· CHAPTER ELEVEN ·

Geophysics

Jamon Van Den Hoek and William Aylward

INTRODUCTION

This chapter weighs the results of the remote sensing program at Zeugma 2000 against topographical features of the city discovered in the rescue excavations, and it makes use of unpublished reports provided by two contractors who carried out independent surveys: Stratascan Geophysical and Specialist Survey Services and GSB Prospection.[1] Geophysical survey at Zeugma commenced after rescue excavation had already begun. Nine surveys (Surveys A–I) were conducted between zones of active excavation, and one of these, Survey A, was tested by excavation towards the end of the rescue project (fig. 1). Most survey areas, like the areas of excavation, are now underwater and thus contain information about an irrecoverable resource, but the data collected provides vital points of connectivity for reconstruction of the ancient city plan. For example, results of the geophysical surveys corroborate archaeological evidence for placing the terraced promontory that overlooked the Euphrates River from the city center at the core of the Hellenistic town. Unlike streets in other parts of the city, alignments in this sector match those on the opposite bank at Apamea. The bridgehead was almost certainly here, on the riverbank below the promontory at Zeugma. While Apamea diminished in Roman times, Zeugma flourished, and residential districts sprang up along the river's west bank on both sides of the promontory. The geophysical surveys reveal different street and house alignments for these residential districts, and in some cases even specific boundaries between zones of development. This data enhances our ability to reconstruct the development of Zeugma's city plan and to chart functional and topographical relationships between Apamea and Zeugma through time.

Also important are topographical connections suggested by the geophysical data for parts of the city now beneath the Birecik reservoir and unthreatened parts of the

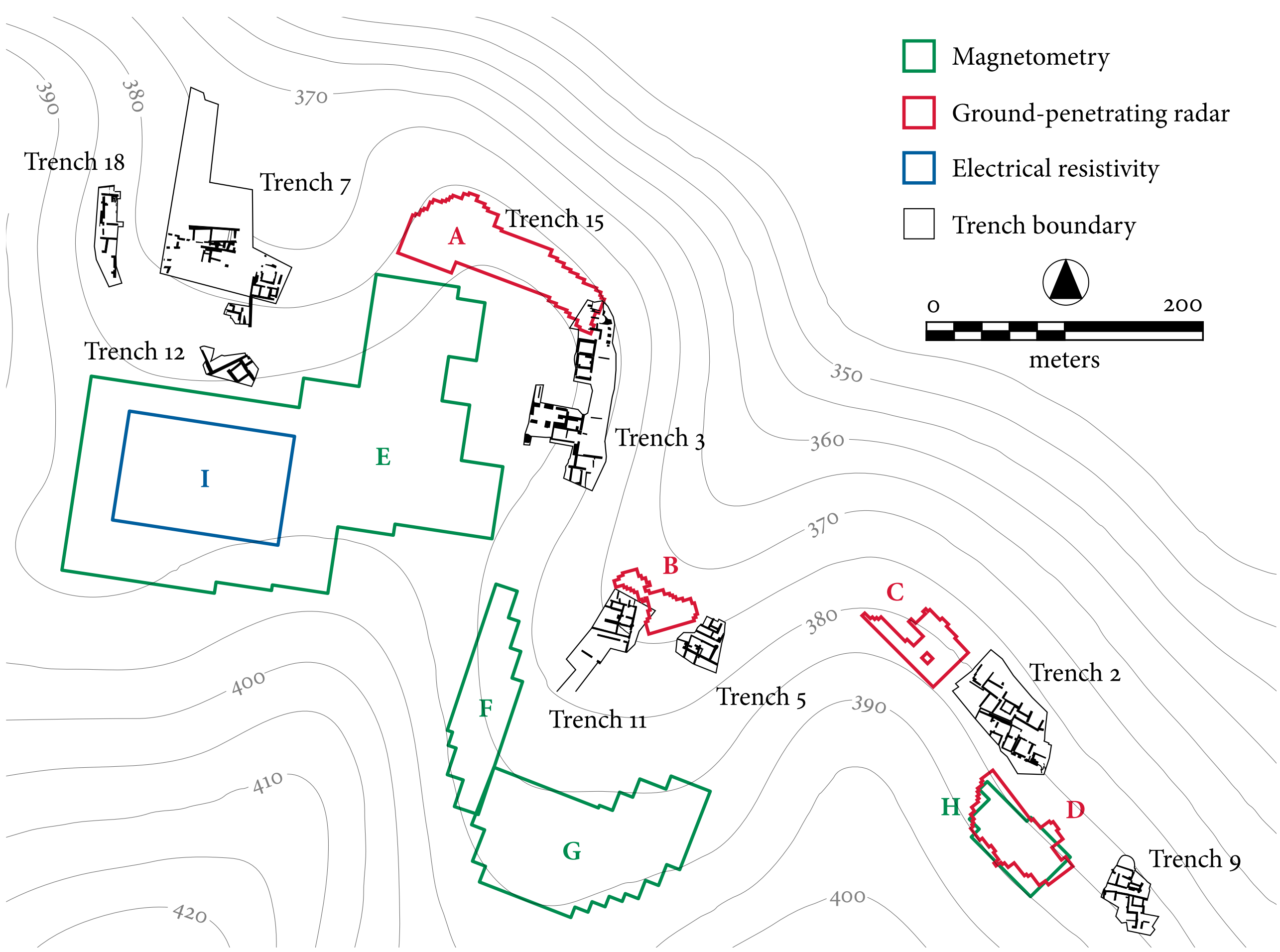
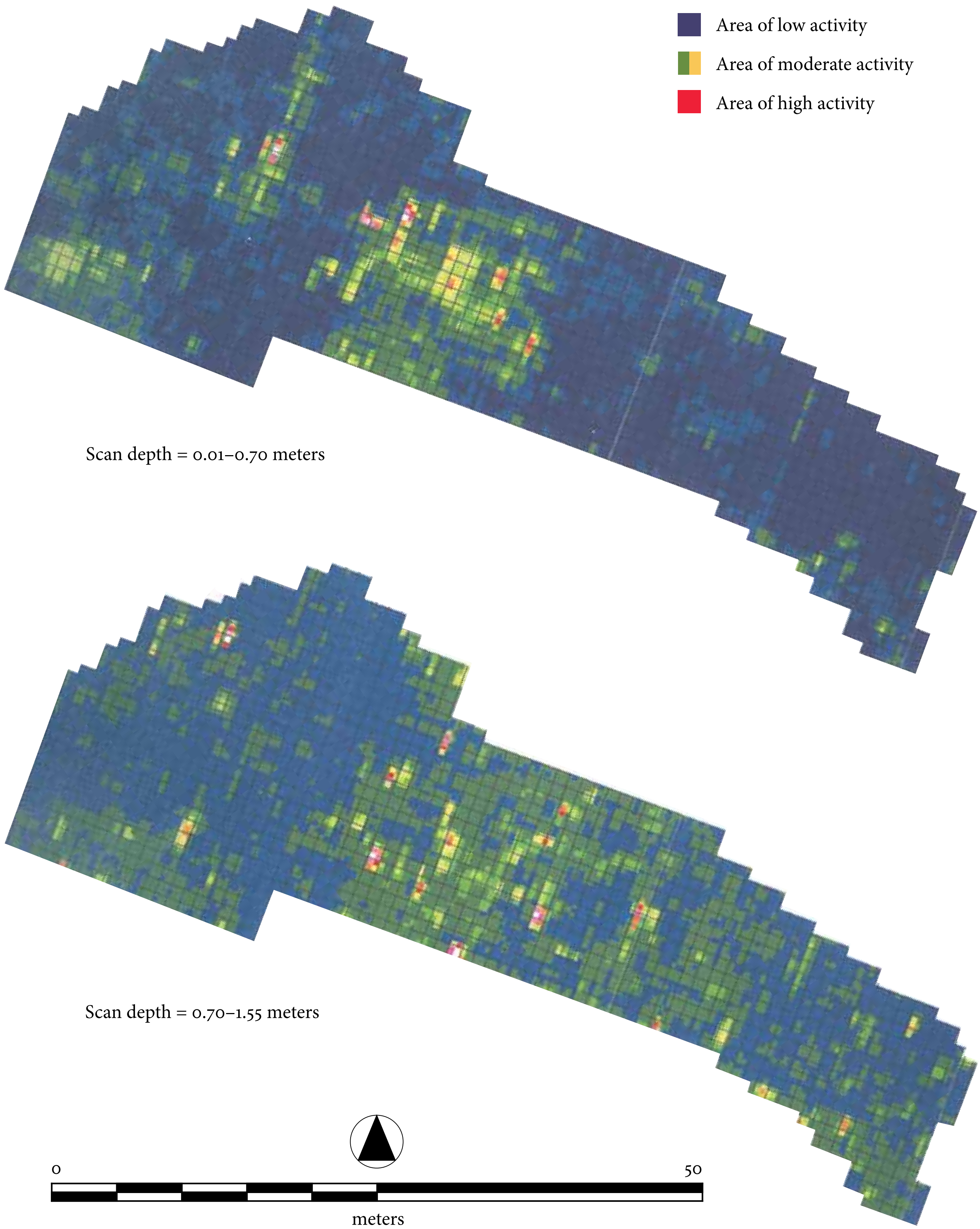
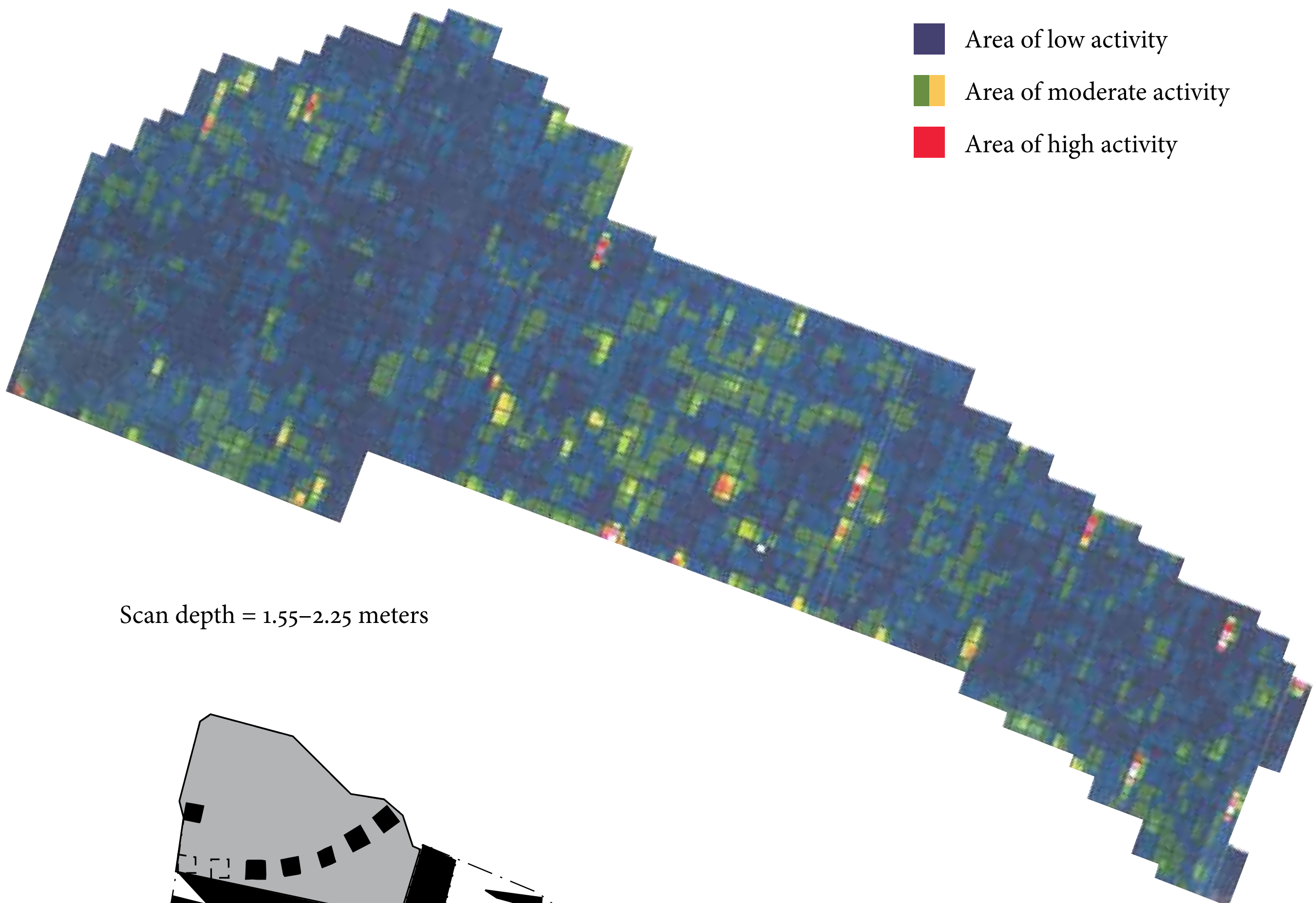


Figure 1. Orientation plan, showing areas of geophysical survey and method employed.



Figures 2a (top) and 2b. Survey A. Ground-penetrating radar (GPR). Grid = 1-m intervals.



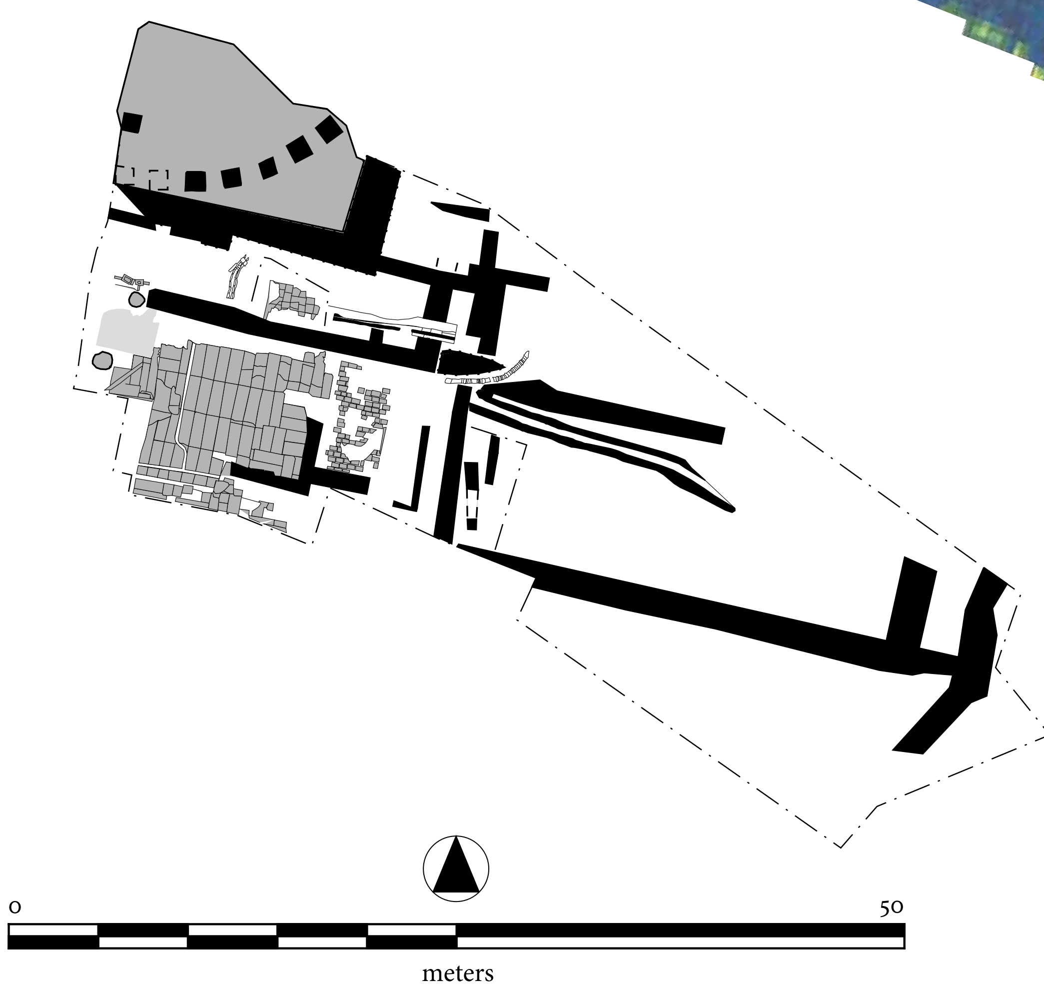


Figure 2c (top). Survey A. GPR. Grid = 1-m intervals.
Figure 2d (bottom). Features excavated in Trench 15 within area of Survey A.

city available for further investigation. The authors hope that the following discussion of methodology, data, and interpretation will be useful as a case study for geophysical survey both in the Euphrates Valley and in the context of rescue archaeology, and that it will complement results of geophysical survey at the now flooded site of Apamea, once on the east bank of the Euphrates, and at sites proposed for military installations on the west bank near Zeugma.[2]

METHODS

Overview

Methods used for geophysical survey during the archaeological rescue work at Zeugma in 2000 were magnetometry, electrical resistivity, and ground-penetrating radar (GPR). About 20,000 sq. m were surveyed, with two surveys, I and E, covering some of the same ground with different methods.[3] In general, the tripartite methodological scheme for geophysics at Zeugma 2000 produced reliable data that contribute to meaningful reconstruction of the city's urban topography. The three ground-based methods for subsurface prospection applied at Zeugma are distinguished by the way geophysical signatures are measured. Results for each method varied against the archaeological profile for the site, which is covered by mature pistachio orchards planted on deep colluvial deposits with abundant broken ceramic and tile. These deposits are on average about 1 m deep, but in some cases up to 3 m deep. Excavations have shown that walls of buried houses are normally preserved to about 1 m. Streets are paved in stone, and rooms are often paved in mosaic. Fired tiles from collapsed roofs appear in high frequency.

Magnetometry

For magnetometry at Zeugma in 2000, the surveyors used a Geoscan FM36 fluxgate magnetometer with two independent fluxgates spaced 500 mm apart on opposite ends of a vertical pole. Fluxgate magnetometers are composed of a permeable nickel-iron alloy core that is magnetized by a primary winding and the earth's magnetic field. Fluctua-

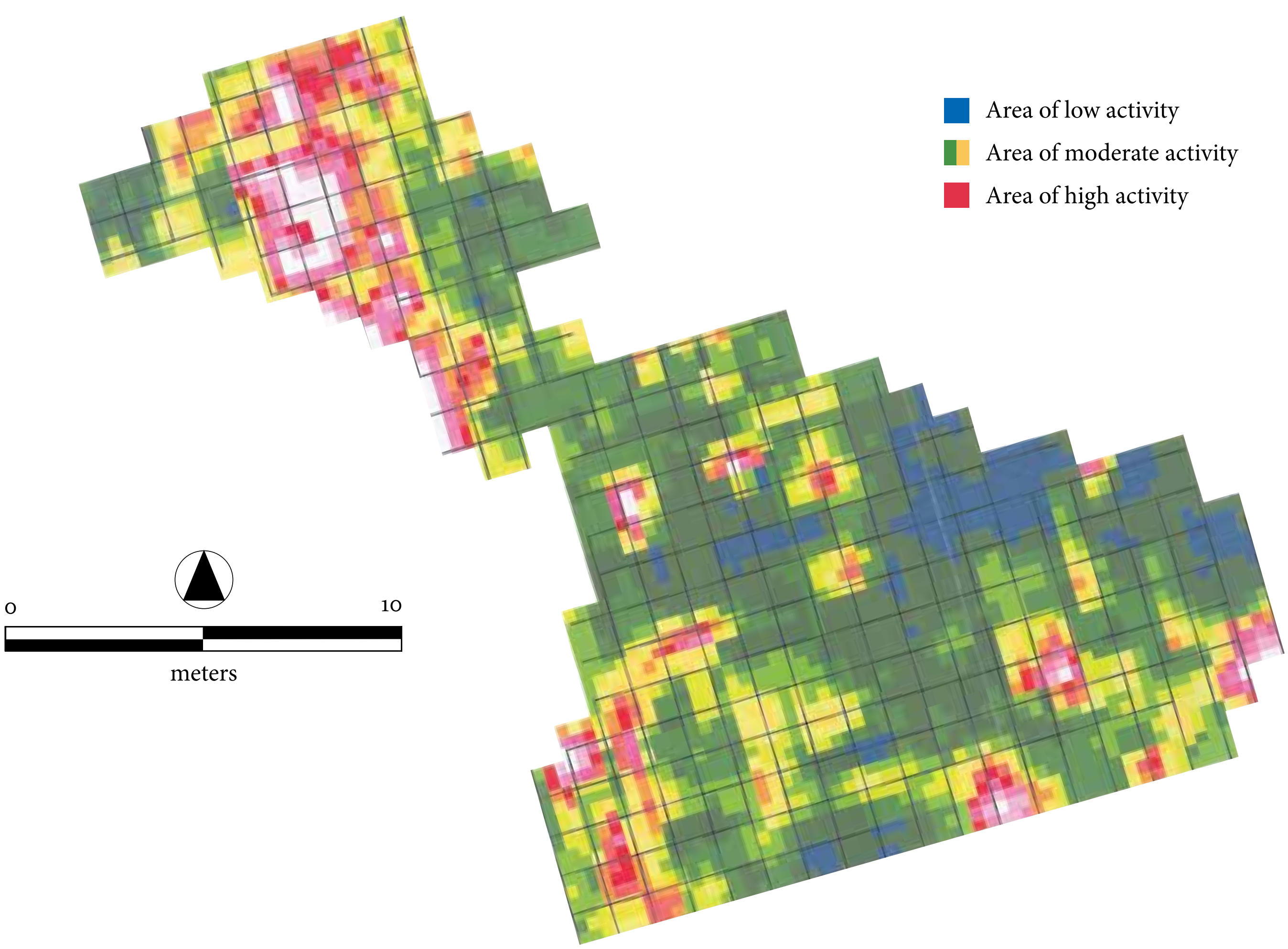


Figure 3. Survey B. GPR. Grid = 1-m intervals. Scan depth = 0.01–0.60 m.

tions in the earth's magnetic field are produced by objects above and below ground with magnetic properties, and the magnitude of these disruptions is measured in nanoTesla (nT) or gamma. Both subsurface anomalies and "noise" (random responses) caused by objects with magnetic properties in or around the survey can be detected by magnetometry.[4]

A magnetometer typically detects features within 1 m of the survey surface, and this means the method was not ideal for the occasional deep (up to three-meter) colluvial deposit at Zeugma. The terrain at Zeugma is also uneven, sloped, and dotted with pistachio trees. In some cases this difficult terrain inhibited data collection. Adequate detection of the city's built environment depended on contrast between magnetic responses from archaeological features and surrounding colluvium. But in each of the four areas tested with magnetometry, the surveyors encountered broad zones of random magnetic response very close to the survey surface, presumably caused by colluvium replete with broken ceramic and tile. Noise was filtered in the data-processing stage, but only to the detriment of meaningful survey data.[5] As a result, whereas in several cases streets and buildings were sometimes perceptible in the processed survey data, excavation at the site has shown that the frequency of such features is normally much higher.[6]

Electrical Resistivity

Electrical resistivity depends on an object's tendency to conduct electricity.[7] For electrical resistivity at Zeugma in 2000, surveyors used a Geoscan RM15 resistance meter with a Twin-Probe arrangement that introduced current into the ground via two electrodes, one current and one potential. The potential difference caused by the current was measured by two potential inner electrodes. An increased distance between the two potential inner electrodes allowed for investigation at greater depths.

The extremely hot and arid conditions of the summer of 2000 at Zeugma were a significant drawback for the electrical resistivity survey. Archaeological features are not markedly distinguished from surrounding fill by electrical resistivity in hot and dry conditions. Parched soil lacks interstitial water between soil particles. Without the conductive properties of water, a soil's low electrolytic conductivity produces abnormally high resistance, and this masks weaker signatures from archaeological features. On occasion, topsoil softened by mechanized plowing impeded robust electrical contact with the subsurface, and this produced spurious readings.[8]

Since electrical resistivity measurements of this type are not affected by above-ground objects of any conductance,

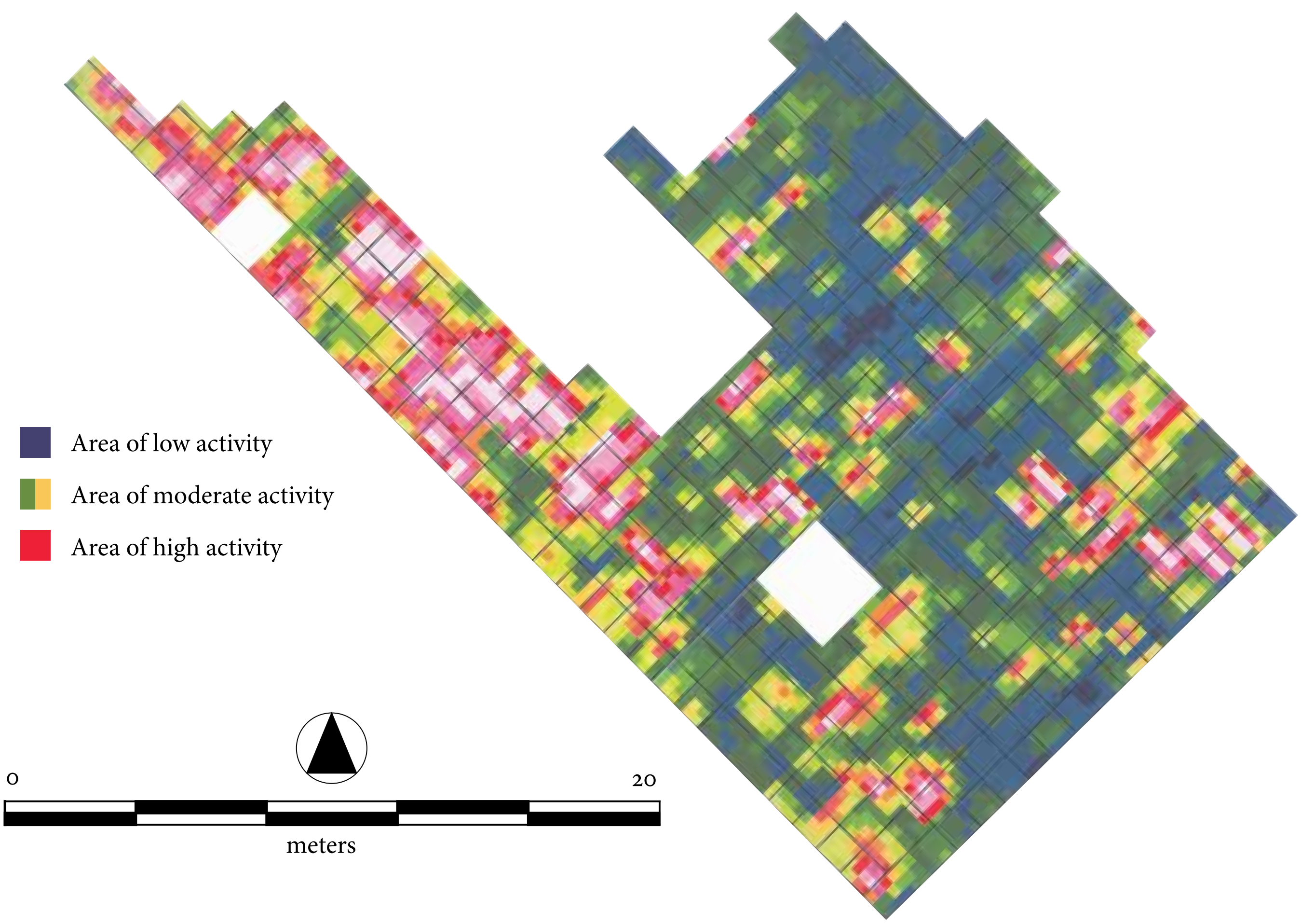


Figure 4. Survey C. GPR. Grid = 1-m intervals. Scan depth = 0.60–1.30 m.

electrical resistivity systems are often used instead of, or as a complement to, magnetic methods. Such was the case in Survey I, where surveyors used both electrical resistivity and magnetometry.[9]

Ground-Penetrating Radar (GPR)

Surveyors at Zeugma applied ground-penetrating radar at four locations on the site.[10] Surveys consisted of 1-m-wide traverses within an orthogonal grid at a rate of 40 scans per meter on a SIR 2000 system manufactured by Geophysical Survey Systems Inc.[11] Data was collected with a mid-range frequency (400MHz) antenna, on or near the ground, which emitted electromagnetic (radar) pulses into the ground. Portions of the radar waves emitted by the antenna were reflected by subsurface objects at locations of electric or magnetic discontinuities and were detected by the receiving antenna on the surface, where the signal was amplified. Electric and magnetic discontinuities produce abrupt changes in the pulse's velocity, normally due to changes in the soil type, interstitial water content, underground cavities, and archaeological features. Thus, reflected signals are generally stronger when an object's properties are in contrast with its surroundings. Subsurface features were mapped in two dimensions based on the amplitude and reflection patterns of the waves.

GPR has several advantages over electrical resistivity methods and magnetometry. GPR data is relatively easy to interpret, and GPR surveys cover more ground in less time. Whereas electrical resistivity measurements must be taken at small intervals in order to achieve high-resolution data, GPR hardware is most often hand-towed or pulled by a vehicle over the survey area, with data collected at a higher rate. Unlike electrical resistivity methods, GPR is most effective in dry, nonconductive soil types, like those found at Zeugma, because saturated media impede a radar wave's ability to pass through a given medium. In addition, GPR scans can be targeted for specific depths by changes to the pulse frequency, with the scan resolution generally diminishing in quality for deeper scans. GPR thus makes possible three-dimensional graphic representations of a survey area, with readings shown relative to depth underground. Deeper scans yield data at lower resolution, but the overall effect of detecting superimposed habitation levels and building phases is an especially important advantage for archaeological prospection.

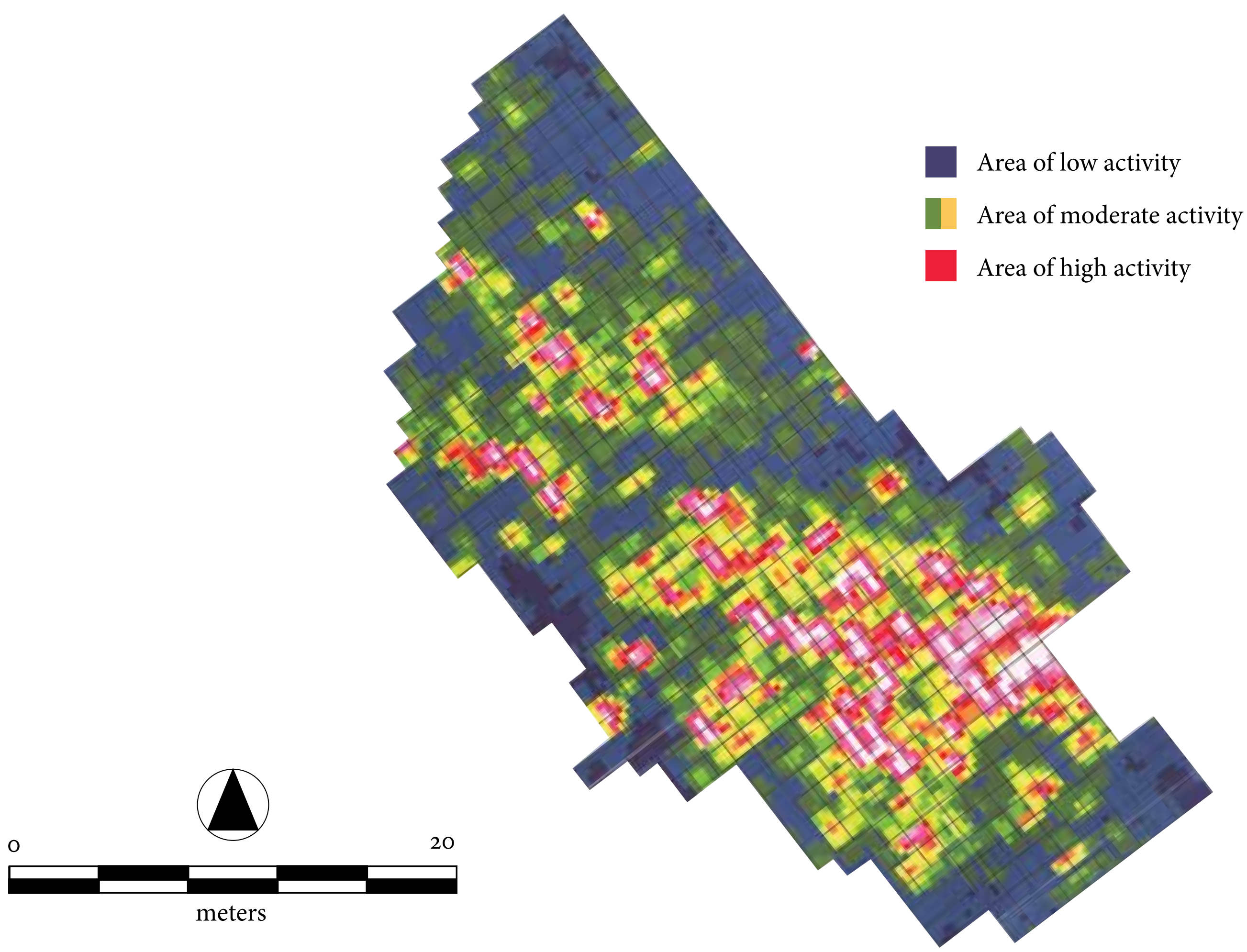


Figure 5. Survey D. Grid = 1-m intervals. Scan depth = 0.01–0.60 m.

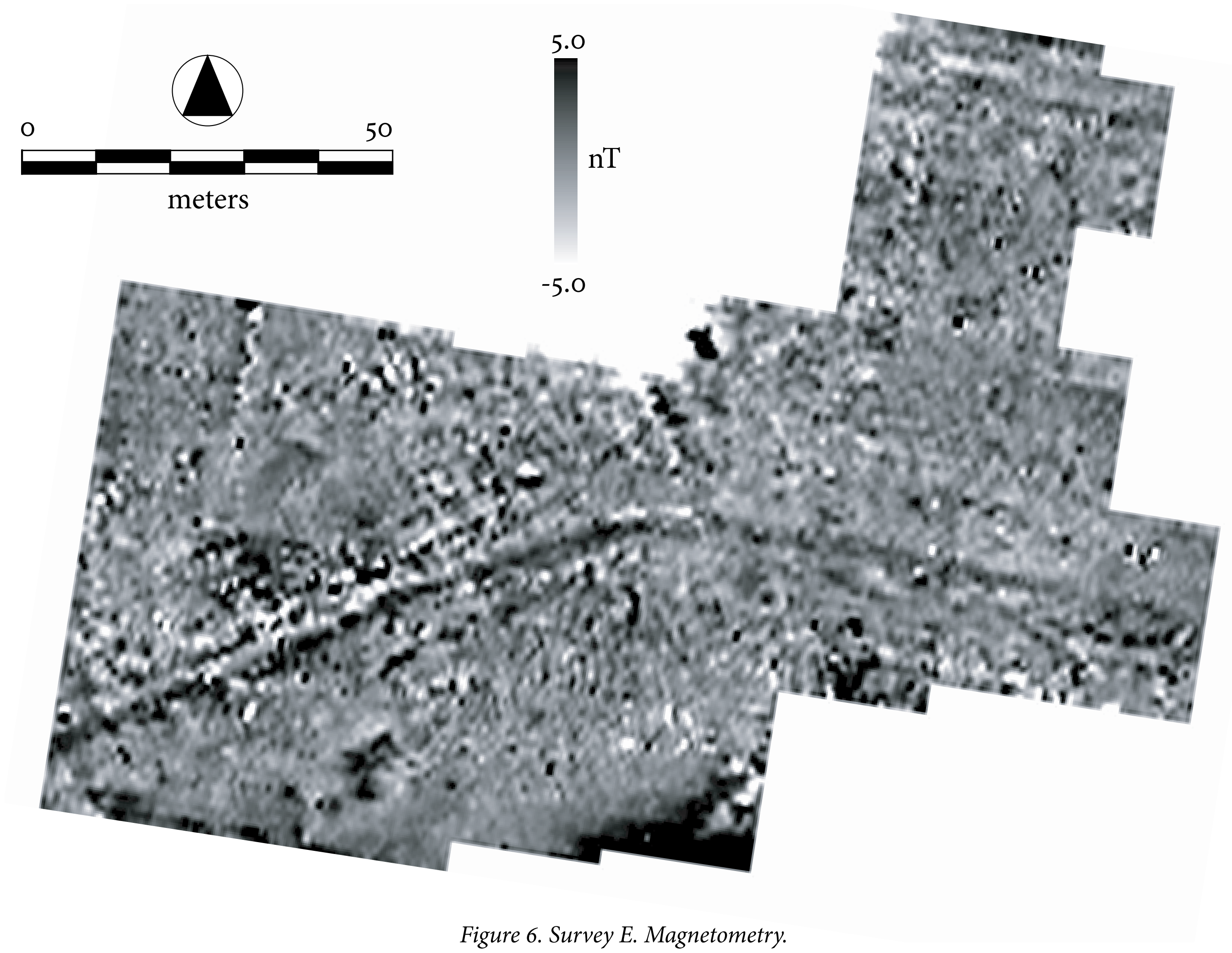


Figure 6. Survey E. Magnetometry.

Data Display

Illustrations selected for this chapter include grayscale display for magnetronomy and electrical resistivity data, and color timeslice plots for GPR data. For grayscale display, the full range of values is subdivided into intervals, and each interval is assigned a shade of gray between black and white. For electrical resistivity, darker shades represent stronger magnetic responses and lighter shades represent weaker ones. For magnetometry, stronger shades of black and white indicate positive and negative magnetic fluctuations, respectively. For the GPR data, timeslice plots depict data retrieved from different depths in the same survey area. The delay recorded between the time a pulse is sent and received is called the timeslice window. Weak reflections in a timeslice window are shown in dark blue or green, whereas stronger reflections appear in brighter colors, such as light green, yellow, orange, red, and white (in order of intensity, with red and white being most intense). The surveyors produced four timeslice plots per area, and we have selected the plots that best inform on the archaeology of Zeugma for presentation in this chapter.

SURVEY RESULTS AND INTERPRETATION

GPR Survey

Survey A

Survey A was the only survey area tested with excavation (Trench 15). Different anomalies were detected in scans conducted at different depths (figs. 2a–c). Most meaningful were a shallow scan set to 0.01–0.70 m, a mid-range scan set to 0.70–1.55 m, and a deep scan set to 1.55–2.25 m. Indications of a large building across scan depths led to the decision to excavate.

The shallow scan detected a group of anomalies at the center of the survey area, linear trends to the east and west of this, and moderate activity at the southwestern corner of the survey area. With the benefit of excavation, these anomalies are now understood as a large concentration of ancient robbing activity that brought detritus near the surface above the southeast corner of a large masonry building, ceramic and mortar hydraulic installations to the east and west of this (e.g., contexts 15192 and 15196), and Cistern 15264 with associated waterworks to the southwest. The mid-range scan picked up some of the anomalies detected

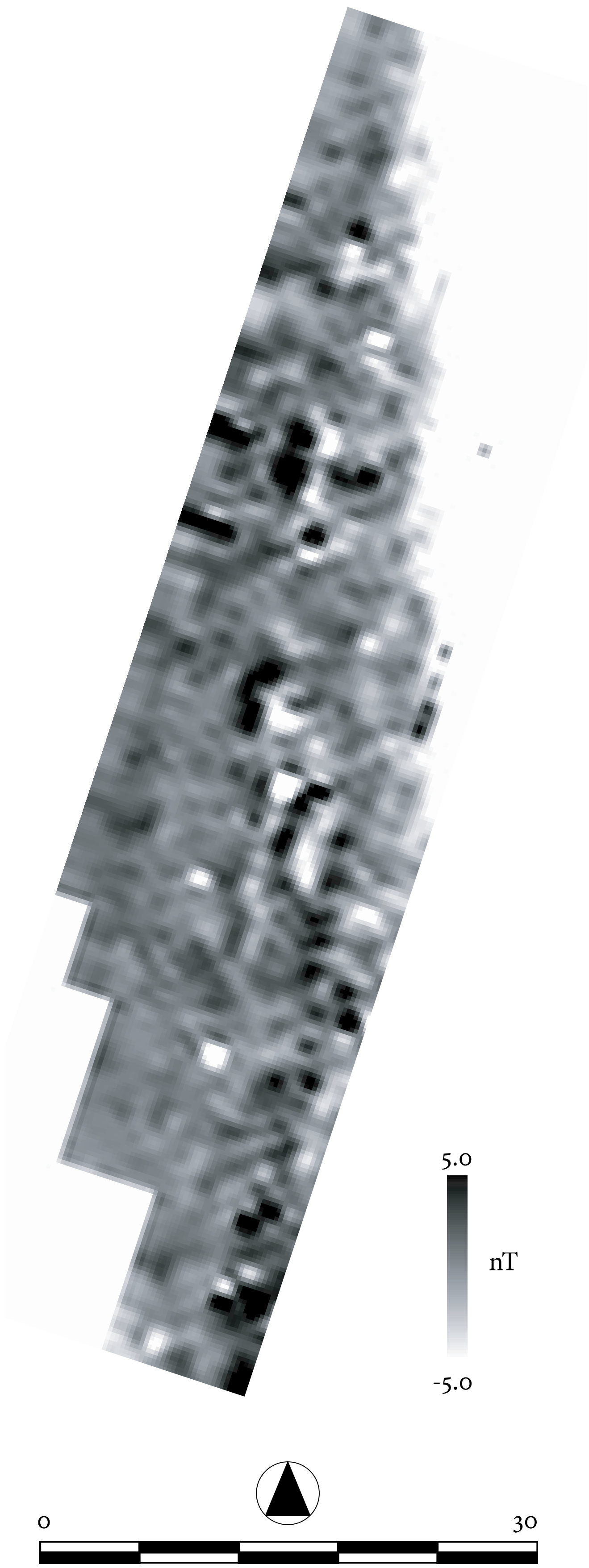


Figure 7. Survey F. Magnetometry.

on the shallow scan, but with weaker signals. This suggests more substantial construction or debris, or both, at a deeper level, but contiguous with overlying levels. The deep scan had a weaker response across the entire survey area, but a few small areas of strong response appear in the same place on the mid-range scan. Some of these areas of high response were deep masonry piers on wall 15287 found by the excavators.

There is an exceptional level of correlation between the GPR results for Survey A and the excavation findings in Trench 15 (fig. 2d). Most of the excavated structures in Trench 15 can be located on at least one of the GPR timeslice plots. A notable exception is Trench 15's wall 15005, a large feature oriented east-west in the southeast part of the trench.[12] A significant correlation is the stone and tile pavement at the center of the trench, which turned out to be a much larger anomaly than suggested by the GPR data.

Survey B

Survey B was conducted to shed light on the unexcavated gap between Trenches 5 and 11.[13] The scan displayed here shows the response from a depth of 0.01–0.60 m (fig. 3). Walls discovered in Trenches 5 and 11 were presumed to continue into the survey area, and the survey results confirmed this (fig. 11). Anomalies consistent with the continuations of walls found in Trench 11 were detected at the western edge of the survey area, and similar signatures detected at the southeast corner of the survey area appeared to be continuations of walls in Trench 5. Data from Survey B suggest the presence of an additional room on the north side of the building excavated in Trench 11. As in the case of Survey A, the complex response in this area may be caused by superimposed layers of building material or collapsed debris. A mosaic pavement should not be ruled out, because rooms discovered in Trench 11 were paved in this technique. Signatures for walls on the east side of the survey area appear to have an orientation consistent with walls discovered in Trenches 5 and 11. In this case, the survey results are especially useful for connecting archaeological features in these adjacent trenches.

Survey C

Survey C was designed to complement excavation results in nearby Trench 2.[14] The scan displayed here shows the response from a depth of 0.60–1.3 m (fig. 4). The signatures for walls in the northeast part of the survey suggest that the house discovered at the northwest part of Trench 2 (the House of the Pelta Mosaic) continued into Survey Area C (fig. 12). A rather large anomaly, at least three meters across, along the southwest part of the survey is similar in complexity to the response detected on the west side of Survey B. The houses in Trench 2 were covered with thick deposits of destruction debris, including burned mud-brick and roof tiles, and an accumulation of this material inside a room would be consistent with the signature of this anomaly. Likewise, given the large quantity of mosaic discovered

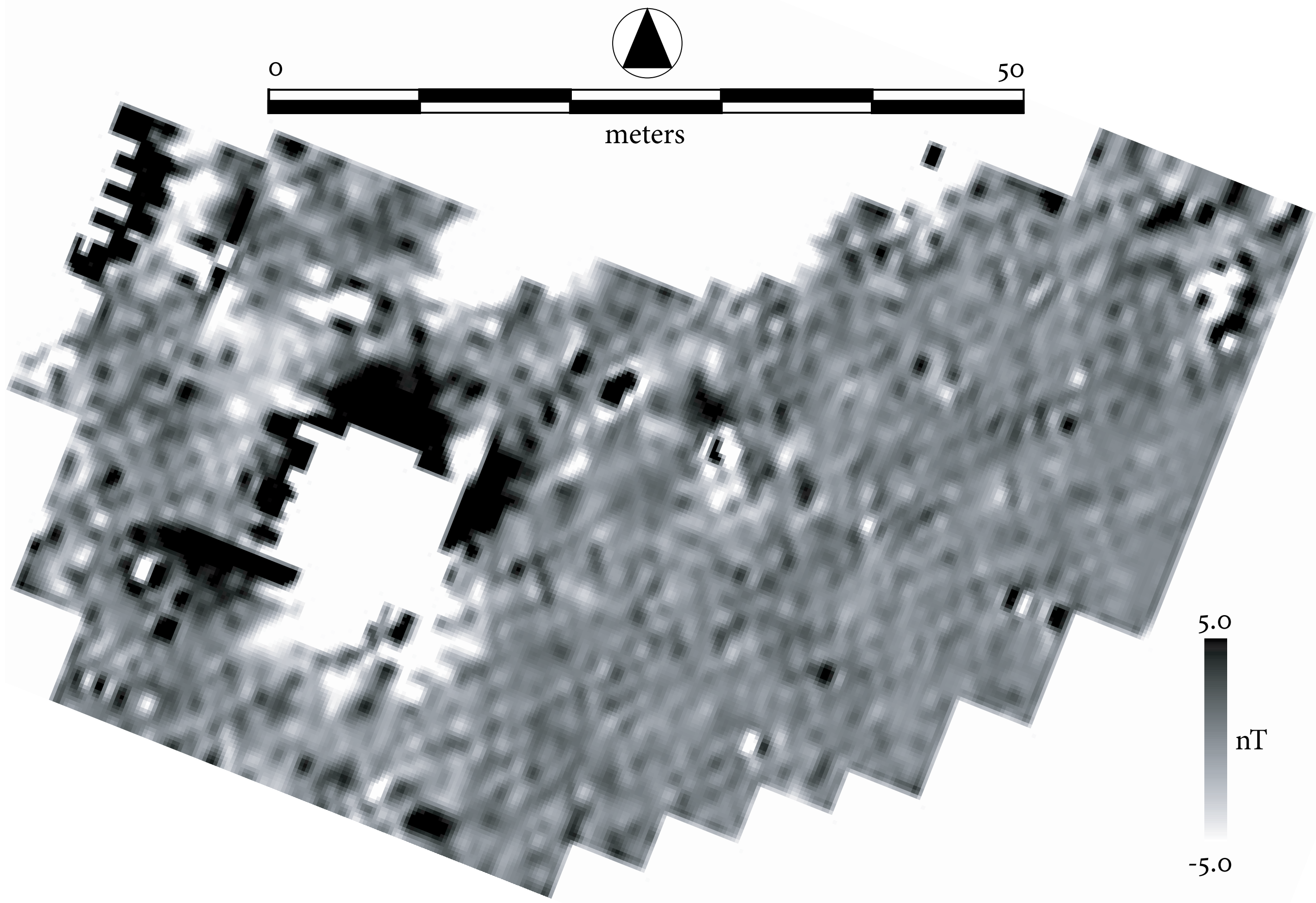


Figure 8. Survey G. Magnetometry.

in Trench 2, it is conceivable that the anomaly in Survey C could indicate the presence of a large mosaic pavement.

Survey D

Survey D was designed to complement excavation results in Trenches 2 and 9.[15] Abundant rock on the survey surface introduced noise into the survey results, and in some cases this masked weaker responses from archaeological features. Nonetheless, many of the same features show up on multiple timeslice plots, and this suggests deep constructions or deposits. The scan displayed here shows the response from a depth of 0.01–0.60 m (fig. 5). The majority of the anomalies detected in the survey conform to one of the rectilinear alignments evident in Trenches 2 and 9, and these probably belong to either walls or drains (fig. 12). At the southwest part of the scan, a large anomaly, about 1.50 m wide, has the same signature as the large anomalies detected in Survey B and C. A large mosaic pavement or a room filled with burnt collapsed building debris would not be inconsistent with the archaeological discoveries in Trench 2. There are no obvious correlations between the data from Survey D and Trench 9.

Magnetometry Survey

Survey E

Survey E is the largest of the magnetometric survey areas (fig. 6). A substantial linear trend across the entire survey area is most probably a street paved in limestone.[16] The signature may be enhanced by fired materials, such as drain pipes, under or alongside the street.[17] The presumed street is about 4 m wide, and it can be traced from the southwest corner of the survey area to its center, where the trend turns slightly to the east. The change in orientation is significant for reconstruction of the city plan. Buildings and streets excavated to the north and east of this survey area (e.g., in Trenches 3, 11, and 15) have a different orientation than buildings discovered to the west (e.g., in Trenches 7, 12, 13, and 18).[18] It is therefore conceivable that the bend in the anomaly represents a juncture between districts of the city with different building orientations (fig. 10).

In the very north part of the survey area, another linear anomaly is parallel to the northeast stretch of the street through the middle of the survey area. This anomaly is fainter, but the orientation and alignment are consistent with the signature for a street.[19] The parallel streets in the

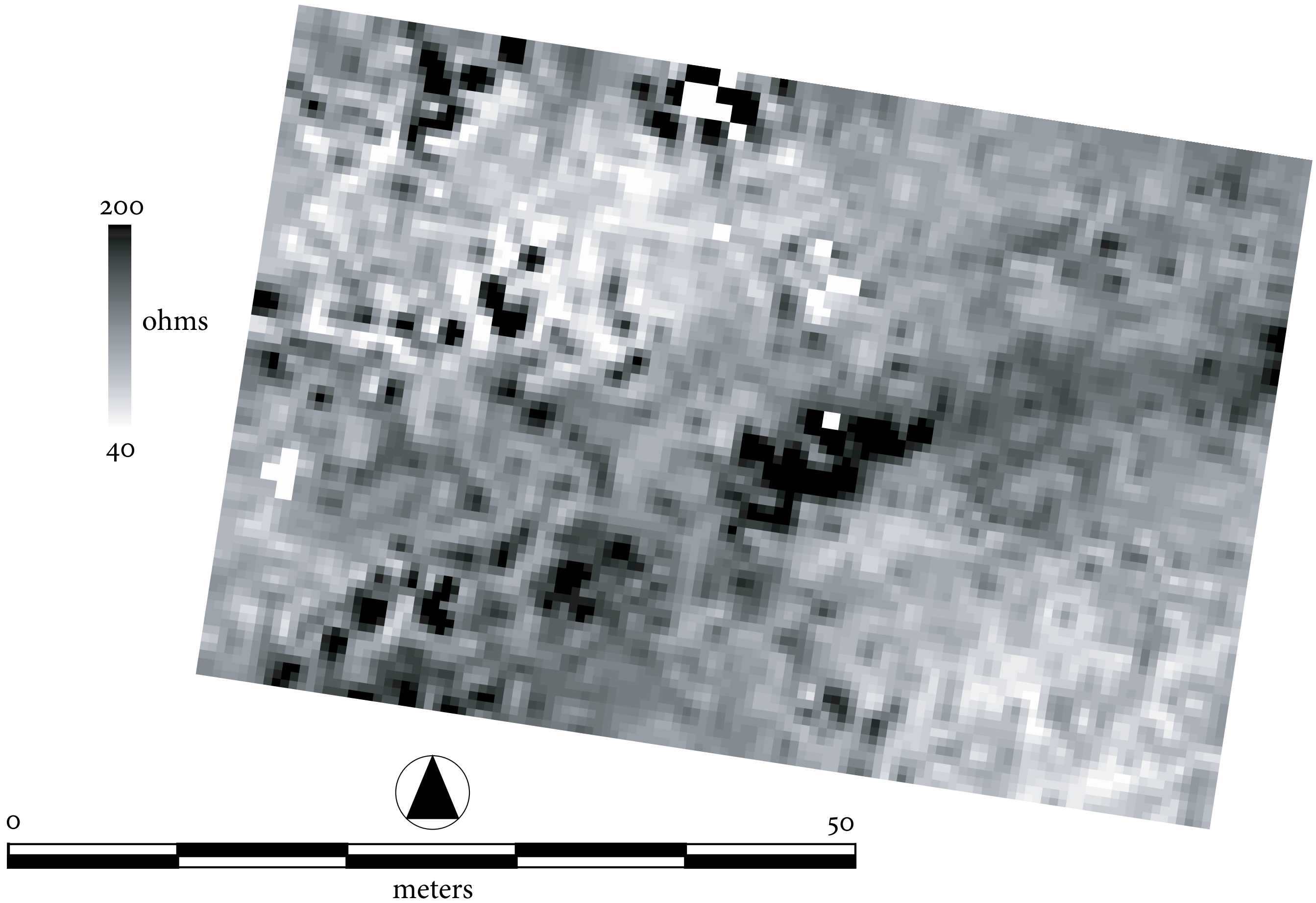


Figure 9. Survey I. Electrical resistivity.

northeast half of Survey E measure 60 m apart on center. There are a number of very faint rectilinear anomalies between these presumed streets, but nothing strong enough to suggest additional streets or buildings.

The paved street discovered in Trench 3 is oriented southeast to northwest — perpendicular to the anomalies in Survey E. The monumental building in Trench 15 is parallel to the anomaly on the north side of Survey E. Framed against these surrounding structures, the anomalies in Survey E take on the distinct appearance of a large city block, conceivably an open plaza or agora, framed on at least three sides by streets and monumental buildings (fig. 10). In rather stark contrast to most of the modern surface topography along the banks of the Euphrates, this part of the site is relatively flat. The substantial terrace walls discovered in Trenches 3 and 15 were probably installed as part of the design for a large open plaza on the terrace to the southwest.

The signatures for streets in the northeast part of Survey E are the first substantial evidence for the size and orientation of city blocks at Zeugma. This can be weighed against results of geophysical survey on the opposite bank of the Euphrates at Apamea, Zeugma's counterpart in the Hellenistic period. City blocks at Apamea have a uniform orientation, and this is consistent with the city's location on a floodplain and its foundation as a Seleucid colony. The evidence from Survey E, complemented by the results of rescue excavations in 2000, shows that city blocks at Zeugma have at least two, and probably more, orientations, each unique to a particular district of the city. Buildings to the east (e.g., in Trenches 2 and 9) and to the west (e.g., in Trenches 7, 12, and 13) of the buildings and streets clustered around Survey E have independent orientations. Variant building orientations are consistent with Zeugma's location on the undulating topography of the Euphrates' west bank and the city's growth in fits and starts from Hellenistic into Roman imperial times. Of all the building orientations known from Zeugma, the orientation clustered around Survey E is the only one that matches Apamea's. The uniform building orientation on both sides of the Euphrates on this particular axis suggests that this area is the likeliest spot for not only Zeugma's earliest Hellenistic settlement but also the bridgehead that linked the two cities.

Survey F

Several anomalies were detected in this survey area, most with a near north-south or east-west orientation (fig. 7). These anomalies are consistent with the suspected signature for walls in the other areas of magnetometric survey at Zeugma, and the features detected in Survey F probably

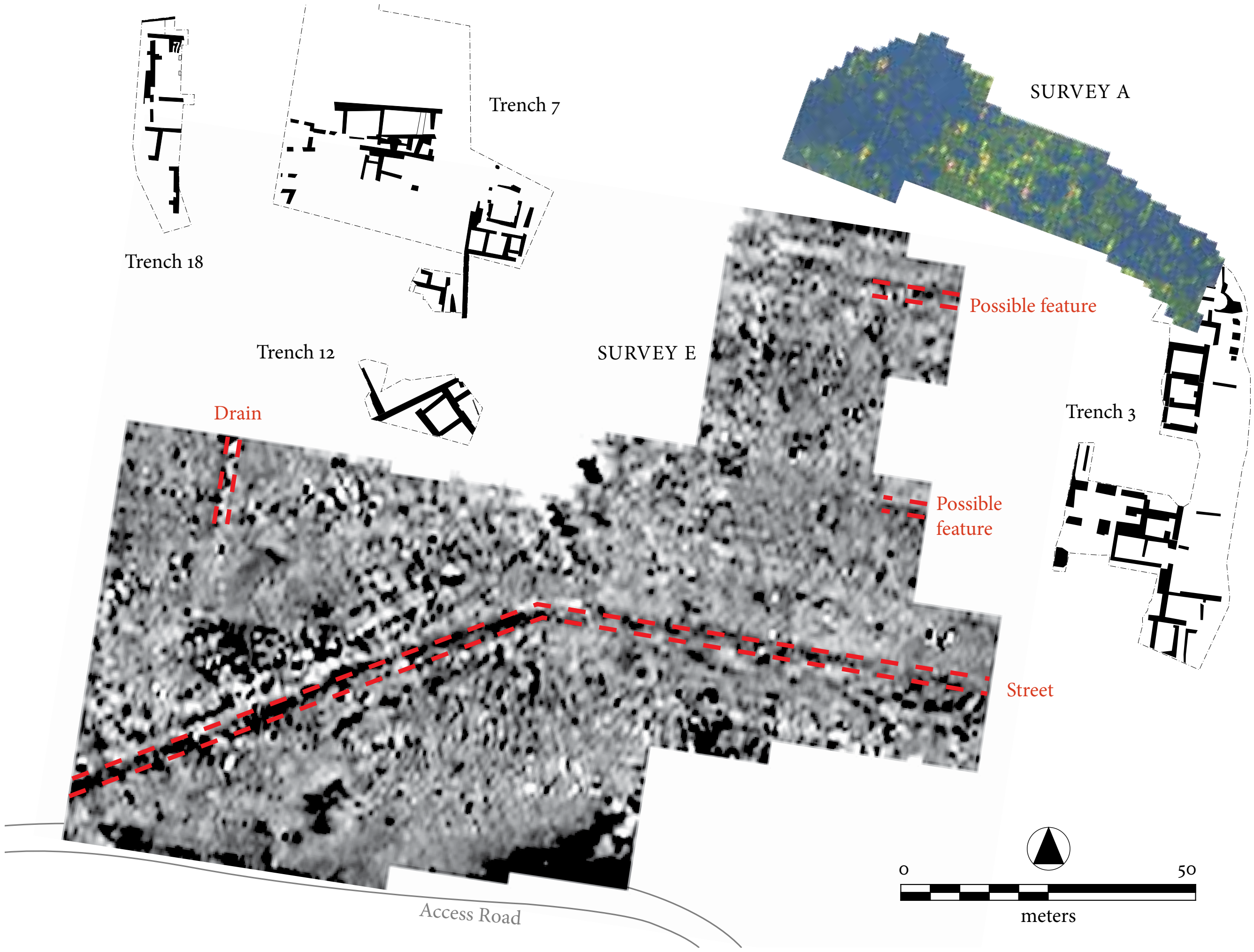


Figure 10. Survey E with extrapolation and Trenches 7, 12, and 18.

belong to structures on the terrace above the street discovered in Trench 14 (fig. 11).[20] A sizable anomaly oriented southeast to northwest is indicated by two signals on the same alignment, and this has a similar appearance to the streets discovered in Survey E. Factors inhibiting results in this area were small survey size and a metal fence on the northeast side of the survey area that introduced considerable magnetic interference.[21]

Survey G

Readings in this western and central part of this survey area were largely clouded by earth-moving machinery parked nearby (fig. 8). The magnetic responses were quite weak, and it is difficult to connect survey results with any excavated features in Trenches 5, 11, or 14 (fig. 11).

Survey H

No anomalies of archaeological interest were able to be detected, due to the high quantity of magnetic gravel on the survey surface area.

Electrical Resistivity Survey

Survey I

Survey I's electrical resistivity measurements allowed for comparison of results with the magnetometry survey on the same spot (Survey E). Despite the arid soil conditions, adequate electrical contact was achieved and acceptable data obtained (fig. 9). The application of two methods to the same area provides supplemental information for interpreting data. The electrical resistivity results support the magnetometry-based interpretation of the anomalies in the survey area as a major road, approximately 5 m wide, oriented southwest to northeast, with a change in orientation that may signal a boundary between zones of inhabitation in the ancient city (fig. 13).

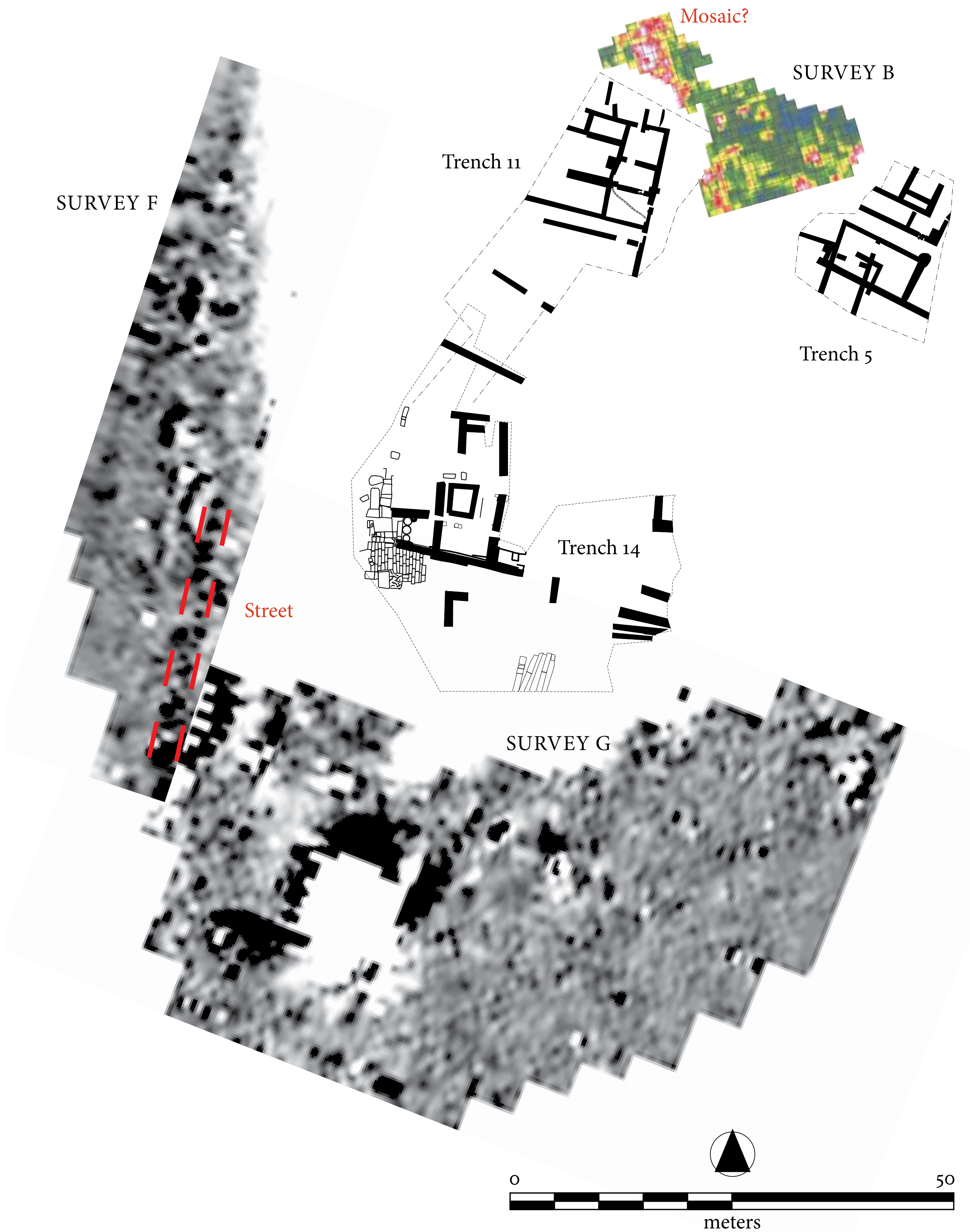


Figure 11. Surveys B, F, and G with extrapolation and Trenches 5, 11, and 14. Schematic plan of Trench 14 after Abadie-Reynal et al. 2001, fig. 2.19.

Figure 12. Surveys C and D with extrapolation and Trenches 2 and 9.

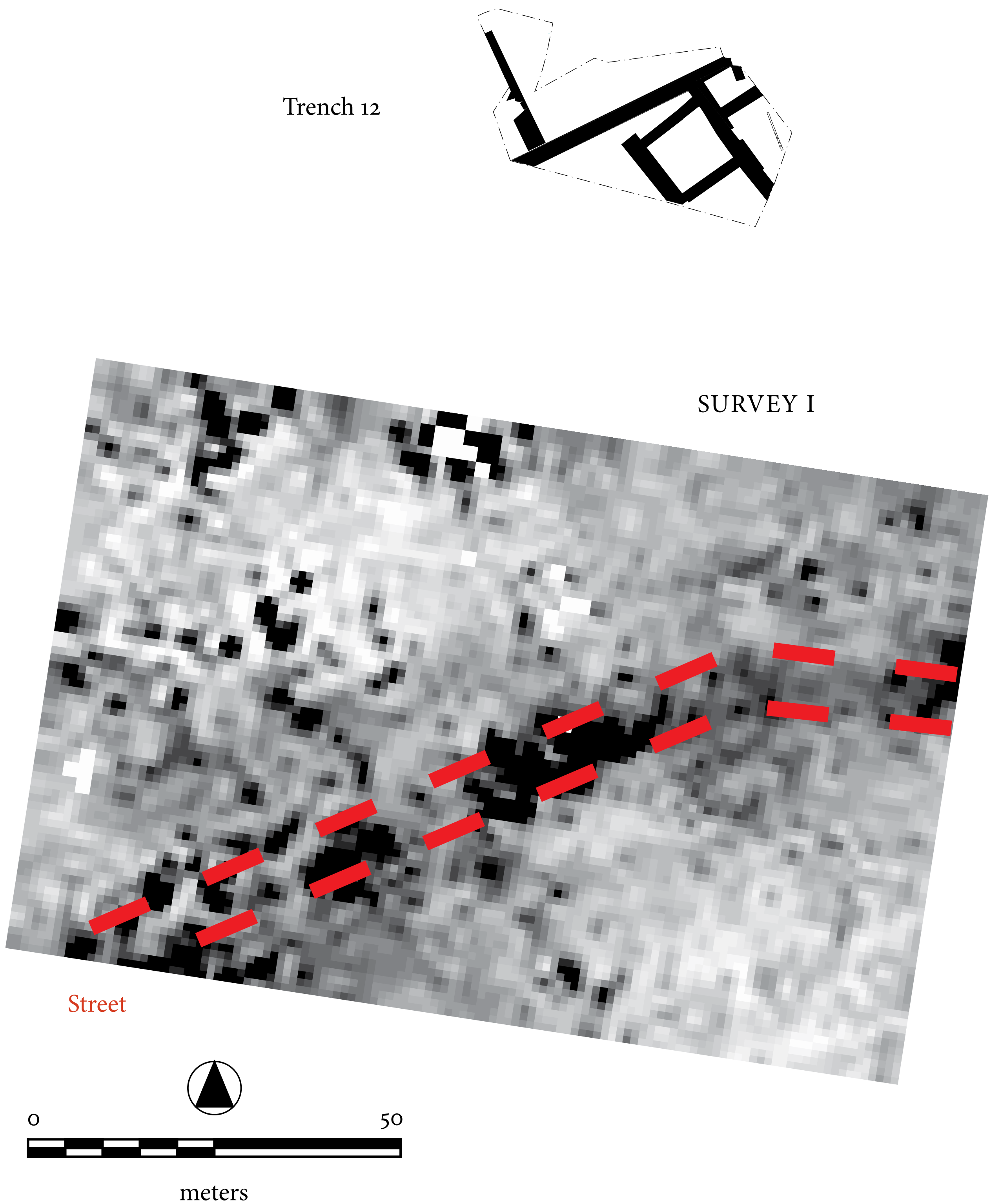


Figure 13. Survey I with extrapolation and Trench 12.

NOTES

1. The unpublished geophysical reports do not present results in the context of the excavation findings. Results of these geophysical surveys were not utilized in published interim reports on the archaeological work of 2000.
2. For geophysical survey at Apamea, see Abadie-Reynal et al. 1999, 334–51; 1998, 397–401; 1997, 362–70; 1996, 311–24. For geophysical survey at Zeugma's military installations, see Hartmann and Speidel, volume 3, and 2003, 105–10.
3. Stratascan Geophysical and Specialist Survey Services conducted GPR surveys in four areas (here renamed A, B, C, and D) between July 26 and August 11, 2000 (Barker and Mercer 2000). Between September 12 and 16, 2000, GSB Prospection (S. Ovenden-Wilson, C. Stephens, and A. Shields) conducted magnetometry surveys in four areas (here renamed E, F, G, and H) and an electrical resistivity survey (here renamed Survey I).
4. For fluxgate magnetometry in archaeology, see Gaffney and Gater 2003, 61–74; Kvamme 2003, 441; Sharma 1997, 76–7, 105-9.
5. For the significance of data filtering, see Gaffney and Gater 2003, 102–6; Kvamme 2003, 437.
6. Noise was also encountered from ferromagnetic gravel on the surface of Survey H, earth-moving machinery parked west of Survey G, vehicles parked south of Survey E, and a wire fence to the east of Survey F.
7. For resistivity surveys in archaeology, see Gaffney and Gater 2003, 56–60; Kvamme 2003, 441–2; Sharma 1997, 248–9.
8. Open or recently backfilled excavation trenches near the survey areas may have also interfered with the data, although to what degree is uncertain.
9. Most objects that can be detected through magnetism can also be detected through electrical resistivity surveys because of the relationship between electricity and magnetism as described by Maxwell's equations: cf. Scollar 1990, 520.
10. For GPR in archaeology, see Gaffney and Gater 2003, 74–6; Kvamme 2003, 442–3; Sharma 1997, 323–5.
11. GPR plots were produced with Radan software. A filtering algorithm was applied to reduce noise and improve the clarity.
12. See the discussion of Trench 15 by Aylward, this volume.
13. Excavations in Trenches 5 and 11 were ongoing at the time of the survey.
14. Excavations in Trench 2 were ongoing at the time of the survey. Part of the survey was obstructed by a first-aid station set up by the excavators.
15. Excavations in Trench 9 had been completed at the time of the survey.
16. GSB Prospection 2000, 2: "Such a response is normally characteristic of a ditch but such an interpretation is unlikely given the wider archaeological context. The alignment of the anomaly and its width suggests that it may represent a road. Such an interpretation appears to fit with the topography and known layout of the site. However, it is not clear as to why a road should give such a response. Assuming it is paved limestone it should be a negative anomaly or a quiet band of data. The latter, however, is unlikely to be visible due to the surface noise. It is possible that the anomaly indicates some change along the edge of the road or that the road may be at least partially constructed of, or associated with, fired material such as crushed brick or tile."
17. E.g., Kvamme 2003, 441; Sharma 1997, 105–8.
18. With the exception of Trench 3, features in these trenches are discussed in the chapter by Tobin, this volume. For the paved street in Trench 3, see Early 2003, 15–7.
19. GSB Prospection 2000, 2.
20. See Abadie-Reynal 2001, 259, 275–92.
21. GSB Prospection 2000, 3: "The limited size of the survey area makes it difficult to identify patterns and formulate any precise interpretation."

BIBLIOGRAPHY

Abadie-Reynal, C., et al. 1996. "Mission archéologique de Zeugma: Rapport sur la campagne de prospection 1995." *Anatolia Antiqua* 4:311–24.

———. 1997. "Mission de Zeugma-moyenne vallée de l'Euphrate." *Anatolia Antiqua* 5:349–70.

———. 1998. "Zeugma-moyenne vallée de l'Euphrate: Rapport préliminaire de la campagne de fouilles de 1997." *Anatolia Antiqua* 6:379–406.

———. 1999. "Zeugma-moyenne vallée de l'Euphrate: Rapport préliminaire de la campagne de fouilles de 1998." *Anatolia Antiqua* 7:311–66.

———. 2001. "Zeugma: Rapport préliminaire des campagnes de fouilles de 2000." *Anatolia Antiqua* 9:243–305.

Barker, P.P., and E.J.F. Mercer. 2000. "A Report for Oxford Archaeological Unit on a Geophysical Survey Carried Out at Zeugma, Turkey, July/August 2000," Job Ref. No. 1480. Unpublished.

Early, R., et al. 2003. "Rescue Work by the Packard Humanities Institute." In *Zeugma: Interim Reports*, edited by J.H. Humphrey, 8–56. *JRA* Suppl. 51. Portsmouth: Journal of Roman Archaeology.

Gaffney, C., and J. Gater. 2003. *Revealing the Buried Past: Geophysics for Archaeologists*. Stroud: Tempus.

GSB Prospection. 2000. "Geophysical Survey Report 200/90: Zeugma, South East Turkey." Bradford: GSB Prospection. Unpublished.

Hartmann, M., M.A. Speidel, and M. Drahor. 2003. "The Roman Army at Zeugma: Recent Research Results." In *Zeugma: Interim Reports*, edited by J.H. Humphrey, 100–26. *JRA* Suppl. 51. Portsmouth: Journal of Roman Archaeology.

Kvamme, K.L. 2003. "Geophysical Surveys as Landscape Archaeology." *AmerAnt* 6:435–57.

Scollar, Irwin. 1990. *Archaeological Prospecting and Remote Sensing*. Cambridge: Cambridge University Press.

Sharma, P.V. 1997. *Environmental and Engineering Geophysics*. Cambridge: Cambridge University Press.