

FUSION OF AERIAL IMAGES AND MAGNETIC PROSPECTION

FOR ARCHEOLOGICAL SITES

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ABSTRACT

Archeological prospecting using aerial photographs is well introduced in practice. Nowadays new prospecting field methods, like electric resistivity measurements or the registration of anomalies of the magnetic field can deliver also "images" of the archeological structures beneath the soil. The evaluation results of such artificial images could be combined with the results of the interpretation and restitution process from aerial or terrestrial images resulting in a more complete and detailed knowledge of the archeological site, before excavation starts.

The paper presents two actual examples of this fusion process, whereas data is digitized from aerial or terrestrial images and magnetic anomalies registrations. Both projects cover a substantial unexcavated area of several hectares. On both sites excavation based on the previous evaluation process has started.

1 THE OSTIA ANTICA PROJECT

1.1 Ostia Antica, historic and research context

Excavations in Ostia Antica, the former harbour of The Roman Imperium were intensified especially from 1938 to 1942, when the World Exhibition takes place in Rome (1942). Nevertheless about 40 ha of the ancient city still remained untouched. This is about 50 to 60% of the original built up area. For future urbanistic research this was always a handicap. The type of buildings varies within the different quarters (regiones) of the city. 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 started archaeological prospecting for urbanistic research. Aerial photo interpretation and evaluation, digital terrain modelling and geophysical prospecting (caesium magnetometry and resistivity surveying) were successfully combined (Heinzelmann, et. al., 1997).

1.2 Aerial photogrammetry and terrestrial surveying.

A b/w stereopair flown in 1985 by the company S.A.R.A. Nistri using a WILD RC10 photogrammetric camera at an image scale of 1:11.500 shows within the unexcavated parts of the ancient city of Ostia structures like streets, buildings and walls (Fig. 1). The stereomodel was oriented using control points from an different photogrammetric project, the „Atlante di Ostia antica”, published by the Soprintendenza archeologica di Ostia (Ed. Marsilio, 1995). The „Atlante“ was based on large scale colour aerial images, flown by Compagnia Generale Ripresearee (CGR Parma) using a Carl Zeiss RMK A Camera (f=305,38 mm, image scale 1:3000), which, due to the recording time (june 1993) unfortunately show no uncovered archeological remains at all. That is why this material served to establish a uniform geometric frame for further research only. Exploiting the potential of the b/w images first a dense set of 3D points and breaklines were measured in the areas of interest. The data was transformed afterwards to a regularly spaced Digital Terrain Model (DTM), using the HIFI (Ebner et.al, 1980) software package of the Chair for Photogrammetry and Remote Sensing. In conjunction with the digitized b/w images and the DTM digital orthophotos were prepared at a scale of 1:2000. Now the evaluation process of the archeologic content of the aerial images was possible using the monoplottting approach. Introduced to this technique by R. Brand the archeologist in charge M. Heinzelmann was able to digitize and classify all the visible structures at a Digital Photogrammetric Workstation (DWPS) PHODIS-ST 10.

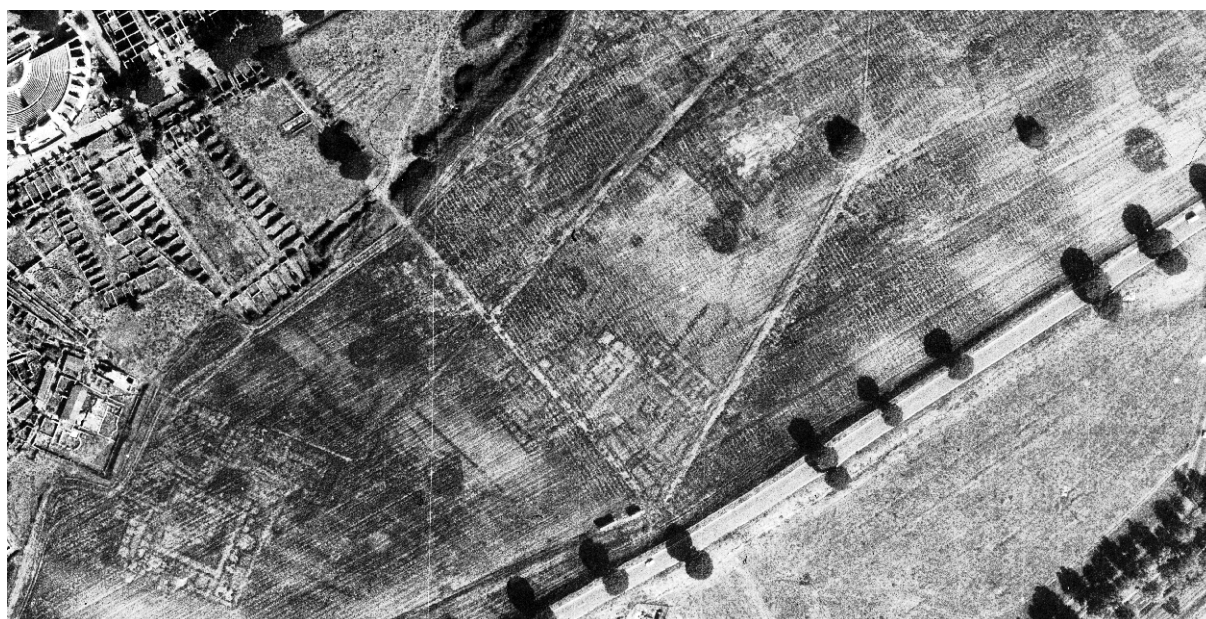


Fig. 1 **Ostia-Antica**. Extract from the b/w orthophoto of the regio V, with the so-called Via del Sabazeo (from NW to SE), the Porta Secondaria in the South and parts of the Republican city wall. The basilica (in the middle) is not very clearly shown.

As main product a scaled vektor plot of the mostly linear details stored in the database was obtained. The DTM was used again as information source when the magnetogram of the same area was treated as „orthophoto information“ in a second monoplottting evaluation process. Now also nonvisible details beneath the soil could be adressed. Georeferencing of the magnetogram has to be solved previously, which may be a serious problem in absence of really identical points in both systems. Superimposition of the two vektor plots representing the identified features in both data sources results in a more detailed and complete survey of the archeological remains. This fact is clearly shown by the example choosen here, a large basilica detected in the south of regio V (Fig. 1)

In order to set up magnetic measurements and later on archeologic excavations terrestrial surveying is needed too. As magnetic and resistivity data are collected in local square grid, spaced e.g. 40 m, this grid has to be linked to the geodetic coordinate system in which the final evaluation process takes place.

1.3 Magnetometry in quadro sensor configuration

An surface of about 15 hectare in size, the largest untouched area in the south-east of the ancient city (regio V) was selected first for geophysical prospecting in 1996. The limits of this test area were chosen very close to the excavated parts of the regio. As this area is still used for agriculture the archaeological structures should remained more or less untouched and buried not very deeply.

In a 10 days campaign in August 1996 caesium magnetometry was applied only, because resistivity surveying seemed to slow for the whole area. Moreover the temperatures sometimes above 36° Celsius, gave reason to very dry soil, which may have caused severe electrical contact problems to the ground. Therefore a very limited test for resistivity surveying was carried out only. For the first time a quadro sensor caesium magnetometer system mounted on a non magnetic chariot was succesfully tested. 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 the chariot. A 5th magnetometer can be used for compensating the daily magnetic variation synchronised in a variometer mode. Some effort has to expend to set up the whole system. Scintrex (Canada) succeeded in fast delivery even for the modified sensor-systems SM4G - Special. J Faßbinder solved many problems due to the interface electronics and the distance triggering and R. Appel succeeded finishing a software package for the data processing of the quadro sensor system. The quadro sensor configuration corresponds to a double duo-sensor configuration, which has been already successfully tested. In an open area with a smooth surface 1 hectar with 0.1/0.5 m spatial resolution (about 500,000 registrations) may be measured with the quadro sensor system in 2-3 hours. The reason for the rather slow field procedure in this case was mainly the rough surface within the investigated area.

Field survey was carried out on the base of a 40 m grid, which was marked by wooden pegs. Data processing was done during night by the normal procedure of a duo-sensor configuration with resampling and speed dependent shift correction resulting in 0.25 interpolated pixels (Becker 1999). The diurnal geomagnetic variations were corrected to the mean value of a 40 m line, which followed nicely the path of the daily variation, and to the mean value of a 40 m grid. Other effects due to the nearby traffic on the Via Ostiense could not be corrected by this method and remained in the

data. Final data processing and visualization was done using the program packages SURFER6 and OPTIMAS6 (Golden Software, USA).



Fig. 2 **Ostia-Antica 1996**. Part of the magnetogram of regio V with structures of archaeological evidence. The newly discovered basilica of Constantinus I, the Great, is visible in the corner near the gate of the Via del Sabazeo(from north to south) and the city wall to the south. Caesium magnetometry SM4G-Special in quadro sensor configuration, 40 m grid.

The interpretation of the archaeological structures within the magnetograms (sample in Fig. 2) were in some parts very simple and clear, but in others rather problematic possibly caused by the multi layer structure of building phases of this important city over the centuries. The peculiar wide positive / negative anomalies (black / white stripes in the magnetogram (Fig. 2) were 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 could be slightly improved by highpass filtering of the data.

The most significant discovery in 1996 was an early christian basilica. This could be the basilica of Constantinus I., the Great, also mentioned in the *liber pontificalis* in the vatican, clearly recognizable in the magnetogram. This nearly eastwest oriented building consisted of 3 arches with an apsis, but without a lateral hall. The part of the basilica adjacent to the Via del Sabazeo is not clearly visible, but the atrium west to the main building can be distinguished. At the southern side of the atrium a round building 9.0 m in diameter is discernible, probably the baptisterium. Also clearly visible is another older building underneath which certainly was leveled for the foundations of the basilica. This interpretation was proved by a directed sondage excavation in spring 1998. Excavations were continued in 1999 touching streets and buildings in vicinity of the basilica and will restart again in summer 2000.

2 THE PALMYRA PROJECT

2.1 Historical background and area of investigations

In Hellenistic times, the caravan city of Palmyra, situated in the Syrian desert, had almost no direct contact with the great centres to 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 cities on the Euphrates and Tigris, such as Seleucia or Dura-Europos, and later to Parthian cities such as Hatra. After the peace treaty between Rome and the Partians (20 B.C.), Palmyra had 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, was 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 is still in contrast to the actual knowledge about the city of Palmyra in Hellenistic times. The size and location of the city at Hellenistic time is completely unknown, except of the temple of Bel.

Following the ideas of Schmidt-Colinet (Schmidt-Colinet, 1997) the Hellenistic city of Palmyra is probably situated in the south of the Roman city wall of Diocletianus which is still an upstanding monument like many other buildings of the Roman age (Schmidt-Colinet, 1995). Nowadays this area is a vast field of stones and thistles but without any architectural structures to be recorded above ground. Only after careful fieldwalking some single buildings eroded to the foundations appear, but their dating is almost uncertain. In spring 1997 after a long period of heavy rains some of the buildings near the surface showed up as wet soil marks, but they vanished within several hours and could not be mapped in a larger context.

2.2 Surveying and photogrammetric recording

Magnetic prospecting has been established over the last three decades as a new promising method in archeological research (Becker 1999). Increasing the sensitivity of the instrumentation and the knowledge upon the magnetisation phenomena in the soil, today very small anomalies in the range of some Picoteslas of the local magnetic field are detectable (Fassbinder et.al. 1999).

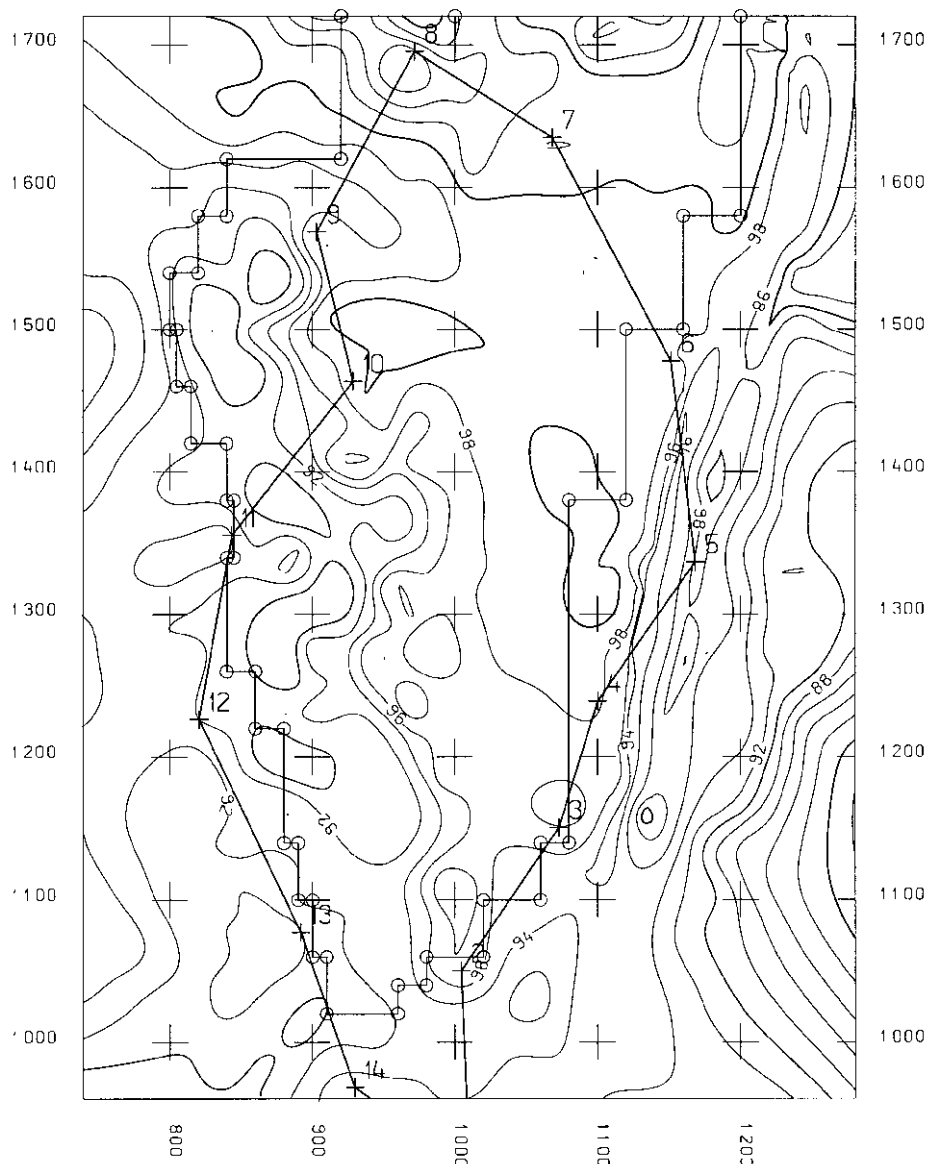


Fig. 3 **Palmyra 1997-1998**. Contour line map of the area of Hellenistic city, derived from oblique stereo photographs. At right hand side (direction to north) the wadi is distinctable. The map displays the borderline of the whole magnetogram captured so far, as well as the polygon of french archeologists (points from 2 to 14). Original map scale 1:1000, here approximately 1:5000.

Usually magnetic and resistivity measurements are carried out in a grid spaced 40 or 20 m. After setting up a 40m spaced grid over the whole area of "Hellenistic Palmyra" geophysical measurements could take place. French archeologists had fixed some years ago a local polygonal network and tracked the poor visible remains of buildings, burials and stone alignments („streets“) along the wadi (Fig. 3 and 4). This measurements were connected to the grid used for the magnetic measurements. In 1998 also the photogrammetric recording of the whole area with a hand held semimetric camera (ROLLEI 6006) was accomplished by M. Stephani. Four stereopairs were recorded from the western surrounding hills and additional mono and stereo oblique photographs were taken from the roman city wall north from the „Hellenistic city“. Previously signalized and surveyed points served as control information.

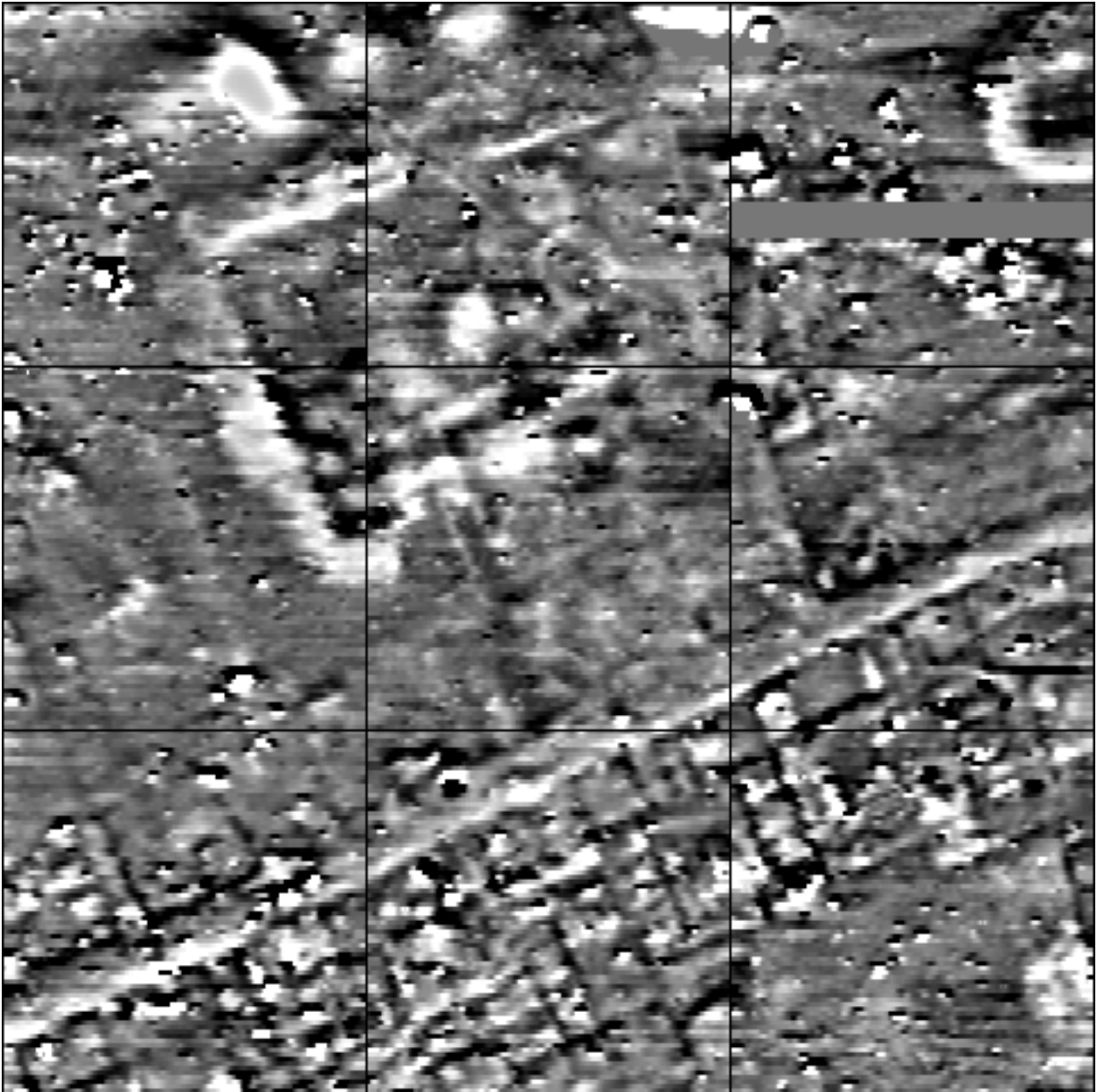


Fig. 4 **Palmyra 1997-1998**. Magnetogram of a part of the Hellenistic city, showing a major street, some narrow lanes with adjacent houses and a huge hypogeum (36 to 52 m) in the middle. Caesium magnetometry SM4G-Special in duo sensor configuration, after reduction of the diurnal geomagnetic variation by line-mean value, 40m grid, north upwards.

2.3 Geophysical prospection

In March 1997 non-destructive geophysical methods were tested first in the so named "Hellenistic city" of Palmyra for archaeological prospecting. An approximately 500 m long initial line 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:

1. **MAGNETOMETRY:** 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. Time mode sampling allowed for coverage of 1 hectare per day (400.000 measurements). Data processing was made during the night using GEOPLOT V2.2 software with graphic facilities for visualization the measurements as grey-shading plots. Caesium Magnetometry covered a total area of about 8 hectares in fifty 40x40 m squares comprising nearly 1.600.000 measurements. Magnetometry visualizes archaeological structures as negative alignments (stone walls) and also as positive anomalies for mudbricks and burnt areas (see Fig. 4).

2. **RESISTIVITY:** 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, using a 20m-grid, about 50.000 measurements). This work was done by geophysicists from Damascus University, who were trained on both instruments during this first Syro-German joint mission. Resistivity showed stone walls much clearer than caesium magnetometry, but field work is about 5 to 10 times slower. Resistivity depends upon a small amount of humidity in the soil also. Therefore resistivity surveying should be used for detailed prospecting work of specific building structures only.

In the 1998 campaign caesium magnetometry was applied with two complete duo sensor systems which were operated by H. Becker and J. Faßbinder. Almost the whole area of the Hellenistic city was prospected south from the wadi. There was only a rather small strip left south of the modern street to the oasis. This part will be measured in the near future when the modern street will be closed for heavy traffic completely. Up to now it became almost clear, that caesium magnetometry was the best method for making the city ground map of Hellenistic Palmyra.

2.4 Fusion of the available information

Ground measurement formed an unified frame for both, the topographical and the geophysical evaluation of the the measurements. Using the stereopairs about 800 more or less regularly distributed points on the surface were determined. Breaklines were also indentified within the stereos and captured. With this data a regularly spaced Digital Terrain Model (DTM) was calculated using the HIFI software package. Contour lines at a scale of 1:1000 and perspective views of the area (Fig. 5) were derived from the DTM and plotted subsequently. An orthophoto mosaic derived from oblique terrestrial images and using the DTM information is under preparation.

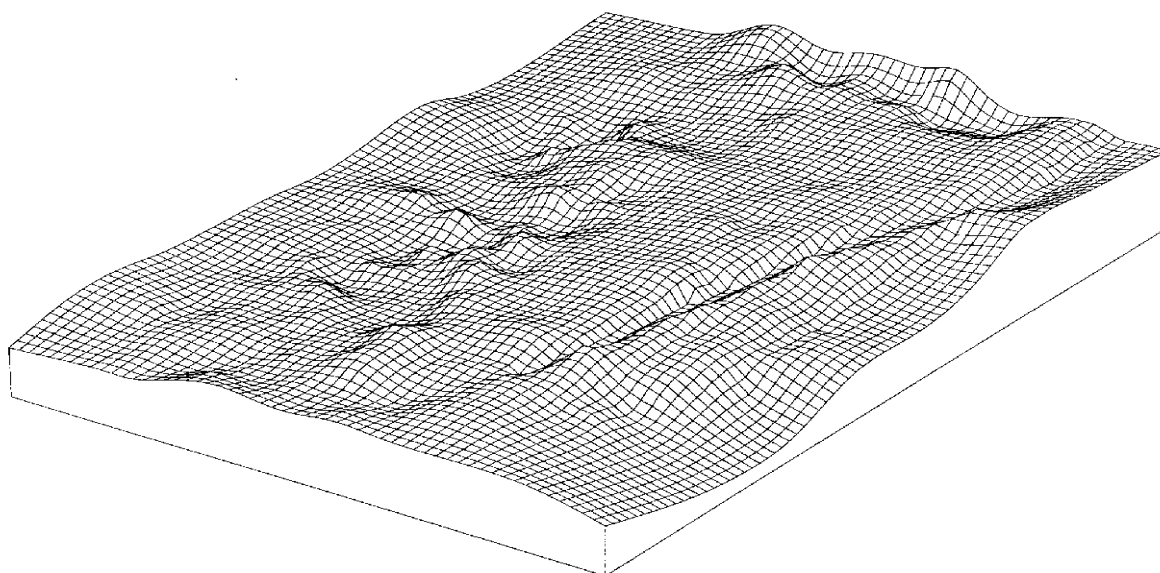


Fig. 5 **Palmyra 1997-1998.** Perspective view from NE to the area where the Hellenistic city is situated. The wadi runs from west to south-east

From the geomagnetic measurements it could be found that the „hellenistic city“ was organized by three main streets running from west to the east. The main axis was a street parallel and very close to the modern asphalt road. The next parallel street to this main axis came to an dead end on the western side. There were many narrow lanes between these two streets showing an almost radial orientation. This secondary streets were probably very active because of numerous houses on both sides. The houses could be clearly detected 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 could be found in the neighbourhood of the houses. The other axis to the west showed a quite different pattern of buildings.

The buildings were much larger in this area. This street parallel to the wadi lead to the main necropolis to the west following almost the same track used until today. In the very west of the surveyed area the trace of a wide city wall could be identified, completely invisible on the surface. Outside this city wall a very dense clustering of burial monuments was located which continues to the huge west necropolis, but there were some burial monuments inside the city also. The most exciting discovery was 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 was absolutely no trace of this building at the surface. Especially its western half could be seen in the magnetogram clearly, possibly due to a rather strong magnetized filling of the excavation for the subsurface building. This structure was also tested by resistivity 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 area between these two northern streets was found completely free of any building structures except some ovens and some small graves.

Using the coordinate system fixed by the surveying field work a small area was selected in late spring 1999 for a first archaeological test excavation proving the structures in the magnetograms and their interpretation. This excavation work of several houses along the main street will be continued an april 2000. Field work of surveyors and archeologists is intended to be visualized this year with the LISCAD software using field computers.

3 CONCLUSIONS

Also the use of aerial photography and photogrammetry is not even new in archeology, the digital age opens the door to the combination of the gained geometric and/or semantic information from images with information obtained from other sensors. This should be taken into account especially when the sensors deliver "images" like magnetometry and resistivity. As aerial photography has the drawback, that even in absence of evidence of archeological remains in the photos, this does not necessarily mean that there are no archeological remains buried in the ground, other method of evidence are highly demanded. From our experience with combination of magnetic prospection with aerial images both disciplines can support each other. The aerial images more often give an initial starting point for more detailed research of a special area. They also can establish a stable geometric frame for detailed investigations and excavations. Ground research methods are usually less fast. They deliver more detailed information of the object beneath the soil. Future improvements of this systems will be possible with quick and precise positioning systems. Differential GPS with accuracy in the order of centimeters is well suited for this task and will speed up field work considerable. Differential GPS technique assures a larger flexibility in defining the borderline of the area to be investigated, because the field registrations are quasi simultaenously recorded and ground coded. Data recording in profil mode can be substituted by a dedicated point to point registration. Adequate interpolation, smoothing and visualisation procedures have to be developed in the future.

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