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Archaeological geophysics in arid environments: Examples from Israel

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A B S T R A C T

Israel is a country with mostly arid environments where is localized extremely large number of archaeological objects of various age, origin and size. The archaeological remains occur in multi-layered and variable geological–archaeological media. In many cases physical properties of the ancient objects are disturbed by long-term influence of arid conditions. These disturbances strongly complicate interpretation of observed geophysical anomalies since the useful signal/noise ratio is often sufficiently reduced. Another disturbing factors are the influence of uneven topography, oblique polarization (especially, for magnetic field analysis) and industrial-engineering objects of different kinds situating in the vicinity of studied remains. From a rich arsenal of the developed techniques (the most part of them is described in Khesin et al. (1996)) in the paper are presented the methods of advanced quantitative analysis of potential geophysical fields and 3D magnetic field modelling. A brief archaeological-geophysical review indicates that in Israeli archaeological sites were applied practically all near-surface geophysical methods: beginning from the paleomagnetic examination and ending by microwave remote sensing. Such a diversity of applied methods and constant accomplishing of geophysical, archaeological and other data stipulate creating of a multi-linkage as between the various geophysical methods, so also with other archaeologically related databases.

1. Introduction

Israel is located between 29° and 33° north of the equator and is characterized as a subtropical region, between the temperate and tropical zones, where the Earth's magnetic field is strongly inclined. Israeli territory is mostly characterized by semi-arid and arid climate (Enzel et al., 2008). Such climate causes an increased productivity and water-use efficiency due to higher CO_2 which would tend to increase ground cover, counteracting the effects of higher temperatures (Brinkman and Sombroek, 1996). As a result of this effect, the soils of Israel are complex formations with variable physical properties even within small areas.

The territory of Israel, in spite of its comparatively small dimensions (about of 21,000 km^2), contains an extremely large number of archaeological remains due to its rich ancient and Biblical history. Many authors (e.g., Kempinski and Reich, 1992; Kenyon, 1979; Meyers, 1996) note that the density of archaeological sites on Israeli territory is the highest in the world. Ancient remains of different age and origin occur in the subsurface layers at depth till 10 m and deeper (in multi-layered archaeological sites).

Geophysical methods have been successfully applied to reveal and delineate archaeological remains and have proved to be rapid, effective and non-invasive tools for the study of a broad range of various targets in Israel (e.g., Boyce et al., 2004; Dolphin, 1981; Eppelbaum and Itkis, 2003; Eppelbaum et al., 2001b, 2003, 2006a, 2006b, in press; Ginzburg and Levanon, 1977; Itkis, 2006; Itkis and Eppelbaum, 1998; Itkis et al., 2003; Sternberg et al., 1999; Weinstein-Evron et al., 2003; Witten et al., 1994).

Barker (1993:1) emphasizes: "Unlike the study of an ancient document, the study of a site by excavation is an unrepeatable experiment". Non-invasive geophysical experiments have no limitations on the repeatability of data acquisition and analysis. They have great potential due to their different physical principles, varied scales of survey, range of locations of measuring sensors and different combinations of methods that can be applied. Processing and interpretation of geophysical data may also differ. Geophysical surveys provide a ground plan of cultural remains before excavation or may even be used instead of excavations. Road and plant construction, selection of areas for various engineering and agricultural aims are usually accompanied by detailed geophysical (first of all, magnetic) investigations. Such investigations can help estimate the possible archaeological significance of the area under study. Rapid (first results may be obtained during a few hours to several days) and reliable interpretation of geophysical data can

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provide protection for archaeological remains from unpremeditated destruction. Cost of these investigations is usually many tens of times less than the total expenditure of archaeological investigations. Among the range of ancient targets in Israel, the most typical sites of different chronological ages and origins that were examined using different geophysical methods, were selected for presentation in this paper.

2. Noise complicating geophysical investigations in archaeological sites in ISRAEL

It is well-known that geophysical observations at archaeological sites are complicated by numerous factors (Eppelbaum and Khesin, 2001; Eppelbaum et al., 2006b; Itkis, 2006) (Fig. 1). Below we briefly consider these disturbances.

Artificial noise. The *Industrial* component comprises power-lines, cables, buildings, different underground and transport communication systems that strongly affect practically all physical fields applied in archaeogeophysics (to a lesser degree – piezoelectric and self-potential (SP) methods). The *Instrumental* component is associated with the technical properties of geophysical instruments (e.g., "shift zero" of gravimeters and accomplishing electrode's noise in SP) and their spatial location. *Difficulties in electrode grounding* are of some significance in geophysical prospecting with the electrode system of measurements, such as resistivity and SP methods (geophone grounding – for seismic and piezoelectric methods). It is one of the typical technical problems arising in arid and semi-arid regions. The last component of artificial noise is the absence of information about previous archaeological excavations at the site being studied, data, that are not available for planning geophysical investigations and their analysis.

Natural disturbances. The first component of *nonstationary* noise comprises temporary variations in geophysical fields, such as tidal variations in the gravity field, ionosphere disturbances influencing magnetic and electromagnetic Very Low Frequency (VLF) fields and climatic changes affecting the SP field. A second component of nonstationary noise reflects meteorological conditions (rain, lightning, snow, hurricanes, etc.) obviously disturbing observations in all geophysical methods. *Soil-vegetation factors* are associated with some soil types (e.g., water-logged ground or loose ground in deserts) and dense vegetation complicates accessibility of geophysical equipment. *Uneven terrain relief* causes physical limitations for equipment transportation and geophysical data measurements. This disturbance is generally two-fold for potential and quasi-potential fields: first, there is the effect of the form and physical properties of the topographic bodies forming the relief and, secondly, there is the effect of variations in the distance from the measurement point to the hidden target (Khesin et al., 1996). *Uneven relief* also strongly distorts ground penetrating radar (GPR) and seismic observations.

The complex structure of geo-archaeological sections is the most important physical–archaeological disturbance. A further component is the *variety of anomalous sources* which are composed of two factors: *variable surrounding medium* and *variety of archaeological targets*. Both these factors are very crucial and complicate interpretation of all geophysical fields. The first of the above-mentioned factors is typical for arid (semi-arid) regions.

Oblique polarization (magnetization) complicates geophysical fields such as magnetic, VLF, SP, thermal, resistivity and piezoelectric. *Oblique polarization* disturbs these geophysical fields in the following manner: the major extremum is shifted from the projection of the upper edge of the object on the plan, and an

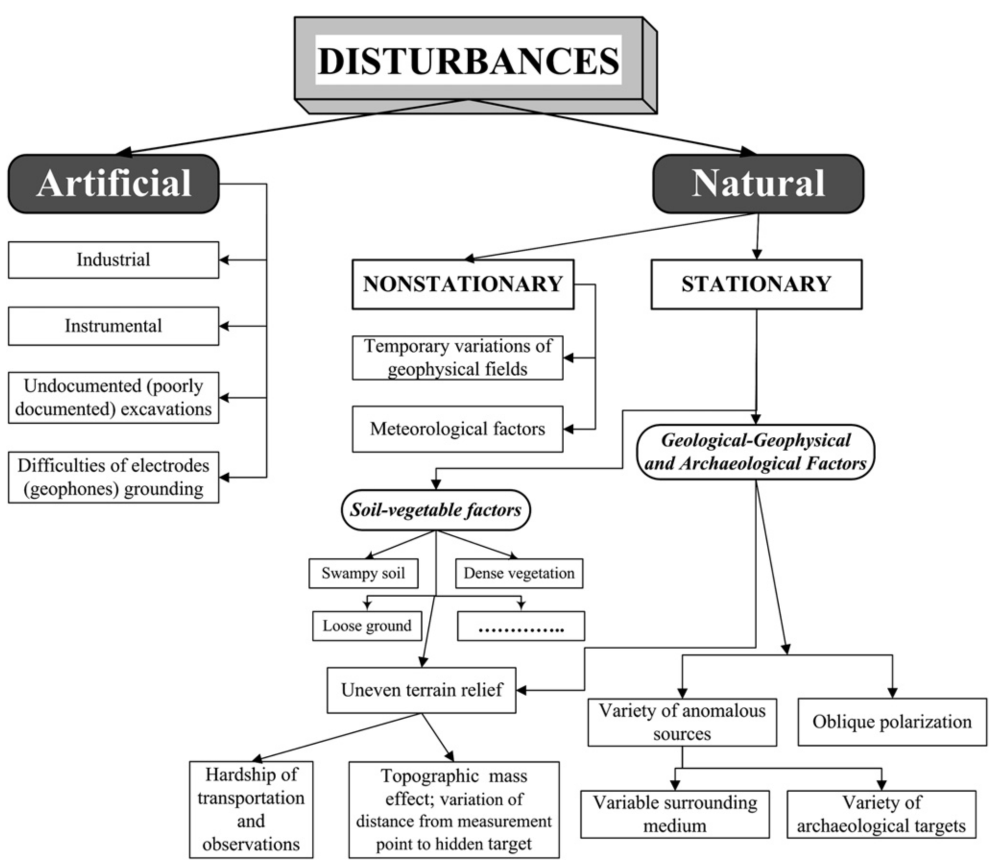

Fig. 1. Archaeological geophysics: Classification of disturbance factors (after Eppelbaum et al., 2001b, 2006b, revised and supplemented).

additional extremum may appear (Khesin et al., 1996). It should be noted that oblique magnetization is the characteristic peculiarity for arid (semi-arid) regions of the world due to their geographical location.

3. Development of physical–archaeological models (PAMs)

3.1. Some particulars relating to the application of detailed magnetic investigations in archaeological sites in Israel

The detailed magnetic survey is the most widely used geophysical tool in studying archaeological remains in Israel (Boyce et al., 2004; Eppelbaum and Itkis, 2003; Eppelbaum et al., 2000b, 2001b, 2003, in press; Itkis, 2006; Itkis and Eppelbaum, 1998; Itkis et al., 2003). Therefore, we will consider the conditions of its application in detail.

Interpretation of magnetic surveys in Israel is complicated by the strong inclination of the Earth's magnetic field (about 42–46°). In addition, the multi-layered and variable structure of the upper part of the geological sequence (Dan, 1988; Horowitz, 1979) presents difficulties in the determination of the level of the normal magnetic field within the sites studied. Industrial iron and iron-containing objects sometimes produce an intensive noise effect. Uneven terrain relief also disturbs the delineation of buried objects and complicates examination of magnetic anomalies. A significant number of the archaeological targets studied are situated in the vicinity of industrial–agricultural objects that also disturb archaeological-geophysical measurements. The complex conditions of the survey require application of sophisticated geophysical equipment and advanced methods of qualitative and quantitative interpretation. To this end, the methods that have been developed (Eppelbaum et al., 2000a, 2001b, 2003; Khesin et al., 1996) allow the elimination of various types of noise, to reveal archaeological remains, calculate their depth, size and physical characteristics using modern technique of inverse problem solution and 3D modelling.

In the areas under study, besides the obvious optimal square grids used in surveys, triangular grids may be effectively applied (Itkis, 2006). The selection of a magnetic sensor level (ranging in intervals of 0–3 m) depends on the concrete archaeological/geological situation. The complex and multi-layered structure of many archaeological sites and their remains, and known ambiguity of interpretation of results from single geophysical methods, calls for an integration of different geophysical methods (Khesin and Eppelbaum, 1997; Khesin et al., 1996), where magnetic and electric methods are important components of an optimal set. The necessity of close integration between archaeology, geophysics and chemistry is clearly illustrated by Pollard and Bray (2007).

The goal of applying geophysical surveys to archaeological sites is to obtain quantitative information about the geometric and physical characteristics of buried archaeological remains, e.g., development of physical–archaeological models (*PAMs*) of desired objects. The *PAMs* of different hierarchical complexity (the simplest *PAMs* reflect recognition of the desired target while complete *PAMs* represent 3D models of archaeological remains), may be a substitute for direct excavations in the recognized areas (as well as for prohibition of industrial activity) and for generating further strategies for archaeological investigations at sites where ancient remains have been discovered.

According to our experience (Eppelbaum et al., 2001a, 2001b, 2003, 2006a, 2006b; Finkelstein and Eppelbaum, 1997; Khesin et al., 1996), the general scheme of magnetic data processing and interpretation at archaeological sites may consist of the procedures that are presented in a flow chart (Fig. 2). Detailed information concerning the techniques of the applied procedures may be found in the above-mentioned publications.

3.2. Multimodel approach to magnetic data examination

The magnetic method is one of the most widely used geophysical methods for recognition of buried archaeological targets. Quantitative interpretation of magnetic anomalies was traditionally oriented to a single model to identify buried objects. In the case of the existence of several hypotheses relating to the parameters of the body causing the disturbance (i.e. the buried object) usually only one model was selected, roughly presenting the object in the domain Ω_x of *k*-dimensional space of physical–archaeological factors. At the same time, as a rule, ancient remains are complicated objects broken by human activity and various geological/environmental processes. Additional noise affecting interpretation includes rugged terrain relief, oblique polarization of geological objects and archaeological remains, and heterogeneous host medium. As a consequence, response function Λ_i – geophysical field – may ambiguously represent the ancient target. Therefore, domain Ω_x may be divided into several subdomains $\Omega_1,\ldots,\Omega_m$ and in each of them a single model will dominate (Eppelbaum, 2005). In such a way we could develop *m* physical–archaeological models of the same target, each corrected for a separate subdomain $\Omega_1,\ldots,\Omega_m$. The multimodel approach may be realized at varying levels of geophysical field registration. As a result, different models of explanation may be used in the process of quantitative interpretation. Integrating several response functions Λ_i we can obtain a more accurate and reliable physical–archaeological model of an ancient target.

For quantitative analysis of magnetic anomalies, the usually used models are: thin bed (*TNB*), thick bed (*TKB*), horizontal circular cylinder (*HCC*) and horizontal plate (*HP*) (Fig. 3). These four models can be presented with various modifications (for instance, inclined upper and lower edges and inclined dipping), which practically cover all available major types of archaeological remains. For *TNB*, *TKB* and *HCC*, improved modifications to the point method, tangent method and areal method, were developed. They are relevant for the above-mentioned complex environments, including where the level of the normal magnetic field is unknown (Khesin et al., 1996). Let us consider two examples of simple models. The model presented in Fig. 4 illustrates utilization of two different interpretations of the same ancient remnant by performing a magnetic survey at two different levels (0.1 and 3.0 m, respectively). Indeed, from the survey at the 0.1 m level it is a typical *TKB* model (Fig. 4a) and at the 3.0 m level, observations of the anomalous body may be interpreted as an *HCC* (Fig. 4b) (see also Fig. 3). Results of the *TKB* model interpretation were used to determine a center of the upper edge of the anomalous body (Fig. 4a) and the *HCC* model for localization of a center of *HCC* (Fig. 4b). Combining these two models (we have two response functions Λ_1 and Λ_2 from subdomains Ω_1 and Ω_2), we can develop a common generalized model of the anomalous body.

3.3. Case studies using different geophysical methods and the development of physical–archaeological models (PAMs)

3.3.1. Magnetic prospecting

3.3.1.1. Site of Nahal-Zehora II. The prehistoric site of Nahal-Zehora II is situated in the Menashe Hills in central Israel (Fig. 5). The site comprises a Pottery Neolithic (6th–5th millennia B.C.) stratigraphic sequence, including the Late Yarmukian culture and phases of the Wadi Raba culture (Gopher, 1995). The site yielded rich ceramic, lithic and faunal remains and was inhabited by agriculturists based on cereals and pulses and the management of sheep–goat herds as

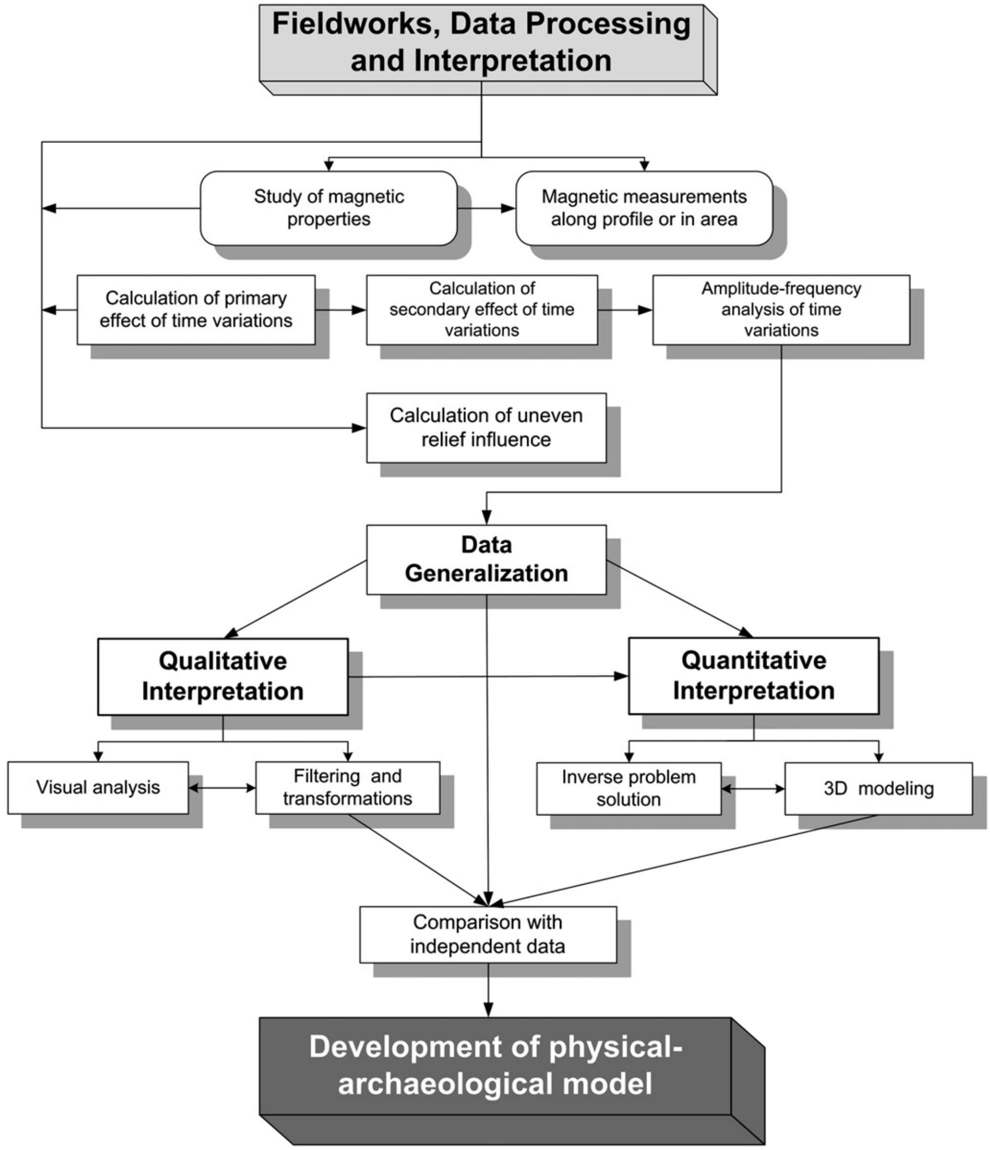

Fig. 2. High-precision magnetic prospecting: A generalized flow chart.

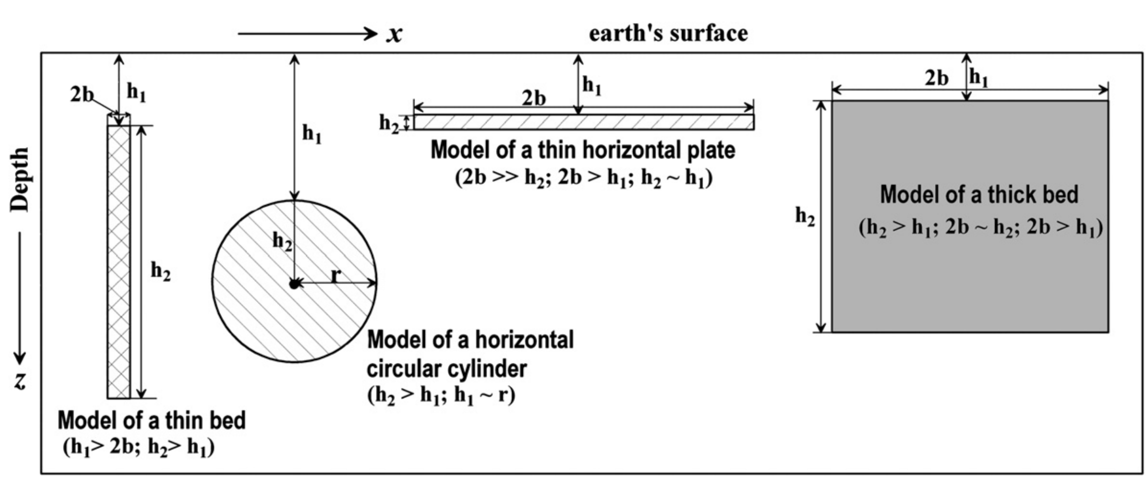

Fig. 3. The main geometrical approximations of anomalous bodies used in archaeogeophysics.

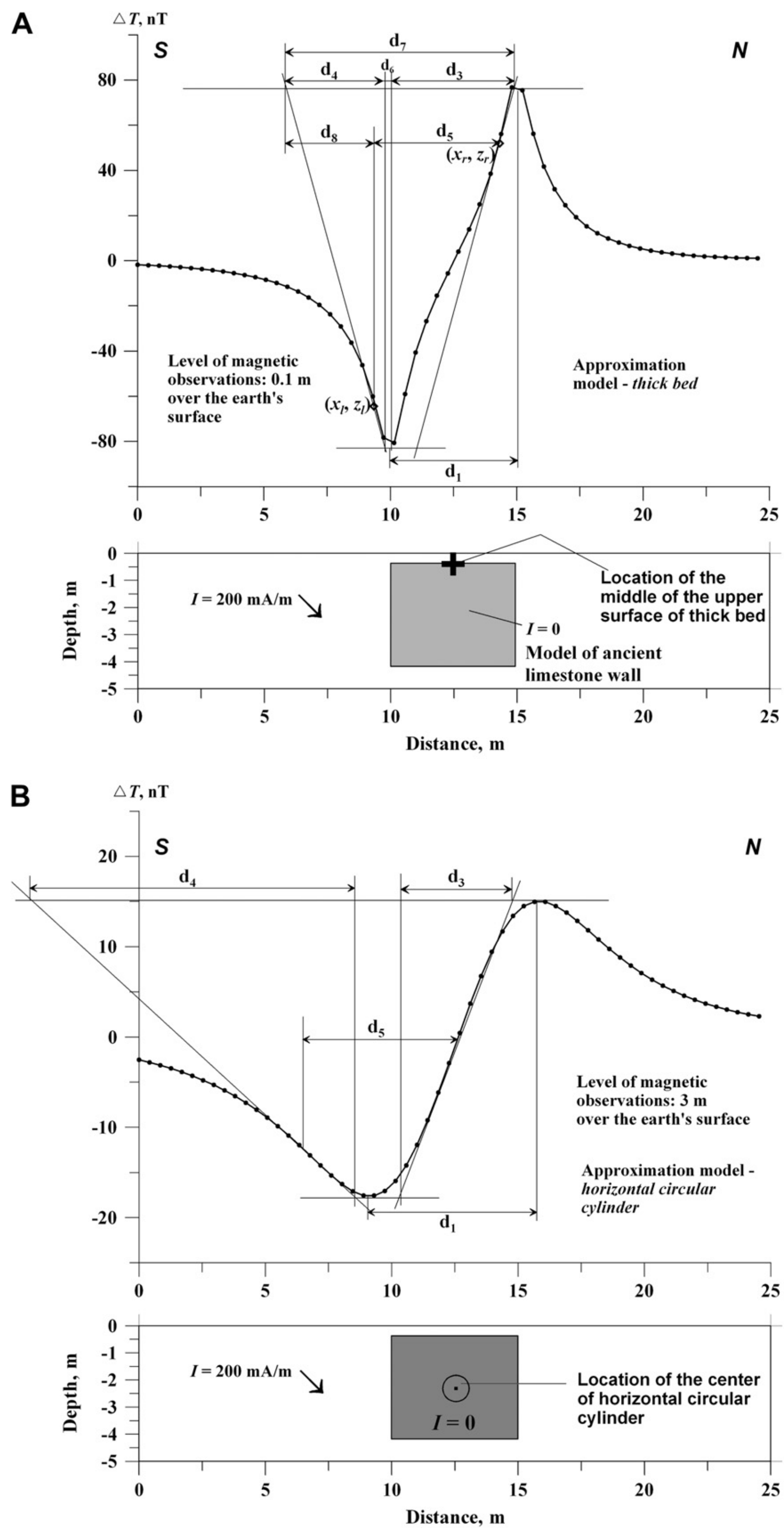

Fig. 4. Realization of two-level observations with two different interpretation models utilized: (A) model of a thick bed, (B) model of the horizontal circular cylinder. Effective magnetization of the models shown here and the following figures is denoted as *I*.

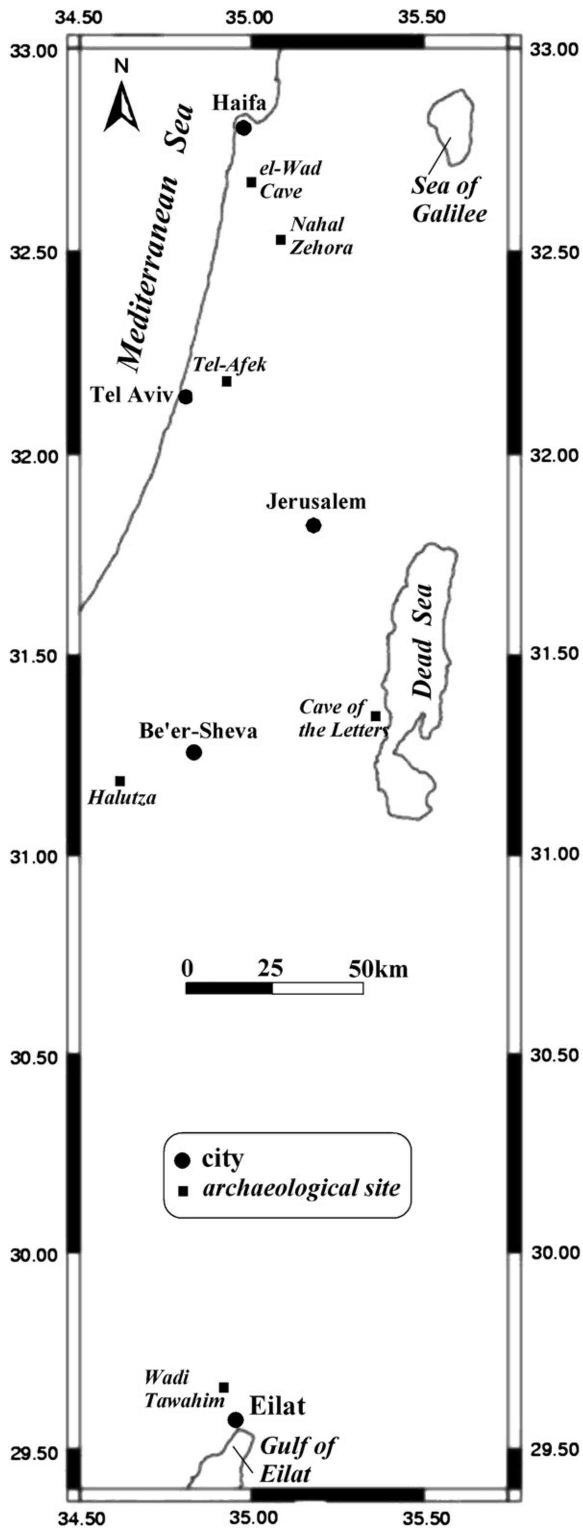

Fig. 5. Map of the area under study showing the sites mentioned in the text.

well as pigs and cattle. Both cultures are represented by stone built houses as well as a rich variety of stone, mudbrick and limeplaster installations. Pits and stone piles were also exposed (Gopher, 1995). All the above-mentioned targets, as follows from literature analysis and magnetic susceptibility measurements that were performed, can produce local magnetic anomalies.

For the first time in Israel, detailed areal magnetic measurements (grid 1×1 m) were conducted in a sufficiently large area 60 m $\times$ 80 m with a total number of 5178 observation points (Fig. 6a). The height of the magnetic device was 80 cm above the ground due to the presence of a variety of sources of limited noise. For the field measurements a proton magnetometer "MMP-203" was used and for registering temporary magnetic variations a quantum magnetometer "MM-60" was used (the same as in the site of Halutza – see below). Measurements performed of the magnetic susceptibility of the soil (S-N kappametric profile is shown in Fig. 6a) were utilized at the subsequent stages of the examination of magnetic anomalies. An example of the examination of anomaly **G** is shown in Fig. 6b (inverse problem solution) and Fig. 6c (3D modelling). For the inverse problem solution, an *HCC* model has been used. This model has been defined by iterative 3D modelling using the GSFC program (description of this program is given in Khesin et al., 1996). The developed *PAMs* for this survey area were used in the development of excavation strategies for further archaeological investigations at this site (Eppelbaum et al., in press).

3.3.2. Integrated magnetic and SP investigations

3.3.2.1. Site of Halutza. The site of Halutza is located 20 km southwest of Be'er-Sheva town, in southern Israel (Fig. 5). It was the central city of southern Palestine in the Roman and Byzantine periods and was founded as a way station for Nabatean (7th–2nd centuries BC) traders traveling between Petra (Jordan) and Gaza and occupied through the Byzantine period (4th–7th centuries AD) (Kempinski and Reich, 1992; Kenyon, 1979).

Combined geophysical investigations consisting of magnetic and self-potential (SP) measurements were performed in an area of 200 m^2 using a 1×1 m grid (Fig. 7a, b). According to *a priori* information, limestone structures had been excavated in this area of the site. It was expected that limestone remains occur in the medium with magnetization of 70–100 mA/m that could produce the appearance of small negative magnetic anomalies; SP anomalies arising are based on the difference between the electric properties of the target/medium and the generation of the oxidation–reduction processes.

The magnetic sensor level was located at 30 cm above the earth's surface. SP measurements were performed using a micro-Voltmeter with high input impedance and special non-polarized electrodes (*Cu* in $CuSo_4$ solution) (Eppelbaum et al., 2001a). The potential-array scheme (with a base point electrode) was applied; depth of electrode grounding was 10–15 cm. Visual analysis of the maps (Figs. 7a, b) indicates that the SP and magnetic fields have different trends, but the recognized negative anomalies in the southern part of this site were spaced 2 m apart. Quantitative interpretation of SP and magnetic anomalies gave similar depths: 90 and 70 cm, respectively. The corresponding *PAMs* for the performed examination are displayed in Fig. 7c, d. The ancient walls excavated in direct proximity to the surveyed area occur at a depth of about 80 cm. It allows us to suggest that similar objects are the sources of the anomalies found in the area covered by the integrated geophysical survey.

3.3.3. Resistivity method

3.3.3.1. Site of Tel Afek. The archaeological site of Tel Afek, dating to the Late Bronze Age (1550–1200 BC), is situated about 10 km east of Tel-Aviv (Fig. 5). One of the main geophysical–archaeological problems at this site consisted of mapping walls of ancient structures that were almost completely covered by sediments. At this site, Ginzburg and Levanon (1977) previously applied the resistivity method (altogether 8 profiles were observed) based on the essential differences in geoelectric characteristics between the ancient objects and sediments, and effectively localized several buried wall foundations in the area studied. One of the electric resistivity

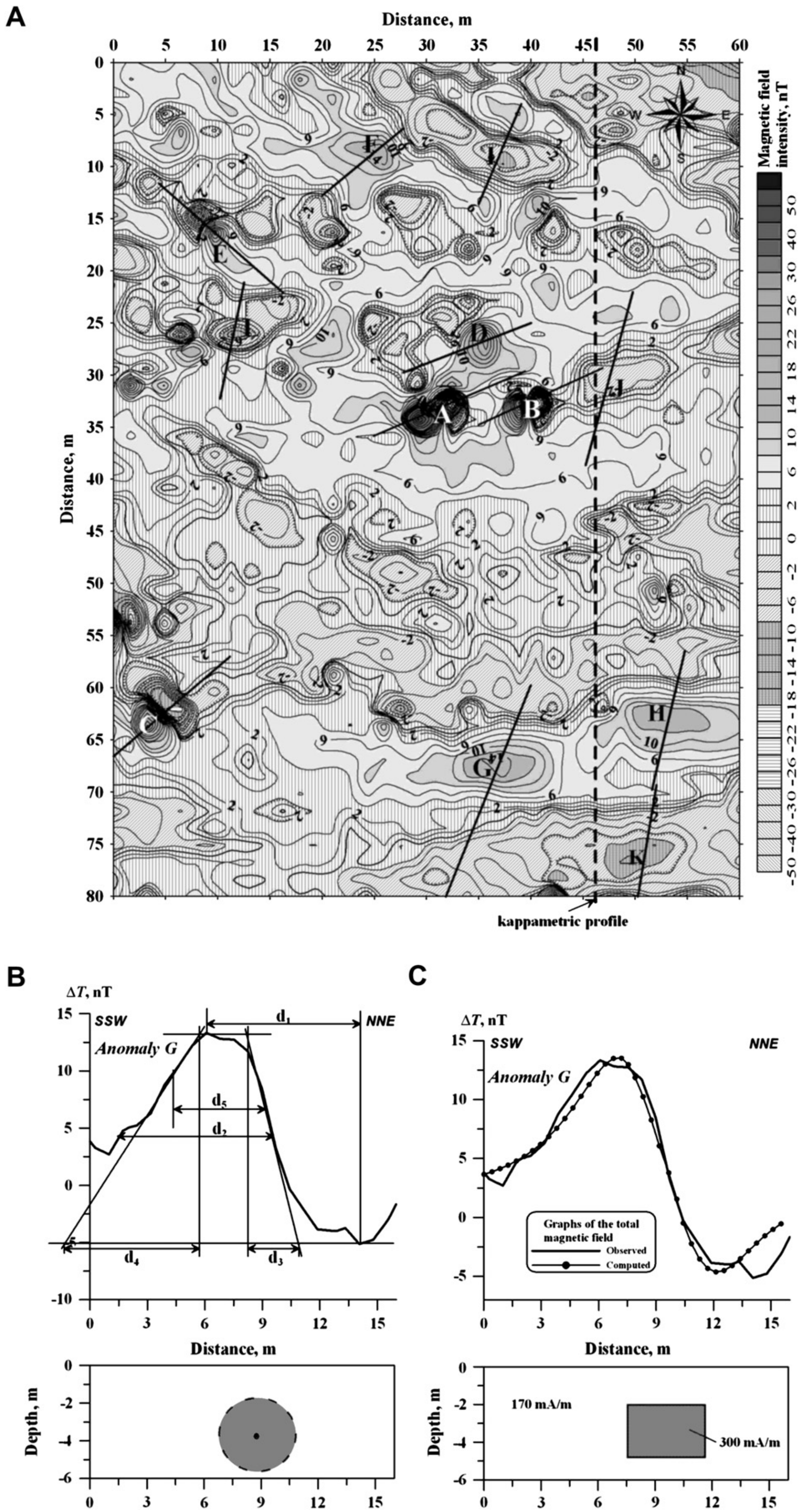

Fig. 6. Examination of magnetic anomalies in the Nahal-Zehora site (Menashe Hills, central Israel). (a) Map of the observed magnetic field ΔT (solid lines and letters indicate the location of the investigated profiles and anomaly index, respectively), (b) quantitative analysis of magnetic anomaly **G**, (c) results of 3D magnetic field modelling over the same anomaly.

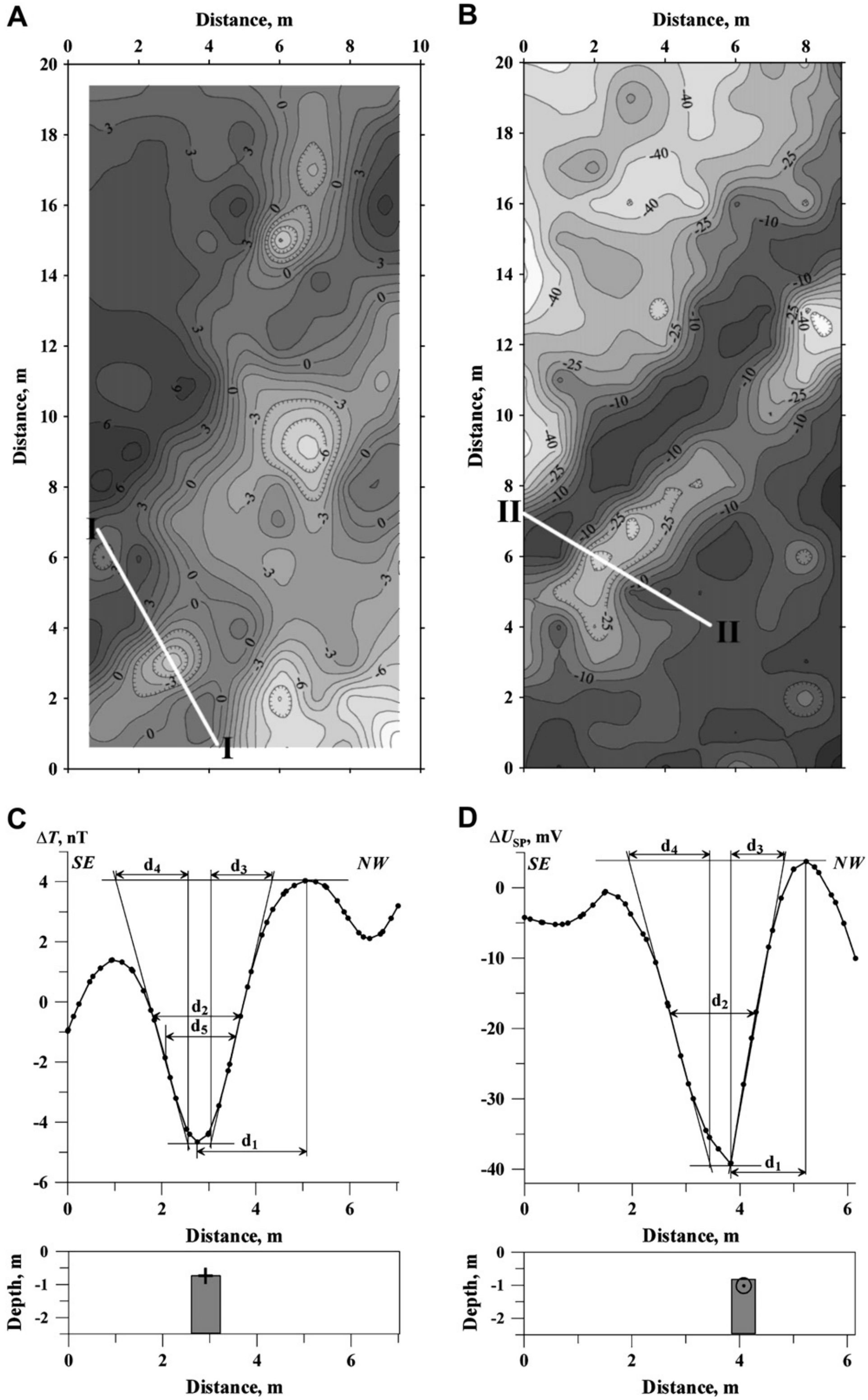

Fig. 7. Maps of magnetic (a) and self-potential (b) fields in the Halutza site (Negev desert, southern Israel), and results of the quantitative interpretation for profile I – I (c) and II – II (d). A cross indicates the position of the middle of the upper edge of the anomalous body for magnetic anomaly (Fig. 7c), and a small circle is inscribed in the upper edge of the anomalous body for the SP anomaly (Fig. 7d).

anomalies was examined (Fig. 8) by applying the advance interpretative methods developed in magnetic prospecting (Eppelbaum, 1999). For developing a *PAM*, the *HCC* model was applied. As evident from Fig. 8, the interpretation is in good agreement with the archaeological data.

3.3.4. *Piezoelectric method*

3.3.4.1. Site of Wadi Tawahim. The site of Wadi Tawahin, dating to the Early Islamic Period (7–10 centuries B.C.), is located 5 km north of the town of Eilat (Fig. 5). The study aimed at locating buried quartz veins that were natural sources of gold for ancient

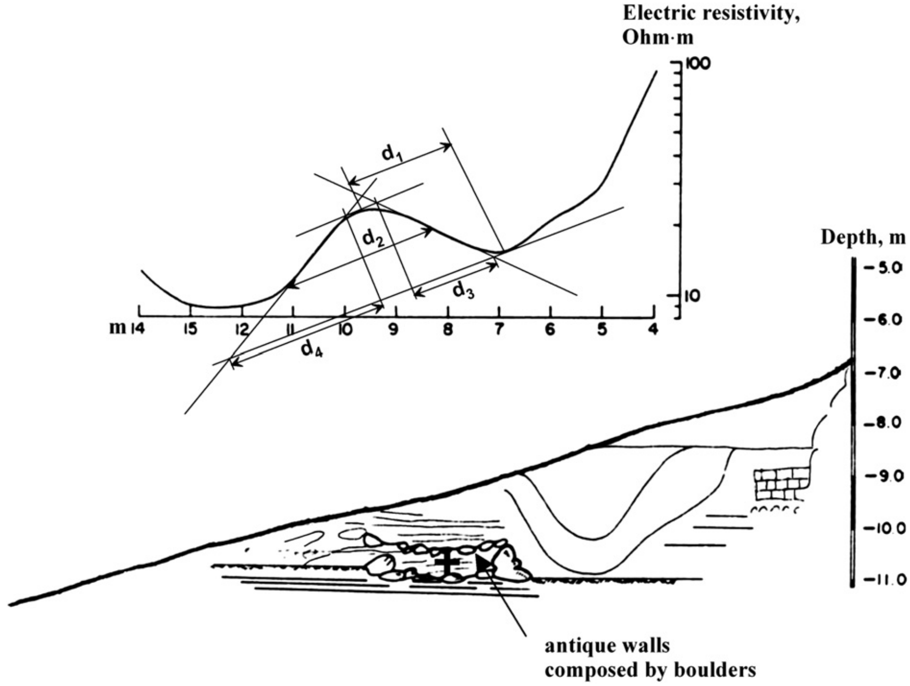

Fig. 8. Inverse problem solution for resistivity anomaly in the archaeological site of Tel Afek, central Israel (initial data from Ginzburg and Levanon, 1977). A cross in the section designates the location of the center of the anomalous body.

metallurgy (Neishtadt et al., 2006). The geological sequence is extremely heterogeneous at the local scale (varying from boulders to silt), and covers the quartz veins (Gilat et al., 1993) complicating their identification. Taking into account that piezoelectric investigations are the best methods for delineation of quartz veins, several experimental profiles were made using a MORION-2001 instrument (Neishtadt et al., 2006). Measurements (both electrode spacings and shotpoint distances were 5 m) conducted over a quartz vein covered by surface sediments (approximately of 0.4 m thickness) produced a sharp (500 µV) piezoelectric anomaly (Fig. 9). Piezoelectric values recorded over the host rocks (clays and pebbles) were close to zero. It should be noted that the methods developed in magnetic prospecting for a thick bed interpretation model (see Fig. 3) were successfully applied to examine this anomaly.

3.3.5. GPR survey

3.3.5.1. Cave of the Letters. The Cave of the Letters, located in the tectonically active Dead Sea Rift Zone (Fig. 5), is a limestone cave whose Roman deposits have yielded a priceless collection of archaeological artifacts – pottery, coins and bronze objects, as well as 70 documents of this epoch notably the 'Bar-Kokhba's letters' (Reeder et al., 2004). The cave served as a refuge for Jewish commanders and their families, towards the end of the Second Jewish Revolt against the Romans (~135 BC).

The cave floor is covered with roof fall that obscures the underlying archaeological deposits. A GPR survey (physical principles of this method entail delineation of targets with different electromagnetic properties), was used in the interpretation and reconstruction of living floors below the roof fall. As part of the GPR analysis, a 3D data set was collected from a 5.5 m × 2.5 m grid in Hall "B" of the cave (Fig. 10). 3D data sets of such *PAM*s greatly aided in interpreting the framework of the subsurface materials and provided a more detailed view of the geometry of individual units (Reeder et al., 2004).

3.3.6. Seismic refraction method

3.3.6.1. El-Wad Cave. The well-known prehistoric el-Wad Cave is located on Mount Carmel in northern Israel (Fig. 5). According to Weinstein-Evron (1998), el-Wad (13,000–10,600 BC) is a key-site for the study of the Upper Paleolithic and the Natufian cultures in the Levant. The cave was examined using seismic refraction (this method is based on the study of elastic waves propagated with different velocities in various geological rocks and ancient targets) in order to measure the thickness of the upper sediment layer in the various unexcavated segments of the cave (Weinstein-Evron et al., 2003). The energy source used was a 5 kg hammer and 24 geophones with an internal frequency of 10 Hz that were arranged in 24 channels. For increasing resolution, spacing between the geophones was set at 0.5 m (Weinstein-Evron et al., 2003). An impressive *PAM* resulting from such an investigation is presented in Fig. 11.

3.4. Other geophysical methods used for subterranean mapping

Among other geophysical techniques that have been applied to date in Israel to delineate buried archaeological remains and their classification, we note the following case studies. Paparo (1991) applied near-surface thermal prospecting to delineate the remains of a Crusader fortress in the city of Netanya, on the Mediterranean coast. Experimental microwave remote sensing was performed at the Tseelim site (northern Negev desert), and results indicate that this methodology might be applied for delineation of buried archaeological targets (Daniels et al., 2003). The possibilities of the multifocusing methodology (an effective procedure developed in seismic prospecting) applied to the GPR method, was tested at an archaeological site in the vicinity of Modiin (central Israel) to identify buried objects (Berkovitch et al., 2000). Another method, vertical electric sounding, has been applied to delineate prehistoric caves in Mount Carmel (Weinstein-Evron et al., 2003) as well as for mapping the stalagmite-rich Soreq Cave in central Israel (Ezersky

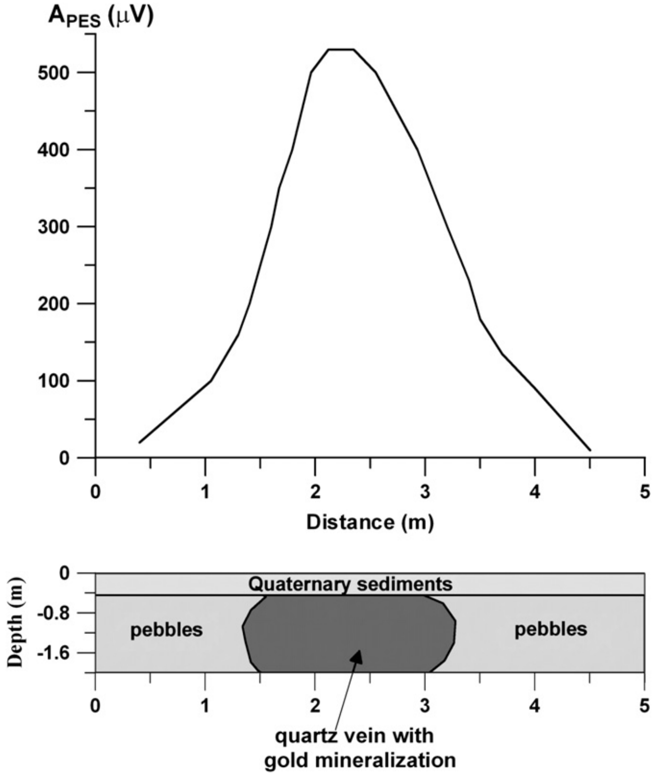

Fig. 9. Piezoelectric anomaly over an ancient gold-bearing mine, southern Israel (after Neishtadt et al., 2006).

et al., 2000). Weiss et al. (2007) fruitfully tested a system developed for detection and accurate mapping of ferro-metallic objects buried below the seabed in the vicinity of Atlit (northern Mediterranean coast of Israel).

Seismo-archaeological examination oriented to detect and catalogue ancient earthquakes was successfully carried out at several Israeli archaeological sites, for instance Karcz and Kafri (1978), Marco et al. (2003), Nur and Ron (1997), Ellenblum et al. (1998), Korjenkov and Mazor (1999) and Marco (2008).

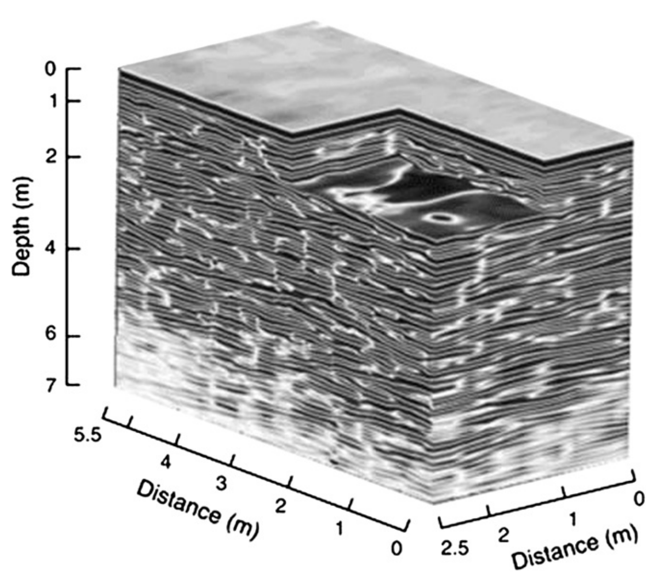

Fig. 10. GPR survey at the Cave of Letters (Dead Sea): 3D cube with electric resistivity tomography lines and archaeological cave floor exposed (after Reeder et al., 2004).

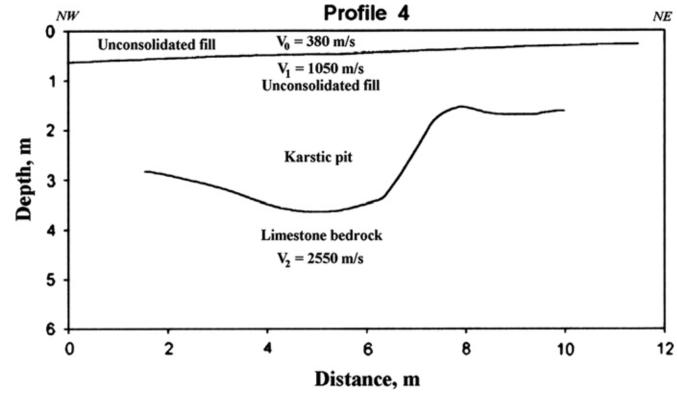

Fig. 11. Seismic refraction profile of Chamber IV of el-Wad Cave, Mount Carmel (northern Israel) (after Weinstein-Evron et al., 2003).

Eppelbaum and Khesin (1995) proposed a new scheme for VLF data interpretation and proved the feasibility of applying it in Israel for solving various environmental and archaeological problems. As was shown in Eppelbaum (2009), advanced analysis of microgravity anomalies (including multilevel gravity measurements) and 3D modelling could be successfully applied for contouring and quantitative examination of some types of archaeological targets in Israel (e.g., ancient caves, walls, pavements and abandoned sites of primitive metallurgy). In another study, Eppelbaum et al. (2006c) assessed the possibility of archaeotemperature determination by measuring modern temperatures observed in shallow boreholes.

Paleomagnetic investigations for calculating age have been effectively applied at many archeological sites including Abu Matar, Ashqelon, Tel Miqne and Megadim (Sternberg et al., 1999), Bizat Ruhama (Laukhin et al., 2001), Evron Quarry (Ron et al., 2003), Timna, Yotvata, Mitzpe Evrona, Givat Yocheved, Beer Ora Hill and Tel Kara Hadid (Ben-Yosef et al., 2008).

3.5. Development of multi-dimensional physical–archaeological database

The continuous increase in geophysical–archaeological data and their revision have necessitated the development of an Integrated Archaeological–Geophysical Data Base (IAGDB). Obviously, it must be multi-componental and dynamic in character (Eppelbaum and Ben-Avraham, 2002). Besides spatial topographic coordinates (x, y, z) of archaeological sites, the IAGDB should include all values of geophysical field (s) observations *over* or *under* the earth's surface, results of repeated measurements of the geophysical field (s) over different periods of time as well as during archaeological excavations (Fig. 12). It is also necessary to digitize the geophysical survey results of previous years and their relation to other databases (e.g., geological, geochemical, paeleostructural, paleosedimentation, paleobotanical, paleobiogeographical).

As a basis for the IAGDB development one could use *Access*, obviously, with utilization of all necessary graphic archaeological–geological data sets. Development of such continuously expanding database will increase effectiveness of geophysical examination of archaeological targets by simplifying and hasten the planning, implementation and analysis of archaeological-geophysical investigations. From a regional point of view, the Israeli IAGDB could be connected with similar databases from neighboring countries in the Mediterranean region, Near and Middle East.

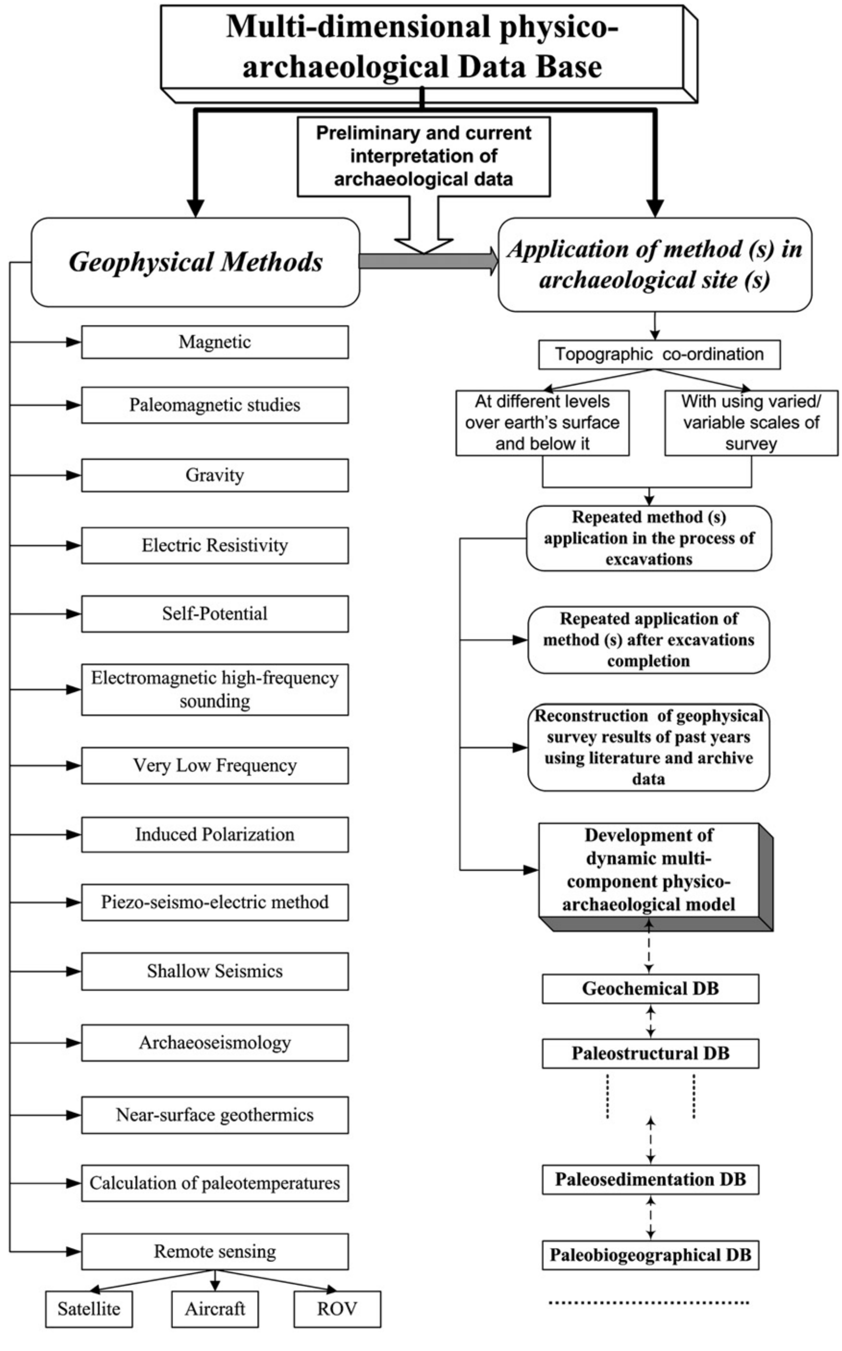

Fig. 12. Development of a multi-component physical–archaeological database for Israeli environments.

4. Conclusions

Detailed geophysical investigations accompanied by integrated geophysical data processing and interpretation are powerful means for rapid and reliable detection and imaging of archaeological remains in arid and semi-arid environments. The cost of these non-invasive investigations is markedly less than the total expenditure of archaeological excavation. The final aim of different processing methods, application of algorithms and interpretations, is the creation of physical–archaeological models (*PAM*s) of the ancient buried remains. *PAM*s of different types may be used to undertake excavations in recognized areas and for planning future archaeological investigations at sites where ancient remains have been discovered. The current approach to the application and integrated analysis of geophysical methods requires the development of a multi-dimensional, dynamic physical–archaeological database.

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