REPORT ON A GEOPHYSICAL PROSPECTION OF THE NORTHWEST QUARTER OF GERASA / JARASH 2011

Georg Kalaitzoglou, Rudolf Knieß, Achim Lichtenberger, Dana Pilz and Rubina Raja

Introduction

In 2011, a Danish-German project to investigate the north-west quarter of ancient Gerasa / Jerash was begun (see report by Lichtenberger and Raja [this volume]). The project is funded by the Deutsche Forschungsgemeinschaft (DFG) and the H.P. Hjerl Hansen Mindefondet for Dansk Palæstinaforskning. The first season included an architectural field survey, geodetic survey and geophysical survey. The main aim of the project is the investigation of the urban layout of this quarter; on the basis of the results of the 2011 season, it is intended that excavations will continue for many years to come. Fieldwork took place between 5 and 19 September 2011, involving a joint team from Aarhus University and Ruhr University Bochum. The geophysical survey was carried out by Rudolf Knieß and Dana Pilz of the Berlin-based company Eastern Atlas.

The north-west quarter of Gerasa is the most elevated area within the walled city, being located on an extensive hill with some steep slopes. Almost the entire area is covered with stones and blocks of archaeological origin, up to 1m across. The bedrock, which is intermittently visible on the slopes, consists of karstic limestone. Archaeological structures related to buildings and terracing can be identified, consisting for the most part of limestone blocks.

The area was challenging for geophysical survey; the complex topography, steep slopes and uneven soil coverage made it impossible to walk easily across the terrain whilst maintaining the constant contact with the ground required by ground-penetrating radar (GPR). Furthermore, the archaeological features consist of limestone with similar geophysical characteristics to the underlying geology. Two methods, *viz*. magnetometry and GPR, were tested. In the event, it turned out that only a large scale geomagnetic survey would yield useful archaeological results. The Eastern Atlas MAG-DRIVE system was therefore converted so that the magnetometry sensors could be carried over the area (**Fig. 1**). Three small fields with little surface disturbance were also selected for GPR survey. In total, an area of almost 4 hectares was surveyed.

Differential GPS and Data Positioning

Data positioning for the geomagnetic survey was achieved through differential GPS, using single frequency Novatel receivers. The system rover was attached to the magnetic array and carried over the investigated areas. A relative data accuracy of 0.1m can be assumed. For the positioning of the GPR data, the corners of the survey fields were recorded by GPS and then related to the geomagnetic data. For the precise overlay of archaeological and geophysical survey data, a local point adaption was applied. These images are available in Palestine 1923 / Palestine Belt projection and are easy to reproject into any co-ordinate system required[1].

Geomagnetic Survey

Geomagnetic anomalies are caused by changes in the complex magnetic properties of

1. Transverse Mercator Projection and the Palestine 1923 geographical datum were used here. To comply with the local Jarash grid, co-ordinates had to be shifted 1.1m to the west. We thank the Department of Antiquities at Amman for helping us to obtain the relevant measuring points. We would also like to thank Thomas Lepaon (Jerash Archaeological Project, University of Tours) for information regarding the geodetic survey.

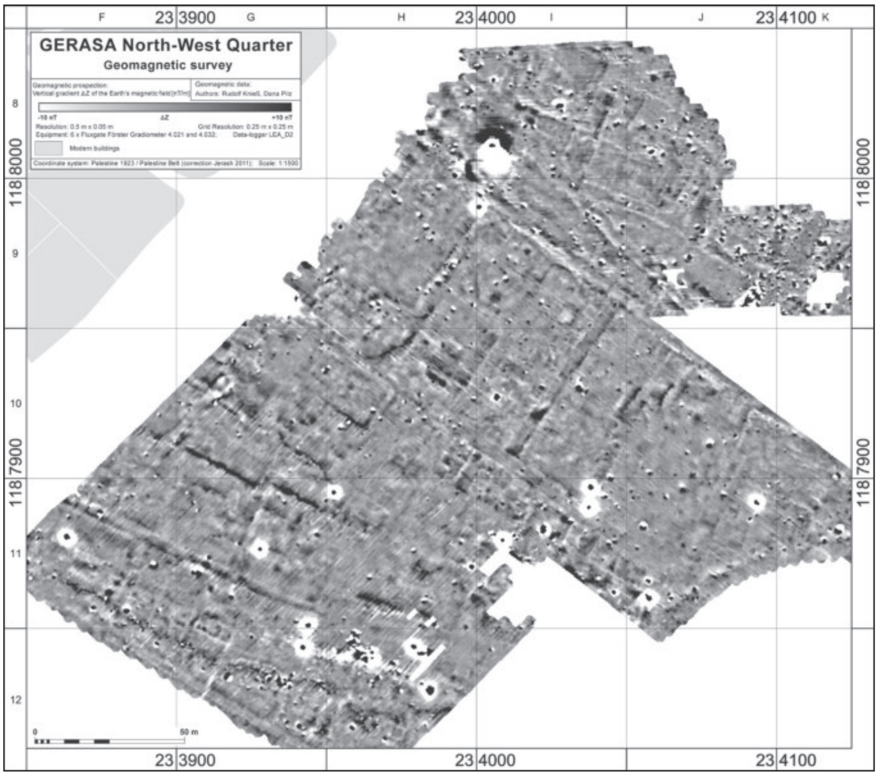
1. *The MAG-DRIVE geomagnetic system at work.*

the soil. The amplitude of the magnetic anomalies is determined by contrasts in magnetic susceptibility between archaeological structures and the surrounding soil, as well as by the volume and depth of the magnetic structure. Generally, iron oxides such as haematite, magnetite or maghaemite are carriers of magnetisation. These minerals are ubiquitous in the soil, in the form of microscopically small grains. As a result of microbiological processes, these minerals accumulate in pit and ditch fills, especially within organic materials. In the survey under discussion here, the main building material is limestone, which does not generally carry any iron oxides. Negative magnetometry readings can therefore be expected for subsurface archaeological structures. A second type of magnetisation is caused by fire. The amplitude of magnetic anomalies derived from thermoremnent magnetisation is usually noticeably higher than magnetic anomalies in unburned materials. Kilns and accumulations of pottery, bricks and tiles can often be detected on this basis. As geological and modern structures can produce strong magnetic anomalies which differ in shape and type, it is sometimes possible to distinguish between them. Furthermore, modern disturbance such as iron pegs (from previous archaeological surveys) and scrap metal on the ground surface can be identified as dipole anomalies of very high amplitude. For the geomagnetic investigations at ancient Gerasa, an array of six fluxgate gradiometer probes was specially built for the survey. The three-wheeled, MAG-DRIVE hand cart carrying the probes was modified to allow the array to be carried by hand (**Fig. 1**). Instead of the wheels, two wooden handles were attached to the system. This made it possible to cover wide areas and investigate steep slopes and areas of dense stone coverage. The probes register the gradient of the vertical component of the Earth's magnetic field with an accuracy of 0.1 nT (nanotesla). The measured gradient (i.e. the difference between two vertical sensors in a gradiometer probe) is insensitive to the large background fluctuations in the Earth's magnetic field and is only affected by the magnetisation of local anomalies in the ground.

The results of the geomagnetic survey are presented at **Fig. 2**, with grey-scale values of ±10 nT which give a good overall impression of the features detected[2]. **Fig. 2** includes the survey boundaries and clear dipole anomalies (negative minimum and positive maximum) with amplitudes of more than ±50 nT, which are considered near-surface metal objects of modern origin. Large dipoles mostly result from large iron pegs remaining in the ground.

Promising results were obtained under current ground surface conditions. Looking closely at the data, it can be seen that – in addition to numerous archaeologically relevant anomalies – there are a number of heavily disturbed zones. These effects are mostly associated with

2. Grey-scale images are available in dynamic scales of ±5 nT, ±10 nT, ±20 nT, ±50 nT and ±100 nT.



2. Map of the geomagnetic survey area, including grey-scale image with a dynamic scale of ±10 nT (nanotesla) and dipole anomalies (modern iron).

very steep slopes or areas of high stone density. In these areas it was impossible to achieve the continuous perpendicular direction of the sensors needed for gradiometer measurements. Tilted sensors cause 'stripes' in the magnetic data. Furthermore, the array was carried at different heights over the ground depending on the topographic gradient. The presence of stone fragments on the ground surface also influences data quality. Despite these complicating circumstances, there are numerous clear anomalies in the geomagnetic data which are indicative of archaeological features. This is because of the care taken during the survey to record long profiles on substantial connected areas. The data show that steep slopes and the 'ridges' of the terrace system correlate with elongated positive anomalies in the geomagnetic data. As for the linear negative anomalies, the fact that both surface and subsurface structures are displayed in the data should be taken into account.

An attempt at archaeological interpretation was made on the basis of the grey-scale plots (**Fig. 3**). By including co-ordinates of visible surface structures, the interpretation can be refined further; even weak anomalies might indicate archaeological features. Owing to the complex ground conditions and presence of surface stones, only obvious structures were marked. These are shown at **Fig. 7**. With the exception of near-surface metal objects, the present interpretation distinguishes between two types of anomalies:

(1) Dark grey, *viz*. negative anomalies with amplitudes between –5 nT and –20 nT. These tend to represent linear features like walls or stone settings, but can also point to single stones. Negative anomalies are caused by diamagnetic and paramagnetic materials like limestone, which is the primary building material in this region.

(2) Light grey, *viz*. positive anomalies with amplitudes between +5 nT and +20 nT. These probably indicate pit and / or ditch fills, or backfills associated with collapse. In the southern part of the survey area these anomalies highlight the terrace system and also indicate steps in the terrain.

Ground Penetrating Radar (GPR)

Ground penetrating radar (GPR) works by projecting high frequency electromagnetic waves into the ground. The waves are reflected and refracted by different layers and features such as stones and walls. Analysing differences

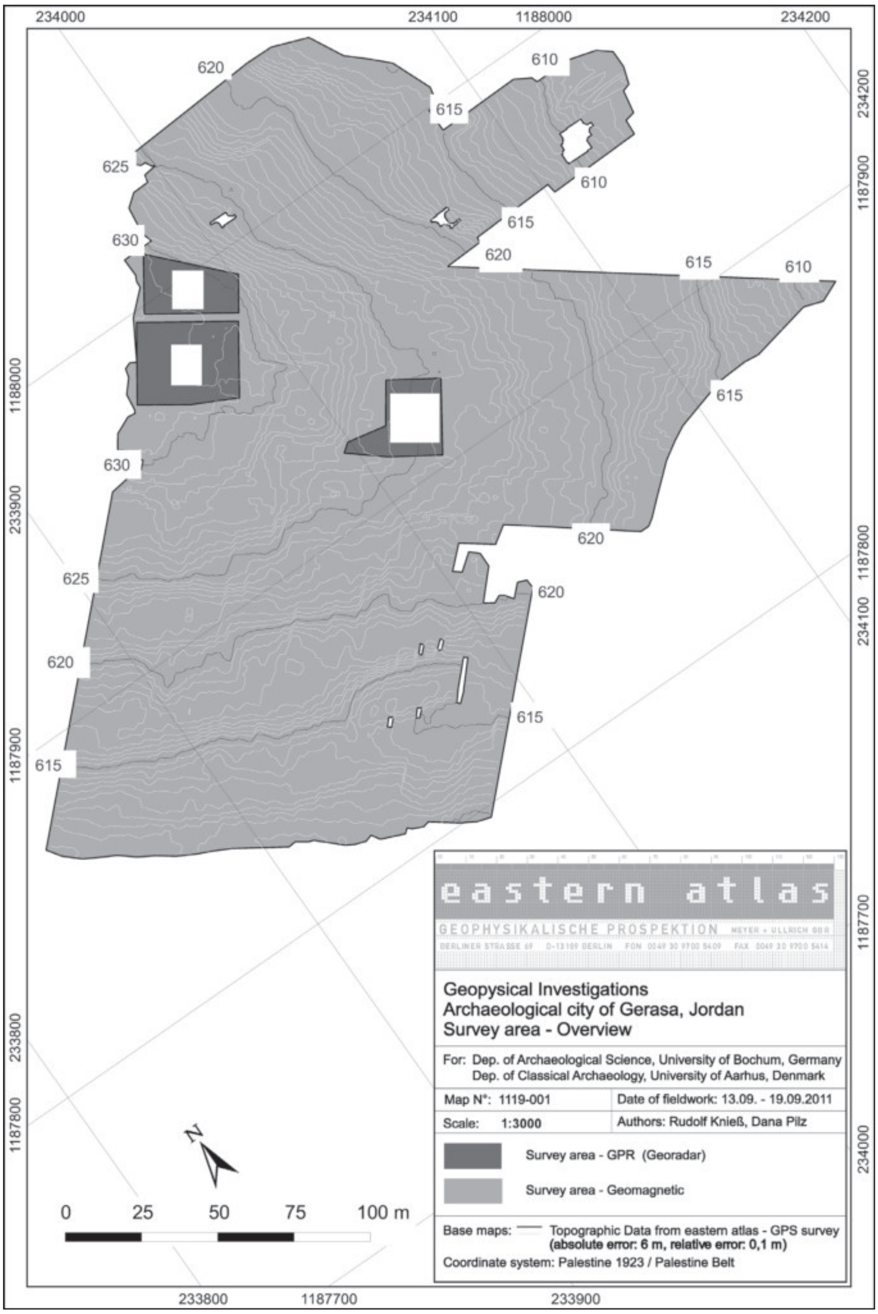
3. *Map of the geomagnetic survey area, including grey-scale image with a dynamic scale of ±10 nT (nanotesla), dipole anomalies (modern iron) and topographic features.*

in the travel time and amplitude of the electromagnetic waves gives information about the position, depth and specific properties of buried objects and layers. Spherical resolution and depth of penetration depend on the GPR antenna's frequency and the electromagnetic properties of the ground. As a rule of thumb, higher frequencies give better spherical resolution, but reduced ground penetration. At Jarash, an SIR-3000 GPR system with a 270 MHz antenna was used. Owing to soil conditions, the electromagnetic waves did not penetrate deeply and retained only minor reflections. Nevertheless, GPR was used at three small sites where geomagnetic data showed only a few archaeological features. The chosen fields were the flattest in the survey area and had comparatively few stones on the surface. The location of the GPR investigation areas within the geomagnetic survey area can be seen at **Fig. 4**.

For presentation and interpretation, the GPR data (vertical profiles) were converted to horizontal sections, i.e. so-called time slices. The data are displayed at three depth levels. Each section represents a time interval of 10 ns (two-way transit time). The physical layer thickness of *ca.* 0.50m results from an estimation of the average electromagnetic wave propagation velocity of v = 0.10 m/ns. This estimate of velocity is based on an analysis of reflection signals in the data and soil characteristics found on the site. The horizontal sections show the distribution of reflective objects and structures at different depths. Highly reflective structures such as fills or stones appear in black.

Results

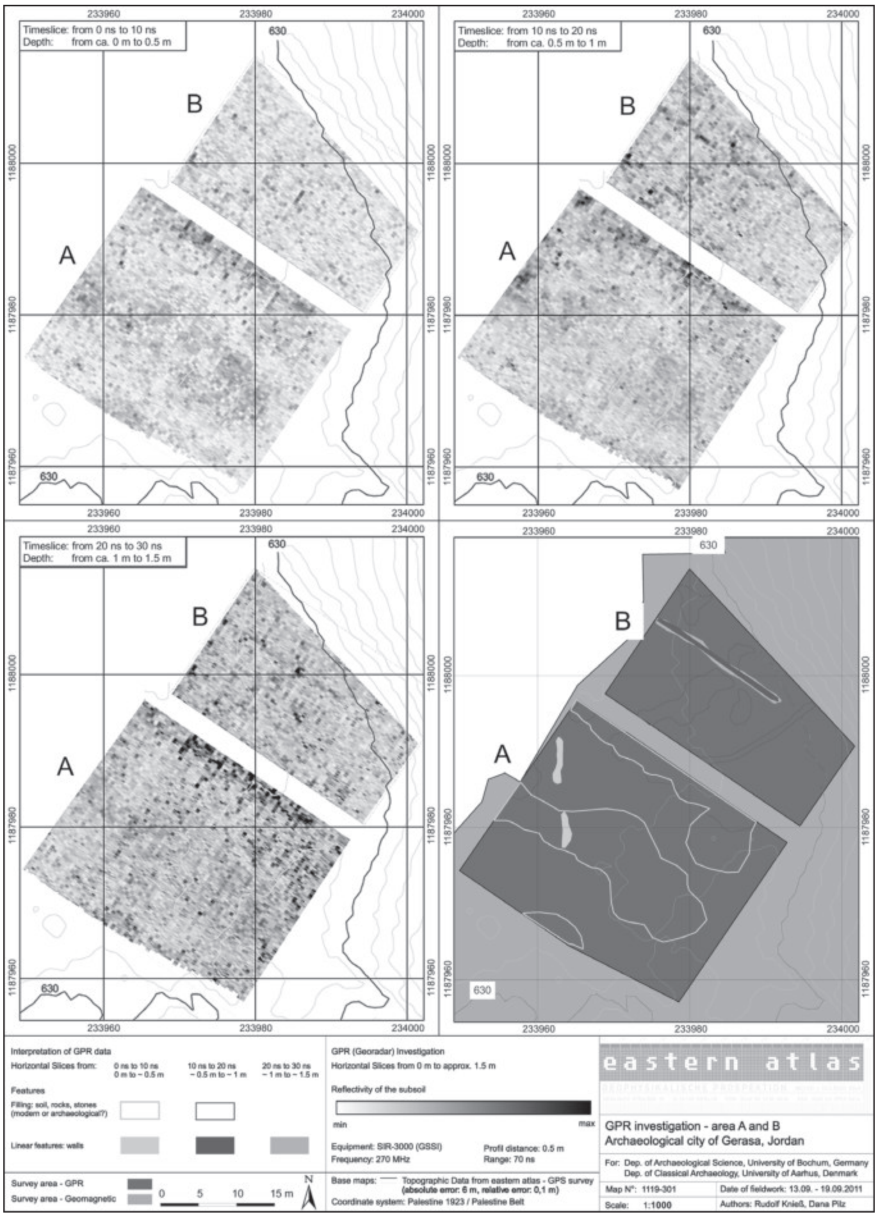
The GPR data are displayed in three depth levels from 0 m to a maximum depth of 1.5m, representing layers of 50cm thickness. The time slices and interpretation are found at **Fig. 5** for Areas A and B and **Fig. 6** for Area CD. Owing to the ground surface conditions, only small areas could be investigated by GPR. The electromagnetic characteristics of the archaeological features were akin to the soil, so their identification was nearly impossible. Stone fragments on the surface cause small black dots (marking areas of high reflectivity) to appear in the uppermost time slice of all investigated sites. This is due to antenna uplift being expressed as a multiple reflection. Additionally, it should be noted that the geomagnetic data display little evidence for archaeological features in the GPR areas.



4. Geophysical survey area: overview with the georadar (GPR) areas.

In Areas A and B, only weak, fuzzy differentiations of electromagnetic reflectivity can be determined. These most likely relate to modern fills, but this needs to be verified. Some weak linear indications may relate to walls. Area CD displays relevant reflection signals only between the depths of 0.5m and 1m. Two linear features are present, which correlate well with geomagnetic anomalies. These features possibly relate to walls or street structures. Less defined fuzzy areas were also noticeable and most likely relate to areas of debris fills.

The GPR data are not as clear and interpretable as the geomagnetic results. The soil conditions did not allow the electromagnetic waves to penetrate to sufficient depth and the physical properties of the structures of interest did not differ from the properties of the surrounding soil. Nevertheless, some linear features characterised by higher reflectivity were found in all three investigated areas, which may indicate stone settings or walls. In Area CD, they accord with the

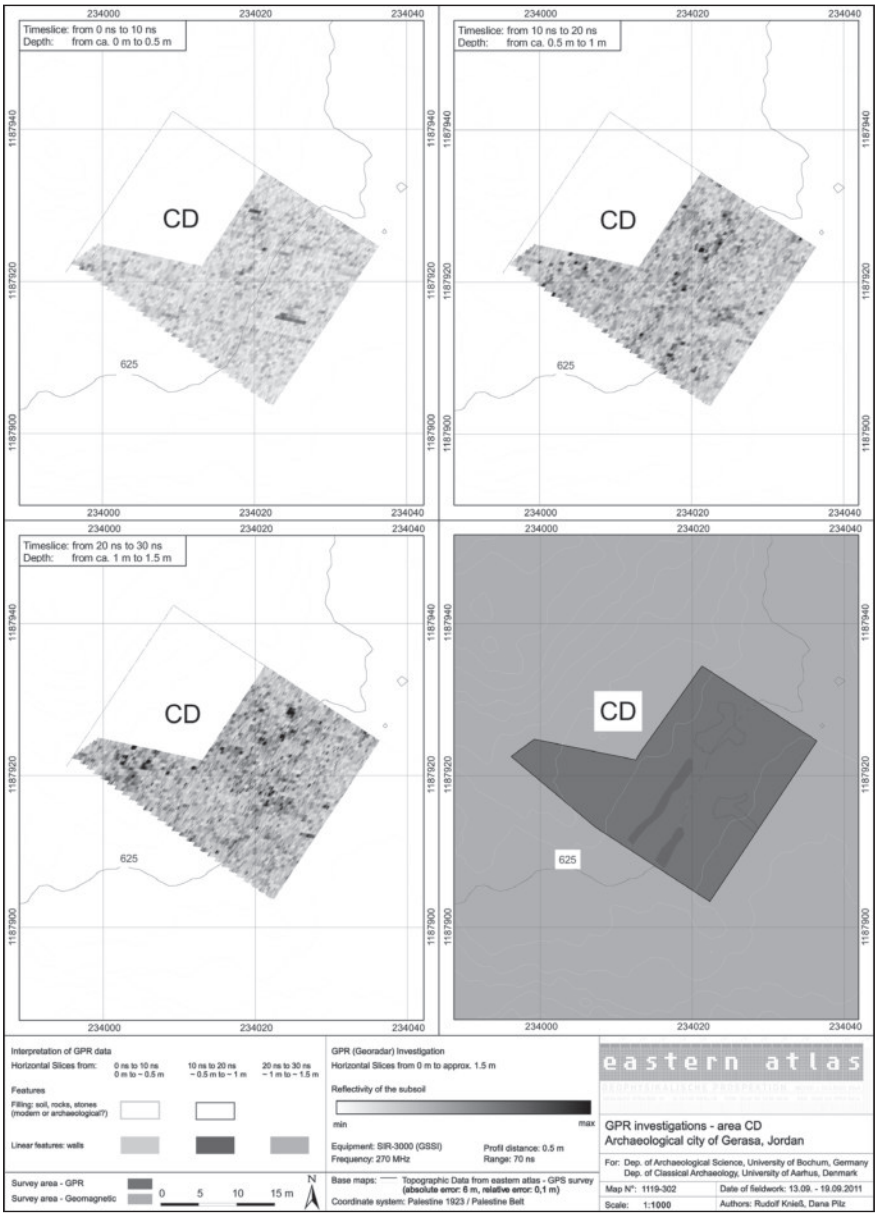


5. GPR investigation: areas A and B.

geomagnetic anomalies, whereas in Areas A and B they accord neither with the magnetic anomalies, nor with surface features. Finally, zones of debris fill – most likely of modern origin – were found in the GPR survey areas.

Archaeological Interpretation

The archaeological interpretation must be undertaken with due caution, because some effects (e.g. those produced by drainage systems or clay water-pipes) cannot yet be sufficiently differentiated. On the other hand, it is evident that pottery leaves distinct anomalies, as can be seen at **Fig. 7** (squares F-10 and G-10). There, the bulldozed soil located parallel to the track leading up the hill is full of pottery and gives a strong positive reflection. Although the magnetograms (**Figs. 2** and **3**) show several more anomalies, which seem to correlate with architectural structures, more precise interpretation will require further archaeological investigation. Comparison between the structures visible on the surface and the results of the geomagnetic survey is therefore based only on the most clearly defined features (**Fig. 7**) and focuses on methodologically relevant observations. For a better understanding of **Figs. 3, 7** and **8**, the surface structures measured by tachymeter are illustrated in black outline only.



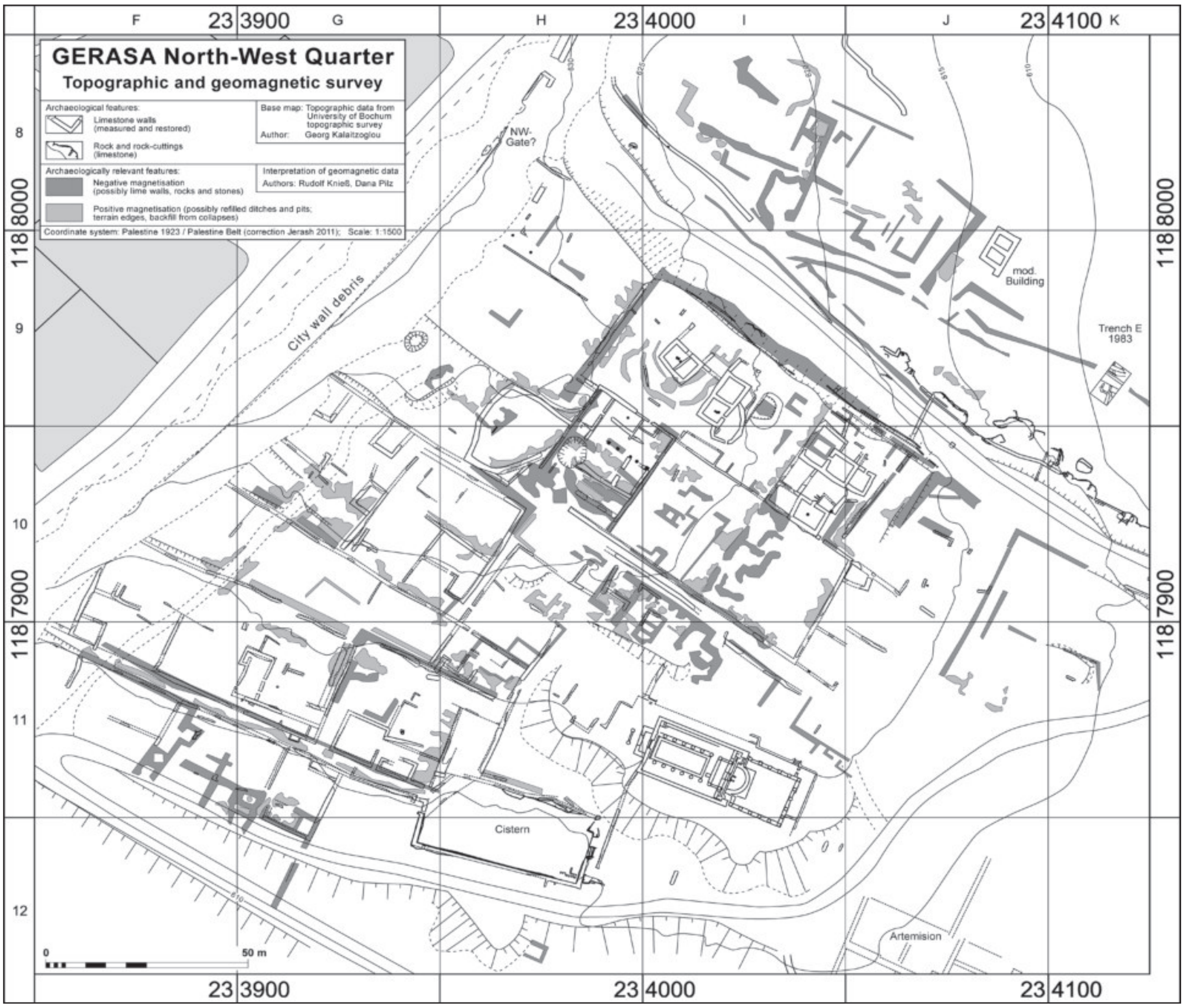
6. GPR investigation: area CD.

Negative Conclusions

Limited or negative conclusions are few and can be minimised with a combination of geodetic measurement and geomagnetic survey. Topographic effects are recognisable in the southern part of square G-10 (**Fig. 7**), as well as further to the south and south-west where a few anomalies occur between terraces as a result of the steep slope. The same is true for the eastern half of square H-11, where none of the measured walls and structures could be detected west of the Synagogue Church. Even the edges of the rock-cut cistern further south failed to yield a distinct anomaly. On the terrace north of the South Road (**Fig. 7**; squares F-10 / 11 to H-11), only a few anomalies – mostly fills or wall debris – were identified.

Even the low cliff behind the modern dirt road at the northern limit of the north-west quarter of the site yielded no coherent anomalies (**Fig. 7**; squares I-9 to K-10). As for the northern limit of the uppermost building terrace (**Fig. 7**; square I-9), there doesn't appear to be sufficient differentiation between the natural rock and the narrow retaining walls that could be measured with the tachymeter. In this area, the magnetogram displays only a clear linear anomaly.

In sum, the magnetograms display only por-



7. Topographic map of the north-west quarter with the clearest geomagnetic features.

tions of the walls and buildings preserved on the ground surface. This appears to be the result of low magnetic contrast caused by a lack of surrounding soil. In combination with terrestrial measurements, this could be assessed as a positive effect because the geomagnetic survey shows mainly subsurface features.

Positive Conclusions

In multiple areas, the results of the geomagnetic survey have aided completion of our surface plans. The geomagnetic survey filled some gaps in the terrace walls and, most importantly, identified previously unknown subsurface structures (cf. **Fig. 7**). Some of the main results are presented below.

In addition to the late Antique / early Islamic houses visible on the north terrace of the summit, some structures and obvious fills are visible both underneath and beside them (**Fig. 7**; square I-9). The structures on the same terrace with a north-east - south-west orientation probably belong to an older terrace layout (**Fig. 7**; square I-10). It is clear that these structures are situated underneath the late Antique / early Islamic houses, as they only partly correspond to the terrace layout. The distinct negative anomaly in a robbed pit on the north terrace (**Fig. 7**; southern end of square I-9) is most probably caused by a great monolithic altar of igneous rock lying within it[3]. Just to the north-east, a small room is recognisable which was not visible before and must therefore

3. Cf. fig. 8 in Lichtenberger and Raja (this volume).

8. Satellite photo (Google Maps), showing Fig. 6 and the supposed course of the North Decumanus.

be associated with an older terrace layout.

Under the so-called Ionic Building (**Fig. 7**; north-east corner of square H-10), massive substructures occur giving an impression of the original ground plan of this building. This area will be investigated during the 2012 season. It was a great surprise that the large courtyard to the south-east (**Fig. 7**; square I-10) contains structures of a different kind, as well as a possible street leading from the northern to the southern extents of the upper building terrace. This demonstrates that the layout of this terrace was altered more than once in its history. Not known before, as it was not visible on the ground surface, is a row of smaller and larger rooms behind a street lying to the south of the great rectangular courtyard (**Fig. 7**; squares H-10 and I-11). The series of rooms and houses continue along the street towards the east. This demonstrates that the hill was not completely covered with parallel terraces, but that the terraces followed the topography along its southern flanks and were reduced in size at their eastern ends.

At the eastern end of the hilltop, which is today littered with stones and debris that give no indication of ancient structures, interpretation of the magnetic features revealed another large terrace with sharp contours around the point where squares J / K-10 and 11 intersect. At the other end, near the ancient city wall, one can see the corner of a building under a recent football pitch (**Fig. 7**; square H-9). This structure, which is not visible on the ground surface and was not detected by GPR (cf. **Fig. 5**), is preserved under modern backfill; it will be explored during the 2012 season.

On the southern hill slope, the anomalies confirm the location of terrace walls and the retaining walls of the South Road. Further south (**Fig. 7**; squares F-11 and G-11), the geomagnetic survey gives a detailed impression of subsurface structures which can easily be interpreted as walls and rooms. These serve to complete the architectural plan of this terrace and also confirm that the terrace system does not end at the level of the modern dirt road[4].

At the northern edge of the summit, parallel to the modern dirt road, a long and narrow anom-

4. Cf. the wall in square G-12 (**Fig. 7**) leading down the hill; the southern hill slope was evidently completely built over with terraces.

aly was detected. This is the southern retaining wall of the main road used in modern times to enter the city area from the north-west[5]. While its southern retaining wall gives a clear reflection, the northern part does not - although it was measurable by tachymeter. The area immediately north of this road was only partly investigated in 2011. However, it already seems clear that this area was of great importance to the general character of the north-west district, because one of the main axes, *viz*. the North Decumanus, must have been located in this area. North of the modern dirt road, in the depression below the rocky ridge, two parallel anomalies with positive magnetisation lead in a smooth curve from east to west (**Fig. 7**; squares I-9 to K-9). These give the impression of a broad street, which in this area might be the North Decumanus. The unsurveyed area (cf. **Figs. 2** and **3**) marks Trench E, which was excavated in 1983 by an American - British team (Clark. and Bowsher 1986: 343-345, figs.1-3 and pl. I) and measured 5 to 10m. Although this trench reached bedrock 3.8-4.5m below the ground surface and yielded some walls and two columns (**Fig. 7**; square K-9)[6], the excavators did not believe they had found the remains of the North Decumanus. They assumed that the street would not follow a straight line from the North Tetrapylon to the North-West Gate and from the condition of the bedrock surface concluded that it had never been paved with stone (Clark and Bowsher1986: 345).

The excavations at the North Tetrapylon demonstrate that the Tetrapylon, Cardo and North Decumanus are not regularly arranged in relation to each other (Ball *et al*. 1986: 372, fig. 11). If the North Decumanus followed a straight line it must have crossed Trench E, as can be seen in **Fig. 8**. Only the northern edge of its course seems to correspond with some of the anomalies; it would cross the curving course of the thin parallel lines, which might therefore represent a more recent street at a higher level. However, the Decumanus would then have crossed some of the rock edges, which is less plausible. If the narrow line crossing Trench E can be identified with the narrow excavated wall, it would mean that the geomagnetic survey reached a depth of 3.2-3.4m below the ground surface (*ca.* 0.6-0.9m above bedrock), which would be surprising. In order to solve the question of whether the course of the North Decumanus takes both topography and rock formation into account, it will be necessary to ascertain the exact position – as yet unknown – of the north-west gate.

Acknowledgements

The team was supported by members of the Department of Antiquities throughout the season. We would like to thank Acting Director General, Fares A.K. Hmoud, for facilitating our work at Jarash in 2011. We would also like to thank Ahmed Shami and Akram Aiktoum from the Jarash Antiquities Department who supported us both scientifically and logistically. Our work was greatly facilitated by the kind support of Abdel Majjid Mjely and residence in the Archaeologists' Camp. We would also like to thank Jihad Haroun and Khalil Hamdan for friendly and professional advice and guidance. We would like to note that the German Protestant Institute of Archaeology in Amman provided considerable help; in particular, we would like to thank Dieter Vieweger, Jutta Häser and Nadia Shuqair. Finally, we would like to thank Louise Blanke, Thomas Lepaon, Jacques Seigne, Alan Walmsley and Thomas Weber for assisting us before, during and after the season.

Bibliography

Ball, W., Bowsher, J., Kehrberg, I., Walmsley, A. and Watson, P.

1986 The North Decumanus and North Tetrapylon at Jerash: an archaeological and Architectural Report. P. 372 in F. Zayadine (ed.), *Jerash Archaeological Project 1981-1983*. Amman.

Clark, V.A. and Bowsher, J.

1986 A note on Soundings in the Northwestern Quarter of Jerash. Pp. 343-345 in F. Zayadine (ed.), *Jerash Archaeological Project 1981-1983*. Amman.

5. Cf. fig. 3 (BayHSTA BS-Palästina 1129a) in Lichtenberger and Raja (this volume).
6. For the time being it has only been possible to locate Trench E approximately on the plan; new mapping is planned for the 2012 season.