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An Integrated Approach for the Use of GPS and GPR in Archaeological Sites: a Case-Study at Tilmen Höyük in South-Eastern Turkey

Gabriele Bitelli, Marco Bittelli, Federica Boschi, Nicolò Marchetti, Paola Rossi, Luca Vittuari

Argomento del presente lavoro è la presentazione di un protocollo integrato efficace per caratterizzare le proprietà sia pedologiche, sia archeologiche (che siano coerentemente integrate in una strategia di scavo e in una rete geodetica), quale è stato sperimentato sullo scavo di un sito del Bronzo Medio in Turchia sud-orientale, a Tilmen Höyük. L'utilizzo del Ground Penetrating Radar (GPR) per ottenere informazioni sulle proprietà del sottosuolo è diventata una pratica di grande interesse in campo archeologico. Il Georadar può essere affiancato da tecniche di Global Positioning Systems (GPS) per l'analisi e l'integrazione dei dati. L'utilizzo combinato di queste tecniche permette una campagna di prospezioni geofisiche più dettagliata, che include informazioni diverse e dettagliate in un unico sistema georeferenziato. Gli obiettivi di questa ricerca sono quindi stati di: (a) identificare evidenze archeologiche subsuperficiali, caratteri idrologici e pedologici utilizzando il GPR accoppiato ad un sistema GPS di alta precisione, (b) implementare una procedura per l'integrazione dei dati ottenuti in un sistema informativo geografico e (c) creare un modello tridimensionale del sottosuolo basato sulle informazioni ottenute con il GPR. I risultati ottenuti hanno permesso di creare un modello del sottosuolo georeferenziato che permetta di interpretare la struttura del sito antico, non solo dal punto di vista archeologico, ma anche idrologico e pedologico.

1. Introduction

In contemporary archaeological explorations multidisciplinary strategies are frequently pursued, although with varying degrees of success and often at the expense of internal coherence. The present paper stresses the need for a focus on geo-diagnostics from an integrated archaeological, topographical and geophysical approach.

The Tilmen Höyük Archaeological Project is a joint Turco-Italian one: five campaigns have been carried out at this Bronze Age site in south-eastern Turkey between 2003 and 2007 (fig. 1), with a combined approach to excavation, restoration, landscape studies, site management and presentation activities for public awareness. In the Fall of 2007 the Archaeological and Environmental Park of Tilmen Höyük was officially opened. While emphasis has been placed also on cultural and environmental characterization, we rely on a series of assumptions based on present scientific knowledge. Hereby follow the two main ones – for initially characterizing and then successfully exploring and presenting an urban site: 1) accurate topographic survey, coupled with aerial photography, close-range photogrammetry, high precision geodetic referencing and an historical approach to the study of architectural evidence, are fundamental tasks, leading to and accompanying large excavation areas; 2) extensive geophysical surveying is neither ancillary nor preliminary to archaeological excavations, but rather parallel to it, projecting the scattered fragments of a past situation to a larger scale layout.

(N.M.)

2. Ancient Urban Planning at Tilmen Höyük during the Middle Bronze Age

The study of ancient urbanism is not just a matter concerning typologies of buildings or a description of the spatial organization of a given settlement: determining functional differences of space use, identifying space hierachies and social clusters, reconstructing self-representational ideology as reflected in the shaping of settlements are, on the contrary, the end goals for archaeological enquiries on urbanism[1]. This problem may

[1] On the social use of space, see Chermayeff, Alexander 1963; Hillier, Hanson 1984; Kent 1990; Nettinget

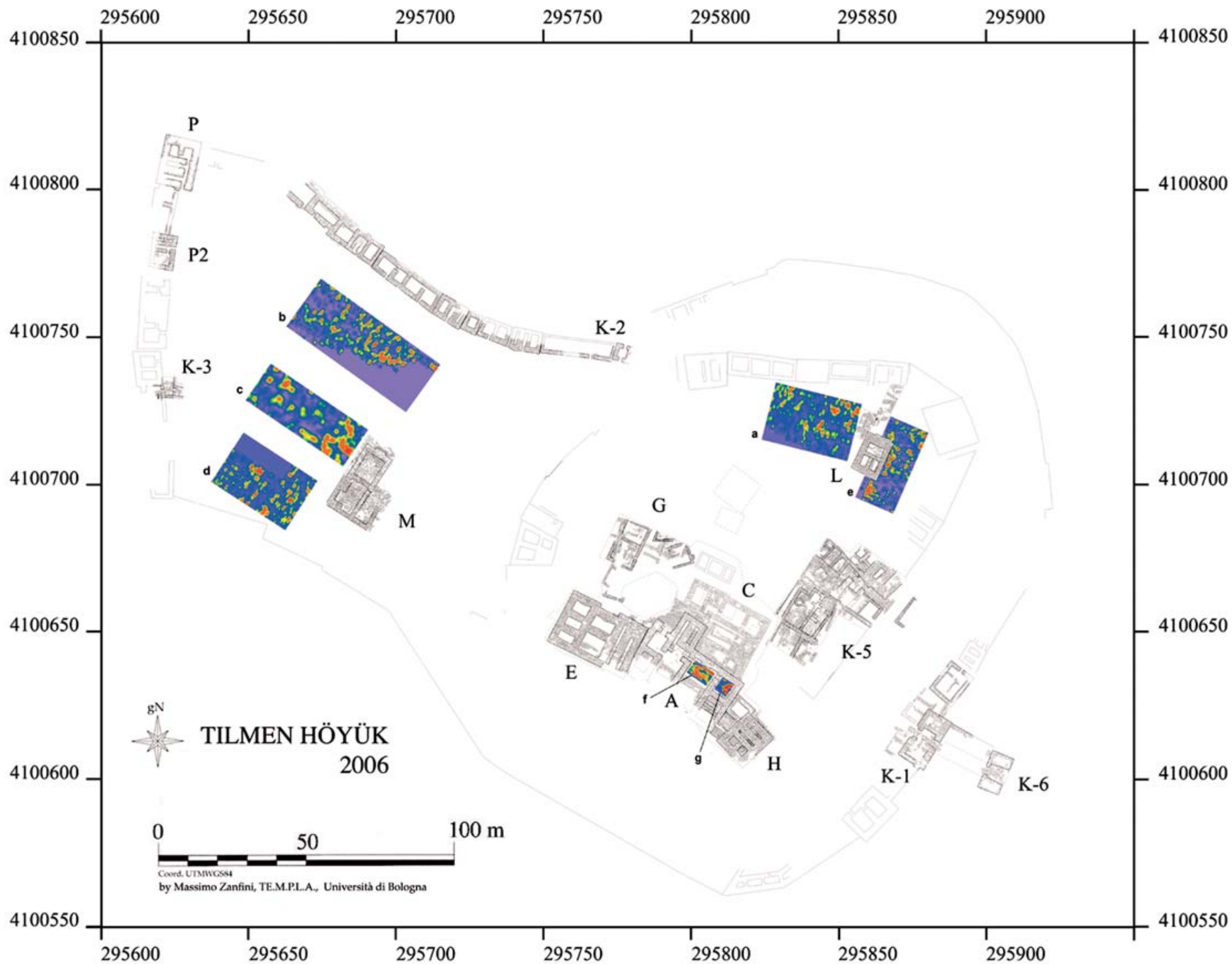

Fig. 1. Topographic map of Tilmen Höyük: MBA structures with thickened skylines; monuments surveyed only by Alkım's Expedition in lighter grey. Sectors in color are those covered by the geo-physic survey (designated by letters in minuscule).

be approached from several points of view: for instance, horizontal excavation exposures (and the consequent study of the eco- and artifacts retrieved) are an effective mean to that aim[2], but they must be coupled with a detailed analysis of the written sources[3], where available, and high precision topographic researches (see § 3), set within a landscape perspective (see e.g. Wilkinson 1990).

The results of surface research on archaeological sites must be, generally speaking, evaluated carefully: the results of superficial scraping at Çatal Höyük, for example, supplied an apparently regular architectural layout, which, when excavated, was found to represent several different chronological phases (Matthews 1996). Same or similar manual operations in southern Iraq, however, gave more coherent results at Abu Salabikh (Postgate 1994) and at Mashkan Shapir (Stone, Zimansky 2004). The most extensive evidence has been obtained through geophysic surveys at sites such as Kusaklı and Kerkenes Dag in Turkey (dating respectively to the Late Bronze and the Iron Ages, see Müller-Karpe 2007; Stümpel, Erkul 2006; Summers, Summers 2006; 2008): all these sites have a limited settlement history in most areas, as it is the case at Tilmen.

At Tilmen, the excavations revealed the layout of a Middle Bronze II (hereafter MB II) capital, 5.5 hectares large, from c. the 18th-17th centuries BC (fig. 1). The lower town has casemate fortifications and could be entered through a main city gate (K-1), besides two small posterns (K-2 and K-3): a sacred area (M), set on a higher ridge along a street coming from postern K-3, was seemingly connected to the public area on the acropolis by means of a wide roadway. Only the western lower town had actually a significant extension, the other parts of it being only represented by narrow strips between the city walls and the acropolis. The acropolis, fortified on three sides by casemates and fortresses, was accessed through a monumental stairway (K-5), from where – after passing by a large residency – an oblique road led to the public area along the southern side of the mound to the south, where some roads met at acute angles . The public compound was the most notable urban feature of the town, being made by three major buildings (E, A, H), the combined rectilinear southern façade of which stretches for 75 m, with a presumable original height of at least 12 m, bust most probably significantly more (fig. 2)[4].

(N.M.)

3. *The use of GPS for georeferencing purposes and site surveying*

3.1. *Absolute Georeferencing*

While for the simple surveying purposes required by traditional presentations a local reference system may be sufficient, to prepare a multifaceted management plan we had to embed in a single coherent reference frame all

et alii 1984; Parker Pearson, Richards 1994; Stark 1998; Tonkiss 1998.

2 This can be achieved through the study of differentiated distribution patterns of material culture assemblages within contexts. The context is the fundamental unity for recovering meaningful information about the interconnections existing in the Past between fixed and mobile artifacts, the relationships between different sets of man-made evidence (Appadurai 1986).

3 See for example Mayer 2003: 238-239 n. 2 s.v. ribītu for the existence of the *ribītu*, the main street of Old Babylonian towns on which abutted the main buildings of the town. An excellent, though unfortunately rare, case offered by textual studies is represented by Harris 1975. Written texts must also, though of course not exclusively, be set within their retrieval context: however, the extraordinary potentialities offered by the ancient Near East – in which an abundant textual documentation has been often found *in situ* – have not too often been exploited in detail: for example, when extensive excavations were carried out, such as for late Neo Babylonian levels in Babylon (Koldewey 1925), contextual information was mostly lacking and the archives are only recently being studied (Baker 2008).

4 For excavation reports see Marchetti 2006; 2006b; 2008a; 2008b; 2008c; on the survey methods see Cerasetti *et alii* 2008. A Turkish expedition first worked at the site between 1959 and 1972 (Alkım 1969; Duru 2003). The constructional features of the public compound were, on a less grandiose scale, usual at the site during the MB II phase: the monumental buildings which have been explored in detail had in fact vertical outer façades reaching the foot of the acropolis (residency K-5 and fortress Q) or of the glacis around the lower town (fortress P).

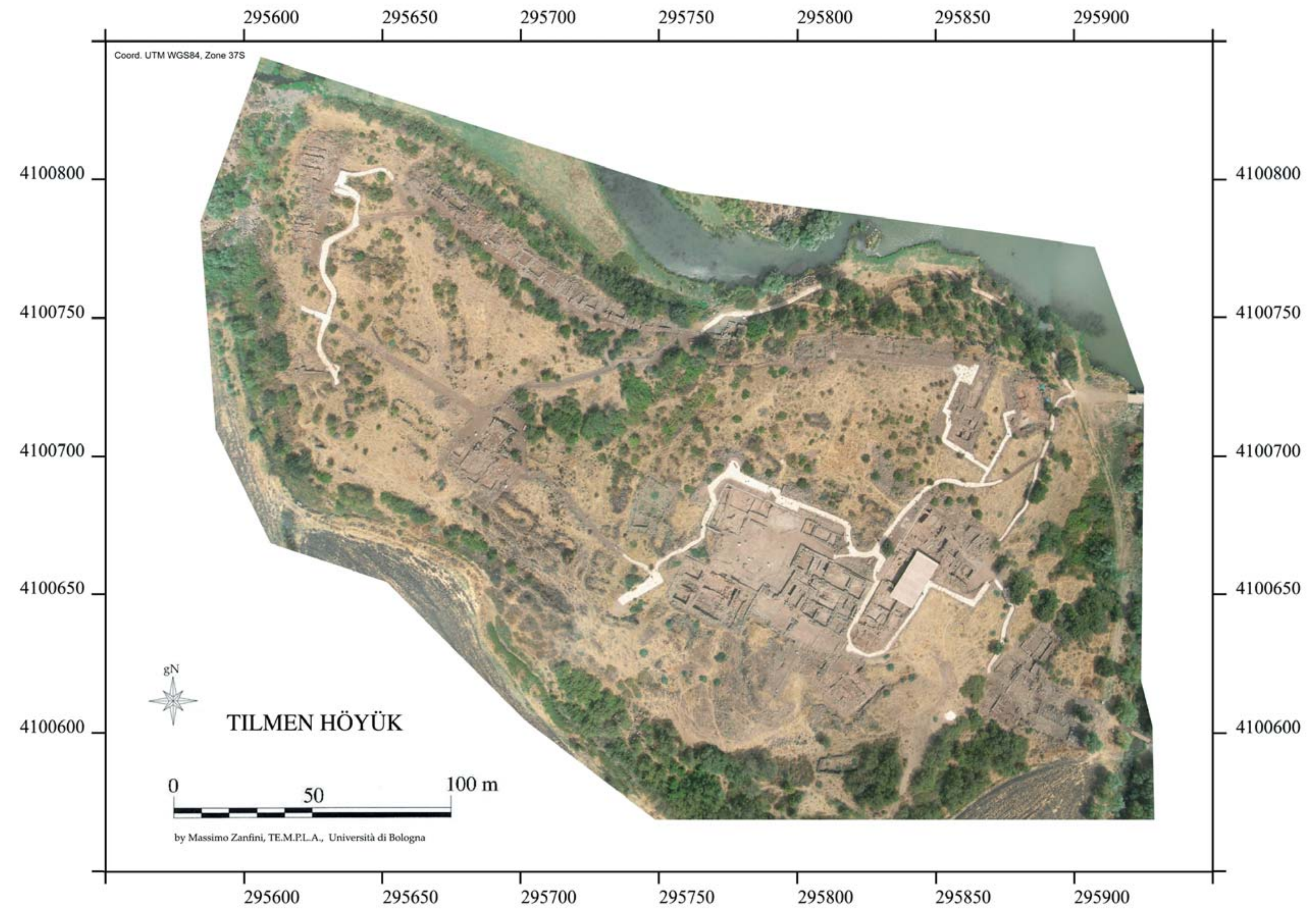

Fig. 2. Orthophoto of Tilmen Höyük (taken in August 2008; the 2nd millennium BC excavated monuments and the visitors paths of the archaeological and environmental park are well visible).

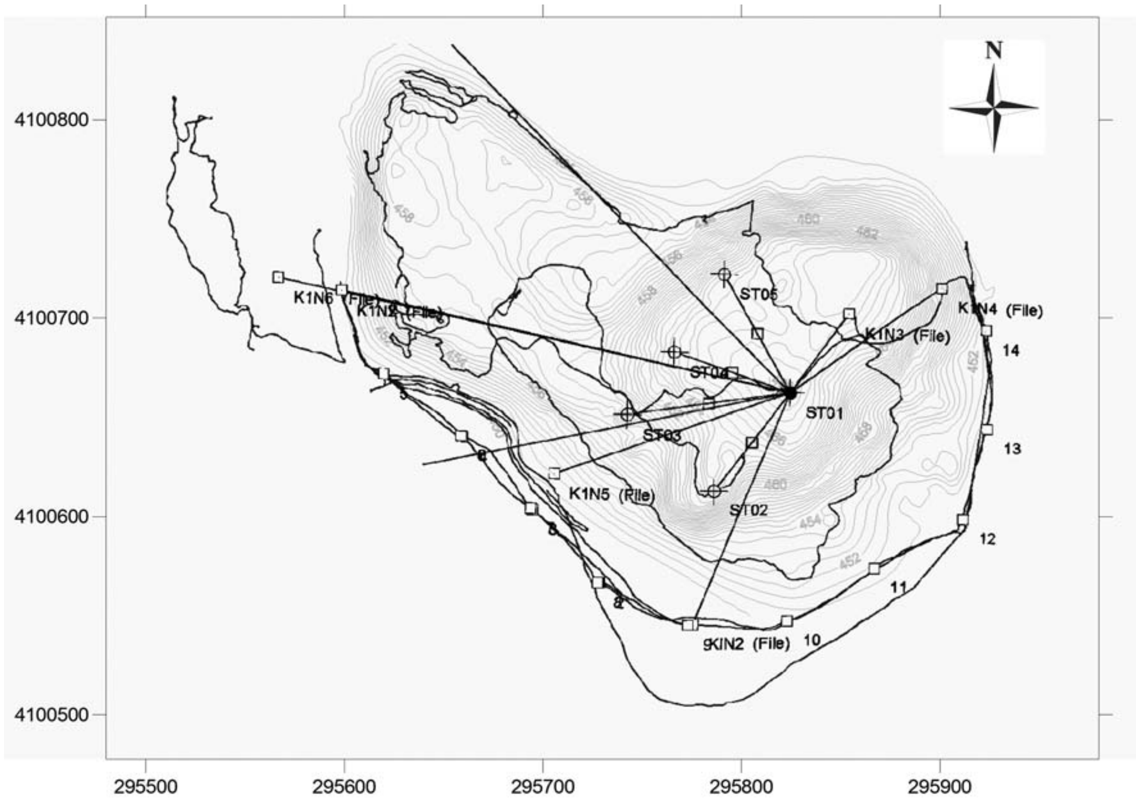

Fig. 3. Continuous tracks and stations determined by GPS measurements using static, rapid-static and kinematic techniques at Tilmen.

the survey works, carried out at different times and scales within the Tilmen archaeological site complex. This task required a shared absolute geodetic reference system (Bitelli *et alii* 2006b) that may guarantee maximum flexibility to integrate a wide array of data coming from different prospection techniques on one side and to consolidate them for future projections to the higher dimensions of regional studies, that require the incorporation of all landscape data in their historical projection (Bitelli 2008). In particular at Tilmen the basic operational platform was the integration of high precision Global Positioning System, Ground Penetrating Radar and total station surveys, to aggregate the separate layers of landscape aspects and artefacts in a most detailed contextual definition (Leick 2004; Wiseman, El-Baz 2007).

Measurements at Tilmen were carried out in 2005 by using Global Positioning System with dual frequency “geodetic class” instruments and suitable processing software. The WGS84 (ITRF2000) geographical coordinates of a master station, named ST01, were determined by means of very long measurement sessions (GPS static method) to the most adjacent GPS permanent stations belonging to the scientific network of the International Geodetic Service (IGS), while for the reduction of the ellipsoidal height to the orthometric value the EGM96 global geoid undulation model was applied (Vittuari 2008).

The master station was placed on the highest spot of the site, while some other secondary stations were measured during the campaign by rapid-static method in order to establish a network of points coherently surveyed and useful as reference for topographical surveys made by means of total stations during the excavations. Final overall elaboration was performed in post-processing, using most accurate ephemeris data (fig. 3).

3.2. *Digital Terrain Model Determination*

The elaboration of an accurate Digital Terrain Model (DTM) for the area is essential for a large number of applications in archaeology (in the context of this work, only the inte-

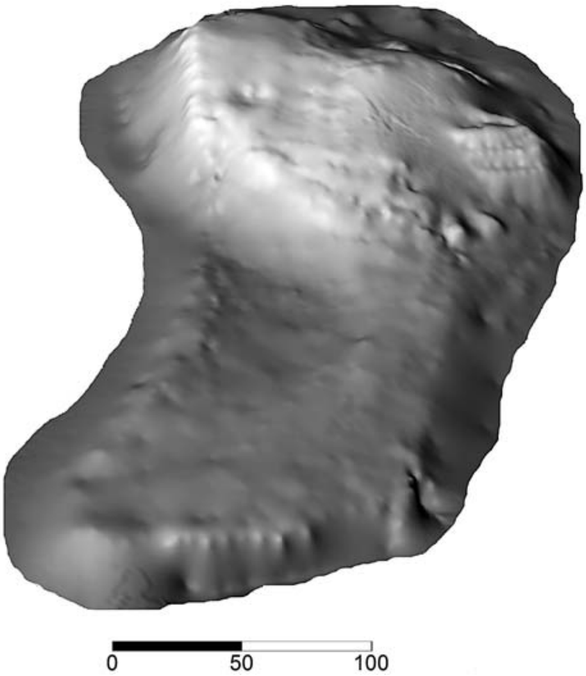

Fig. 4. Shaded view of DTM of the Tilmen mound (from West): acropolis and lower town are clearly visible.

gration with geophysical prospecting is reviewed).

Several geomatic techniques are nowadays available for DTM and DSM (Digital Surface Model) determination, starting from classical topographical surveying to spatial geodesy, from Photogrammetry to Laserscanning, and have been largely applied by the Authors at different sites (e.g. Bitelli *et alii* 2006a). For Tilmen, a combined total station – GPS acquisition was chosen, both for the accuracy requirements and for logistic constraints.

Regarding the classical topographical measurements, several points have been surveyed inside the site by radial measurements, performed with a total station placed at the stations mentioned in § 3.1. The sampling process was adapted to the local morphological characteristics, with a total amount of about 3500 acquired points.

To integrate these data, a kinematic GPS survey was carried out (fig. 3), with a lot of walking in and around the site using two instruments (single and dual frequency), with a third instrument simultaneously acquiring at the master station; the precision of the results, considering the intrinsic reliability of the method and the running positioning of the antennas, can be estimated in the order of a few centimetres. Of course, GPS calculated positions have been referred to the orthometric heights as described in § 3.1.

Starting from these data, several numerical models of the terrain were calculated using the geostatistic kriging approach, with different cell sizes starting from 1 m. In fig. 4 an example is shown, with cell size of one meter and shaded relief representation.

3.3. GPR prospecting georeferentiation

Accurate GPS surveys were also applied for georeferencing the transects performed for geophysical prospecting. In this case double kinematic determination of the stakes was applied, surveying the same stake twice, during different walks, and evaluating the accuracy by the two calculated coordinates sets (heights referred to the m.s.l.). The results of this assessment guaranteed that accuracy and precision were in optimal agreement with the requirements (at centimetre level in relative and a few centimetres in absolute).

(G.B., L.V.)

4. The use of GPR for soil and archaeological surveys[5]

4.1. GPR Survey

A detailed GPR campaign was performed at the site using two types of instrumentation: a GSSI (Geophysical Survey System Inc., USA) SIR-3000 with an antenna operating at 200 MHz and a RAMAC (Ramac Inc., Sweden) with an antenna operating at 250 MHz.

The measurements were performed over grids of 0.5 x 0.5 meters, with meandering acquisition in both North-South and East-West directions, georeferenced by means of the GPS survey described in § 3.3. Various areas have

[5] M. Posselt and S. Pfnorr (Frankfurt) carried out a geophysic survey in 2005 at Tilmen in parallel with that of M. Bittelli, the two teams having exchanged their data. GPR Process is a software developed by Lawrence B. Conyers and Jeffrey Lucius, specifically designed for archaeological applications of the GPR system.

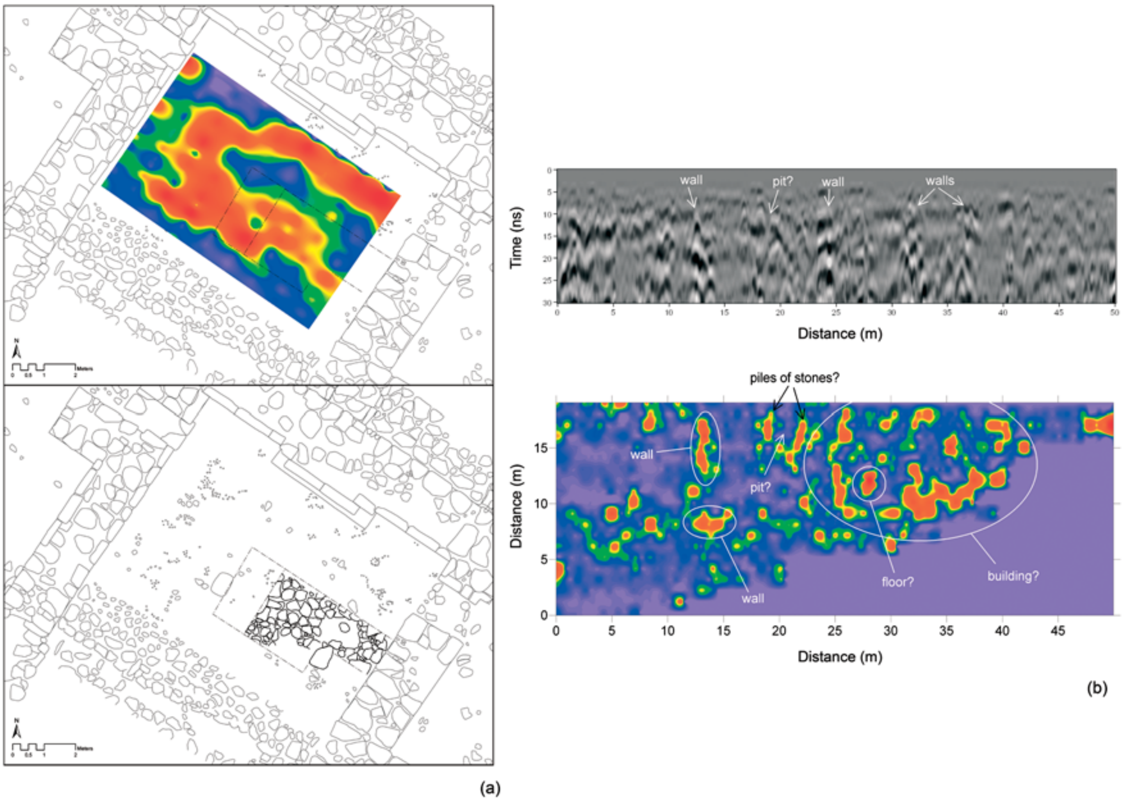

Fig. 5. On the left, GPR time slice of the throne room in Royal Palace A (sector "f") and the plan of an archaeological sounding showing the relation between the GPR reflection and the results of subsequent excavation. On the right, time slice obtained in sector "b" at 30-35 ns with an interpretation of the main reflections (above), also visible in the B-scan (below).

been surveyed as shown in fig. 1, where the letters identify the different surveyed areas.

The soil moisture conditions at the time of the survey were very dry (measured soil moisture was at an average value over the entire area, of 0.15 m^3 m^{-3}), thus facilitating the survey because of the overall low dielectric permittivity of the soil. Several transects were repeated many times, by testing different system setups (such as wave velocities, signal amplification and trace numbers) to identify the best setup for the survey. The dense surface scattering of basalt stones limited the extension of surveyed areas.

4.2. GPR Data Processing, Analysis and Interpretation

Data processing was performed using the software GPR Process, which provided time slices that are a bi-dimensional representation of the reflected signal amplitude at different depths[6]. Maps of the buried features were created by using various time slices. The maps, which may be subsequently used for an archaeological interpretation, represent the signal amplitudes recorded by the GPR. A chromatic scale has been used, with blue indicating low amplitudes and red representing high amplitudes. A variety of maps were created to perform a detailed interpretation of buried features. Identified features were then confirmed by analyzing the corresponding original B-scan trace. Finally, interpretation was written on each time slice for its representation on geo-referenced maps.

All surveyed sectors (see fig. 1 *sub* a-g) displayed significant differences in the dielectric properties of the material both in the horizontal and vertical directions. Vertical dielectric contrast occurs mostly at a depth comprised between 30 and 90 cm. In some cases, the presence of deeper features was also detected. The slice map corresponding to sector "b" (fig. 5b)

[6] For the analysis and interpretation of the GPR traces, see Conyers – Lucius 1996; Arnold *et alii* 1997; Conyers – Goodman 1997; Piro 1998; Conyers *et alii* 2002: 39-40; Conyers 2004: Chapter 7.

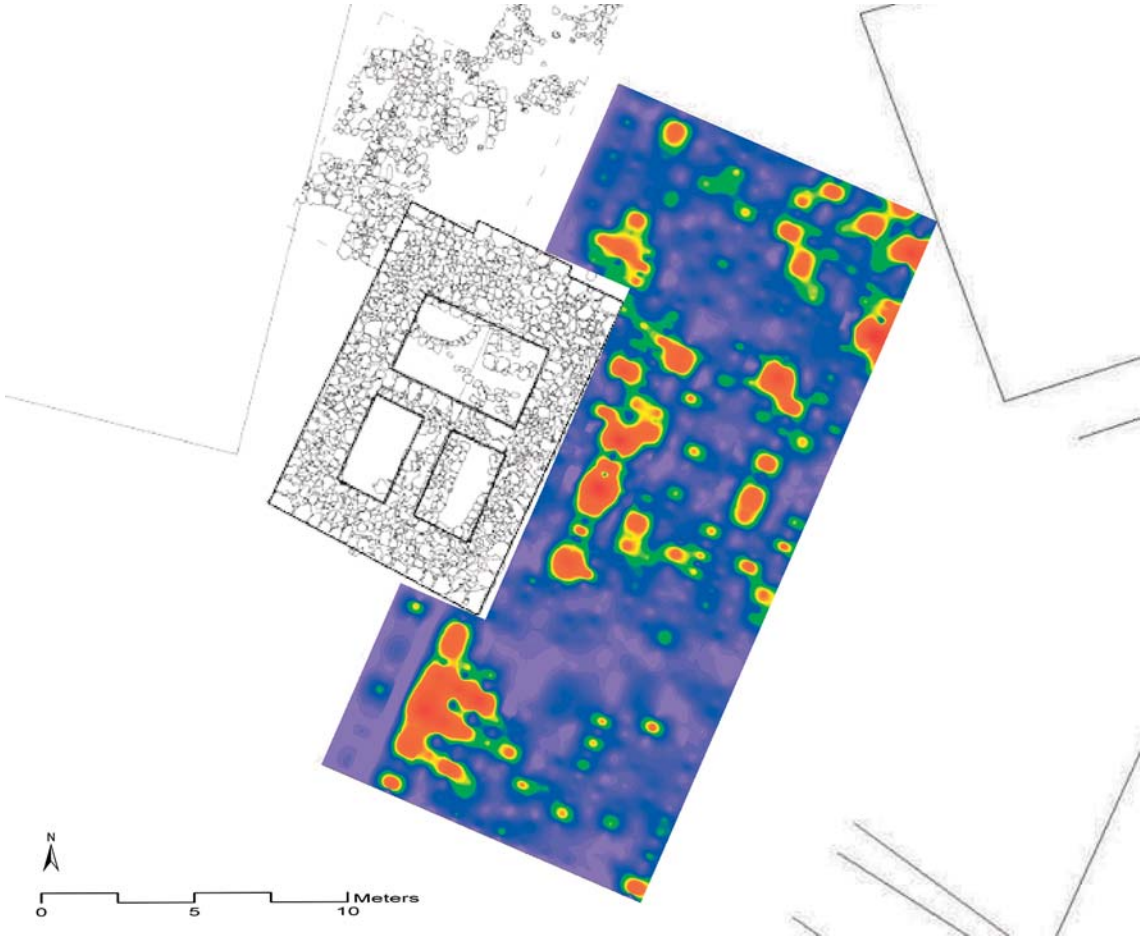

Fig. 6. Map and superimposed time slices for sector "e", east of excavated Building L.

generated an image where parallel walls define two square rooms, with additional structures on both sides. The vertical GPR traces (B-scan) confirmed the presence of walls and other archaeological evidences. It is worth noting that the buried features reveal similar proportions and the same topographical orientation (45 to 60 degrees to the North, and parallel to the line of the northern casemates excavated nearby). These architectural characteristics suggest that the buried features belong to the same period as the casemates, i.e. to MB II.

Sectors from "a" to "e" display the presence of archaeological features, although interpolated traces are not as clear as for sector "b". This may be due to superficial basalt bedrock, which is also responsible for some dielectric anomalies (such as in "c" and "d"). In sector "e" (fig. 6) it is possible to identify a small rectangular building with most likely an outer floor in the South-West corner of the grid (the red feature visible in the map), all elements similar to those excavated in nearby Area L. In sector "a", there are at least three structures which were identified by the GPR survey; the feature in the North-East corner complements a Late Bronze Age (hereafter LBA) structure revealed in the excavations of Area L. In sectors "f" and "g", the GPR survey identified various floors at a depth comprised between 30 and 60 cm, while at deeper levels there are probably walls and other structures. Within sector "f", a test excavation during the 2006 campaign (fig. 5a) confirmed the existence of a corresponding earlier floor (dating from MB I) at the depth indicated by the GPR survey.

Thus, in the lower town, where only MB II and LB I layers are attested to, but where superficial bedrock sometime limits GPR interpretation, some structures have been identified along the street ascending from postern K-3 to temple M, as well as along the northern casemates, here with the possibility of "seeing" also a few installations. In the northern sector of the acropolis, on both sides of Building L, two other isolated rectangular buildings similar to the former have been detected[7], thus giving an impression of a regular line of buildings separated from the casemates by a lozenge-shaped empty space, as proven also in a trench excavated between Building L and the casemates to the North, in which a continuous MB II paved outer surface had previously been exposed.

An additional GPR analysis was performed to measure the water table depth in several areas of the site, for mapping subsurface hydrology. The study was part of a more general environmental assessment of the archaeological site for conservation purposes and for the development of an archaeological park (see Rossi Pisa *et alii* 2008).

(M.B., F.B., P.R.)

5. Conclusions

The understanding of an ancient urban setting cannot be accomplished today without non destructive surveys integrated through a rigorous methodology. Geodetic infrastructures created in the last few decades allow for the adoption of an international reference frame for applications that require a precise information georeferencing. The obvious contrast of the more limited use of GPR in respect of the more extensive one of the geomagnetic method, can be used to the advantage of a stratigraphic, i.e. vertical, approach, as well as for soil information. Significant results for the study and understanding of the early second millennium BC urbanism at Tilmen have been obtained: in fact, the reliability of detailed urban information supplied by geophysic surveys in archaeology becomes greater when the archaeology of a given settlement is already familiar. In this perspective, geophysics represent a complement to the excavations and not just a method for guiding in the selection of excavation areas.

[7] The depth of the westernmost one excludes that it belongs to LBA or Roman superficial layers present in that sector and allows an attribution for it to the MBA phase, probably to MB II; the building to the East, on the contrary, lies beneath a slope for which we have already noticed that later levels were washed away, thus supporting also a date to MB II for it.

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