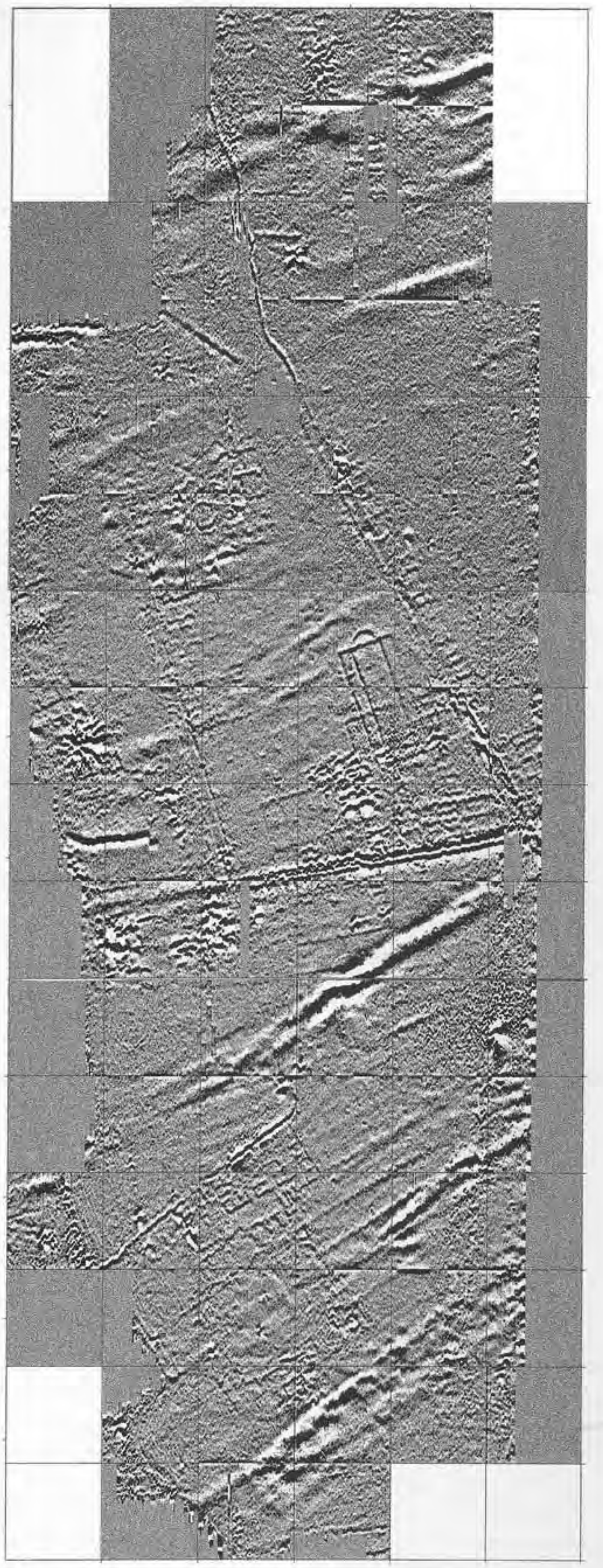


Fig. 3a. Ostia-Antica 1996. Part of the magnetogram of regio V with many structures of archaeological evidence (refer to the text for details). The newly discovery basilica of Constantinus I., the Great, is clearly visible in the corner near the gate of the Via del Sabazeo and the city wall to the south. Caesium magnetometry SM4G-Special in quadro-sensor configuration, sensitivity 10 pT (=0.01 nT Nanotesla), Dynamics-50.0/+ 50.0 nT in 256 grayscales (white/black), raster after resampling 0.25/0.5 m, 1 Hz bandpass filter, reduction of the diurnal geomagnetic variation by line mean value, 40 m grid

Fig. 3b. Ostia-Antica 1996. Part of the magnetogram of regio V after highpass filtering 10 x 5 pixel, same technical data as Fig. 3a, but dynamics -10.0/+ 10.0 nT

Fig. 4. Ostia-Antica 1996. Detail of the magnetogram of regio V with the newly discovered basilica of Constantinus I., the Great, clearly visible in the corner near the gate of the Via del Sabazeo and the city wall to the south. Caesium magnetometry SM4G-Special in quadro-sensor configuration, sensitivity 10 pT (= 0.01 nT Nanotesla), dynamics -50.0 /+ 50.0 nT in 256 grayscales (white/black), raster after resampling 0.25/0.5 m, 1 Hz bandpass filter, reduction of the diurnal geomagnetic variation by line-mean value, 40 m grid

package for the data processing of the quadro-sensor system during the last night before departure to Ostia. Another and more solid Magneto-Scanner had been constructed too, but this needs a van or minibus for transportation.

The quadro-sensor configuration corresponds to a double duo-sensor configuration, which was already successfully tested at the calcolithic fortified settlement of Monte da Ponte, Conceilho Evora, Portugal early in spring 1996, which achived double speed for prospecting compared with a single track instrument (Becker 1997). In an open area with a smooth surface 1 hectar with 0.1/0.5 m spacial resolution (about 500,000 measurements) may be measured with the quadro-sensor system in 2 hours. But for the 15 ha of the test area in regio V about 7 days were necessary. The reason for this rather slow field procedure was a rather rough surface of the field and a very short day because the site was closed at 5.00 p.m. The whole measurements were made by the author, but assisted by 2 or 3 students changing the 40 m lines every 2 m and also pushing the chariot uphill.

Unfortunately the automatic distance trigger by the rotation of the wheel could not be finished in time, therefore manual trigger-pulses were switched every 5.0 m into the data-set and later on interpolated to 0.25 cm. The magnetometer achive a cycle of 0.1 sec (10 measurements per second with 10 pT sensitivity), but this was set to 0.2 sec, which corresponds to a spacial resolution of 20 cm at normal walking speed. The distance values were only triggered on the first magnetometer console and transfered to the second console by synchronizing the interior clocks. In respect to the expected high external noise due to the nearby and very busy road to the sea, the International Airport Rome and many electric cables in the ground for illumination and alarm systems, a fifth magnetometer was used as base station in variometer mode monitoring the geomagnetic time variations. For data processing only the double duo-sensor configuration was used, because the fifth system gave no improvements on the data set. The field survey was carried out on the base of 40 m grids, which were marked by wooden pegs (the baseline had a length of 760 m). Data processing was done during night by the normal procedure of a duo-sensor configuration with resampling and speed dependent shift correction to 0.25 cm on the line (Becker 1999). The diurnal geomagnetic variations were corrected to the mean value of a 40 m line, which follows nicely the path of the daily variation, and to the mean value of a 40 m grid in order not to loose archaeological structure directly orientated in the line. Many anomalies due to the nearby traffic on the Via Ostiense could not be corrected by this method and remained in the data. This correction could only be done by mounting the fifth magnetometer on the chariot too, but then it would be to heavy for the rough conditions on the field in Ostia. A compromise concerning spacial resolution, sensitivity and speed had to be made for the speed firstly regarding the huge area. In a last step (JOIN4 software) the two double tracks were brought together to a 80 x 160 m matrix (spacial resolution 0.25/0.5 m) for a 40 m grid. Geoplot V2.0 software (Geoscan, Bradford) was applied for additional corrections (edge matching and desloping) and first visualization of the magnetograms (only up to four 40 m grids at once). Final data processing and visualization was done by SURFER6 (Golden Software, USA) and OPTIMAS6 (USA) digital image processing. Prints with high resolution inkjet printers were made the first time (Fig. 3a, 3b), but they can not achieve the quality of the monitor photography by medium size cameras (Hasselblad 6x6 with 150 mm lenses) (Fig. 4).

The interpretation of the archaeological structures in the magnetograms are in some parts very simple and clear, but in others rather problematic possibly caused by the multi layer structure of many building phases of this important city over many centuries. The peculiar wide positive/negative anomalies (black/white stripes in the magnetogram Fig. 3a) are geologically caused by the shore lines of the Tiber delta with a concentration of geological magnetite due to the wash of the waves. Their effect can be slightly improved by highpass filtering of the data (Fig. 3b). But there are also many archaeological structures to be seen in the magnetograms. Very dominant shows traces of the Via del Sabazeo (from north to south) possibly due to a channel made by baked bricks in the underground (cloaca maxima), but there are also some other streets visible in the magnetogram by the highly magnetized pavement with basaltic rocks. The Late Republican city wall is drawn only by a narrow line corresponding to the little width of the wall, which was made in opus quasi reticulatum technique. But if one looks at a very oblique angle exactly in the direction of the wall (in Fig. 3a, 3b in 297° from the centre of the gate of Via del Sabazeo to the west = left) is to be defined as a very clear black line (positive magnetic anomaly caused by the building mode as opus quasi reticulatum made from volcanic tuff). Outside of this southeastern part of the city wall there was found a road leading from the porta secondaria directly to the Via del Sabazeo. To the west this road seems to be a bypassing route directly to the Via Laurentina. Adjacent on the outside there is a row of rather early burial monuments. In the interior area of the city there a several buildings arranged in a insulae.

The most significant discovery in 1996 was a early christian basilica, which may be the basilica of Constantinus I., the Great, also mentioned in the liber potificalis in the vatican, which is clearly visible in the corner at the gate of the Via del Sabazeo and the city wall to the south. The overall dimension reaching nearly 90 m in length provides strong evidence having found the basilica of Constantinus I. indeed. This nearly eastwest oriented building consists of three arches with a apsis, but without the lateral hall. The part of the basilica adjactent to the Via del Sabazeo is not clearly visible, but west to the main building there is clearly visible the atrium. At the southern side of the atrium there may be a round building with 9.0 m diameter, which could be a baptisterium. Also clearly visible is another older building underneath the basilica which may be leveled for the foundations of the basilica. In the meantime this interpretation of having discovered the basilica of Constantinus I. was proved by a directed sondage excavation early in 1998.

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J. W. E. Fassbinder, H. Becker, T. Herbich

Magnetometry in the Desert Area West of the Zoser's Pyramid, Saqqara, Egypt

As a joint project of the Bavarian State Conservation Office with the Archaeological Mission from the Polish Center of the Mediterranean Archaeology of Warsaw University, Cairo, Tomasz Herbich, a survey with the cesium magnetometer SM4G-Special Smartmag was undertaken in the October 1996.

Introduction

The Zoser pyramid belongs to the 3rd dynasty (2705–2630 B. C.) and is therefore the oldest monumental grave building in the world. The pyramid is situated inside of an enclosure of 550 length and 300 meters broad. In the south there is the Unas pyramid and the tomb of Haremhab, to the east the pyramid of Userkaf and pyramid of Teti, to the north there is the necropolis of the 3rd dynasty. The desert area west of the Zoser pyramid was believed not to contain much archaeological structures and therefore escaped for long time a systematic archaeological exploration. In 1987 the Polish Center of the Mediterranean Archaeology of Warsaw University, Cairo has undertaken a magnetic survey with a proton magnetometer, resulting in the detection of some clear anomalies.

Instruments and Results

To make a more detailed map with the higher sensive SM4G-Special cesium magnetometer (for further details on the survey procedure and on the cesium SM4G-Special Smartmag magnetometer see the article of H. Becker) and to generate a gray shade plot, the mesurements of 1987 were repeated. Only on the location where Mysliwiec & Herbich found the strong anomalies there were already excavations going on so therefore these areas have been excluded by our measurements.

The measurements were performed on the 8, 9, and 10th October 1996 with two instruments (Fig. 1). To require three days of work can be explained by the working hours of our Egyptian excavation commissar from 9:00 to 12:00 in the morning.

The result of our magnetometer survey is a strong striped gray shade plot (Fig. 2). The reason could be a magnetic storm occuring during the measurements. However this storm should have continued over three days. A more reasonable explanation is the highly magnetic sand of the desert around the pyramid. Then the slight variations of the distance between probe and ground caused by the walking of the surveyors makes a crucial signal on the sensitive instrument.

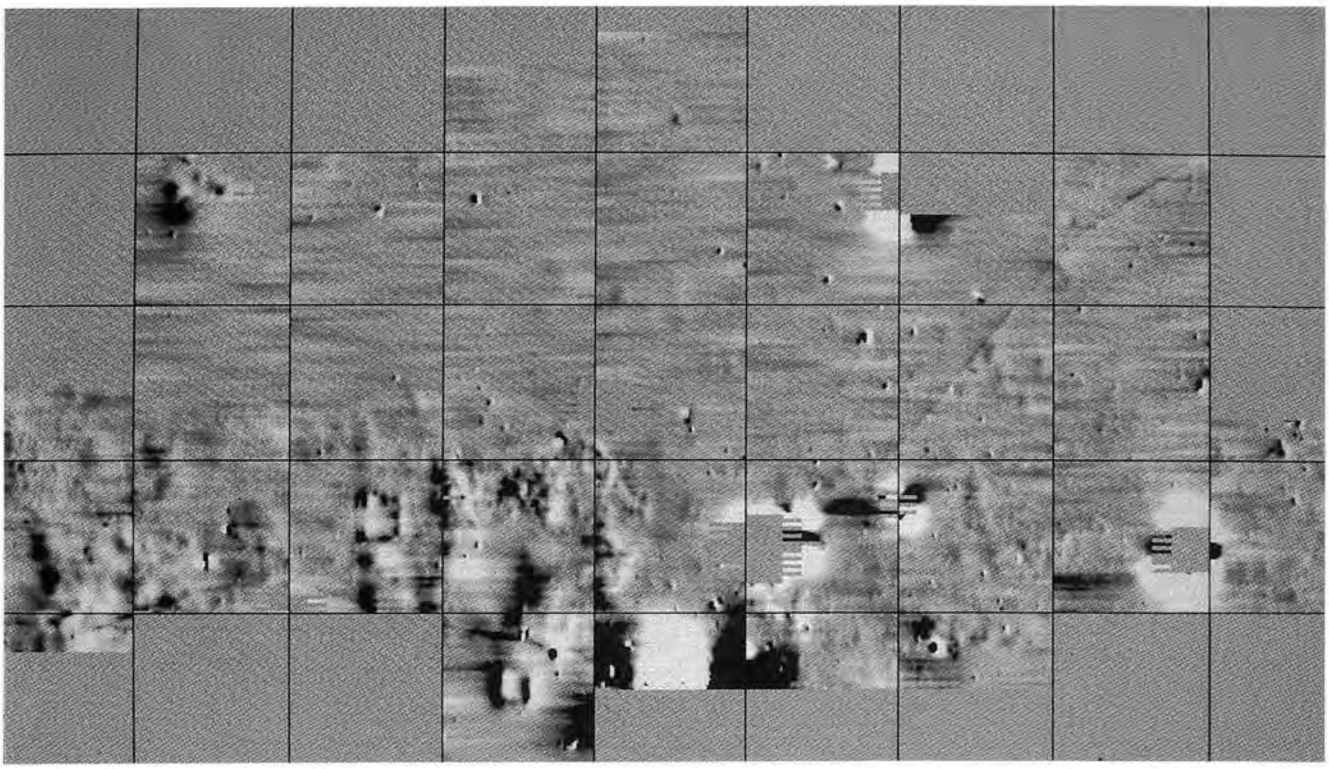

Fig. 2. Saqqara. Magnetic plan of the survey area west of the Saqqara pyramid. Gray shade plot showing clearly the contours of three buildings. Scintrex SM4G-Special smartmag magnetometer, hendheld dou-sensor configuration, dynamics ± 7.5 Nanotesla in 256 grayscales, sampling rate 0.5 x 0.25 meter, 40 x 40 meter grid, north to the right

Our measurements covering 360 x 200 meters discovered clearly the shapes of three before unknown grave buildings (Fig. 2). In shape and in size (10 x 12 meter, see bottom middle of Fig. 2) these buildings are similar to a burial chamber of an Vezir of the 6th dynasty which was just excavated by the Polish mission in October 1997.

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Fig. 1. Saqqara. Magnetometry in west to the Saqqara pyramid 1996. The authors with the hand-held Smartmag SM4G-Special magnetometer system, in the background the Saqqara pyramid (Photo by Tomasz Herbich)

H. Becker, J. W. E. Fassbinder

In Search for Piramesses – the Lost Capital of Ramesses II. in the Nile Delta (Egypt) by Caesium Magnetometry

Cooperation of Bavarian State Conservation Office Munich, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. Fassbinder), Institute for General and Applied Geophysics of Munich University (H.C. Soffel), Pelizaeus Museum Hildesheim (E. Pusch) and NRIAG National Research Institute for Astronomy and Geophysics Helwan-Cairo (A. Hussain Gouda, T. Fahmy), Supreme Council of Antiquities Cairo (Ali Hassan), German Archaeological Institute Cairo (R. Stadelmann), Austrian Archaeological Institute Cairo (M. Bietak)

Are sun dried mudbrick walls made from Nile mud identifiable in debris also of Nile mud surrounding by geophysical prospecting? This question was the main point for the research project "Archaeoprospection Egypt" supported by the Volkwagen foundation. Also supported by the Deutsche Forschungsgemeinschaft this test became part of the project "Rammesses City" of the Pelizaeus-Museum Hildesheim (Dr. Edgar Pusch) since 1996. In the same year this was also a training program for geophysicists of NRIAG, Helwan-Cairo in order to build up a unit for archaeological prospecting with fluxgate magnetometry and resistivity surveying (Prof. Ahmed Gouda Hussain and Prof. H. C. Soffel from the Institute for Geophysics of Munich University). The comparison of fluxgate and caesium magnetometry was also tested in Saqqara in cooperation with the Polish Centre for Mediterranean Studies, Cairo (Dr. Tomaz Herbich).

The northern capital of ancient Egypt Piramesses – house of Ramesses great of victories – of the Ramesside period (about 1,300 to 1,100 B. C.) was also the capital of Egypt in the reign of Ramesses II., the great pharaoh. Its location in the eastern delta is about 100 km north of Cairo near the modern village Qantir and is situated in an very active agricultural area. This ancient capital covering about 30 square km was the greatest metropolis of the 2nd millenium B. C. – possibly greater than Babylon or Niniveh in Mesopotamia. Nowadays this city has vanished completely from the surface. The capital was moved back to Memphis and the monumental stone architecture had been partly reerected in Tanis, also in the delta some 50 km to the north. Almost nothing is found above ground except fragments of pottery, tools and some pieces of stone archtitecture, in a place where one would expect the Ramesside residence with palaces, administration centres, archives, temples and a whole city with villas, living and working areas. There is also some evidence, that several necropolisis might be in the area of the city too.

After a first successful test in 1996 for comparing fluxgate and caesium magnetometry in the west necropolis of Saqqara, the instruments were also tested for two days in Qantir-Piramesses, but nobody actually was convinced that this experiment for prospecting mud in mud could be possibly successful. The instruments used were a fluxgate gradiometer Geoscan FM36 with distance trigger (Fig. 1) and two Scintrex Smartmag SM4G-Special with duo-sensor configuration (Fig. 2), but one sensor of the second magnetometer failed the first day and only one caesium magnetometer with duo-sensor could be used any more. After the first night of data processing the geophysicist told the archaeologists for breakfast (6.00 p.m.!), that he has seen columns, a courtyard, storage rooms with columns – almost a whole palace – in the magnetic data (Fig. 3a, 3b). It became evident, that magnetic prospecting was successfully applicable for mud in mud prospection. But obviously this was a wrong idea, because the magnetization contrast of the sundried mudbrick walls is strong enough even for the detection by fluxgate magnetometry. The magnetic contrast between mudbricks and sediments was found to be mostly negative, as the bricks are made mainly from fresh mud, but the mud of the cultural layers have a much higher magnetization because of processes of activity in the city, especially the use of fire, burning, change of the ph-conditions, which produce highly magnetic minerals in the soil like maghemite and magnetite. But the magnetization processes for archaeological structures in Nile mud are not fully understood yet and the investigation of the magnetic properties of sediments and bricks are still in progress. There are also a few buildings with a positive magnetization contrast, but it is not known by egyptologists if in Ramesside times also burnt bricks were used.

Fig. 1. Fluxgate Gradiometer Geoscan FM36 with distance trigger run by Tariq Fahmy of NRIAG National Research Institute for Astronomy and Geophysics, Helwan-Cairo (Photo by J. Fassbinder)

But the magnetogram (Fig. 3a–5) also demonstrates, that the stone architecture is clearly visible by its sand foundations, even if the stones have been already removed to elsewhere (for example to Tanis where some huge temples originally from Piramesses have been excavated). This is caused by the strong negative magnetic contrast between sand and Nile mud. As for every single column a sand filled pit was used for foundation – this method may be understood as a damping against shear waves of earthquakes – the detailed architectural layout of all stonebuildings becomes identifiable.

While the fluxgate magnetometry with Geoscan FM36 gave similar results for buildings at shallow depth with high magnetization contrast, the resistivity survey with Geoscan RM15 used by a team of the NRIAG National Research Institute for Astronomy and Geophysics, Helwan-Cairo recorded also the difference between sand- and stone-foundations but no mud brick structures at all. Considering the dimension of Piramesses with 15 square km only for the interior city there may be only caesium magnetometry with multi-sensor techniques beeing at least four times faster than fluxgate and about 20 times faster than resistivity surveying even at much higher spacial resolution as a suitable method for prospecting the city map for this metropolis. Archaeological structures at greater depths were detected by caesium magnetometry only. In the meantime after the first test and two campaigns with a total of 20 days measuring in the field about 50 hectare have been prospected by two caesium magnetometers with duo-sensor configuration with 0.5/0.2 m spacial resolution (4 sensors on the area and about 10 million measurements) by two operators. This speed could be doubled by running each magnetometer system by two operators – the main limitation of this method is the distance which a person could possibly walk under hard conditions considering the surface, and the many ditches for irrigation which must be jumped over with about 20 kg of equipment. The use of a quadro-sensor system on wheels would be impossible in Qantir-Piramesses because of these ditches.

The archaeological interpretation of the magnetograms (original and corrected data and a set of highpass filtered data) mainly done by the professional egyptologist Dr. Edgar Pusch may be extremly detailed and various – sometimes even with several building phases and stratas. Considering the tiny partition of 50 hectare (0.5 square km) compared with the extension of the area of the whole metropolis with about 30 square km, the variety of identified buildings and quarters of the city is surprisingly high. "The existence of vast living quarters with villas, gardens, wells and smaller houses aligned along streets as well as lakes and "empty" areas which are tentatively interpretated as harbours or old river beds of the Nile partly with reinforcements of the banks, all East of the excavated site Q IV which in itself contains a huge royal horse stud as excavated during the last 10 years. The region south of Q IV and Q I is covered by vast buildings of unknown function. Those may be interpreted as temples, parts of palaces or administrative buildings, possibly even the famous Foreign Office as depicted in the tomb of Thay at Thebes. Also clearly discernible are two huge halls with several hundred mud brick pillars each at the northern edge of the meas-

Fig. 2. Caesium Magnetometer Scintrex SM4G-Special with duo-sensor configuration and manual distance triggering every 5.0 m, sensitivity 10 pT (picotesla) at a cycle of 0.1 sec (Photo by J. Fassbinder)

Fig. 3a. Qantir-Piramesses 1996. Magnetogram as digital image with 256 grayscales. Raster 0.5/0.25 m, dynamics -–12.8+12.8 nT (black/white), square mean, edge matching and desloping, 20 m grid

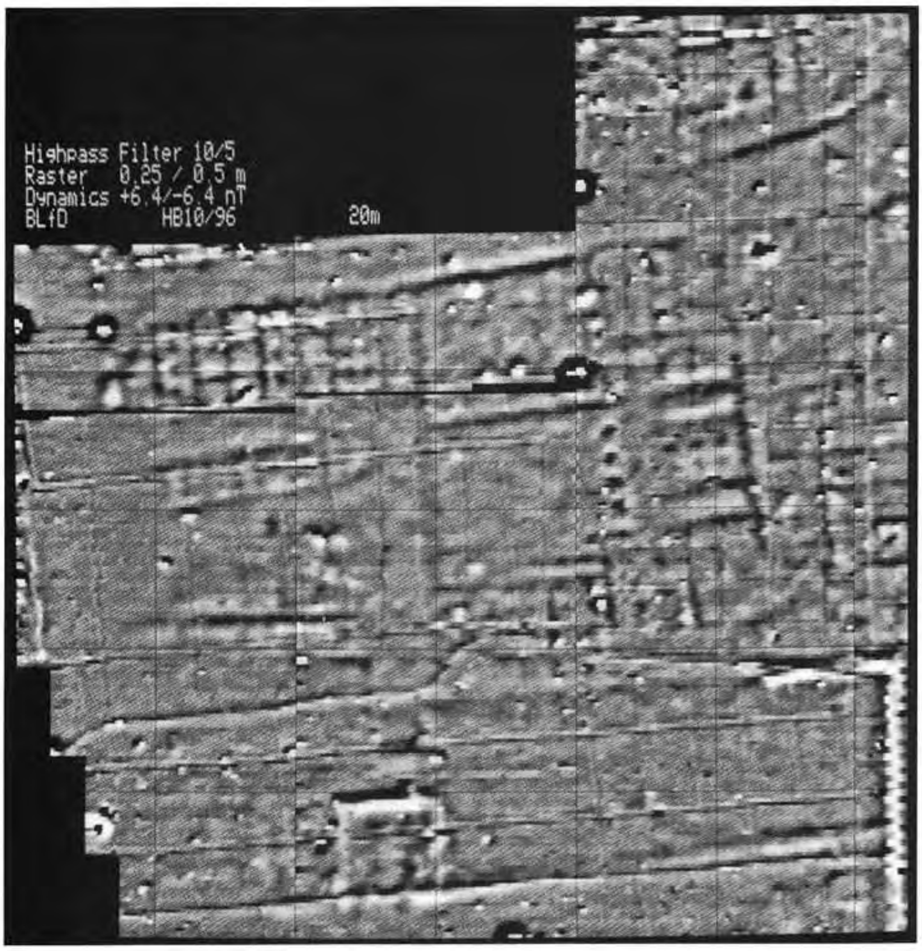

Fig. 3b. Qantir-Piramesses 1996. Magnetogram of the same data after highpass filtering 10 x 5 pixel, technical data see above, but dynamics -6.4/+6.4 nT

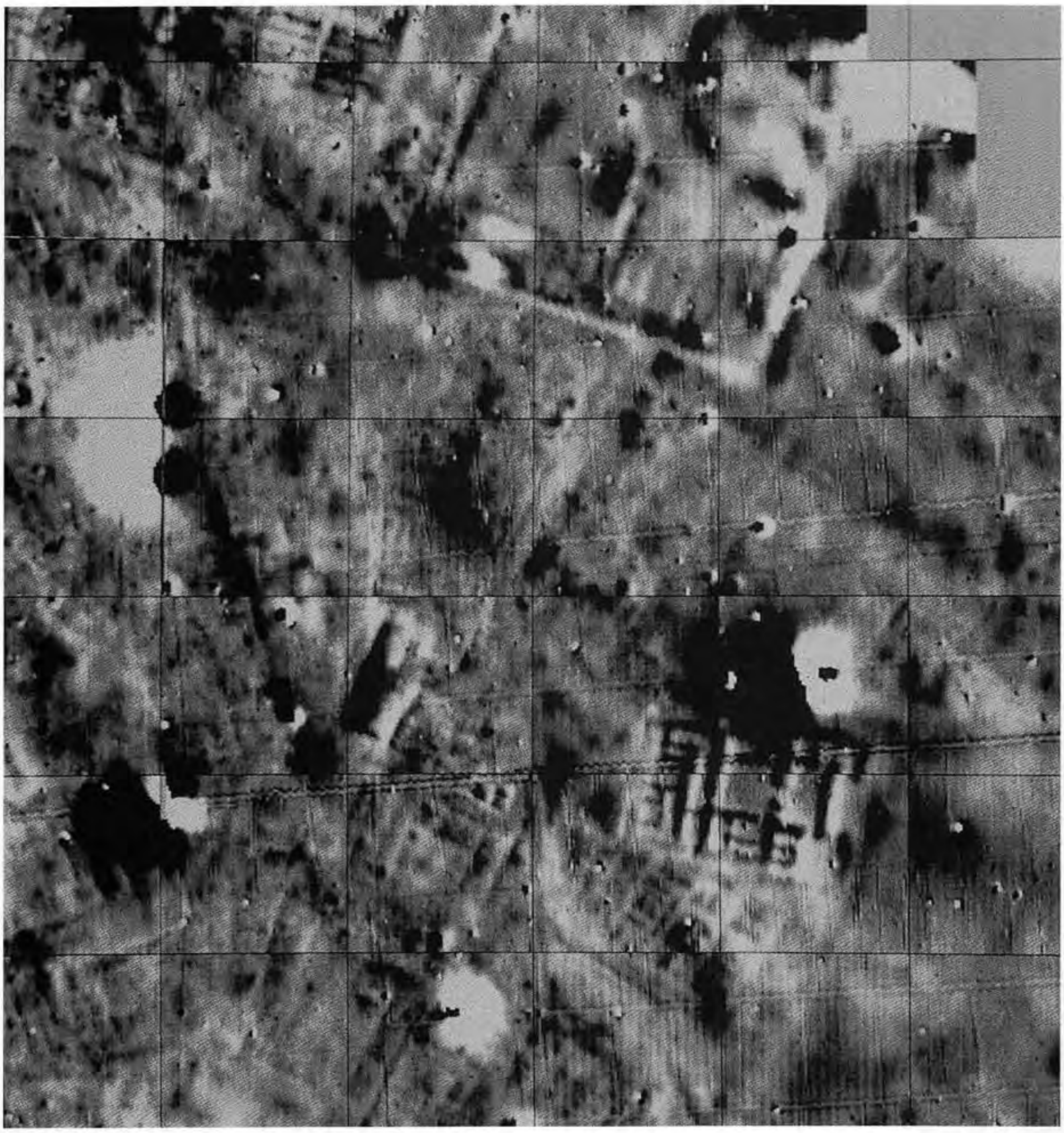

Fig. 4. Qantir-Piramesses East 1997/1998. Magnetogram as digital image with 256 grayscales of a district of the Ramesside capital with Amarna type villas, streets, channels, houses, workshops and a temple building (?) in the centre: original data corrected (40 m grid)

ured area of 1997, which are similar to the so-called Coronation Hall at Tell el-Amarna. Thick enclosure walls and several buildings of definitely the same date are visible in the centre, while the southern and western edge are destroyed by a water way or channel dating to late Roman or even Islamic times according to pottery recovered from it at site Q I" (Pusch et al. 1999).

The magnetogram of the 1998 campaign covering about 23 ha gave almost similar results with many details completing the vast main area nearly one km in west-east direction and half km wide. Further to the northeast of the area of Piramesses a temple site was prospected, which showed some parts of stone architecture with inscriptions and fragments of a colossal statue of Ramesses II. In the very west of the area another quarter of the city was found with a rather different structure of buildings and some smaller temple buildings, which seems to be a necropolis inside the city. Several funerary statuettes found on the surface give some evidence to this interpretation. Possibly the most important finding until now may be a complex building which covers at least an area of 240 to 200 m. consisting of several column halls, courts, vast magazine rooms all situated east of the excavation Q IV with the huge royal horse stud and the court for combat carts. Also in 1998 a room with an golden floor was excavated in this area and interpreted as part of a temple or palace building of Ramesses II. whose cartouche was brought to light also from this golden floor. Although the direct connection of this extraordinary archaeological finding with the detection of the huge building complex by caesium magnetometry is not proved at the moment, it seems to be quite sure, that this is a main palace of Ramesside times unless we have discovered the main palace of the great pharaoh Ramesses II. himself.

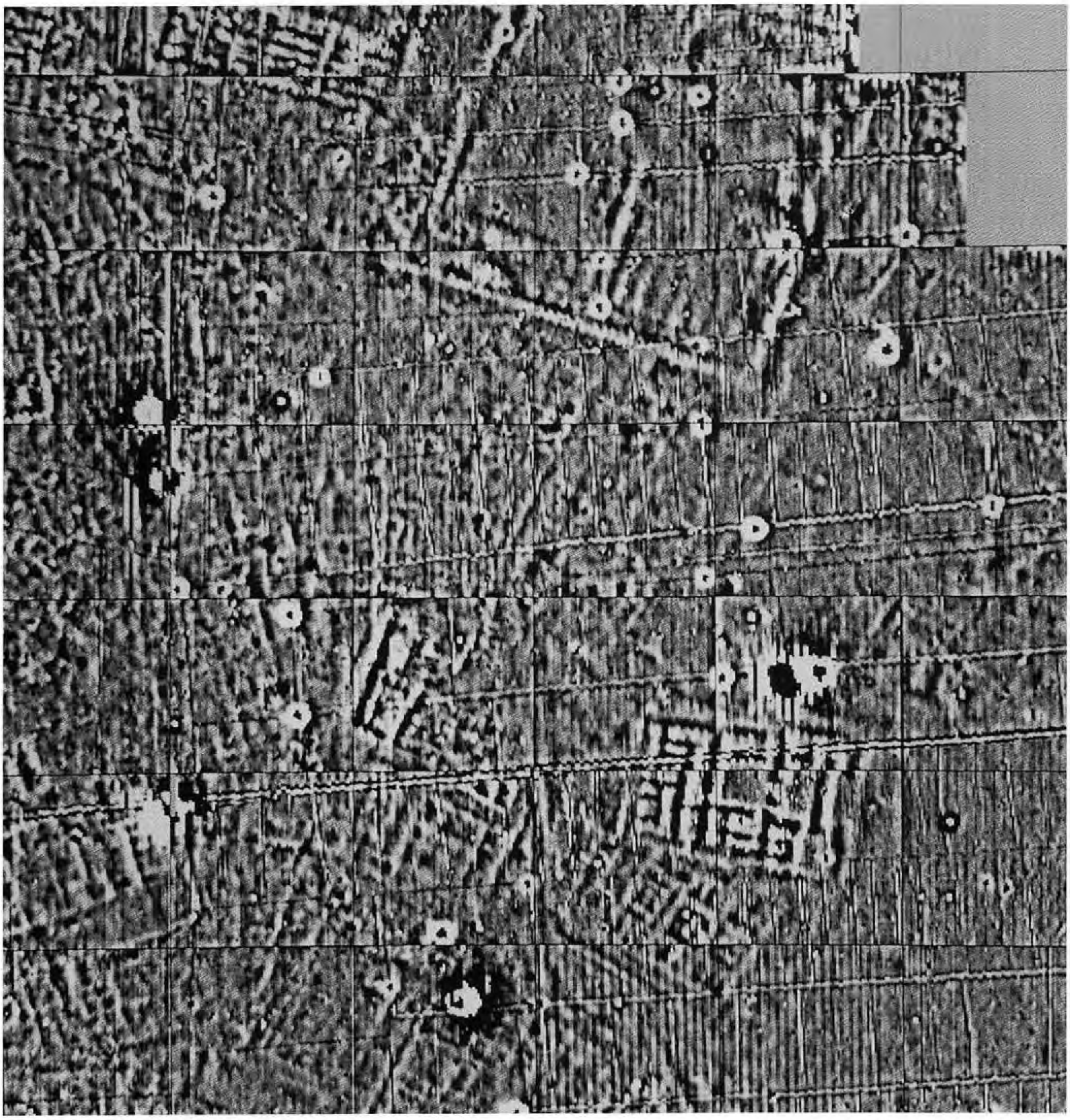

Fig. 5. Qantir–Piramesses East 1997/1998. Magnetogram of the same data as fig. 4, but highpass filtered data 10 x 5 pixel, technical data see Fig. 3a, 3b

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H. Becker, F. Chouker , J. W. E. Fassbinder, D. Sack, C. Schweitzer, M. Stefani

Prospection of the Early Islamic residence Rusafat Hisam (Syria) by Caesium Magnetometry and Resistivity Surveying 1997–1999

Cooperation of Bavarian State Monument Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. W. E. Fassbinder), Institut für Baugeschichte – Historische Bauforschung Berlin (D. Sack, 1997 and 1998 University of Frankfurt), Institute for Geophysics Ludwig-Maximilians-Universität München (H. C. Soffel), Institute for Photogrammetry Technical University München (M. Stephani, 1998–1999), German Archaeological Institute Damascus (S. Freyberger), German Archaeological Institute Madrid (T. Ulbert), Department for Geophysics of Damascus University (Faris Chouker, Khaldoun Kotaish, Bassam al-Shamali, Nazih Jaramani, Dafer Saif).

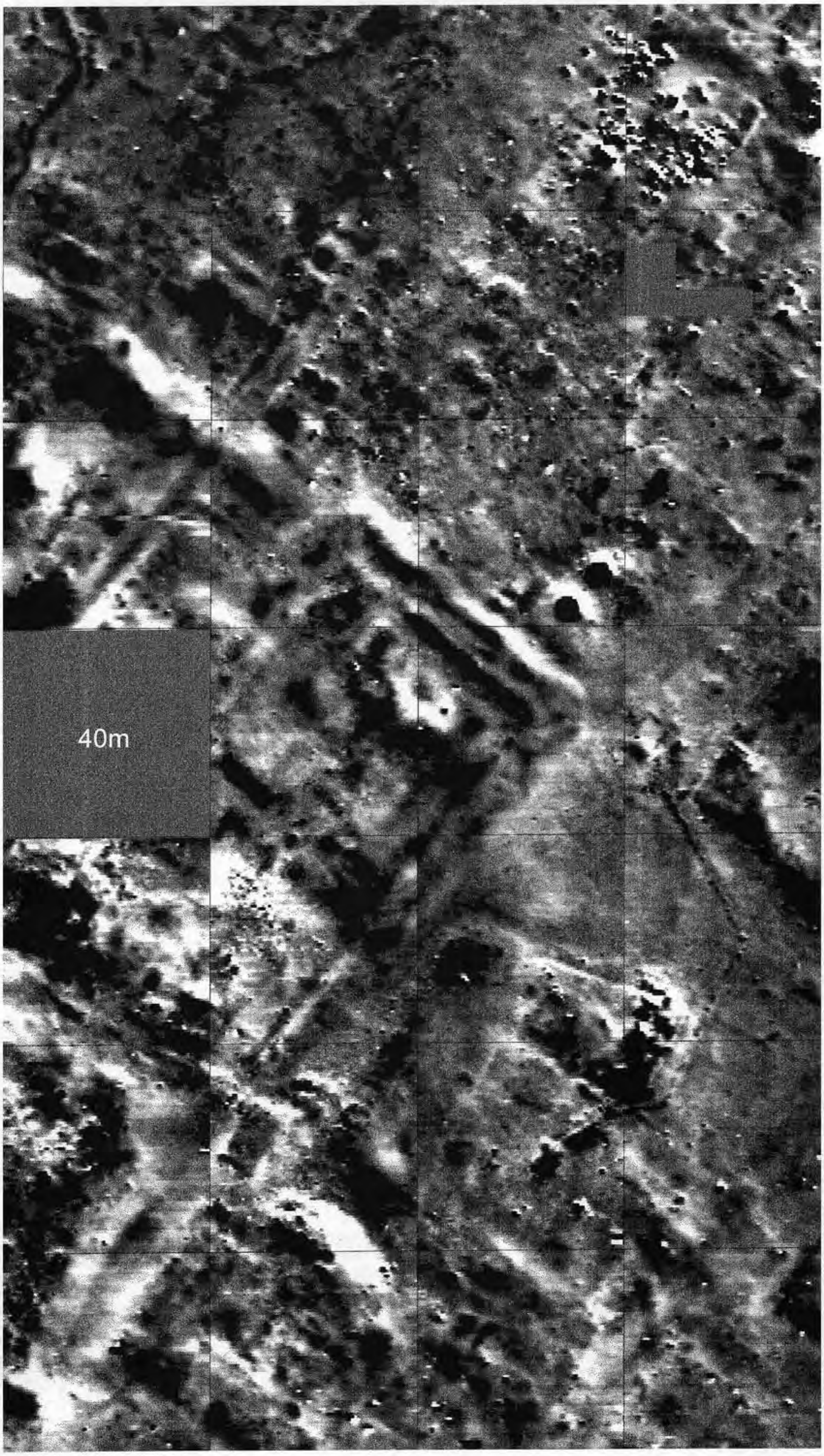
Around the end of the 5th or beginning of the 6th century the city Resafa-Sergiupolis had been fortified. The reliquary of Holy Sergius held in the chappel beside the basilica was not only a centre for pilgrimage of Christians but also of Muslims. One of them was Hisam b. Abd al-Malik, who built at the northern side of the reliquary chappel with an direct entrance to the sanctuary the Great Mosque. Hisam already as prince loved this place in the desert, when the valley of the Euphrates became more and more contaminated by pestilence. It was also here in the desert, when Hisam got the news of his appointment to be caliph (reign from 105/724 to 125/743), and he decided to built south of Resafa-Sergiupolis his new residence Resafa-Rusafat Hisam, which became the new name for the city too. In this huge area (about 3 square kilometres) 1977 a basic survey by fieldwalking and a topographical survey were made, followed 20 years later by a first geophysical prospection, which will be described here. From the first survey in 1977 a rather extensive idea about the charakter of Hisam's residence could be drawn as a loose agglomeration of six palaces with farmhouses and public utilities. The archaeological investigations of the city and the surrounding landscape resulted in a rather precise dating of the place by numismatic evidence from the early Abbasid period to the second half of the 8th century (136/753-54 or 146/763-64). This means that in the seconde quarter of the 8th century there existed besides the fortified byzantine city, which still was a centre for pilgrimage until the 13th century, the Islamic residence, which wąs never fortified. Nowadays in the whole area of this residence many relicts of mudbrick-buildings still can be seen by their sunken walls, which form features like dikes. In the extremly wet spring in 1997 and 1998 many details of the architecture could be observed as damp marks on the ground. These marks were not stable at all and vanished few hours later. Therefore it was impossible to document these phantom features. But for some cases when the magnetization contrast of the mudbrick buildings against their surrounding becomes negligible this would be the only method of tracing theses houses, because there is almost no contrast in resistivity too.

After the test measurement in 1997, there were two prospection campaigns in 1998 and 1999 using the successfully tested combination of caesium magnetometry and resistivity surveying. In this huge residence area of 3 km^2 magnetics was applied for large scale prospection, but resistivity on specific buildings to learn more about architectural details. All houses and palaces of the residence were built by sun-dried mudbricks, but with different techniques. But all walls have also a foundation made out of stone. For these foundations the local anhydrite was used. The walls of the more important buildings were plastered with stuccowork (also anhydrite). The magnetization contrast was found to be extremly low being positive for mudbrick wall in their surrounding debris, but also negative for the stone foundations. These two effects in magnetic contrast can cancel and a structure becomes non detectable with magnetics even if one could see the walls at the surface, which may be very frustrating. But there were also some buildings with burning, which show up in the magnetogram quite nicely. The situation for resistivity was found to be little better, but only in a wet ground condition making the electrical contact possible and showing a good contrast for the stone foundations. But also a mudbrick wall in its debris shows a very slight positive anomaly (better conductivity). This effect was also given for extreme dryness, because the dense mudbricks are holding the moisture for a long time. All campains took place early in the year around Easter, when heavy rains allow good electrical contact to the ground. It was only in 1999, when it was almost impossible to work with resistivity because of an extreme aridity (when the sheep are dying resistivity surveying in the desert becomes impossible). One would wish an instrument with capacitive coupling to the ground.

This combination of magnetics and resistivity for prospecting mudbrick architecture in the desert may be demonstrated best with the complex of palaces III/IV, which was prospected almost complete in the two days campaign in 1997. The palace IV is also well visible at the surface, so there will be a good possibility adding the terrain model to the geophysics. The instruments used for magnetic prospection was the Scintrex SMARTMAG SM4G-Special with duo-sensor configuration (in 1998 and 1999 two instruments were put into action). For resistivity survey, which was run by our Syrian colleagues from Damascus University, a Geoscan RM15 with twin-electrode was used. Unfortunately it was impossible using the multiplexed double-twin configuration because of the contact problems to the ground.

The question was to decide which non destructive technique would be suitable for archaeological prospection for mudbrick architecture. Therefore caesium magnetometry and resistivity survey were applied on the same area (FP 143), where strong evidence for a palace could be seen on the surface by topographical reason. It is known, that resistivity survey should be the best method for prospecting archaeological structures made from stone, but magnetometry would be about 5 times faster in fieldwork. Therefore caesium-magnetometry was covering an area of more than 1.5 hectares after two days (300,000 measurements with 0.1/0.5 m intervalls). Resistivity only covered a quarter of hectare.

A main survey line was chosen from the southeast corner of the inner wall of the palace IV leading to the southwest corner



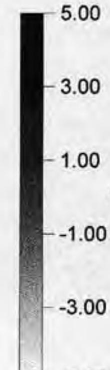


Fig. 1. Rusafat-Hisam 1997/98, palace complex III/IV. Magnetogram as digital image, caesium magnetometer Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 0.01 nT, raster 0.5/0.25 m after resampling, reduction to the line-mean, dynamics –3.2/ +3.2 nT in 256 grayscale (white/black), 40 m grid

Fig. 2a. Rusafat-Hisam 1997, palace complex III/IV. Magnetogram (detail) as digital image. Same technical data as Fig. 1, but 20 m grid

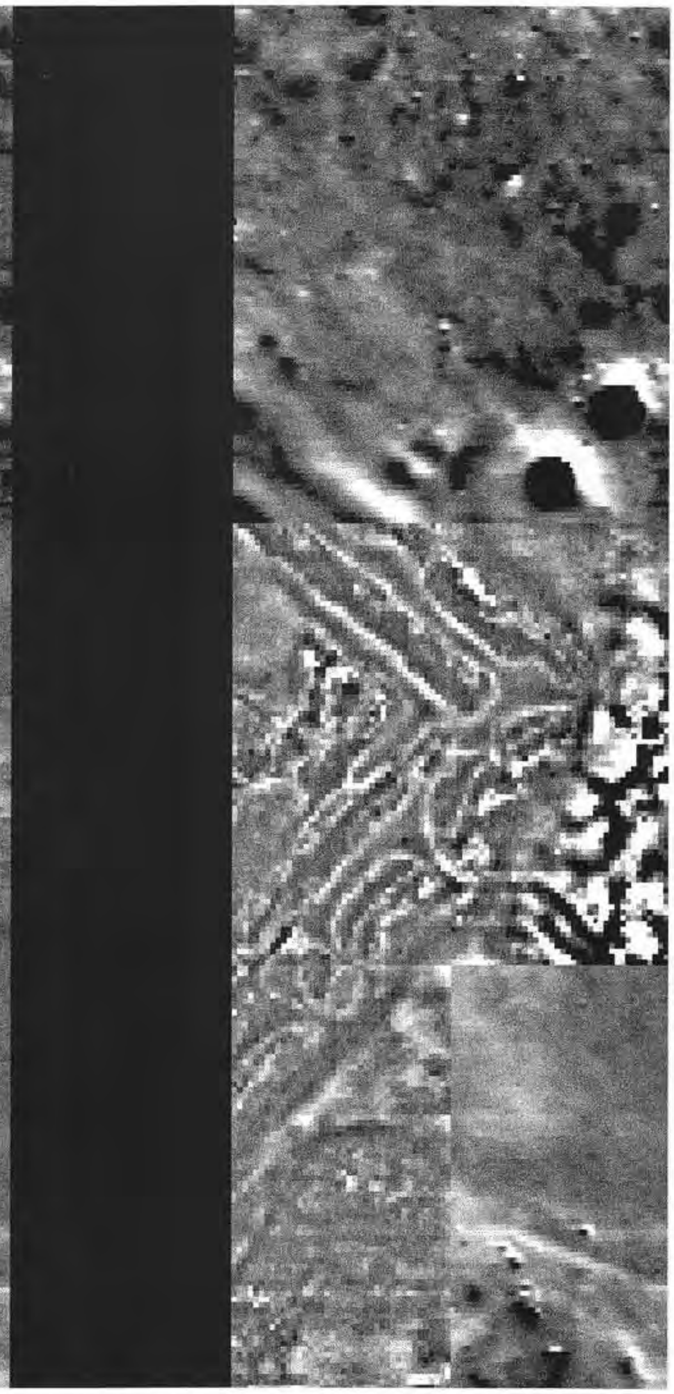


Fig. 2b. Rusafat-Hisam 1997, palace complex III/IV. Compilation of magnetics and resisitivity survey. Resistivity with Geoscan RM15-Advanved with twin-electrode, raster 0.5/0.5 m, dynamics of the original data 30/40 Ohm m, highpass-filtering 8 x 8 pixel, dynamics ± 1.5 Ohm m in 256 grayscale (white=high resistivity, black=good conductivity), 20 m grid

of the city wall of Byzantine Resafa. A 40 m grid was marked by wooden stacks for magnetometry and a 20 m grid was fixed covering the eastern half of the palace for resistivity.

1. For caesium magnetometry a Scintrex Smartmag SM4G-Special was used in the socalled duo-sensor configuration which doubles the speed of fieldwork. This magnetometer has a sensitivity of 0.01 Nanotesla at 0.1 sec cycle. Time mode sampling at 0.2 sec was chosen which gives a spacial resolution on the traverse better than 20 cm. High frequency external geomagnetic disturbances were eliminated by a bandpass filtering at 1 Hz. The diurnal geomagnetic variation was corrected by the reduction of the data after resampling on the line-mean and on the square-mean. Data processing and visualization was made in the same night on a notebook computer using special software packages. Greyshade plotting was made on the screen and a hardcopy was printed in the German Archaeological Institute at Damascus (Fig. 1).
2. For resistivity survey a Geoscan RM15 Advanced resistivitymeter and multiplexer MPX15 was applied with parallel double twin electrodes (3 probes) at 0.5 m separation. Automatic

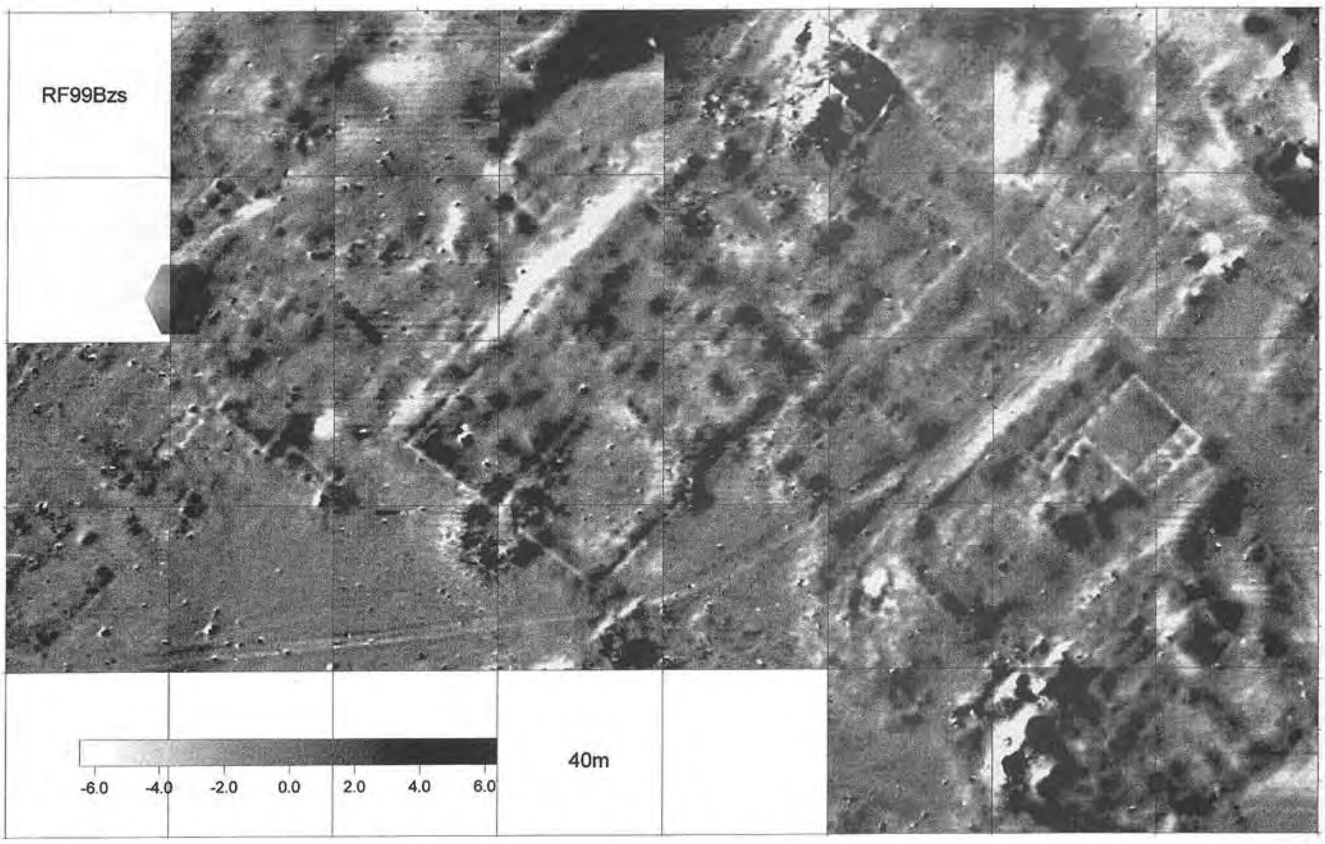
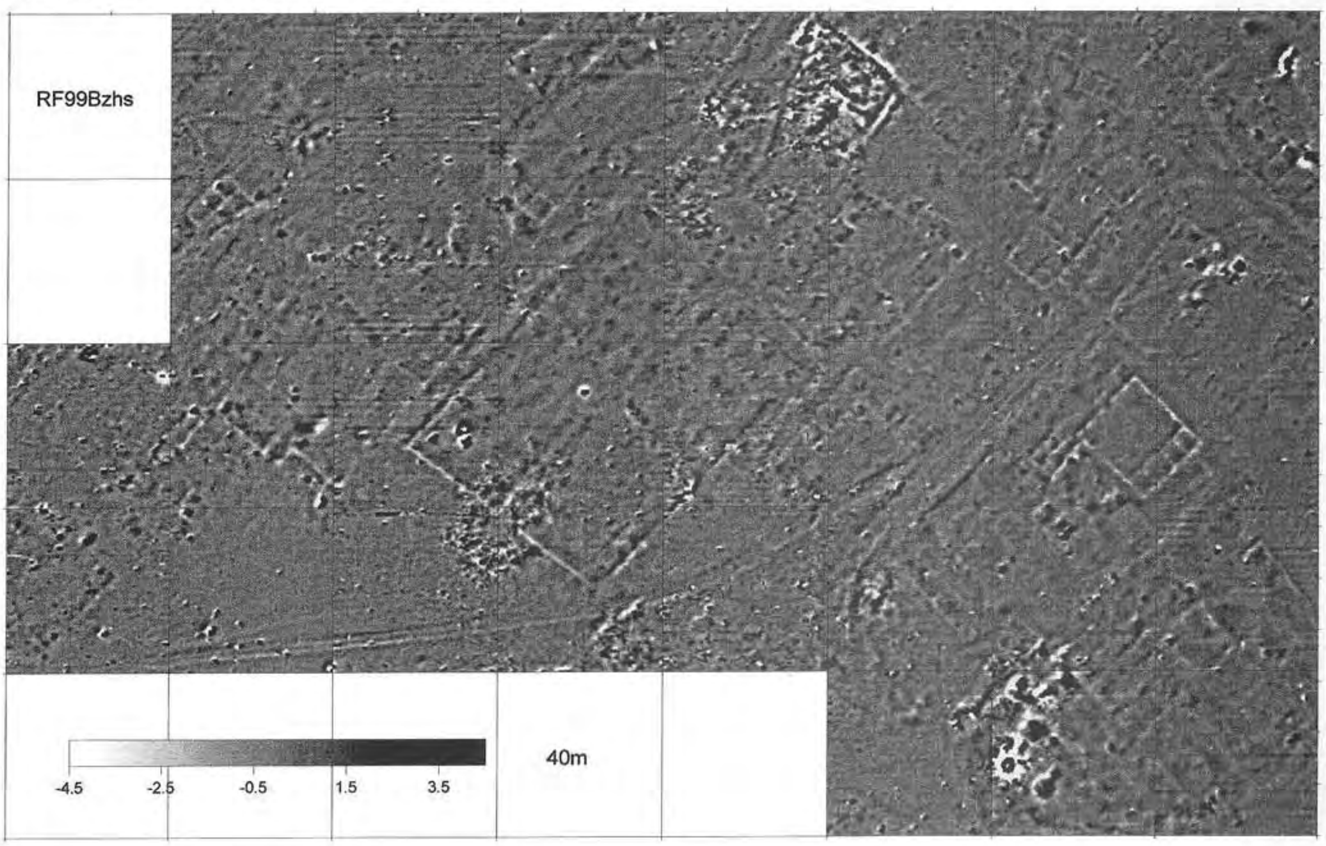


Fig. 3a. Rusafat-Hisam 1999. Magnetogram of the middle area of the residence site with several buildings of different type. Technical details as Fig. 1, but dynamics ± 6,5

Fig. 4 and 5. Rusafat-Hisam 1999. Aerial views of Resafa-Sergioupolis and of the area of the residence of Rusafa-Hisam with a secondary building (FP 148) being surveyed by resistivity taken at the helicopter flight (photograph C. Schweitzer) ▷

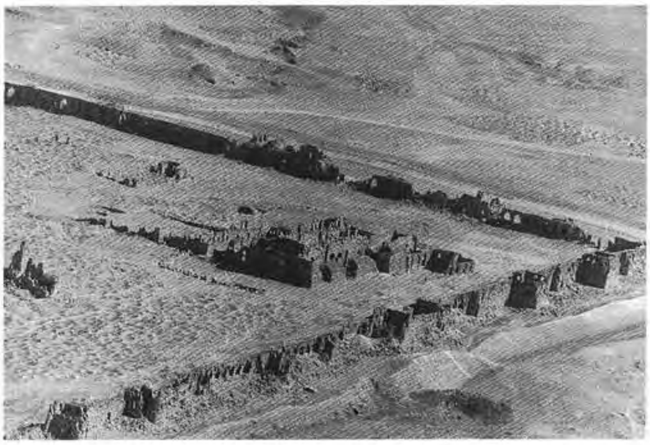
Fig. 3b. Rusafat-Hisam 1999. Same as Fig. 3a, but highpass filtering 10 x 5 nT, dynamics ± 3.5 nT

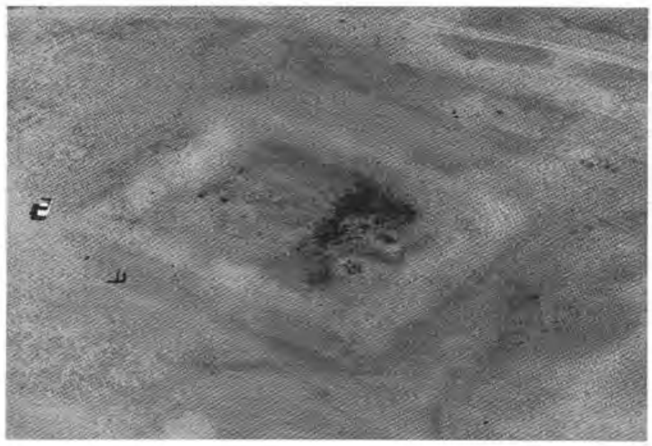


sampling allowed fast measurement at 0.5/0.5 m intervalls. The resistivity survey was done by my geophysicist collegues Kaldun Kotaisch and Bassam Al-Shmali from the Geophysical Institute of Damascus. Data processing after dumping to the notebook computer was undertaken by GEOPLOT V2.2 software package (Fig. 2b).

Both methods resulted in a rather clear image of the archaeological structures. For magnetometry a suitable contrast was found between mudbricks, stone foundations and cultural debris. Resistivity gave an somehow clearer image of the construction of the walls showing also the anhydrite-plaster of the mudbrick walls. By this effect even the interior of the building becomes visible. In palace IV the corridors inside the walls may be seen. However direct measurements of the resisitivity of the plaster exposed to the surface gave no clear evidence for this effect. The rim of both sides of a wall with high resistivity could also be caused by a stone foundation on both sides of a wall, but this is not very likely from architectural reasons.

By this experience magnetometry should be applied for fast and large area coverage first, whereas resistivity survey may be used only for detailled work on specific buildings. The combination of caesium magnetometry and resistivity survey at the Islamic site of Resafa gives a powerful method for nondestructive archaeological prospecting.





In 1998 the palace complex III/IV was completed with caesium magnetometry (operated by H.Becker and J. W. E. Fassbinder). The palace III, which was never clearly visible at the surface, also gave no clear traces in magnetics (Fig. 1). Possibly one should search for the double palace III/IV in another context. The resistivity survey of palace IV was also completed, but only with 1.0 m traverse intervals and 0.5 m sample interval because of time problems, which gave a rather coarse image of the architectural structures. A remeasurement with resistivity in 1999 with an raster 0.5/0.5 m did not realy improve this result because of the contact problems under extremly dry conditions. But the main project in 1998 was the magnetic propection of palace VI and its surroundings. The palace is situated very exposed at an elevation towards the main wadi, but there are only some of the architectural structures visible in the magnetogram. In contrast to palace IV there seems to be almost no magnetic contrast of the mudbrick architecture. But in palace VI some buildings and part of the fortifiction is made from burnt bricks which allow a clear tracing in the magnetometry. The area tested for resistivity surveying at the rampart and the interior of palac VI was not big enough viewing any architectural details. The result of the magnetic prospecting of the surrounding buildings (farm houses ?) looks much better identifying some complete layout plans of houses.

In March 1999 the combined prospection was continued for the 2nd campaign. With two complete caesium magnetometer systems with duo-sensor configuration (operated by H.Becker and C. Schweitzer) a large and representative area (about 18 ha) could be measured giving a comprehensive impression about the architectural structure of many secondary buildings of Hisam's residence. Because of the extremly dry ground resistivity survey was concentrated on two buildings only. A remeasurement of palace IV with 0.5/0.5 m raster and a secondary building (FP Nr. 148) were surveyed, which gave important additional results of architectural details. But also in the magnetograms the architecture of various types of buildings can be identified mainly by a negative magnetic contrast of the stone foundations of the walls. But there are also some burnt down ruins or rooms with higher magnetization visible (Fig. 3a, 3b).

Also in 1999 the topographic survey was continued for detailed digital terrain models (M. Stephani). The Syrian Air Force undertook an extensive helicopter flight over Rusafa-Hisam and Resafa-Sergioupolis for photogrametric aerial photos taken as oblique views (with control points on the ground) out of the open door of the aircraft (M. Stephani, see also Fig. 4 and 5). The combination of the terrestrial and the aerial survey will result in detailed models of most buildings, which are visible at the surface, and will give the ideal base for the compilation of the geophysics.

With the support of these terrestrial-aerial terrain models of the site, the ground geophysics will be finished within one more campaign. A detailed plan of a representative area (the whole area in aerial photo) of the residence of Rusafa-Hisam will be produced as a combined work with geophysical prospection, air- and ground photogrametry and archaeological survey.

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H. Becker, J. W. E. Fassbinder

Combined Caesium Magnetometry and Resistivity Survey in Palmyra (Syria) 1997 and 1998

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. W. E. Fassbinder), Institute for General and Applied Geophysics of Munich University (H. C. Soffel), Institute for Photogrammetry Technical University Munich (M. Stephani), Institut für Klassische Archäologie der Universität Wien (A. Schmidt-Colinet, 1997 German Archaeological Institute Damascus and University of Bern), Museum of Palmyra (Khaled al-As'ad), German Archaeological Institute Damascus (S. Freyberger), Department for Geophysics of Damascus University (Faris Chouker, Khaldoun Kotaish, Bassam al-Shamali, Nazih Jaramani [1998]).

"In Hellenistic times, the caravan city of Palmyra, situated in the Syrian desert, had almost no direct contact with the great centres in the west such as Pergamon in Asia Minor or Rome. During this early period, the politics, economy and culture of Palmyra were all oriented towards the east, to the recently founded cities on the Euphrates and Tigris, such as Seleucia or Dura-Europos, and later to Parthian cities such as Hatra. It was only later, after the peace treaty between Rome and the Partians (20 B. C.), that Palmyra developed closer relations to western centres – to Emesa and Antioch, to the cities in Asia Minor and to Rome – in a periode when, especially through the unifying power of normative Augustan politics, a Hellenistic-Roman 'koine', a common language also in the arts were established. At that period, the first monumental buildings were also built in Palmyra, including sanctuaries, such as the temple of Bel dedicated in A.D. 32, and funerary monuments, such as the tower of Atenatan built in 9 B.C." (Schmidt-Colinet, 1997). This rather clear view of the political and cultural situation of Palmyra stands in contrast to the actual knowledge of the city of Palmyra in Hellenistic times, which is completely unknown except of the above mentioned temple of Bel.

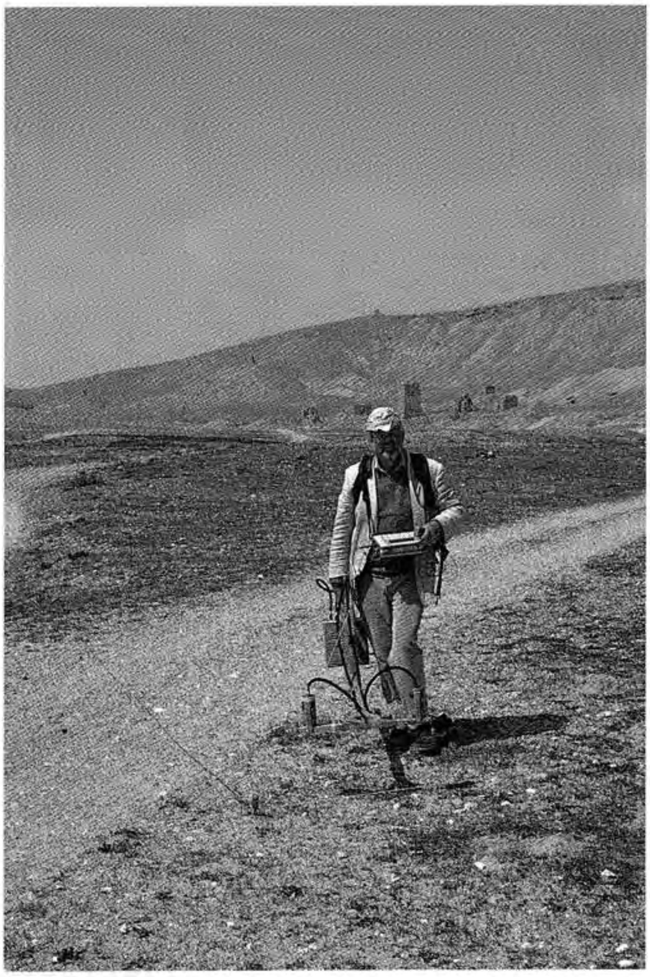
Following the ideas of Schmidt-Colinet the Hellenistic city of Palmyra may be situated in the south of the Roman city wall of Diocletianus which is still an upstanding monument like many other buildings in the Roman city. Nowadays this area is a vast field of ruins but without any architectural structures to be seen above ground. Only after careful fieldwalking some buildings eroded to the foundations appear, but their dating is almost uncertain. In spring 1997 after a long period of heavy rainfalls some building near the surface showed up as vegetation marks, but they vanished within several hours and could not been mapped before.

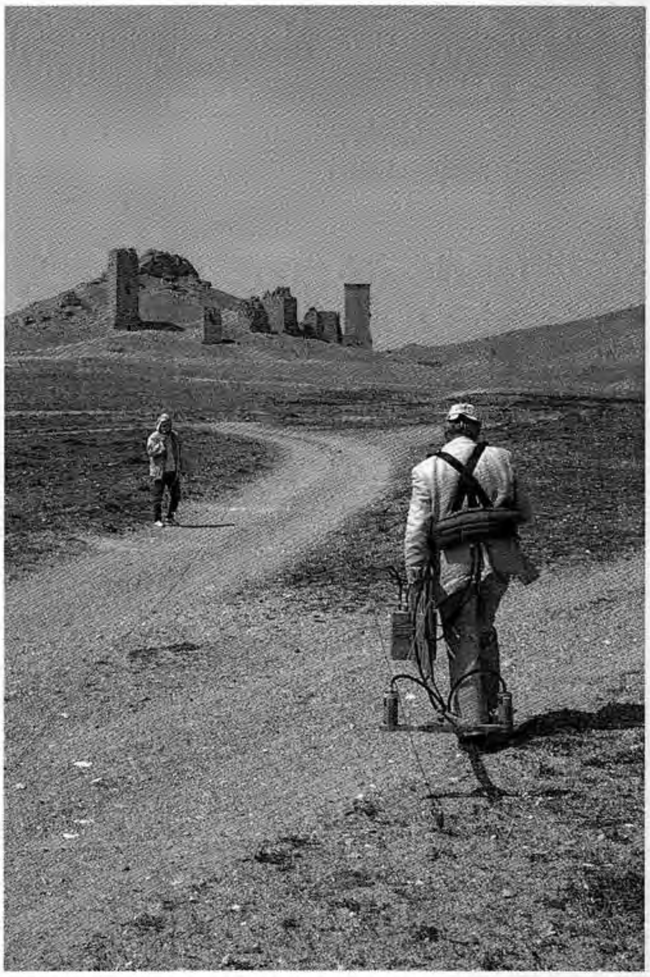
In March 1997 and 1998 nondestructive geophysical methods were tested in the "Hellenistic city" of Palmyra for archaeological prospecting. A 700 m long main line (azimuth = 100/280°) was fixed by stable architectural elements in the field and a 40 m grid was marked by wooden stacks. Two geophysical techniques were applied for this project:

Fig. 1. Palmyra 1997. Western corner of the Hellenistic city situated between the wadi, Roman city wall and the oasis to the south, the huge building complex in the upper part in the middle is the temple of Bel. Extrem oblique view from a hydraulic crane from 8 m hight; marked control points on the ground (white)

1. Caesium magnetometry with Scintrex SMARTMAG SM4G-Special with a sensitivity of 0.01 Nanotesla (10 pT) at 0.1 sec cycle. This instrument was applied with duo-sensor configuration at 0.5 m traverse interval and 0.1 sec cycle which corresponds to about 10 cm sample distance (Fig. 2a). Time mode sampling allowed the coverage of 1 hectare per day (400.000 measurements). Data processing was made using GEOPLOT V2.2 software with graphic facilities for visualization the measurement as grey-shading plots. Caesium Magnetometry covered a total area of about 18 hectares. The archaeological structures showing up by this method as negative alignements (stone walls) and also as positive anomalies for mudbricks and burnt areas (see Fig. 3a, b).

Fig. 2a, b. Palmyra 1997. Caesium magnetometer Scintrex Smartmag SM4G-Special with duo-sensor configuration for prospecting the Hellenistic city south of the wadi





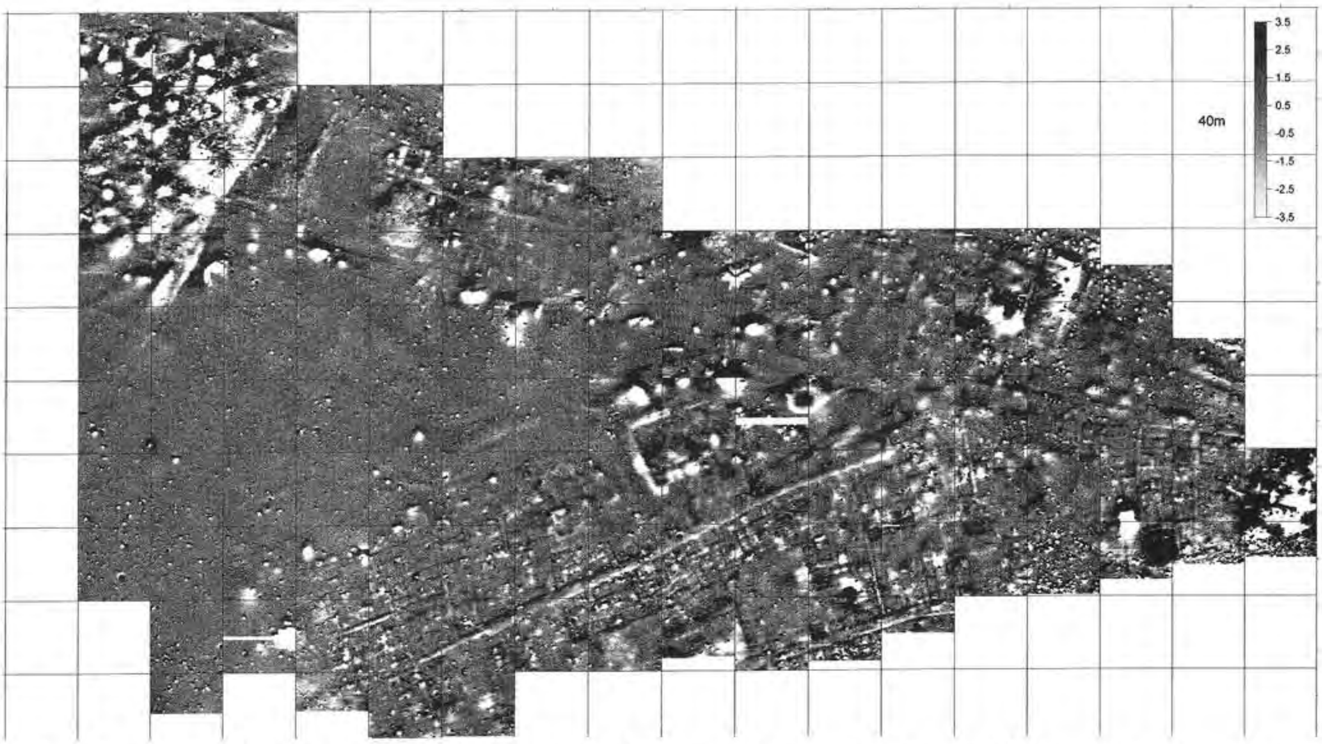
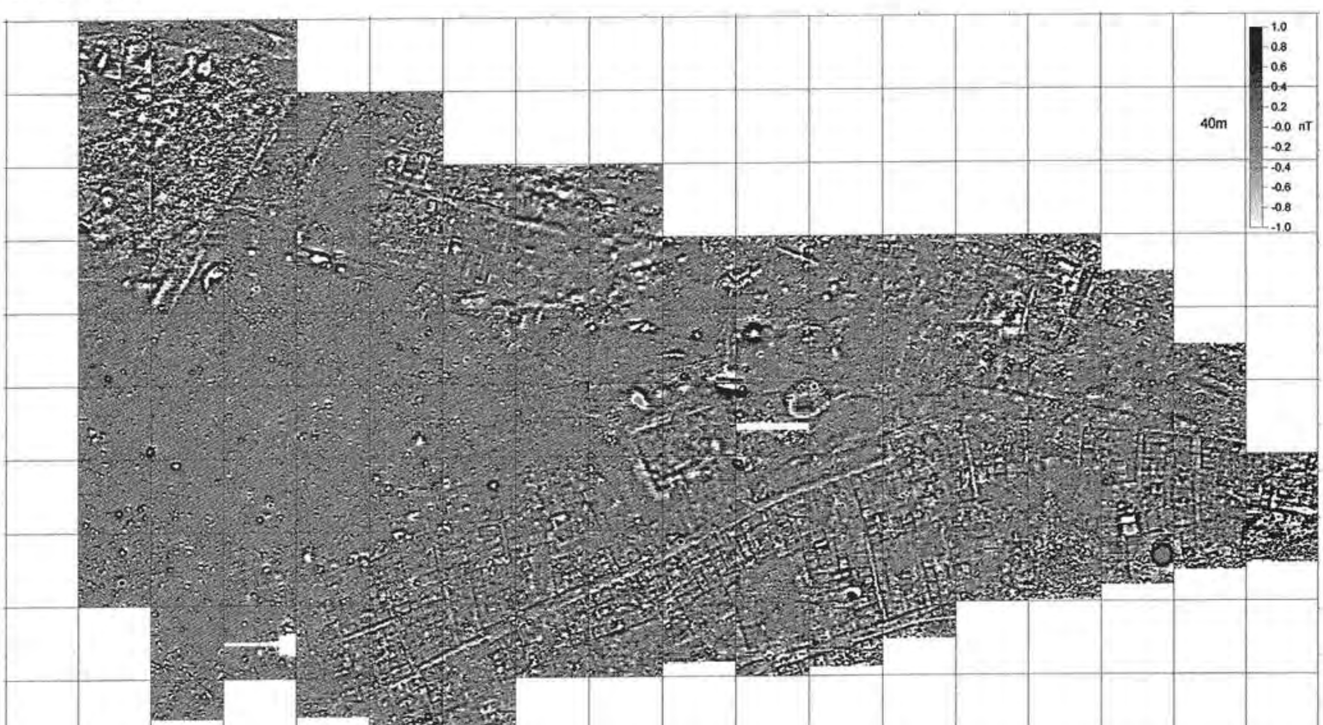


Fig. 3a. Palmyra 1997–1998. Magnetogram of the whole area of the Hellenistic city. Caesium magnetometry SM4G-Special in quadro-sensor configuration, sensitivity 10 pT (=0.01 nT Nanotesla), Dynamics -3.5/+3.5 nT in 256 grayscales (black/white), raster after resampling 0.25/0.5 m, 1 Hz bandpass filter, reduction of the diurnal geomagnetic variation by line-mean value, 40 m grid, north upwards

Fig. 3b. Palmyra 1997–1998. Magnetogram of the same data set after highpass filtering 10 x 5 pixel. Same technical data as Fig. 3a except dynamics -2.0/+ 2.0 nT



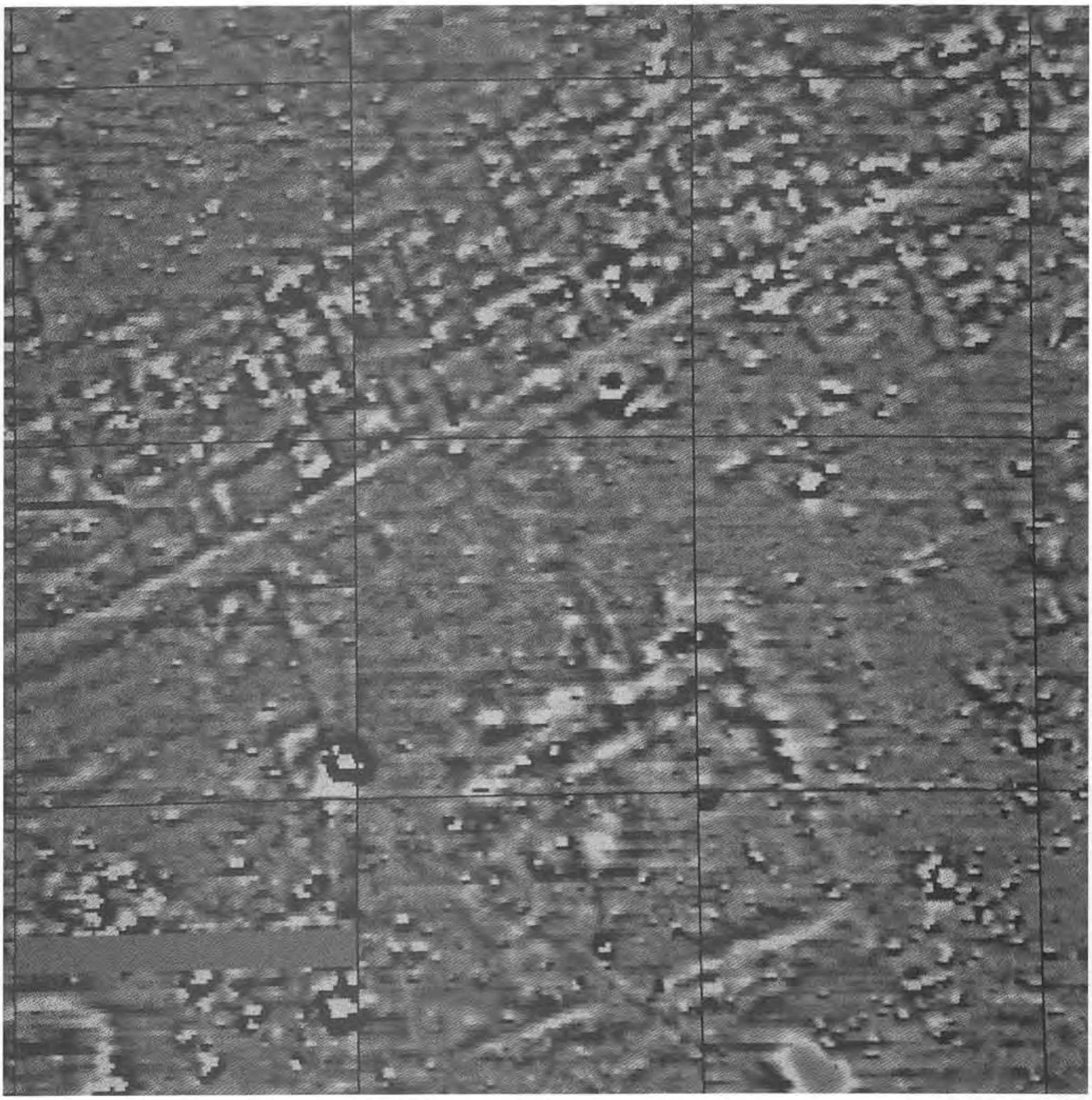


Fig. 4. Palmyra 1997–1998. Magnetogram of a part of the centre of the Hellenistic city, showing a major street, some narrow lanes with adjacent houses, which may be a bazaar or working quarter and the huge hypogaeum (36 to 52 m) in the middle. Caesium magnetometry SM4G-Special in duo-sensor configuration, sensitivity 10 pT (=0.01 nT Nanotesla), dynamics -1.2/+1.2 nT in 256 greyscales (black/white), raster after resampling 0.25/0.5 m, highpass filtering 10 x 5 pixel, 1 Hz bandpass filter, reduction of the diurnal geomagnetic variation by line-mean value, 40 m grid, north upwards

2. A smaller area was measured with the resistivity-meter Geoscan RM15 with double twin electrodes at 0.5/0.5 m intervalls (about 1.5 hectare in thirtytwo 20 m grids, about 50,000 measurements). This work was done by our geophysicist collegues from Damascus University, who were trained on both instruments during this Syro-German joint mission. Resistivity shows stone walls much clearer than caesium magnetometry, but is about 5 to 10 times slower in the field measurement dependent on the spacial resolution. Therefore resistivity surveying should be used only for detailed prospecting work of specific building-structures.

3. On March 25, 1997a pseudo-photogrammetric investigation was undertaken with rather extreme oblique photos (colour and black and white) from a hydraulic crane,which provided a platform about 8 m above ground. The 40 m grid of the prospecting work was used as ground control. It is planned to convert this oblique views by digital image processing techniques in the computer laboratory of the Bavarian State Conservation Office Munich. By this method archaeological structures visible above surface should be added to the geophysical maps.

Results: It became evident by this test, that the combination of magnetometry, resistivity surveying and oblique photogrammetry will result in a rather detailed plan of the archaeological structures above and under the surface. With the second campaign in spring 1998 one could establish a complete city map of the Hellenistic Palmyra as the base for further archaeological activities.

In the 1998 campaign caesium magnetometry could be applied with two complete duo-sensor systems which were operated by the author and J. Fassbinder. Almost the whole rest of the Hellenistic city area was prospected from the wadi to the modern street to the south. There is only a rather small strip left south of the modern street to the oasis, which should be measured when the very busy street can be closed for traffic completely. Another problem for magnetic prospection are myriads of rubbish cans left by the nomads on both sides of the modern road. Neverthless it became almost clear, that caesium magnetometry is the best method for making the city map of Hellenistic Palmyra. This city is organized by three main streets forming a big > pointing to the east (Fig. 3). The main axis may be the street parallel and very close to the modern asphalt road. The next parallel street to this main axis comes to an dead end on the western side. There are many narrow lanes between these two streets showing an almost radial orientation. This secondary street must have been very active because of numerous houses on both sides. It looks like a bazaar or working quarter. The houses are clearly detectable with all rooms, sometimes even with the foundations of columns with an negative magnetization contrast of the limestone foundation to the cultural debris. Many ovens can be detected. The other axis to the west shows a different pattern of buildings which are much bigger in this area. This street parallel to the wadi leads to the main necropolis to the west following almost the same track which is still used today. In the very west of the surveyed area the trace of a city wall can be identified, which is no longer visible on the surface. Outside this city wall a very dense clustering of burial monuments is located which continues to the huge west necropolis, but there are also some burial monuments inside the city. The most exciting finding may be a huge limestone building in the underground near to the point of the triangle conjunction of the two main streets, possibly a hypogaeum some 36 to 52 m in dimension. There is absolutely no trace of this building at the surface, but especially its western half is clearly to be seen in the magnetogram possibly due to a rather strong magnetized filling of the excavation for the subsurface building. This structure was also tested by restistivity surveying which gave almost the same signature of the huge stone building in the underground. Only 40 m to the east another underground burial monument was found, but this only measures 8 to 10 m. Surprisingly the major part of the >-shaped area between these two streets is completely free of any building structures except some ovens and some small graves (Fig. 3). This might have been the caravan site for keeping the cattle or for living in tents like the nomads or even the people of the city today.

In late spring 1999 a first archaeological test excavation had taken place in order to prove the structures in the magnetogram and their interpretation. As the same grid was used for the excavation the direct comparison between prospection and excavation became possible.

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Fig. 1. Marib, Awâm-Temple. View from the south-west, in front the cemetery (excavation from 1998), in the background the oval wall of the temple

J. W. E. Fassbinder, H. Becker, I. Gerlach

Magnetometry in the Cemetery and the Awâm-Temple in Marib, the Capital of the Queen Saba, Yemen

In a cooperation between the Staatliche Museum für Völkerkunde Munich, and the German Archaeological Institute Sana'a, the Bavarian State Conservation Office compiled a magnetometer survey to locate archaeological structures at the Sabaean necropolis close to the Awâm-Temple.

Introduction

The most famous town of ancient Yemen was Marib the capital of the Kingdom of Saba. Marib is divided by the Wadi Dhana into a northern and southern oasis. The most important temples of Marib are the Ba'ran-Temple and the Awâm-Temple. Both were dedicated to the moon God Almquah. The Awâm-Temple is located in the southern oasis, 3.5 km to the south-east of the ancient city of Marib. The oldest inscription on the oval wall of the temple can be assigned in time to the middle of the 7th century B.C., the youngest inscriptions date to the end of the 4th century A. D.

The Awâm-Temple was partly excavated by an American expedition in 1951/52, but is now again completely covered by the sand. The necropolis remained long undiscovered. This expedition 1951/52 were the first who recognized the cemetery. The cemetery is located adjacent to the Awâm-Temple like an 80–100 meter wide band around the southern half of the temple oval. Beginning in the south of the West Gate it ends about 20 meters to the north of the so-called Mausoleum.

During the last years extensive grave robbery took place so that excavation is the only way to save the archaeological findings. The survey area therefore covers the cemetery and the non-excavated part of the Awâm-Temple (Fig. 1).

Magnetometry

For the survey we used the Scintrex Smartmag SM4G-Special cesium magnetometer with ± 0.01 Nanotesla sensitivity at a cycle of up to 0.1 seconds. The instrument was equipped as a noncompensated duo-sensor configuration covering two tracks at one run (Fig. 2). The sensors were configured at 0.5 meter horizontal distance, sampling rate was set to 0.2 seconds, which gives at normal walking speed a spacial resolution of 0.2 x 0.5 meter. The distance control was made manually by switching every 5 meter over the 40 meter line. The high frequency part of the diurnal variation (natural micro-pulsations and technical noise) was cancelled by setting a bandpass filter of 1 Herz in the hardware of the magnetometer processor. The slower magnetic changes of the daily variation of the geomagnetic field was reduced to the mean value of all measured data of a 40 meter line and also to the mean value of all data of a 40 meter grid. All data were interpolated to 0.25 meter in each direction and on the line, dependent on the walking speed. All data were dumped and finally processed on a notebook computer. Digital image processing of the data allows an visualization of the measurement in gray shading technique. The fit of adjacent grid sides were corrected by digital image techniques like edge matching and desloping, which resulted in a rather smooth image for the magnetogram even of the raw data. Highpass filtering allows a reduction to disturbances of iron rubish and resulted in an even clearer image showing some interior structure especially in the area inside the temple.

There arose several severe problems for a geophysical survey. One of the biggest (geophysical) problem was the completely disturbed ground. Outside the temple there were deep pits from 1–2 meters from the grave robbers. The temple is still upstanding so that there is a deep slope to the border of the temple. This required a strong concentration for the measurement because the one disadvantage of a hand held system is the requirement of a constant walking speed between the 5 meter markers and furthermore that the distance of the probes to the ground should also be constant.

Another problem was that the inner side of the Awâm-Temple is covered by sand and therefore requires the highest possible sensitivity of the cesium magnetometer.

The next problem was the low geographical latitude of Yemen. This requires a tilt correction of the probes in a 45° angle to the north therefore once equipped the instrumentats could be used in one direction only.

The biggest problem however aroses in the discussion with the local people. After explaining to them what we are doing they had a fear to lose their job as workers for the excavation team. The result: The local sheik and the owner of the ground allowed us only one day of survey, or alternativley they would kill us. Remembering our experiences with the bedouins of the Wadi Markha we decided to believe him.

Results

The results of the magnetometer survey (Fig. 2, 3) are rather difficult to interpret. All the disturbances reveals a magnetic maximum and minimum of the same intensity and makes it therefore difficult to distinguish between iron rubish and archaeological structures. Another difficulty arises from the disturbances of the open pits and the excavation trenches from the grave rubbers. Nevertheless, the results show also some structures which could be ascribed to the similar burial architecture which was excavated by the German archaeological Institute Sana'a (H. Hitgen 1998 and I. Gerlach 2000). A system of parallel passages, running roughly from east to the west subdividing the cemetery is clearly visible.

The boundary to the Awâm-Temple is recognizable (marked by a white arc in Fig. 3), and an enhancement of the dynamics of the area inside the Awâm-Temple to ± 5.0 Nanotesla allows additionaly the detection of archaeological structures.

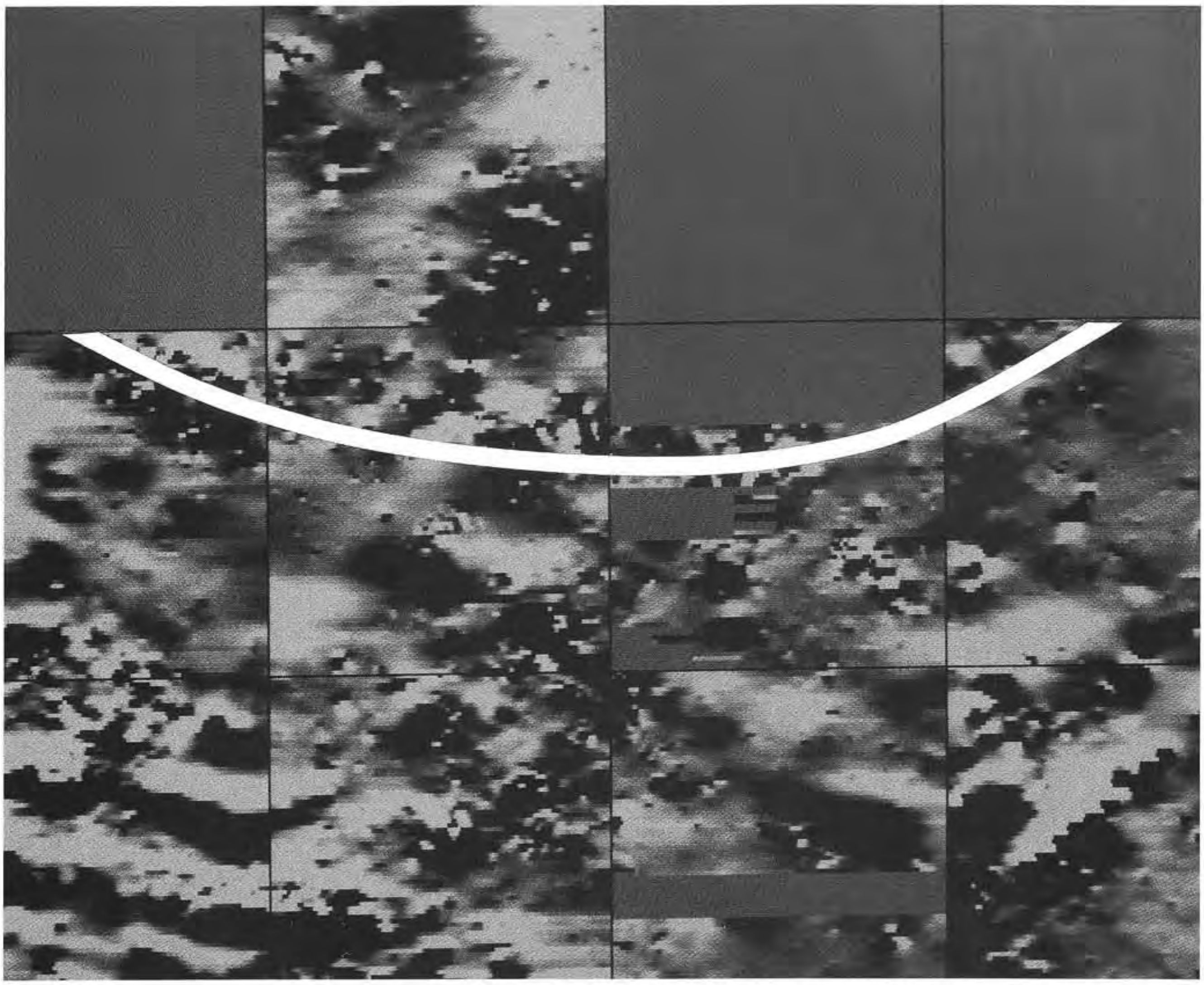

Fig. 3. Marib, Awâm-Temple. Digital image of the magnetic data, dynamics ± 13.0 Nanotesla in 256 grayscales (black to white), 40 m grid, sampling intervall 0.5 x 0.25 meter. Enhanced dynamics inside the temple area (top grid) ± 5.0 Nanotesla; the white arc is the oval wall of the temple

◁ Fig. 2. Marib, Awâm-Temple. Magnetometer survey with the Smartmag caesium magnetometer in the area of the Awâm-Temple; notify the tilting of the probes to the north

Acknowledgements

Thanks to Holger Hitgen for helping us to survive severe discussions with the bedouins during the field work.

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Fig. 1. Suchanicha. "Aerial view" of the northern part of the site containing the younger right angle shaped burials of the Tagar period

J. W. E. Fassbinder, H. Becker

Magnetometry of the Prehistoric Necropolis Suchanicha in the Minusinsk Basin, South Siberia

In cooperation with the Eurasien-Abteilung of the Deutsche Archäologische Institut and the Museum of Minusinsk in 1998 the Bavarian State Conservation Office Munich compiled a geophysical prospection at the prehistoric necropolis at the slope of the Suchanicha Hill (South Siberia).

Introduction

The necropolis is situated on the eastern shore of the Enisej on the slope of the Suchanica Hill (Fig. 1). The cemetary covers a strip of land witch is about 40 meters in broad in the south to 240 meters broad in the north and nearly 900 meters in length. The necropolis of Suchanicha was chosen as a research object, not only because of the central location in the Minusinsk Basin nearby the point where the river Tuba flows into the Enisej, but also because it contains all periods of the South-Siberian prehistory. Excavations of the site reveals burials from the 4th millenium B. C. to the 1st century A. D.

The aim of the prospection was to verify the extension of the necropolis and furthermore to replace further excavation and to complete the archaeological investigation. The area covers more than 12 hectares, so the geophysical prospection (here we used magnetometry) is the only possible means to deliver detailed information beneath the ground in short time and additionaly prevents the site of the total destruction.

In July 1998 a magnetometer prospection was undertaken to measure the graveyard of Suchanica. From the excavations it was know that the burials of all times used stones for their grave architecture. These stone structures were believed to give a good contrast in the resistivity between the loess/chernozem and the stone architectures. However after several attemps we knew that the resistivity meter RM15 could not be used because the ground was completely dried out. Sometimes, and not only in this case, it would have been usefull, to know some more of the Russian language, because the translation of the name Suchanicha simply reveals the word dry.

Instruments

There was more success with the hand held cesium magnetometer. For the magnetometer survey we used a Scintrex Smartmag SM4G-Special cesium magnetometer sytem with ±0.01 Nanotesla sensitivity at a cycle of up to 0.1 seconds. The instrument was equipped as a noncompensated duo-sensor configuration covering two tracks at one run. The sensors were configured at 0.5 meter horizontal distance. Sampling rate was set to 0.2 seconds, which gives at normal walking speed a spacial resolution of 0.2 x 0.5 meter. The distance control was made manually by switching every 5 meter over the 40 meter line. The high frequency part of the diurnal variation (natural micro-pulsations and technical noise) was cancelled by setting a bandpass filter of 1 Herz in the hardware of the magnetometer processor. The slower magnetic changes of the daily variation of the geomagnetic field was reduced to the mean value of all measured data of a 40 meter line and also to the mean value of all data of a 40 meter grid. All data were interpolated to 0.25 meter in each direction and on the line, dependent on the walking speed. All data were dumped and finally processed on a notebook computer. Digital image processing of the data allows an visualization of the measurement in gray shading technique. The fit of adjacent grid sides were corrected by digital image techniques like edge matching and desloping, which resulted in a rather smooth image for the magnetogram even of the raw data (Fig. 6). Highpass filtering allows one to reduce local disturbances of iron rubbish and results in an even clearer image showing some interior structure.

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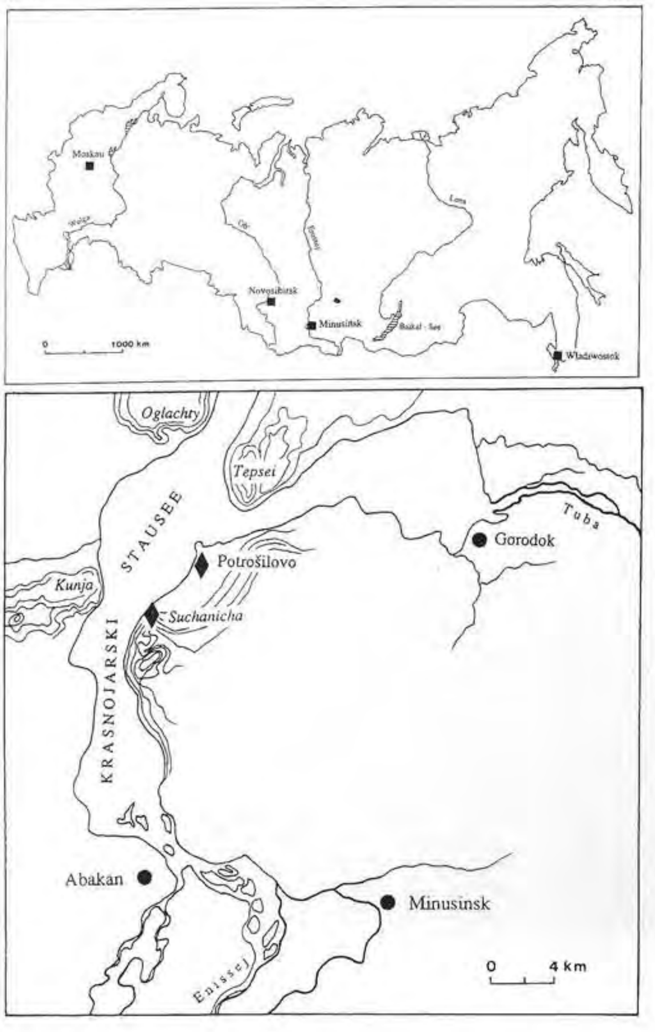

Fig. 3. Suchanicha. View of the survey area from the south, left is the river respectivly lake Enisej, on the right the slope of the Suchanicha hill and in the background in the north the hill Tepsej

Fig. 4. Suchanicha. Magnetometry with the handheld SM4G-Special Smartmag

Fig. 5. Suchanicha. On top a map of Russia, below a map of the Minusinsk basin, the Suchanicha Hill on the shore of the Enisej river (figures from the paper Leont'ev et al. 1996, with the permission of the authors)

Fig. 2. Suchanicha. Rock art which was found on rocks in the south of the site, showing fighting scenes. Although dating of rock art is difficult the picture is probably of the iron age period

Results

Beginning in the south the magnetometry visualized small burials as dots. In the magnetic picture some of them were already destroyed by the damming of the Enisej. Here the oldest burials were found by spot excavation. Fig. 3 shows the site from south to north. Fig. 1 showing an "aerial view" of the site from the Suchanicha Hill to the Tepsei Hill in the north.

The magnetogram cutting from the northern part of the survey area reveals very clearly the round barrows a structure which could be ascribed both to the Afanas'evo culture (~3,000–2,000 B. C.) and to the Okunev culture (~1,800 B. C.). The right angle shaped burrials could be ascribed to the Skythian time subdivided into the Karasuk-Karamennyj Log and Tagar culture (~700–300 B. C.). However a subdivision of these cultures which were found by the excavation is not possible by magnetometry only. The survey reveals that magnetometry in combination with a spot excavation enables the dating and mapping of a large archaeological area. Magnetometry is saving not only time and money but gives detailed maps of the extension and the type of the necropolis.

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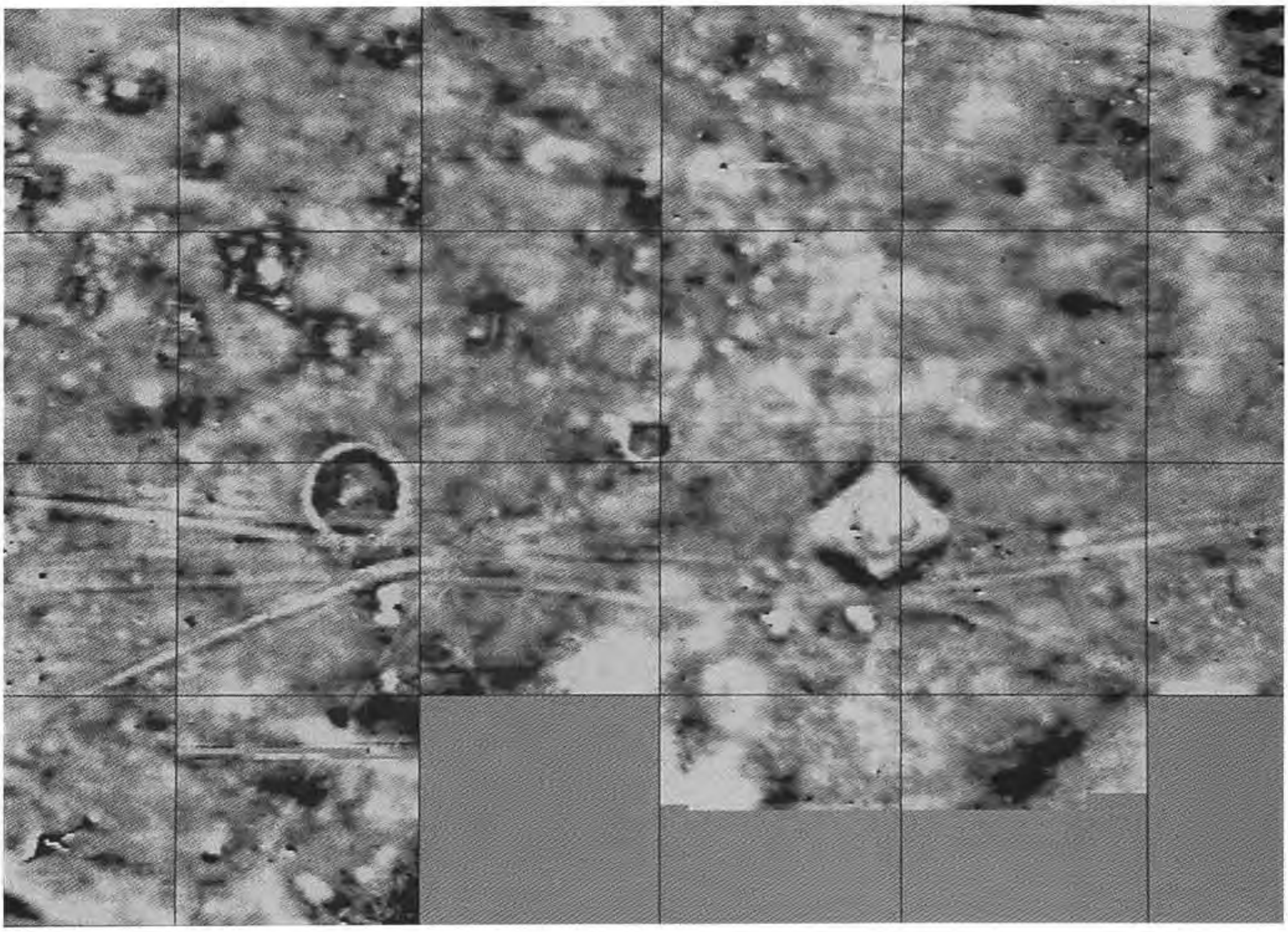
Fig. 6. Suchanicha. Magnetic map detail from the 12 hectares survey showing both the round barrow probably from the early Afanas'evo period and in the north rectangular shaped barrows likely from the Tagar period. Caesium magnetometer SM4G-Special in duo-sensor configuration, sensivity ± 0.01 Nanotesla, dynamics ± 7.5 Nanotesla in 256 grayscales (black to white), sampling interval 0.25 x 0.5 meter, 40 meter grid



The Kurgan of Salbik west of Minusinsk, South Siberia (photography taken in 1898; courtesy Museum of Minusinsk)

Kurgan in the Siberian steppe near Tuva (photography by J. Fassbinder)

H. Becker, J. W. E. Fassbinder

Magnetometry of a Scythian Settlement in Siberia near Cicah in the Baraba Steppe 1999

Cooperation of Bavarian State Conservation Office, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. W. E. Fassbinder), German Archaeological Institute (DAI), Department for Eurasian Studies (H. Parzinger, A. Nagler), Russian Academy of Sciences, Siberian Branch (V. Molodin).

Introduction

The legendary Scythians, controlling in the first millenium B. C. the vast steppes of Central Asia, were first described by Herodotus (5th century B. C.) as mounted nomads and feared warriors. This view was only little altered through the times until today. Even modern archaeology tries to verify this picture from antique times. Archaeological research nowadays is still considering the Scythians as nomads and concentrates mainly on the investigation of their burial buildings – so called kurgans – and on their admirable craftmenship and art style especially for metal work. Although one would think that these capabilities, the organisation and management of numerous people for constructing the huge kurgans, and the highly developed art style in metal work are not likely for people living in the saddle. But the idea of searching for permanent habitations or settlements of the Scythians still would cause a mild smile by most scholars in the field of Central Eurasian archaeology.

In the course of a joint project the Russian colleagues offered the opportunity for investigating a small fortified settlement of the Scythians which was recently discovered in the Baraba steppe south of Barabinsk in Southern Siberia near Cicah. Trial trenches excavated by the Russian archaeologists unearthed a grubenhaus inside a rather small ditched enclosure at the steep shore of a lake. Dating by typological reasons of the ceramics indicates a narrow spectrum in the 8th and the 7th century B. C., which would be clearly Scythian period. It seems rather astonishing that there are still archaeological structures from the late Bronze Age or the Early Iron Age visible on the surface and well preserved, but the steppe seems to be almost resistant against erosion (Fig. 1).

In preparation of the planned excavation of the site at a bigger scale in 2000 the Department for Archaeological Prospection and Aerial Archaeology of the Bavarian State Conservation Office was asked for a geophysical prospection measurement in 1999.The Scythian site of Cicah, partly ploughed in the surrounding area, was also surveyed by field walking through our Russian archaeologist colleagues under Marina Chemyakina from the Siberian Academy, which resulted in a vast distribution of ceramics, stone tools and slags far beyond the ditched site visible on the surface. On the base of this distribution a 40 m grid over 400 x 120 m, laterly enlarged to 400 x 200 m (8 hectare) covering the whole area was topographically surveyed and marked by wooden pegs.

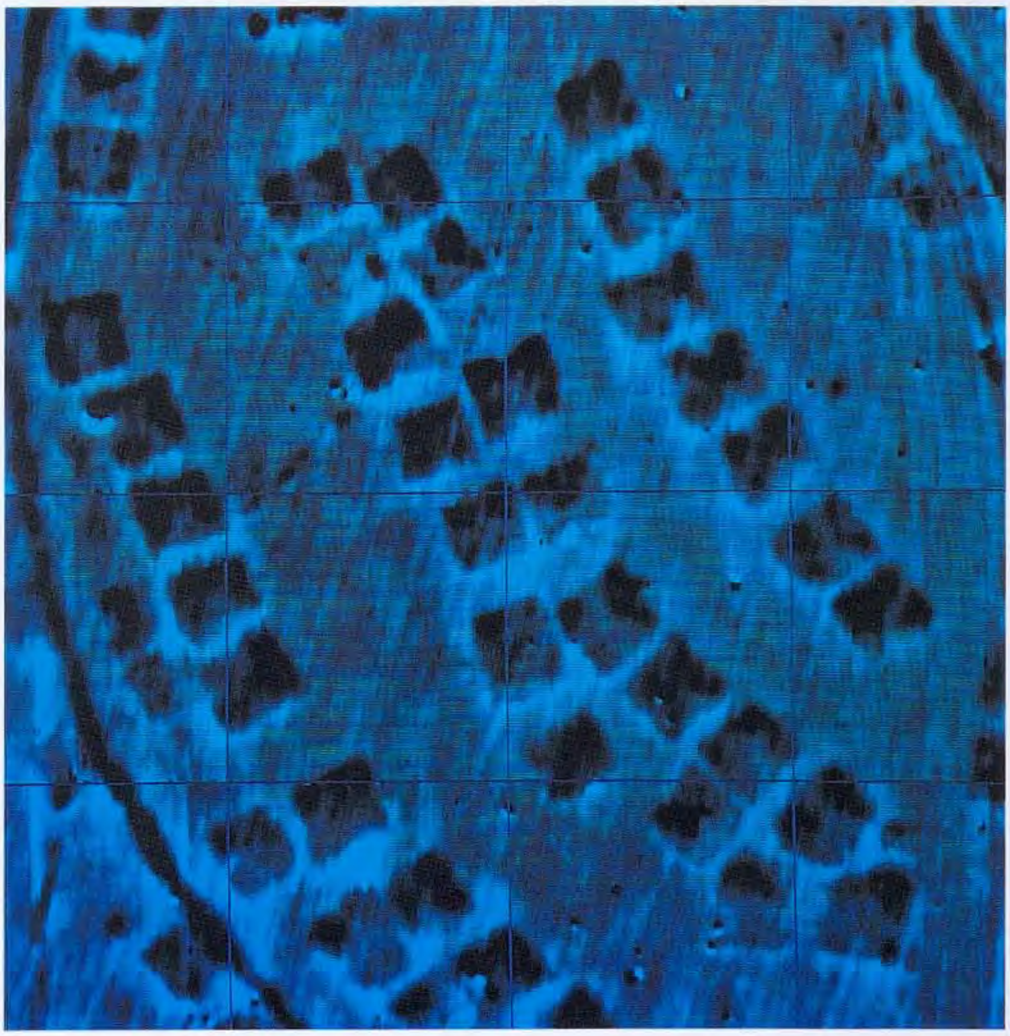
Instruments

The magnetic prospection took place during three days in June 1999 using a Scintrex Smartmag SM4G-Special caesium magnetometer with 10 Picotesla sensitivity at a cycle of up to 0.1 sec. The magnetometer system was run the whole day from morning till evening by the authors covering the whole area of the visible ditched settlement and the surrounding area with the ceramic fragments at an extent of 6 hectare (about 1.5 million measurements) (Fig. 2). This was only possible by using a non compensated duo-sensor configuration covering two tracks at one run. The sensors were configured at 0.5 m horizontal distance, sampling rate was set to 0.2 sec, which gives at normal walking speed a spacial resolution of 0.2 x 0.5 m. The distance control was made manually by switching every 5 m over the 40 m line. The high frequency part of the diurnal variation (natural micro-pulsations and technical noise) was cancelled by setting a bandpass filter of 1 Hz in the hardware of the magnetometer processor. The slower magnetic changes of the daily variation of the geomagnetic field was reduced to the mean value of all measured data of a 40 m line and also to the mean value of all data of a 40 m grid. All data were interpolated to 25 cm in each direction and on the line, dependent on the walking speed. All data were dumped and finally processed on a notebook computer, which resulted in an almost complete visualization of the measurement in grey shading technique. The fit of adjacent grid sides were corrected by digital image techniques like edge matching and desloping, which resulted in a rather smooth image for the magnetogram even of the raw data (Fig. 3). Highpass filtering resulted in an even clearer image showing some interior structure of the grubenhauser like post holes, fireplaces and walls (Fig. 4).

Fig. 1 (above). Cicah-Siberia 1999. View of the site, on the left there is still a visible structure with the ditches and the pits of grubenhauser, on the right the open cornfield covering nearly 80 grubenhauser

Fig. 2 (below). Cicah-Siberia 1999. Magnetogram (detail of Fig. 3) as digital image with bigger scale. The signature of the interior of the grubenhauser becomes visible

1



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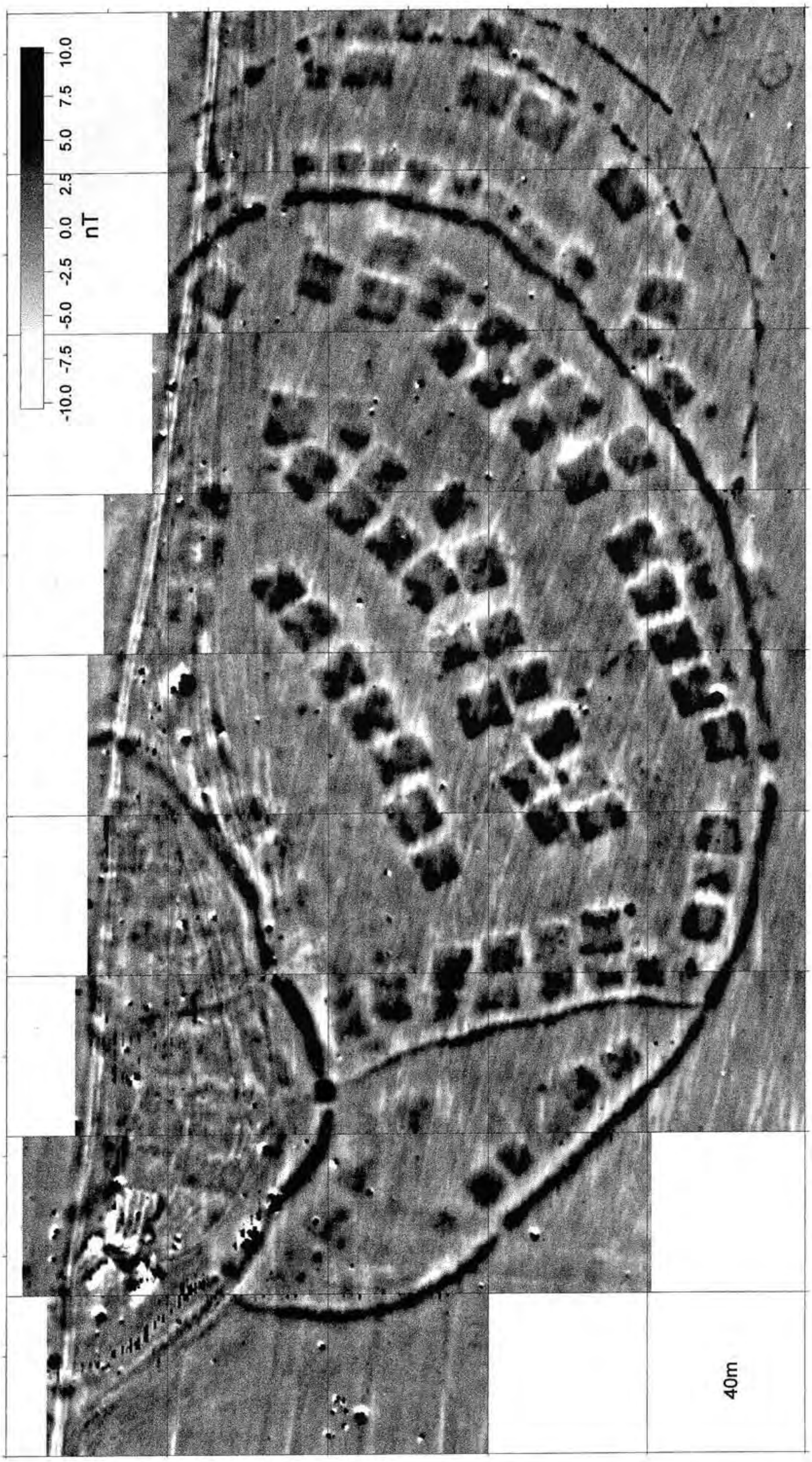

Fig. 3. Cicah-Siberia 1999. Magnetogram in gray shading with 256 grayscale. Caesium magnetometer Smartmag SM4G-Special in duo-sensor configuration, sensitivity ± 10 Picotesla, raster 0.5/0.2 m interpolated to 0.25/0.25 m, dynamics of the total magnetic field –5.0/+ 5.0 Nanotesla (white to black), line mean over 40 m, desloping and edge matching, 40 m grid

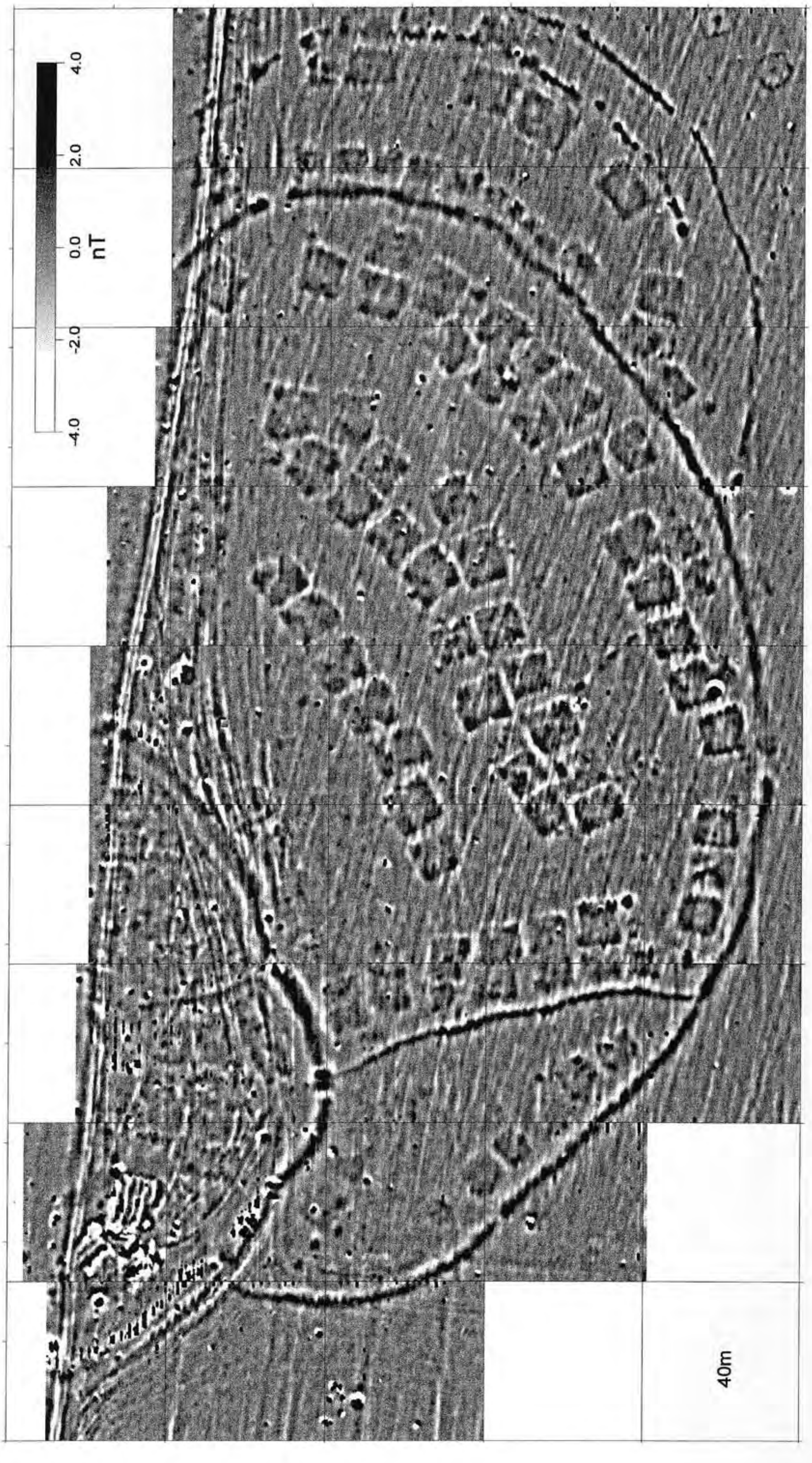

Fig. 4. Cicah-Siberia 1999. Magnetogram after highpass filtering, same technical dates then fig. 3, but dynamics –2.8/+2.8 nT

Results

Russian and German archaeologists, and also the geophysicists were extremly surprised by the results available in the camp every night: In only three days the complete plan of a rather complex fortified settlement consisting of more than hundred grubenhauser was established (Fig. 3). The size of the grubenhauser with 8 x 10 m normaly was found to be almost similar to the houses which were excavated in the trial trenches. The whole settlement is clearly divided into several sectors by ditches and palisades, which also show some gates. The houses seem to be aligned along streets, but these are not visible in the magnetogram. Outside (north) of the main ditch of the settlement a series of smaller houses is aligned, which may be storage houses or workshops, because of their size.

Considering the different signature of the grubenhauser in the area of the citadel, where the houses are still open and the ploughed area of the lower city, where the grubenhauser were cut in the Siberian loess and are filled by top soil (Chernozem), the main magnetization might be dominated by the Le Borgne effect (Le Borgne 1965). Investigations of the magnetic properties of the soil, which might give an answer about the magnetic properties of the site are in progress.

The overall setup of this fortified settlement divided by ditches and palisades consists of the "citadel" with a main ditch still open in the very southern and northern part and situated directly at the steep shore of the lake and the rather complex "lower city" which may have developed in several steps over a longer period. Especially the northern extension of the city bordered by two palisades rather than a main ditch may have been built in the final period.

Outside to the external northern gate and oriented to this two burials appear, which may indicate the necropolis in this direction possibly covering the whole area from the settlement to two great kurgans several hundred meters in the distance, which are still visible above ground. Further work should concentrate on the magnetic prospecting of the necropolis, which shows no more signs at the surface, exept of the mentioned great kurgans.

But there is no question about the scientific value of this combined prospecting of the site: A well organized fortified settlement with citadel and lower city containing more than hundred grubenhauser was detected, which opens a new view on the nomad people of the steppes living rather in town like settlements and not only in tents. Further work in surveying, field walking and magnetic prospecting will change the ideas about the habitation of the nomads. One would even think about great urban centres of the Scythians in the Central Eurasien steppes.

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Fig. 1. The situation of the Celtic oppidum "Alkimoennis" between the river Altmuhl (left side) and the Danube on the right side with the monastery Weltenburg. Bayerisches Landesamt fur Denkmalpflege, Photograph Otto Braasch, Archivnr. 7136/090, 7.11.1982 ▷

Appendix

Third International Conference on Archaeological Prospection (1999): Program

Organization Commitee: Doris Ebner, Jörg Fassbinder, Walter Irlinger, Robert Hetu, Dorit Reimann, Peter Weinzierl
Host organization: European Geophysical Society EGS
The International Advisory Board will be considered as responsible for the program:
Michel Dabas, Jörg Fassbinder, Walter Irlinger, Jürg Leckebusch, Wolfgang Neubauer, Armin Schmidt

■ *Wednesday (September 8)*

16:00 – 20:00 Registration: Alte Munze (Old Mint)
Hofgraben 4, 80539 Munich

■ *Thursday (September 9)*

9:00 – 9:45 **Opening session**

9:45-10:00 Break and Souvenir picture

Aerial Prospection and Remote Sensing
10:00 – 12:00 Oral session
Chair: Tomek Herbich

K. Leidorf
Aerial archaeology in Bavaria

M. Brown
Macro- and micro-land division in the later prehistoric period: Aerial survey, pit-alignments and GIS in South-East Scotland

M. Doneus, C. Gugl
Interpretation and mapping of aerial photographs using digital photogrammetry and GIS

B. Song
Aerial archaeology in China: possibilities, perspectives and results

D. Donoghue, C. Brooke
Airborne thermal prospection in the 8-12 micro meter wavelength range

G. Leroux
Aerial prospection at low altitude in Brittany and Pays de la Loire: region, results and synthesis of 1989-1999 researchs

12:00 – 13:30 Break

Radar Prospection
13:30 – 15:30 Oral session
Chair: Neil Linford

M. Dabas, C. Camerlynck, G. Bossuet
Detection of neolithic cultural layers by GPR in a lacustrine area: the case of Chalain (Jura, France)

D. Goodman, Y. Nishimura, S. Piro
High-resolution GPR surveys for archaeological prospections, data acquisition and elaboration techniques

J. Leckebusch, R. Peikert
Automated extraction of 3-D features from georadar data for interpretation and visualization

Y. Nishimura, D. Goodman
A trial GPR survey for accomplishment of deeper penetration in wet soil conditions

H. Kamei, H. Igarashi, Y. Ueda
FM-CW GPR and its signal processing

W. Neubauer, A. Eder-Hinterleitner, S. S. Seren, P. Melichar
Integrated geophysical prospection of Roman villas in Austria

15:30 – 16:00 Break

Resistivity Prospection, Electromagnetic Prospection, Prospection Generally
16:00 – 18:00 Oral session
Chair: Salvatore Piro

A. Schmidt
Recent work on pseudosections for archaeology

I. Trinks, H. Stümpel, S. Lorra
Integrated geophysical surveys for archaeological prospecting – new results

S. Groh, W. Neubauer, A. Eder-Hinterleitner
A resistivity survey to locate the forum of the Roman town Flavia Solva (Austria)

B. Hoffmann, A. Neville, F. Teichner, D. Wooliscroft
The first geophysical survey at the Roman villa of Milreu (Algarve/Portugal)

W. Edwards, M. Okita
Application of GPR to the study of subterranean chamber graves in Kyushu, Japan

C. F. Gaffney, J. A. Gater
Popularising archaeological geophysics: the "Time Team" experience on British Television

20:00 **Wellcome Party**

■ *Friday (September 10)*

Modelling, Magnetometry
9:00-11:00 Oral session
Chair: Michel Dabas

A. Eder-Hinterleitner, W. Neubauer, P. Melichar
Magnetic modelling for the 3D reconstruction of the neolithic circular ditch system of Steinabrunn/Austria

M. Kandler, M. Doneus, A. Eder-Hinterleitner, P. Melichar, W. Neubauer, S. S. Seren
Carnuntum – The largest archaeological landscape in Austria and the impact of archaeological prospection

P. Hirschegger-Ramser, P. Ferschin, M. Kandler, W. Neubauer
Computer aided virtual reality reconstruction based on prospection data. An example from the Roman town Carnuntum, Austria

C. W. Pierce, C. A. Shell
Three dimensional geophysics and visualization

C. Batt
The use of in situ magnetic susceptibility measurements to interpret archaeological deposits

M. Cole, A. David, J. W. E. Fassbinder, N. Linford, P. Linford, A. Payne
Comparative high resolution caesium vapour and fluxgate gradiometer survey at a range of archaeological sites in England

11:00 – 11:30 Break

Magnetometry
11:30 – 12:50 Oral session
Chair: Juerg Leckebusch

B. S. Ottaway
Archaeological relevance of CS-Magnetometry

W. Neubauer, A. Eder-Hinterleitner, P. Melichar
Large scale geomagnetic survey of an early neolithic settlement in Lower Austria (5,250-4,950 B.C.)

S. Buteux, C. Gaffney, J. Gater, S. Ovenden-Wilson
Fluxgate, Caesium Vapour and excavation: establishing the validity of high sensitivity and high sample density magnetic measurements

G. N. Tsokas, R. O. Hansen
The use of complex attributes in interpreting magnetic data from archaeological sites

12:50 – 14:00 Break

Magnetometry
14:00-16:20 Oral session
Chair: Armin Schmidt

A. Gibson, H. Becker
Archaeological prospection at the Hindwell neolithic enclosure in the Walton Basin, Wales, UK

E. Lueck, M. Meyer
Geopysical preparation of an archaeological excavation in the Highlands (Mardorf, Hessen)

J. J. M. Wippern
Integrated archaeological prospection: some case studies

C. Benech, G. Desivgnes, A. Tabbagh
Simultaneous interpretation of electromagnetic and magnetic data using linear filtering

A. Payne
Functional variability in Wessex Hillforts: new evidence from geophysical survey

M. Posselt, B. Zickgraf
Magnetometer survey at the early La-Tène barrow at Glauberg, Germany and its environs

T. Weski
The value of prospection from a users point of view

16:20 – 16:30 Break

Fig. 2. The city of Kelheim and the "Liberation Hall" in the background (Bayerisches Landesamt für Denkmalpflege, Photograph Klaus Leidorf, Archivnr. 7136/082a, 20.8.1991)

Fig. 3. Airphoto of the "Liberation Hall" on a cloudy day (Bayerisches Landesamt für Denkmalpflege, Photograph Otto Braasch, Archivnummer 7136/015a, 4.12.1986)

16:30 – 20:00 **Poster session**

1. F. Almeida, R. Moura, A. Rocha, A. Silva, C. Martins
   Geophysical techniques and GIS applied to archaeological prospection in Porto Old Town Center (Portugal)
2. C. Benech, N. Florsch, J C. Gaborit, G. Thebaut
   Integration of geophysical survey into archaeological prospecting strategy: the case of Apamée upon Euphrat
3. G. Bossuet, P. Barral, C. Petit, C. Camerlynck, M. Dabas
   Diachronic interpretation in magnetic prospection.
   The archaeological sites of Ribemont-sur-Ancre (Somme, France) and Authumes (Saône-et-Loire, France)
4. T. C. Brunet, A. U. González, V. M. Herrera, J. M. V. García, A. L. R. Alcalde, S. O. Villajos
   Remote sensing analysis and the design of archaeological prospections: a regional study of settlement patterns at Eastern Andalucia (Spain)
5. F. Cammarano, B. Di Fiore, P. Mauriello, D. Patella
   Application of a 3D probabilistic multi-methodological tomography to cultural heritage
6. A. C. De Lima Canto
   Spatial, geoarchaeological and palaeoenvironmental analysis of the archaeological site "Furna do Estrago" – Brazil
7. B. Cech, G. Walach
   The importance of integrated prospection techniques for archaeological investigations on mining sites in rugged alpine topography
8. H. Chapman
   The prospection of archaeological features in wetland landscapes: an approach using cell-based GIS modelling of high resolution GPS data
9. M. Chlodnicki, T. Herbich
   The magnetic survey at Tell el Farkha, Egypt
10. F. Chouker
    Archaeological site investigation by means of geoelectric measurements in Tel-Halawi (Northern Syria)
11. R. Chujo
    Assignment of mummies in Chusonji temple to Fujiwara chieftains with the aid of NMR for silks in these coffins
12. Z. Czajlik
    Archaeological aerial photography in Hungary:
    A landscape vanishes
13. M. Doneus, W. Neubauer, A. Eder-Hinterleitner
    3D reconstruction of archaeological sites based on prospection data
14. M. G. Drahor, E. Sengül
    Large scale geophysical investigations in Ulucak Höyük archaeological site
15. G. Fuchs, I. Kainz
    Archaeological prospection of the Koralmbahn in Austria
16. V. V. Glazounov
    Archaeomagnetic object dating at conditions of shape magnetic anisotropy

17. H. J. Greenfield
Surveying early agricultural sites in Southern Africa: the application of the Geonics EM-38 conductivity meter to the Early Iron Age site of Ndondondwane, South Africa

18. K. Hamilton, J. G. McDonnell, A. Schmidt
Assessment of early lead working sites in the Yorkshire Dales by archaeological prospection

19. A. Hesse
The ten commandements of the genuine surveyor in archaeology

20. G. Indruszewski
Geophysical prospection in the Oder Mouth area – contributions to archaeological target verification

21. G. Indruszewski, W. Karrasch
Aerial reconnaissance as an aid to reconstruct coastal geomorphological processes.

22. U. Koppelt, N. Abrahamsen, G. Dittrich, J. Frandsen, Y. Hofmann, C. Kroner
Interpretation enhancement of archaeometric investigations due to joint interpretation of geophysical fields

23. N. Kozhevnikov
Barun-Kahl: history of purely geophysical discovery of the oldest iron age site at the Western Shore of Lake Bakail

24. R. K. Krivanek
Contribution of caesium magnetometer prospections to archaeological projects in Bohemia

25. S. Lemke, L. Mankowski, D. Hayes, S. Martin
Geophysical characterization of a sugar mill on St. Croix, U.S. Virgin Islands

26. M. Martinaud, F. Madani
Resistivity vertical filtering for horizontal prospecting. Physical basis and archaeological case histories

27. Y. Marukawa, Y. Lu, H. Kamei
Reconstructing the 3D distribution of the magnetic field data and its application

28. P. Mauriello, D. Monna, I. Bruner
Development of a system of geoelectrical data acquisition and elaboration

29. C. Meyer, E. Danckwardt
DC Tensor geoelectrics – now applicable to archaeological prospection

30. W. Neubauer, A. Eder-Hinterleitner, M. Doneus, P. Melichar
Archaeological prospection of the middle neolithic site Puch/Kleedorf, Lower Austria

31. W. Neubauer, A. Eder-Hinterleitner, P. Melichar
Geomagnetic survey of the middle neolithic circular ditch system Glaubendorf II, Lower Austria

32. J. Orbons
Prospecting Roman pottery industries in the Argonne, France

33. J. Orbons
Archaeological pioneering prospection in Rumania

34. A. E. Patzelt, M. Waldhör, B. Greiner
Resistivity and GPR survey of two Early Mediaeval grave yards in Southern Germany

Fig. 4. The Weltenburg monastery on the southern bank of the Danube river and the "Weltenburg Gap", the river's last preserved natural stretch (Bayerisches Landesamt für Denkmalpflege, Photograph Otto Braasch, Archivnr. 7136/497, 24.4.1985)

35. C. Peters, C. Batt, R. Thompson, I. Dewar, G. Wilmot
Mineral magnetic study of enhanced soils
from Old Scatness Broch, Shetland

36. C. Peters, M. Church, C. Mitchell
Investigation of hearth fuel sources on Lewis using mineral magnetism

37. M. Posselt, B. Zickgraf
Geophysical prospection of Linearbandkeramik sites in the landscape archaeology of the Western Wetterau and the Usinger Becken, Hessen, Germany

38. H. Sakai, K. Maekawa, T. Uno
A comparative study of electromagnetic survey
and excavation results at archaeological sites containing kilns and buildings

39. N. Schleifer, J. Bigalke, M. Koetter, A. Junge
Geophysical application of the induced-polarization (IP)-effect for the detection of medieval wells

40. A. Schmidt, R, Coningham
Archaeological geophysics in South Asia

41. G. Schönfeld
Wetland-Archaeology in Lake Starnberg , Bavaria

42. R. W. Vernon, G. McDonnel, A. Schmidt, M. Fletcher
Geophysical surveys on two Yorkshire blast furnace sites, England

43. A. R. Volker
Geophysical mapping of archaeological structures
in Sachsen-Anhalt (Germany)

44. R. Walker, C. Adam, L. Somers
Processing and presentation of geophysical data

45. R. Zantopp
Archaeological prospection from the air in the district around the open mining of the Cologne Basin
in Northrheinwestfalia/German

46. M. Zupancic, D. Najdovski
Decoding an invisible Late Roman inscription using GPR imaging and EM modelling

■ *Saturday (September 11)*

8:00 ~ 21:00 **Field trip:**
The city of Kelheim and the archaeological museum (Fig. 2); Liberation Hall.(Fig. 3); Celtic Oppidum Michelsberg (Fig. 1); Monastery of Weltenburg (Fig. 4).

Methods and Equipment used by the Department Archaeological Prospection and Aerial Archaeology at the Bavarian State Conservation Office, Munich

J. W. E. Fassbinder, W. E. Irlinger
Combining magnetometry and archaeological interpretation: a square enclosure in Bavaria

H. Becker
Duo- and quadro-sensor configuration for high-speed/high-resolution magnetic prospecting with caesium magnetometry

Prospection in cooperation with foreign authorities

J. W. E. Fassbinder, H. Becker
Magnetic prospection of a Megalithic Necropolis at Ibbankatuwa (Sri Lanka)

J. W. E. Fassbinder, H. Becker
Magnetometry in the garden of the Sigiriya rock fortification (Sri Lanka)

H. Becker
In search for the city wall of Homers Troy – development of high resolution caesium magnetometry 1992–1994

H. Becker, J. W .E. Fassbinder, F. Chouker
Magnetic and resistivity prospection in Munbaqa-Ekalte (Syria) 1993

H. Becker
Ultra high resolution caesium magnetometry at Monte da Ponte, Concelho Evora, Portugal 1994 -1996

H. Becker, J. W. E. Fassbinder
The discovery of the Royal capital of Awsan at Hagar Yahirr, Wadi Markha, Yemen by satellite images, aerial photography, field walking and magnetic prospecting

H. Becker
Discovery of a first Neolithic settlement in the Meseta of Central Spain near Ambrona (Soria) by caesium magnetometry in 1996

H. Becker
Prospecting in Ostia Antica (Italy) and the discovery of the Basilica of Constantinus I. in 1996

J. W. E. Fassbinder, H. Becker, T. Herbich
Magnetometry in the desert area west of the Zoser's pyramid, Saqqara, Egypt

H. Becker, J. W. E. Fassbinder
In search for Piramesses – the lost capital of Ramesses II. in the Nile delta (Egypt) by caesium magnetometry

H. Becker, F. Chouker , J. W .E. Fassbinder, D. Sack,
C. Schweitzer, M. Stefani
Prospection of the Early Islamic residence Rusafat Hisam (Syria) by caesium magnetometry and resistivity surveying 1997-1999

H. Becker, J. W .E. Fassbinder,
Combined caesium magnetometry and resistivity survey in Palmyra (Syria) 1997 and 1998

J. W. E. Fassbinder, H. Becker, I. Gerlach
Magnetometry in the cemetery and the Awâm-Temple in Marib, the capital of the Queen Saba, Yemen

J. W. E. Fassbinder, H. Becker
Magnetometry of the prehistoric necropolis Suchanicha in the Minusinsk Basin, South Siberia

H. Becker, J. W. E. Fassbinder
Magnetometry of a Scythian settlement in Siberia near Cicah in the Baraba steppe 1999

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