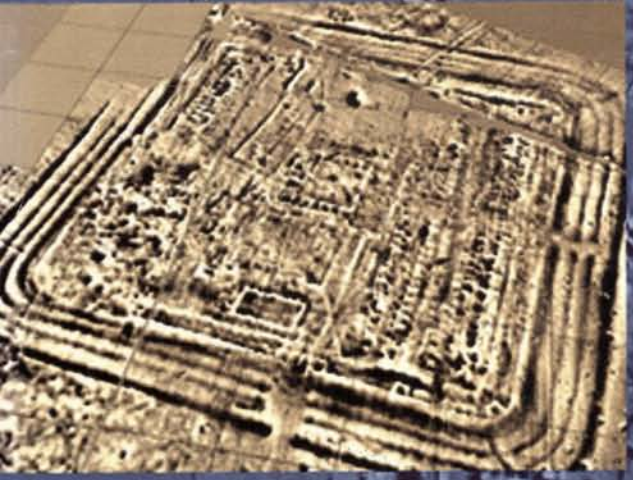
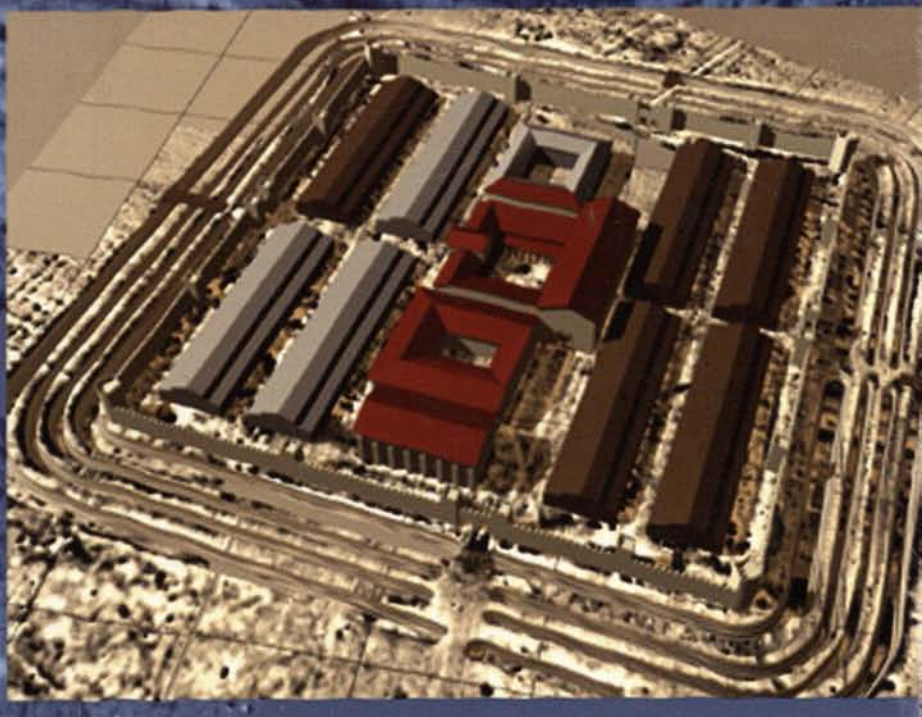


MAGNETIC PROSPECTING IN ARCHAEOLOGICAL SITES



ICOMOS

MONUMENTS AND SITES
MONUMENTS ET SITES
MONUMENTOS Y SITIOS

VI

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

Helmut Becker, Jörg W.E. Fassbinder

MAGNETIC PROSPECTING IN ARCHAEOLOGICAL SITES

ICOMOS
DEUTSCHES NATIONALKOMITEE
Geschäftsstelle:
Bayer. Landesamt für Denkmalpflege
Postfach 10 02 03 - 80076 München
Bibliothek

MONUMENTS AND SITES
MONUMENTS ET SITES
MONUMENTOS Y SITIOS
VI

Monuments and Sites / Monuments et Sites / Monumentos y Sitios
edited by ICOMOS
Editorial Board: Sherban Cantacuzino, Axel Mykleby, Michael Petzet, Roland Silva, Giora Solar, Marilyn Truscott
Office: International Secretariat of ICOMOS, 49-51 rue de la Fédération, F-75015 Paris

ICOMOS is very grateful
to the Messerschmitt Foundation
for its generous
support of this publication

Front Cover: Ruffenhofen, Bavaria. Magnetometry and reconstruction of the Roman fortress showing the defences with four ditches and wall, towers, gates and the interior buildings made from wood and stone. Compilation of the magnetograms by Helmut Becker, computer animation by Helmut Becker and Alexander Pohl.

Back cover: Uruk – city of Gilgamesh in Iraq. Compilation of aerial photo and magnetogram in the area South, covering the city gate, parts of the city wall, canals and the New Year's Chapel (bait akitu). caesium magnetometry by Helmut Becker and Jörg Fassbinder (2001), Bavarian State Conservation Office in Munich. Aerial photo (detail) taken by the Royal Air Force in 1935, courtesy of the German Archaeological Institute, Oriental Department, Berlin.

Page 4: Magnetometer cart from 1990, equipped with the Scintrex caesium magnetometer in gradiometer configuration
(photo: Deutsches Museum, München, by courtesy of Deutsches Museum, Bonn)

C 2001 ICOMOS and Bavarian State Conservation Office

Editorial Staff: Karlheinz Hemmeter, Jörg W.E. Fassbinder, Walter E. Irlinger, Michael Petzet, John Ziesemer

Typesetting and Printing: Lipp GmbH, Graphische Betriebe, Meglingerstraße 60, 81477 München

Publication obtainable from: Lipp GmbH, Graphische Betriebe, Meglingerstraße 60, 81477 München, info@lipp.de

ISBN: 3-87490-675-2

Contents

Foreword 5

From Magnetic Prospecting to Virtual Archaeology 6-13

Combining Magnetometry and Archaeological Interpretation: A Square Enclosure in Bavaria 14-19

Duo- and Quadro-sensor Configuration for High Speed / High Resolution Magnetic Prospecting with Caesium Magnetometer 20-25

Magnetic Prospection of a Megalithic Necropolis at Ibbankatuwa (Sri Lanka) 26-29

Magnetometry in the Garden of the Sigiriya Rock Fortification (Sri Lanka) 30-32

In Search for the City Wall of Homer's Troy – Development of High Resolution Caesium Magnetometry 1992-1994 33-39

Magnetic and Resistivity Prospection in Munbaqa-Ekalte (Syria) 1993 40-42

Ultra High Resolution Caesium Magnetometry at Monte da Ponte, Concelho Evora, Portugal 1994-1996 43-46

The Discovery of the Royal Capital of Awsan at Hagar Yahirr, Wadi Markha, Yemen by Satellite Images, Aerial Photography, Field Walking and Magnetic Prospecting 47-54

Discovery of a First Neolithic Settlement in the Meseta of Central Spain near Ambrona (Soria) by Caesium Magnetometry in 1996 55-58

Prospecting in Ostia Antica (Italy) and the Discovery of the Basilica of Constantinus I in 1996 59-63

Magnetometry in the Desert Area West of the Zoser's Pyramid, Saqqara, Egypt 64-65

In search for Piramesses – the Lost Capital of Ramesses II in the Nile Delta (Egypt) by Caesium Magnetometry ... 66-70

Prospection of the Early Islamic Residence Rusafat Hisam (Syria) by Caesium Magnetometry and Resistivity Surveying 1997-1999 71-75

Combined Caesium Magnetometry and Resistivity Survey in Palmyra (Syria) 1997 and 1998 76-80

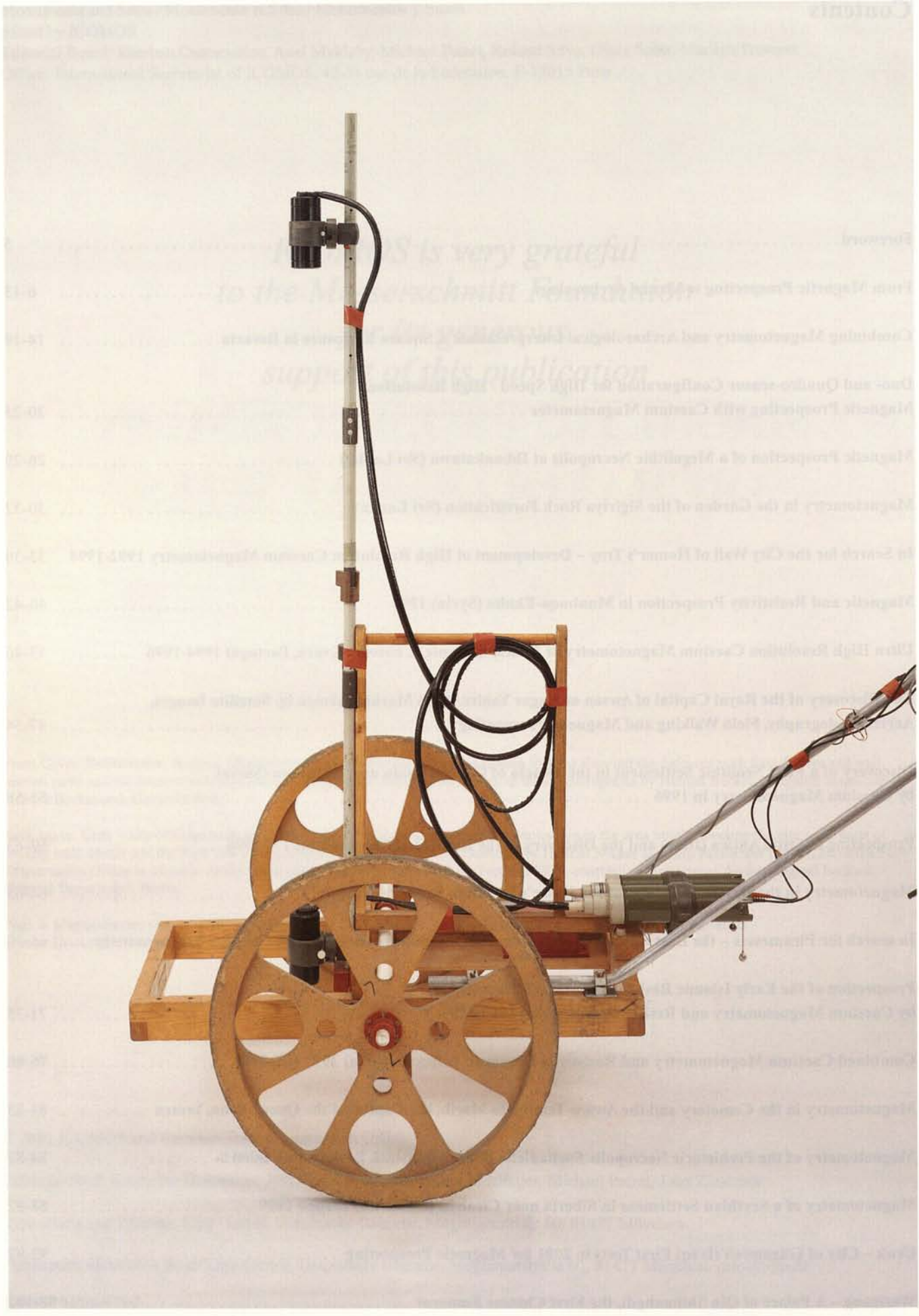
Magnetometry in the Cemetery and the Awâm-Temple in Marib, the Capital of the Queen Saba, Yemen 81-83

Magnetometry of the Prehistoric Necropolis Suchanicha in the Minusinsk Basin, South Siberia 84-87

Magnetometry of a Scythian Settlement in Siberia near Cicah in the Baraba Steppe 1999 88-92

Uruk – City of Gilgamesh (Iraq) First Tests in 2001 for Magnetic Prospecting 93-97

Wazigang – A Palace of Qin Shihuangdi, the First Chinese Emperor 98-102



Foreword

„Surveying and Documentation of Historic Buildings, Monuments and Sites – Traditional and Modern Methods" is the theme of the International Symposion organised by the International Committee for Architectural Photogrammetry (CIPA) in Potsdam, Germany (18th -21st September 2001). One of the most successful modern methods in archaeological prospection is the highly sensitive magnetometry. On the occasion of the conference in Potsdam ICOMOS is therefore introducing some examples of magnetic prospecting in archaeological sites, published in its series of "Monuments and Sites". These are examples which have partly been taken from another publication of the German national committee of ICOMOS, the publication of the Third International Conference on Archaeological Prospection, organised by the Bavarian State Conservation Office and the European Geophysical Society (EGS) in co-operation with ICOMOS Germany, Munich 9-11 September 1999 (ICOMOS-Journals of the German National Committee XXXIII, Munich 1999).

The last 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 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 the most successful. Air photography has been employed widely in archaeology for quite some time. Magnetometry, first successfully applied by Martin Aitken in 1957, has established itself as the most effective geophysical method. Measuring methods have improved substantially since Irwin 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 and development in different applications of caesium magnetometers was conducted by the Bavarian State Conservation Office, notably by Helmut Becker and Jörg Fassbinder who kept improving measuring procedures. Continuous study of the theoretical principles contributed enormously to the understanding of the methods. The examination of the magnetic properties of archaeological sites and the discovery of magnetic soil bacteria, in particular, drew word-wide attention and can be regarded as the essential pioneer work in magnetic prospecting. The first measuring car bearing a caesium magnetometer developed by the Bavarian State Conservation Office is now already on exhibition in the Bonn branch of the „Deutsches Museum für Forschung und Technik in Deutschland nach 1945".

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, the Ramsessidean city of Qantir in Egypt and the city of Gilgamesh, Uruk, in Iraq, where the geophysicists have worked to 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 centres 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 beginning of the 21st 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

Helmut Becker

From Magnetic Prospecting to Virtual Archaeology

Remarkable developments have been made over the last decades in geophysical prospecting for archaeological purposes, beginning in the 1950s with the use of electricity to measure soil resistivity and of magnetics in the form of proton magnetometers (Aitken, 1961, 1974). Until quite recently the use of magnetics in particular had become practically unrivalled through continual improvements involving measuring techniques in the field and procedures for analysis, interpretation and presentation. Milestones included construction of a differential proton magnetometer in the 1960s, automation of digital data collection, electronic processing of the data and finally digital imaging (summarized in Scolar et al. 1990). Building on this work at the Rhenish State Museum in Bonn, at the beginning of the 1980s the author was able to develop caesium magnetometry to the point where it could be used in archaeological prospecting, working first at the Institute for Geophysics at the University of Munich and then at the Bavarian State Conservation Office.

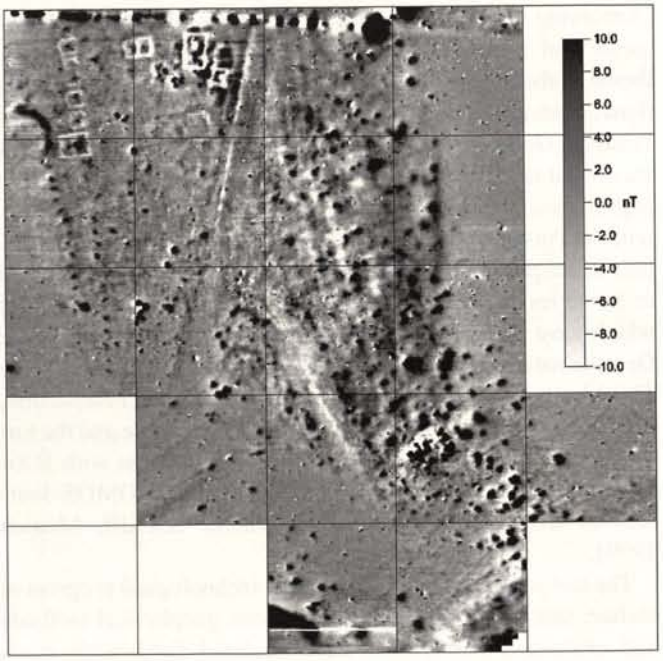


Fig. 1. Roman castellum at Ruffenhofen. Magnetogram of the street of grave monuments. SMARTMAG SM 4G-Special as quadro-sensor. Sensitivity 0.01 nT (10 picotesla), raster 0.1/0.5 m interpolated to 0.25/0.25 m, dynamics –7.0/+7.0 nT in 256 gray scales (black/white) 40 m grid, magnetometer prospecting H. Becker, Mag.Nr. 6928/074-00B.

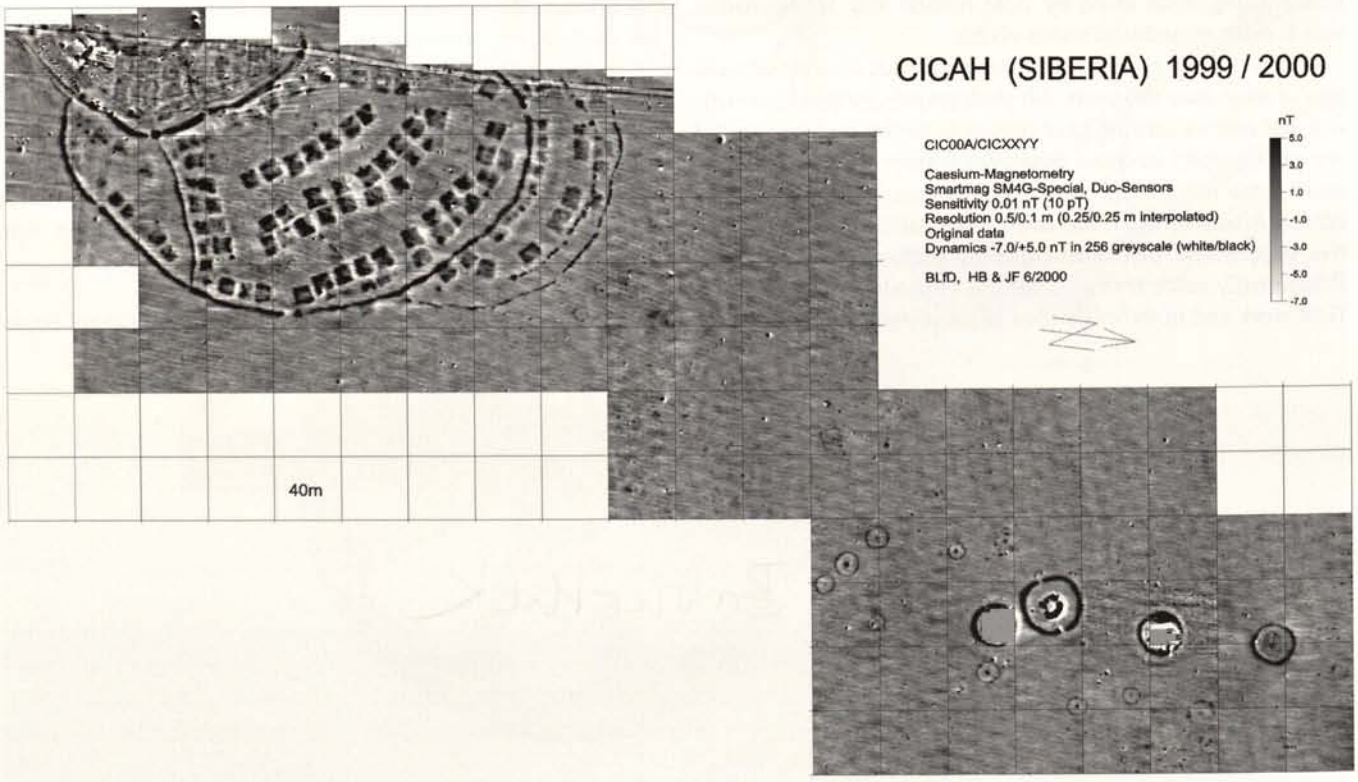


Fig. 2. Cicah (Siberia). Magnetogram of the measurements from 1999-2000 with the entire Scythian settlement (city) from the 8th-7th centuries BC and the (presumably later) necropolis with four large *kurgans*. SMARTMAG SM4G-Special as duo-sensor. Sensitivity 0.01 nT (10 picotesla), raster 0.1/0.5 m interpolated to 0.25/0.25 m, dynamics –5.0/+5.0 nT in 256 gray scales (black/white), 40 m grid, magnetometer prospecting H. Becker und J. Faßbinder.



Fig. 3. Roman castellum at Ruffenhofen. Defensive walls, towers, gates, trenches, and parts of interior construction in stone shown as vegetation features in the grainfield. Aerial photograph from 5 July 2001, photographer K. Leidorf, archive number 6928/074-3; SW8018-10.



Fig. 4. Qantir-Piramesse. Compilation of the magnetograms from 1996 to 2000 on the topographic map. SMARTMAG SM4G-Special as duo-sensor. Sensitivity 0.01 nT (10 picotesla), raster 0.1/0.5 m interpolated to 0.25/0.25 m, dynamics –7.0/+7.0 nT in 256 gray scales (black/white), mean value between original data and high pass filter, 40 m grid, magnetometer prospecting H. Becker and J. Faßbinder (1996-2000), Chr. Schweitzer (1999, 2000), topography V. Fuchs, D. Kaltenbach.

The development "from nanotesla to picotesla" in the mid-1990s can be characterized as a "quantum leap" in a literal sense: a magnetometer with picotesla sensitivity, heretofore used in aeromagnetics, was put to use on the ground for archaeological prospecting (Becker 1995). Development of the caesium magnetometer, known as CS2/MEP720 (Scintrex/Picodas, Canada), became possible in close collaboration with Robert Pavlik (Picodas) after prospecting of the city fortifications of Homeric Troy in 1992 gained worldwide attention (Becker 1993). Still in use today, it is the most sensitive magnetometer that has ever been employed in archaeological prospecting. In addition to its high sensitivity the essential improvement of the CS2/MEP720 over older caesium magnetometers is a new procedure for time mode sampling of the data. Ten values can be stored per second; at a fast walking tempo this accords with measurement intervals of c. every 10 cm. This time mode sampling of the data first made possible so-called non-compensated (against time variations) measurements (as opposed to time-based variations) through the use of band-pass filters to cancel the high frequency portion of time variations. This simultaneously laid the foundation for use of the gradiometer as a duo-sensor magnetometer.

Also at this time Jörg Faßbinder completed his dissertation on the magnetic characteristics and genesis of ferrimagnetic minerals in the ground, as related to magnetic prospecting of archaeological monuments (Faßbinder 1994). He had discovered a new biogenic magnetizing process: so-called magnetic bacteria that have built-in magnetite single crystals are involved in the rotting of organic materials and the subsequent formation of soil. When soil formation is complete the bacteria die, leaving the magnetite crystals in the formally organic structure. Traces of a (non-magnetic) wooden post, for example, thus become magnetic and can be identified even from above ground with highly sensitive magnetometers through the anomaly of the geomagnetic field. This makes magnetic prospecting possible for the broad field of wood/earth archaeology at our latitude.

A true triumph in the use of magnetics for archaeological prospecting occurred with introduction of the multi-sensor technique in 1995 (Becker 1999). In the so-called duo-sensor configuration the two sensors of a vertical gradiometer are used horizontally, whereby the total geomagnetic field can be recorded in two tracks. The speed of measurement in the field is thus doubled. The duo-sensor configuration opens up new possibilities for high resolution prospecting, also covering large areas.

A further increase in the speed of measurement using caesium magnetometry was achieved in 1996 with introduction of the specially manufactured SMARTMAG-SM4G caesium magnetometers (Scintrex, Canada): up to four complete magnetometer systems with two gradiometer processors, data storage banks and a power supply can be fitted on a newly constructed cart. The analysis process corresponds to that of a double duo-sensor configuration. Thus the speed of measurements in the field can be increased four-fold. Very strong geomagnetic variations during magnetic storms can be compensated through a fifth magnetometer system as a variometer. In uneven or difficult topography the SMARTMAG-SM4G-Special can also be carried as a duo-sensor. Since a cable between the sensor and the magnetometer processor is not necessary, this arrangement can even be used under extreme conditions by one person. The SMARTMAG-SM4G in the duo-sensor configuration has also proved highly successful for projects in foreign countries, which have been carried out using this apparatus exclusively since 1996. The SMARTMAG duo-sensor configuration can be characterized as the most successful development so far for magnetic prospecting. Measurements made in Bavaria in 2000 were done using the SMARTMAG quadro-sensor if possible. Without this apparatus it would have been quite impossible to measure the huge site at Ruffenhofen with a Roman castellum, *vicus* and street of graves (c. one-half square kilometer) in the brief breaks available between agricultural use. The same is true for the Celtic earthwork enclosure in Weiltingen.

During the prospecting of Piramesse (Becker, Faßbinder), the city of Rameses in the Egyptian delta, an area of more than one square kilometer was covered for the first time (50 million measurements in a raster of 0.1/0.5 m, interpolated to 0.25/0.25 m). With Piramesse estimated to extend c. 30 square kilometers, the area measured so far cannot be considered representative, but nonetheless entire urbanized quarters could already be distinguished, with temples, palaces (probably including one of the main Rameses palaces), villa districts, dense residential areas and a shoreline more than one kilometer in length. Up to four settlement strata are superimposed in some places. The analysis of the measurements from 1996 to 2000 were standardized so that the magnetograms of the prospected areas were presented as the mean of the original data with the high pass filter. The compilation of these mean value magnetograms onto the topographic maps best reflects the "city map" of the Rameses metropolis (fig. 4).

Nearly sensational results were also produced in Cicah (Siberia) where magnetic prospecting was carried further (Becker, Faßbinder). After the major part of a Scythian urban site from the 8th-7th centuries BC could be prospected in just three days in 1999, in 2000 the entire city and its necropolis were to be covered. Because two grave sites had already been surveyed just beyond the outer city gate at the edge of the area measured in 1999, it was anticipated that it would be easy to prospect the necropolis that was presumably directly adjacent. But in fact it was necessary to prospect an area of c. four hectares, without any results, until another grave site was finally found. In order to prospect this (probably more recent) necropolis at a distance of 240 m, an area of more than 26 hectares had to be measured; more than 20 graves, including four large so-called kurgans, were found (fig. 2). The necropolis belonging to the urban site from the 8th-7th centuries is still being sought, although continued prospecting work does not appear very promising without any further points of reference for its approximate location on the expanse of the Siberian steppe.

Continued collaboration with the archaeologists and engineers of the Technical Center for Protection of Cultural Properties in Shaanxi Province (China) is described by Jörg Faßbinder in his progress report. Since it was again not possible to work in the mausoleum of the First Chinese Emperor Qin Shihuang, we concentrated on one of his residences near the village of Wah ze Gang. The caesium magnetometer SMARTMAG SM4G-Special was used here as a duo-sensor.

Although the discussion so far has focused primarily on the development of measuring techniques using caesium magnetometry and on the presentation of magnetograms, it must also be emphasized that, with as much as a ten-fold increase in the speed of measurement, the problems of magnetic prospecting are now to be found on a totally different plane. The areas prospected with the multi-sensor technique have sometimes covered more than 200 hectares per year, which puts the processes of visualization, analysis and interpretation to a new test. This



Fig. 5. Roman castellum at Ruffenhofen. Magnetogram of the castellum from a bird's eye view as the basis for reconstruction and computer animation.

amount of data cannot be tackled with traditional (manual) methods of analysis. Some aspects of measuring technology have also changed on an international level: there is now a demand for a combination of techniques in geophysical prospecting, in particular high resolution magnetics, electricity and ground-penetrating radar. In the Bavarian State Conservation Office we unfortunately have not been able to contribute to the use of ground radar, which is so far the only method for three-dimensional representation of underground archaeological structures, because we still do not have the essential apparatus. The situation is even worse regarding visualization, analysis and interpretation of data: long overdue developments in the presentation and interpretation of the magnetograms cannot be completed because we do not have the modern computers and analysis programs. Current developments are focusing on automatic production of plans through pattern recognition, 3-D visualization of the magnetograms on the digital field model, interpretation based on geographic information systems (ArcViewGIS) and computer animation and simulation. Archaeological prospecting could achieve a new dimension with this step toward virtual archaeology. The first test run using 3-D visualization and computer animation helps to illustrate how urgently we need to introduce these methods into the routine work of archaeological prospection:

The Roman castellum at Ruffenhofen in Middle Franconia at the foot of the Hesselberg is one of the fortresses along the limes. The location of the castellum has long been known; already in 1892 it was investigated in excavations by the Imperial Limes Commission. In 1981 a series of aerial photographs by O. Braasch threw new light on a site that had been neglected by researchers. The photos rather clearly show a previously identified storehouse, part of the defensive wall, the plan of the *principia*, and four (!) trenches.

Ruffenhofen subsequently became an El Dorado for aerial archaeology. In addition to O. Braasch, the images by H. D. Deinhard, K. Leidorf, J. Mang and H. Thoma helped to greatly further knowledge of the area of the castellum and *vicus,* making it possible to produce sketches. Up till now the absence of exact

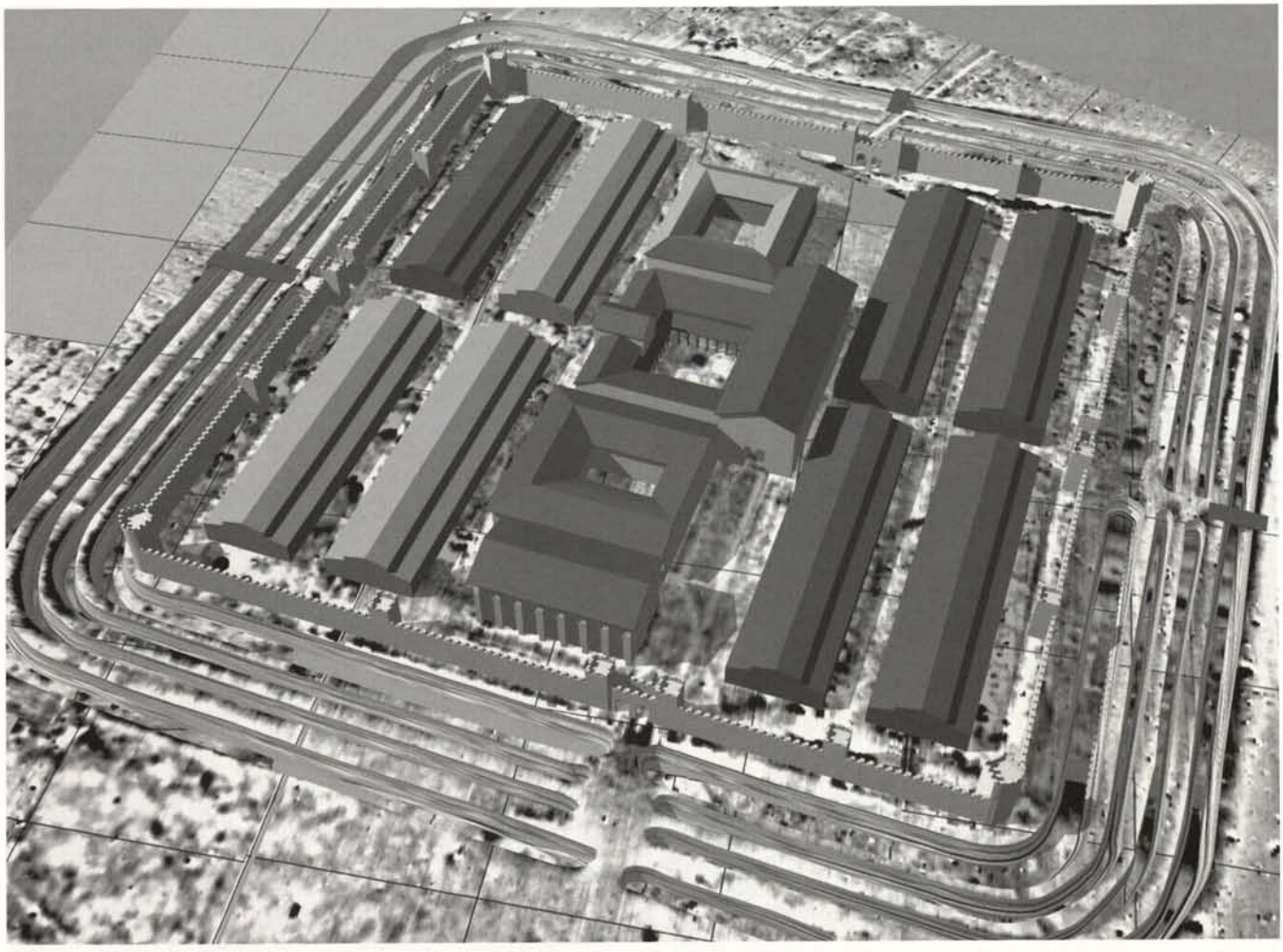


Fig. 6. Roman castellum at Ruffenhofen. Still image from the computer animation with the inner structures of the castellum, computer animation H. Becker, A. Pohl 2000

control points for distortion correction of the oblique photos has made it difficult to unify them for a ground plan that covers the entire area. A new aerial photo by K. Leidorf from July 2001 shows practically the entire castellum and the baths so that a majority of the previous images from the last twenty years can be considered outdated – further proof of the importance of continuity in aerial archaeology (fig. 3).

The castellum is in a desolate condition today. Plowing has already brought the lower layers of the foundation walls to the surface and large numbers of important metal artifacts have been stolen.

From 1998 to 2000 the castellum and large sections of the *vicus* were magnetically prospected for the first time (Becker et al. 2000). A newly developed equipment cart with a quadro-sensor arrangement for the caesium magnetometer Scintrex SMARTMAG SM4G demonstrated its successful use in the field here. The advancements made in measuring using this new technique are such that now large archaeologically relevant landscapes can be surveyed in a relatively short time. The magnetograms show astonishingly clearly the entire castellum, the large baths, and almost the entire camp which stretches 700 m to the south (see the detail in fig. 5). A large fire in the entire castellum caused such a strong contrast in the magnetization that it is possible to distinguish between stone and wooden buildings. In the strongly magnetized fire debris, the almost non-magnetic walls of sandstone produce a negative anomaly (light in the magnetogram), whereas wooden foundations are characterized as a positive magnetic anomaly (black).

Prospecting of the *vicus* was largely completed in 2000. The great success of the millenium year was the prospecting of a necropolis belonging to the castellum (fig. 1). A double row of fire burials and numerous stone grave monuments are lined up so that they appear to be arranged in their own street of graves. This almost recalls, on a smaller scale, the street of graves in Palmyra in Syria. As in Palmyra, the large grave monuments in Ruffenhofen must also have had inscriptions, from which it will finally be possible to read the name of the castellum and its division. Continued prospecting will show if this is the only



Fig. 7. Roman castellum at Ruffenhofen. Magnetogram of the castellum with the *vicus* and the baths. SMARTMAG SM4G-Special as quadrosensor. Sensitivity 0.01 nT (10 picotesla), raster 0.1/0.5 m interpolated to 0.25/0.25 m, dynamics –7.0/+7.0 nT in 256 gray scales (black/white), 40 m grid, magnetometer prospecting H. Becker, Mag.Nr. 6928/074-00A.

necropolis or if others might be located at a greater distance on the streets leading out of the castellum. With production of the magnetograms it immediately became clear to the experts that this is an archaeological monument of great significance. Where else is a Roman castellum, the entire *vicus* and a street of graves located in the open landscape? The problems facing preservationists for the protection of this unique archaeological ensemble were deemed enormous, even hopeless: an area of one-half square kilometers (50 hectares) would have to be removed from intensive agricultural use and given special protection.

On the basis of the magnetograms and known reconstructions of Roman buildings and other castella, an initial computer animation was developed by Alexander Pohl for the castellum with its interior structures. After a very exact and detailed reconstruction with a walk-through animation of individual buildings (barracks, warehouse, gate, *principia* with vestibule), faithful down to the smallest architectural feature, it became obvious that the computer available to us was not sufficient for a complete animation of the entire castellum. Therefore a simpler model – described as a "shoe box model" – was designed. A still image from the computer animation of the castellum, which can be walked-through from different perspectives, can be seen in fig. 6 (Becker, Pohl). A project that at first seemed like child's play instead turned out to be the very best medium for conveying the importance of this archaeological monument to the public. While the experts were still discussing among themselves whether the proposed reconstruction of the defensive walls and the battlemented towers would be possible, working groups had long gone into action in the Hesselberg district and plans had been developed for how the castellum could be protected, researched further, and made accessible to the public. By July 2001 the community-led negotiations with the farmers had proceeded so far that the entire castellum could be removed from intensive agricultural use – probably the most important prerequisite for lasting protection. Erection of an information booth on the castellum in the small museum of Weiltingen is also planned. Defensive walls, towers and fortification ditches of the castellum are to be marked in the landscape using special plantings.

The expectations concerning conveyance of the importance of an archaeological monument which is rather problematic from a preservation perspective to the public seem to be fulfilled. Inscription of the limes on the World Heritage List presumably could also raise the castellum in Ruffenhofen to this level. There remains an urgent need to continue to expand this very successful start in virtual archaeology.

References

Aitken, M. J., *Physics and Archaeology,* London 1961 and Oxford 1974.

Becker, H., 1993, "Die Suche nach der Stadtmauer des homerischen Troia", in: *Denkmalpflege Informationen*, hrsg. v. Bayer. Landesamt für Denkmalpflege, Ausg. D Nr. 18 / 22. März 1993, 1-12.

Becker, H., 1995, "From Nanotesla to Picotesla – a new window for magnetic prospecting in archaeology", in: *Archaeological Prospection*, 2, 217-228.

Becker, H., 1999, "Duo- and Quadro-Sensor Configuration for High-Speed/High-Resolution Magnetic Prospecting with Caesium Magnetometer", in: *Archaeological Prospection*, Arbeitshefte des Bayerischen Landesamtes für Denkmalpflege, vol. 108, 100-105.

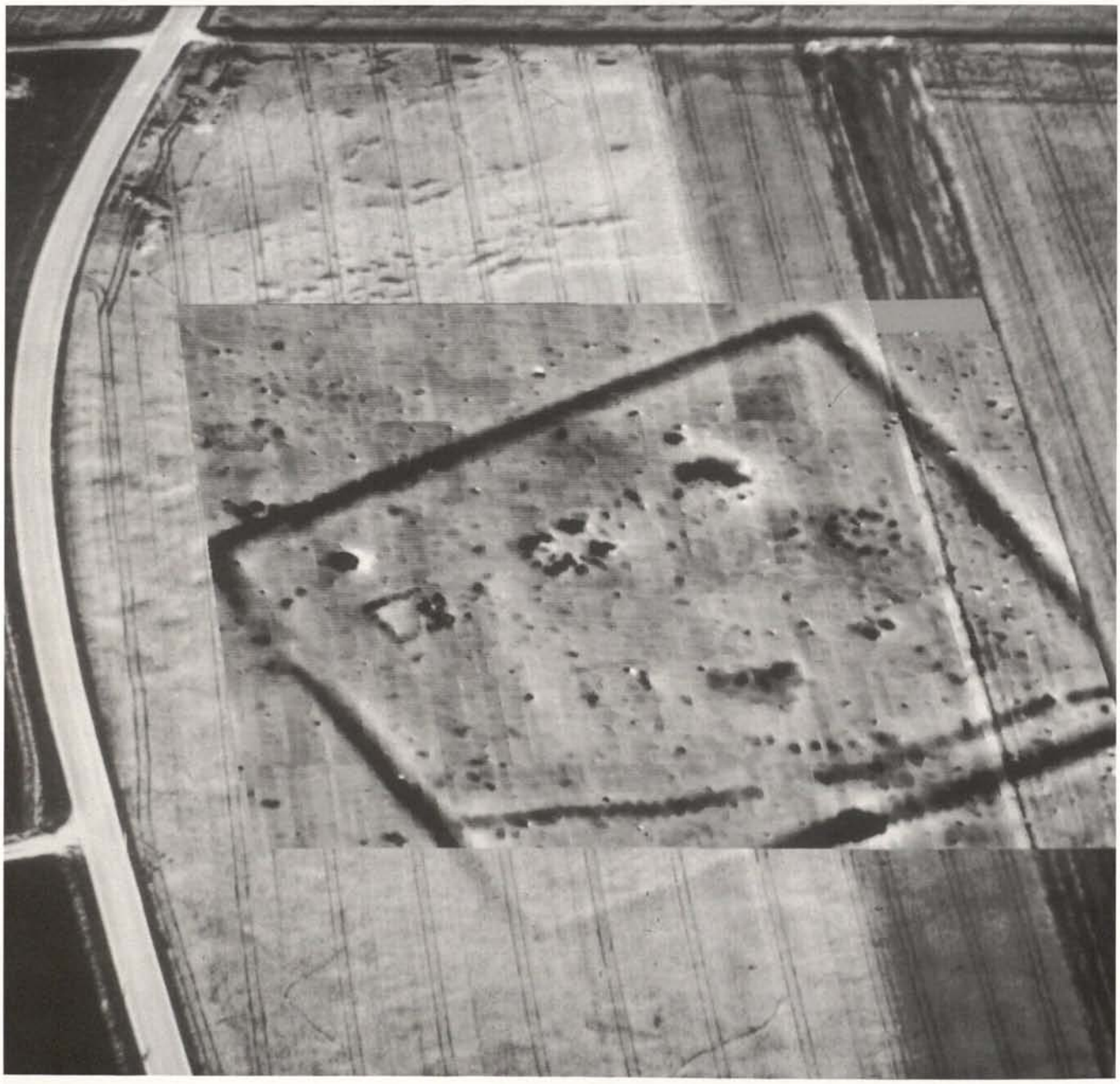
Becker, H., Deinhardt, H.-D., Thoma, H., 2000, "Prospektion des Kastells Ruffenhofen mit Luftbild und Geophysik, Gemeinde Wittelshofen, Landkreis Ansbach, Mittelfranken", in: *Das archäologische Jahr in Bayern 1999*, Stuttgart 2000, 56-59.

Becker, H., 2001, "Prospektion und Visualisierung der spätkeltischen Viereckschanze von Weiltingen, Markt Weiltingen, Landkreis Ansbach, Mittelfranken", in: *Das archäologische Jahr in Bayern 2000*, in press.

Faßbinder, J. W. E., 1994, *Die magnetischen Eigenschaften und die Genese ferromagnetischer Minerale in Böden im Hinblick auf die magnetische Prospektion archäologischer Bodendenkmäler*, Buch am Erlbach 1994.

Faßbinder, J. W. E., Stanjek, H., Vali, H., 1990, "Occurrence of magnetic bacteria in soil", in: *Nature,* 343, 161-163.

Scolar, I., Tabbagh, A., Hesse, A., Herzog, I., 1990, *Archaeological prospecting and remote sensing,* Cambridge University Press 1990.



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.

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 diurnual 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



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

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.

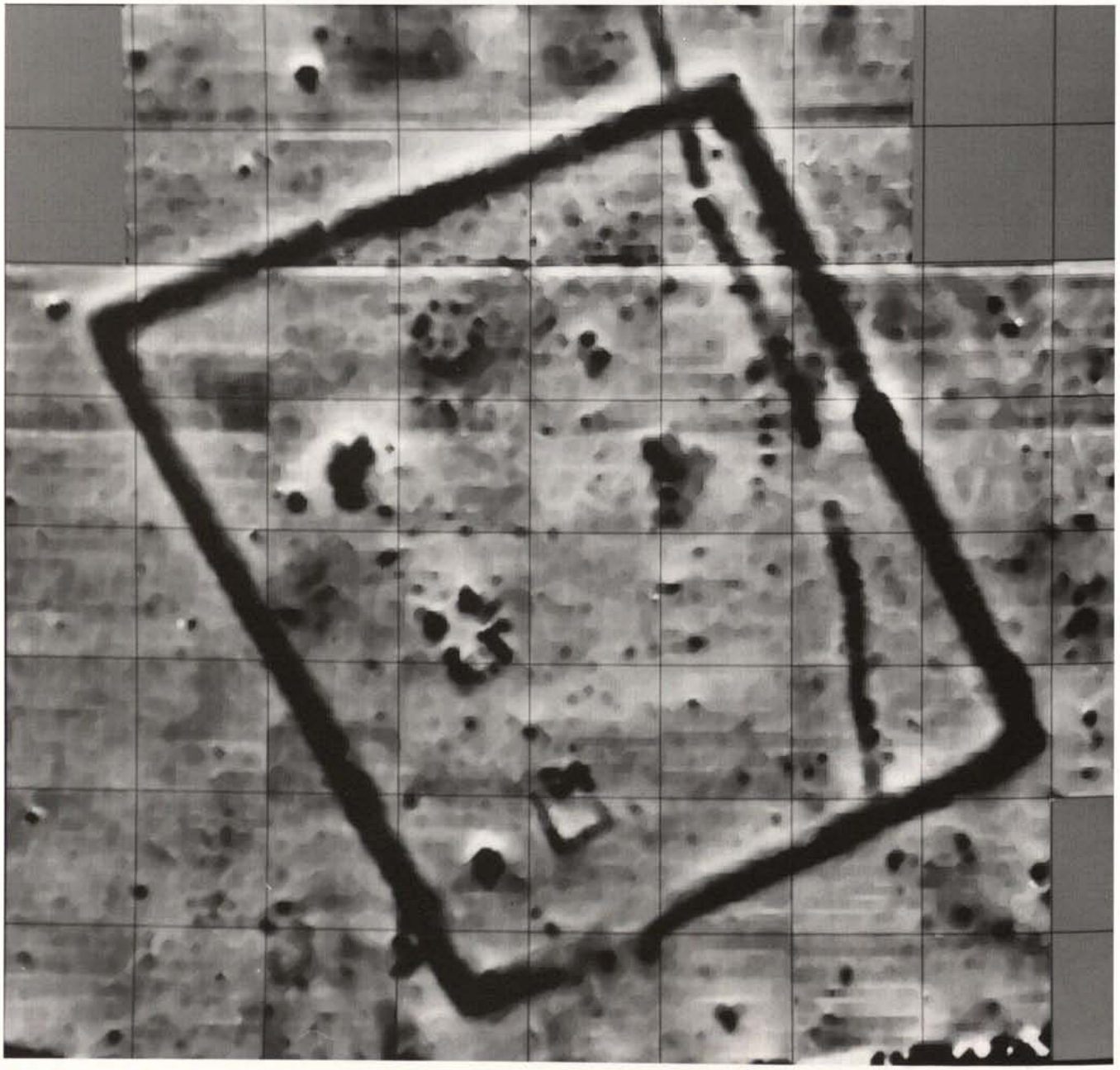
Ninety seven percent of the magnetometer data in a 20 m grid varies in the range of -4.5 to +4.5 Nanotesla from the mean value of the earths magnetic field. All of the stronger anomalies can be ascribed to burned structures or to pieces of iron rubbish. In situ burning is easily distinguishable from 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



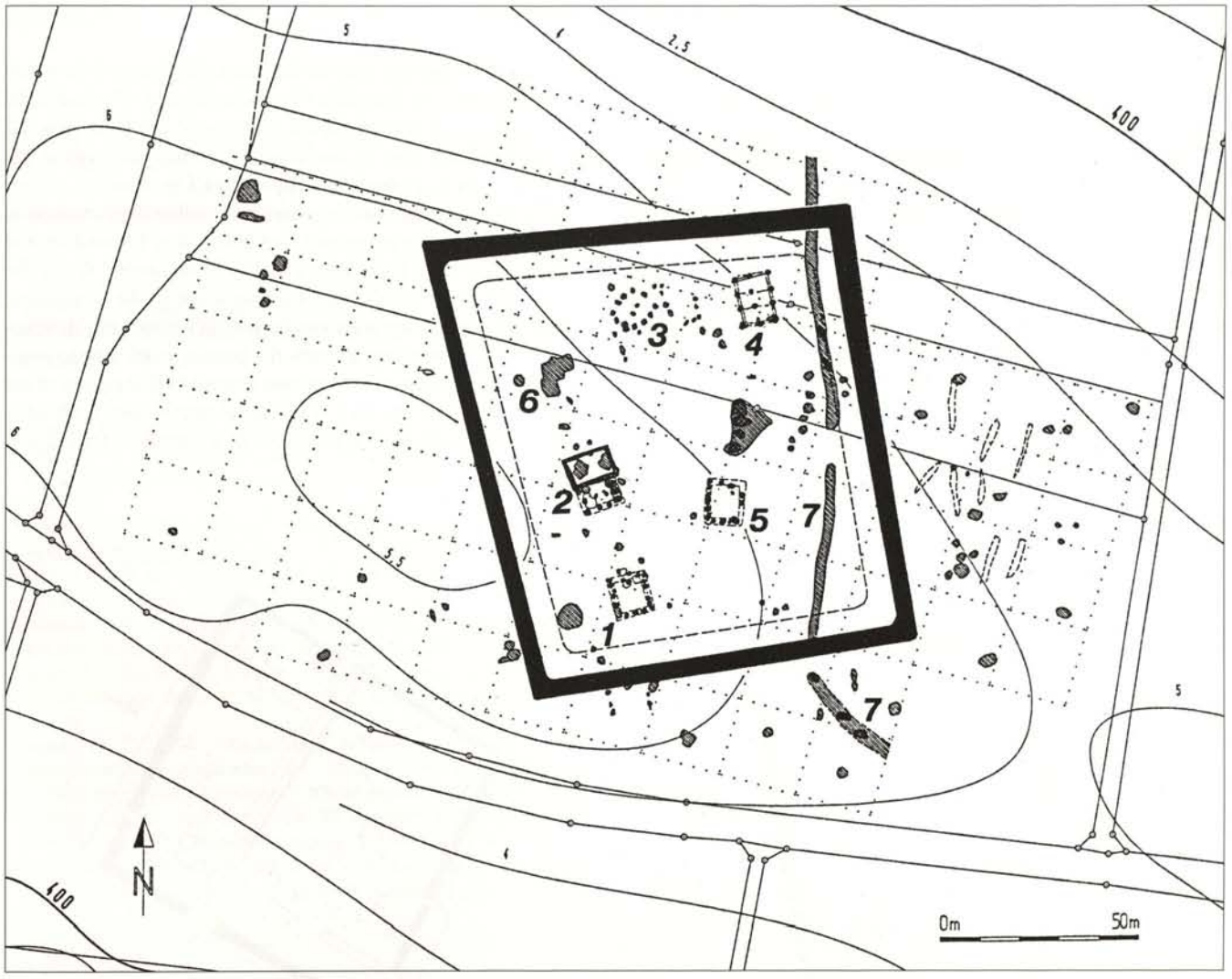


Fig. 4. Egweil. Graphic plan on the basis of the digital image processing of the magnetic picture. Drawn as an overlay from the computer and plotted together with the geographical card

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 for 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).

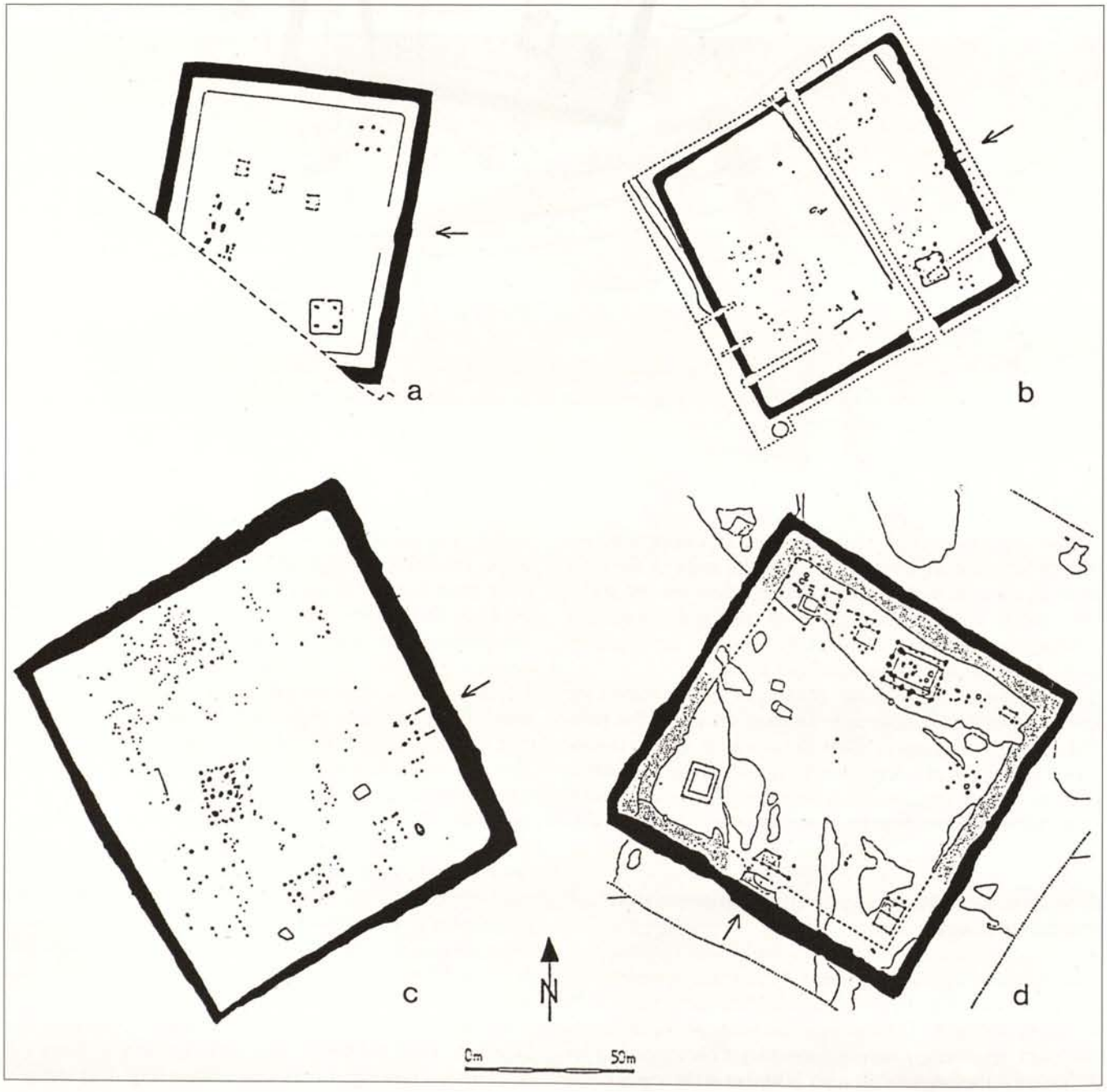
Inside the enclosure we detected clearly the structures of five buildings. These buildings are visible by traces of posts and small ditches (see Fig. 4,1–5). One of them (Fig. 4, 2) seems to

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.



References

Aitken, M. J. 1958. "Magnetic prospecting I", *Archaeometry,* 1, 24–29

Aveling, E. 1997. "Archaeology: Magnetic tracing of a giant henge", *Nature,* 390, 232–233

Becker, H. 1982. "Befestigungswerke auf dem Galgenberg bei Kopfham", *Arch. Jahr Bayern,* 1981, 72–73

Becker, H. 1995. "From Nanotesla to Picotesla – a new window for magnetic prospecting in archaeology", *Archaeological Prospection,* 2, 217–228

Becker, H. 1997. "Entwicklung und Einsatz von Multi-Sensor-Konfigurationen zur magnetischen Prospektion archäologischer Denkmäler", *Arch. Jahr Bayern,* 1996, 195–197

Bittel, K., Schiek, S., Müller, D. 1990. *Die Keltischen Viereckschanzen,* Stuttgart

Belshé, J. C. 1957. "Recent magnetic investigations at Cambridge University", *Adv. Phys.,* 6, 192–193

Braasch, O. 1990. "Flugbeobachtungen an spätkeltischen Viereckschanzen in Südostbayern", *Aerial Photography and Geophysical Prospection in Archaeology,* Proc. 2. Int. Symposium Brussels 1986, 2, 49–72

Decker, K.V., Scollar, I. 1962. "Iron-age square enclosures in Rhineland", *Antiquity,* 36, 175–178

Fassbinder, J. W. E., Stanjek, H., Vali, H. 1990. "Occurrence of magnetic bacteria in soil", *Nature,* 343, 161–163

Fassbinder, J. W. E., Stanjek, H. 1993. "Occurrence of bacterial magnetite in soils from archaeological sites", *Archaeol. Polona,* 31, 117–128

Graham, I. D. G., Scollar, I. 1976. "Limitation on magnetic prospection in archaeology imposed by soil properties", *Archaeo-Physika,* 6, 1–126

Irlinger, W. E. 1994. "Rechteckige Strukturen im Luftbild. Die Interpretationsmöglichkeiten am Beispiel der Flurformen und spätkeltischer Viereckschanzen", *Aerial Archaeology in Eastern and Central Europe,* Inter. Symp. 26.-30. September 1994 Kleinmachnow. Forsch. Arch. Land Brandenburg, 3, 177–184

Irlinger, W. E. 1996a. "Die keltischen Viereckschanzen. Erkennungsmöglichkeiten verebneter Anlagen im Luftbild", *Archäologische Prospektion. Lufbildarchäologie und Geophysik,* Arbeitshefte Bayer. Landesamt f. Denkmalpflege, 59, 183–190

Irlinger, W. E. 1996b. "Kommentierter Katalog zu den Luftbildfundstellen keltischer Viereckschanzen in und um München", *Archäologische Prospektion Lufbildarchäologie und Geophysik,* Arbeitshefte Bayer. Landesamt f. Denkmalpflege, 59, 307–324

Kaufmann, D. 1997. "Zur Funktion Linearbandkeramischer Erdwerke", *Vortr. Niederbayer. Archaeologentag,* 15, 41–87

Klein, F. 1996. "Zur Viereckschanze 'Klinge' bei Riedlingen, Kreis Biberach, Baden-Württemberg", *Vortr. Niederbayer. Archaeologentag,* 14, 155–172

Krause, R., Wieland, G. 1993. "Eine keltische Viereckschanze bei Bopfingen am Westrand des Rieses", *Germania,* 71, 59–112

Le Borgne, E. 1955. "Susceptibilitée magnétique anomale du sol superficiel", *Ann. Géophys.,* 11, 399–419

Lovley, D. R., Stolz, J. F., Phillips, E. J. P., Nord, G. L. 1987. "Anaerobic production of magnetite by a dissimilatory iron-reducing microorganism", *Nature,* 330, 252–254

Maher, B. A., Taylor, R. M. 1988. "Formation of ultrafine-grained magnetite in soils", *Nature,* 336, 368–370

Mullins, C. E. 1977. "Magnetic susceptibility of soils and its significance in soil science – a review", *J. Soil Sci.,* 28, 223–246

Murray, M. 1995. "Viereckschanzen and feasting: Socio-political ritual in Iron-Age Central Europe", *J. Europ. Archaeology,* 32, 125–151

Schaich, M., Watzlawik, S. 1996. "Die spätlatènezeitliche Viereckschanze von Hartkirchen", *Arch. Jahr Bayern,* 1996, 104–107

Schwarz, K. 1959. *Atlas der spätkeltischen Viereckschanzen Bayerns,* München

Schwarz, K. 1975. "Die Geschichte eines keltischen Temenos im nördlichen Alpenvorland", *Ausgrabungen in Deutschland,* 1, 324–358

Scollar, I., Lander, "A. 1972. A subtraction circuit for the differential operation of two commercial proton magnetometers", *Prospezioni Archeologiche,* 7, 93–98

Tite, M. S., Mullins, C. E. 1971. "Enhancement of the magnetic susceptibility of soils on archaeological sites. Archaeometry", 13, 209–220

Acknowledgements

Thanks for the help in field work to Josef Lichtenauer. Improvement of the english was done by Robert H. Hetu. Many thanks to an anonymous reviewer.

◁ 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

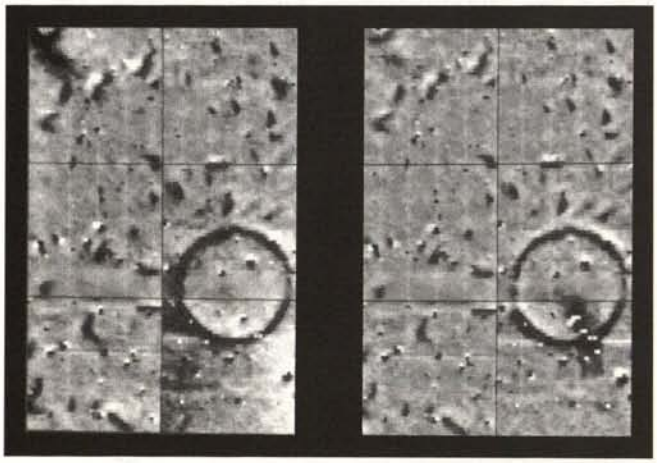


Fig. 1. Wolfertschwenden, Roman burial or mausoleum directly under a power line, duo-sensor configuration of CS2/MEP720 system, digital image of the magnetogram of six 20 m grids, raster 0.25/0.5 m, dynamics -6.4/+6.4 nT in 256 greyscale (white/black). a) reduction of the diurnal variation by the line 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: **s**ensitivity, **s**peed and **s**pacial 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)



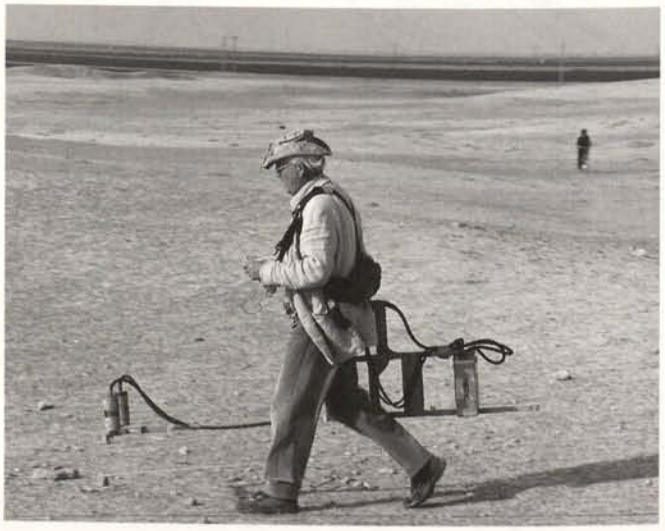
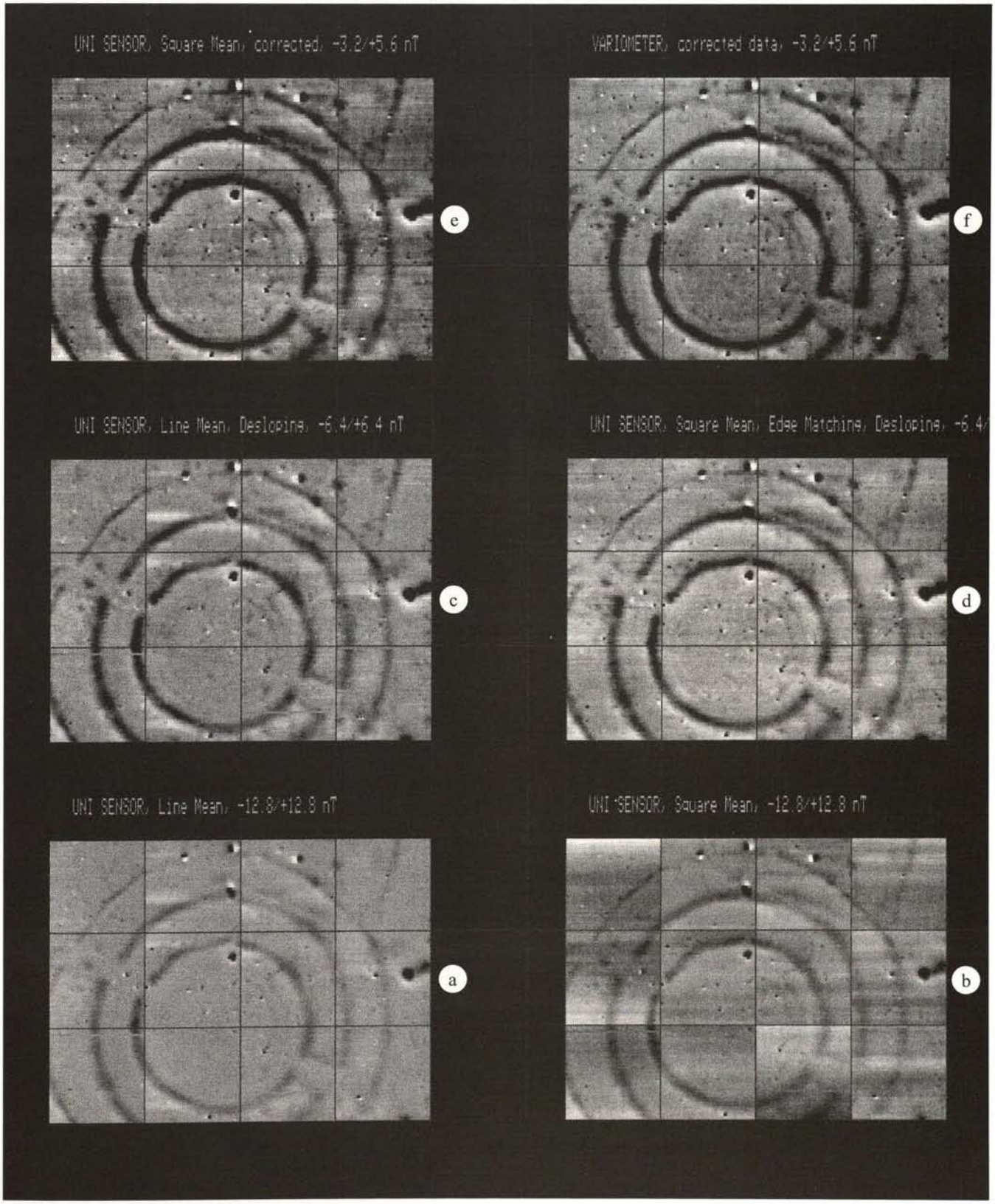


Fig. 3a–f. Reprocessing uni-sensor Schmiedorf-Osterhofen 1986. Caesium magnetometer Scintrex/Picodas CS2/MEP720, sensitivity 0.001 nT, raster 0.5/0.25 m, 20 m grid. a) uni-sensor, line mean reduction, dynamics -12.8/+12.8 nT. b) uni-sensor, square mean reduction, dynamics -12.8/+12.8 nT. c) uni-sensor, 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-



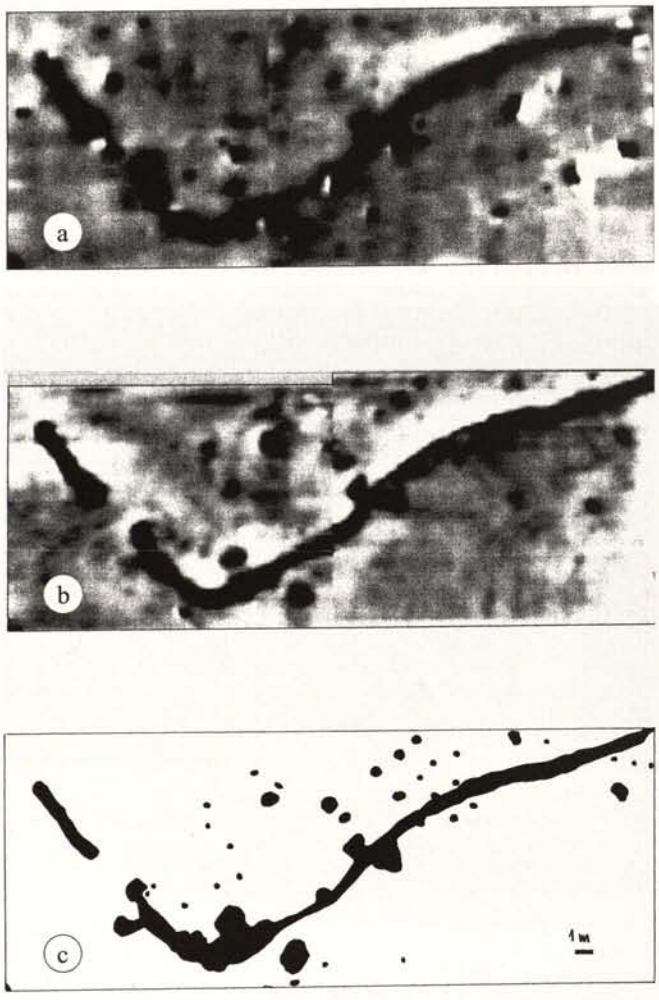


Fig. 4a–c. Murr 1995–1996. Example for surface- and open trench prospecting with duo-sensor on wheels (CS2/MEP720) and man carried application (Smartmag SM4G-Special). (a) Sureface measurement with CS2/MEP720 on wheels; raster 0.5/0.25 m; dynamics -3.2/+3.2 nT. (b) Open trench measurement with hand carried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

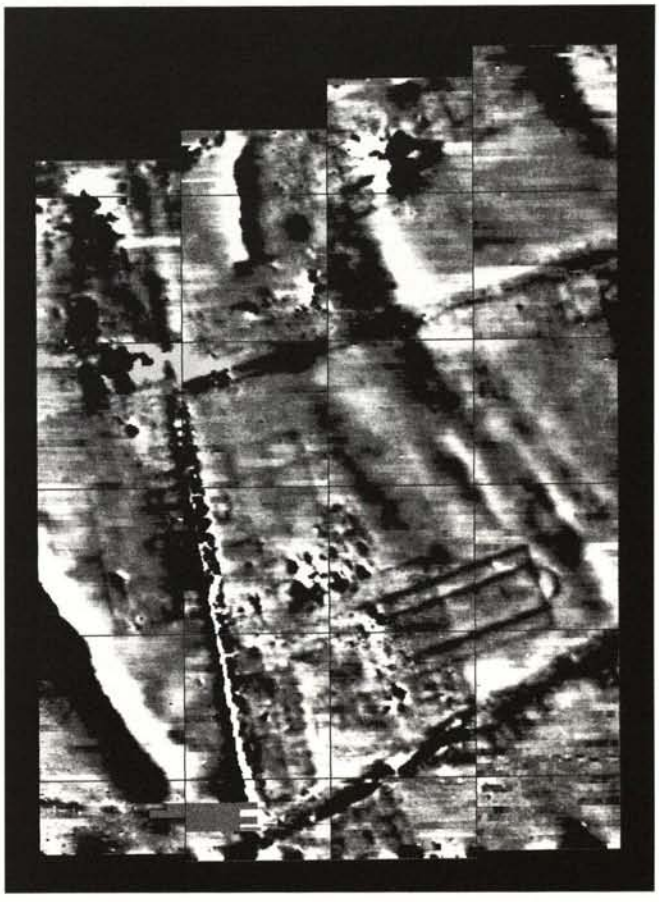


Fig. 6. Ostia Antica 1996 Magnetogram (detail with the basilica of Constantinus I.) in greyshading, dynamics -50.00/+50.00 nT in 256 greyscale (white/black), sensitivity ± 10 pT, raster after resampling 0.5/0.25 m, 1 Hz bandpass-filtering, reduction on 40 m line means, 40 m grid, Mag Nr. OS96-A

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-

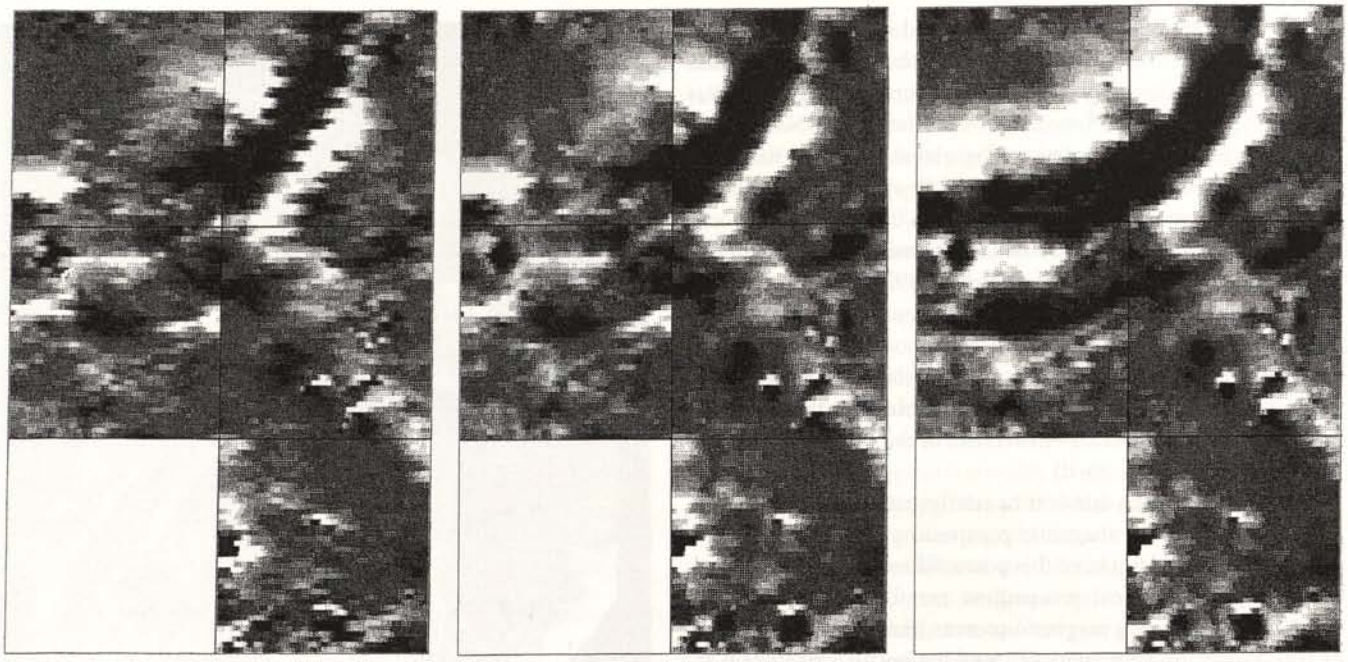


Fig. 7. Monte da Ponte. Speed dependant shift correction and influence of the line mean and square mean reduction of the temporal geomagnetic variation. Magnetogram of five 20 m grids at the second wall (see Fig. 4), raw data (left), speed dependant shift correction with reduction on the line mean (middle),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

References

Becker, H., 1990. "Combination of aerial-photography with ground-magnetics in digital image processing technique", *Aerial photography and geophysical prospection in archaeology,* Proc. 2. Int. Symposium Brussels 1986 2, 25–35

Becker, H., 1995. "From Nanotesla to Picotesla – a new window for magnetic prospecting in archaeology", *Archaeological Prospection,* 2, 217–228

Becker, H., 1996. "Magnetische Prospektion der neolithischen Siedlungen von Murr 1995 und 1996", *Archäologie im Landkreis Freising,* 6, 232–245

Becker, H., Jansen, H. G., 1996. "Vergleich von Fluxgate-Gradiometer mit Cäsium Magnetometer in der archäologischen Prospektion", *Archäologische Prospektion. Luftbildarchäologie und Geophysik,* Arbeitsh. Bayer. Landesamt f. Denkmalpflege, 59, 273–276

Becker, H., 1997. "Geophysikalische Prospektion in Vale de Rodrigo. Concelho Evora, Portugal", *Madrider Mitt.,* 38, 21–35

Becker, H., 1997. "Hochauflösende Magnetik am Beispiel der archäologischen Prospektion", in: M. Beblo (Hrsg.), *Umweltgeophysik,* 59–70

Becker, H., 1998. "Magnetische Prospektion archäologischer Stätten am Beispiel Troia (Türkei), Piramesse Ägypten) und Ostia Antica (Italien)", *Nürnberger Blätter zur Archäologie,* 13, 85–106

Eder-Hinterleitner, A., Neubauer, W., Melichar, P., 1996. "Reconstruction of archaeological structures using magnetic prospection", *Analecta praehistorica Leidensia,* 28, 132–137

Heinzelmann, M., Becker, H., Eder, K., Stephani, M., 1997. "Vorbericht zu einer geophysikalischen Prospektionskampagne in Ostia Antica", *Mitt. Deutsches Arch. Institut Rom,* 104, 537–548

Kalb, Ph., Höck, M., 1997. "Untersuchungen im Megalithgebiet von Vale de Rodrigo, Concelho Evora, Portugal", *Madrider Mitt.,* 38, 1–20

Neubauer, W. 1990. "Geophysikalische Prospektion in der Archäologie", *Mitt. Anthropol. Ges. Wien,* 120, 1-60

Stümpel, H., 1995. "Untersuchungen in KUSAKLI 1992–1995, geophysikalische Prospektion", *Mitt. Deutsche Orient Ges.,* 127, 5–36

Melichar, P., 1990. "Eine geomagnetische Prospektionsmethode im Dienst der Archäologie", *Aerial photography and geophysical prospection in archaeology,* Proc. 2. Int. Symposium Brussels 1986, 177–182

Neubauer, W., Melichar, P., Eder-Hinterleitner, A., 1996. "Collection, visualisation and simulation of magnetic prospection data", *Analecta Praehistorica Leidensia,* 28, 121–129

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.

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



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).

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.

References

Aitken, M. J. 1974. *Physics and Archaeology,* Clarendon Press, Oxford

Becker, H. 1990. "Digitale Bildverarbeitung und graphische Datenverarbeitung in der archäologischen Prospection", *Archäologische Informationen,* 13, 179–186

Becker, H. 1990. "Combination of aerial-photography with groundmagnetics in digital image processing", in: C.Leva & J. Hus (eds.), *Aerial photography and geophysical prospection in archaeology,* Proceedings 2nd International Symposium Brussels, 25–35

Fassbinder, J. W. E., Stanjek, H., Vali, H. 1990. "Occurrence of magnetic bacteria in soil", *Nature,* 343, 161–163

Le Borgne, E. 1955. "Susceptibilitée magnétique anomale du sol superficiel", *Ann. Géophys.,* 11, 399–419

Le Borgne, E. 1960. "Influence du feu sur les propriétés magnétiques du sol et sur celles du chiste et du granite", *Ann. Géophys,* 16, 159–195

Mullins, C. E. 1977. "Magnetic susceptibility of soils and its significance in soil science, a review", *J. Soil Sci,* 129, 223–246

Weißhaar, H.-J. 1992. "Megalithgräber unter Kokospalmen", *Archäologie in Deutschland,* Heft 3/1992, 10–15

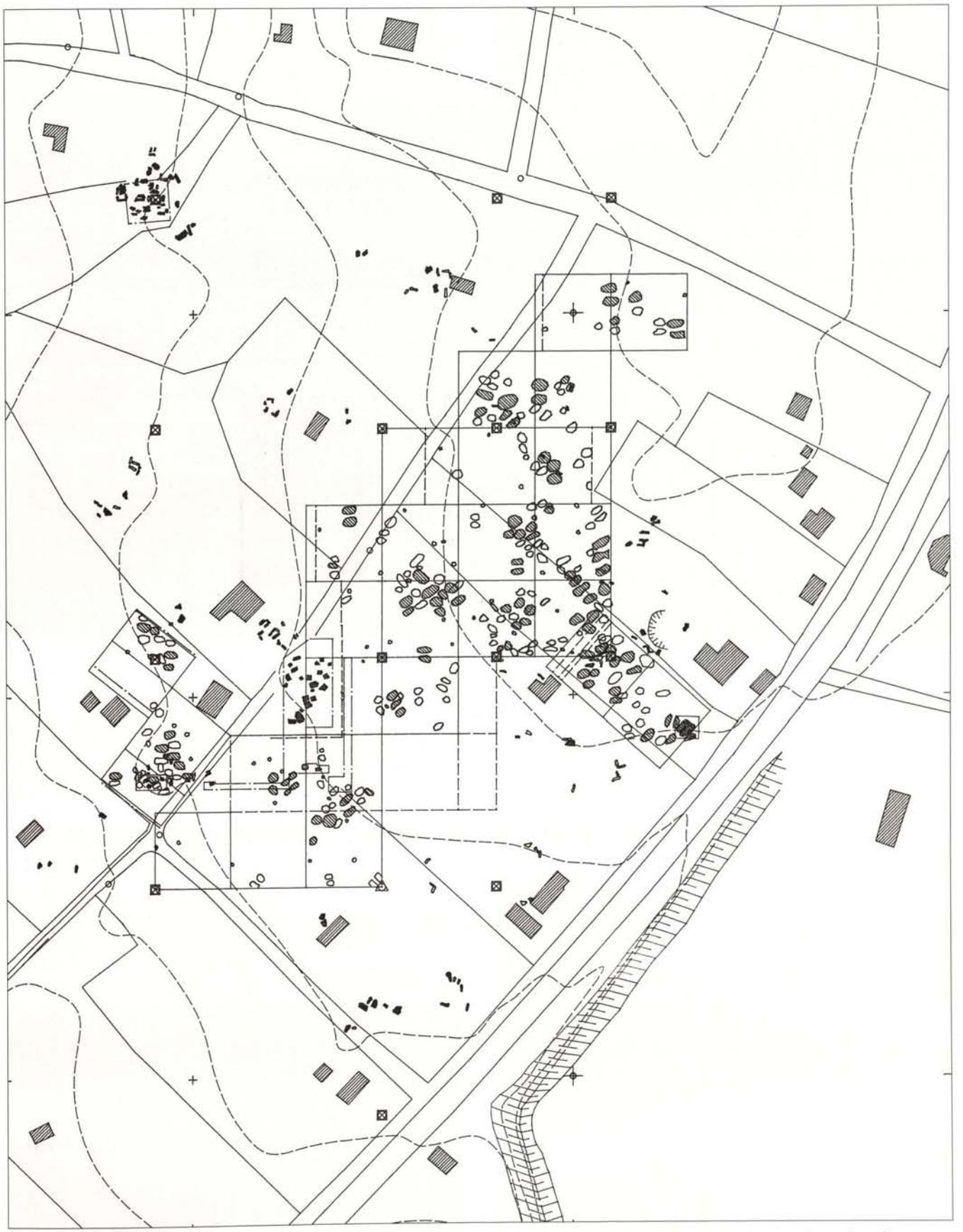


Fig. 4. Ibbankatuwa. Plan of the whole necropolis at Ibbankatuwa based on the interpretation of the magnetic prospecting data and on the excavation plan



Fig. 1. Sigiriya. Excavated garden architecture

J. W. E. Fassbinder, H. Becker

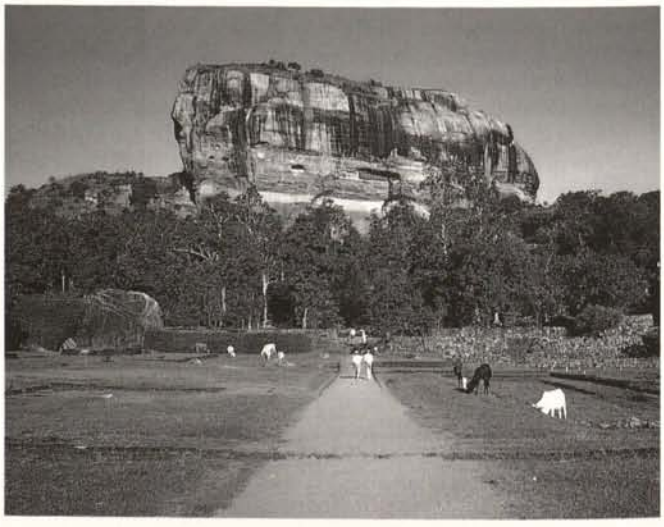
Magnetometry in the Garden of the Sigiriya Rock Fortification (Sri Lanka)

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.

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

Fig. 2. Sigiriya rock from the west



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

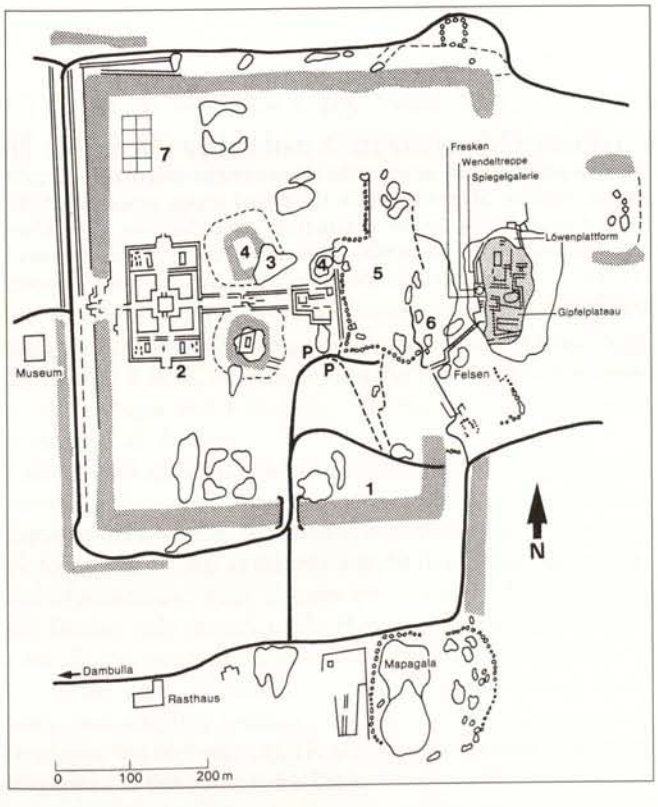
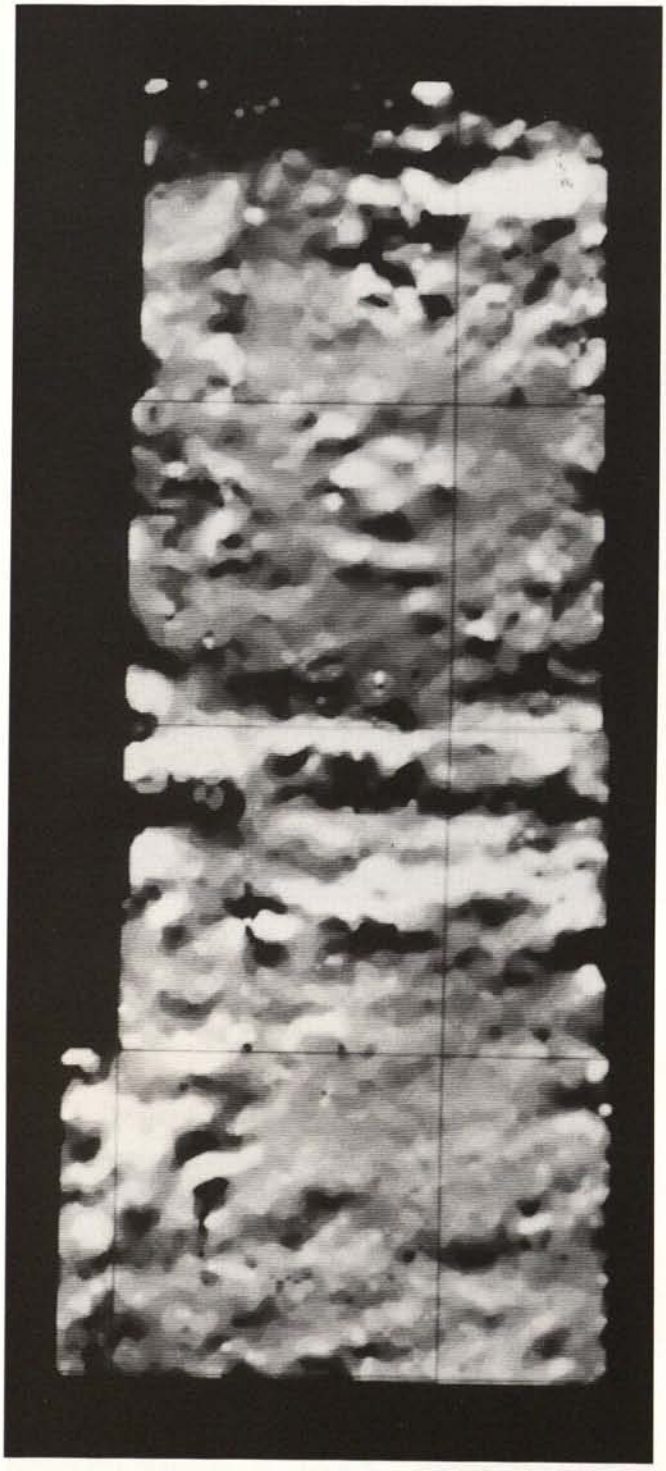


Fig. 5. "Aerial view" of the Sigiriya garden





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.

References

H.-J. Aubert, 1984. *Sri Lanka,* Stuttgart

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 6th "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= 8950.000
X= 10925.000
Y= 9600.000
X= 10925.000
"TROIA VI"
"ILIUM IX"
"PERGAMOS" VI
"ACROPOLIS" IX
"West Tor IX"
"Skäisches Tor ?"
"AGORA" IX
"UNTERSTADT" VI
Dardanisches Tor
"ILIUM IX"
"Süd-Tor VI"
röm. Stadtmauer Ilium IX
Y= 8950.000
X= 10000.000
100 m
Y= 9600.000
X= 10000.000



▽ 6b

6a △



◁◁ 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

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

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



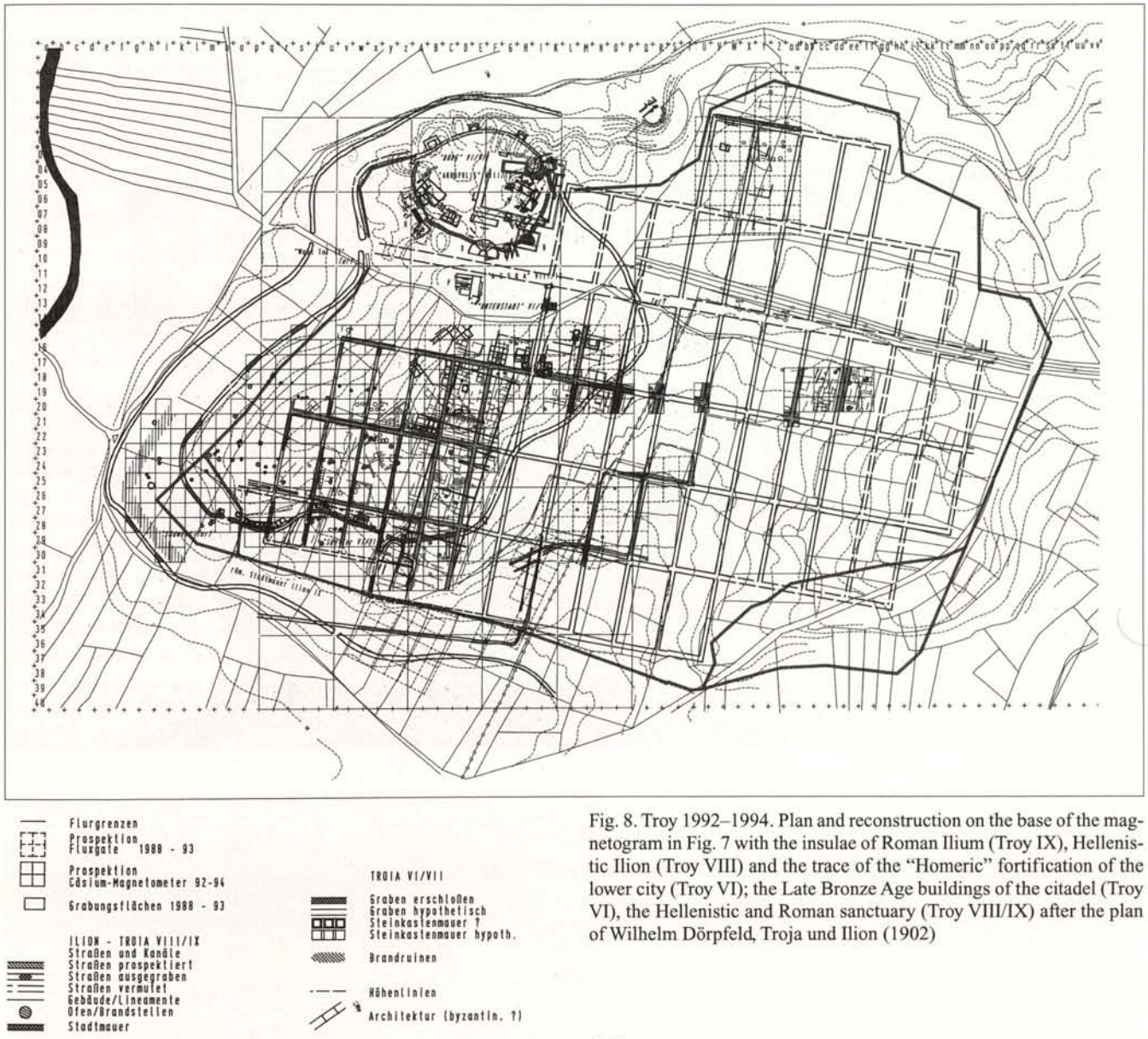


Fig. 8. Troy 1992–1994. Plan and reconstruction on the base of the magnetogram in Fig. 7 with the insulae of Roman Ilium (Troy IX), Hellenistic Ilion (Troy VIII) and the trace of the "Homeric" fortification of the lower city (Troy VI); the Late Bronze Age buildings of the citadel (Troy VI), the Hellenistic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

References

Becker, H., 1993. "Die Suche nach der Stadtmauer des homerischen Troia. Eine Testmessung zur magnetischen Prospektion mit dem Cäsium-Magnetometer", *Denkmalpflege Informationen,* hrsg. v. Bayer. Landesamt für Denkmalpflege, Ausgabe D Nr. 18/22. März 1993, 1–12

Becker, H., 1995. "From Nanotesla to Picotesla – a new window for magnetic prospecting in archaeology", *Archaeological Prospection,* 2, 217–228

Becker, H., Fassbinder, J. W .E., Jansen, H. G., 1993. "Magnetische Prospektion in der Untersiedlung von Troia 1992", *Studia Troica,* 3, 117–134

Becker, H., Jansen, H. G., 1994. "Magnetische Prospektion 1993 der Unterstadt von Troia und Ilion", *Studia Troica,* 4, 105–114

Dörpfeld, W., 1902. *Troja und Ilion. Ergebnisse der Ausgrabungen in den vorhistorischen und historischen Schichten von Ilion 1870–1894*

Jablonka, P., König, H., Riehl, S., 1994. "Ein Verteidigungsgraben in der Unterstadt von Troia VI. Grabungsbericht 1993", *Studia Troica,* 4, 51–73

Jansen, H. G., 1992. "Geomagnetische Prospektion in der Untersiedlung von Troia", *Studia Troica,* 2, 61–69

Korfmann, M., 1992. "Die prähistorische Besiedlung südlich der Burg Troia VI/VII", *Studia Troica,* 2, 123–146

Schliemann, H., 1874. "Bericht über die Ausgrabungen in Troia in den Jahren 1871–1873", *Artemis,* München und Zürich, 1990 (Nachdruck von Schliemann: *Trojanische Altertümer,* Leipzig 1874)




MAGNETIK 3 / 93 Cs - Hametometer 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
BLfD
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

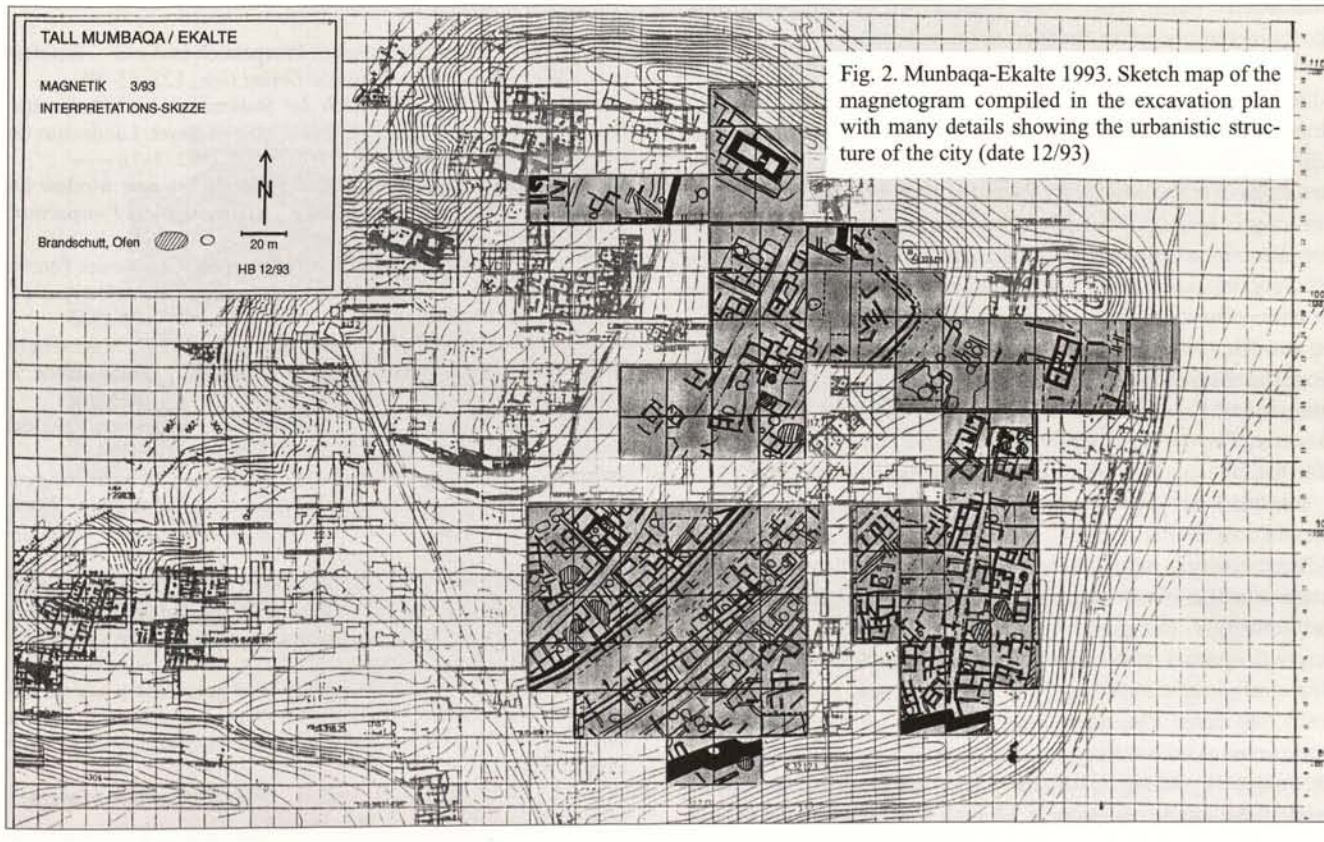


Fig. 2. Munbaqa-Ekalte 1993. Sketch map of the magnetogram compiled in the excavation plan with many details showing the urbanistic structure of the city (date 12/93)

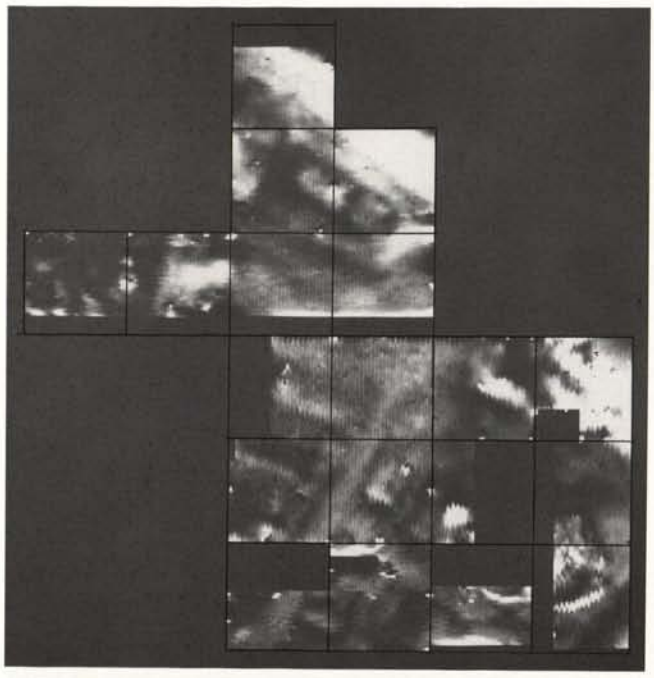


Fig. 3a. Munbaqa-Ekalte 1993. Magnetogram (detail) of the area behind the north gate with the big stone-building and the test site for resistivity surveying. Same technical data for magnetics than Fig. 1 (below)

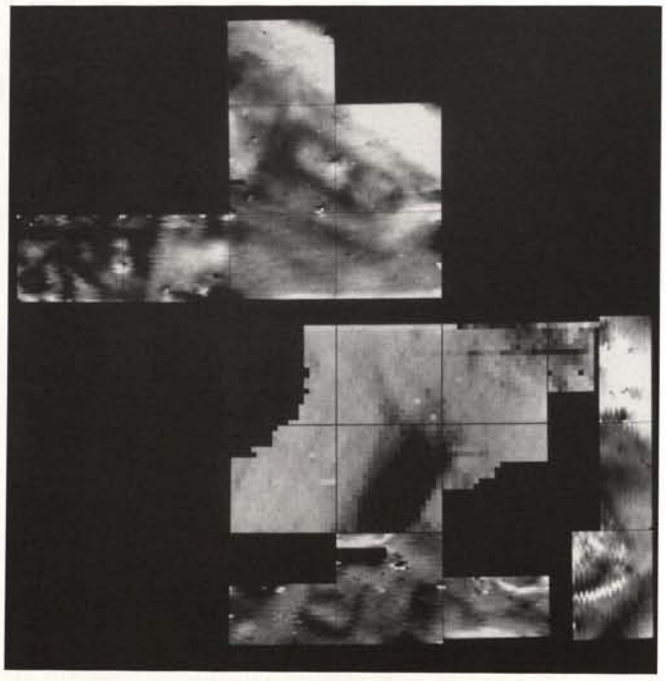


Fig. 3b. Munbaqa-Ekalte 1993. Compilation of magnetics and resistivity in digital image processing

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.

References

Becker, H., 1991. "Zur magnetischen Prospektion in Assur – Testmessung 1989", *Mitteilungen Deutsche Orient Ges.,* 123, 65–80

Becker, H., 1993. "Die Suche nach der Stadtmauer des homerischen Troia", *Denkmalpflege Informationen,* hrsg. v. Bayer. Landesamt für Denkmalpflege, Ausgabe D Nr. 18/22. März 1993, 1–12

Becker, H., 1995. "From Nanotesla to Picotesla – a new window for magnetic prospecting in archaeology", *Archaeological Prospection,* 2, 217–228

Becker, H., 1994. "Vom Nanotesla zum Picotesla – Ein neues Fenster zur magnetischen Prospektion archäologischer Denkmäler", *Arch. Jahr Bayern,* 1993, 185–187

Becker, H., Fassbinder, J. W. E., Jansen, H. G., 1993. "Magnetische Prospektion in der Untersiedlung von Troia 1992", *Studia Troica,* 3, 117–134

Becker, H., Jansen, H. G., 1994. "Magnetische Prospektion 1993 der Unterstadt von Troia und Ilion", *Studia Troica,* 4, 105–114

Chouker, F., 1991. *Archaeological site investigation by means of geoelectrical and geomagnetical measurements in North Syria,* Workshop on Geophysical data inversion in archaeological site investigation

Chouker, F., Al-Jaramani, N., 1993. *Resistivity survey for the depth evaluation of the archaeo-cistern on the site of Kherbet El Umbashi,* unpublished report, France archaeological expedition of the Kherbet Al-Umbashi

Fassbinder, J. W. E., 1994. *Die magnetischen Eigenschaften und die Genese ferrimagnetischer Minerale in Böden im Hinblick auf die magnetische Prospektion archäologischer Bodendenkmäler,* Buch am Erlbach

Fassbinder, J. W. E., Stanjek, H., Vali, H., 1990. "Occurrence of magnetic bacteria in soil", *Nature,* 343, 161–163

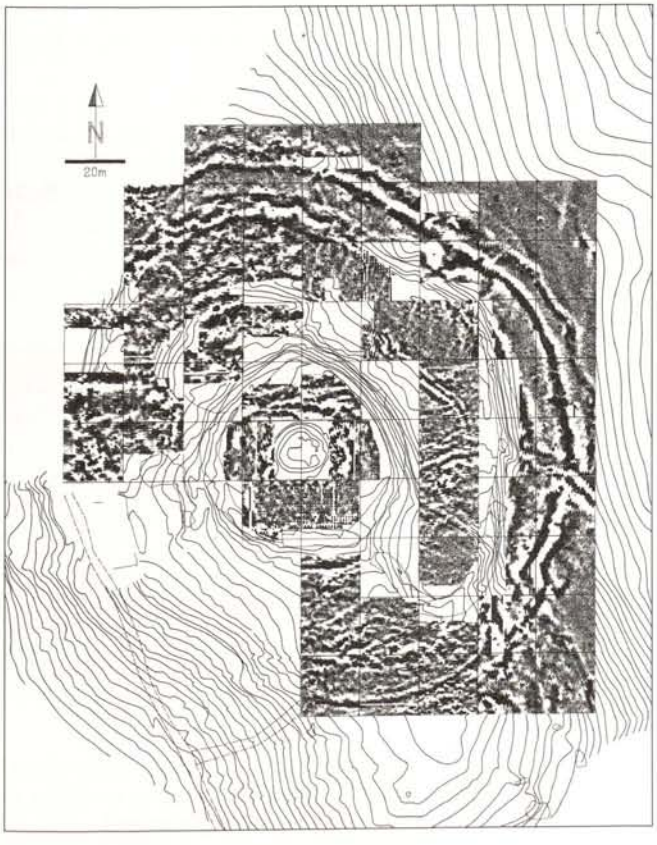
H. Becker

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 Picoteslasystem 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)

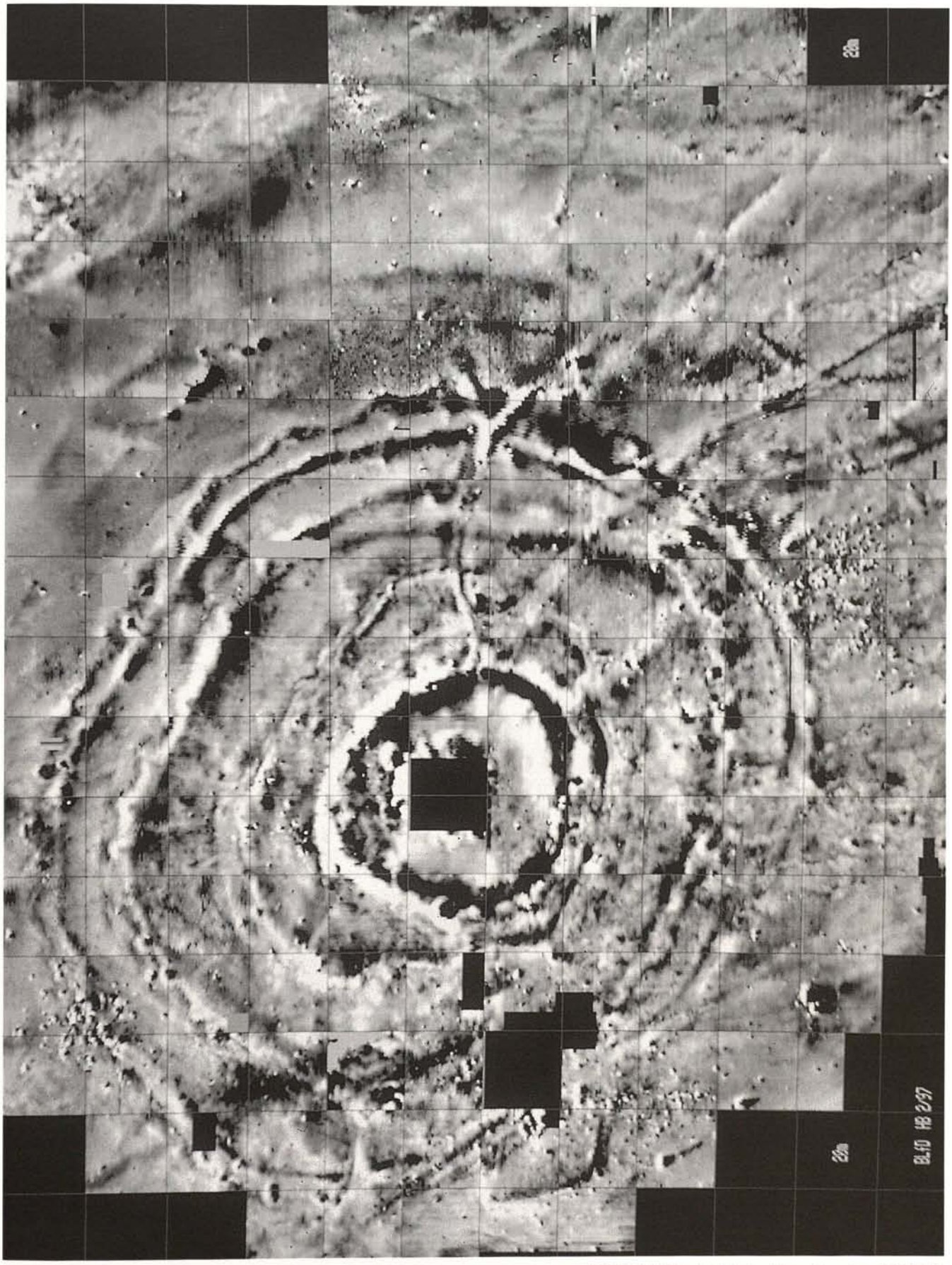


Fig. 5. Monte da Ponte 1994–1997. Magnetogram as digital image. Caesium magnetometer CS2/MEP720 (technical details see above) and SMART-MAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster after resampling 0.5/0.25 m, dynamics -6.4/+6.4 nT to -3.2/+3.2 nT (outer area) in 256 greyscales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

References

Becker, H., 1994. "Testmessung zur elektrischen Prospektion eines Megalithgrabes in Vale de Rodrigo 3, Concelho Evora, Portugal", *Madrider Mitteilungen,* 35, 78–84

Becker, H., 1995. "From Nanotesla to Picotesla – a new window for magnetic prospecting in archaeology", *Archaeological Prospection,* 2, 217–228

Becker, H., 1997. "Geophysikalische Prospektion in Vale de Rodrigo, Concelho Evora, Portugal", *Madrider Mitteilungen,* 38, 21–35

Kalb, P., Höck, M., 1997. "Untersuchungen im Megalithgebiet von Vale de Rodrigo, Concelho Evora, Portugal", *Madrider Mitteilungen,* 38, 1–20

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.

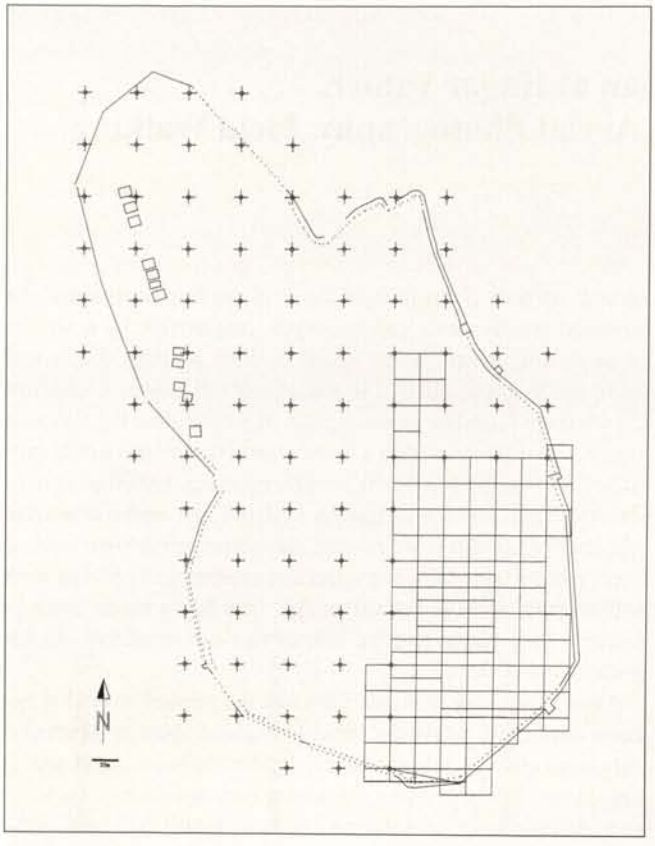


Fig. 2. Hagar Yahirr 1995. Plan of the site with 20 m grid of the magnetic survey. Plan after Breton 1994, Archäologische Berichte Jemen VIII, page 181; north orientation corrected to magnetic North 1/1995

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) ▷





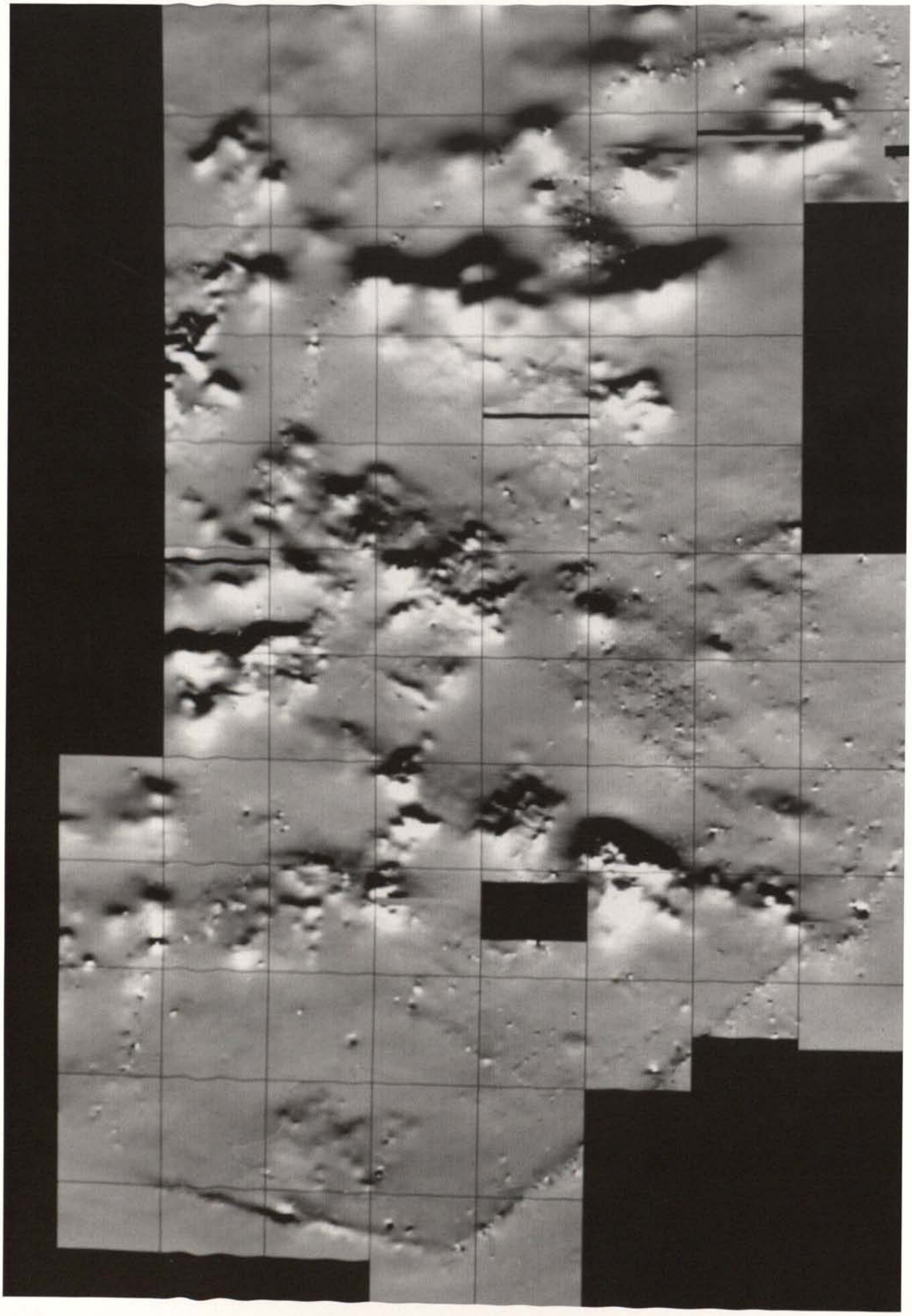
Fig. 6. Aerial photo plan of Hagar Yahirr after digital image processing (contrast enhancement), scaling on the base of Fig. 3, magnification of the aerial photo by MAPSXX 1:30,000 with makro system HR CCD-Camera (1024x1024 pixel in 256 gray levels) ▷

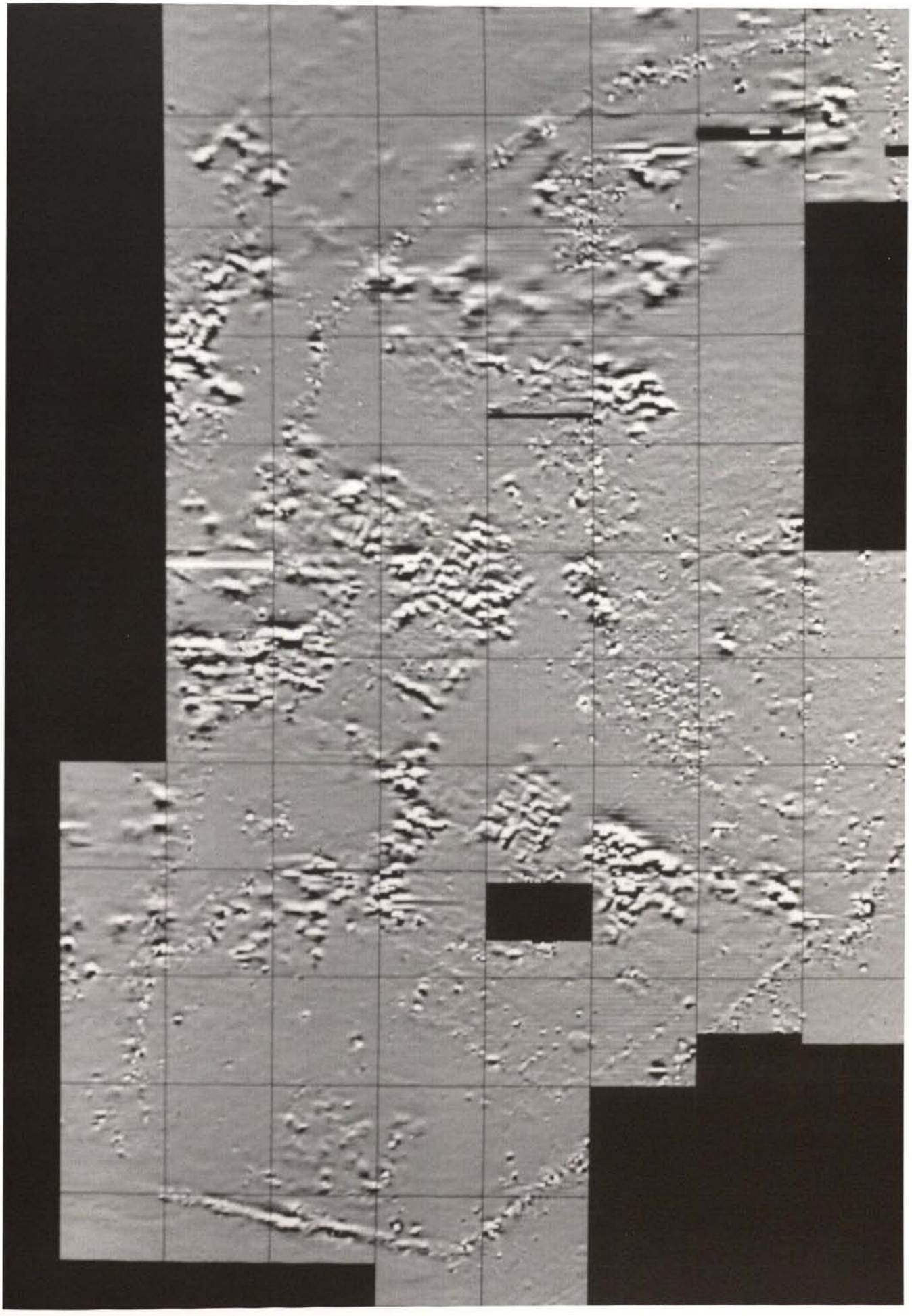


Fig. 4. Digital image (section of Fig. 6) of the Southeastern area of Hagar Yahirr, which may have been the Temenos or Akropolis of Awsan

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.

References

Becker, H., 1990. "Combination of aerial photography with groundmagnetics in digital image processing technique", *Aerial photography and geophysical prospection in archaeology,* Proc. 2. Int. Symposium Brussels 1986, 25–35

Becker, H., 1991. "Zur magnetischen Prospektion in Assur. Testmessung 1989", *Mitteilungen Deutsche Orient-Gesellschaft,* 123, 123–131

Becker, H., 1991. "Digitale Bildverarbeitung und graphische Datenverarbeitung in der archäologischen Prospektion", *Arch. Jahr Bayern,* 1990, 193–196

Becker, H., Fassbinder, J. W. E., Jansen, H. G., 1993. "Eine Testmessung zur magnetischen Prospektion in Troia", *Arch. Jahr Bayern,* 1992, 180–182

Becker, H., Fassbinder, J. W. E., Chouker, F., 1994. "Magnetische und elektrische Prospektion in Munbaqa-Ekalte", *Mitt. Deutsche Orient Ges.,* 126, 65–80

Becker, H., 1995. "From Nano- to Picotesla – A new window for magnetic prospecting in archaeology", *Archaeological prospection,* 217–228

Breton, J.-F., 1994. "Les fortifications d'Arabie méridionalle du septième au premier sciècle avant notre ère", *Archäologische Berichte Jemen,* VIII, 1–203

Brunner, U., Haefner, S., 1990. "Altsüdarabische Bewässerungsoasen", *Die Erde,* 121, 135–153

Clark, A., 1990. *Seeing beneath the soil – prospecting methods in archaeology,* London

Pirenne, J., 1980. "Prospection Historique dans la Région du Royaume de Awsan", *Raydan,* III, 213–255

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



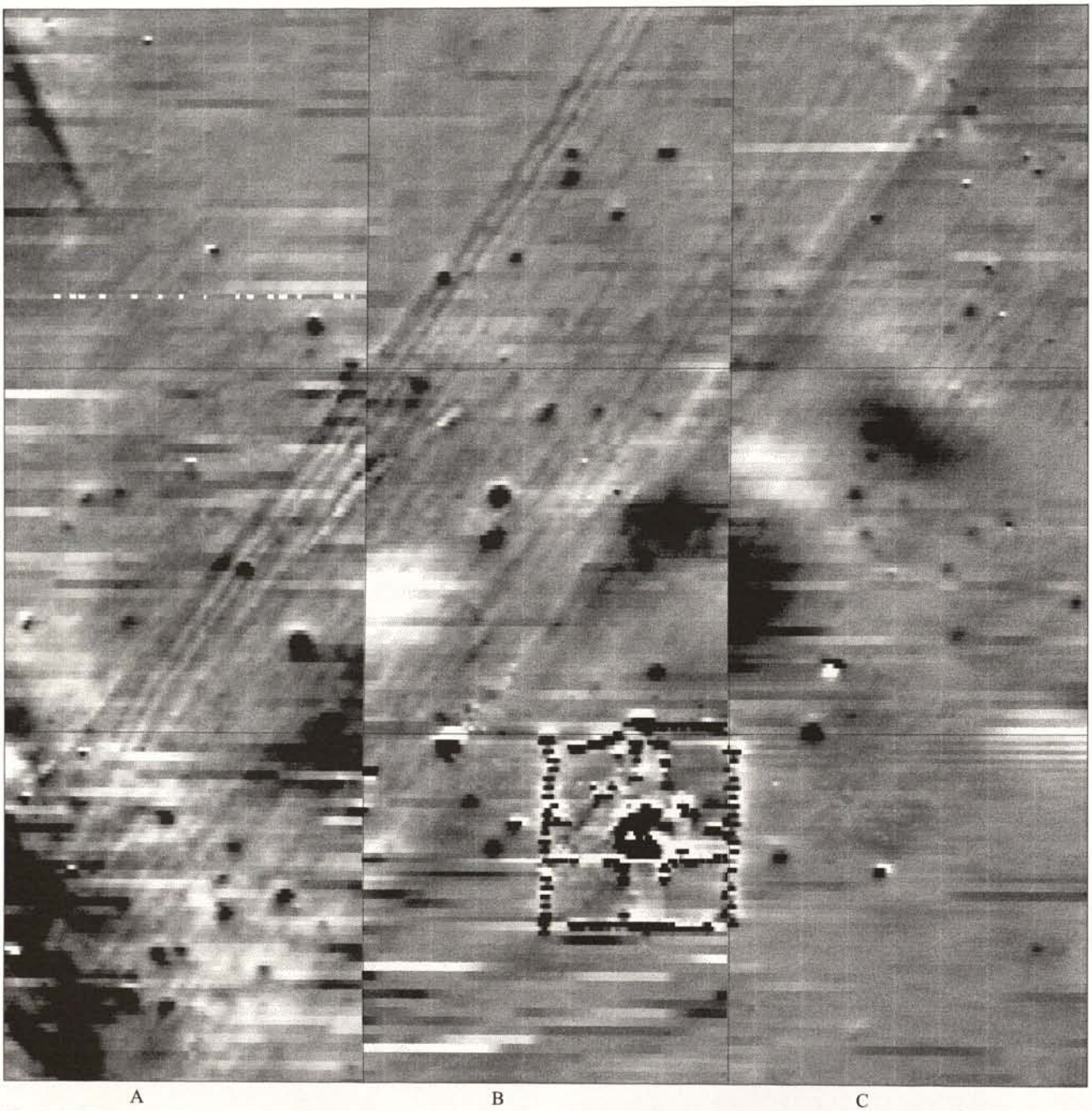


Fig. 2. Ambrona-La Lampara 1996. Magnetogram after digital image processing. The distinct anomaly in B2 marks the pit with an Early Neolithic burial. Caesium magnetometry Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster 0.5/0.25 m, dynamics -3.2/+3.2 nT in 256 grayscales,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

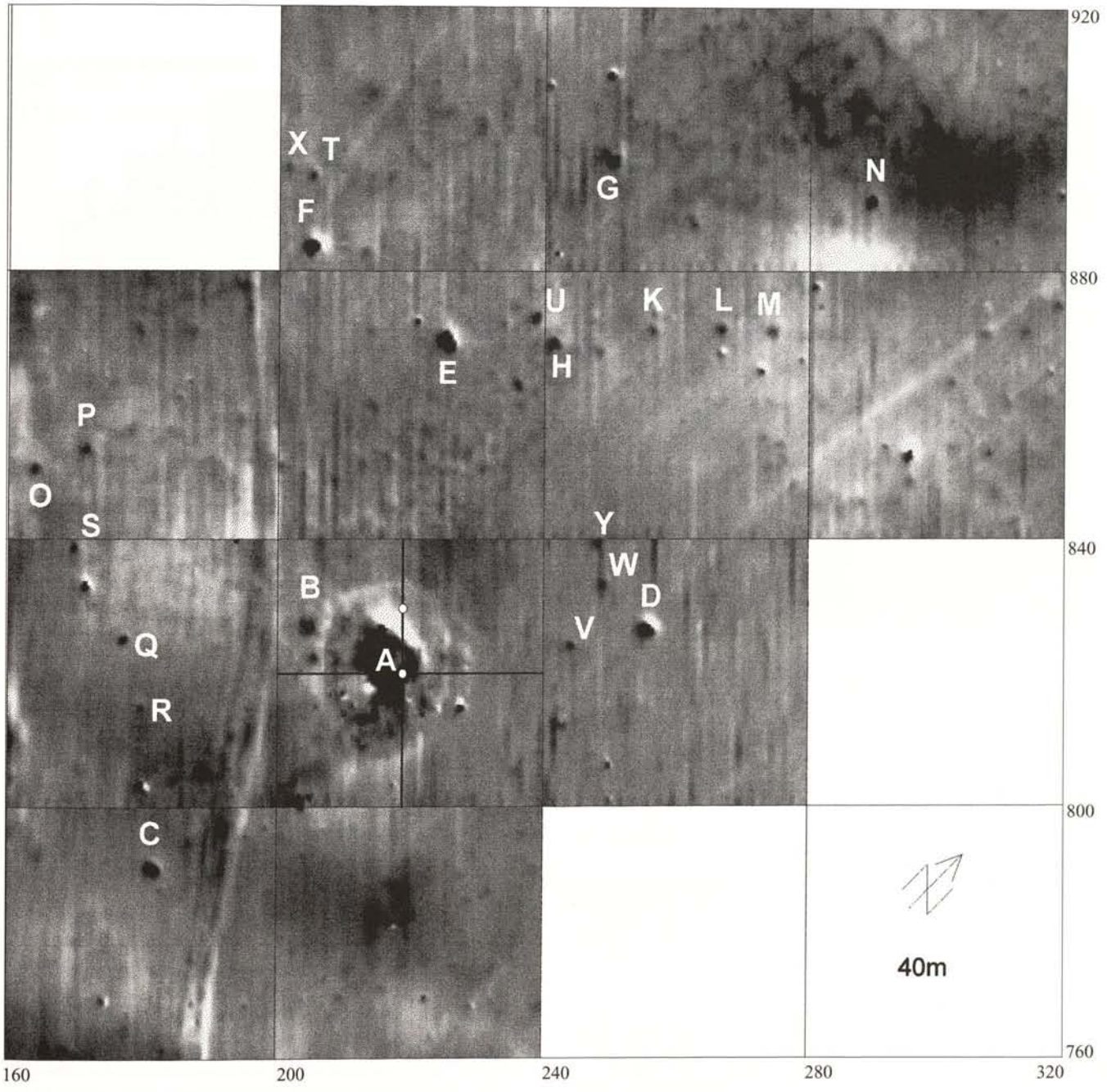


Fig. 3. Ambrona-Dolmen de la Sima 1998. Magnetogram of the round barrow (A) and its surroundings. Caesium magnetometry Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster 0.5/0.25 m, dynamics -4.0/+4.0 nT in 256 grayscales, 40 m grid

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-

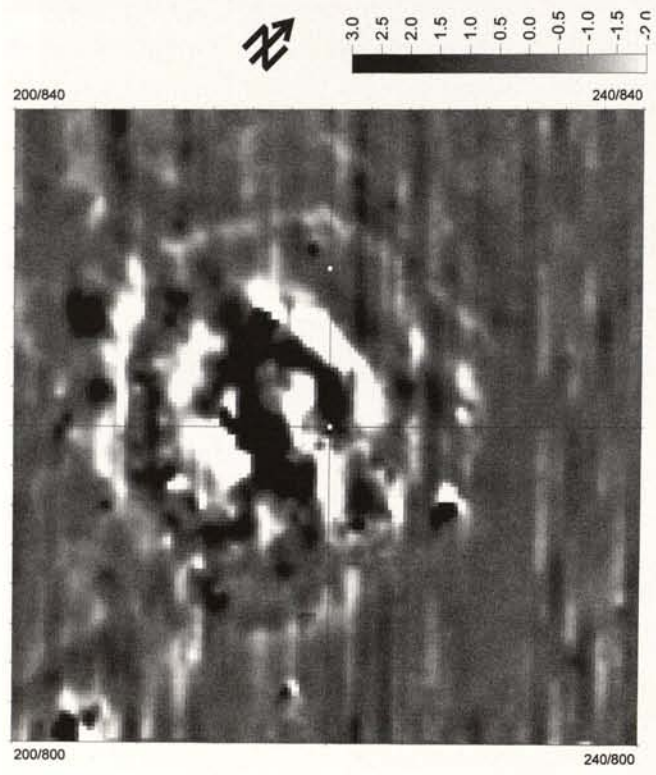


Fig. 4a. Ambrona-Dolmen de la Sima 1998. Magnetogram (detail) of the round barrow with a rectangular chamber. Caesium magnetometry Scintrex SMARTMAG SM4G-Special with duo-sensor configuration, sensitivity 10 pT, raster 0.5/0.25 m, highpass filtering 10 x 10 pixel, dynamics -2.0/+2.0 nT in 256 grayscales,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

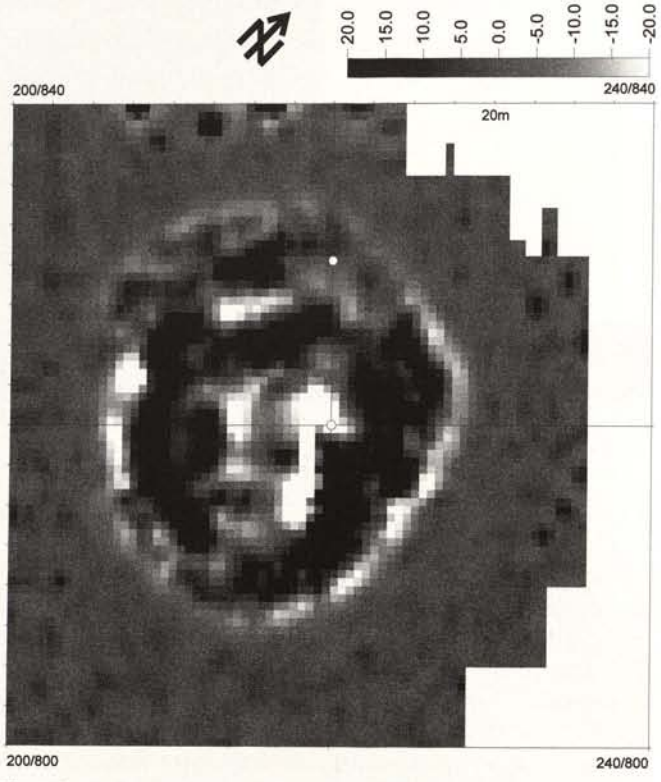


Fig. 4b. Ambrona-Dolmen de la Sima 1998. Resistivity diagram of the round barrow. Geoscan RM15-Advanced resistance meter with twin electrode, raster 0.5/0.5 m, dynamics -20.0/+20.0 units (original data 40.0/240.0 Ohm m), 20 m grid

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 steap 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.

References

Becker, H., 1999. "Zur magnetischen Prospektion 1996 und 1997 an prähistorischen Fundplätzen in der Umgebung von Ambrona (Prov. Soria)", *Madrider Mitteilungen,* 40, 53–60

Becker, H., 2000. "Geophysikalisch-archäologische Prospektion in der Umgebung von Ambrona, Prov. Soria, Spanien 1998", *Madrider Mitteilungen,* 41, in press

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



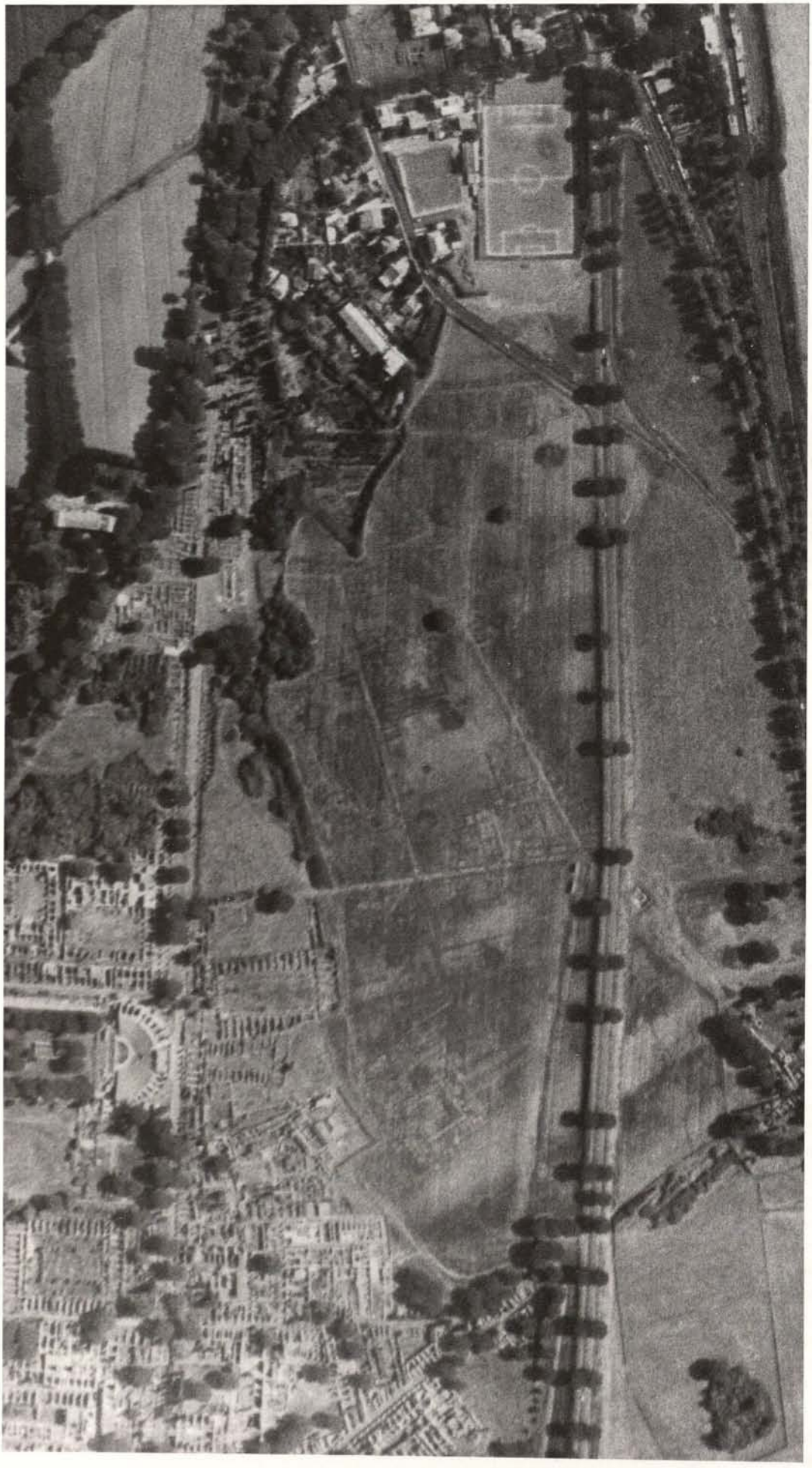


Fig. 2. Ostia-Antica. Aerial photo of unknown source (after world war II.) of the regio V with the so-called Via del Sabazeo, the Porta Secondaria in the South and parts of the Republican city wall as crop marks. This field showing the crop marks is covered almost completely by the first test for magnetic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

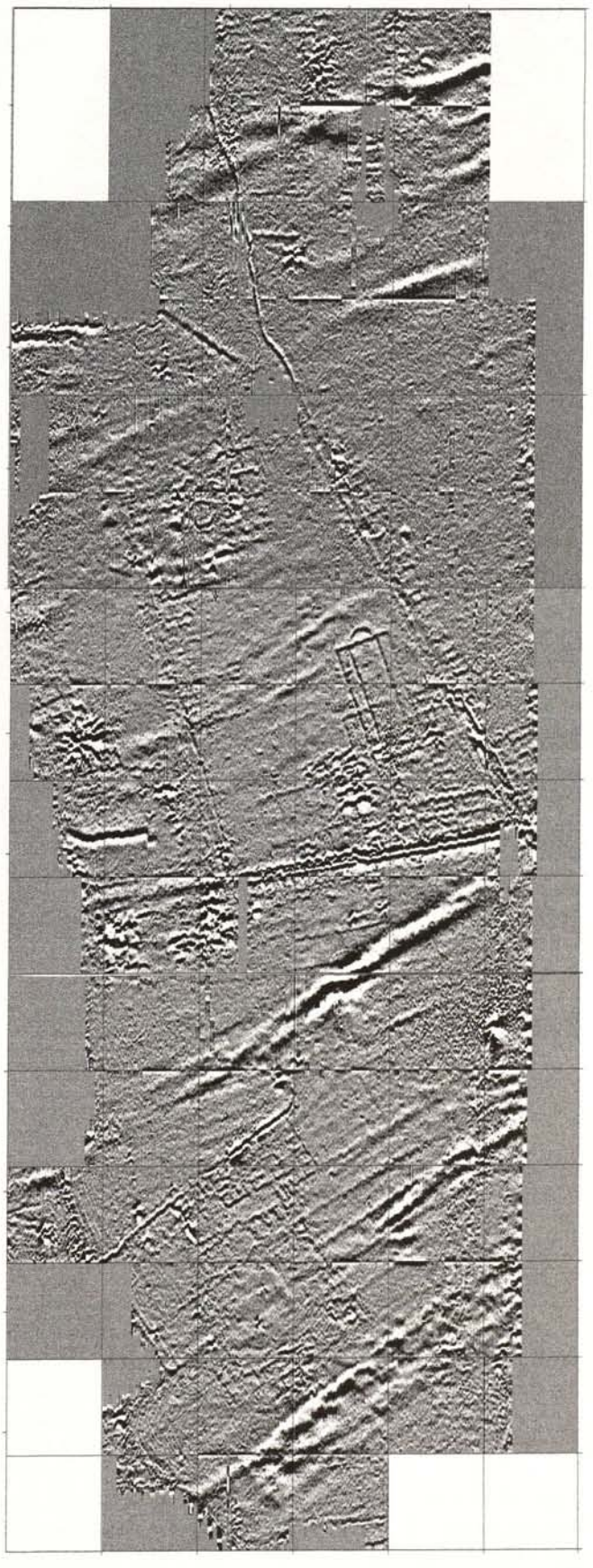


Fig. 3b. Ostia-Antica 1996. Part of the magnetogram of regio V after highpass filtering 10 x 5 pixel, same technical data as Fig. 3a, but dynamics -10.0/+ 10.0 nT

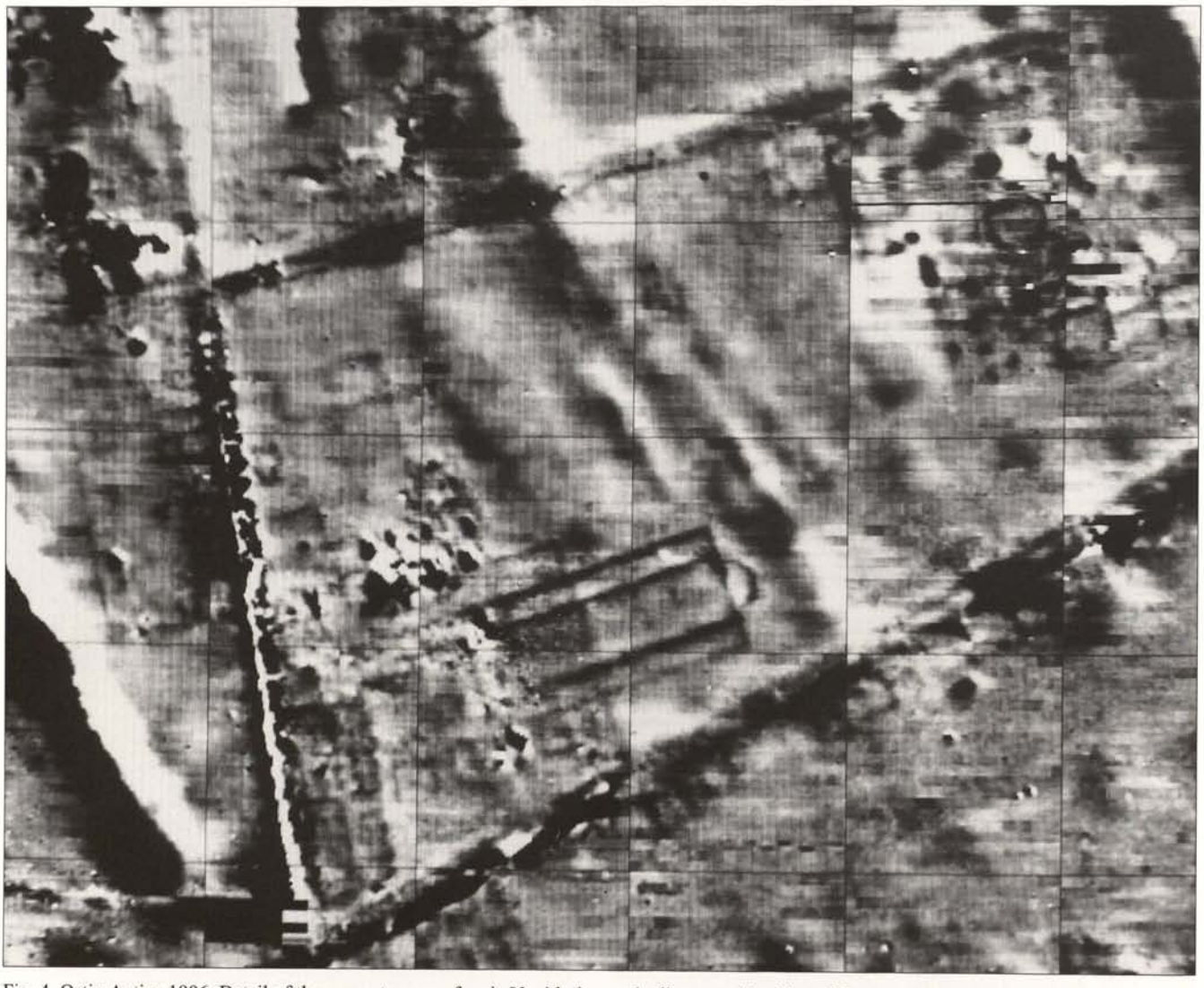


Fig. 4. Ostia-Antica 1996. Detail of the magnetogram of regio V with the newly discovered basilica of Constantinus I., the Great, clearly visible in the corner near the gate of the Via del Sabazeo and the city wall to the south. Caesium magnetometry SM4G-Special in quadro-sensor configuration, sensitivity 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.

References

Becker, H., 1997. "Geophysikalische Prospektion in Vale de Rodrigo, Concelho Evora, Portugal", *Madrider Mitteilungen,* 38, 21–35

Becker, H., 1997. "Hochauflösende Magnetik am Beispiel der archäologischen Prospektion", in: M. Beblo (ed.) *Umweltgeophysik,* Berlin, 59–70

Becker, H., 1997. "Basilika Kaiser Konstantins in Ostia Antica mit modernstem Magnetometer entdeckt?" *Denkmalpflege Informationen,* hrsg. v. Bayer. Landesamt für Denkmalpflege, Ausgabe B Nr. 106/22. August 1997, 1–2

Heinzelmann, M., Becker, H., Eder, K., Stephani, M., 1997. "Vorbericht zu einer geophysikalischen Prospektionskampagne in Ostia Antica", *Mitt. Deutsches Archäologisches Institut Rom,* 104, 537–548

Becker, H., 1998. "Magnetische Prospektion archäologischer Stätten am Beispiel Troia (Türkei), Piramesse Ägypten) und Ostia Antica (Italien)", *Nürnberger Blätter zur Archäologie,* 13, 85–106

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

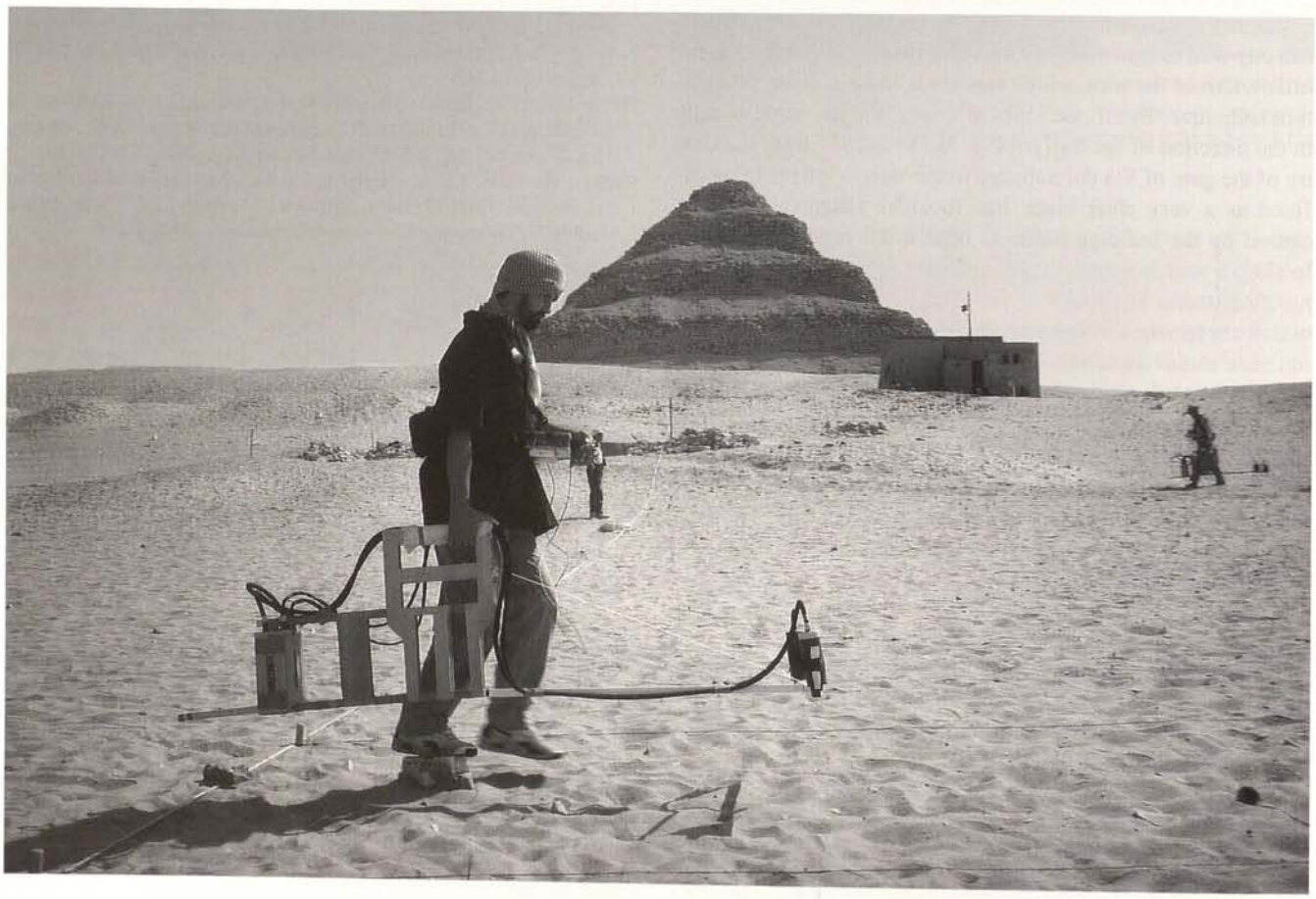
The Zoser pyramid belongs to the 3rd dynasty (2705–2630 B. C.) and is therefore the oldest monumental grave building in the world. The pyramid is situated inside of an enclosure of 550 length and 300 meters broad. In the south there is the Unas pyramid and the tomb of Haremhab, to the east the pyramid 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.



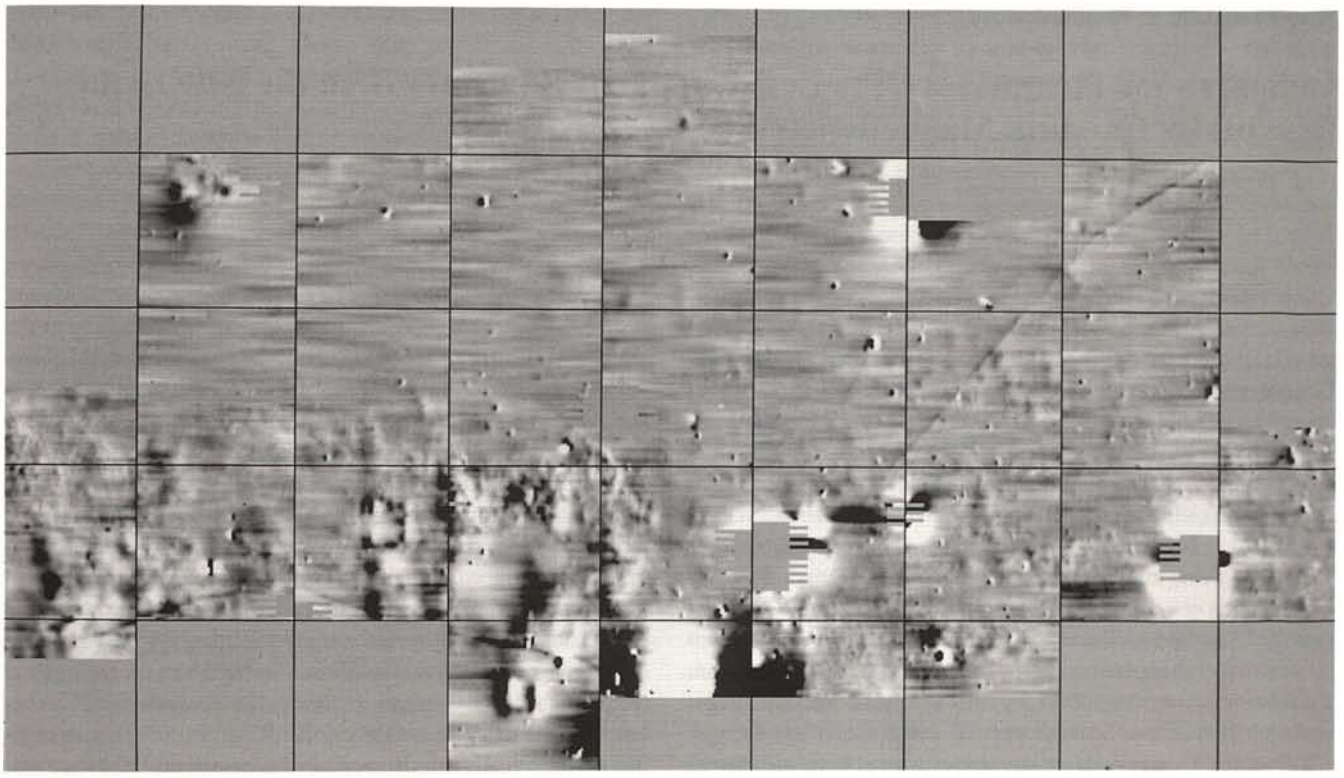


Fig. 2. Saqqara. Magnetic plan of the survey area west of the Saqqara pyramid. Gray shade plot showing clearly the contours of three buildings. Scintrex SM4G-Special smartmag magnetometer, hendheld dou-sensor configuration, dynamics ± 7.5 Nanotesla in 256 grayscales, sampling rate 0.5 x 0.25 meter, 40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

References

Mysliwiec, K., Herbich, T., Niwinski, A. 1995. "Polish resaerch at Saqqara in 1987", *Centre d'archéologie Méditerranéenne de l'académie polonaise des Sciences, Études et Travaux,* 17, 178–203

Stadelmann, R. 1991. *Die ägyptischen Pyramiden. Vom Ziegelbau zum Weltwunder,* Mainz

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

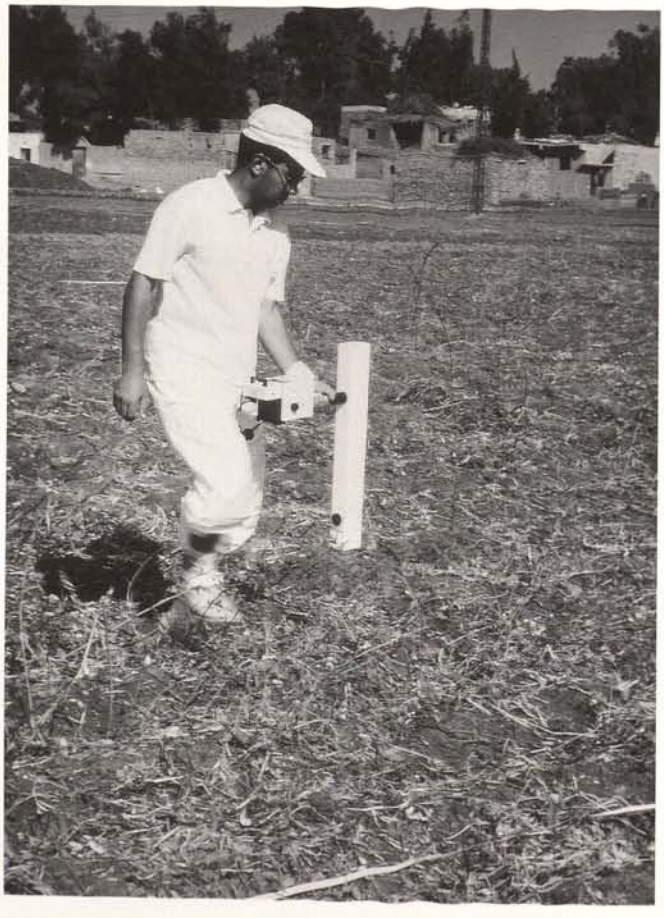
Cooperation of Bavarian State Conservation Office Munich, Department Archaeological Prospection and Aerial Archaeology (H. Becker, J. Fassbinder), Institute for General and Applied Geophysics of Munich University (H.C. Soffel), Pelizaeus Museum Hildesheim (E. Pusch) and NRIAG National Research Institute 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

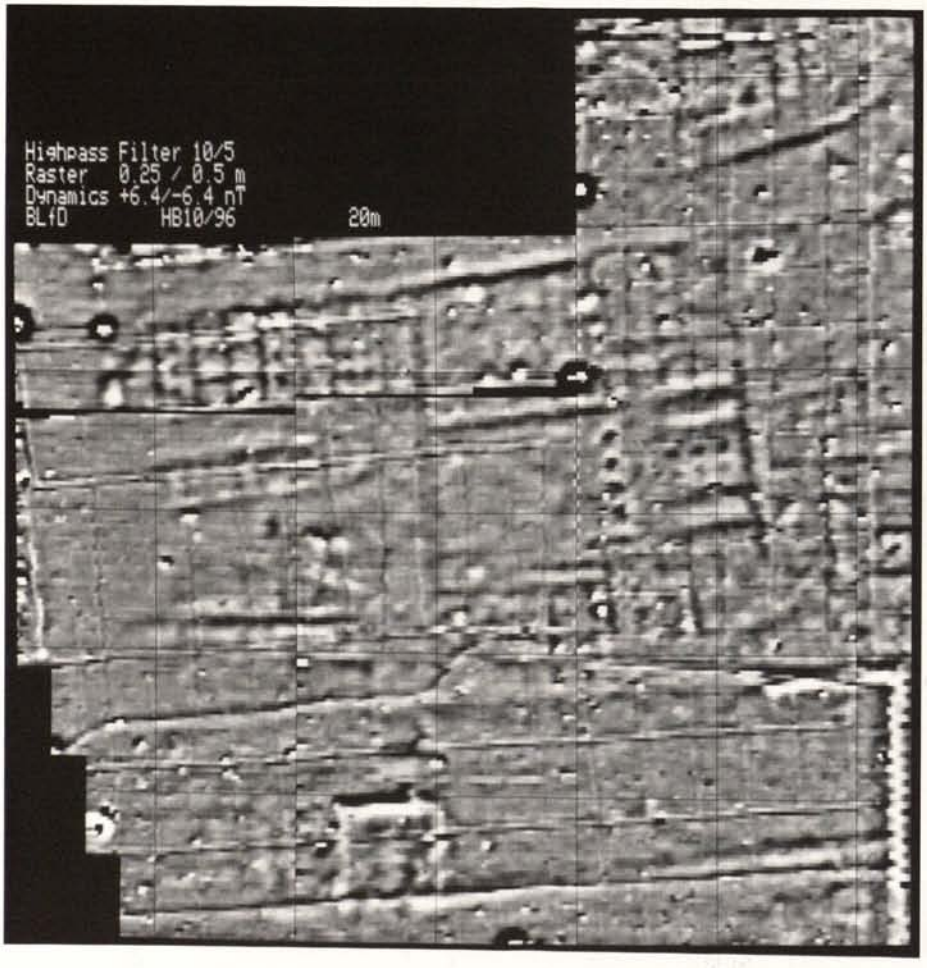


Fig. 3b. Qantir-Piramesses 1996. Magnetogram of the same data after highpass filtering 10 x 5 pixel, technical data see above, but dynamics -6.4/+6.4 nT

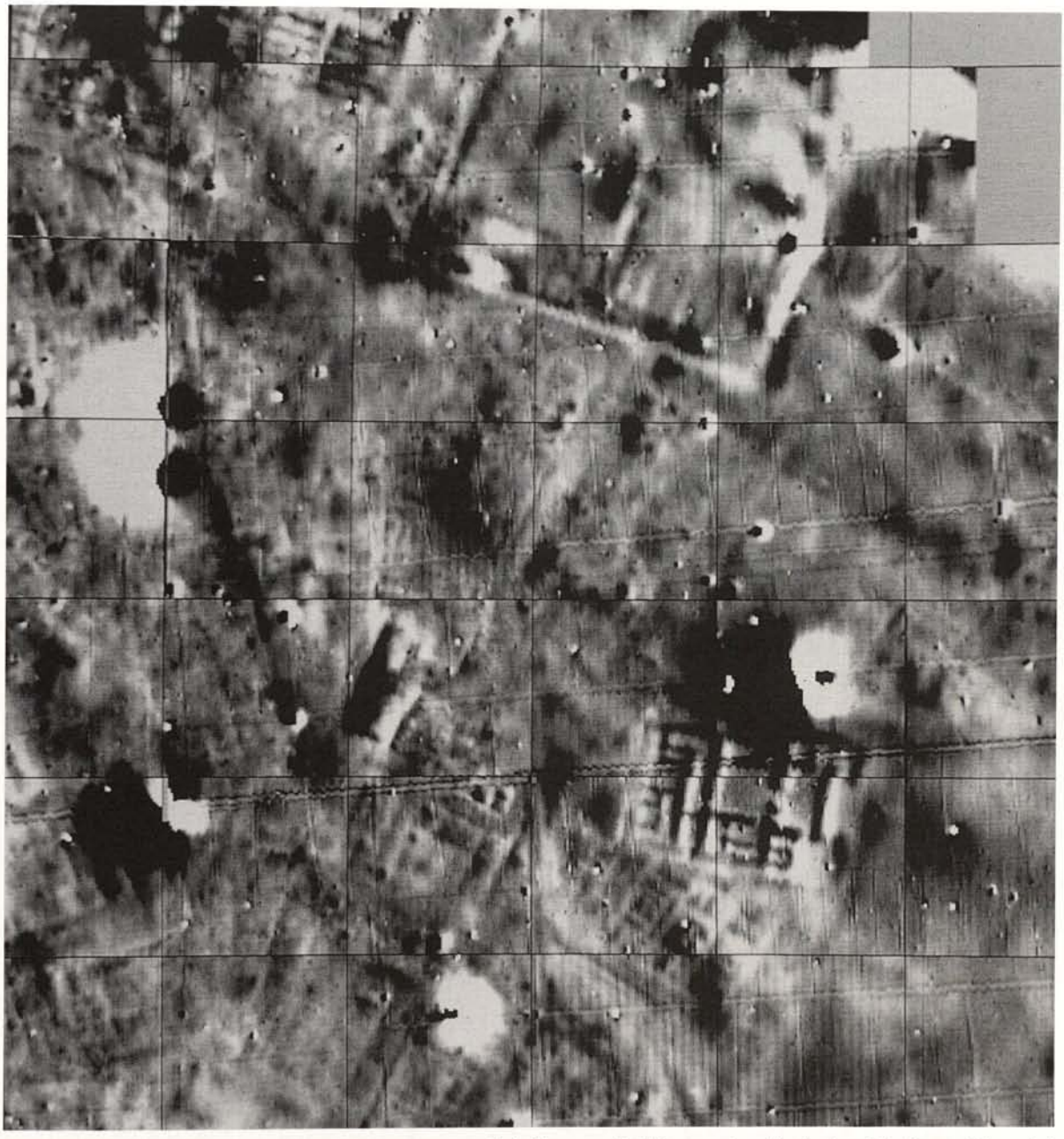


Fig. 4. Qantir-Piramesses East 1997/1998. Magnetogram as digital image with 256 grayscales of a district of the Ramesside capital with Amarna type villas, streets, channels, houses, workshops and a temple building (?) in the centre: original data corrected (40 m grid)

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.

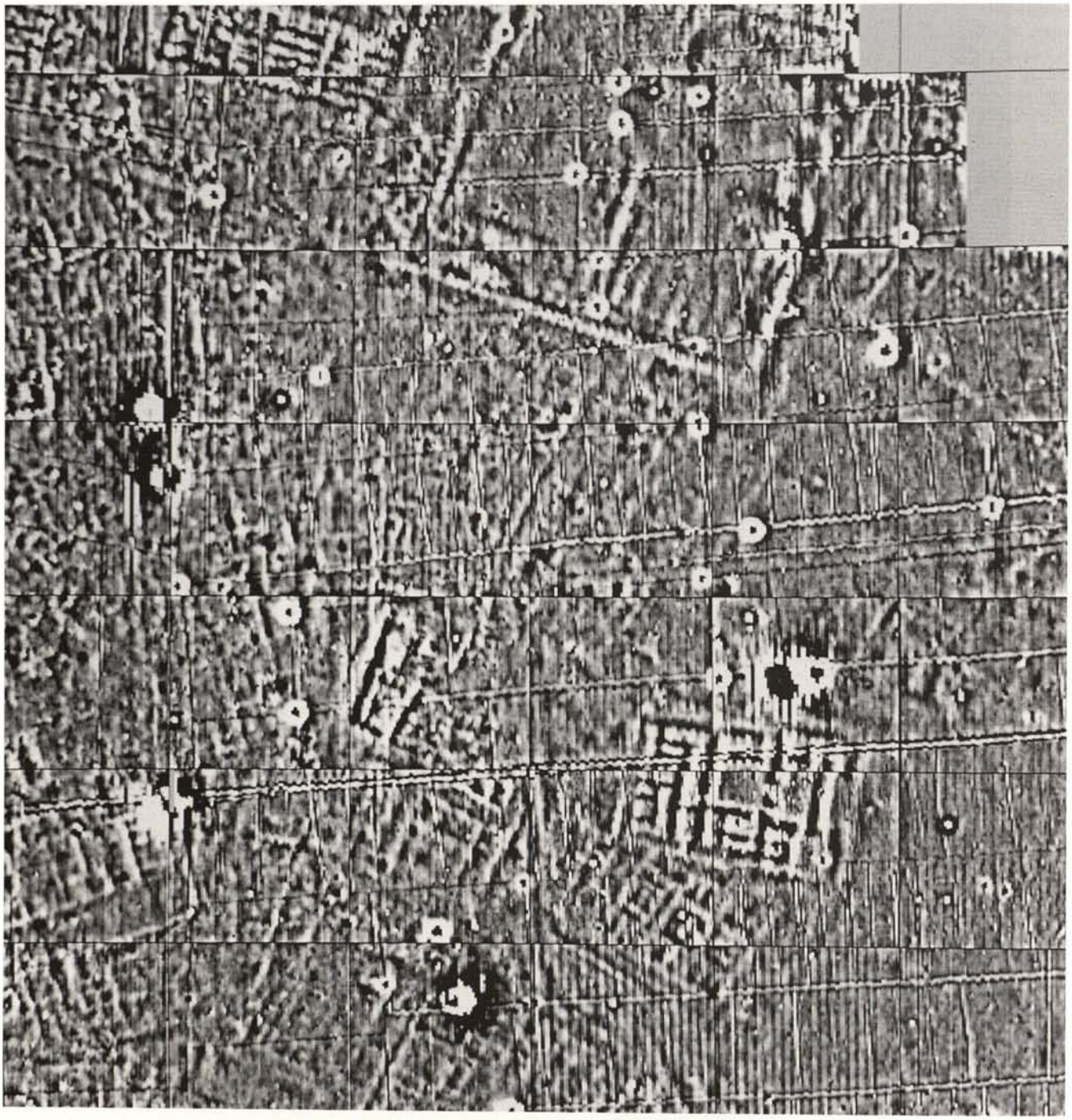


Fig. 5. Qantir–Piramesses East 1997/1998. Magnetogram of the same data as fig. 4, but highpass filtered data 10 x 5 pixel, technical data see Fig. 3a, 3b

References

Becker, H., 1997. "Entwicklung und Einsatz von Multi-Sensor Konfigurationen zur magnetischen Prospektion archäologischer Denkmäler", *Arch. Jahr Bayern,* 1996, 195–197

Becker, H., 1998. "Magnetische Prospektion archäologischer Stätten am Beispiel Troia (Türkei), Piramesse (Ägypten) und Ostia Antica (Italien)", *Nürnberger Blätter zur Archäologie,* 13, 100–102

Becker, H., Fassbinder, J. W. E., 1998. "Caesium mangnetometry for large area prospection at Quantir-Piramesse (Egypt)", *Ann. Geophys.,*16, 223

Pusch, E., Becker, H., Fassbinder, J., 1999. "Towards a Map of Piramesses", *Egyptian Archaeology,* in press

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 Photogrametry 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 was 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 gray-scale (white/black), 40 m grid

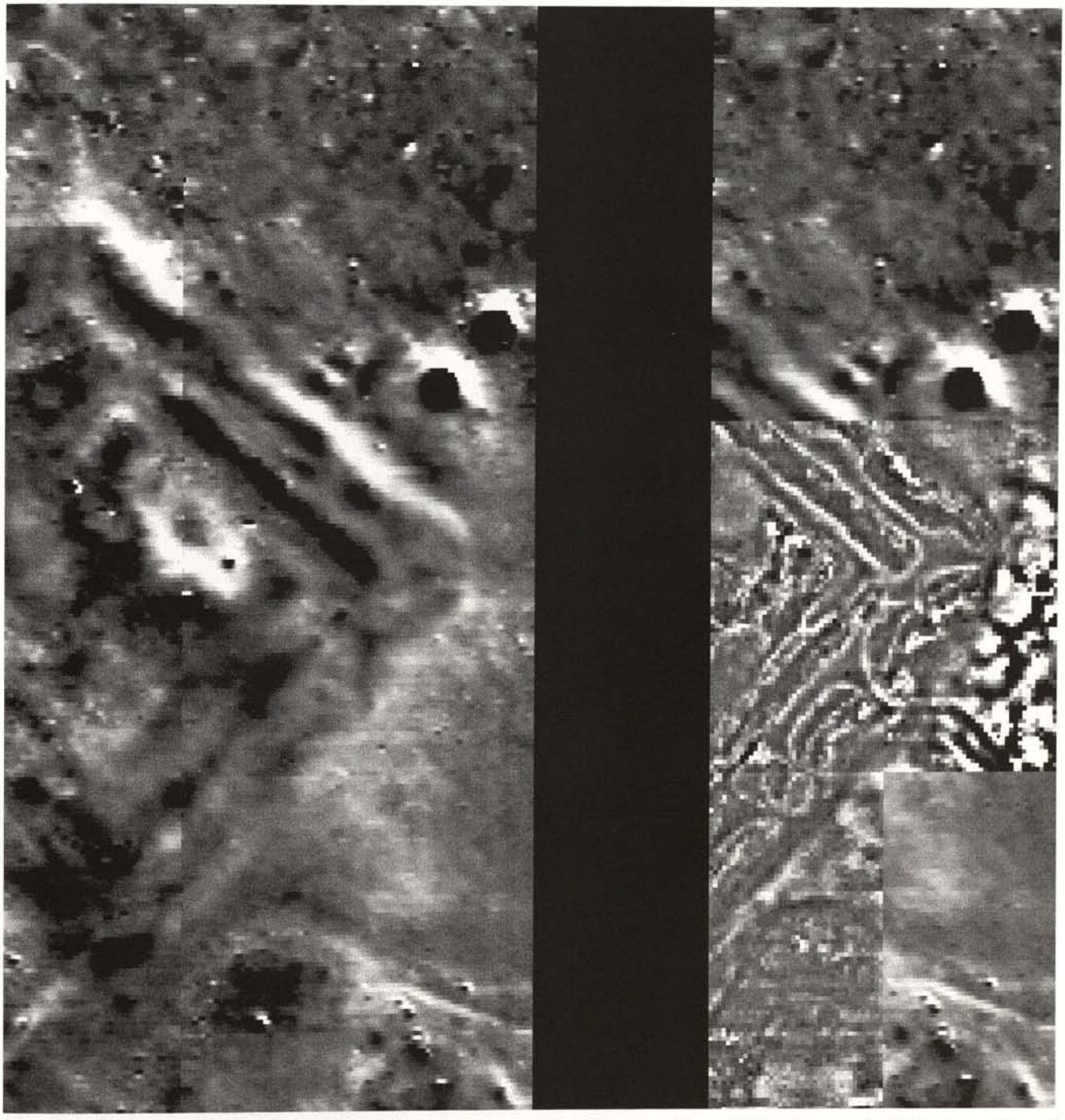


Fig. 2a. Rusafat-Hisam 1997, palace complex III/IV. Magnetogram (detail) as digital image. Same technical data as Fig. 1, but 20 m grid

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 resistivity-meter and multiplexer MPX15 was applied with parallel double twin electrodes (3 probes) at 0.5 m separation. Automatic

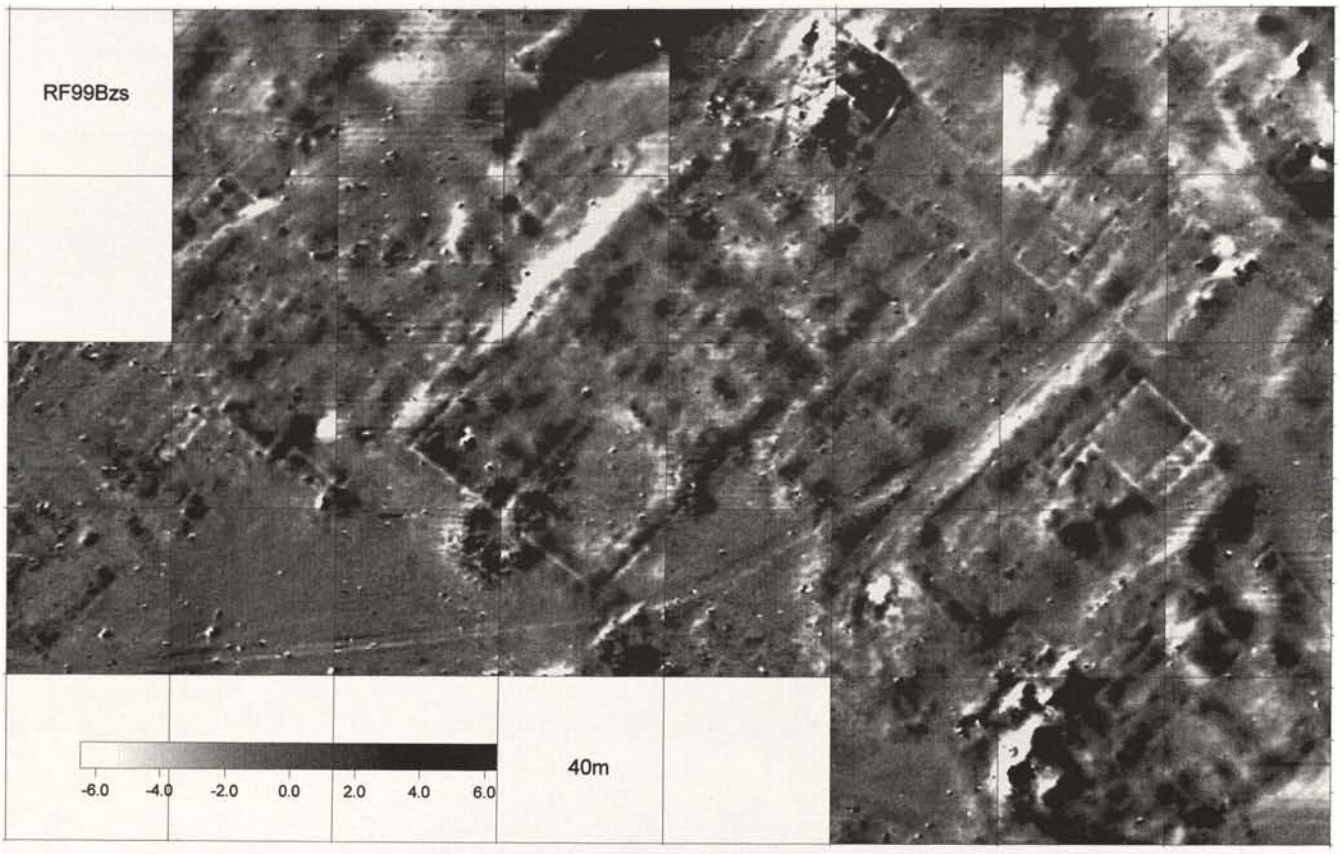
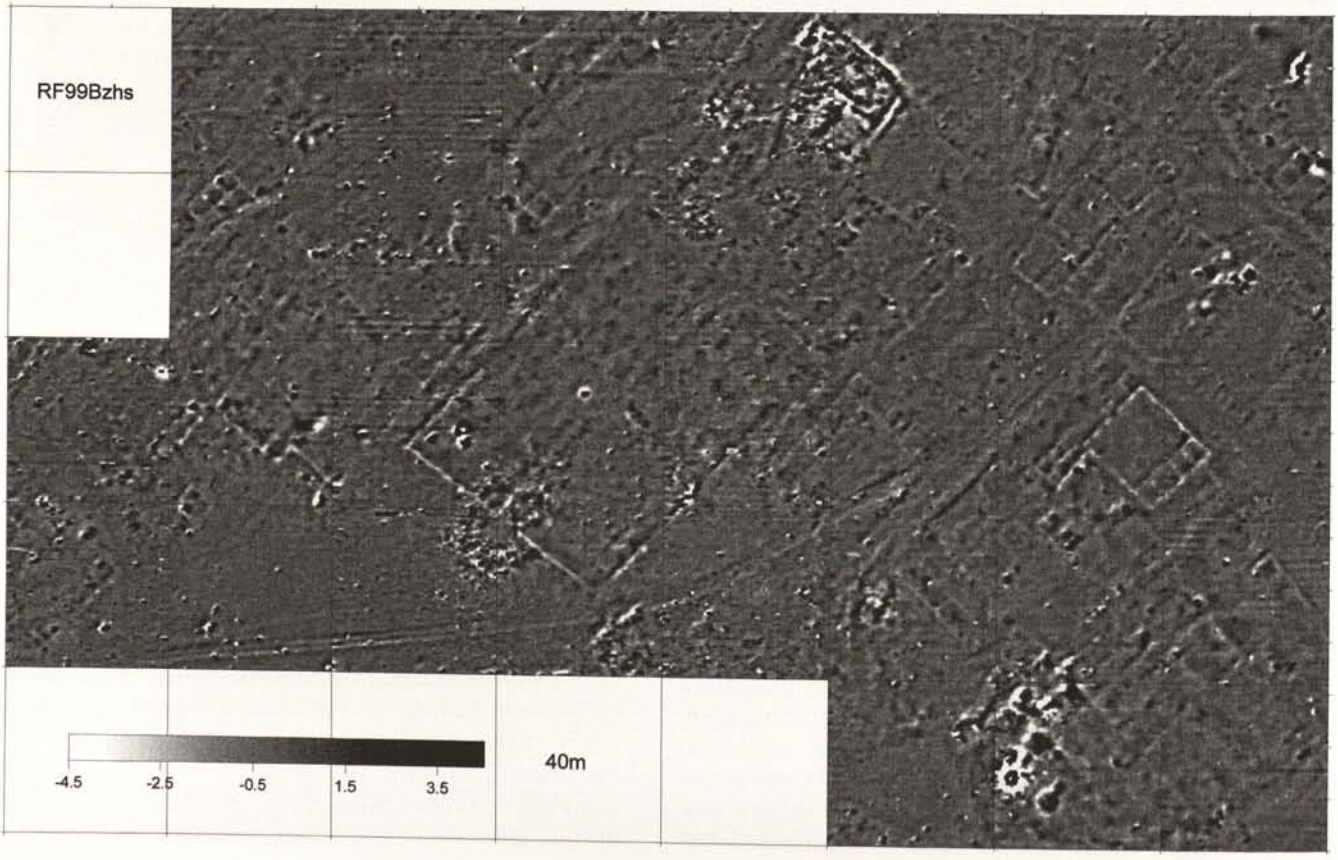


Fig. 3a. Rusafat-Hisam 1999. Magnetogram of the middle area of the residence site with several buildings of different type. Technical details as Fig. 1, but dynamics ± 6,5

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.

References

Becker, H., *A Testmeasurement for Geophysical Prospection at Resafa 1997.* Unpublished report for the General Directorate of Antiquities and Museums of Syria

Sack, D., Becker, H., 1998. "Zur städtebaulichen und baulichen Konzeption frühislamischer Residenzen in Nordmesopotamien mit ersten Ergebnissen einer Testmessung zur geophysikalischen Prospektion in Resafa-Rusafat Hisam", *Diskussionen z. Arch. Bauforschung,* 7, 270–286



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.

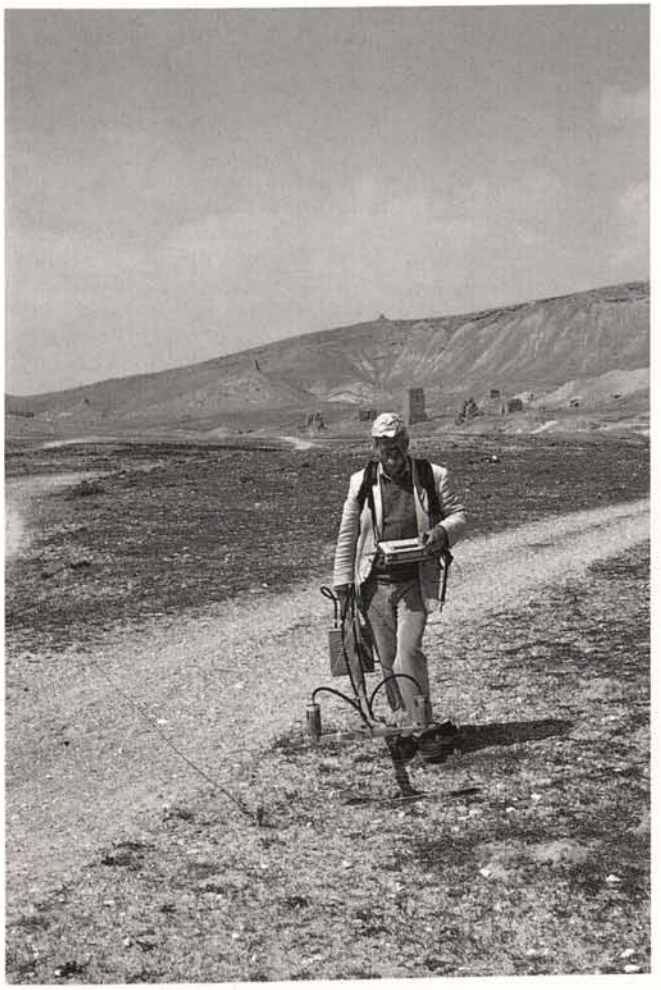
In March 1997 and 1998 nondestructive geophysical methods were tested in the "Hellenistic city" of Palmyra for archaeological prospecting. A 700 m long main line (azimuth = 100/280°) was fixed by stable architectural elements in the field and a 40 m grid was marked by wooden stacks. Two geophysical techniques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

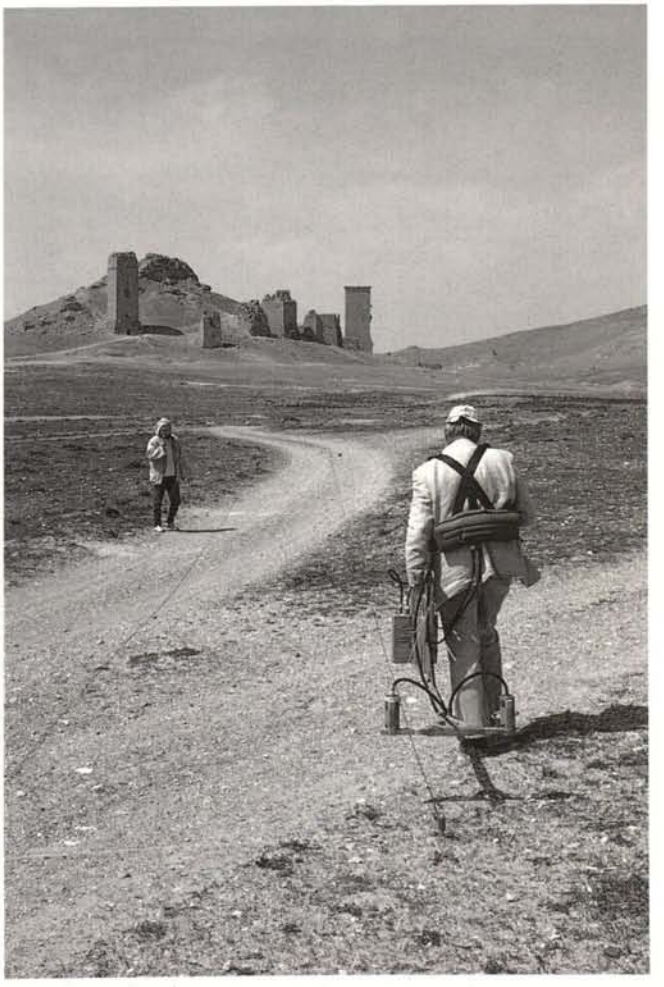


Fig. 1. Palmyra 1997. Western corner of the Hellenistic city situated between the wadi, Roman city wall and the oasis to the south, the huge building complex in the upper part in the middle is the temple of Bel. Extrem oblique view from a hydraulic crane from 8 m hight; marked control points on the ground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





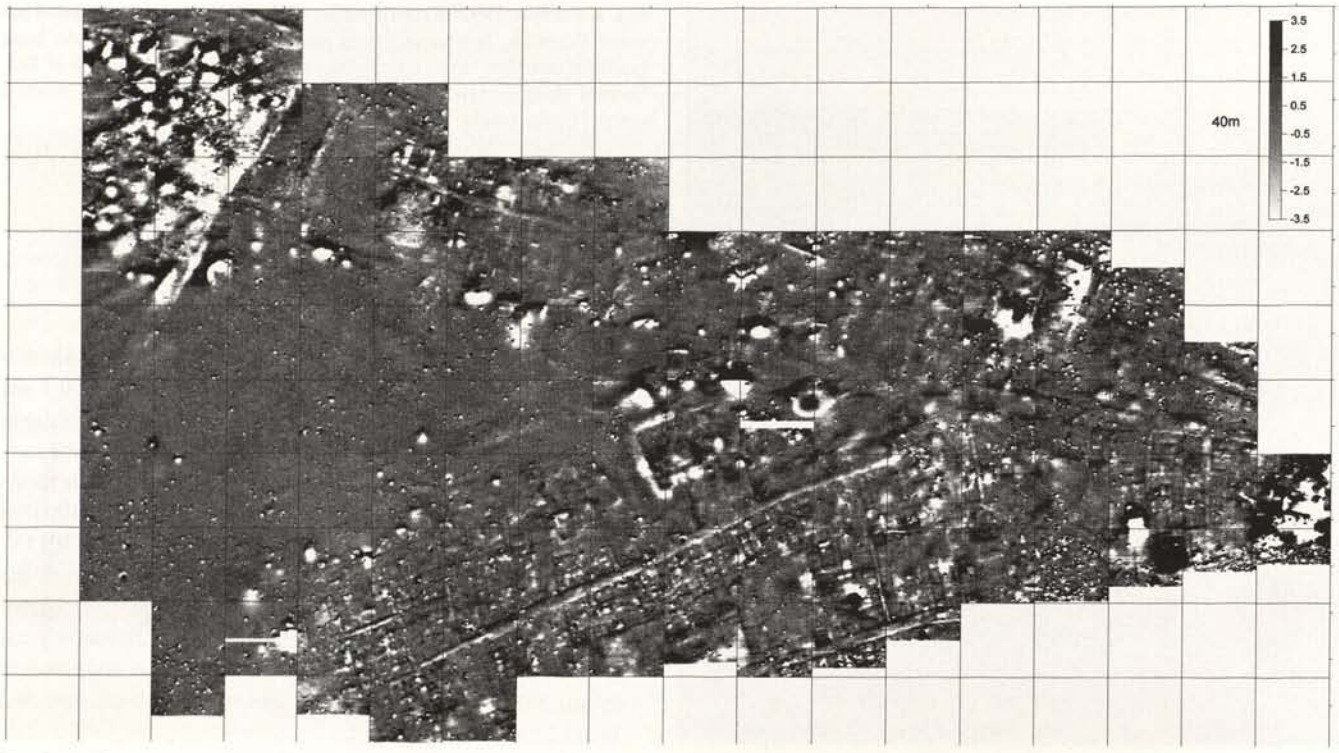
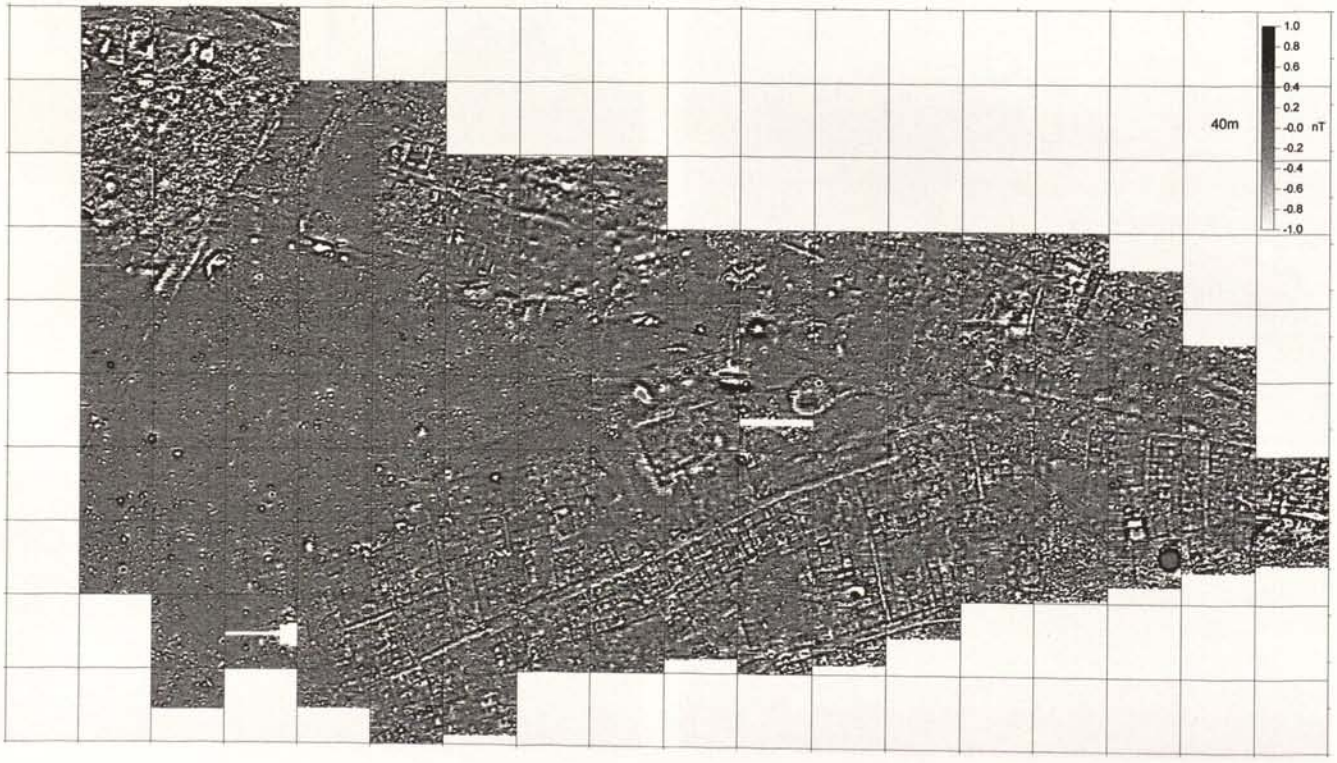


Fig. 3a. Palmyra 1997–1998. Magnetogram of the whole area of the Hellenistic city. Caesium magnetometry SM4G-Special in quadro-sensor configuration, sensitivity 10 pT (=0.01 nT Nanotesla), Dynamics -3.5/+3.5 nT in 256 grayscales (black/white), raster after resampling 0.25/0.5 m, 1 Hz bandpass filter,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



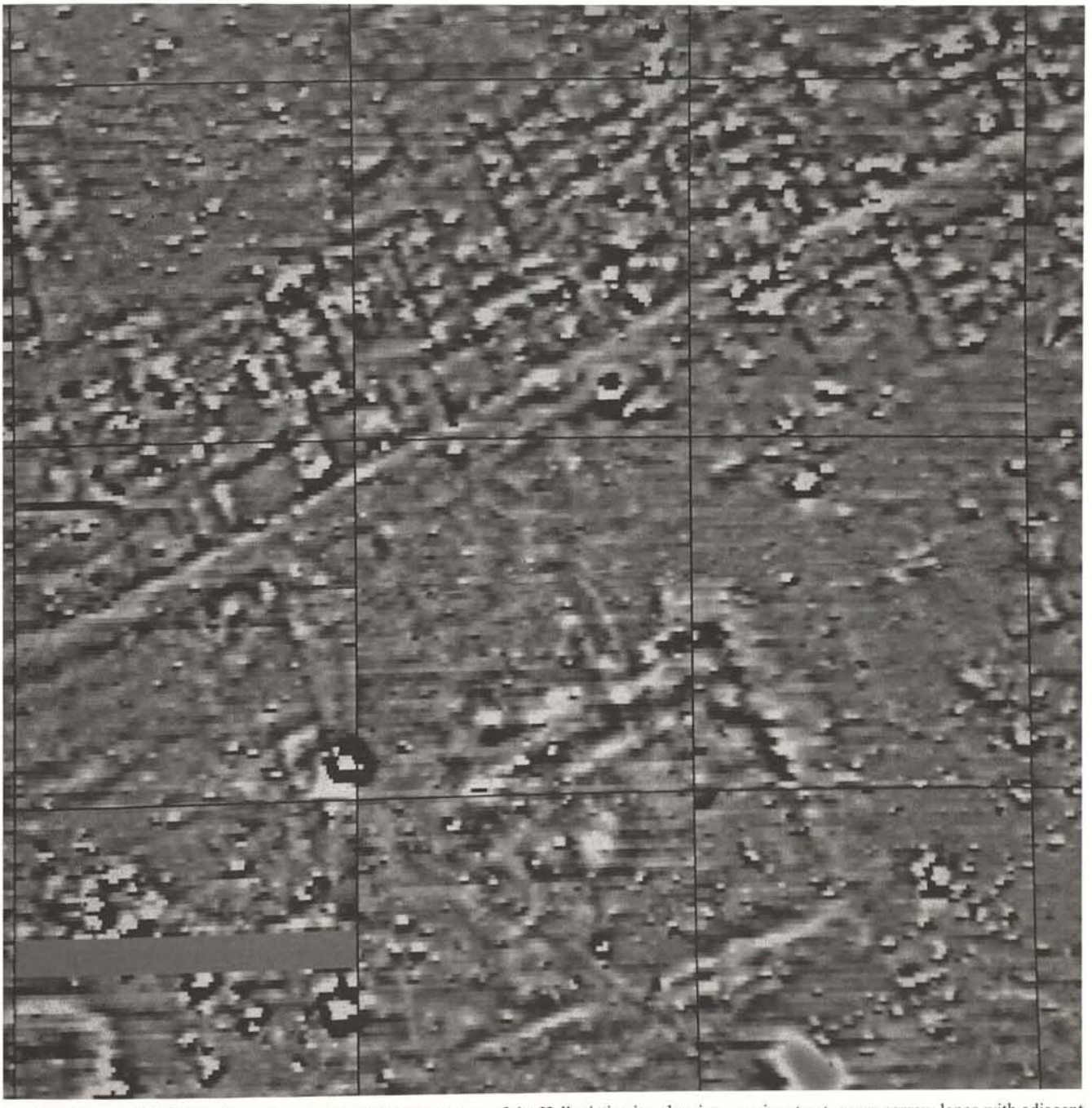


Fig. 4. Palmyra 1997–1998. Magnetogram of a part of the centre of the Hellenistic city, showing a major street, some narrow lanes with adjacent houses, which may be a bazaar or working quarter and the huge hypogaeum (36 to 52 m) in the middle. Caesium magnetometry SM4G-Special in duo-sensor configuration, 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.

References

Becker, H., 1997. *Preliminary report about the geophysical prospection at Palmyra 1997.* Unpublished report for the General Directorate of Antiquities and Museums of Syria

Schmidt-Colinet, A., 1997. "Aspects of 'Romanization': The Tomb Architecture at Palmyra and its Decoration", in: S. E. Alcock (ed.) *The Early Roman Empire in the East,* 157–177



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 non-

compensated 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.



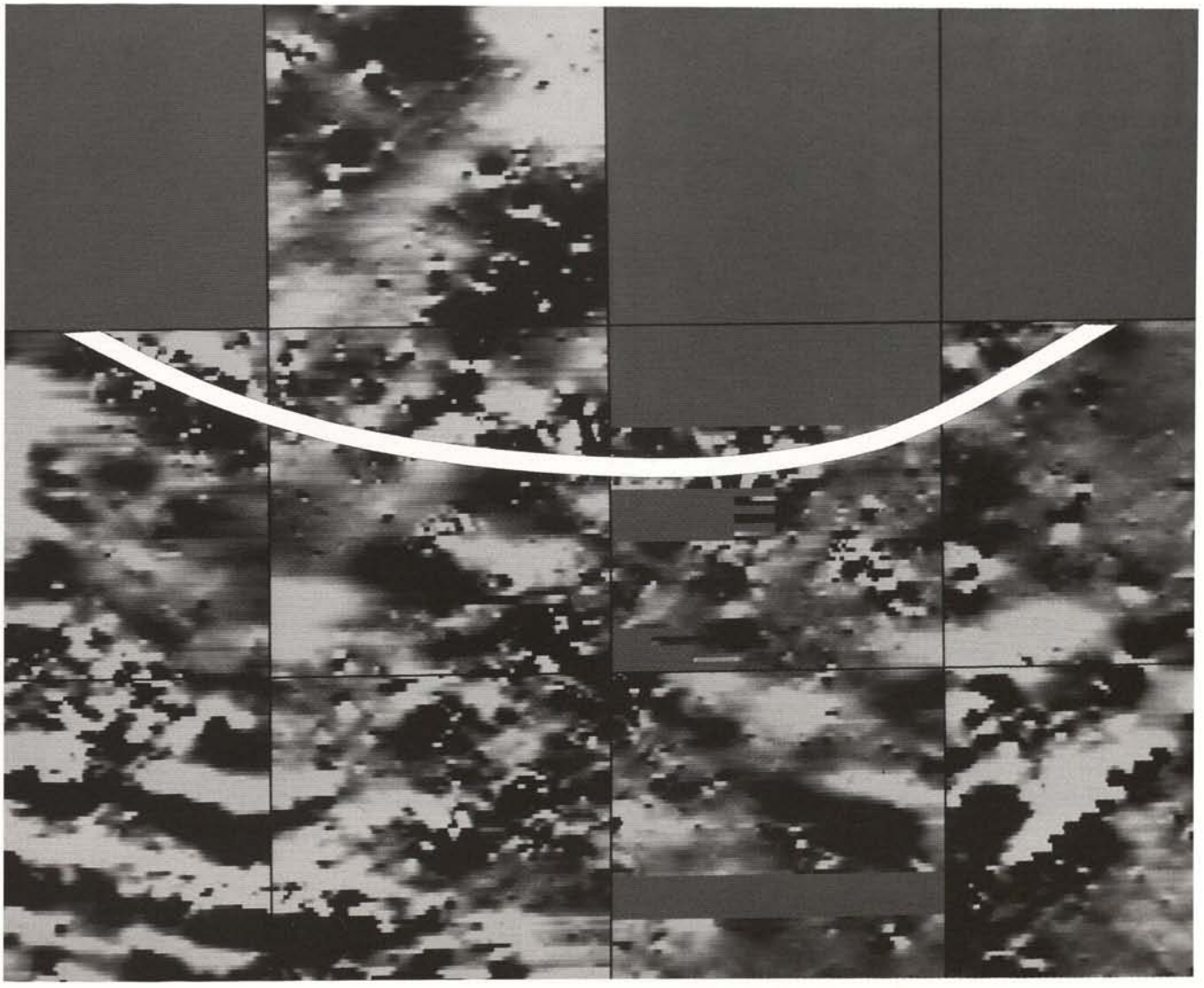


Fig. 3. Marib, Awâm-Temple. Digital image of the magnetic data, dynamics ± 13.0 Nanotesla in 256 grayscales (black to white), 40 m grid, sampling intervall 0.5 x 0.25 meter. Enhanced dynamics inside the temple area (top grid) ± 5.0 Nanotesla; the white arc is the oval wall of the temple

Acknowledgements

Thanks to Holger Hitgen for helping us to survive severe discussions with the bedouins during the field work.

References

Albright, F. P. 1958. "Excavations at Marib in Yemen", in: Bowen, R. L., Albright, F. P. (Editors), *Archaeological Discoveries in South Arabia,* Publications of the American Foundation for the Study of Man, Vol. II, Baltimore, 235–238

Gerlach, I. 1999. *The cemetery of the Awâm-Temple in Marib,* Seminar for Arabian Studies, London (unpublished report)

Gerlach, I., Hitgen, H. 2000. "Eine Totenstadt am Rande der Wüste. Der Friedhof des sabäischen Awâm-Heiligtums in Ma'rib/Jemen", in: Deutsches Archäologisches Institut (Hrsg.), *Archäologische Entdekkungen. Die Forschungen des Deutschen Archäologischen Instituts im 20. Jahrhundert, Antike Welt,* Sonderheft (in press)

Hitgen, H. 1998. "The 1997 excavations of the German Institute of Archaeology at the Cemetery of Awâm in Marib", *Proceedings of the Seminar for Arabian Studies,* 28

Hitgen, H. 1999. "Die sabäische Totenstadt im Almaqah-Tempel von Awâm in Ma'rib, in: Saba'", Ausstellungskatalog, Kunsthistorisches Museum Wien, 9. November 1998 bis 21. Februar 1999, 247–249

◁ 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

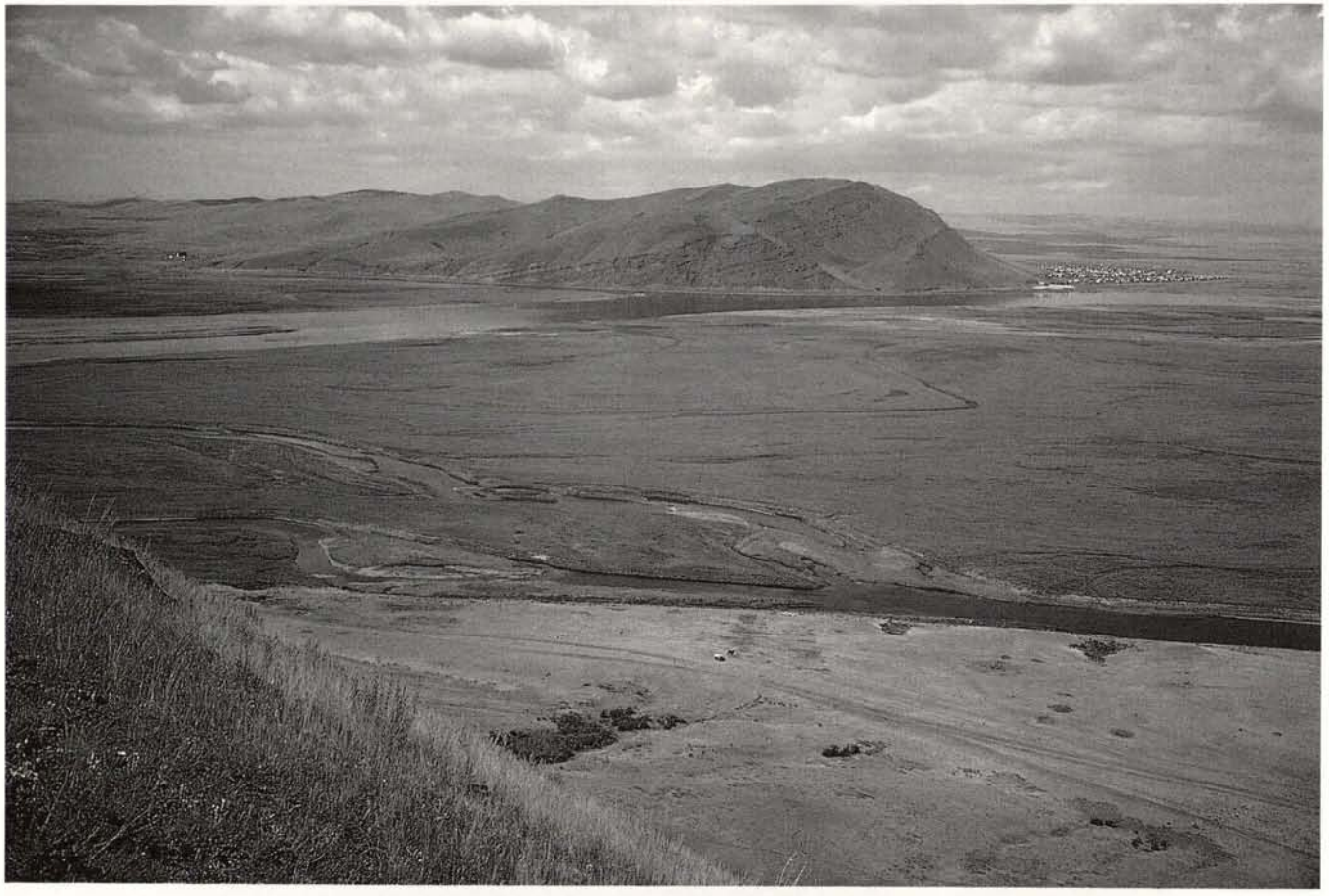


Fig. 1. Suchanicha. "Aerial view" of the northern part of the site containing the younger right angle shaped burials of the Tagar period

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

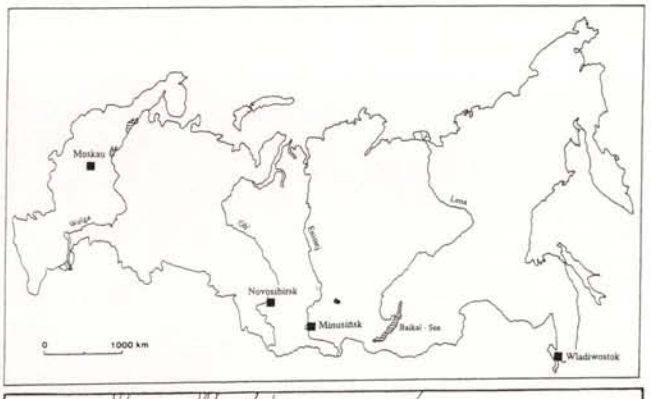
There was more success with the hand held cesium magnetometer. For the magnetometer survey we used a Scintrex Smartmag SM4G-Special cesium magnetometer sytem with ±0.01 Nanotesla sensitivity at a cycle of up to 0.1 seconds. The instrument was equipped as a noncompensated duo-sensor configuration covering 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.



3 △



▽ 5 4 △



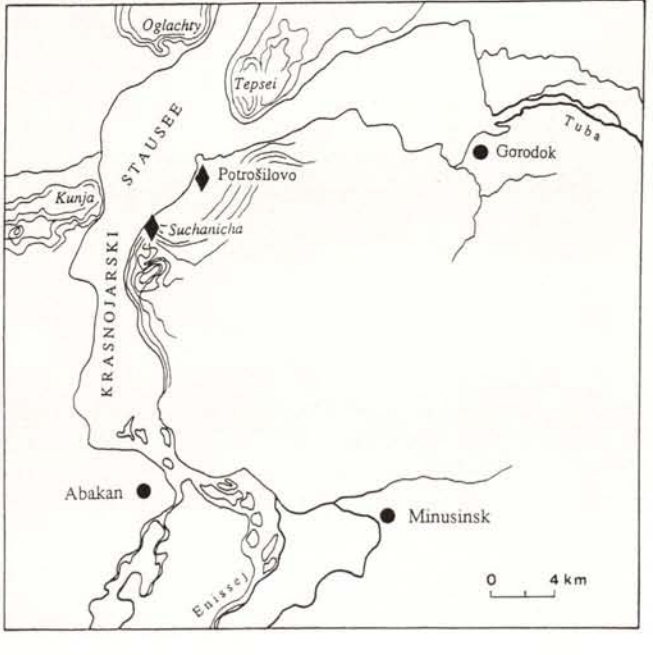


Fig. 3. Suchanicha. View of the survey area from the south, left is the river respectivly lake Enisej, on the right the slope of the Suchanicha hill and in the background in the north the hill Tepsej

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.

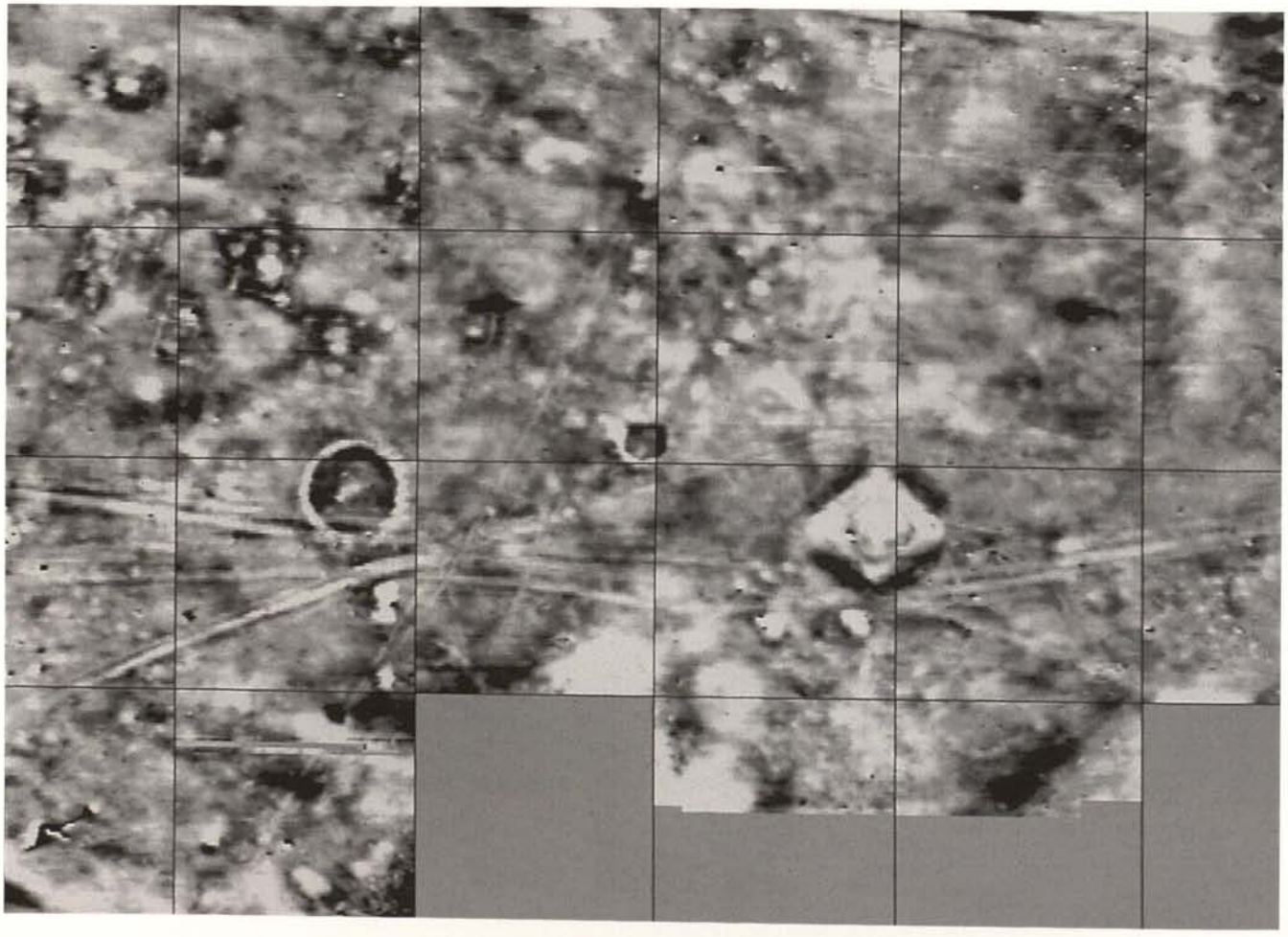
The magnetogram cutting from the northern part of the survey area reveals very clearly the round barrows a structure which could be ascribed both to the Afanas'evo culture (~3,000–2,000 B. C.) and to the Okunev culture (~1,800 B. C.). The right angle shaped burrials could be ascribed to the Skythian 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.

References

Leont'ev, N., Parzinger, H., Nagler, A. 1996. "Die russisch-deutschen Ausgrabungen beim Berg Suchanicha am mittleren Enisej", *Eurasia Antiqua,* 2, 175–204

Parzinger, H. 1998. "Archäologie am Rande der Steppe," *Antike Welt,* 29, 97–108

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



2



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

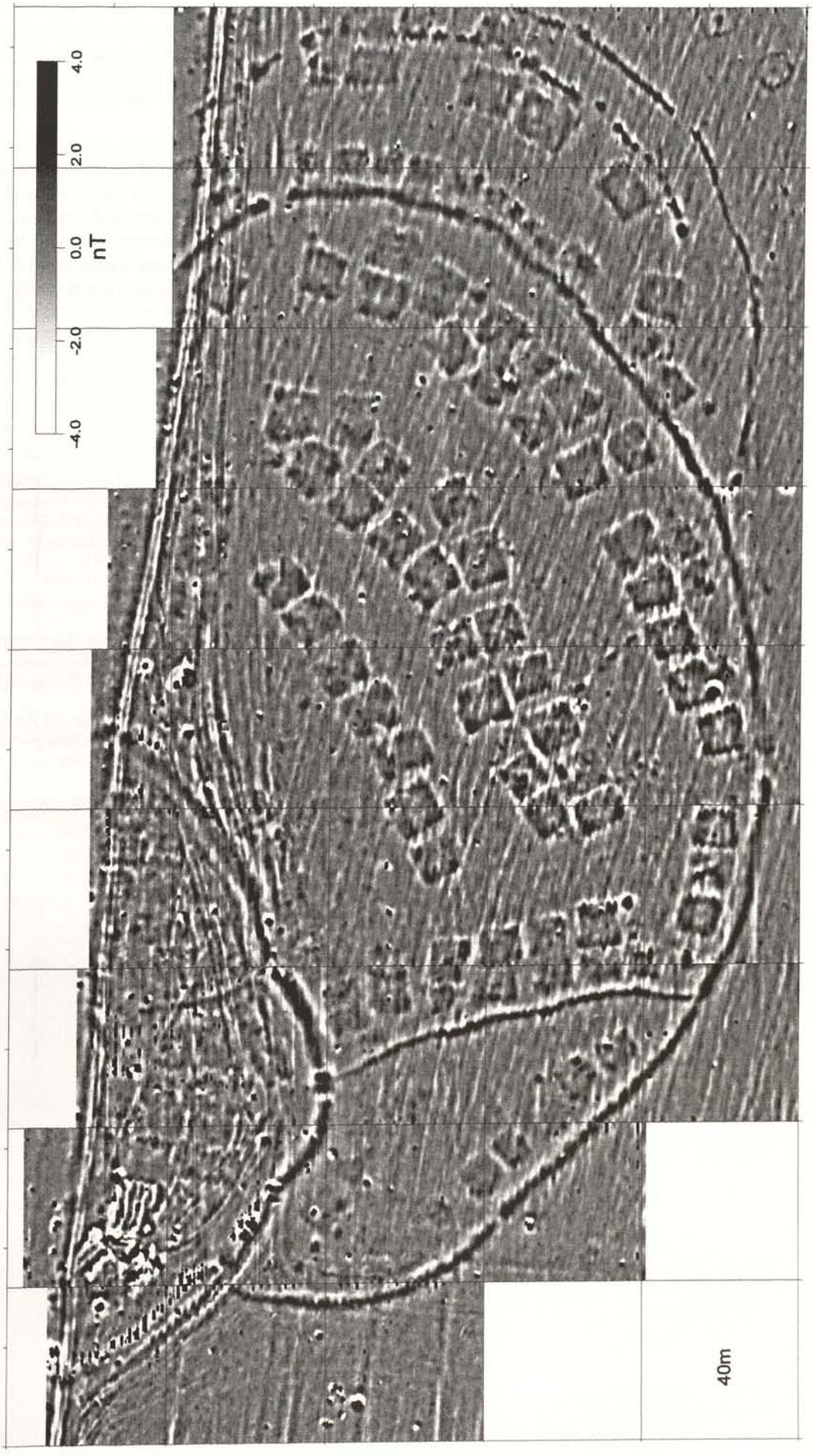


Fig. 4. Cicah-Siberia 1999. Magnetogram after highpass filtering, same technical dates then fig. 3, but dynamics –2.8/+2.8 nT

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.

References

Becker, H. 1997. "Entwicklung und Einsatz von Multi-Sensor-Konfigurationen zur magnetischen Prospektion archäologischer Denkmäler", *Arch. Jahr Bayern,* 1996, 195–197

Fassbinder, J. W. E., Stanjek, H., Vali, H. 1990. "Occurence of magnetic bacteria in soil", *Nature,* 343, 161–163

Fassbinder, J. W. E., Stanjek, H. 1993. "Occurence of bacterial magnetite in soils from archaeological sites, *Archaeologia Polonia,* 31, 117–128

Le Borgne, E. 1965. "Les propriétés magnétiques du sol. Application à la prospection des sites archéologiques", *Archaeo-Physika,* 1, 1–20

Phillips, E. D. 1965. *The Royal Hordes. Nomad Peoples of the Steppes,* London

Parzinger, H. 1998. "Archäologie am Rande der Steppe. Die Eurasien-Abteilung des Deutschen Archäologischen Instituts", *Antike Welt,* 29, 97–108

Helmut Becker, Jörg W. E. Fassbinder

Uruk – City of Gilgamesh (Iraq)
First tests in 2001 for magnetic prospecting

Uruk – the biblical Erech – still remains one of the most famous sites in Mesopotamia. Even when Babylon became the capital of Akkad and Sumer Uruk was always the main religious and cultural centre of ancient Mesopotamia. The dawn of civilisation is connected with the name of Uruk – the development of urbanism and the beginning of writing and literature in the 3rd millennium. Gilgamesh, hero, half man half God, was King of Uruk. In the Epic of Gilgamesh a lot of information about the ancient city and ancient life in Mesopotamia can be found.

"The Epic of Gigamesh was surrendered in several versions. All but a few of the Akkadian texts come from the library of Ashurbanipal at Niniveh (near Mosul in Northern Iraq). Unlike the Creation Epic, however, the Gilgamesh Epic is known also from versions which antedate the first millennium B.C. From the middle of the second millennium fragments of an Akkadian recension current in the Hittite Empire have come down, and the same Bogarköy archives have also yielded important fragments of a Hittite translation as well as a fragment of a Hurrian rendering of the epic. From the first half of the second millennium we possess representative portions of the Old Babylonian version (Tablets I-III, and X.). Certainly this version was a copy of an earlier text, possibly from the turn of the second millennium, if not slightly earlier" (Prichard 1958). In this early text we find one of the keys for the magnetic prospecting of the city wall of Uruk:

(...)
He [Gilgamesh] brought report of before the Flood,
Achieved a long journey, weary and [w]orn.
All his toil he engraved on a stone stela.
Of ramparted Uruk the wall he built,
Of hallowed Eanna (temple of Anu and Ishtar in Uruk),
the pure sanctuary.
Behold its outer wall, whose cornice is like copper,
Peer at the inner wall, which non can equal!
Seize upon the threshold, which is from the old!
Draw near to Eanna, the dwelling of Ishtar,
Which no future king, no man, can equal.
Go up and walk on the walls of Uruk,
Inspect the base terrace, examine the brickwork:
Is not its brickwork of burnt brick?
Did not the Seven [Sages] lay its foundations?
(...)

(Remainder of the column lost)

The important point for magnetometry – some 5.000 years later – is the fact that Gilgamesh used baked (burnt) bricks for the city wall he built. We assume that the early city wall of Uruk had a mantle of baked bricks, filled with cheaper mud bricks, which would give an ideal base for magnetic prospecting, because of the high susceptibility and remanent magnetisation of burnt clay. Therefore we tried to prospect the city wall in an area where the wall still shows on the surface, and we planned to locate one of the city gates, which are also almost unknown.



Fig. 1. Uruk-Warka. Aerial photo (detail) of test area I (with the canal), taken by the Royal Air Force in 1935, courtesy of the German Archaeological Institute, Oriental Department.

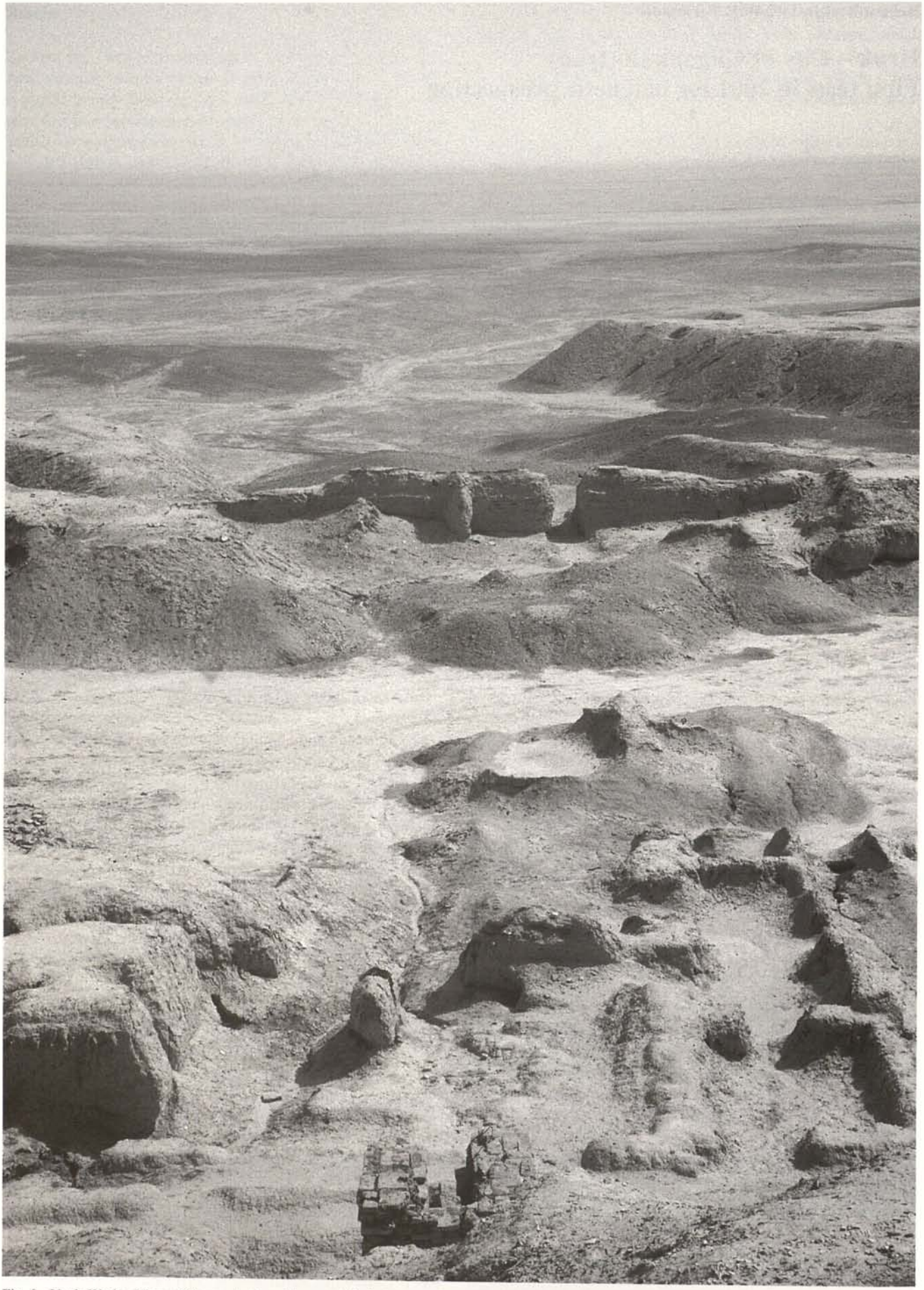


Fig. 2. Uruk-Warka. View of the central temple area with the Eanna Ziggurat (high temple). Photo by Margarete van Ess, German Archaeological Institute, Oriental Department.

Again from the Epic of Gilgamesh, as well as from many iconographic illustrations we have descriptions of rituals using a bark on a canal, e.g. from Uruk on a cylinder seal from the beginning of the 3rd millennium a ritual scene is shown with a boat on a canal and a shrine and altar mounted on the back of a bull. Like in other cities of ancient Mesopotamia, a sanctuary of a special type was situated in Uruk, outside the walls of the city, but belonging to it, called the New Year's Chapel (bait akitu). Once a year (on New Year's Day, when the king was allowed to enter the inner temple area) the image of the principal deity of the settlement (in Uruk it was Ishtar) was carried to the sanctuary in a procession, accompanied by throngs of worshipers. In certain instances, a sacred road through a special gate linked the outlining sanctuary to the temple (Oppenheim 1964). For Uruk we have the description of Gilgamesh leaving the city on a bark for a ritual course. This means that we should expect a canal or even a system of canals in the city. This question led to controversial discussions among archaeologists. Recently with the help of a series of aerial photos taken by the Royal Air Force in1935 Margarete van Ess identified structures in the city of Uruk as canals.

Based on these questions of how to understand the Epic of Gilgamesh from an archaeological point of view, the first Iraqi-German joint archaeological project after the Gulf War was started in February 2001. Before the planned excavation missions to this very famous place high-tech geophysical prospecting was applied in an eight-day field campaign, a co-operation of the German Archaeological Institute (Ricardo Eichmann, Margarete van Ess), the Iraqi Department for Archaeology (Zuhair Rajab joined the project as representative) and the Bavarian State Conservation Office (Helmut Becker, Jörg Faßbinder). These tests of magnetic prospecting were meant to answer the question if this method would be suitable even for a multi-layered mound consisting mainly of debris from sun-dried mud brick – the old problem of prospecting archaeological structures made of mud in a surrounding of mud. Experience from other sites in oriental countries had shown that only magnetic prospecting had been the right method.

But how to reach a place in Southern Iraq in 2001? Travelling to Iraq 10 years after the Gulf War is still not easy with the embargoes still being valid. We flew to Amman (Jordan) and then had a long journey by taxi to Baghdad. We are indebted to the custom authorities for letting us pass with our equipment almost without severe problems. During the night of our arrival in Baghdad British and American forces bombarded a factory in the southern area of the city. After a first alarm and some heavy explosions we knew that we were in Baghdad. We very much admired the behaviour and calmness of the Iraqi people – nobody being unfriendly to foreigners although the situation of the people is very bad and almost unbearable. Even in the south at Uruk-Warka, which is not too far from Samawah we heard explosions, but life in the German expedition house in the ruins of Uruk was without any stress – almost like paradise, disturbed only by our generator for running the computers and recharging the batteries for the magnetometers.

Uruk has always been closed for any cross-country traffic, so there is actually only one track used by cars to reach the tiny camp village of Warka with the expedition house and some huts inhabited by the guard and his numerous family. The rest of the tribe was en route to Saudi Arabia with hundreds of camels. Another track follows the fence around and outside the ruins. The Arabs avoid the ruins because they are afraid of ghosts which are supposed to haunt this place. All this results in a unique situation for archaeology, because many archaeological structures can already be traced on the untouched surface. Weathering and numerous changes of rain and wind over many thousands of years have modelled the material on the surface according to their density, showing many different structures of colour and relief. Robbery is a fairly small problem, being concentrated on the Kassite necropolis south of the city wall. The closed and untouched surface also has ideal conditions for magnetic prospecting – a completely different situation from the other sites of Mesopotamia. For instance, Babylon with its badly disturbed surface would cause far more problems for magnetic prospecting. In Uruk after about 70 years of archaeological excavation, during which lorries on railways were used for transportation of the debris, which was piled up to enormous heaps around the central area, only the central temples or palace areas are blocked for ever for magnetic prospection. The climate in the second half of February with its moderate temperatures was quite ideal for such an expedition. We were also lucky only to have experienced one sand storm, which made work outside the house almost impossible. Also the soft surface of the ruins of Uruk with many layers of very fine ashes made walking rather difficult and exhausting.

Fig. 3. Uruk-Warka. Aerial photo (detail) of test area II taken by the Royal Air Force in 1935, courtesy of the German Archaeological Institute, Oriental Department. Open trench of the city wall, excavated in the 1935 campaign, in the south the ruins of the New Year's Chapel (bait akitu).



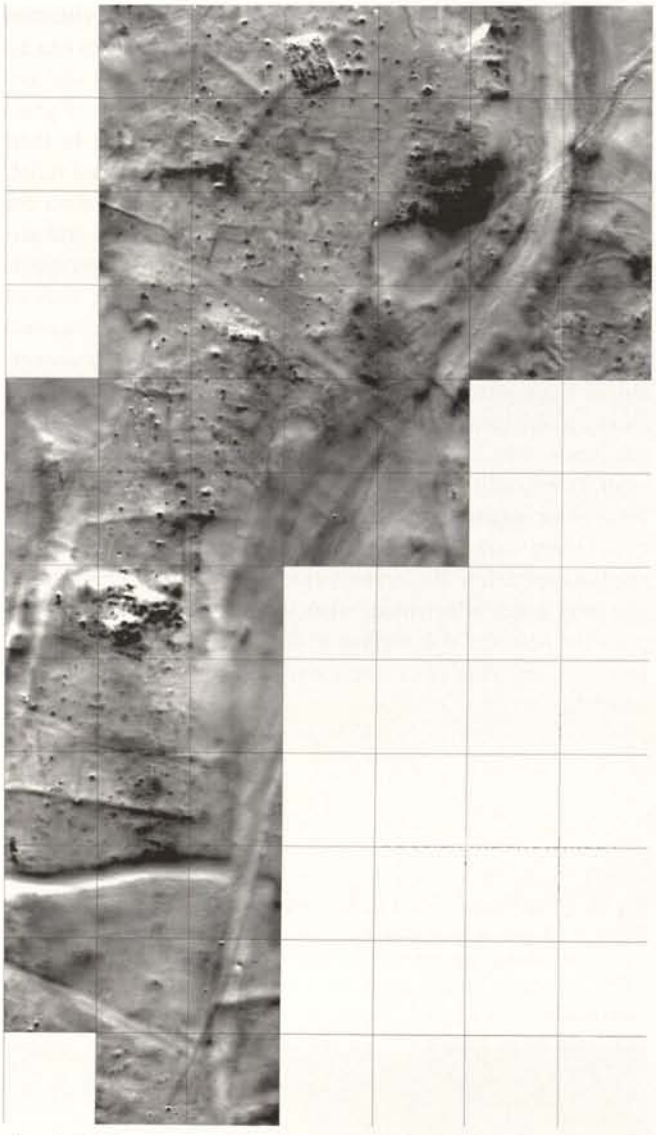


Fig. 4. Uruk-Warka 2001, test area I (West). Magnetogram in grey shading of the area covering the larger part of the aerial photo in fig. 1, which shows the main and secondary canals, the street system, the city structure with some very clear houses, severe damage to a city quarter by a flood (on the western side of the main canal). Caesium magnetometry, Scintrex SMARTMAG SM4G-Special with duo-sensor-configuration, sensitivity 0.01 nT (10 Pico-Tesla), dynamics – ± 15.00 nT in 256 greyscale (white/black), raster 0.1/0.5 m interpolated to 0.25/0.25 m, 40 m-grid, magnetic prospection by Helmut Becker and Jörg Faßbinder, Bavarian State Conservation Office.

Caesium magnetometry was applied with Scintrex SMARTMAG-SM4G-Special in the so-called duo-sensor configuration. Two test areas were chosen for prospecting the canals in the city, the city wall and its gates. We laid out a 40 m grid orientated to magnetic North, which was fixed to the main topographical system of Uruk at the end of the campaign, and started in an area (area I West) inside the city wall with old layers and some traces of buildings visible on the surface (52 grids of 40 x 40 m = 8.5 hectares). The second area II (South) was measured for prospecting the city wall of Uruk (42 grids of 40 x 40 m = nearly 7 hectares). This area was chosen for covering a part of the city wall since there a depression in the wall could possibly mark a city gate. In parts of this area the wall was still about some 4 or 5 m high, but flattened to some decimetres in the eastern direction. Outside the wall in a distance of about 200 m a huge building made of baked bricks with the stamp of King Nebuchadnezzar II (604-562 B.C.) was already visible on the surface. The building was supposed to be a temple or the southern New Year's Chapel (bait akitu) (see back-cover).

The results of magnetic prospecting in the two test areas are fantastic (see magnetograms in figs. 4 and 5). Already the first evening we realised that we had traced the main canal as well as some house structures, including the very clear plan of an old Babylonian house built of baked bricks (fig. 4). The following days we found that the old city of Uruk had a complete canal system with a nearly 5 m-wide main canal and two or three secondary canals in the area to the west. Besides this canal system a street system existed at different levels. Another very interesting discovery in this area I West were vast ravages of the settlement patterns by a flood mainly on the western side of the canal.

In area II South the city wall gave a clear magnetic anomaly mainly caused by the mantle of burnt bricks on both sides as described in the Epic of Gilgamesh. The southern city gate shows a very wide opening of nearly 16 m. The gate was also mantled with baked bricks. These facts from the magnetogram help to imagine the splendid pictures of the Ishtar gate in Babylon. There is also strong evidence that this gate was actually used as a water gate for the passage of the main canal through the city wall.

In the area towards the so-called bait akitu building, a vast cemetery was identified in the magnetogram. Ceramics on the surface from numerous robbery pits in this area indicate that this was part of a large necropolis of the Kassite epoch.

Also the supposed New Year's Chapel (bait akitu) situated nearly 200 m south of the city gate, showed very clear magnetic anomalies due to the high magnetisation of the burnt bricks. The architectural details with three cellular structures on the western side of the building with a large court and a surrounding wall are very different from the known plans of temples. There is a direct canal from the gate in the city wall to a smaller gate (of burnt bricks) beyond the New Year's Chapel and a smaller canal leading to its western side and forming an elongated basin for boats to anchor. Everything seems to correspond exactly to the illustrations and descriptions of the New Year's ritual, except the fact, that we are dealing with the first millennium instead of the third. But there may be an older building underneath Nebuchadnezzar's chapel.

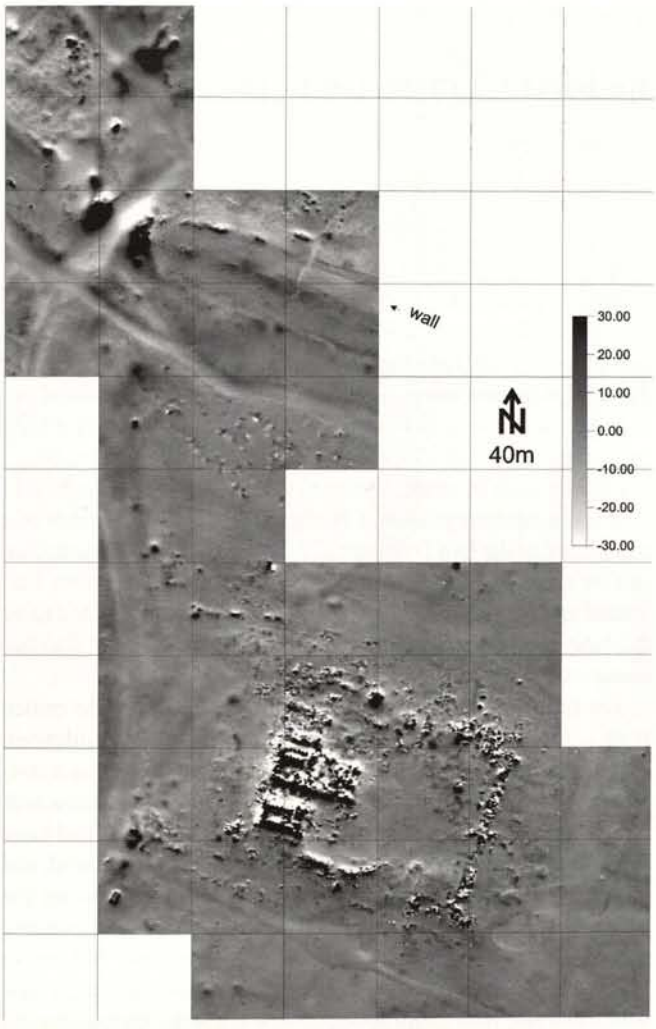


Fig. 5. Uruk-Warka 2001, test area II (South) showing the city wall, a complex gate (possibly a water gate for the main canal), a Kassite necropolis in the middle and the New Year's Chapel (bait akitu) in the south. The archaeological trench from 1935 in the city wall is still visible in the magnetic prospecting in 2001, same technical data as fig. 4 (see also fig. on the back cover).

References

Prichard, J.B., 1958: "The Epic of Gilgamesh." In: *The Ancient Near East, An Anthology of Texts and Pictures.*

Oppenheim, A.L., 1964: *Ancient Mesopotamia, Portrait of a Dead Civilization.*

Jörg W. E. Fassbinder, Helmut Becker

Wazigang – A Palace of Qin Shihuangdi, the First Chinese Emperor

An international research project of geophysical prospection was carried out at Wazigang, Qian County, Shaanxi Province, China, in September 1999 and 2000, a co-operation of the Bavarian State Conservation Office, the Department for Archaeological Prospection and Aerial Archaeology, Munich, and the Shaanxi Province Conservation Centre for Historical Monuments, Xi'an. Involved in the fieldwork in China were the geophysicists Dr. H. Becker and Dr. J. Faßbinder (Bavarian State Conservation Office), Prof. Dr. Qin Jaoming, Dr. Jiang Baolian und Dr. Liang Xiaoqing (Technical Centre of the Shaanxi Province Conservation Centre for Historical Monuments), Prof. Ye Xinshi (Northwest Polytechnical University, Box 189, 710072 Xian) as well as the archaeologist Dr. W. Irlinger and the cartographer J. Lichtenauer from the Laboratory in Munich.

Introduction

In the third century B.C., the power of the principality of the Qin in the central plain of today's Shaanxi Province was strongly increasing. Step by step the Qin state was annexing the other six powerful states of its neighbours. During the time of the First Emperor Qin Shihuang the Qin state created a very powerful empire covering a large territory. The capital of the Qin Empire Xianyang, named "Wangji", was situated in the central Shaanxi plain, close to the actual capital Xi'an. In this area the Qin people built many palaces and parks. Written records describe about 270 giant projects: palaces, gardens and other big buildings. Most of these palaces included administration buildings, working rooms and living rooms. Today, however, all of these palaces are in ruins and only the remains of some of them have been found or confirmed by archaeologists. The best-known monument of Quin Shihuangdi, however, is the famous Terracotta Army at Lintong (see fig. 1).

Qin Shihuang (259-210 B. C.), born as Ying Zheng, became king of the Qin State in 247 B.C. At the age of 22 he came to power after having annexed the six rival principalities of Qi, Chu, Yan, Han, Zhao and Wei, and established the first feudal empire in China's history. In the year 221 B.C. when he had unified the country, he styled himself emperor and named himself Qin Shihuangdi ("First Heavenly Emperor of Qin"), hoping that his successors would be the second, the third and so on. Emperor Qin had over two hundred palaces built in the Guanzhong Plain around the capital, one of which is Wazigang palace.

The Wazigang site was discovered in the 1980s. Wazigang in the community of Wudian is a small village, situated about 80 km north-west of the city of Xi'an and about 15 km north-east of the city of Qianxian. The very exposed site is situated on top of a large loess hill measuring about three times 5 km, which is enhanced in its height about 60-70 meters above the surrounding area.

Among others, this site was suggested as testing site by our Chinese colleagues in 1999. The topographical top of the place can be seen from far away because of its small rammed earth pyramid at the summit of a large loess hill. The geographical coordinates of the rammed earth pyramid were measured by a GPS instrument as N: 34° 37,902' ± 0,02' E: 108° 08,710' ± 0,02'. During the past 20 years, Chinese archaeologists have undertaken a series of surveys around Wazigang and found the ruins of a palace site of the Qin Dynasty (221-206 B.C.). The site was chosen by us as test area because all crops had already been harvested and because of the loess subsoil which we expected to be the best from experiences in Bavaria and Siberia, but also because of the archaeological conditions.

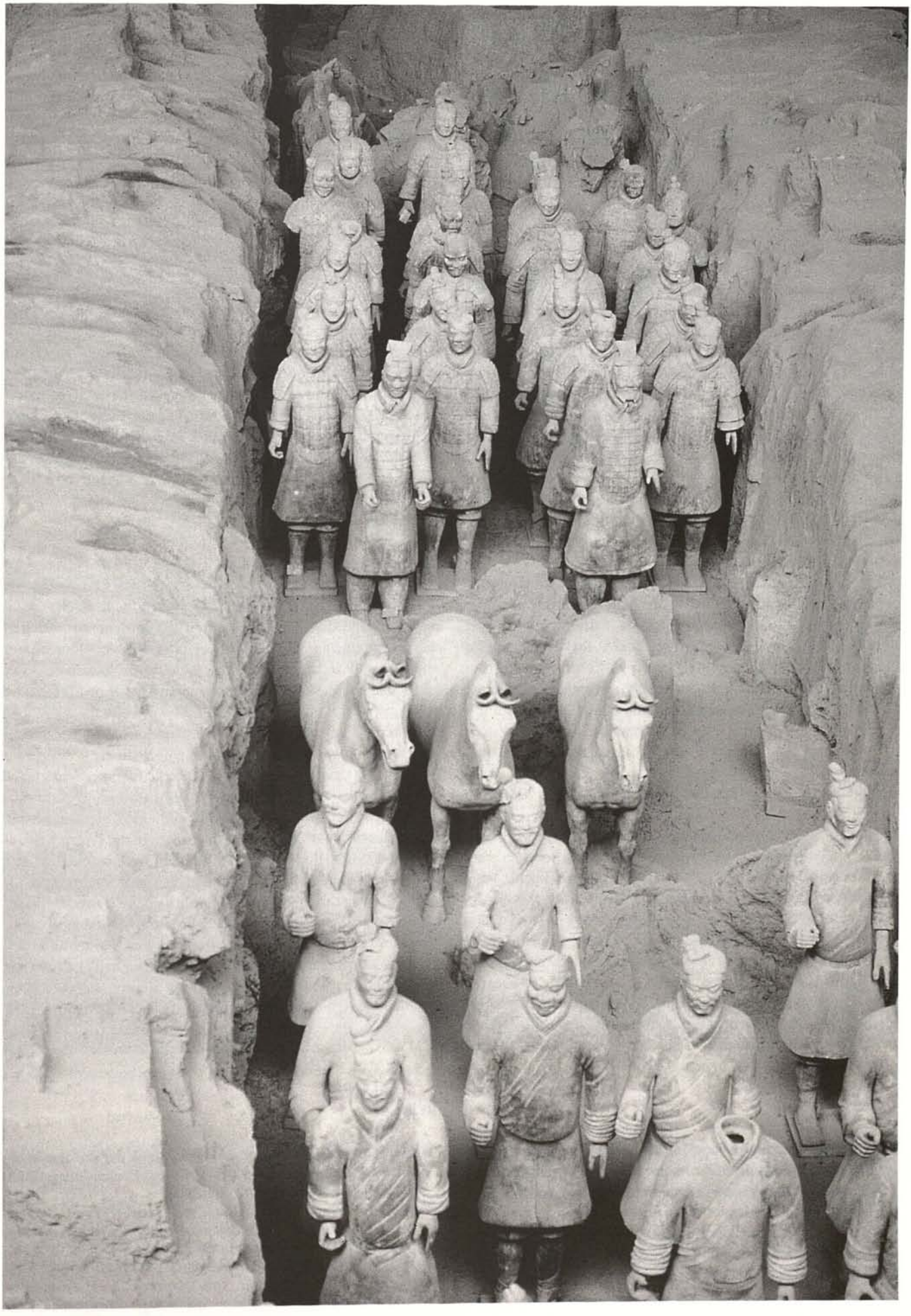
The farmers had found pottery as well as roof tiles decorated with a decoration typical of the temples, palaces or residences. The stamps of the roof tiles proved that the site had been a residence of the Emperor Qin Shihuang. A variety of construction materials, bricks, roll roof tiles, tile-ends and pottery had been unearthed in the ruins of the palace. They are hard and solid, and most are dark grey. Hollow bricks were used for paving the stairs; they mostly were decorated on the surface with patterns of dragons, phoenix clouds and thunder. The floor tile bricks show seven types of decoration; plain, check, rhombus, saw tooth, sun and flower. However, no one knew the archaeological structures of the ruined palace site in detail until 1999.
From the surface nothing can be seen except the earthen pyramid measuring 30 meters from east to west, 25 meters from north to south and about 5,8 meters in height. This pyramid is made of air-dried mud bricks. Around this pyramid we performed our first magnetometer tests. These tests confirmed our assumption that the site might have archaeological structures beneath the ground.

In spring and summer of 2000 our Chinese colleagues performed further surveys. Furthermore, they made a complete topographical map of the site. Now we were able to estimate very precisely the total extension of the area of about 800 x 1000 meters. Along the modern loess terraces the extension of the mud brick structures could be verified on many decisive sites.

Methods of geophysical prospection

In recent years archaeological field work has become much faster and more sophisticated by the use of new devices, high-tech methods and evaluation possibilities. Air photography, geophysical methods, remote sensing, GPS, GIS, VR and 3D animation and reconstruction have proved to be successful applications in archaeology.

Fig. 1. Lintong: Soldiers of the Terracotta Army of the First Chinese Emperor, Qin Shihuangdi. ▷



Magnetometry as a non-destructive geophysical method for archaeological prospection was used in China for the first time on the ruins of the palace site. In 1999 we undertook a trial magnetometer survey with the so-called duo-sensor configuration of this area. The preliminary results clearly indicated the remains of large walls and other structures.

In the year 2000 we continued the caesium magnetometry. For the measurements we used the caesium Scintrex SMARTMAG SM4G special magnetometer with a sensitivity of ± 10 pT at 0.1 sec cycle. A 40 m-grid over 400 x 240 m, later enlarged to 400 x 480 m (~18 hectares), covered the site which was topographically surveyed and marked by wooden pegs before the prospection started. The instrument was applied in the duo-sensor configuration at 0.5 m traverse interval and 0.25 m sample interval as a total field magnetometer. The sensors were configured at a horizontal distance of 0.5 m, the sampling rate was set to 0.1 sec, which at normal walking speed gives a spatial resolution of 0.1 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 were 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, depending on the walking speed.

The data were dumped and finally processed on a notebook computer, resulting in an almost complete visualisation of the measurement in grey shading technique. Data processing was done using software with graphic facilities for visualising the measurement as grey-shading plots. 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).

With this method, the archaeological structures appear as negative or positive anomalies, indicating the remnants of earth-rammed structures, architectural foundations, pillar holes and garden areas.

The aim of the second survey (September 2000) was to provide complete coverage of the inner palace area. For the detection of stamped mud brick structures in loess over such a large area a narrow sampling interval of 25 x 50 cm was necessary, in addition to rapid survey. Caesium magnetometry covered a total area of about 18 hectares at Wazigang in 10 days. This was made possible by very good planning and organisation by our Chinese colleagues. Furthermore, we had access to all the fields because they were already harvested. If not, our Chinese colleagues organised the harvesting of these fields so that it was possible to measure almost all the areas of interest.

Results

The mud brick structures show mostly as strong positive magnetic anomalies. The results of the magnetic prospection resulted in a detailed map of the Emperor's residence. They revealed the structures of the palace garden, administration buildings working quarters and barracks, as well as the remnants of the main palace. The main palace was found to be in the central line of the main axis from the south gate to the still visible mud brick pyramid, which was part of the palace buildings (basement construction for the palace). Furthermore, we found garden structures and, on the western side of the area, the structure of a garden palace. Up to now, similar maps of garden palaces have not been found yet and are not known to Chinese archaeologists. The central area of the site is restricted by the south gate. In the west we clearly detected the wall. Parts of the northern wall have also been detected in the northwestern area. However, in the east and the north, modern terraces of the loess are responsible for the disappearance of the antique structures. An outer wall which could be in a distance of more than 700 m from the earth pyramid has not yet been detected.

Trench excavation

During our survey the Chinese colleagues were performing a trench excavation at the south gate and cutting a wall segment of the north side of the area. The excavation confirmed the results of the magnetic prospection and revealed rammed earth structures, but also allowed an exact dating of the archaeological structures. The excavation also confirmed that these strong magnetic anomalies are due to the enrichment of the hundreds of pieces of pottery and roof tiles covering the earth rammed structures of the wall. Obviously these roof tiles covered the wall to protect it from erosion caused by rain.

Evaluation and interpretation

In October 2000 Mr. Ye and Mr. Qin visited the Munich laboratory of prospection. Together we finished the data processing of the measurements of 2000 and performed the combined geophysical and archaeological interpretation of the data. Josef Lichtenauer digitised the cartographic map made by the Chinese colleagues.

Based on the magnetogram, the Chinese colleagues reconstructed the main halls of Wazigang palace, using software for 3D modelling technique. The size of the halls was reconstructed using the map of archaeological interpretation and additional knowledge from already excavated buildings of the Qin period. The Chinese books "Kao Gong Ji" written in the Warring States Period (475-221 B.C.) and "The Rules of Architecture" written in the Song Dynasty (420-479 A.D.) also give important references. In general, the Qin palaces consisted of halls, corridors, gardens, pavilions, living rooms, bath rooms, winding lobbies, watchtowers, warehouses and cellars, set into a graceful entity. At the Wazigang archaeological site, the main halls had hip and gable roofs, earth-rammed foundations, sloping entrance stairs and doorsteps, corridors, courtyards and enclosure wall.

References

Becker, H., *Mit der archäologischen Prospektion auf den Spuren des Ersten Chinesischen Kaisers Qin Shihuang*. Denkmalpflege Informationen Ausg. B Nr. 114 / 12. Mai 2000.

Fassbinder, J. W. E., Becker, H., Qin, J., Ye, X., Jian, B., Liang, X., *Magnetometry of a palace of Qin Shihuang, the First Emperor of China 259-210 B.C.* Gephys. Res. Abstracts 3, 2001.

Liang Sicheng, *The History of Chinese Architecture*, China 1998.

Fassbinder, J.W.E., Irlinger W.E. (eds.), *Archaeological Prospection*. Third International Conference on Archaeological Prospection, 1999.

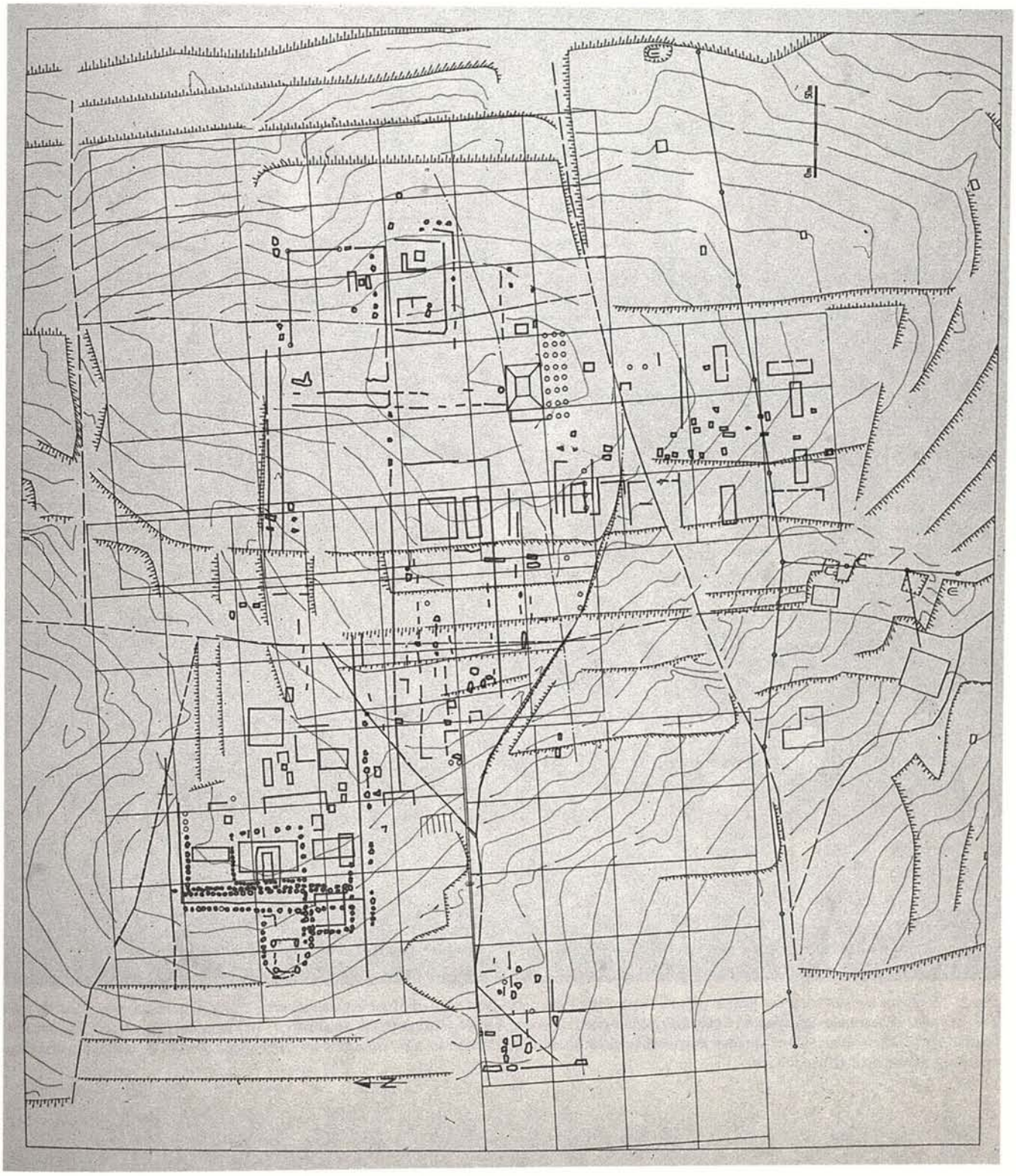


Fig. 2. Interpretation map of the total measured area of the Wazigang palace.

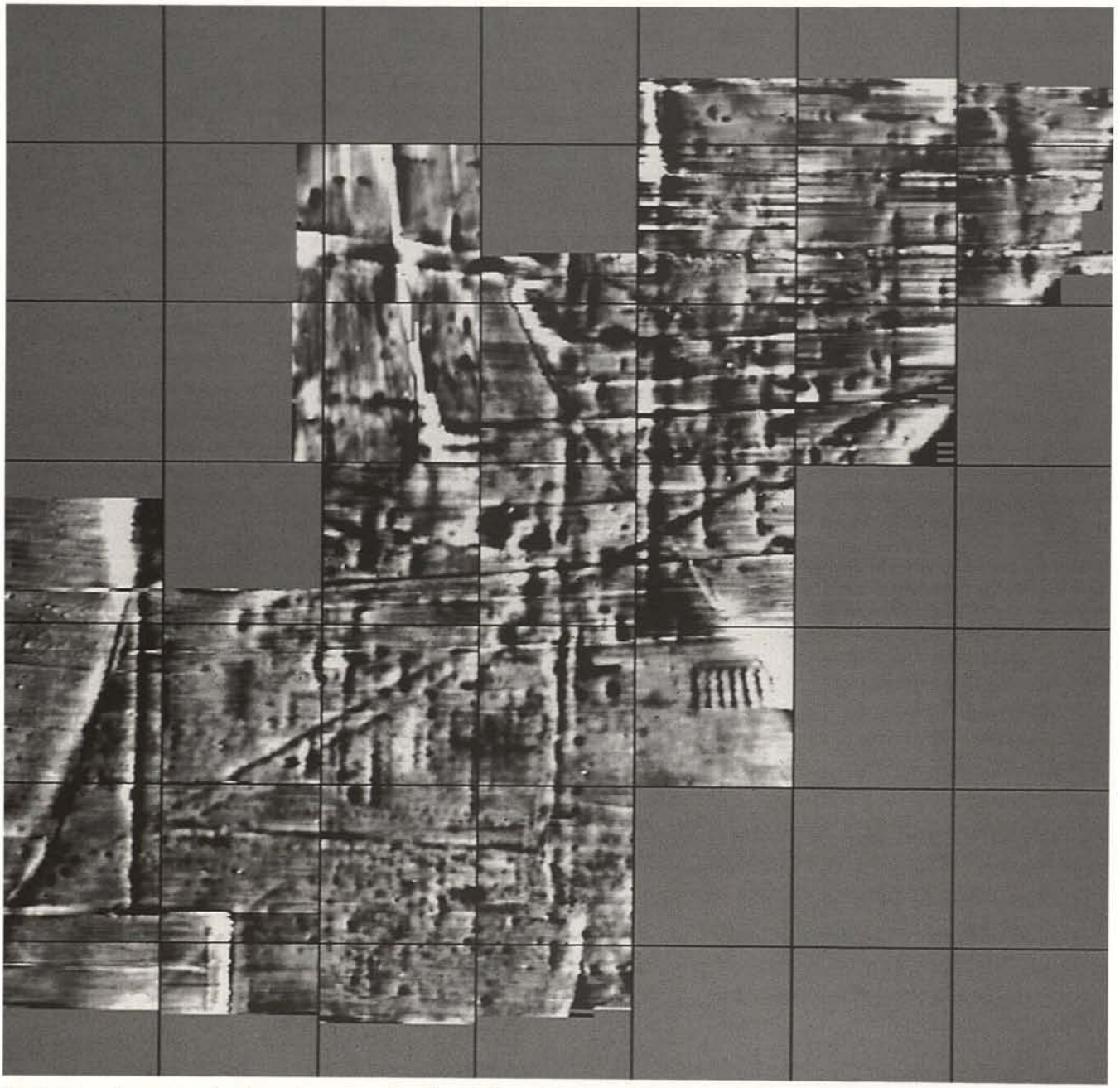


Fig. 3. Magnetogram showing the garden palace. A portion of the north-western part of the residential area. Magnetogram in grey shading with 256 greyscale. Caesium magnetometer Smartmag SM4G-Special in duo-sensor configuration, sensitivity +-10 Picotesla, raster 0.5/0.2 m interpolated to 0.25/0.25 m, dynamics of the total magnetic field 52.220 ±10.000 Nanotesla nT (white to black), line mean over 40 m, desloping and edge matching, 40m-grid, north to the left.

Monuments and Sites / Monuments et Sites / Monumentos y Sitios

Published so far / publiés jusqu'à présent /publicados hasta el momento: Australia, Bolivia, Bulgaria, Canada, Cuba, Cyprus, Czech Republic, Dominican Republic, Egypt, Hungary, India, Israel, Jamaica, Japan, Russia, Sri Lanka, South Africa, Zimbabwe (18 vols.), Colombo 1996 (out of print / épuisés / agotados)

Monumentos y Sitios de Chile, Santiago de Chile 1999
Monuments and Sites: Finland, Helsinki 1999
Monuments and Sites: Indonesia, West Java 1999

New Series / Nouvelle Série / Nueva Serie:

I International Charters for Conservation and Restoration
Chartes Internationales sur la Conservation et la Restauration
Cartas Internacionales sobre la Conservación y la Restauración, 2001

II The Terracotta Army of the First Chinese Emperor Qin Shihuang, 2001

III The Terracotta Army, Studies on the Polychromy of Antique Sculptures (in the press / en train d'être imprimé / es en prensa)

IV Puebla, Patrimonio de Arquitectura Civil de Virreinato, 2001

V Vernacular Architecture (in the press / en train d'être imprimé / es en prensa)

VI Magnetic Prospecting in Archaeological Sites, 2001

to be obtained from / s'adresser à / comprar a:
Karl M. Lipp Verlag, Meglingerstr. 60, 81477 München, Tel. +49-89-78 58 08-0, Fax +49-89-78 58 08 33, info@lipp.de

