CORE
Metadata, citation and similar papers at core.ac.uk
Provided by Elsevier - Publisher Connector

Journal of King Saud University (Science) (2011) **23**, 83–89

King Saud University
Journal of King Saud University (Science)
www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Archaeogeophysics–archaeological prospection – A mini review

Awni T. Batayneh *

Department of Geology and Geophysics, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia

Received 5 June 2010; accepted 17 June 2010
Available online 20 June 2010

KEYWORDS
Archaeogeophysics–archaeological prospection;
Geophysical methods;
Rescue archaeology;
Non-destructive techniques;
Modern development

Abstract Geophysical methods have been used with increasing frequency in archaeology since 1946; aerial photography has been used since 1919. The geophysical methods that are most commonly used at present are electrical resistivity, magnetic, and ground penetrating radar. Magnetometry, particularly when used in a gradient mode or with a continuously recording base station, is used at almost all sites where any geophysical methods are used.

Electromagnetic soil-conductivity systems are also being increasingly used because of their very high rate of data acquisition. Less commonly used methods include self-potential, microgravity, radiometric, thermal infrared imagery, and sonic or seismic techniques. Recent developments in image processing and graphic representation have contributed substantially to the archaeologist's ability to do "rescue archaeology", that is, to carry out high-speed, non-destructive reconnaissance surveys for ancient human cultural evidence in advance of modern industrial development.
© 2010 King Saud University. All rights reserved.

1. Introduction

1.1. Definition and significance

"Archaeogeophysics" and "archaeological prospection" are the terms to non-destructive identification of features and relics buried at archaeological sites. Archaeologists are also beginning to think of archaeogeophysics or archaeological prospection, as the use of geophysical methods in archaeology, was first began in Europe in the 1940s followed by the Middle East. "Archaeomagnetic dating" is the study of the source of ancient artifacts to document ancient trade and communication patterns (Aitken, 1974). Dating technologies are included along with prospection methods in the broader term "archaeophysics". A survey of the broader field of physics applied to archaeology is available in excellent summaries by Aitken (1974) and Wolfman (1984).

Archaeologists frequently use the term "rescue archaeology". It refers to emergency evaluation of an area for human cultural resources. This normally is done in advance of industrial development area. The term "non-destructive archaeology" refers to use remote sensing methods to provide 3D information about a large size of land. The key element here is that the evaluation is done without disturbing the land.

* Tel.: +966 56 8086395; fax: +966 1 4675804.
E-mail address: awni@ksu.edu.sa

1018-3647 © 2010 King Saud University. All rights reserved. Peer-review under responsibility of King Saud University.
doi:10.1016/j.jksus.2010.06.011

ELSEVIER
Production and hosting by Elsevier

Archaeologists commonly use the term "remote sensing", incidentally, for more than just photo or LANDSAT image analysis. It includes the whole range of surface geophysical and geochemical methods.

Because of early recognition of ancient man-made structures in Europe and the Middle East, geophysical work in archaeology has been concentrated there. Practitioners in this field have communicated informally with each other but not any scholarly associations, and no journal dedicated solely to archaeological prospection exists; one specialty journal, Prospezioni Archeologiche, was published only from 1966 to 1973 (Carabelli, 1966; Linington, 1966; Aspinall and Lynam, 1968, 1970; Foster, 1968; Tite and Mullins, 1969). Recently, several journals such as Archaeometry, Journal of Field Archaeology, Geophysics, and the Journal of Archaeological Science have published occasional papers on the subject since 1983 (i.e. Bevan, 1983; Benner and Brodkey, 1984; Wynn and Sherwood, 1984; Gibson, 1986; Stringer, 1986; Vaughan, 1986).

1.2. Fundamentals of prospection

"Archaeogeophysics" or "archaeological prospection" is fundamentally concerned with the identification of contrasts between materials inside and outside of archaeological structures. If there are underground remains, these can have an affect on the surface of the ground which can cause variations in physical properties. By measuring these physical changes across buried features, there is a possibility of detecting subsurface remains. If the differences in the physical constants are considerable, remote sensing technique will be easily facilitated. It is difficult to discover deeply buried remains regardless of the degree of contrast. In these instances it becomes necessary to detect weak signals, regardless of the geophysical methods being employed. Signals from deeper targets contain information from surrounding soils, which also makes it difficult to discover smaller targets within the geophysical dataset.

Prospecting for archaeological sites is different than prospecting for hot springs, underground water or for veins of ore. Archaeological sites are generally localized and rarely have significant vertical or horizontal dimensions in the ground. Prospecting therefore requires data collection at very fine intervals in order to discover archaeological sites. Furthermore, targets in archaeological prospection studies rarely exceed the depth of 5 m. With ordinary ground probing, this depth is within the range of surface noise. Measurement methods and data analysis software for probing deep strata are therefore not suitable for detailed analysis of structures positioned at shallow depths. Because of these differences, the expected results may not materialize right away if common methods are used for site prospection. Keeping these points in mind, engineers and prospectors that embark on archaeological prospection using modern technology must familiarize themselves with the unique conditions for archaeological prospection in order to have any measurable success with their surveys.

2. Applicable geophysical methods

2.1. Aerial archaeology

The terms "aerial" or "remotely sensed information" already indicate how aerial archaeology works: it uses the distant view. Archaeological sites show up on the ground surface by light-shadow-contrasts (shadow marks), tonal differences in the soil (soil marks) or differences in height and color of the cultivated cereal (crop marks). In that way, settlements, graveyards, fortifications produce specific structures that can be identified easier from a high viewpoint. "Aerial archaeology" is one of the oldest prospection methods adopted first in England just after World War I, where Roman and Pre-Roman structures found (Beazeley, 1919).

Archaeologists have frequently used this technique since then before a site is excavated (Aitken, 1974; Binford, 1964). It is very productive technique and in relation to other methods it is cheap, because you can cover quite a large area within a small number of flight-hours and you can use any existing aerial photograph for your interpretation. A good example to illustrate the aerial photographs of the area around Hornsburg in Lower Austria shown in Fig. 1 given by the Institute for Prehistory and Protohistory of the University of Vienna (1996).

Since the 1960s, "airborne" and "space-borne digital imagery" has been used experimentally for "archaeological prospection" (Stringer and Cook, 1974; Lyons and Avery, 1977; Ebert, 1984) with only limited success. Berlin et al. (1977) have successfully used LANDSAT imagery to map areas in northern Arizona that had been cultivated and then abandoned almost 700 years ago. Perisset and Tabbagh (1981) have demonstrated that digital imagery in the infrared can be used in archaeological applications.

2.2. Seismic methods

Seismic refraction methods have been used occasionally since the late 1950s (Carson, 1962). The sonic spectroscope method was used to test stone and brick walls for voids and variations in thickness (Carabelli, 1966). High-resolution surveys were used first in the near-offshore environment to examine paleo-beach deposits for potential sites ancient human occupation (Stright, 1986). Geophysicists have experimented with refraction seismic methods in archaeological applications with rela-

Figure 1 Aerial photograph (after the Institute for Prehistory and Protohistory of the University of Vienna, 1996) showing archaeological site of the area around Hornsburg in Lower Austria. Archaeological site is shown by black arrows on the ground surface.

tively little success (Aitken, 1974). Refraction methods work best in mapping undisturbed layers that have velocities increasing with depth. The method becomes less useful and interpretation becomes very qualitative and difficult when there are velocity inversions representative of human cultural disturbance, or highly 3D objects such as burial sites or stone foundations.

Seismic-reflection methods are known to work well in marine applications. Shipwrecks buried in sediments in the Mediterranean stand out clearly by means of this kind of technique (McGhee et al., 1968). Seismic-reflection methods have also been used to detect cavities in otherwise homogeneous rock masses or in ancient stone structures. Seismic reflection methods were also used to map faults and cavities.

High-resolution mapping technologies are the most recent application of seismic reflection in archaeology. Recently, they were used effectively to map sites of potential human occupation and migration (Stright, 1986). Fig. 2 shows the result of 3D seismic travel time tomography (Valenta and Dohnal, 2007) over the castle of Devin, Czech Republic.

2.3. Magnetic and archaeomagnetism methods

"Magnetic method" is the most frequently geophysical tool used for archaeological prospection, because of speed and resolution in mapping large areas. It was first used in 1957 in England (Belshe, 1957; Aitken et al., 1958), and has since become the backbone of archaeological prospection. It was now used even more frequently than electrical prospection methods. This method is used to map buried stone foundations and to outline the locations of forges and kilns, hearths, and campfire sites (Gibson, 1986). The utility of magnetic susceptibility measurements of topsoil in the mapping of anthrosoils (soils modified by human activity) was described by Colani and Aitken (1966). Recent advanced in technology led to acquire large database and more precise evaluation of field data (Weymouth, 1986; Scollar et al., 1986; Al-Zoubi et al., 1998; Batayneh et al., 2001, 2006; Batayneh, in press).

"Archaeomagnetism" (Tite and Mullins, 1971; Tarling et al., 1986) is a developing science that seeks to obtain site-occupation dates (dating method) from the orientation of the remnant magnetic field found in stones lining at ancient kilns. "Archaeomagnetism" is a non-prospecting method. Recent summaries of this specialty are available in Wolfman (1984) and Tarling et al. (1986). "Isotopic analysis" is another non-prospecting method. It is used both for dating purposes (for example, radiocarbon dating) as well as for provenance studies. Fig. 3 (Batayneh, in press), shows a 3D map of high-pass filtered total magnetic field over the Nabataean Hawar archaeological site in southern Jordan. The magnetic data shown in Fig. 3 indicates a fluctuation over visible rectangle (cistern), while there is only negligible scatter in the part of the map outside the cistern walls. The cistern was 16 m east to west by 26 m north to south. Because of these significant magnetic changes, the general location and dimensions of the cistern were determined.

2.4. Electrical methods

The use of electrical methods in archaeology predates the use of magnetic methods. First used in 1946 in England (Aitken, 1974). This technique is now frequently used in archaeology to map large areas rapidly because of the development of instruments and softwares (Al-Zoubi et al., 1998; Batayneh et al., 2006; Batayneh, in press). These methods are divided into the non-contacting electromagnetic (EM) or induction

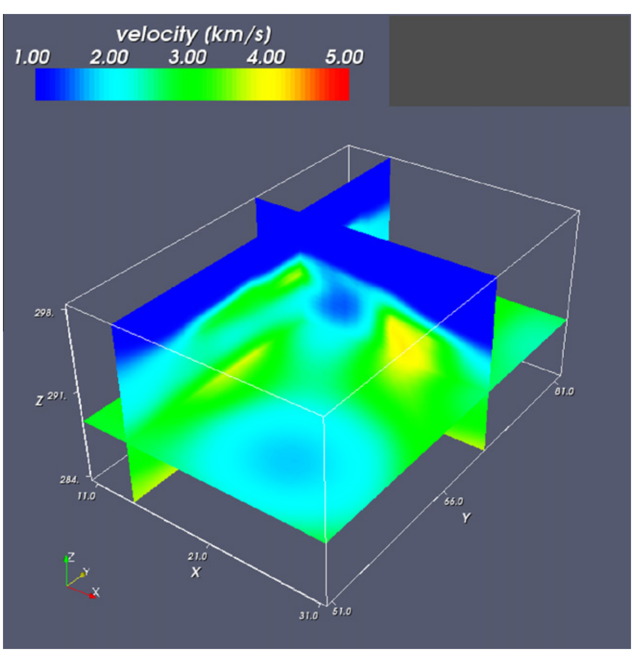

Figure 2 3D seismic travel time tomography survey over the castle of Devin, Czech Republic (after Valenta and Dohnal, 2007).

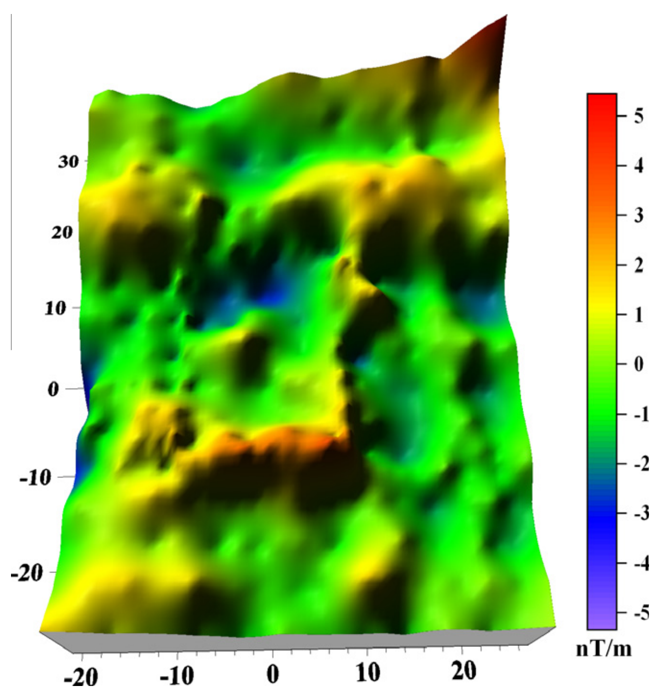

Figure 3 3D map of high-pass filtered total magnetic field over the Nabataean Hawar archaeological site in southern Jordan (after Batayneh, in press). The magnetic data indicates a fluctuation over visible rectangle (cistern), while there is only negligible scatter in the part of the map outside the cistern walls. The cistern was 16 m east to west by 26 m north to south.

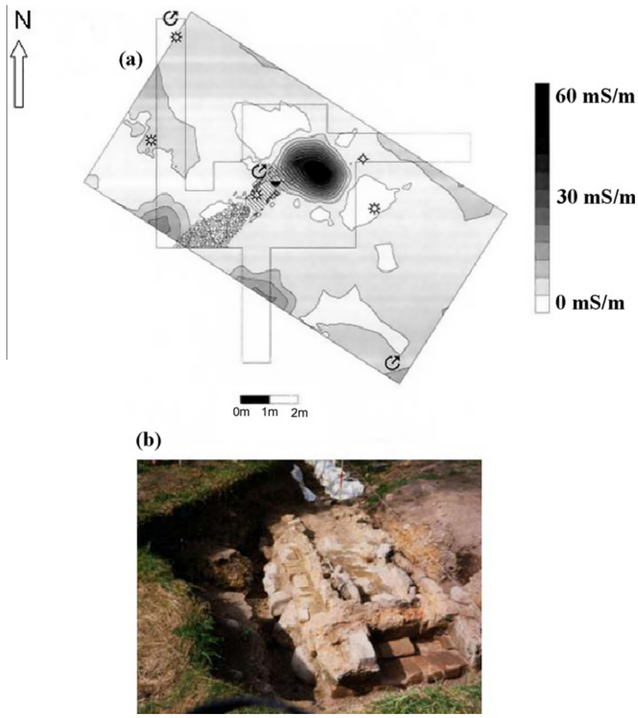

Figure 4 Survey results from Geonics Slingram EM 38 and EM 31 (a) together with excavation (b) at Vendel church in Sweden (after Persson, 2005).

methods, and the soil-contacting (galvanic or resistivity) methods.

Initial works with EM methods was carried out by Scollar (1962), Foster (1968), and Tite and Mullins (1969, 1970). Tabbagh (1986) has given a good summary of EM work. EM methods were also used in archaeological prospection in the United States with considerable success (Bevan, 1983; Wynn and Sherwood, 1984). Fig. 4 shows a survey results from EM 38 and EM 31 together with excavation at Vendel church in Sweden (Persson, 2005).

Galvanic or soil-conduction electrical methods have been used since the 1950s (Aitken, 1974). The best-known method is resistivity profiling, and typically a Wenner, dipole–dipole and pole–pole arrays. Sumner (1976), Batayneh and Al Zoubi (2000), Batayneh (2001), Batayneh and Al-Diabat (2002), Batayneh and Barjous (2003), and Batayneh (2005) have provided a good description of methods and arrays in common use along with their relative advantages. Fig. 5 shows an electrical 2D resistivity tomography (Wenner array) results from the Umm er-Rasas archaeological site in central Jordan (Batayneh et al., 2006). The profile shows conductive zone as a result of water seepage under the architectural features of the site of Umm er-Rasas. The "induced polarization" (IP) and "self-potential" (SP) methods are also soil-contacting methods. They were first used in England in 1968 (Aspinall and Lynam, 1968, 1970). The SP method was used for reconnaissance archaeological mapping by Wynn and Sherwood (1984). Because of the too small signals in a field survey caused by oxidized metal burial artifacts, the use of induced polarization technique in archaeology was limited.

The most recent technique innovation in "archaeological prospection" is "ground probing radar" or "ground-penetrating radar" (GPR) was first used in the USA in the early 1970s.

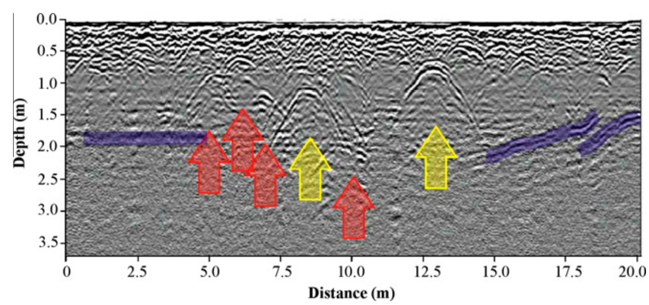

Figure 6 GPR profile from the historic cemetery of Alabama (after Jones, 2008). Blue lines indicate horizontal and sloping reflectors. Yellow arrows indicate distinct hyperbolic reflections due to discrete subsurface objects. Similar, but with less distinct reflections are indicated with red arrows. The shallower hyperbolic reflections are likely caused by tree roots.

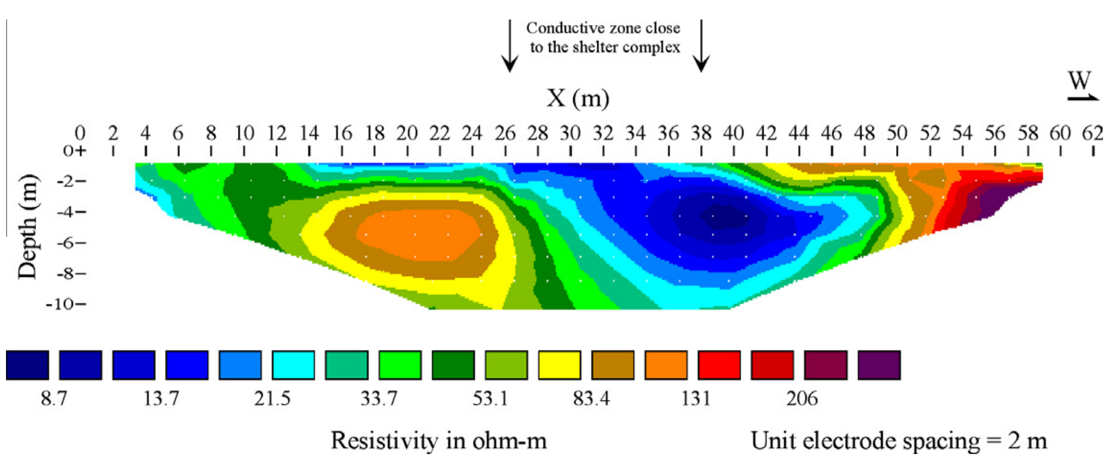

Figure 5 Survey results from 2D inversion of electrical resistivity tomography (Wenner array) from the Umm er-Rasas archaeological site in central Jordan (after Batayneh et al., 2006). The profile shows conductive zone as a result of water seepage under the architectural features of the site of Umm er-Rasas.

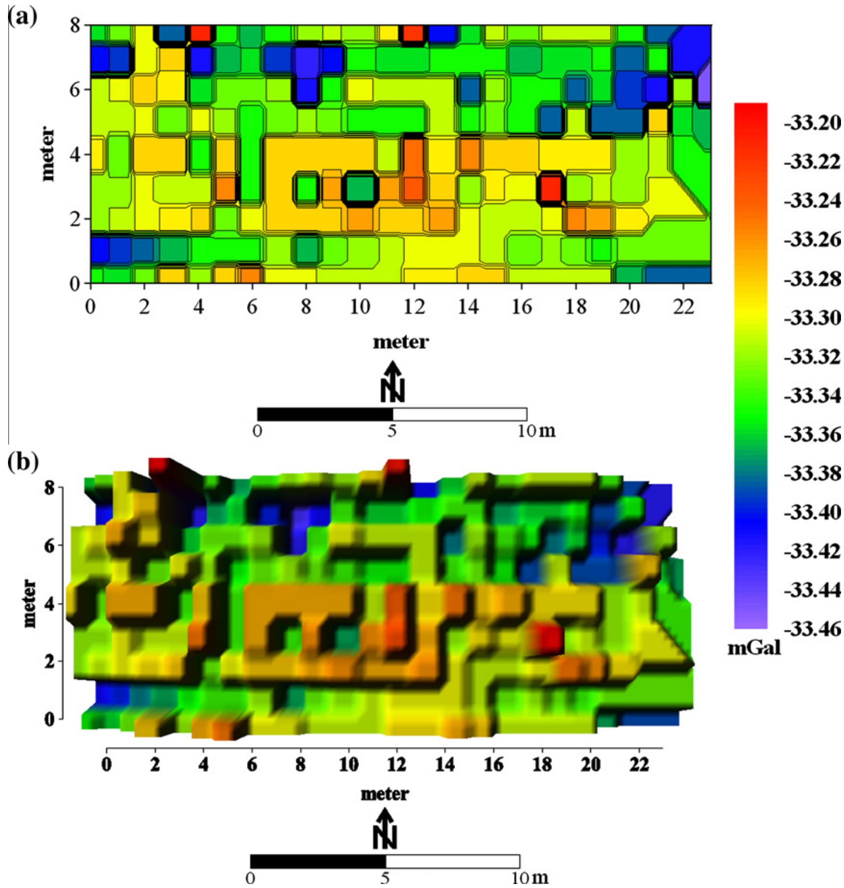

Figure 7 (a) Bouguer gravity anomaly map. (b) 3D gravity anomaly over the mosaic floor of Umm er-Rasas archaeological site (after Batayneh et al., 2006). The 3D gravity data indicates a fluctuation (high density) over the building walls and foundations, while there are only negligible scatter anomalies (low density) in the part of the map outside the building walls.

It was originally designed to serve as an aid to engineering geology studies (Dolphin et al., 1978; Ulriksen, 1982; Batayneh et al., 2002). It is rapidly becoming geophysical technique and used in intrasite mapping for archaeologists (Bevan, 1983; Vaughan, 1986; Imai et al., 1987). GPR is of limited use where either the soil or rocks are of high conductivities. Fig. 6 (Jones, 2008), shows a typical record obtained by means of a GPR system.

2.5. Gravity method

The gravity method has seen limited use, principally because of the enormous time and energy involved in making adequate elevation and terrain corrections (Linington, 1966; Fajklewicz et al., 1982). A microgravimetric and gravity gradient methods was used for engineering applications and to search for underground cavities (Arzi, 1975; Blizkovsky, 1979; Butler, 1984). Along with other geophysical methods, gravity method (Fig. 7) was used to outline underground structures at the Umm er-Rasas archaeological site in Jordan (Batayneh et al., 2006).

3. Limitations of geophysical methods

Geophysical methods used in archaeology are not an unqualified panacea for the archaeologist. In fact, there are several reasons why geophysical methods do not work, or are not cost-effective, in archaeological applications. A primary reason is that they are for the most part instrumentation, computer, and interpretation intensive. Use of a geophysical consultant can be prohibitively expensive. Data processing and image enhancement methods are also expensive, usually requiring custom application to each data set. Archaeologists do not usually deal with the relatively large costs that geoscientists are much more accustomed to.

Non-anthropogenic sources for geophysical anomalies are also a major problem with geophysical measurements over archaeological sites. Often, anomalies caused by ancient human cultural activity lie beneath the noise threshold of the surrounding geologic environment. Sometimes, ancient anthropogenic anomalies are unobservable due to the large variations caused by modern cultural interference (power lines, roads, etc.). This means that there will be areas, especially where population density is large, where geophysical prospecting for archaeological sites can be carried out with only extreme difficulty. It is also not unusual for physical properties to vary little with the human disturbance of a solid horizon. This problem forces the archaeologist or geophysicist to search for more than one physical property in which contrasts are sufficient to be useful in mapping. Resolution and depth limitations are important restraints on the use of geophysical methods in most applications. Because most anthropogenic features are near the surface, this does not usually cause problems for an archaeologist working on the earth's surface.

References

Aitken, M., 1974. Physics and archaeology, second ed. Clarendon Press, Oxford.

Aitken, M., Webster, G., Rees, A., 1958. Magnetic prospecting. Antiquity 32, 270–271.

Al-Zoubi, A., Haddadin, G., Batayneh, A., 1998. Geophysical methods for locating a prehistoric site in the Al Hummaymeh area, southwest Jordan. Journal of Environmental and Engineering Geophysics 3, 157–161.

Arzi, A., 1975. Microgravimetry for engineering applications. Geophysical Prospecting 23, 408–425.

Aspinall, A., Lynam, J., 1968. Induced polarization as a technique for archaeological surveying. Prospezioni Archeologiche 3, 91–93.

Aspinall, A., Lynam, J., 1970. An induced polarization instrument for detection of near surface features. Prospezioni Archeologiche 5, 67–76.

Batayneh, A., 2001. Resistivity imaging for near-surface resistive dyke using two-dimensional DC resistivity techniques. Journal of Applied Geophysics 48, 25–32.

Batayneh, A., 2005. 2D electrical imaging of an LNAPL contamination, Al Amiriyya fuel station, Jordan. Journal of Applied Sciences 5, 52–59.

Batayneh, A., in press. The use of magnetometry and pole–dipole resistivity for locating Nabataean Hawar archaeological site in the SW-Jordan. Archaeological and Anthropological Sciences Journal.

Batayneh, A., Abueladas, A., Moumani, Kh., 2002. Use of ground-penetrating radar for assessment of potential sinkhole conditions: an example from Ghor al Haditha area, Jordan. Environmental Geology 41, 977–983.

Batayneh, A., Al-Diabat, A., 2002. Application of 2D electrical tomography technique for investigating landslides along Amman-Dead Sea highway, Jordan. Environmental Geology 42, 399–403.

Batayneh, A., Al Zoubi, A., 2000. Detection of a solution cavity adjacent to a highway in southwest Jordan using electrical resistivity methods. Journal of Environmental and Engineering Geophysics 5, 25–30.

Batayneh, A., Al-Zoubi, A., Tobasi, U., Haddadin, G., 2001. Evaluation of archaeological site potential on the Tall al-Kharrar area (Jordan) using magnetic and electrical resistivity methods. Environmental Geology 41, 54–61.

Batayneh, A., Barjous, M., 2003. A case study of dipole–dipole resistivity for geotechnical engineering from Ras en Naqab area, south Jordan. Journal of Environmental and Engineering Geophysics 8, 31–38.

Batayneh, A., Khataibeh, J., AlRshdan, H., Tobasi, U., Al-Jahed, N., 2006. The use of microgravity, magnetometry and resistivity surveys for the characterization and preservation of an archaeological site of Umm er-Rasas, Jordan. Archaeological Prospection 14, 60–70.

Beazeley, G., 1919. Air photography in archaeology. Geographical Journal 53, 330–335.

Belshe, J., 1957. Recent magnetic investigations at Cambridge University. Advances in Physics 6, 192–193.

Benner, S., Brodkey, R., 1984. Underground detection using differential heat analysis. Archaeometry 26, 21–26.

Berlin, G., Ambler, J., Hevly, R., Schaber, G., 1977. Identification of Sinagua agricultural fields by aerial thermography, soil chemistry, pollen/plant analysis and archaeology. American Antiquity 42, 588–600.

Bevan, B., 1983. Electromagnetics for mapping buried earth features. Journal of Field Archaeology 10, 47–54.

Binford, L., 1964. A consideration of archaeological research design. American Antiquity 29, 425–441.

Blizkovsky, M., 1979. Processing and application in microgravity surveys. Geophysical Prospecting 27, 848–861.

Butler, K., 1984. Microgravimetric and gravity gradient techniques for detection of subsurface cavities. Geophysics 49, 1084–1096.

Carabelli, E., 1966. A new tool for archaeological prospecting – the sonic spectroscope for the detection of cavities. Prospezioni Archeologiche 1, 25–35.

Carson, H., 1962. A seismic survey at Harpers Ferry. Archaeonze 5, 119–122.

Colani, C., Aitken, M., 1966. Utilization of magnetic viscosity effects in soils for archaeological prospection. Nature 212, 1446–1447.

Dolphin, L., Tanzi, J., Beatty, W., 1978. Radar probing of Victorio Peak, New Mexico. Geophysics 43, 1441–1448.

Ebert, J., 1984. Remote sensing applications in archaeology. Advances in Archaeological Method and Theory 7, 293–362.

Fajklewicz, A., Glinski, A., Sliz, J., 1982. Some applications of the underground tower gravity vertical gradient. Geophysics 47, 1688–1692.

Foster, E., 1968. Further developments of the pulsed induction metal detector. Prospezioni Archeologiche 3, 95–99.

Gibson, T., 1986. Magnetic prospection on prehistoric sites in western Canada. Geophysics 51, 553–560.

Imai, T., Sakayama, T., Kanemori, T., 1987. Use of ground-probing radar and resistivity surveys for archaeological investigations. Geophysics 52, 137–150.

Institute for Prehistory and Protohistory of the University of Vienna, 1996. http://www.univie.ac.at/Luftbildarchiv/intro/aa_aaint.htm.

Jones, G., 2008. Geophysical mapping of historic cemeteries. Technical Briefs in Historical Archaeology 3, 25–38.

Linington, R., 1966. Test use of a gravimeter on Etruscan chamber tombs at Cerveteri. Prospezioni Archeologiche 1, 37–41.

Lyons, T., Avery, T., 1977. Remote Sensing: A Handbook for Archaeologists and Cultural Resource Managers. US Government Printing Office, Washington, DC.

McGhee, M., Luyendyk, B., Boegemen, D., 1968. Location of an ancient Roman shipwreck by modern acoustic techniques – a critical look at marine technology. In: Proceedings of the Marine Technology Society, 4th Annual Conference, Washington, DC.

Perisset, M., Tabbagh, A., 1981. Interpretation of thermal prospection on bare soils. Archaeometry 23, 169–189.

Persson, K., 2005. Integrated geophysical–geochemical methods for archaeological prospecting. Licentiate thesis in Land and Water Resources Engineering. The Royal Institute of Technology, Stockholm.

Scollar, I., 1962. Electromagnetic prospecting methods in archaeology. Archaeometry 5, 146–153.

Scollar, I., Weidner, B., Segeth, K., 1986. Display of archaeological magnetic data. Geophysics 51, 623–633.

Stright, M., 1986. Evaluation of archaeological site potential on the outer continental shelf using high-resolution seismic data. Geophysics 51, 605–622.

Stringer, C., 1986. Palaeoanthropology and palaeolithic archaeology in the People's Republic of China. Journal of Archaeological Science 13, 291–292.

Stringer, W., Cook, J., 1974. Feasibility study for locating archaeological village sites by satellite remote sensing techniques: report to the US National Aeronautics and Space Administration for Contract No. NAS5-21833, Task 110-N, Washington, DC.

Sumner, J., 1976. Principles of Induced Polarization for Geophysical Exploration. Elsevier, New York, 277pp.

Tabbagh, A., 1986. Applications and advantages of the Slingram EM method for archaeological prospecting. Geophysics 51, 576–584.

Tarling, D., Hammo, N., Downey, W., 1986. The scatter of magnetic directions in archaeomagnetic studies. Geophysics 51, 634–639.

Tite, M., Mullins, C., 1969. Electromagnetic prospecting – a preliminary investigation. Prospezioni Archeologiche 4, 95–102.

Tite, M., Mullins, C., 1970. Electromagnetic prospecting on archaeological sites using a soil conductivity meter. Archaeometry 12, 97–104.

Tite, M., Mullins, C., 1971. Enhancement of the magnetic susceptibility of soils on archaeological sites. Archaeometry 13, 209–219.

Ulriksen, C., 1982. Application of the impulse radar to civil engineering. PhD thesis. Lund University of Technology, Sweden, 179pp.

Valenta, J., Dohnal, J., 2007. 3D seismic travel time surveying – a comparison of the time-term method and tomography (an example from an archaeological site). Journal of Applied Geophysics 63, 46–58.

Vaughan, C., 1986. Ground penetrating radar surveys used in archaeological investigations. Geophysics 51, 595–604.

Weymouth, J., 1986. Archaeological site surveying program at the University of Nebraska. Geophysics 51, 538–552.

Wolfman, D., 1984. Geomagnetic dating methods in archaeology. Advances in Archaeological Method and Theory 7, 363–458.

Wynn, J., Sherwood, S., 1984. The self-potential (SP) method – an inexpensive reconnaissance and archaeological mapping tool. Journal of Field Archaeology 11, 195–204.