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POTENTIAL GEOPHYSICAL FIELDS – INEXPENSIVE EFFECTIVE INTERPRETATION TOOL AT ARCHAEOLOGICAL SITES IN THE NEAR EAST

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In the Near East occur a giant number of archaeological objects of various age, origin and size. The most territory of the Near East relates to arid and semi-arid regions that unambiguously physically and chemically complicates the upper part of archaeological sequence. Geodynamical active, multi-layered, and geologically variable surrounding media in many cases damages ancient objects and disturbs their physical properties. This calls to application different geophysical methods armed by the modern interpretation technology. Potential geophysical fields (magnetic, gravity, resistivity, self-potential and thermal) are non-expensive, rapid and effective tools for investigation of the most part of archaeological remains. It is confirmed by a review of successful potential field application at the different archaeological sites in the Near East countries. In the magnetic prospecting an advanced system of archaeomagnetic data processing and interpretation has been developed for complex physical-environmental conditions. The main elements of the developed system have been successfully transferred to other potential geophysical fields. Several examples illustrate effective application of potential geophysical methods over some typical archaeological remains.

INTRODUCTION

The territory of the Near East contains extremely large number of archaeological remains due to its richest ancient history (e.g., Kenyon, 1979; Meyers, 1996). Low-expensive and prompt potential geophysical fields (magnetic, gravity, resistivity, self-potential and thermal) are applied for the revealing, localization and classification of archaeological remains as rapid, effective and non-invasive tools for the study of a broad range of various targets (e.g., Green, 1973; Ginzburg and Levanon, 1977; Lakshmanan, 1987; Paparo, 1991; Gaber et al., 1999; Eppelbaum, 2000; Eppelbaum et al., 2000b, 2001b; Chouker, 2001; Ibrahim et al., 2002; Ates et al., 2003; Ciminale, 2003; Eppelbaum and Itkis, 2003; El-Bassiony and Weller, 2004; Drahor, 2004; Abdallatif et al., 2005; Odah et al., 2005; Borradaile and Almqvist, 2006; Drahor et al., 2007; Batayneh et al., 2007; Ekinci et al., 2007; Kaya et al., 2007; Weiss et al., 2007; Bollongino and Vigne, 2008; Casana et al., 2008; Gaffney et al., 2008; Boyce et al., 2009; Eppelbaum et al., 2010; Modin, 2010; Batayneh, 2011; Berge and Drahor, 2011; Taha et al., 2011; Issawy, 2012; Novo et al., 2012).

Employment of potential geophysical fields has significant preferences due to their different physical principles and varied scales of survey, various locations of measuring sensors and different possible combinations of methods. A significant role plays also fact that the cost of such studies (first of all, magnetic survey) is much lower than the cost of geophysical investigations carried by other methods.

Potential geophysical surveys provide a ground plan of cultural remains before excavations or may be even used instead of excavations. Road and plant construction, selection of areas for various engineering and agricultural aims are usually accompanied by detailed geophysical investigations. Rapid and reliable interpretation of geophysical data should provide protection of archaeological remains from unpremeditated destruction. Besides this, non-invasive potential geophysical fields are the most significant tools by the studying the world recognized religious and cultural artifacts (Eppelbaum, 2010a). The final aim of potential geophysical field application at archaeological sites is development of Physical-Archaeological Model (*PAM*) reflecting the main peculiarities of the studied ancient targets.

In magnetic prospecting an advanced system of magnetic data processing and interpretation for complex physical environmental condi-

tions (oblique magnetization, rugged terrain relief and unknown level of the normal field) has been developed (Alexeyev et al., 1996; Khesin et al., 1996; Eppelbaum et al., 2001a; Eppelbaum, 2011b, 2013). Different components of this system have been successively tested at the archaeological sites in Israel (Eppelbaum et al., 2000b, 2001b, 2003, 2004a, 2006a, 2008, 2010) and Cyprus (preliminary 3D magnetic field modeling). One of the most important advantages is the proved possibility to apply the interpretation methodologies (with necessary modifications) for analysis of other potential fields (Eppelbaum, 1999; Eppelbaum et al., 2001a, 2010; Eppelbaum, 2009, 2011a; Eppelbaum and Khesin, 2012). It permits to employ a unified interpretation scheme for all potential geophysical field examination (Table 1).

Among the variety of ancient objects discovered in the Near East, the most typical sites of different ages and origins (taking into account also a frequency of geophysical method application) are discussed in this paper.

DIFFERENT KINDS OF NOISE APPEARING IN POTENTIAL GEOPHYSICAL FIELDS APPLICATION IN ARCHAEOLOGICAL SITES

It is well-known that geophysical observations at archaeological sites are complicated by numerous factors (Eppelbaum and Khesin, 2001; Eppelbaum et al., 2010) (Figure 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 potential fields applied in archaeogeophysics (to a lesser degree – self-potential (SP) method). *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 with the electrode system of measurements in resistivity and SP 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 (or incompleteness) of *information about previous archaeological excavations* at the site being studied that do not allow to use these data for planning of future 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 field, short- and middle-period temperature variations strongly influence to the thermal data observed in shallow wells, and climatic changes affecting the SP field.

Table 1

Elements of a potential geophysical field processing and interpretation system under complex environments

FIELD	Time variation correction	Terrain correction using correlation method	Informational and wavelet algorithms for revealing buried targets	Inverse problem solution				3-D integrated modeling of fields
				rugged relief	arbitrary magnetization (polarization)	approximation of anomalous object		
						1 - 3 models	***4 - 5 models***	
Magnetic	+ ⊙	⊙	+⊙	⊙	⊙	⊙	⊙	+ ⊙
Gravity	+	⊙		⊙	⊙	⊙	+	+ ⊙
Thermal	+ ⊙	⊙		⊙	⊙	⊙	–	⊗
Resistivity	⊙	⊙		⊙	⊙	⊙	–	+
SP	+	+		+	⊙	⊙	–	–

+ formal presence of procedure; – absence of procedure; ⊙ principally new or nonconventional procedure developed by the authors; ⊗ partially realized

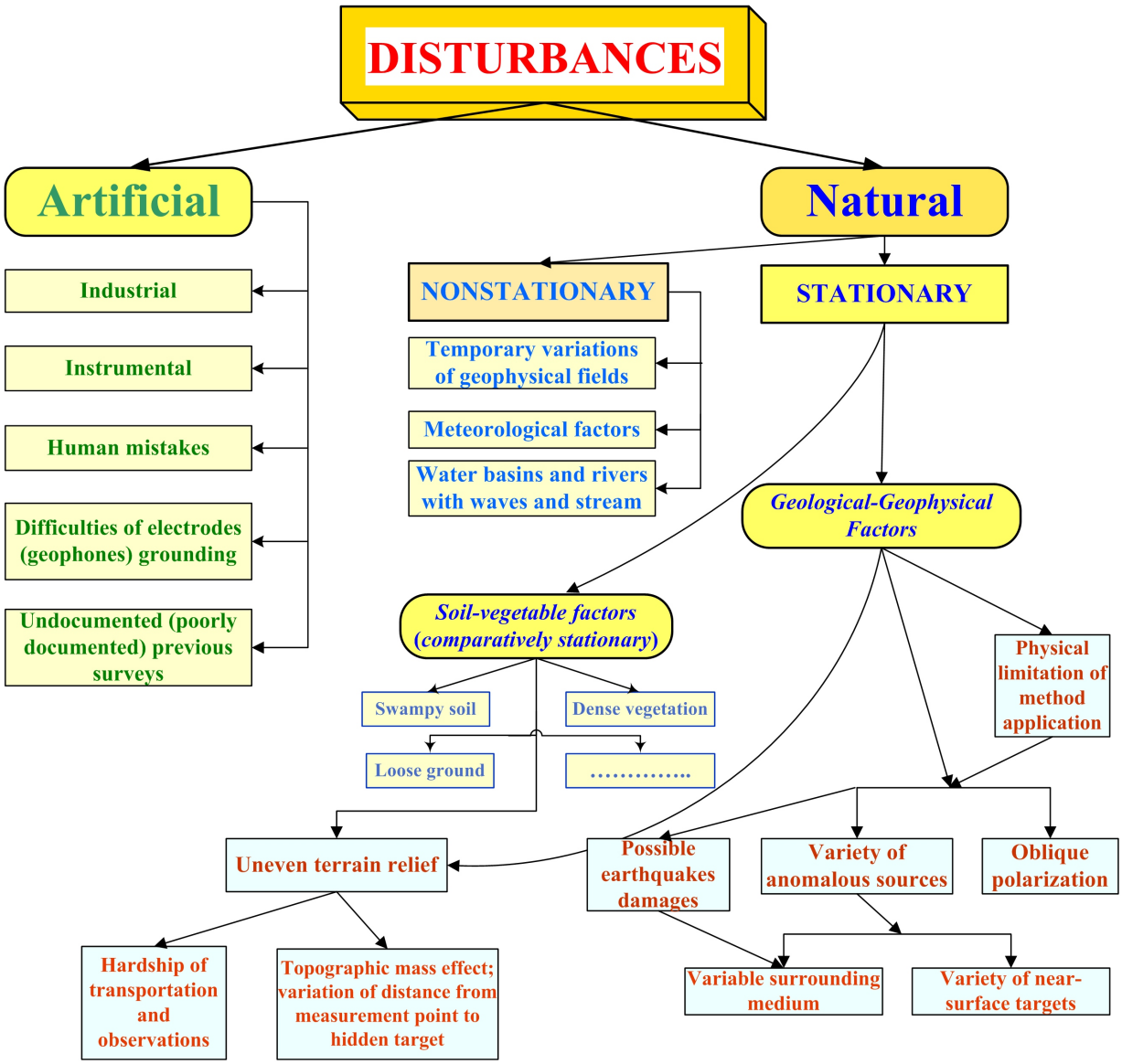

Figure 1. A General scheme of noise classification for potential geophysical fields (after Eppelbaum (2010), with modifications)

A second component of nonstationary noise reflects *meteorological conditions* (rain, lightning, snow, hurricanes, etc.) obviously disturbing observations in all geophysical methods.

Disturbing *water surface* (water in basins or rivers) may also affect the gravity and magnetic fields measurements, and sometimes – other potential fields).

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 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).

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.

Physical limitation of method application indicates is the geophysical field suitable for employment at the concrete archaeological site.

Possible earthquake damages (for example, the seismological pattern of the Eastern Mediterranean for the period 1900-2012 is presented in (Eppelbaum and Katz, 2012) may significantly distort (and even to crash) the desired ancient targets.

Oblique polarization (magnetization) complicates magnetic, SP, thermal and resistivity methods. It should be noted that in microgravity method may also appear an effect similar to oblique polarization by gravity observations over strongly inclined surface and definite occurrence of archaeological remains (Eppelbaum, 2011a). *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 additional extremum may appear (Khesin et al., 1996; Eppelbaum, 2013). It should be noted that oblique magnetization is the characteristic peculiarity for all Near East countries due to their geographical location.

POTENTIAL GEOPHYSICAL FIELDS ANALYSIS

Magnetic survey

The detailed magnetic survey is widely used geophysical tool for identifying archaeological remains in the Near East (e.g., Green, 1973; Itkis and Eppelbaum, 1998; Eppelbaum, 2000; Eppelbaum et al., 2003a, 2010; Eppelbaum and Itkis, 2000, 2003; Ates et al., 2003; El-Bassiony and Weller, 2004; Itkis et al., 2003; Abdallatif et al., 2005; Odah et al., 2005; Herbich and Peeters, 2006; Kaya et al., 2007; Gaffney et al., 2008).

Some examples from the Near East

Total magnetic field surveys

Possibly one the first underwater magnetic survey in the Near East has been carried out in the site of Cape Andreas, Cyprus. Performed investigation enabled to classify buried iron and other ancient targets (Green, 1973).

A series of magnetic anomalies was interpreted as shafts and accompanying ground structures (circuit walls) at the site of Deiral-Barsha (Middle Egypt). Several of these features have already been verified in excavations. The magnetic study has also led to the discovery of a previously unrecognized dirt road cutting across the necropolis to the Nile valley (Herbich and Peeters, 2006).

Gaffney et al. (2008) have successfully applied the Foerster magnetometer at the world heritage site of Cyrene, Libya. Despite to the disturbing influence of uneven topography and variable subsurface media, several small anomalies reflecting some archaeological remains were detected.

Geomagnetic research in the Tell Tweini, the Bronze Age site (Lattakia, Syria) has shown that the ground plan of the site could be joined with the previously excavated structures (Bretschneider and Van Lerberghe, 2008).

Author of this paper has been carried out preliminary 3D magnetic field computations for development of *PAM* for the archaeological site Politiko-Phorades (central foothills of the Troodos Mts., Cyprus).

Magnetic gradientometric investigations

Ates et al. (2003) have employed gradientometric survey at the Kerkenes site of the Iron Age (30 km SE of the town of Yozgat, Turkey). The authors have shown that results of high-pass filtering of the observed data could help recognize earlier unknown archaeological remains.

Magnetic gradientometric investigations at the archaeological site in Kyme (60 km north of Izmir, Turkey) were applied to obtain highly resolved digital raster images which were utilized for recognition of near-surface archaeological remains (Ciminale, 2003).

An effective example of gradient magnetic data modeling is presented in El-Bassiony and Weller (2004). The authors demonstrated a good agreement between observed and modeled gradient values observed at the northern cemetery of Saqqara (Egypt) (*PAM* of the buried potteries was employed), known as “The Great Archaic Tombs”.

Magnetic gradientometric tracing was productively employed in the site of Abu Sir (Land of Forgotten Pyramids), Northern Egypt. The depth to the buried archaeological features was estimated by the utilization of radially averaged power-spectrum curve (Abdallatif et al., 2005).

Magnetic gradientometric imaging enabled to recognize numerous archaeological features NE of the Zoser Pyramid, Giza, Egypt (Odah et al., 2005).

Kaya et al. (2007) delineated archaeological remains at the Emirag archaeological site (Anatolian plateau, Turkey) by the way of computation of maxima of the horizontal gradients outlining the boundaries of the source bodies.

3D map of gradientometric anomalies over the Nabataean Hawar archaeological site (southern Jordan) reliably indicates a visibly rectangle magnetic pattern over a buried water cistern (Batayneh, 2011).

Taha et al. (2011) recognized several gradientometric anomalies produced by some buried constructions made from fire - brick and mud - brick building material.

Short description of the developed system and several examples from Israel

Interpretation of magnetic surveys in Israel is complicated by the strong inclination of the Earth's magnetic field: about 42-46° (in the Near East – about 27-52°). In addition, the multi-layered and variable structure of the upper part of the geological sequence (Horowitz, 1979; Dan, 1988) presents difficulties in the determination of the level of the normal magnetic field within the sites studied. Sometimes ancient seismological activity found essential reflection in the observed magnetic pattern. Industrial iron and iron-containing objects sometimes produce an intensive noise effect. Uneven terrain relief also disturbs the effect of buried objects and complicates examination of magnetic anomalies. A significant number of the archaeological studied targets are situated in the vicinity of various industrial-agricultural objects that also disturb the archaeogeophysical measurements. The complex conditions of the survey require application of sophisticated geophysical equipment and advanced methods of qualitative and quantitative interpretation (Khesin et al., 1996; Eppelbaum et al., 2001b, 2010; Eppelbaum, 2011b). Detailed magnetic survey was successfully analyzed in the sites of Banias, Beit-Gouvrin, Beit Shemesh, Emmaus, Eynan, Evora, Halutza, Kissufim Road, Megiddo, Munhata, Nahal-Zehora, Nahal Nagit, Sha'ar Ha-Golan, Tel Kara Hadid, Yodefat, etc. (Eppelbaum et al., 2000a, 2001b; 2003a; Eppelbaum et al., 2004a, 2006a, 2007, 2010; Itkis and Eppelbaum, 2009). Studying of magnetic susceptibility of ancient remains and surrounding media was carried out practically at all archaeological sites where the magnetic survey was performed (Eppelbaum and Itkis, 2001; Itkis and Eppelbaum, 2009).

Some qualitative conclusions about the ancient targets might be obtained from the analysis of low-intensive temporary magnetic variations observed over the desired archaeological targets (Finkelstein and Eppelbaum, 1997).

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. Methods of geophysical field integrated analysis (informational and wavelet methodologies) are presented in detail in Khesin et al. (1996), Khesin and Eppelbaum (1997), Eppelbaum et al. (2011) and Eppelbaum and Khesin (2012).

The generalized scheme of magnetic data examination at archaeological sites is presented in Figure 2.

When anomalies are observed on an inclined profile, then the obtained parameters characterize a certain fictitious body. The transition from fictitious body parameters to those of the real body is performed using the following expressions (the subscript "*r*" and "*f*" stand for a parameter of the real and fictitious body, respectively) (Khesin et al., 1996):

$$\left.\begin{aligned} h_r &= h_f + x_{\text{of}} \tan\omega_{\text{o}} \\ x_r &= -h_f \tan\omega_{\text{o}} + x_{\text{of}} \end{aligned}\right\}, \qquad (1)$$

where h is the depth of body upper edge occurrence (or center of sphere / horizontal circular cylinder), x_{o} is the shifting of anomaly maximum from the projection of the center of disturbing body to the earth's surface (caused by oblique magnetization), and ω_{o} is the angle of the terrain relief inclination ($\omega_{\text{o}} > 0$ when the inclination is toward the positive direction of the x-axis).

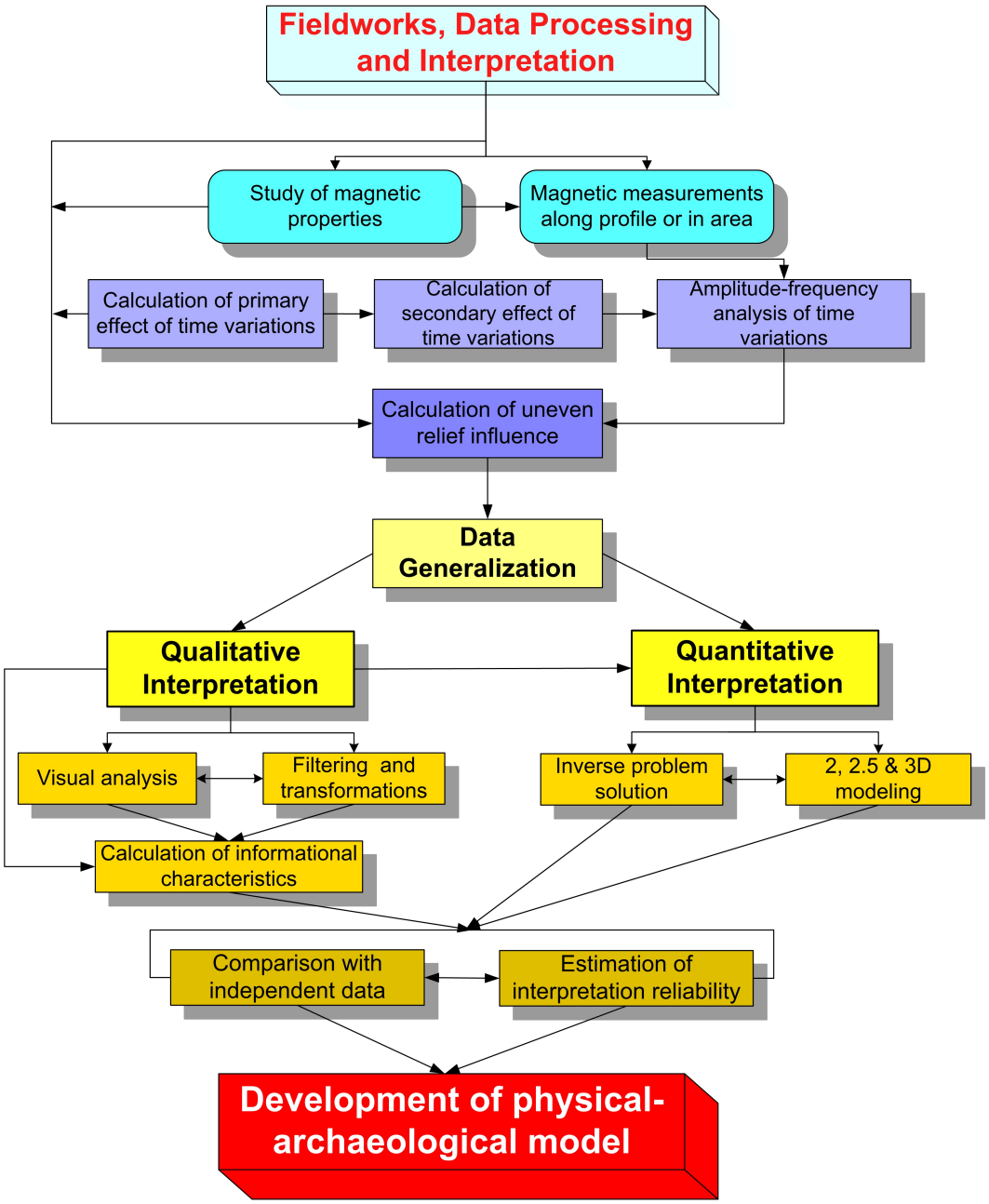

Figure 2. High-precision magnetic prospecting: A generalized block-scheme

The constructed *PAMs* of different hierarchical complexity (the simplest *PAMs* reflect recognition of the desired target while complete *PAMs* represent 3D models of archaeological remains) are used for substantiation of 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.

Sometimes, for removing the noise of different origin, distributed as quasi-white noise, it is useful to transform observed geophysical fields to some informational features. Eppelbaum et al. (2003a) proposed to use the following expression:

$$J_i = U_i\left(\sum_i^n U_i\right)^{-1} \log\left[U_i\left(\sum_i^n U_i\right)^{-1}\right]K, \qquad (2)$$

where U_i is the geophysical observation at i^{th} point ($U_i > 0$) at the area under study and n is the total number of observations, K is the some coefficient.

Let us consider converting of magnetic survey data, observed at the site of Munhata, to the informational parameter J_i. The site of Munhata is located on a terrace at the outlet of Nahal Tabor to the Jordan Valley, some 11 km south of the Lake Kinneret (northern Israel), 215 m below sea level. The depth of archaeological remains at the Munhata site is between 2 and 3 meters. The magnetic survey at this site was expected to be successful taking into account the considerable contrast between features of interest (built mainly of different kinds of basalts) and dark brown surrounding soil. The magnetic survey was carried out to the north of the excavation area.

In the compiled magnetic map (Figure 3A) it is difficult to reveal the anomalous objects, but map processed by the use of Eq. (2) (Figure 3B) clearly displays the desired objects (they outlined by white rectangular and circular frames). The known archaeological objects excavated to the south of the surveyed area are presented in Figure 3C. Obviously, that archaeological targets shown in Figure 3C (discovered objects) and informational images presented in Figure 3B (proposed objects) have a good agreement. Thus, Figure 3B represents the simplest qualitative *PAM*.

Inverse problem solution occupies a very important place in the magnetic anomalies analysis. The developed interpretation schemes enable to perform quantitative analysis of magnetic anomalies produced by five main interpretation models: thin bed, thick bed, horizontal circular cylinder (HCC), sphere, and thin plate (Khesin et al., 1996; Eppelbaum et al., 2001b; Eppelbaum, 2011b, 2013). A simple example of inverse problem solution for the model of buried archaeological cavity (J = 0) occurring in the magnetized medium (J = 300 mA/m) with underlying layer of J = 150 mA/m is displayed in Figure 4. Strong oblique magnetization (44°, typical for Israeli archaeological sites) and inclined surface relief complicate quantitative analysis of this anomaly. Simple visual analysis of the magnetic curve indicates that minimal amplitude of this anomaly might not coincide (see vertical green dash line) with the projection of hidden ancient object to the earth' surface. Application of the developed methodology of inverse problem solution (improved versions of tangents, characteristic points and areal methods) (Khesin et al., 1996; Eppelbaum, 2011b; Eppelbaum and Mishne, 2011) enabled to determine the position of sphere center (a model of HCC was applied; for transferring from fictitious to real body location Eq. (1) was employed) with high accuracy (Figure 4). Hence, a trouble-free quantitative *PAM* has been constructed.

Magnetic anomalies analysis at Ashqelon-Marina (southern Israel) had the aim to examine this area prior to large-scale commercial development. Within this area over 90 pits were identified and most of them were revealed using detailed magnetic prospecting (field works were performed by S.Itkis). The overlying layer of dark brown sandy soil was found to be over 0,5 m in thickness. The pits were all full of refuse (pottery, flints, bones, and stone vessel fragments, some botanical remains and shells). These features were displayed in the magnetic map as ring (radius of 1,5-2 m) positive anomalies (12-20 nanoTesla (nT)). Figure 5 shows an example of magnetic anomaly interpretation over one such ancient garbage pit (the disturbing body was approximated here by the model of a thick bed) (after Eppelbaum et al., 2000b). This is a *PAM* of more high level comparing with Figures 3 and 4.

Next example illustrates efficient application of magnetic survey at the ancient metallurgical site of Tel Kara Hadid. This site (Early Islamic period, 7th-11th centuries A.D.) is located on the western side of the southern Arava Valley, several km north of Eilat in southern Israel. The site contains to a series of copper mines and smelting camps of that period. The same type of slag, reflecting a uniform technology, characterizes all these smelting sites. On the magnetic map two anomalies are clearly detected (Figure 6A), which were recognized as furnaces used in ancient metallurgy. Positions of the upper edges of the anomalous bodies (approximation models of thick (Anomaly 1) and thin (Anomaly 2) beds were used) and their magnetization were determined (Figure 6B). A 3D modeling of the magnetic field was applied to develop the final *PAM* (Figure 6C) (after Eppelbaum et al. (2001b), with modifications).

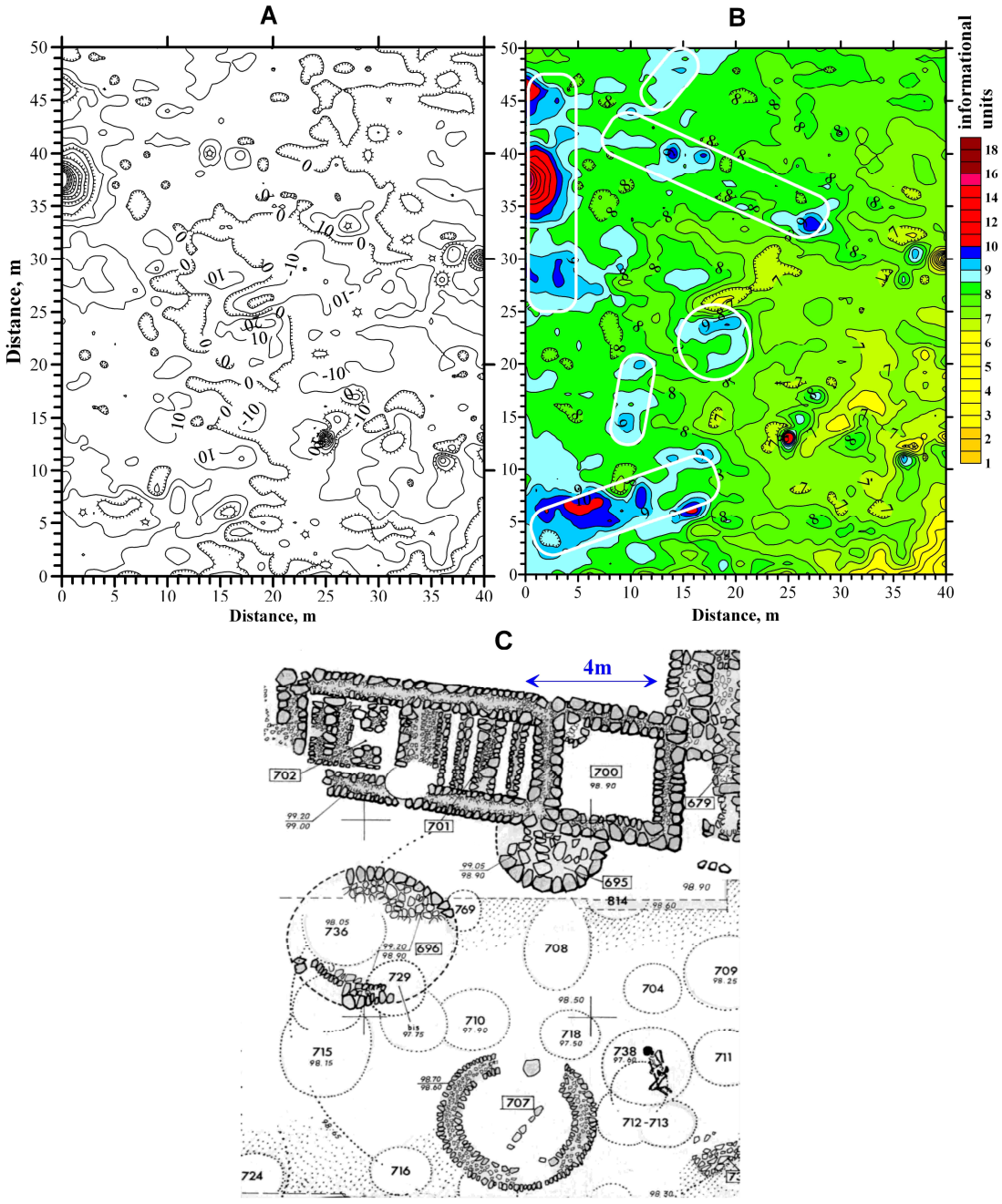

Figure 3. Magnetic maps of the northern part of Munhata site: (**A**) observed magnetic map (after Eppelbaum et al., 2000a), (**B**) the same magnetic map after transformation by the use of Eq. (2), (**C**) excavated part of the Munhata site, some 10 m south of the studied site (after Commenge, 1996)

Among other successful magnetic field analysis at archaeological sites in Israel the following published results are distinguished. A paper of Boyce et al. (2004) suggesting to magnetic marine studying of submerged Roman Harbour (Caesarea Maritima, central Israel) is of a great interest. The magnetic survey identified the presence of an extensive hydraulic concrete foundation below the ruined harbour moles. The magnetic anomaly patterns indicate that the concrete foundation was laid out in a header fashion. Magnetic lows within the structure have localized the baffles that were composed by sand to stabilize the concrete foundation walls. Weiss et al. (2007) fruitfully employed a system developed for detection and accurate mapping of ferro-

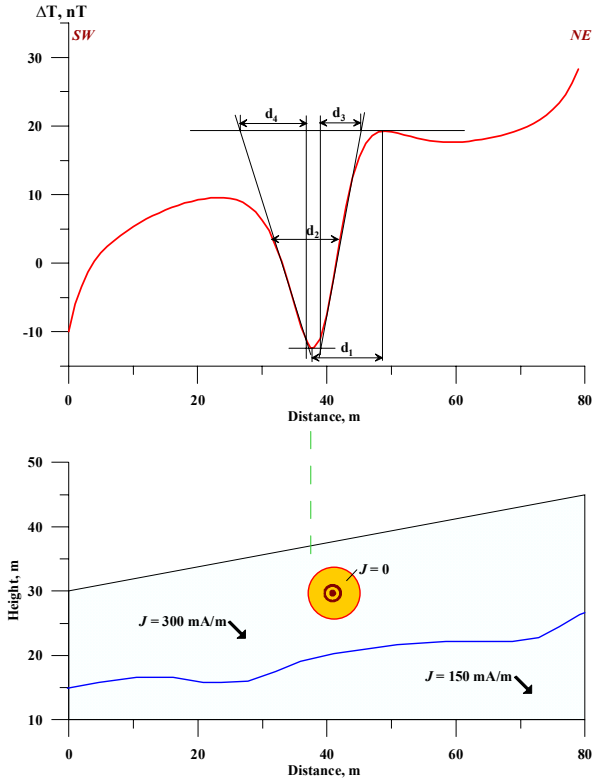

Figure 4. Model example of magnetic field quantitative analysis under complicated environments. Symbol ⊙ designates location of the sphere center and arrows show the position of the total magnetic field vector

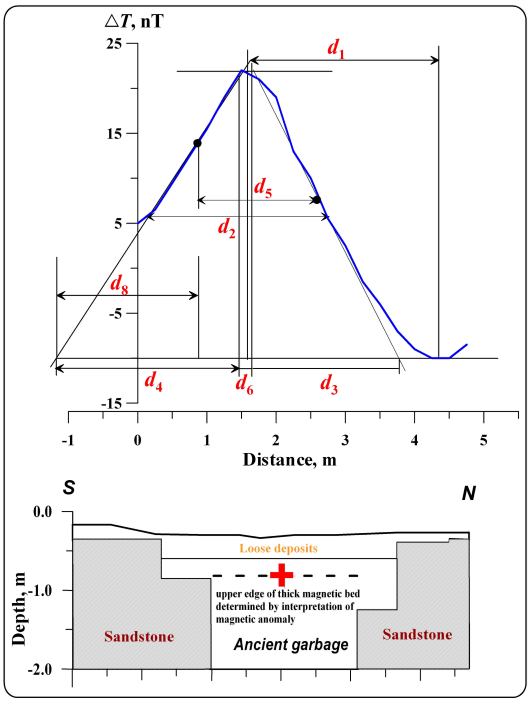

Figure 5. Interpretation of magnetic anomaly due to ancient garbage at the site of Ashqelon-Marina

metallic objects buried below the seabed in the vicinity of Atlit (northern Mediterranean coast of Israel). A continuation of this investigation (Boyce et al., 2009) has demonstrated that ancient ship ballast (basalts) could be reliably detected and mapped on the seabed using precise magnetic survey.

Paleomagnetic data analysis in many cases assists to recognize an intricate magnetic pattern at archaeological sites. Borradaile and Almqvist (2006) analyzed young viscous remagnetization directions at the Neolithic monuments in Cyprus and Armageddon site (Megiddo) in northern Israel. Ben-Yosef et al. (2008) comprehensively investigated several ancient metallurgical sites of the southern Levant (Israel, Jordan and Syria).

Paleomagnetic investigations were effectively applied at Abu Matar, Ashqelon, Tel Miqne and Megadim (Sternberg et al., 1999), Bizat Ruhama (Laukhin et al., 2001), Evron Quarry (Ron et al., 2003), Kebara Cave (Sternberg and Lass, 2007), Timna, Yotvata, Mitzpe Evrona, Givat Yocheved, Beer Ora Hill, Tel Kara Hadid (Ben-Yosef et al., 2008; Shaar et al., 2010), etc. Segal et al. (2003) carried out paleomagnetic tests on two archaeological structures as an oven and a limekiln in the Crusader fortress Vadum Iacob (northern Israel). These fireplaces enable determination of the local direction and intensity of the geomagnetic field on August 24, 1179, when its construction was suddenly terminated.

Self-Potential Field

Drahor (2004) reported on the successful application of SP observations at several archaeological sites in Anatolia (Turkey). Gradient SP measurements were performed by the non-polarizable electrodes with utilization of the $Cu–CuSO_4$ solution. Qualitative analysis of SP images was confirmed by the subsequent excavations.

Apparently, firstly SP measurements at archaeological sites in Israel were performed at the sites of Banias, Shaar-Ha-Golan and Halutza (Eppelbaum et al., 2001a, 2003b, 2004b). Later SP survey was performed at the site of Emmaus-Nikopolis (Eppelbaum et al., 2007), where low-intensive SP anomalies were registered over small caves of an artificial origin.

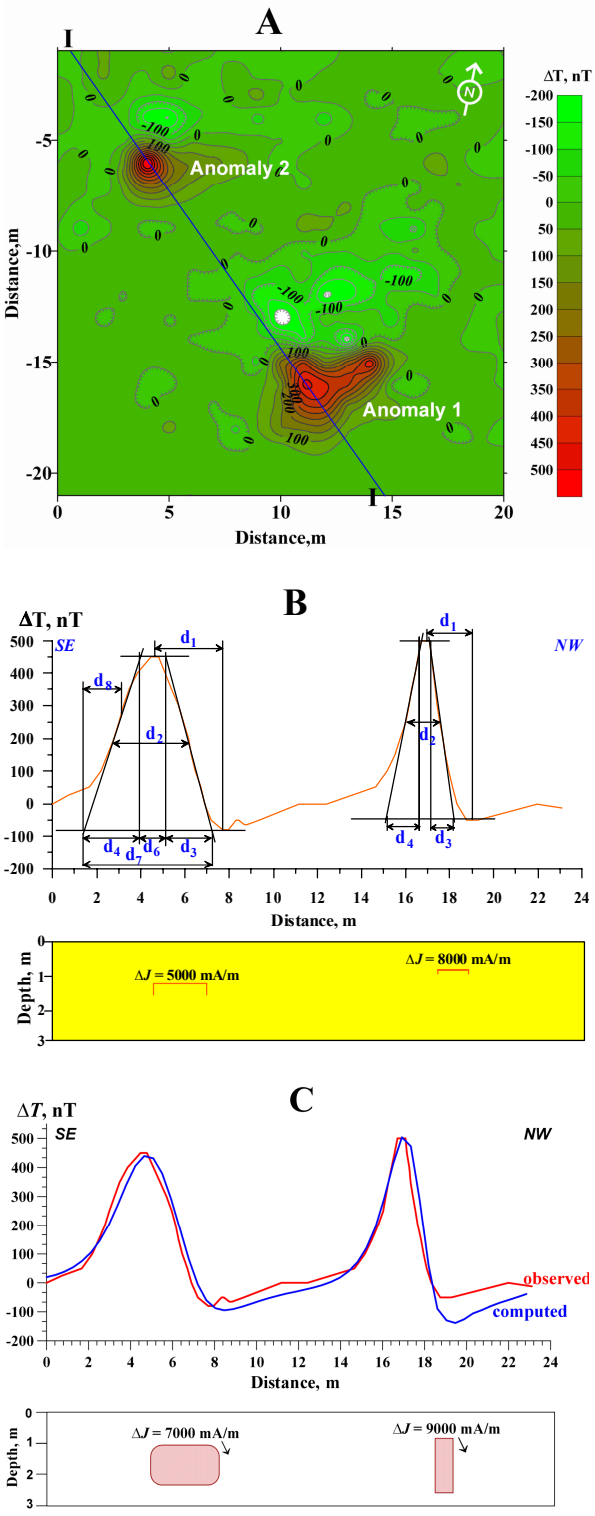

Figure 6. Solving inverse problem and 3-D modeling of magnetic field in the Tel Kara Hadid site (southern Israel). (**A**) Magnetic map of the studied site. **B:** Rapid interpretation of magnetic anomalies using developed procedures along profile I – I. **C**: Results of 3-D modeling along profile I – I. ΔJ is the defined effective magnetization of the studied furnaces, and arrows show the determined position of the total magnetic field vector

Let us consider combined SP/magnetic investigations at the site of Halutza which is located 20 km SW of Be'er-Sheva town, in southern Israel. Halutza was founded as a way station for Nabatean traders traveling between Petra (Jordan) and Gaza. Combined geophysical investigations consisting of magnetic and SP measurements were performed in an area of 200 m^2 using a 1 x 1 m grid (Figures 7A,B). According to *a priori* information, limestone structures had been excavated in the area of the site. It was expected that limestone (nonmagnetic) remains occur in the medium with magnetization of 70-100 mA/m that could produce the appearance of small negative magnetic anomalies; SP anomaly arising is based on the difference of 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 microVoltmeter 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; the depth of electrode grounding was 10-15 cm. Visual analysis of the maps (Figures 7A,B) indicates that the SP and magnetic fields have different trends, but the recognized negative anomalies in the southern part of this site are placed 2 m apart. Quantitative interpretation of SP and magnetic anomalies (Eppelbaum et al., 2003b) gave similar depths: 90 and 70 cm, respectively. The corresponding *PAMs* for the performed examination are displayed in Figures 7C and 7D. 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 the similar objects are the sources of anomalies in the area covered by the integrated geophysical survey.

Different Resistivity Methods

VES

About one hundred Vertical Electric Sounding (VES) profiles were observed at Tel-Halawi hill on the left bank of the Euphrates in northern Syria. Significant part of the revealed anomalies was verified by the subsequent excavations (Chouker, 2001).

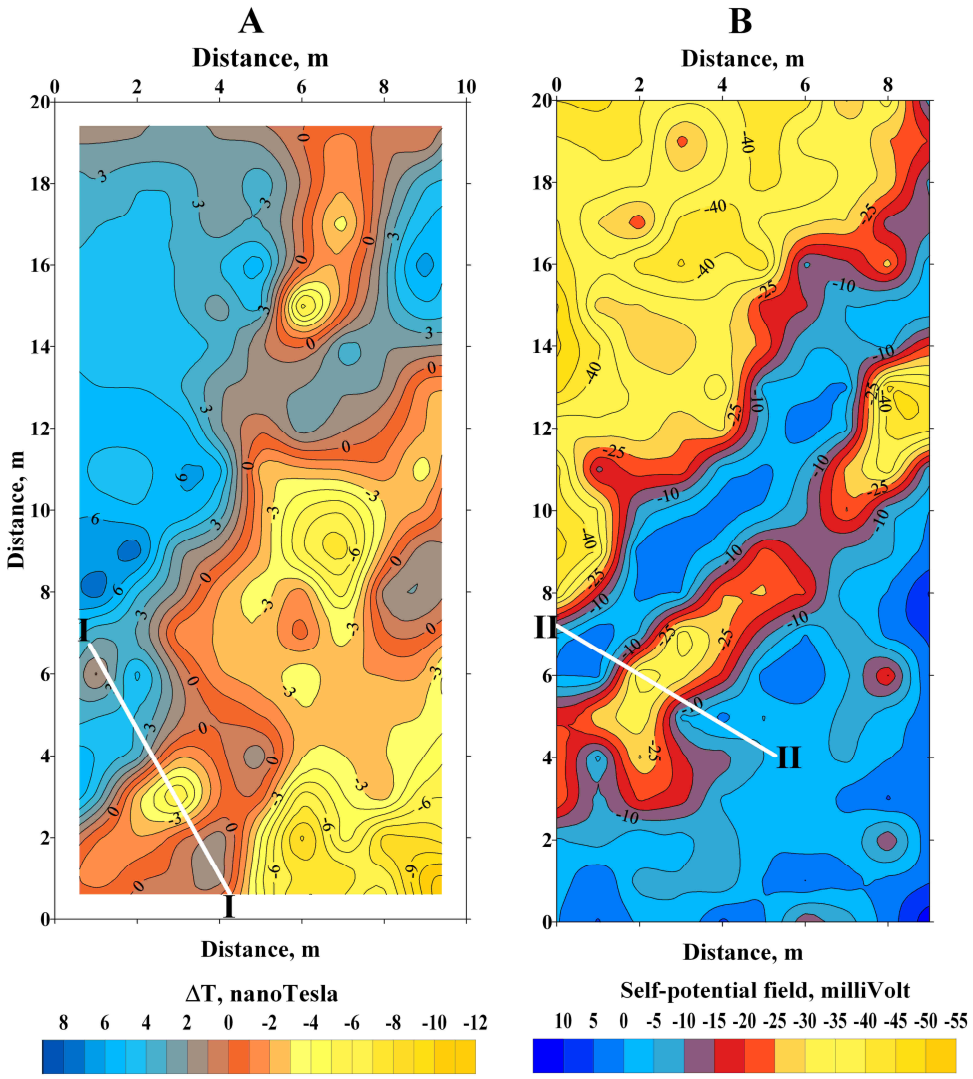

Figure 7A & B. Maps of magnetic (**A**) and self-potential (**B**) fields in the Halutza site (Negev desert, southern Israel)

VES surveys were used to construct lithoresistivity cross-sections along the Behbiet ElHigara and ElKom ElAkhder archaeological sites in the Nile Delta, Egypt (Ibrahim et al., 2002).

El-Qady et al. (2005) successfully applied 3D inversion of VES data in the Saqqara archaeological site (ancient Egyptian capital). The final 3D resistivity models (series of *PAMs*) constructed for this site delivers new useful subsurface geological and hydrogeological information.

Geoscan Resistanse

A Geoscan RM-15 Resistance Meter survey was carried out in the Abydos Cemetery region, Upper Egypt. As a result earlier unknown ancient walls, tombs and remans of temple were recognized (El-Gamili et al., 1999).

Ibrahim et al. (2002) employed a Geoscan RM-15 Resistance Meter for careful examination of the Behbiet ElHigara and ElKom ElAkhder archaeological sites in the Nile Delta, Egypt.

Electric Resistivity Tomography

Electrical Resistivity Tomography (ERT) has been productively explored in Tel Yavne for identifying the thickness of cultural debris, the plan view extent of cultural debris, and the underlying bedrock contact (Bauman et al., 2005).

Nahas et al. (2006) displayed effective application of ERT at the coastal sites of Yavne, Yavne Yam and Tel Nami on the Israeli Mediterranean and Bethsaida at the Lake Kinneret.

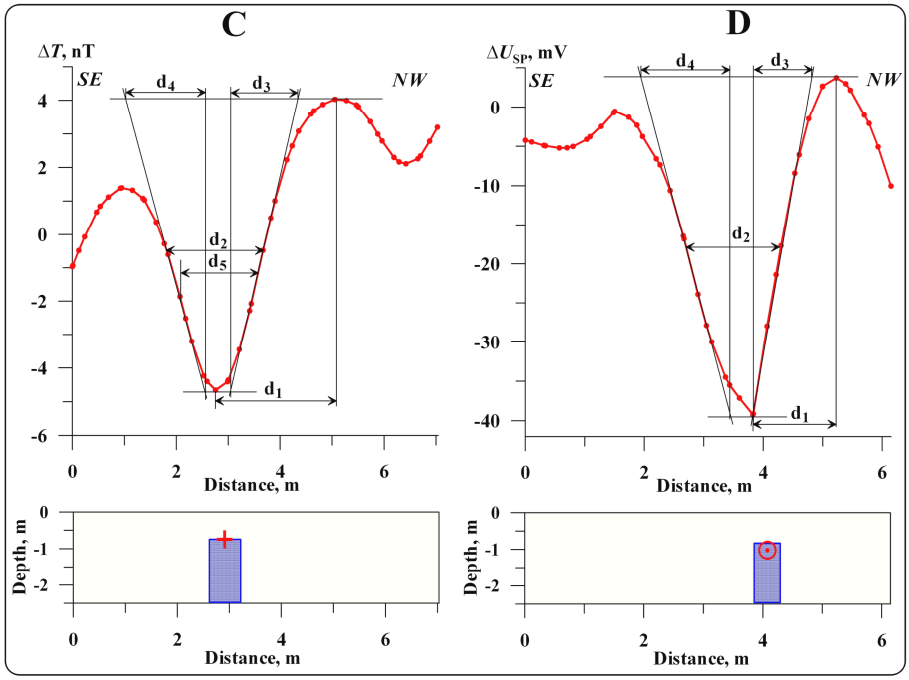

Figure 7C & D. Results of the quantitative interpretation for profile I - I (**C**) and II - II (**D**). A cross indicates the position of the middle of upper edge of anomalous body for magnetic anomaly (Fig. 6C), and a small circle is inscribed in the upper edge of anomalous body for the SP anomaly

ERT survey was carried out at the archaeological site of Parion (Biga Çanakakle, NW Turkey) by the use of Wenner-Schlumberger array with electrode spacing of 1 m. The parallel geoelectrical sections were used to obtain volumetric representation and depth slices. The high resistivity values may indicate some sarcophaguses location (Ekinci et al., 2007).

Non-conventional ERT investigations performed at the Neolithic site Tel Qarqur (western Syria) have shown the potential of this technology to document archaeological stratigraphy to more than 40m below the surface (Casana et al., 2008).

ERT methodology was successfully applied for detecting the layered stratigraphy of the Old Smyrna Höyük site in the city of Izmir, Turkey (Berge and Drahor, 2011).

2D inversion of electrical resistivity tomography (Wenner array) was carried out at the Umm er-Rasas archaeological site (central Jordan). The obtained images show conductive zone as a result of water seepage under the architectural features of the site (Batayneh, 2011).

Many linear anomalies corresponding to buried walls were delineated by the ERT employment at the Tell El-Dabaa site in the eastern part of the Nile Delta, Egypt (Taha et al., 2011).

Comparing ERT slices with the results of excavations in the site of Khirbat Faynan (Biblical Punon, Jordan) enabled to obtain an important data for the subsequent investigations (Novo et al., 2012).

Resistivity Sounding

Resistivity survey was profitably applied at the site of Nahal-Tut for identification of remains of Roman fortress in northern Israel in 1997 (personal communications with Drs. Yu.Gurevich and S.Itkis).

Wenner array was applied for examination of the Royal Ptolemic Necropolis in the ancient Alexandria, Egypt (Gaber et al., 1999). Results of this investigation were used for substantiation of subsequent archaeological excavations.

A large-scale resistivity imaging survey was performed in the acropolis area of Archaic Cnidos, SW Turkey. The obtained data was processed by the use of a 3D inversion algorithm based on a robust technique. The inversion results revealed that a rectangular gridding pattern and a dense structuring existed in the depth range 0.35–1.5 m in the acropolis that enabled to substantiate the following archaeological-geophysical investigations (Drahor et al., 2007).

An enhanced methodology of resistivity data analysis was used at the archaeological site

of Qurnet Murai, Luxor City (Egypt). The authors successfully applied a simulated immersion method of boundary detection to smooth 2D resistivity images generated for synthetic and field data over 3D targets (Elwaseif and Slater, 2010).

Modin (2010) reported on the series of successful electric resistivity studies in the city of Memphis (ancient capital of Egypt).

Ginzburg and Levanon (1977) very successfully applied resistivity method in Jerusalem for studying the thickness of the wall of the Mount of the Temple and determination of the underground location of pre-Herodian city walls in the City of David, as well as at the site of Tel-Afek. Resistivity mapping of the site of Tel-Afek is the classic example of this method application. The archaeological site of Tel Afek, dating to the Late Bronze Age (1550-1200 BC), is situated about 10 km east of Tel-Aviv. One of the main geophysical-archaeological problems at this site consisted in mapping walls of ancient structures, almost completely covered by sediments. One of the electric resistivity anomalies was examined (Figure 8) with applying the advance interpretative methods developed in magnetic prospecting (Eppelbaum, 1999). For developing a *PAM*, the *HCC* model was applied. As evident from Figure 8, the interpretation is in good agreement with the archaeological data.

It should be noted that that this interpretation methodology may be applied also for analysis of the ERT data obtained at various slices below the earth's surface.

Analysis of Thermal Data

Temperature monitoring

A temperature monitoring with the aim to to estimate experimentally the intensity and amplitude of thermal shocks during and after excavation has been performed at three Syrian sites of the arid steppe, Qaramel, Dja'de and Aswad (Bollongino and Vigne, 2008). Estimation of the temperature variations at different depths in the soil suggests that ancient DNA has suffered negative thermal conditions shortly after burial and again during excavation.

Temperature field examination in near-surface

Paparo (1991) applied near-surface thermal prospecting to qualitative delineation of the remains of a Crusader fortress in the city of Netanya (central Israeli Mediterranean coast). In his investigation, limestone and kurkar (silicious limestone) ancient remains were identi-

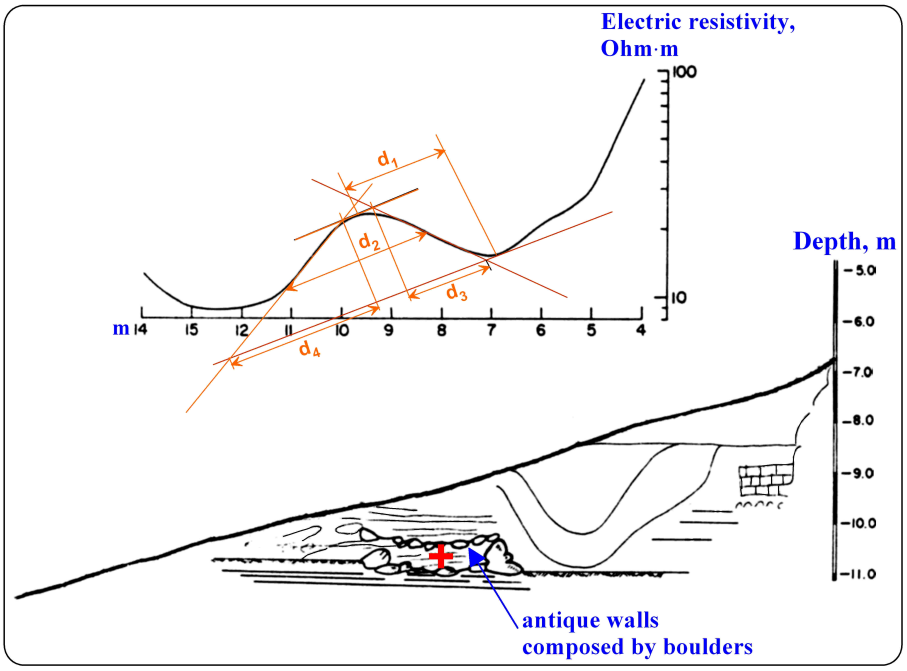

Figure 8. Inverse problem solution for resistivity anomaly in the archaeological site of Tel Afek, central Israel (initial data from Ginzburg and Levanon, 1978; interpretation after Eppelbaum, 1999). A cross in the section designates the location of the center of anomalous body

fied in the clay and loam surrounding. This investigation demonstrated more high effectiveness comparing with the previous thermal studying in the site of Gamla, northern Israel (Paparo, 1991). Obviously, it was caused by a complex geological-archaeological sequence of the Gamla area and insufficient calculation of some disturbing factors. A complete methodology of the near-surface temperature investigations at archaeological sites was presented in Eppelbaum (2009). It is necessary to underline that for interpretation of temperature anomalies may be used not only quantitative interpretation methods developed in magnetic prospecting (Eppelbaum, 2009), but it is also possible to apply under certain conditions 3D magnetic software (Eppelbaum et al., 2013).

Temperature field investrigation in boreholes

Eppelbaum et al. (2006b) assessed the possibility of archaeo-temperatures determination by the measurements of modern temperature values observed in shallow boreholes. It should be noted that obtained values of ancient temperatures would help estimate the present physical-chemical conditions of materials utilized in the antique time for building constructions.

Gravity Field

Obviously, the most effective microgravity application example is the comprehensive gravity measurements in the Cheops pyramid (Giza, Egypt). After a series of adjustments, the pyramid was divided into 25 blocks and the bedrock into eight blocks. The processing and analysis of gravity measurements inside, above, and around the pyramid led to an evaluation of the structure's overall density and of density changes in the structure (Lakshmanan, 1987, 1991).

Detailed gravity investigations were performed in the Late Byzantine 'Lion Church', in the ancient town of Ummer-Rasas (Jordan). Microgravity method founds a number of archaeological features with contrasting density properties. The archaeological interpretation of such structures is suggest a presence of two possible floors of a building with remains of walls, rooms, paths and foundations (Bataynen et al., 2007).

The microgravity investigations carried out the Valley of the Kings Luxor (Egypt) in the area above the tomb of Seti I and 11th Ramses. On the basis of 3D gravity modeling a free room and a deep hole with debris were revealed (Issawy, 2012).

Analysis of the numerous archaeological and geological publications as well as the author's investigation (e.g., Eppelbaum, 2011a) indicates that the ancient objects supposed for examination by the use of microgravity survey in Israel may be classified (in the decreasing order) by the following way: (1) underground ancient cavities and galleries, (2) walls, remains of temples, churches and various massive constructions, (3) pavements and tombs, (4) Roman aqueducts [under favorable physical-geological environments], (5) areas of ancient primitive metallurgical activity (including furnaces) [under favorable physical-geological environments]. Examining the different archaeological targets in Israel, it was supposed that microgravity method might be effectively applied at least on 20-25% of ancient sites (Eppelbaum, 2011a).

It is necessary to underline that physical measurement of vertical gravity derivatives cannot be replaced by computing of this parameter obtained by any transformation procedures: the second vertical derivative of gravity potential W_{zz} values computed from the field Δg_B, as rule, show decreasing values comparing with the W_{zz} obtained from physical measurements. A few model examples showing buried ancient targets delineation (e.g., pavement and caves) on the basis of detailed gravity analysis are presented in Eppelbaum (2011a). A simplified model example of buried pavement (this model has been developed on the basis of excavations at the Megiddo site, northern Israel) delineation is shown in Figure 9. A buried pavement having the positive density contrast of 400 kg/m^3 and occurring at a depth of 1,8 m in uniform medium could be easily recognized by microgravity survey (Figure 9A, integrated anomalous effect from two bodies). Let us assume a low-density layer (2100 kg/m^3) over the pavement. It makes the delineation of the pavement practically impossible in field conditions (registered anomaly is oscillating about 1 microGal) (Figure 9A, integrated anomalous effect from three bodies). At the same time values of the second vertical derivative of gravity potential W_{zz} (computed for the levels of 0,3 and 1,5 m) with a measurable accuracy testify to a presence of disturbing body (Figure 9B).

The similar graphs were developed for the models of buried ancient caves of various radius, ancient iron furnaces, Roman aqueducts, etc.

DEVELOPMENT OF MULTI-DIMENSIONAL PHYSICAL-ARCHAEOLOGICAL DATABASE

The constant increase in geophysical-archaeological data and their revision has necessitated the development of an Integrated Archaeological-Geophysical Data Base (IAGDB). Obviously, it must be multi-componential 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 the potential (and not only) geophysical fields (s) observations *over* or *under* the earth's surface, results of the repeated measurements of the geophysical fields (s) repeated measurements over different periods of time, as well as during archaeological excavations (Figure 10). It is also necessary to digitize the geophysical survey results of previous years and to distinguish their relation to other databases (geological, geochemical, paeleostructural, paleosedimentation, paleobotanical, paleobiogeographical, etc.) (Eppelbaum et al., 2010).

As a basis for the IAGDB development one could use Access DB (obviously, with utilization of all necessary graphic archaeological-geological data sets). Development of such a constantly growing database will increase effectiveness of geophysical examination of archaeological targets by simplifying and speeding up the planning, implementation and analysis of archaeogeophysical investigations.

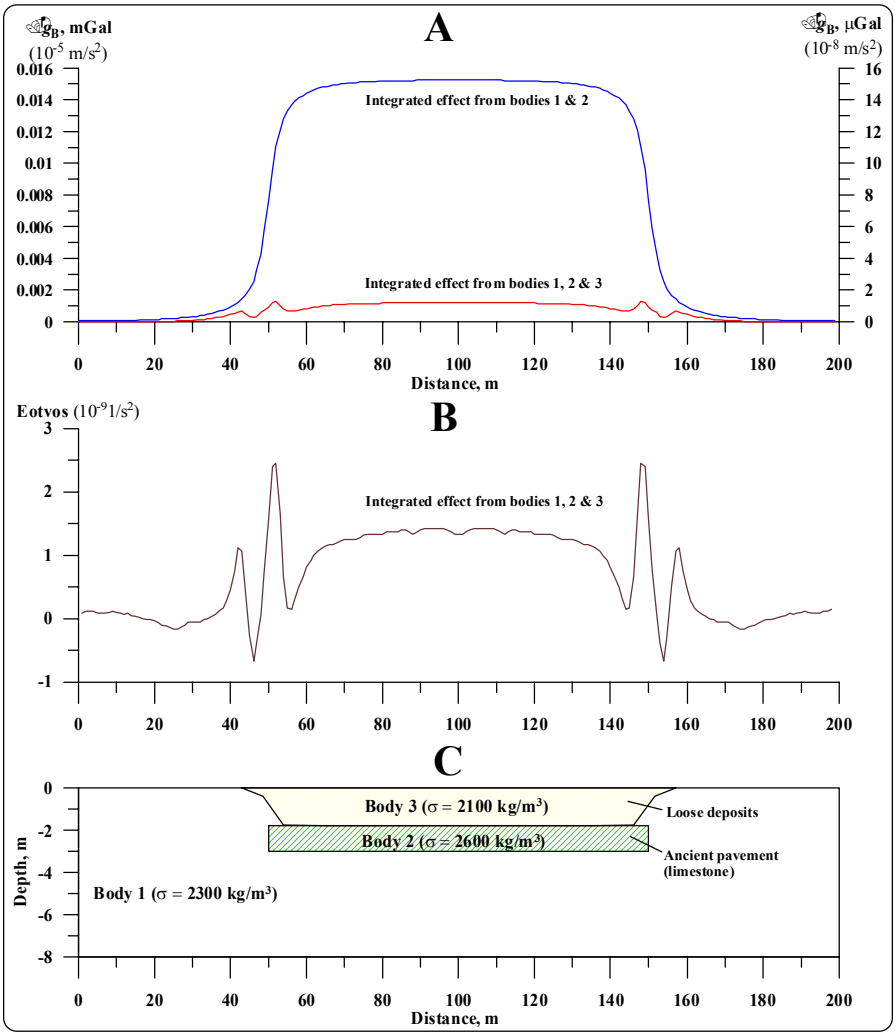

Figure 9. Comparison of Bouguer gravity and vertical gradient anomalies. (**A**) Bouguer gravity, (**B**) vertical gradient g_z (W_{zz}) computed for the base of 1.2 m, (**C**) archaeological sequence

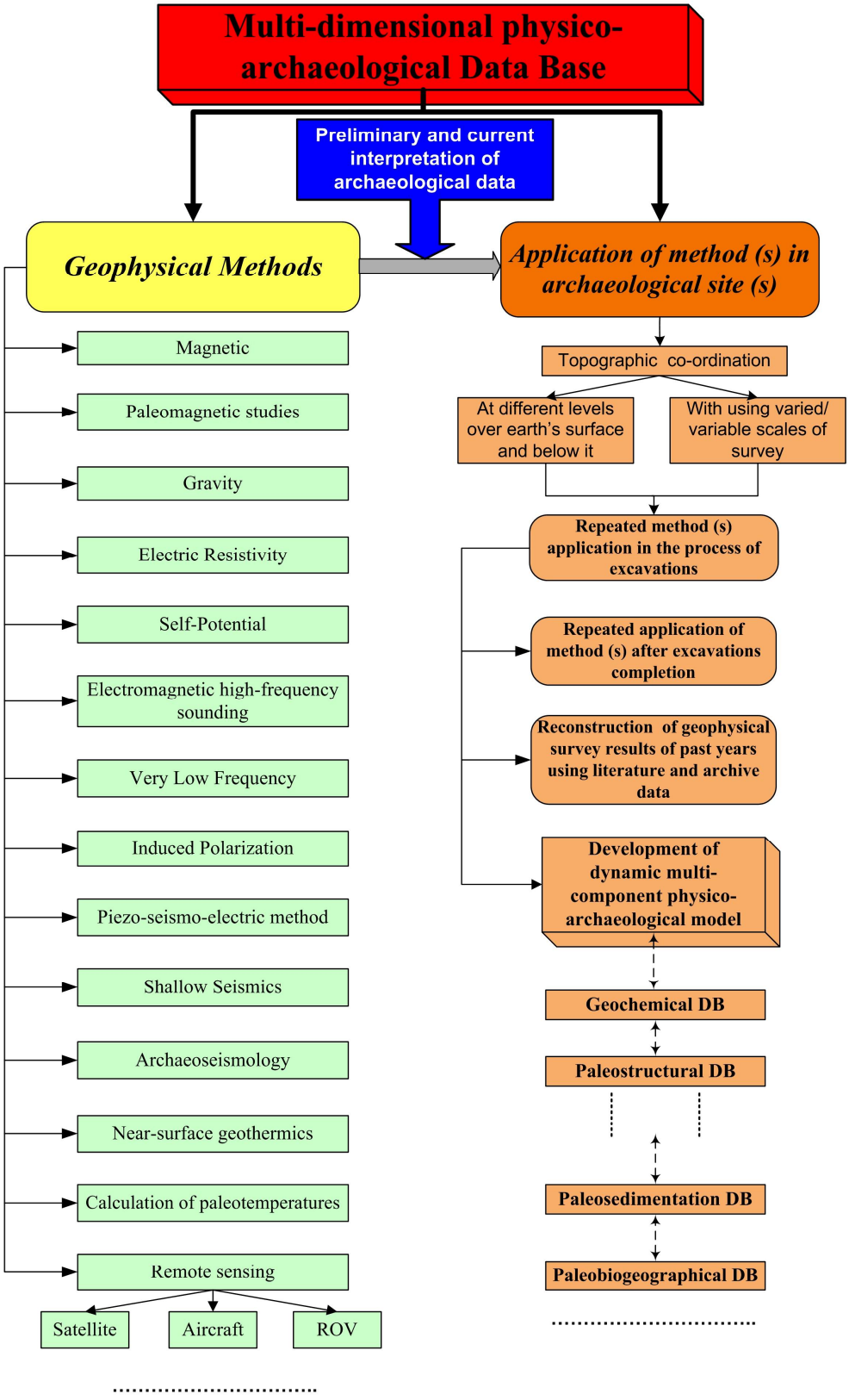

Figure 10. Development of 4D archaeogeophysical Data Base

From a regional point of view, the Israeli IAGDB could be connected with similar databases from neighboring countries in the Mediterranean, the Near and Middle East. The next step, apparently, will include creation of Virtual Archaeology models (Pelfer et al., 2004; Jeffery, 2007) on the basis of combined simultaneous analysis of all possible geophysical, physical, chemical, environmental and other indicators.

FUTURE PERSPECTIVES: REMOTE OPERATIVE VEHICLE MULTILEVEL SURVEY

Among the natural stationary disturbances such factors as swampy soil, dense vegetation, loose ground and uneven terrain relief often complicate performing land archaeogeophysical survey. The new Remote Operated Vehicles (ROV) generation – small and maneuvering vehicles – can fly at levels of few (and even one) meters over the earth's surface (flowing the relief forms (*drape flight*)) and carry out combined geophysical measurements. The ROV geophysical investigations may be performed during short time period and will have a low exploitation cost. For instance, modern magnetometers can provide a frequency up to 50 observations per sec. If we will assume ROV velocity of 30 km/hour, it means that we will receive an observation step of about 0,17 m. This value is more than sufficient to supply a necessary detailness of archeogeophysical investigations. Measurements of geophysical fields at different observation levels could provide new unique archaeological-geophysical information (for instance, see Eppelbaum (2005), besides this, the most effective application of characteristic point method for inverse problem solution (Khesin et al., 1996) demands knowledge of geophysical field behavior at two levels). In addition, multilevel areal observations might be utilized for the procedure of downward continuation on the basis of Gauss' theorem. It was proposed that integrated ROV flat and inclined observations will help to obtain new parameters of the studied archaeological sequences (Eppelbaum, 2010b).

The ROV archaeogeophysical surveys at the areas of world recognized religious and cultural artifacts (where excavations practically always are suppressed and surface survey is hampered) might have a great importance (Eppelbaum, 2010).

It is proposed that the most prospective geophysical integration for ROV should include measurements of magnetic and gravity fields (Eppelbaum, 2008a). GPS (with utilization of the improved wide-band Kalman filtering (Eppelbaum and Mishne, 2011)) will assure an exact topogeodetic relation for the proposed observations. Integration of land and ROV geophysical data will provide a distinctive success in the archeological sites examination (Eppelbaum, 2008a).

CONCLUSIONS

Many tens of thousands of archaeological sites occur in complex geological media in the Near East. Potential geophysical fields (first of all, magnetic prospecting and different resistivity methods) at present are the most employed and efficient geophysical methods at archaeological sites in this region. For analysis of magnetic data a powerful interpretation methodology applicable under complex geological-archaeological environments has been developed. It is proved a transfer of the elements of this interpretation system to other potential geophysical fields. The final aim of different processing methods application, employment of various algorithms and interpretations, is creation of the *PAMs* of the ancient buried remains. *PAMs* of different types may be used to undertake excavations in recognized areas and for planning upcoming archaeological investigations at sites where ancient remains have been discovered. Development of the multi-dimensional dynamic physical-archaeological database will help effectively join different branches of geophysical, archaeological and related sciences. It is anticipated that employments of a new generation of remote operated vehicles for geophysical field multi-altitude observations might cardinal improve all the system of observation and examination in archaeogeophysics.

REFERENCES

ABDALLATIF, T.F., ABD-ALL, E.M., SUH, M., MOHAMAD, R.M. and EL-HEMALY, E.A. 2005. Magnetic Tracing at Abu Sir (Land of Forgotten Pyramids), Northern Egypt. *Geoarchaeology: An International Journal*, 20, 5, 485-503.

ALEXEYEV, V.V., KHESIN, B.E. and EPPELBAUM, L.V. 1996. Geophysical fields observed at different heights:

A common interpretation technique. *Proceed. of the Meeting of Society of Explor. Geophysicists*, Jakarta, 104-108.

ATES, A., ERDEM, E., BILIM, F. and AYDYN, M. 2003. Magnetic enhancement over buried features in Kerkenes archaeological site, Yozgat, Turkey. *Jour. of the Balkan Geophysical Soc.*, 6, 3, 137-143.

BATAYNEH, A. 2011. Archaeogeophysics–archaeological prospection – A mini review. *Jour. of King Saud University* (Science), 23, 83-89.

BATAYNEH, A., KHATAIBEH, J., ALRSHDAN, H., TOBASI, U. and AL-JAHED, N. 2007. The use of microgravity, magnetometry and resistivity surveys for the characterization and preservation of an archaeological site at Ummer-Rasas, Jordan. *Archaeological Prospection*, 4, 60-70.

BAUMAN, P., PARKER, D., COREN, A., FREUND, R. and REEDER, P., 2005. Archaeological reconnaissance at Tel Yavne, Israel: 2-D electrical imaging and low altitude aerial photography. *CSEG Recorder*, 6, 28-33.

BEN-YOSEF, E., TAUXE, L., RON, H., AGNON, A., AVNER, U., NAJJAR, M. and LEVY, T.E. 2008. A new approach for geomagnetic archaeointensity research: insights on ancient metallurgy in the Southern Levant. *Journal of Archaeological Science*, 25, 2863-2879.

BERGE, M.A. and DRAHOR, M.G. 2011. Electrical resistivity tomography investigations of multilayered archaeological settlements: Part II – A case from Old Smyrna Höyük, Turkey. *Archaeological Prospection*, 18, 291-302.

BOLLONGINO, R. and VIGNE, J.-D. 2008. Temperature monitoring in archaeological animal bone samples in the Near East arid area, before, during and after excavation. *Jour. of Archaeological Science*, 35, 873-881.

BORRADAILE, G.J. and ALMQVIST, B.S. 2006. Installation age of limestone masonry determined from its viscous remagnetization. *Geoarchaeology,* 21, 1, 29-60.

BOYCE, J.I., REINHARDT, E.G., RABAN, A. and POZZA, M.R. 2004. The utility of marine magnetic surveying for mapping buried hydraulic concrete harbour structures: Marine Magnetic Survey of a Submerged Roman Harbour, Caesarea Maritima, Israel. *The International Jour. of Nautical Archaeology*, 33, 1, 122-136.

BOYCE, J.I., REINHARDT, E.G. and GOODMAN, B.M. 2009. Magnetic detection of ship ballast deposits and anchorage sites in King Herod's Roman harbour, Caesarea Maritima, Israel. *Jour. of Archaeological Science*, 36, 1516-1526.

BRETSCHNEIDER, J. and VAN LERBERGHE, K. (Eds.). 2008. In search of Gibala. An archaeological and historical study based on eight seasons of excavations at Tell Tweini (Syria) in the A and C fields (1999-2007). *Aula Orientalis*, Barcelona, 157p.

CASANA, J., HERRMANN, J. and FOGEL, A. 2008. Deep subsurface geophysical prospection at Tell Qarqur, Syria. *Archaeological Prospection*, 15, 207-225.

CHOUKER, F. 2001. Archaeological site investigation by geoelectrical measurements in Tel-Halawi (Northern Syria). *Archaeological Prospection*, 8, 257-263.

CIMINALE, M. 2003. A High-resolution magnetic mosaic at the Kyme archaeological site (Turkey). *Archaeological Prospection*, 10, 119-130.

COMMENGE, C. 1996. Horvat Minha (el-Munhata). *Excavations and Survey in Israel*, 15, 43.

DAN, J. 1988. The soils of the land of Israel. In: *The Zoogeography of Israel*, W. Junk Publishers, Dordrecht, 95-128.

DRAHOR, M.G. 2004. Application of the self-potential method to archaeological prospection: some case histories. *Archaeological Prospection*, 11, 77-105.

DRAHOR, M.G., GÖKTÜRKLER, G., BERGE, M.A., KURTULMUS, T.Ö. and TUNA, N. 2007. 3D resistivity imaging from an archaeological site in south-western Anatolia, Turkey: a case study. *Near Surface Geophysics,* 5, 195-201.

EKINCI, Y.L., KAYA, M.A. and DEMIRCI, A. 2007. Electrical resistivity tomography investigation at the ancient site of Parion, Northwest Turkey. *Trans. of the 13th European Meet. of Environmental and Engineering Geophysics*, Istanbul, Turkey, 1-4.

EL-BASSIONY, A. and WELLER, A. 2004. Modelling the magnetic field gradient for archaeological structures in Saqqara (Egypt). *Trans. of the 10th European Meet. of Environ. and Engineering Geophysics*, Utrecht, The Netherlands, B011, 1-4.

EL-GAMILI, M.M., EL-MAHMOUDI, A.S., OSMAN, S.Sh., HASSANEEN, A.Gh. and METWALY, M.A. 1999. Geoelectric resistance scanning on parts of Abydos cemetery region, Sohag Governorate, Upper Egypt. *Archaeological Prospection*, 6, 225-239.

EL-QADY, G.M., MONTEIRO SANTOS, F.A., HASSANEEN, A.Gh. and TRINDADE, L. 2005. 3D inversion of VES data from the Saqqara archaeological area, Egypt: a case study. *Near Surface Geophysics*, 3, 227-233.

ELWASEIF, M. and SLATER, L. 2010. Quantifying tomb geometries in resistivity images using watershed algorithms. *Jour. of Archaeological Science*, 37, 1424-1436.

EPPELBAUM, L.V. 1999. Quantitative interpretation of resistivity anomalies using advanced methods developed in magnetic prospecting. *Trans. of the XXIV General Assembly of the Europ. Geoph. Soc.*, Strasbourg, 1, 1, 166.

EPPELBAUM, L.V. 2000. Applicability of geophysical methods for localization of archaeological targets: An introduction. *Geoinformatics*, 11, 1, 19-28.

EPPELBAUM, L.V. 2005. Multilevel observations of magnetic field at archaeological sites as additional interpreting tool. *Proceed. of the 6th Conference of Archaeological Prospection*, Roma, Italy, 1-4.

EPPELBAUM, L.V. 2009. Near-surface temperature survey: An independent tool for buried archaeological targets delineation. *Jour. of Cultural Heritage*, 12, 1, e93-e103.

EPPELBAUM, L.V. 2010a. Methodology of detailed geophysical examination of the areas of world recognized religious and cultural artifacts. *Trans. of the 6th EUG Meet.*, Geophysical Research Abstracts, Vienna, Austria, 12, EGU2010-5859, 1-3.

EPPELBAUM, L.V. 2010b. An advanced methodology for Remote Operation Vehicle magnetic survey to delineate buried targets. *Trans. of the 20th General Meeting of the Intern. Mineralogical Association*, *CH30G: Archaeometry* (*general session*): Composition, technology and provenance of archaeological artifacts, Budapest, Hungary, 103.

EPPELBAUM, L.V. 2011a. Review of environmental and geological microgravity applications and feasibility of their implementation at archaeological sites in Israel. *International Jour. of Geophysics*, doi: 10.1155/2011/927080, ID 927080, 1-9.

EPPELBAUM, L.V. 2011b. Study of magnetic anomalies over archaeological targets in urban conditions. *Physics and Chemistry of the Earth*, 36, 16, 1318-1330.

EPPELBAUM, L.V. 2013. Interpretation of magnetic anomalies due to archaeological and environmental targets classified as "quasi thick bed bodies" in complex physical-geological environments. *Proceed. of the 2013 SAGEEP Conference*, Denver, Colorado, USA, 26, 1, 415-424.

EPPELBAUM, L.V., ALPEROVICH, L., ZHELUDEV, V. and PECHERSKY, A. 2011. Application of informational and wavelet approaches for integrated processing of geophysical data in complex environments. *Proceed. of the 2011 SAGEEP Conference*, Charleston, South Carolina, USA, 24, 24-60.

EPPELBAUM, L. and BEN-AVRAHAM, Z. 2002. On the development of 4D geophysical Data Base of archaeological sites in Israel. *Trans. of the Conf. of the Israel Geol. Soc. Ann. Meet*., MaHagan - Lake Kinneret, Israel, 21.

EPPELBAUM, L., BEN-AVRAHAM, Z., ITKIS, S. and KOUZNETSOV, S. 2001a. First results of self-potential method application at archaeological sites in Israel. *Trans. of the EUG XI Intern. Symp*., Strasbourg, France, 657.

EPPELBAUM, L., BEN-AVRAHAM, Z., and ITKIS, S. 2003a. Ancient Roman Remains in Israel provide a challenge for physical-archaeological modeling techniques. *First Break*, 21, 2, 51-61.

EPPELBAUM, L.V., BEN-AVRAHAM, Z. and ITKIS, S.E. 2003b. Integrated geophysical investigations at the Halutza archaeological site. *Proceed. of the 64 EAGE Conf.*, Florence, Italy, P151, 1-4.

EPPELBAUM, L.V. and ITKIS, S.E. 2000. Magnetic investigations in the Proto-Historic site to the east of Tel Megiddo. In: *Monograph Series of the Inst. of Archaeology,* Tel Aviv Univ., Megiddo III, 18, 504-514.

EPPELBAUM, L.V. and ITKIS, S.E. 2001. Detailed magnetic investigations at the ancient Roman site Banias II (northern Israel). *Proceed. of the 1st Intern Symp. on Soil and Archaeology*, Szazhalombatta, Hungary, 13-16.

EPPELBAUM, L.V. and ITKIS, S.E. 2003. Geophysical examination of the Christian archaeological site Emmaus-Nicopolis (central Israel). Collection of Papers of the XIX CIPA Conf.*: New Perspectives to Save the Cultural Heritage*, Antalya, Turkey, 395-400.

EPPELBAUM, L.V., ITKIS, S.E., FLECKENSTEIN, K.-H. and FLECKENSTEIN, L. 2007. Latest results of geophysical-archaeological investigations at the Christian archaeological site Emmaus-Nicopolis (central Israel). *Proceed. of the 69th EAGE Conference*, P118, London, Great Britain, 1-5.

EPPELBAUM, L.V., ITKIS, S.E. and KHESIN, B.E. 2000a. Optimization of magnetic investigations in the archaeological sites in Israel. In: *Filtering, Modeling and Interpretation of Geophysical Fields at Archaeological Objects*, Special Issue of *Prospezioni Archeologiche*, 65-92.

EPPELBAUM, L.V., ITKIS, S.E. and KHESIN, B.E. 2004a. Initial visualization of magnetic survey results at the Prehistoric archaeological sites in Israel. *Proceed. of the 5th Intern. Symp. on Eastern Mediterranean Geology*. Thessaloniki, Greece, 2, 747-750.

EPPELBAUM, L.V., ITKIS S.E. and PETROV, A.V. 2000b. Physics and archaeology: magnetic field as a reliable tool for searching ancient remains in Israel. *Scientific Israel*, 2, 68-78.

EPPELBAUM, L.V. and KATZ, Y.I. 2012. Key features of seismo-neotectonic pattern of the Eastern Mediterranean. *Azerb.Nation. Acad. Sci. Proceeding. Sciences of Earth*, 3, 29-40.

EPPELBAUM, L.V. and KHESIN, B.E. 2001. Disturbing Factors in Geophysical Investigations at Archaeological Sites and Ways of Their Elimination. *Proceed. of the IV Conf. on Archaeological Prospection*, Vienna, Austria, 99-101.

EPPELBAUM, L.V. and KHESIN, B.E. 2012. *Geophysical Studies in the Caucasus*. Springer. 411p.

EPPELBAUM, L.V., KHESIN, B.E. and ITKIS, S.E. 2001b. Prompt magnetic investigations of archaeological remains in areas of infrastructure development: Israeli experience. *Archaeological Prospection*, 8, 3, 163-185.

EPPELBAUM, L.V., KHESIN, B.E. and ITKIS, S.E. 2006a. Some peculiarities of geophysical investigations at archaeological sites in Israel. *Russian Archaeology*, 1, 59-70.

EPPELBAUM, L.V., KHESIN, B.E. and ITKIS, S.E. 2010. Archaeological geophysics in arid environments: Examples from Israel. *Jour. of Arid Environments*, 74, 7, 849-860.

EPPELBAUM, L.V., KHESIN, B.E., ITKIS, S.E. and BEN-AVRAHAM, Z. 2004b. Advanced analysis of self-potential data in ore deposits and archaeological sites. *Proceed. of the 10th European Meeting of Environmental and Engineering Geophysics*, Utrecht, The Netherlands, 1-4.

EPPELBAUM, L.V., KUTASOV, I.M. and BARAK, G. 2006b. Ground surface temperature histories inferred from 15 boreholes temperature profiles: Comparison of two approaches. *Earth Sciences Research Jour.*, 10, 1, 25-34.

EPPELBAUM, L.V. and MISHNE, A.R. 2011. Unmanned airborne magnetic and VLF investigations: effective geophysical methodology of the near future. *Positioning*, 2, 3, 112-133.

FINKELSTEIN, M. and EPPELBAUM, L. 1997. Classification of the disturbing objects using interpretation of low-intensive temporary magnetic variations. *Trans. of the Conf. the Geological Society of America*, Salt Lake City, 29, 6, 326.

GABER, S., EL-FIKY, A.A., ABOU SHAGAR, S. and MOHAMADEN, M. 1999. Electrical resistivity exploration of the Royal Ptolemic Necropolis in the Royal Quarter of ancient Alexandria, Egypt. *Archaeological Prospection*, 6, 1-10.

GAFFNEY, C., GAFFNEY, V., CUTTLER, R. and YORSTON, A. 2008. Initial Results using GPS navigation with the Foerster magnetometer system at the World heritage site of Cyrene, Libya. *Archaeological Prospection*, 15, 151-156.

GINZBURG, A. and LEVANON, A. 1977. Direct current resistivity measurements in archaeology. *Geoexploration*, 15, 47-56.

GREEN, J.N. 1973. An underwater archaeological survey of Cape Andreas (Cyprus) I969-70: A preliminary report. *Proceed. of the 23rd Symp. of the Colston Research Society*, Bristol, 04-08 April, 1971, 141-178.

HERBICH, T. and PEETERS, C. 2006. Results of the magnetic survey at Deir al-Barsha, Egypt. *Archaeological Prospection*, 13, 11-24.

HOROWITZ, A. 1979. The Quaternary of Israel. Academic Press. NY. 394p.

IBRAHIM, E.H., ELGAMILI, M.M., HASSANEEN, A.Gh., SOLIMAN, M.N. and ISMAEL, A.M. 2002. Geoelectrical investigation beneath Behbiet ElHigara and ElKom

ElAkhder archaeological Sites, Samannud area, Nile Delta, Egypt. *Archaeological Prospection*, 9, 105-113.

ISSAWY, I. 2012. The role of micro-gravity in archaeology in Luxor, Egypt. *Proceed. of the Near-Surface Geoscience: 18th Europ. Meet. of Environmental & Engineering Geophysics*, Paris, 1-4.

ITKIS, S.E. and EPPELBAUM, L.V. 2009. Magnetic survey in the vicinity of the Paneas. *In*: *Paneas: The Survey, the Aqueduct*, *the northern cemeteries and excavations in the northwestern Suburb*, The Israel Antique Authority, Jerusalem, 143-151.

ITKIS, S., KHESIN, B., EPPELBAUM, L. and KHALAILY, H. 2003. The Natufian site of Eynan (Hula valley, northern Israel): Magnetic prospecting reveals new features. *Israel Journal of Earth Sciences*, 52, 3-4, 209-219.

JEFFERY, K.G. 2007. New generation grid for environmental science. *Environmental Modelling & Software*, 22, 281-287.

KAYA, M.A., EKINCI, Y.L., YIĞIT P. and LIGHTFOOT, C.S. 2007. Magnetic investigation at the Amorium archaeological site, Emirdağ, Afyon, Turkey. *Jour. of the Balkan Geophysical Soc*., 10, 1, 1-7.

KENYON, K.M. 1979. Archaeology in the Holy Land. Norton. NY. 359p.

KHESIN, B.E., ALEXEYEV, V.V. and EPPELBAUM, L.V. 1996. Interpretation of Geophysical Fields in Complicated Environments. Kluwer Academic Publishers. Ser.: Modern Approaches in Geophysics. Boston – Dordrecht – London. 367p.

KHESIN, B.E. and EPPELBAUM, L.V. 1997. The number of geophysical methods required for target classification: quantitative estimation. *Geoinformatics*, 8, 1, 31-39.

LAUKHIN, S.S., RONEN, A., POSPELOVA, G.A., SHARONOVA, Z.V., RANOV, V.A., BURDUKIEWICZ, J.M., VOLGINA, V.A. and TSATSKIN, A. 2001. New data on the geology and geochronology of the Lower Palaeolithic site Bizat Ruhama in the Southern Levant. *Paleorient*, 27, 1, 69-80.

LAKSHMANAN, J. 1987. Microgravity probes the Great Pyramid. *The Leading Edge*, 1, 10-17.

LAKSHMANAN, J. 1991. The generalized gravity anomaly: Endoscopic microgravity. *Geophysics*, 56, 5, 712-723.

MEYERS, E.M. (Ed.). 1996. The Oxford Encyclopedia of Archaeology in the Near East. 5 Vols. Oxford University Press. Oxford.

MODIN, I.N. 2010. Electric prospecting in technical and archaeological geophysics. D.Sci. Thesis. Moscow State Univ. Moscow (in Russian).

NAHAS, C., BAUMAN, P., JOL, H., REEDER, P. and FREUND, R. 2006. Geophysical investigations at coastal archaeological sites in Israel. *Proceed. of the SAGEEP Confer.*, Seattle, Washington, 1397-1406.

NOVO, A., VINCENT, M.L. and LEVY, T.E. 2012. Geophysical surveys at Khirbat Faynan, an ancient mound site in southern Jordan. *International Jour. of Geophysics*, Article ID 432823, 1-8.

ODAH, H., ABDALLATIF, T. F., EL-HEMALYAND, A. and ABD EL-ALL, E. 2005. Gradiometer survey to locate the ancient remains distributed to the northeast of the Zoser Pyramid, Saqqara, Giza, Egypt. *Archaeological Prospection*, 12, 61-68.

PAPARO, H. 1991. Temperature study of the archaeological site Crusades Fortress Um Haled (Netanya). *Trans. of the Conf. of Israel Geol. Soc., Annual Meeting*, Akko, Israel, 77.

PELFER, P.G., BARCELO, J.A., MCDONAILL, C. and PELFER, G. 2004. ArchaeoGRID, a GRID for archaeology. *Proceed. of the IEEE Nuclear Science Symp. Conf.*, 4, 2095-2099.

RON, H., PORAT, N., RONEN, A., TCHERNOV, E. and HORWITZ, L. 2003. Magnetostratigraphy of the Evron Member – implications for the age of the Middle Acheulian site of Evron Quarry. *Journal of Human Evolution*, 44, 633-639.

SEGAL, Y., MARCO, S. and ELLENBLUM, R. 2003. Intensity and direction of the geomagnetic field in 24 August, 1179 measured in Vadum Iacob (Ateret) Crusader Fortress, northern Israel. *Israel Jour. of Earth Sciences*, 52, 203-208.

SHAAR, R., RON, H., TAUXE, L., KESSEL, R., AGNON, A., BEN-YOSEF, E. and FEINBERG, J.M. 2010. Testing the accuracy of absolute intensity estimates of the ancient geomagnetic field using copper slag material. *Earth and Planetary Science Letters*, 290, 201-213.

STERNBERG, R. and LASS, E.H.E. 2007. An archaeomagnetic study of two hearths from Kebara Cave, Israel. In: Kebara Cave, Mt. Carmel, Israel: The Middle and Upper Paleolithic Archaeology, Part I, *American School of Prehistoric Research*, 49, Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, 123-130.

STERNBERG, R., LASS, E., MARION, E., KATARI, K. and HOLBROOK, M. 1999. Anomalous archaeomagnetic directions and site formation processes at archaeological sites in Israel. *Geoarchaeology*, 14, 5, 415-439.

TAHA, A.I., EL-QADY, G., METWALY, M.A. and MASSOUD, U. 2011. Geophysical investigation at Tell El-Dabaa "Avaris" archaeological site. *Mediterranean Archaeology and Archaeometry*, 11, 1, 51-58.

WEISS, E., GINZBURG, B., COHEN, T.R., ZAFRIR, H., ALIMI, R., SALOMONSKI, N. and SHATVIT, J. 2007. High resolution marine magnetic survey of shallow water littoral area. *Sensors*, 7, 1697-1712.

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