Geophysical prospecting in Slovenia:
an overview with some observations related to the natural environment

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Abstract

Decade of geophysical investigations for archaeological purposes at the Department of Archaeology, the University of Ljubljana, have produced a series of useful information for academic archaeological analyses as well as for the protection of the archaeological cultural heritage from construction intervention. It is my opinion that cooperation with the archaeological profession is constructive as it substantially contributes to the attainment of reflective information on the results of archaeological excavations and other archaeological sources, all of which have augmented into a combined research plan for the future. The success of this cooperation is clearly illustrated already by the database including more than 150 locations at home and abroad, also presenting good potential for being incorporated in theoretic discussions concerning the potential of applied geophysics in archaeology. One of the main problems with archaeological prospecting is still the evaluation of the suitability of individual techniques with regard to the various natural environments and the types of archaeological remains. This is a rather ambitious theme that I am opening to discussion with this article. Numerous problems will obviously remain unsolved even with the publishing of this article; the solutions that I am presenting are the result of my own experience and I thus ground them on my own data exclusively. I shall illustrate my thoughts on this theme with the results of select investigations which satisfactorily describe the possibilities provided by geophysical prospecting for the detection of certain characteristic types of archaeological remains in diverse natural environments. The majority of these investigations have already been published in the archaeological literature, for this reason I have limited the scope of this article to those data that contribute, from various points of view, to the clarification of the potential of geophysical prospecting under diverse working conditions. The results from geophysical investigations on prehistoric sites are still lacking of any applicable conclusions, despite the relatively large number of investigations that were carried out within the framework of archaeological prospecting primarily along the routes anticipated for the construction of highways; for this reason I shall for the most part present the research determinations attained through investigations on Roman sites in various natural environments.

Izvleček

Desetletje geofizikalnih raziskav za potrebe arheologije na Oddelku za arheologijo Univerze v Ljubljani je dalo vrsto koristnih informacij tako za akademske arheološke analize kot tudi za zaščito arheološke kulturne dediščine pred gradbenimi posegi v prostor. Sodelovanje z arheološko stroko ocenjujem kot konstruktivno tudi zaradi izdatne pomoči pri pridobivanju povratnih informacij o rezultatih arheoloških izkopavanj in drugih arheoloških virov, kar je preraslo v skupno načrtovanje raziskav za prihodnost. Uspešnost sodelovanja nazorno ilustrira že baza podatkov, ki obsega preko 150 lokacij doma in v tujini, kar predstavlja dober potencial tudi za vključevanje v teoretične diskurze o potencialu uporabne geofizike v arheologiji. Po mojem je eden od temeljnih problemov arheološke prospekcije še vedno ocena ustreznosti posameznih tehnik v odvisnosti od naravnih danosti in tipa arheoloških ostalih. To je zelo ambiciozna tema, ki jo odpiram s tem člankom. Veliko problemov bo seveda tudi s tem prispevkom ostalo nerešenih, rešitve, ki jih po-nujam, so rezultat lastnih izkušenj in jih zato utemeljujem samo na podatkih, do katerih sem prišel sam. Razmišljanja o tej temi ilustriram z rezultati izbranih raziskav, ki zadovoljivo opisujejo možnosti geofizikalne prospekcije za detekcijo nekaterih značilnih tipov ostal in konkretnih naravnih okolij. Večina teh raziskav je bila že objavljena v arheološki strokovni literaturi zato se v tem članku omejujem le na tiste podatke, ki z različnih gledišč prispevajo k pojasnjevanju ocene potenciala geofizikalne prospekcije pri različnih delovnih pogojih. Rezultati geofizikalnih raziskav na prazgodovinskih najdiščih so kljub razmeroma velikemu številu raziskav, ki so bile opravljene v okviru arheološke prospekcije predvsem na trasah, predvzemena za gradnjo avtocest, še brez uporabnih zaključkov, zato razlagam predvsem ugotovitve, do katerih sem prišel z raziskavami na antičnih najdiščih v različnih naravnih okolijah.
INTRODUCTION

The first geophysical prospecting on an archaeological site in Slovenia was executed by Eng. Franc Miklič (IGGG, Ljubljana) in 1969 at Dolge njive in Vrhnika (Miklurk 1970, 39-40). Andy Waters from the University in Bradford commenced systematic geophysical prospecting in 1986 on the initiative of dr. Božidar Slapšak (see Waters 1989, 74-77). Doctorate students at the same University, Cris Gaffney and Vincent Gaffney, continued his work in the years 1988 and 1989. In 1990, the then Secretariat for Science and Technology granted the Department of Archaeology at the Faculty of Philosophy, University of Ljubljana, the means to purchase geophysical equipment (a Resistance meter Geoscan RM15 and Fluxgate gradiometer Geoscan FM36, Geoscan Research, Bradford, UK). Due to other ongoing research projects requiring geophysical equipment, we collaborated with other Institutes that also enabled research with a field instrument for measuring the apparent magnetic susceptibility (a Kappameter KT-5; the Administration of Culture, Republic of Slovenia), a proton magnetometer for measuring the total magnetic field (a Geometrics G 819; IGGG Ljubljana and a GemSystem GSM19; the Faculty for Electrotechnics, University of Ljubljana), and georadar measurements (using a GSSI SIR 3; MIC d. o. o., Ljubljana).

The research strategy, from the outset of independent geophysical prospecting at the Department of Archaeology in 1990, was primarily directed towards collecting data on anomalies in physical fields resulting from archaeological remains that are situated in various natural environments. We avoided selecting -economic- and -noneconomic- archaeological sites based upon their anticipated archaeological potential, their level of conservation, their natural features and the presumed detectability of archaeological remains under their respective conditions. Consequently, the general concept that has been grounded on these principles currently enables a comprehensive evaluation of the suitability of various geophysical techniques for the detection of particular types of archaeological remains situated in various natural environments on the basis of a relatively extensive database (more than 150 locations here and abroad).

The more significant primary objectives of geophysical prospecting can be summarized as follows:

To determine the correspondence between various geophysical techniques for the detection of particular types of archaeological remains situated in various natural environments, where the division of Slovenia into regional systems is used to determine the geological/pedological foundations. These regional systems can be classified as the functions of basic geology, relief, climatic conditions and the hydrosphere. The result of these factors are the soil and pedosequences, which are defined as soil sequences that appear in the same or similar foundation (Stritar 1990, 51). Pedosequences generally correspond to the boundaries of regional systems and define them in a geographic sense and, furthermore, dictate their present-day agricultural purpose. Natural and anthropogenic components of the regional system influence each in themselves, as well as on the whole, upon the potential of archaeological prospecting.

One of the basic principles of geophysical prospecting is to apply a variety of geophysical techniques at the same archaeological site, wherever possible, irrelevant of the estimated detectability of the anticipated archaeological remains. Current applications include magnetometry using a fluxgate gradiometer and a proton magnetometer, measuring the magnetic susceptibility, the apparent resistivity and self potentials, as well as georadar measurements. Such an approach procures more data, which consequently enables a better interpretation (e.g. the principle of anomaly associations in the physical field).

To determine the -critical- or -border- values of the multitudinous anomalies measured in the physical expanse. It is an empirical or statistically determined value which represents the lower limit of a -significant- anomaly characteristic for a particular type of archaeological remain in an established archaeological context and natural environment. Basically, it is a matter of distinguishing the signal to noise ratio; to do so, the value span, which is a result of noise, must first be established. These so-called -critical- values can, in an archaeological context, also determine the boundaries between varying activity areas which, for instance, C. Carr (1982) first defined for the resistivity method.

To employ an approach similar to combining multi-channel satellite shots into a composite picture, replacing the satellite shots with a data series from archaeological prospecting. The conjunction of various geophysical data as well as geophysical data together with data from archaeological field survey is thus enabled (see i.e. unsupervised classification; Ladefoged et al. 1995, 471-481).

Concerning the stance of geophysical prospecting in archaeology, I generally agree with the evaluation of Boucher (1996, 139): -It would appear that
there is an underlying philosophy of archaeological prospection being primarily a locational or evaluation tool and its increased use in pre-planning permission determinations has firmly channelled it in this direction-. The same author continues and ascertains that the possibilities for instating geophysical methods into the entire specter of archaeological analyses should be considered more frequently and more earnestly. The author’s well-intentioned and illustrative assertion, which probably expresses the general conviction on geophysical prospecting in the field of archaeology, nevertheless overlooks select significant investigations that were rendered on archaeological materials and were aimed at comprehending the results from geophysical prospecting (see i.e. Carr 1982). I believe that laboratory analyses of a relatively small number of soil samples also contribute to improved archaeological interpretational evidence, especially as concerns ‘activity areas’. Accordingly, further analyses are then carried out upon samples exclusively from regions that were determined, on the basis of previous geophysical prospecting, as potential centers of particular activities in the archaeological past. Geophysical prospecting thus incorporates granulometrical analyses, X-ray analyses, differential thermal analyses and laboratory measurements of the magnetic susceptibility.

THE DATABASE FOR GEOPHYSICAL PROSPECTING

This article presents a review of the current stance of geophysical prospecting in the region of Slovenia in view of the evaluated potential of individual geophysical techniques subject to the natural characteristics and the type of archaeological remains. The Department of Archaeology has, in addition to the above mentioned investigations carried out in Slovenia within the framework of various international projects, completed geophysical prospecting at numerous archaeological sites abroad (they are omitted due to their divergence from the concept of this article).

Owing to the relatively large amount of geophysical prospecting performed since 1990 the creation of a suitable database was considered a prerequisite for the successful execution of the primary goal, which I deem to be the determination of the suitability of various geophysical techniques for archaeological prospecting subject to the type of archaeological remain and the natural characteristics. The whole database comprises more than 150 geophysical investigations on archaeological sites in Slovenia and abroad. In the Table 1 are included some sites which are illustrative for mentioned goals.

Information cited in the literature may be helpful to some degree when determining the potential of geophysical techniques, although it is insufficient for a more precise evaluation. The most evident limitation is that predominantly results from successful geophysical investigations are cited in the literature, that is, the majority of cases were executed on recognized archaeological sites with well preserved archaeological remains and various other favorable natural characteristics. Noticeably fewer publications are more research oriented and deal with the effectiveness of geophysical techniques under various working conditions (see Bevan 1996a; 1996b and 1996c). An extensive investigation was organized in which numerous various techniques were tested, for example, within the region of the Selinunte archaeological park, Sicily (Finetti 1992, 83-232). Publications concerning geophysical investigations that failed to produce the anticipated results are even more seldom (see i.e. Nishimura et al. 1991, 757-765).

Much attention has been dedicated to national archaeological databases, in the past few years, that also incorporate results from geophysical investigations (see i.e. Linford, Cottrell 1994, 133-134; http://www.eng-h.gov.uk/). This could be an indication that archaeological prospecting, and consequently also geophysical investigations, have sufficiently asserted themselves throughout the academic world serving for archaeological settlement analyses, as well as for the everyday conservation of the cultural heritage. These types of databases are usually quite specific and with a strongly accentuated goal to record and document anomalies in the physical fields resulting from various archaeological features; they tend to follow the recognized trend of persuading archaeologists in the effectiveness and almost infallibility of these sorts of investigations that are based upon modern electronics and computer technology. Newer databases are created in program packages that serve as tools for examining extensive databases for geographic information systems (i.e. ArcView, Esri). The primary advantage of these databases is that they enable a link between the textual part of the database and the graphic foundations composed of georeferential information on geophysical investigations and aerial photography (see i.e. Doneus, Neubauer 1998, 29-56). I also chose this type of open database structure as it enables the combination of diverse types of information concerning archaeology, archaeological prospecting and the natural environment.
The trends in geophysical investigations in archaeology indicate that the phase of -filtering- so-called -raw- values has, having experienced its culmination at the end of the 1980's and the beginning of the 1990's, finally expired. At that time, such an extensive selection of investigations was not yet available considering that they only came into full swing with the development of microcomputers. Initially the trend was to present and process the data in the foreground with the intention of emphasizing the significant anomalies in the physical fields, which result from the presence of archaeological structures against the various noise in the background. The aim was to substitute the missing values, which were the aftereffect of optimizing field work so as to accelerate the process of data collection. Various modification masks that were used for digital image enhancement prior to this were usually applied. A later research trend can best be illustrated on the example of magnetometry. Research evolved in the direction of the development of better instruments with greater resolution and highly accelerated data collection capabilities (see i.e. Becker 1995, 217-228), as well as the development of program and machine equipment enabling enormous amounts of data to be processed. This still speaks in favor of investing in magnetometers with a higher resolution, which due to their being robust (see Doneus, Neubauer 1998, 32), are useful only up to the first physical obstacle - with some instruments, this could already be a small step in the field (i.e. the demarcation of a lot) - and useful only on entirely flat surfaces - which is irrelevant throughout most of Slovenia. Furthermore, the high resolution factor of instruments is pronounced exclusively in magnetically -quiet- areas. Consequently, there have been numerous articles published during the past few years discussing the results of magnetometric investigations on so-called Neolithic rings (see i.e. Eder-Hinterleitner, Neubauer, Melichar 1996, 185-197; Kuzma et al. 1996, 71-79; Becker 1995, 222; Doneus, Neubauer 1998, 42-47). These rings, in terms of geophysical prospecting, manifest themselves as negative topographic anomalies, or rather ditches, that were filled with upper horizons of soil over time and are usually more magnetic than horizons lying further below (Clark 1990). This explains the weak contrast in the magnetic susceptibility between ditches and the medium through which they cut, which is usually clay, a homogeneous composition. This weak anomaly in the Earth’s magnetic field can nevertheless be measured using a Cesium gradiometer which has a resolution of at least 0.1 nT/m, while newer versions have a factor of even 0.01 nT (1pT). Many of these Neolithic rings are also visible already from aerial photographs. The difference between a Cesium magnetometer and a more inexpensive one, such as a fluxgate gradiometer, becomes negligible on -regular- and, as far as magnetic characteristics are concerned, heterogeneous sites where the background is quite variable. This could be illustrated by H. Becker’s investigations in the Troy region, where the advantages of a Cesium magnetometer are demonstrated; yet I believe that the results fail to sufficiently substantiate this assertion. Practically equivalent results were obtained with the Geoscan FM36 fluxgate gradiometer, which is simpler to use and also considerably more inexpensive.

Bevan (Geosight, USA) chose a different approach to geophysical prospecting in archaeology. His prospecting results are cited in three unpublished reports (Bevan 1996a; 1996b and 1996c). Relying on the basis of numerous investigations at very diverse sites, he was the first to provide an evaluation of the suitability of various geophysical techniques subject to the natural characteristics and the types of archaeological remains. Only recently have proposals recommending appropriate solutions for regulating databases for geophysical prospecting begun to be published (Linford, Cottrell 1994a, 71-72; 1994b, 133-134; Doneus, Neubauer 1998, 29-56). Due to the enormous amounts of data, they should be linked in such a manner that immediate access to information, essential for either academic settlement analyses or for the protection and conservation of the archaeological cultural heritage, is enabled.

While establishing the database for geophysical prospecting, the fundamental principles of the English Heritage Geophysical Survey Database (SDB), proposed by the Ancient Monuments Laboratory (www.eng-h.gov.uk) in 1994, were taken into consideration. As the national database for archaeological sites (ARKAS) (Tecco-Hvala 1992, 62-63) is a project underway for many years already at the Institute of Archaeology, Scientific Research Center of Slovenian Academy of Sciences and Arts, the particularities of this database were also considered while creating the one for geophysical prospecting. The database is intended to provide an organized register of archaeological sites according to the established criteria for organizing archaeological databases while taking into consideration the specifics of geophysical investigations. The register includes all sites upon which prospecting was executed between the years 1990 and 1998. A description of the geographic location of the site, the use of
surface area and the chronological determination are attributes that are recorded applying the same procedure as used at ZRC SAZU in managing the archaeological database (ARKAS://www.zrc-sazu.si/aspweb/ARCAS-normal.htm/); the database structure is presented in the article by S. Tecco-Hvala (1992, 62-63). The remaining information fields are selected and organized in such a way so as to enable an evaluation of the potential of geophysical investigations for determining the various types of archaeological remains in diverse natural surroundings. I used the division of Slovenia into regional systems (pedosequences) as established by Stritar (1990, 29-30) for describing the natural surroundings. This division, despite certain doubts regarding the precision in the classification of natural surroundings, seems the most suitable solution for describing the potential of geophysical prospecting methods in various natural environments. The practicability of this division is seen especially in that it substantiates pedosequences on the basis of their basic geological foundation, while at the same time it also takes into consideration the essential geographic determinants which, together with the pedological composition, dictate the current purpose of the surface area. The quotient of success and consequently also the evaluation of the suitability of geophysical investigations was determined relevant to corroborative archaeological excavations. The estimated suitability of individual prospecting techniques were recorded for those sites not yet excavated, based upon comparisons with similar archaeological sites wherever justification by excavation was possible.

Unrestricted accessibility to such a database which primarily enables access to all prospecting information, including numerical files that contain -raw- values of field measurements, represents, in my opinion, a constituent part of a database that is to serve as a register for geophysical investigations. Immediate access to data matrices is thus enabled and consequently data processing is delayed, as are reinterpretations of results or the incorporation of data matrices in expert, or hybrid systems, and neuron networks. A relatively frequent situation presents different teams at the same archaeological site collaborating at various intervals in the geophysical investigations and applying diverse geophysical techniques. This is also the main reason that M. Dabas and I prepared the framework for a database of geophysical investigations also at the Mont Beuvray (France) archaeological site (1997, 199-210); F. Laudrin set up the register in the program File Maker (Centre archéologique européen du Mont Beuvray).

AN EVALUATION OF THE SUITABILITY OF GEOPHYSICAL TECHNIQUES

Ideally, selection of the most suitable geophysical techniques is dictated only by the targeted archaeological objects that we wish to locate. In reality, the targeted archaeological objects account for only a larger or smaller part in determining the most appropriate geophysical techniques. Correspondingly, an anomaly in the physical field, resulting from the presence of a targeted archaeological object, is termed a signal, while all other irregularities in the physical fields, resulting from various other factors, are termed noise. The most suitable selection is not evidenced by the geophysical technique when the anticipated amplitude of the signal is the greatest, but rather when the ratio of the signal versus noise is the greatest. This is termed the signal to noise ratio.

Geophysical investigations are generally executed in a field for which we know, at least approximately, of its archaeological potential as regards the type of archaeological remain that can be detected using geophysical techniques. The targeted objects are commonly various elements of a settlement structure (walls, ruination layers, refuse pits, postholes, ditches, various trade workshops, hearths and stratigraphic sequences manifesting traces of anthropogenic activity, etc.). Better results are usually attained in the instance that the anticipated type of archaeological remain is at least approximately known. The physical parameters, of which the greatest difference is between the archaeological object and the plot of ground upon which it is situated, are determined contingent upon the data concerning the archaeological and natural surroundings. The most effective strategy for geophysical prospecting is then selected on the basis of the evaluated contrast of particular physical parameters (e.g. resistivity/conductivity, the magnetic susceptibility and the permittivity, as well as the magnetic permeability) for a particular type of archaeological remain, the noise from the surroundings, the surface condition, as well as the geological and pedological composition of the terrain.

My own presentation evaluating the effectiveness of geophysical techniques is essentially only a slightly altered and supplemented variation of that proposed by B. Bevan (1996a) for presenting his own investigations. These results are not published, however they are in essence accessible to the wider public. The principal determinant, in my opinion, for the small number of such investigations in this field is the strong tendency toward specialization in
only one geophysical technique. Numerous articles have been published by various authors in which the results from several geophysical techniques, or rather instruments, applied at the same site are presented, yet these publications discuss the results of each of the techniques independent of the results of any other technique; comparative studies, generating a detailed review of the potential of these various techniques at different sites, is lacking (see i.e. Finetti 1992, 83-232).

The information presented in Table 1, assessment data for my evaluation of the suitability of geophysical prospecting techniques, is in many ways imperfect as regards a naturalistic and tech-

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Table 1. The table presents some of the archaeological sites upon which geophysical prospecting was executed. Tab. 1. Preglednica nekaterih arheoloških najdišč na katerih smo opravili geofizične raziskave.
nical approach. For instance, the division of the natural environment into regional systems, or pedosequences, as proposed by A. Stritar (1990, 29-30), was applied for describing the natural environment. This division nevertheless corresponds perfectly to select more general determinations that were attained during my investigations on the various geological foundations (e.g. the signal to noise ratio is approximately the same on particular pedosequences with the same type of archaeological remains). There is essentially no simple manner in which all the various factors that inevitably influence upon geophysical prospecting can be considered.

### EXAMPLES OF GEOPHYSICAL PROSPECTING

To illustrate the suitability of geophysical techniques in various natural environments, classified subject to their diverse pedosequences or regional systems, I selected investigations on archaeological sites that were well researched using geophysical methods and on which the results satisfactorily describe the potential of the particular method in its respective natural circumstances. At the same time, my aim was to incorporate as many diverse natural environments and types of archaeological remains as possible.

The majority of the article is devoted to Late Roman hill-top settlements which are often situated where prehistoric hillforts previously existed. This type of archaeological site is quite common in Slovenia and will thus represent a frequent target of research using archaeological prospecting methods. The work conditions are extremely demanding as concerns geophysical investigations, therefore I believe it is entirely justified that I present my own experiences on these types of archaeological sites in the forefront.

The only geophysical prospecting within a prehistoric fortification that I know of, although very extensive, was executed in southern England (Payne 1996, 163-184); already simple magnetometry investigations procured substantial insight into the organization of the settlement. I was unable to rely on these data during my own investigations of prehistoric fortifications andLate Roman hill-top settlements as the natural conditions are entirely different here. Prehistoric fortifications in southern England are primarily situated on level plateaus that are overgrown with grass and raised only a few meters above extensive flat lands. These are considered incomparably better conditions for geophysical prospecting than on any of the somewhat similar archaeological sites in Slovenia, where unlevel terrain, dense vegetation, the occasional thick layer of Late Roman ruins or just slight prehistoric archaeological cultural horizons are regularly encountered. All these factors indeed bear serious limitations for most types of geophysical prospecting techniques. The actual absence of archaeological publications concerning geophysical investigations on these types of archaeological sites is also an indirect indication of this. The results of geophysical investigations at other archaeological sites were selected so as to illustrate certain particularities in the regional systems of which we should be mindful while planning prospecting. The archaeological sites discussed
in the article (fig. 1) are sorted according to their geologic-pedologic foundation:

Pedosequences on noncarbonaceous rock
- Ajdovščina above Rodik (1)

Pedosequences on hard carbonaceous rock
- Ajdovski gradec near Bohinjska Bistrica (2)
- Škocjan (3)
- Cvinger near Meniška vas (4)

Pedosequences on soft carbonaceous rock
- Groblje near Buče (5)

Pedosequences on clay and loam
- Grafendorf (Austria)
- Velike Malence (6)
- Čatež along the Sava (7)

Pedosequences on gravel and sand
- Ilovca near Vransko (8)

PEDOSEQUENCES ON NONCARBONACEOUS ROCK

Ajdovščina above Rodik (Fig. 2)

The site at Ajdovščina above Rodik (Marchesetti 1903; Slapšak 1978; 1985 and 1988) (Fig. 2), situated on pedosequences on noncarbonaceous rock (flysch) (see: Orehek 1972; Orehek, Silvester 1964 and 1967), serves well to illustrate the strategy for archaeological prospecting on prehistoric and Late Roman settlements. The research project was initiated and led by Slapšak (Department of Archaeology, University of Ljubljana) (see Mušič, Slapšak 1998; Mušič et al. 1995; and Mušič, Slapšak, Perko 1999). I shall use this site to clarify the potential of archaeological prospecting (Fig. 3) on Late Roman hill-top settlements, which represent an extremely complex problem, at least as far as geophysical research is concerned. The reasons for this are numerous and they differ from site to site. The natural conditions, ranging from moderate to very unlevel terrain with dense vegetation and a very inconstant thickness of ground and/or archaeological cultural horizon, are on the one hand, the most significant. While on the other hand, the surface and therefore also the archaeological remains are often covered with a layer of Late Roman ruins. These are the essential factors that expressly influence upon the reduction of the signal to noise ratio and which consequently lower the detectability of archaeological remains for almost all...
geophysical techniques, some of which are almost even entirely disenabled (e.g. the resistivity). As it is in the interest of the science of archaeology to investigate the range of geophysical methods also under these circumstances, I chose to carry out a detailed analysis of the individual geophysical techniques applied at select sites in Slovenia. In the continuation I shall present the results from certain so-called hill-top sites situated in diverse regional systems (=pedosequences).

In addition to Ajdovščina above Rodik, situated on pedosequences of noncarbonaceous rock, the prehistoric and Roman settlement at Škocjan, the prehistoric and Late Roman settlement at Ajdovski gradec near Bohinjska Bistrica and the prehistoric settlement at Cvinger near Meniška vas all serve to exemplify the potential of geophysical prospecting techniques on such archaeological sites, the majority of which in Slovenia are situated on pedosequences of hard carbonaceous rock (limestone, dolomite).

**Digital Elevation Model**

On the basis of measurements of the relative differences in the heights above sea level, derived from a reference point with absolute Gauss-Krueger coordinates, a precise topographic map of the site and a Digital Elevation Model (DEM) were created; the small relative differences in the above sea level heights significant for archaeological interpretation...
Fig. 3: Ajdovščina above Rodik. A schematic depiction of the applied prospecting techniques and the laboratory analyses of soil samples.

Sl. 3: Ajdovščina nad Rodikom. Shematični prikaz uporabljeneh prospeksijskih tehnik in laboratorijskih analiz vzorcev tal.
can be illustrated applying analytical hill shading (Fig. 4). The above sea level heights were measured with a precision of 1 cm at 1 m intervals between the measuring points. A total of 44,400 points were measured for the DEM (a surface area of 44,400 m²). Raw data was interjected in both directions applying bicubic interpolation (Davis 1986, 204-207) and measurements were thus simulated at 0.5 m. Positive topographic anomalies visible on the DEM are the result of Late Roman architectural debris. The course of the prehistoric rampart is also clearly discernible.

The resistivity method using twin probes (Resistance meter RM15, Geoscan Research, Bradford) was applied for the purpose of geoelectric mapping (Fig. 10) with a distance of 0.5 m between the mobile electrodes (C1P1). The resolution between the Geoscan RM15 measuring instrument is 0.5 Ohm.m. At a distance of 0.5 m between the mobile electrodes the effective depth reaches 1 - 1.5 m under favorable conditions of ground humidity; this is sufficient, in view of the data on archaeological remains at numerous Roman sites, for a precise delimitation of highly resistive architectural remains. This is also sufficient under favorable natural conditions for areas of various purposes which are within a complex of buildings, or rather in their direct vicinity, and whose apparent resistivity can also be lower than the background value (ditches and caves). The smallest alterations that were registered in the apparent specific electric resistivity totaled approximately 5 % of the value of the measured background. The alterations were
measured in a grid with 1 m between profiles and with the same distance between measuring points. A total of 36,400 m² was measured using the resistivity method. The matrix of raw values was condensed using bicubic interpolation (see Davis 1973, 204-207) and the readings at 0.5 m intervals were thus simulated.

**Magnetometry**

Magnetometry was executed using a fluxgate gradiometer (Fluxgate gradiometer FM36). The surfaces upon which high thermoremanent magnetization from trade workshops was discovered are designated. These surfaces were investigated using a proton magnetometer (Geometrics G819 in GemSystem GSM19).

**Fig. 5:** Ajdovščina above Rodik. Pedosequences on noncarbonaceous rock. Magnetometry using a fluxgate gradiometer (Fluxgate gradiometer FM36). The surfaces upon which high thermoremanent magnetization from trade workshops was discovered are designated. These surfaces were investigated using a proton magnetometer (Geometrics G819 in GemSystem GSM19).

**Sl. 5:** Ajdovščina nad Rodikom. Pedosekvenca na nekarbonatnih kamninah. Magnetometrija s pretočnim gradiometrom (Fluxgate gradiometer FM36). Označene so površine, na katerih smo ugotovili močno termoremanentno magnetizacijo (železarskih?) obrtnih delavnic. Te smo raziskali tudi s protonskim magnetometrom (Geometrics G819 in GemSystem GSM19).

of the Earth’s magnetic field \( (dZ/dz, \text{nT/m}) \) (Fig. 5 and 6) with regard to the zero reference point. Only one reference point was applied for all measurements. Any errors that could occur during the repeated transfer of the zero reference point to a new location were thus avoided and consequently a unified background measurement of the entire settlement was also secured. The distance between the measuring points in the direction of the profile (west-east) was 0.5 m, and 1 m between the profiles (north-south). The total number of measurements of the vertical gradient of the magnetic field was 95,200 (a surface area of 47,600 m²). Theoretically, this instrument could be used to measure magnetic anomalies above
archaeological objects such as ferromagnetic iron artifacts and ferrimagnetic ceramic objects (e.g. firing kilns for pottery, metallurgic iron-smelting furnaces, bricks, tiles, etc.) (Heathcote, Aspinall 1981, 61-70; Papamarinopoulos, Tsokas, Williams 1985, 483-490; 1986, 111-112). Areas with thermoremanent magnetization (Fig. 5) were investigated also using the Geometrics GSM 819 in GemSystem GSM19 proton magnetometers (Fig. 7 and 8). The distance between measuring points was the same in both directions, that is 1 m and 0.5 m respectively.
Magnetic Susceptibility

The apparent magnetic susceptibility was measured using a Kappameter KT-5 field instrument (Geofyzika, Brno). This instrument is used to measure the susceptibility of the ground up to approximately 3 cm. The variableness of the magnetic susceptibility, which is largely the result of the conversion of weakly magnetized iron minerals into more magnetic forms due to raised temperatures from the use of fire, is measured in this way. The magnetic susceptibility is otherwise only a physical property that is defined as a quotient between the measured intensity of magnetization and the inducing magnetic field, which is the Earth’s magnetic field in this instance. Consequently, among methods of magnetic measurement, measuring the magnetic susceptibility is considered equivalent to magnetometry. Measurements of the magnetic susceptibility of the various materials that are searched for during magnetic prospecting usually serve merely as a significant source of information on the magnetic characteristics of the target objects and the media in which they exist. Measurements of the magnetic susceptibility on the surface have been established as an independent prospecting method in geophysical prospecting for archaeology (see Mušič, Orengo 1998; Mušič, Slapšak, Perko 1999). The distance between the measuring points was the same in both directions (2 m). This relatively large distance between measuring points was chosen so as to save precious survey time. Initially, the plan was to use data concerning the range of values for the magnetic susceptibility on the surface of the settlement only as a piece of information on the magnetic characteristics of the materials present on the settlement and then to apply it in the interpretation of the magnetometry. While processing the data, I soon discovered that the level of correlation between the results...
from the intensive field survey (the number of pottery fragments or slag per surface unit; 4 m²) and the magnetic susceptibility was unexpectedly high (Fig. 11). For the purpose of researching the correlation between the concentration of material surface finds and the susceptibility of the ground, the measurements were extended to an incomparably larger part of the settlement surface than initially anticipated and the entire surface that was investigated during the intensive field survey was measured (Fig. 12). A surface area of 22,800 m² was measured using the Kappameter KT-5, with a total of 5700 measurements.

Fig. 8: Ajdovščina above Rodik. Pedosequences on noncarbonaceous rock. High thermoremanent magnetization (A: 1 - a blacksmith’s furnace?, 2 - deposit of metallurgical refuse products?) above the structures of metallurgical workshops were detected in areas 6 and 7 (Fig. 5) using a GemSystem GSM19 proton magnetometer, as well as a detail of thermoremanent magnetization from the forge in area 6 (B).

Sl. 8: Ajdovščina nad Rodikom. Pedosekvenca na nekarbonatnih kamninah. S protonskim magnetometrom GemSystem GSM19 smo ugotovili močno termoremnanentno magnetizacijo nad objekti metalurških delavnic (A: 1 - kovaške peči?, 2 - deponije odpadnih produktov metalurgije) na območju 6 in 7 (Sl. 5) in detalj termoremanentne magnetizacije peči na območju 6 (B).
The GSSI SIR3 served as the main measuring instrument for georadar research. All measurements were carried out using a monostatic antenna with a central frequency of 500 MHz. The situation and direction of the profiles was the same as for the other geophysical techniques. The distance between the parallel profiles measured was 1 m. The situation and level of preservation of the walls of Late...
Roman architectural remains under the heap of ruins was determined using georadar techniques. Objects with thermoremanent magnetization were detected in numerous places and, on the basis of magnetometry, magnetic susceptibility and field survey, I believe them to be the remains of some sort of industrial activity (ironworks?) (Fig. 9).

Archaeological Field Survey

Each collecting unit within the intensive field survey measured 4 m² (2 x 2 m). The majority of surface finds are Roman pottery fragments (tiles, bricks, pottery ware) (for a more precise explanation see Vidrih Perko 1997, 341-358) and various types of metallurgical refuse products (from ironworks). The surface finds were divided into pottery fragments (pottery, brick, tiles) and metallurgical refuse products. The distribution of these two types of finds were used in addition to the results from geophysical research to classify the various activity areas dating to the Late Roman period (see Mušič, Slapšak 1998, 81-93; Mušič, Slapšak, Perko 1999, 132-146).

In addition to the -standard- prospecting techniques mentioned above, with which the activity areas were classified, geochemical prospecting (see Mušič et al. 1995), granulometrical analyses, differential thermal analyses, X - ray analyses and laboratory measurements of the magnetic susceptibility (see Dmc, Mušič, Osredkar 1994...
Prospecting Results

A very high positive gradient in Area 2 (Fig. 5; 6 and 7) indicates a strong thermoremanent magnetization in the south-eastern corner of the area; this section can be interpreted, in an archaeological context, a kiln or forge. Thermoremanent magnetization is the result of the conversion of weakly magnetized iron minerals into more magnetic forms at high temperatures. Based on the shape of the anomaly, my inference is that it is a well preserved structure with a narrowing, or rather framework, made either of brick or fired stones. It is also possible that the entire inside is filled with a block of material with high magnetic susceptibility. A smaller area with much higher values than the background (10-30 nT/m) is connected with the forge on its eastern side, although the values are still much lower than in the area of the forge (up to 100 nT/m). My deduction is that the area is for industrial activity refuse products with high magnetic susceptibility. The lower values were measured due to the smaller pieces, or rather the diversely oriented magnetic dipoles, of which the magnetic effect basically equalizes itself and thus outwardly results with a smaller vector sum. Both magnetic anomalies are interpreted as a consequence of the same industrial activity. A very irregularly shaped magnetic anomaly of the same intensity as the anomaly by the forge, determined as the effect of refuse products resulting from industrial activity, was detected in the north-western corner of area 2. Similarly, it would seem that this anomaly is also indicative of the same effect from depositing industrial activity refuse products with high magnetic susceptibility.

Similar to the application with the fluxgate gradiometer (Geoscan FM36) (Fig. 6), a proton magnetometer (GemSystem GSM19) was used to measure a high amplitude (200 nT) anomaly at the same location, only confirming the initial determinations (Fig. 7). A low extreme of the same magnetic anomaly (-) was also measured north-west of the anomaly (+) probe. This one was directed approximately 10° east of the geographic North. A strong positive declination indicates that thermoremanent magnetization definitely predominates over the induced magnetization and it is probably directed towards the magnetic field from the Late Roman period when the trade ceased to function and the furnace finally cooled down. This shape of anomaly is indicative of a strong dipole characteristic, resulting from the thermoremanent magnetization of a well preserved structure still standing in its original location.

The magnetic anomalies in areas 6 and 7 (Fig. 5 and 8) were also investigated using the GemSystem GSM19 proton magnetometer. Similar to the application with the fluxgate gradiometer (Fig. 5), an area with high thermoremanent magnetization, probably representing the remains of industrial workshops in-situ (blacksmith's workshop?) (Fig. 8A: 1), was also detected using the proton magnetometer, as well as somewhat weaker magnetic anomalies probably resulting from the depositing of metallurgic refuse products (sl. 8A: 2). An almost identical situation was already discovered prior to this in area 2 (Fig. 5 and 6). The lower magnetic anomalies could be the result of diversely oriented smaller magnetic dipoles, these could be pieces of slag in this instance. Better results were achieved using the proton magnetometer GemSystem GSM19, primarily as concerns the geometry of the structure with thermoremanent magnetization in area B (Fig. 8B) showing a distinct semicircular cut in the ground plan.

The example set at Ajdovščina above Rodik has demonstrated that the georadar method is by far the most effective for detecting walls under thick
Fig. 12: Ajdovščina above Rodik. The values of the apparent magnetic susceptibility higher than the so-called critical, or border values, which amount to 0.6 x 10^{-3} SI, are presented. The high susceptibility values correspond well with the high gradients of the magnetic field.

Sl. 12: Ajdovščina nad Rodikom. Prikazane so vrednosti nadvizezn magnetne susceptibilnosti, višje od t. i. kritične oz. mejne vrednosti, ki v tem primeru znaša 0.6 x 10^{-3} SI. Visoke vrednosti susceptibilnosti se dobro ujemajo z visokimi gradienti magnetnega polja.

Layers of ruins (Fig. 9). This method was also applied to detect structures with high thermoremanent magnetization, all interpreted as the remains of industrial workshops (ironworks?) and deposits of metallurgic refuse products on the basis of magnetometry. Explicit radar reflections were perceived from all these structures. All these determinations are significant for evaluating the potential of geophysical techniques at Late Roman settlements, where the architectural remains are covered with thick layers of ruins. Perhaps the most important determination from georadar investigations for the purpose of researching the urbanistic design of such settlements and their architectural heritage, is that the walls are not always situated directly beneath the higher part of heap of ruins. Consequently,
A statistical comparison of the mean values of the iron content in seven samples of natural soil from Brkini flysch (m = 2.96 %) - among which a sample collected in the direct vicinity of the settlement was also included - with 14 soil samples from within the settlement (m = 2.43 %), established that, at a confidence level of 95 %, there are no statistically characteristic differences between the median values of iron content. The same result was attained applying the Kolmogorov-Smirnov test, which compares the distribution of both samples, and the Mann-Whitney W test, which compares the medians of both samples. Only the standard deviations differentiate as concerns their statistical characteristics, although I attributed this to the number of samples, especially in the comparative group of the chemical composition of the natural background, where only eight samples were available for statistical processing.

Pedosequences on noncarbonaceous rock. The profile from which soil samples for chemical analyses (Fig. 12; x = 180, y = 220-90) were taken begins outside the settlement before the defensive rampart, it crosses the rampart and the Late Roman architectural debris and continues deep into the heart of the settlement of the so-called empty space, where anomalies which could correspond to archaeological structures or perhaps to certain settlement activities failed to be determined using other prospecting techniques. The differences in height are somewhat emphasized.
Ajdovščina above Rodik. Pedosequences on noncarbonaceous rock. K-mean cluster analysis of the content of 7 elements in the geochemical profile at Ajdovščina above Rodik (Fig. 12). This statistical method was applied so as to group the samples, on the basis of their standardized contents (%) of the stated elements, into two classes. Class 1 incorporates samples with higher contents of Al, Fe, Mg, Na and P, as well as lower values of Ca. I consider these samples to be chemical anomalies at the site, resulting due to contamination from industrial activity (ironworks?). All other samples are attributed to class 2, which I define as the geochemical background of the settlement. Sl. 15: Ajdovščina nad Rodikom. Pedosekvenca na nekarbono-nastnih kamninah. K-mean clustrska analiza vsebnosti 7 prvin v geokemičnem profilu na Ajdovščini nad Rodikom (sl. 12). S to statistično metodo sem vzorce na podlagi standardiziranih vsebnosti (%) navedenih prvin grupiral v 2 razreda na podlagi podobnih kemijskih značilnosti vzorcev. V razred 1 sodijo vzorci, ki imajo višje vsebnosti Al, Fe, Mg, Na in P ter nižje vrednosti Ca. Zaradi tega štejem te vzorce za kemično anomalijo na podlagi statističnih parametrov. The first class includes those between the medial value and the standard deviation of 1, while the second class includes all values higher than the standard deviation of 1. The correlation between the hip of ruins and the apparent resistivity of the debris are, quite surprisingly, lower than the mean value.

A high level of correlation between the magnetic susceptibility (Kappameter KT-5) (Fig. 12) as well as between the magnetic susceptibility and the field survey (Fig. 11) was determined throughout the entire settlement. Laboratory measurements (for a more detailed explanation see Dime, Mušič, Osredkar 1994, 225-230; Mušič, Slapšak 1998, 81-93; Mušič, Slapšak, Perko 1999, 132-146) ascertained that the raised values of susceptibility of the top, approximately 3 cm thick horizon of soil, resulted from contamination with ceramic and/or metallurgic dust (ironworks?), most likely the result of decaying fragments of pottery and slag on the settlement surface.

As no intervention other than pasturage occurred on the settlement from the Late Roman period until today, the suitability of geochemical analyses for detecting regions and their respective purposes in the archaeological past could be checked (see Mušič et al. 1995). Samples were taken from one profile (Fig. 12), which based on the result from prospecting techniques, incorporated an area serving various purposes during the Late Roman period. Sampling was carried out under the direction of S. Pirc and N. Zupančič (NTF, Department of Geology). The profile begins at the northern end of the settlement, beyond the settlement under the prehistoric and Late Roman rampart, it traverses the strong magnetic anomaly with the thermoremanent type of magnetization on the outer part of the prehistoric rampart, running over the wall it continues deep into the heart of the settlement, where it crosses the debris as well as the apparently -empty- parts of the settlement. We were interested in determining whether there is a statistically characteristic difference in the chemical composition of the natural soil on the flysch rock of the Brkini hills and the settlement floor. This difference could be the result of intensive industrial activity (ironworks?) during the Late Roman period. The results of the chemical analyses from the geochemical map of the Brkini hills in Istria were applied for this purpose (Zupančič 1990). The content of Fe in the soil of the Brkini flysch was compared statistically with that in the samples collected from the geochemical profile (Fig. 13). No statistically characteristic differences were demonstrated in the content of iron within and beyond the settlement. This result is likely the consequence of high oscillation in the iron content in the soil of the Brkini flysch. A larger

A microlief of the surface does not provide a sufficient basis for drawing a precise ground plan from (Fig. 4), but rather the walls must be located using georadar measurements.

The corrected values of the apparent resistivity were divided into two classes on the basis of the statistic parameters. The first class includes those between the medial value and the standard deviation of 1, while the second class includes all values higher than the standard deviation of 1. The correlation between the hip of ruins and the apparent resistivity of the debris is weak, or rather much lower than anticipated (Fig. 10). Topographic anomalies, which are the result of debris and the apparent specific resistivity that is higher than the medial value, correspond only in select places in the southeastern area. Exclusively a negative correlation between the topography and the apparent resistivity was determined on all other parts of the settlement. These results enable us to conclude that all the measured values of the apparent resistivity of the debris are, quite surprisingly, lower than the mean value.

Geophysical prospecting in Slovenia: an overview with some observations related to the natural environment

Fig. 15: Ajdovščina above Rodik. Pedosequences on noncarbonaceous rock. K-mean cluster analysis of the content of 7 elements in the geochemical profile at Ajdovščina above Rodik (Fig. 12). This statistical method was applied so as to group the samples, on the basis of their standardized contents (%) of the stated elements, into two classes. Class 1 incorporates samples with higher contents of Al, Fe, Mg, Na and P, as well as lower values of Ca. I consider these samples to be chemical anomalies at the site, resulting due to contamination from industrial activity (ironworks?). All other samples are attributed to class 2, which I define as the geochemical background of the settlement.

Fig. 12: K-mean cluster analysis of the content of 7 elements in the geochemical profile at Ajdovščina above Rodik (Fig. 12). This statistical method was applied so as to group the samples, on the basis of their standardized contents (%) of the stated elements, into two classes. Class 1 incorporates samples with higher contents of Al, Fe, Mg, Na and P, as well as lower values of Ca. I consider these samples to be chemical anomalies at the site, resulting due to contamination from industrial activity (ironworks?). All other samples are attributed to class 2, which I define as the geochemical background of the settlement.
number of samples from the direct vicinity of the settlement should be tested for a more reliable interpretation in determining the content of iron in the natural background. Small differences in the content of certain elements are present within the settlement (Fig. 14). The chemically anomalous region was defined by applying the K-mean cluster analysis, through which all samples were grouped into two classes (Fig. 15). One class designates the background, the other designates the anomaly. Higher content of iron was determined in the area of thermoremanent magnetization on the rampart, above the heap of ruins, as well as within the settlement, where distinctive anomalies failed to be determined using other prospecting techniques (Fig. 16).

**PEDOSEQUENCES ON HARD CARBONACEOUS ROCK**

Ajdovski gradec near Bohinjska Bistrica  
(Fig. 17)

Pieces of iron slag, or various ironworks refuse products, were discovered in almost all trenches during Schmid’s archaeological excavations in 1936 (see Gabrovec 1966). Schmid also discovered small ditches, which he interpreted as the remains of a smeltery, in two trenches in houses II and III on the eastern side of the settlement. On the basis of these data, I chose magnetometry as the most suitable geophysical method for detecting industrial zones with metallurgical activity (Fig. 18).
The anticipated thickness of the soil is rather small and the terrain is quite unlevel as the settlement is situated atop a hill with pedosequences on hard carbonaceous rock (limestone). Measuring the microrelief is one of the most effective prospecting techniques in these conditions. A microrelief, or rather a Digital Elevation Model, is really only a precise topographic map; although due to its testimonial value in archaeological interpretation, I consider it a prospecting technique. Interpretation of archaeological remains is based on observing small topographic differences in the formation of the surface at a settlement (Fig. 19 and 20).

The measured values of the vertical gradient of the magnetic field (Geoscan FM36) were between -30 nT/m in +40 nT/m. The values of the magnetic susceptibility of the bedrock and the pedologic horizons at the archaeological site must be known for an interpretation of the magnetic anomalies that result from induced magnetization. The mean...
The value of the apparent magnetic susceptibility (Kappapameter KT-5) of limestone is $0.018 \times 10^{-3}$ SI for 22 measurements. The mean value for the same number of measurements of noncontaminated soil samples is $0.12 \times 10^{-3}$ SI. This means that the ground is 6 times more magnetic than the limestone geologic foundation. Such a contrast in the magnetic susceptibility can, in addition to the unlevel morphology of the terrain and the low lying limestone geologic foundation, cause relatively strong magnetic anomalies of a similar size as the amplitude of induced magnetization on archaeological structures.

Figure 18 depicts the negative gradients in blue and the positive gradients in red. The positive gradients designated in red are more important for determining metallurgic activity. It is evident in all figures that the red fields are very irregular shapes and approximately equally distributed throughout the entire investigated area. High positive gradients are not present solely on the terraces but also along the less inclined slopes on the eastern side of the settlement. I am of the opinion that they are magnetic anomalies resulting from the combination of all the magnetic fields in the archaeological cultural layers, as well as magnetic anomalies resulting from...
natural factors. As we are primarily interested in the strong thermoremanent type of magnetization, in the instance of metallurgic activity, I chose to display the distribution of only positive gradients, those higher than +5 nT/m. The number of anomalous regions reduced greatly in this instance, although they are still numerous. As the magnetic anomalies are strong, they are probably a thermoremanent type of magnetization resulting from metallurgic refuse products or from some smaller structures that incorporate the thermoremanent type of magnetization (refuse products - pieces of slag). Almost all strong magnetic anomalies are situated along the outer edge of the leveled surfaces, or terraces. This corresponds with the postulation that the leveled surfaces, or smaller terraces, are suitable for habitation as well as for preserving the archaeological cultural layers; however, we cannot exclude the possibility that we are dealing with the topographic effect of a folding terrace slope, and thus the limestone could be near the surface or even exposed.

The purpose of measuring the microrelief is to enable a depiction of even the smallest morphologic unit upon an archaeological site, thus permitting a determination of the archaeological remains on the basis of the surface configuration. The larger archaeological remains, such as ramparts, ditches, communication ways and terraces, represent the target objects for measuring the microrelief. Mapping the differences in height could be, in this respect, considered an independent prospecting method used for determining the archaeological morphologic shape of a site. At the same time, this type of map also serves as a precise topographic map for all other geophysical methods; for example, it is used for recognizing...
magnetic anomalies resulting from the so-called -topographic effect- (see Mušič, Orengo 1998, 178-179, Fig. 16).

Topographic features that are significant for archaeological interpretation are designated on Fig. 19. I classify the following characteristic morphologic forms:

Distinct positive topographic forms representing the remains of a prehistoric and/or Late Roman rampart can be traced around the settlement. It is a closed rampart that runs around the outer edge of the settlement directly along the line where the natural terrain turns into a steep slope facing outwards. The rampart is discontinued only along the eastern and western part (Fig. 19: the western and eastern entrance into the settlement). These discontinuations are situated right at today’s entrance into the settlement, although the topography of the terrain indicates that communications in prehistory and/or the Late Roman period ran along the same direction and through the entrances situated just as they are today. The rampart divides into two, such that the inner part extends parallel with the outer one along the northwestern segment.

Throughout the settlement smaller and larger segments were leveled; I have termed these segments as -terraces-. Some of the terraces were probably naturally leveled, while some of them were probably man-made. The purpose terraces served within the settlement is unclear, although most likely they were meant to level the karstic limestone geologic foundation so as to gain housing surface. It is less likely that the terraces were used for agricultural cultivation purposes. Furthermore, thicker archaeological cultural layers can be anticipated along the -terraces-. It can be concluded on the basis of the above mentioned that the leveled surfaces, or terraces, are important indications of archaeological cultural layers.

Fig. 20: Ajdovski Gradec near Bohinjska Bistrica. Pedosequences on hard carbonaceous rock. The Digital Elevation Model showing analytical hill shading and the positions of georadar profiles in area A, which covers the flat plateau atop the settlement and area B, where the profiles traverse the prehistoric rampart.

An almost entirely leveled plateau is situated atop the settlement and marked off by a steep slope on the western side and a gentle slope along the eastern side. Architectural remains are presumably situated on the plateau, or in the near vicinity. The Digital Elevation Model is almost completely flat in the northern part of the plateau where there is currently a clearing. The southern part is overgrown with thick vegetation and it is morphologically quite unlevel. The map of the microrelief reveals forms similar to architectural remains (Fig. 19: architectural remains/basic geology). It should be emphasized that conclusions based solely on the morphology of the terrain can be misleading.

A Digital Elevation Model must first be created for these types of topographically unlevel sites to enable execution of the georadar method. Only in this manner, corresponding to the surface shapes, can the georadar image be interpreted. One of the most evident morphological forms on almost all prehistoric hillforts is the rampart (Fig. 19; 20 and 21). As we wish to evaluate the potential of georadar investigations for detecting remains such as prehistoric ramparts, we traversed a segment of the rampart along the southeastern side of the settlement with a few profiles (Fig. 20 and 21). Distinct radar reflections in the shape of a hyperbola were determined along the edge of the plateau where the terrain falls into a steep slope;
they could be the result of a large mass of rock material corresponding to the rampart or perhaps they are reflections from the karstic limestone foundation. The same shapes also continue into the settlement (Fig. 22).

**Škocjan (Fig. 23)**

The suitability of geophysical prospecting was tested at the prehistoric hillfort at Škocjan (Fig. 23) so as to evaluate the archaeological poten-
tial of this type of site situated upon a karstic geologic foundation. The resistivity method was applied using the Twin Probes (Geoscan RM15) instrument, as well as magnetometry using the Fluxgate gradiometer FM36 (Fig. 24). Due to the variable morphology of the terrain, a microrelief was mapped upon which the results from the magnetometry were also displayed (Fig. 25), so as to correct the so-called -topographic effect- resulting from the combined effect of the contrast in the magnetic susceptibility between the weak magnetic limestone geologic foundation and the strong magnetic underground variegation and the configuration of the surface. No data directly applicable for archaeological interpretation was attained using the resistivity method. Nonetheless, these data are indirectly significant as they enable us to determine, in addition to the microrelief, the changes in the morphology of the karstic bedrock under the surface, which were furthermore applied in the interpretation of the magnetometry.

Certain data was attained in this manner, which we consider significant for evaluating the potential of geophysical investigations on prehistoric hillforts throughout the Karst region. Transverse linear anomalies from the vertical gradient of the magnetic field, which are at least partly the result of terracing in the past, are evident on the magnetogram (Fig. 24) in the lower half of the diagram. Very distinct positive magnetic anomalies were detected up and to the left, most likely the consequence of thermoremanent magnetization of bricks.

Transverse linear anomalies are partly the result of the -topographic effect- in places of greater level differences, which can be clearly seen in the diagram showing the microrelief as well as the
magnetometry (Fig. 25). This could be indicative of natural forms or of sub-recent terracing. In addition to these magnetic anomalies, numerous other linear anomalies which cannot be connected to the configuration of the surface or the bedrock are evident in Figure 24. These lines could be the result of terracing in the archaeological past. Strong magnetic anomalies (Fig. 24 and 25) (architectural remains?), most likely resulting from thermoremanent magnetization of bricks, were measured on entirely level ground with relatively lower values of apparent electric resistivity than other parts of the terrain; consequently, the -topographic effect-can be eliminated in this instance.

Fig. 24: Škocjan. Pedosequences on hard carbonaceous rock. Linear anomalies, visible on the lower half of the magnetogram, are probably the result of terraces, at least in part. Very strong positive magnetic anomalies, most likely the result of thermoremanent magnetization of bricks, were also measured in the upper left hand corner (architectural remains?).

Sl. 24: Škocjan. Pedosekvenca na trdih karbonatnih kamninah. Linearne anomalije v spodnjem delu slike so verjetno vsaj deloma rezultat terasiranja v arheološki preteklosti. Močna termoremanentna magnetizacija levo zgoraj je posledica arhitekturnih ostal in iz opeke (arhitekturne ostaline??).

Fig. 25: Škocjan. Pedosequences on hard carbonaceous rock. Magnetic anomalies resulting from the so-called -topographic effect-can be discerned on the combined depiction of magnetometry and the Digital Elevation Model.

Sl. 25: Škocjan. Pedosekvenca na trdih karbonatnih kamninah. Na kombiniranem prikazu magnetometrije in digitalnega modela reliefa lahko izločimo magnetne anomalije, ki so posledica t.i. -topografskega efekta.
As the results from geophysical prospecting on Cvinger near Meniška vas (Fig. 26) have already been presented in detail elsewhere (Mušič, Orengo 1998, 157-186), only select determinations important for evaluating the potential of magnetometry and the magnetic susceptibility for detecting prehistoric ironworks industrial zones, or rather an ironworks smeltery complex with a primitive smelting furnace for extensive attainment of iron or the karstic bedrock, shall be summarized in this article. The primary characteristic of such industrial zones are metallurgic refuse products in the shape of blocks of underground slag found in larger and smaller underground pits (see: Smekalova, Voss, Abrahamsen 1993, 83-103).

We succeeded in delimiting the prehistoric ironworks smeltery complex (Fig. 27) using geophysical investigations. Based on the size of the entire industrial zone and the number of blocks of underground slag, the hypothesis concerning the smeltery furnaces used for extensive ironworks metallurgic processes was thus indirectly confirmed. These furnaces were constructed to be used only once.

It was also determined that the three-dimensional magnetic modeling method is useful at such archaeological sites for a precise quantitative interpretation. I used the Magpoly (USGS) computer...
The determination that the ironworks smeltery complex could be delimited also by mapping the apparent magnetic susceptibility using even less sophisticated instruments than for instance a Kappameter KT-5 was also significant.

As concerns magnetometry prospecting at similar sites in the Dolenjska region, it is also important that this so-called -topographic effect-does not affect the magnetometry results while carrying out prospecting at ironworks smeltery complexes.

PEDOSEQUENCES ON SOFT CARBONACEOUS ROCK

Groblje near Buče (Fig. 28)

The results from geophysical investigations at the site of the Roman villa at Groblje near Buče, where A. Vogrin (1990), ZVNKD Celje (the Institute for the Protection of the Natural and Cultural Heritage, Celje), conducted rescue excavations, are published in numerous articles (Mušič 1994, 9-19; 1994-1995, 59-72; 1996, 83-137). I have limited this article to emphasizing select facts important for evaluating the suitability of geophysical investigations on pedosequences of soft carbonaceous rock. Roman walls of a provincial villa, preserved only in part and discovered during excavations are consequential for an evaluation of the potential of geophysical investigations. Only the foundations, constructed using local stone (Miocene sandstone, sandy marl and limestone conglomerates), were relatively well preserved. They are situated at a depth of 40 cm on the northern side, and somewhat deeper (up to 70 cm) on the southern side. The width of the walls, or rather the foundations, is approximately equal throughout measuring 60 cm.

The ground on soft carbonaceous rock (marl) is relatively thick and lacking of a thickly grained stony structure due to the rapid rate of decay. Consequently, pedosequences on soft carbonaceous rock can be treated as a homogeneous and isotropic medium as concerns geophysical investigations. The results from geoelectric mapping and magnetometry precisely confirm this. To a large degree only the foundations of the wall, lying up to 70 cm deep, are preserved, nonetheless the results from geoelectric mapping are quite clear (Fig. 29); likewise are also the magnetometry results (see Mušič 1994; 1996 and 1997). This is somewhat surprising as the architectural remains are built of local stone, usually indicative of a weak contrast...
with the ground, a consequence of the same types of stone decaying.

PEDOSEQUENCES ON CLAYS AND LOAM

Grafendorf (Austria)

As mentioned already introductorily, one of the guiding fundamentals of geophysical prospecting research is the application of as many diverse geophysical techniques at the same archaeological site as possible. To portray the complementarity of georadar investigations, magnetometry and geoelectric mapping only one of the geophysical profiles was used for the Roman archaeological site at Grafendorf in Austria (Fig. 30 and 31), as the research will be published in full elsewhere. I allowed myself this one exception as archaeological excavations have already been carried out there to confirm this type of interpretative procedure. The aim was to suitably illustrate this segment of geophysical investigations as it will serve as a guiding principle in planning future archaeological prospecting. E. Pochmarski from the Department of Archaeology, University of Graz, conducted the archaeological project at the Grafendorf site. I divided the geophysical profile into several parts such that they clarify the archaeological context of the anomalies in the physical fields (Fig. 31). I am thus introducing the concept of anomaly associations in the physical fields which I substantiate on the basis of the general -geophysical image- of the region. This approach enables interpretations founded on anomalies in various physical fields at the same point (e.g. a wall) or within a region (e.g. ruins).
The border between areas 1 and 2 represents the edge of the archaeological site in its strictest meaning, or rather the limit to which the Roman architectural remains extend.
**Area 1** (from 0 to 7 m). This area is situated beyond the boundary of the archaeological site. Only weak reflections from the direct horizontal reflector are visible on the radar shot. I believe these reflections are the result of the soil stratification due to contemporary use of the ground for agricultural purposes (the border of arable land) and for natural pedogenetic factors.

**Area 2** (from 7 to 12.5 m). A very well-defined reflection between 9.5 and 10 m is the result of a shallow lying wall. Two highly resistive anomalies and negative gradients of the vertical component of the magnetic field were also measured in this same place. The positioning of the prods on both anomalies correspond precisely with the well-defined radar signal. Otherwise, the highly resistive anomalies extend from 6.5 to 12.5 m. The values are somewhat lower than those above the wall, however they are still higher than the background measurements. It most likely represents the echo of the layer of ruins in the direct vicinity of this wall. In view of the negative gradient of the magnetic field, I believe that it is a stone wall with low magnetic susceptibility. The material
the resistive anomalies were determined resulting from the ruins; this confirms the supposition that it is chaotic, stony ruination material.

**Area 3** (from 12.5 to 20 m). Reflections were detected on the georadar profile in the layer that toned (from 12.5 to 17 m), as well as reflections in the irregular layers (from 17 to 20 m). The values of electric resistivity in these places are slightly higher than in the background. Very high positive gradients of the vertical component of the magnetic field above the layer that tones indicate ruination layers with high magnetic susceptibility, characteristic of ceramic objects. The archaeological context of magnetic anomalies is suggestive of a layer of tiles. A weak radar reflection representing the echo of a poorly preserved partition wall was also measured in the same area. A weak, highly resistive anomaly and a well-defined negative gradient of a magnetic field were measured here. On the basis of these data I determined the existence of a partition wall built of stone with low magnetic susceptibility. A negative gradient of the vertical component of the magnetic field was measured above the reflections from the irregular layers, thus indicating that the layer is most likely stone ruins.

**Velike Malence** (*Fig. 32*)

A Roman archaeological site is situated north-east of Velike Malence, or rather in the direct vicinity of the St. Martin church (*Fig. 32*). Excavations conducted by P. Petru (Petru 1970-1971), geoelectric mapping carried out in 1986 by Andy Waters from the University of Bradford, UK, as well as other types of archaeological data attained from field surveys and probe excavations, have all contributed to the knowledge that relatively well preserved Roman architectural remains lie beneath the surface. Extensive rescue excavations were carried out by Ph. Mason and U. Bavec in 1993, which enabled a comparison between the results from geophysical investigations and the discovered architectural remains on at least a smaller part of the research area (see Mušič 1996, 106-112).

Determinations influential upon the evaluation of the potential of geophysical investigations on pedosequences of clays and loam can be summed up as follows:

The results from the resistivity method are very good under certain conditions (*Fig. 33: A*). Numerous linear, highly resistive anomalies due to walls and/or foundations, ruination layers and stone enclosures can be traced (see Mušič 1996, 112-113).
The magnetometry results obtained using the Fluxgate gradiometer FM36 instrument were generally less distinct than from geoelectric mapping. This is due to the small contrast in the magnetic susceptibility between the walls and the soil in which they are situated. Entirely the same can be said of the measurements of the total magnetic field using the proton magnetometer (Geometrics G819). Nevertheless, lines with weak negative gradients of the vertical gradient of the magnetic field, resulting from the lower susceptibility of the walls, can still be traced (Fig. 33: B). In addition to the low magnetic anomalies which are the result of the difference in the induced magnetization, a few more areas with strong thermoremanent magnetization characteristic of brick are also evident on Figure 33: B (see Mušič 1996, 111-115).
Čatež along the Sava (Fig. 34)

This site, similar to the Roman site at Velike Malence, is situated on pedosequences of clays and loam; good results were thus anticipated primarily using the resistivity method. The architectural remains of a Roman structure were successfully delimited applying this method (Fig. 35: A). The strong contrast between the apparent resistivity is the result of an essentially clay foundation which is humid and very conducive, and the well preserved architectural remains are situated directly beneath the surface and they represent a medium with very high resistivity. A flat anomaly with high values of resistivity is located within the architectural structure (Fig. 35: A); with no distinct configuration, it could perhaps be the effect of the ruination layers of ceramic tiles or a hypocaust. Two thin lines were discerned on the southern and eastern side, their resistivity values
were somewhat higher than the background (Fig. 35: A). They could represent contemporary architectural remains (wall) or perhaps modern ditches with infrastructures within.

Here the magnetometry results present clearly visible linear anomalies on the eastern and northern side of the structure (Fig. 35: B). Weak negative gradients were measured in the direction of both lines, which means that the magnetic susceptibility is somewhat lower than the background in these areas. Consequently, the magnetometry in these areas can be interpreted similar to that applying geoelectric mapping. Architectural remains (walls) with lower magnetic susceptibility than the background are a possibility. Similar results were also attained during magnetometric investigations at other archaeological sites in the vicinity (e.g. Velike Malence; Mušič 1996, 105-120). The highest positive gradients of the magnetic field were measured within the structure (Fig. 35: B and Fig. 36), which is indicative of a thermoremanent type of magnetization of bricks (roofing tiles?). The negative gradients follow in lines, indicating the directions of the stone walls (Fig. 35: B and Fig. 36).
Ilovca near Vransko (Fig. 37)

The archaeological data significant for evaluating the results from geophysical investigations are summarized according to I. Lazar’s publication (1997, 159-164), where she presents the results from archaeological excavations carried out in 1995. The time span of this Roman archaeological site, ranging from the end of the 1st through the entire 2nd century and to the first quarter of the 3rd, was determined on the basis of material finds and Roman coins. Fifty percent of the coins discovered are attributed to the second half of the 2nd century. This is considered evidence substantiating that the height of activity in this area was during this time. The author continues and claims that the archaeological layers were destroyed by floods to the extent that the stratigraphy of the cultural layers could not be reconstructed precisely. Along the southern side of the excavated area the walls of limestone and pebbles were extremely well preserved. Limestone quarry stones were red on the inside, the effect of being exposed to high temperatures. Two brick kilns were discovered during excavations of the central part.

Kiln 1 - The western kiln (Fig. 39: W) was better preserved. It was constructed using bricks with square and rectangular cross-sections. Only two of the original five brick vaults were preserved. The space was filled with fragments (ceramic?) of various forms. The channel was built from large pieces of brick with rectangular cross-sections and inverted tiles. Stamps of the *Legio II Italica* were discovered on the bricks used for the construction of the kiln.
Kiln 2 - The eastern kiln (Fig. 39: E) was situated somewhat higher than the western one and was thus also more exposed to destruction due to cultivation. The brick vaults of the kiln were entirely destroyed. On the basis of the foundations it was determined that the kiln was constructed with seven vaults. The channel and the central part of the kiln was filled with various pieces of brick. The construction was otherwise quite similar to that of the adjacent kiln.

The walls enclosing the kilns were 100 cm wide and preserved to a height of 70-90 cm. All four corners conclude in a circular shape.

To a large degree, only the location of the gravel fill was determined using the Twin probes resistivity method. The range of values of the apparent resistivity of the natural background is so wide on this type of pedosequence that it incorporates all types of archaeological remains. Consequently, only characteristic shapes of anomalies can serve
Fig. 36: Čatež along the Sava. Pedosequences on clays and loam. The gradient of the vertical component of the magnetic field (Geoscan FM36) within the area of the Roman architectural remain (n = 4200, m = -0.8 nT/m, s = 5.9 nT/m, min = -48 nT/m, max = +75 nT/m).

Fig. 37: Ilovca near Vransko. Pedosequences on gravel and sand. The geodetic map of the highway segment near Vransko including the investigated area where a Roman brick-kiln was discovered using magnetometry.
as a foundation for their determination. In this instance, highly resistive anomalies, undoubtedly resulting from the architectural remains of the Roman kilns (Fig. 38: A), were measured only in...
select areas. All other highly resistive anomalies were entirely the result of natural causes.

Strong positive gradients of the vertical component of the magnetic field were measured above the clay architectural elements within the two-part brick kilns (Fig. 38: B; 39; 40; 41 and 42) with high magnetic susceptibility and a thermoremanent type of magnetization. The highest amplitude of positive gradients of the magnetic field above the kiln is 82 nT/m (Fig. 42). The walls are built of pebbles with very low magnetic susceptibility. The lowest amplitude of the gradient of the magnetic field above the stone walls is -30 nT/m. A preserved, or rather -frozen-, remanent magnetization dating to when the kiln cooled down the last time is present within the architectural elements of the interior of the kiln. I estimate the declination (D) in the thermoremanent magnetization of the kiln to be -2°. A declination evaluated in this manner is of course quite superficial and cannot be regarded in terms of magnetic dating. The magnetic anomaly is a vector sum of the induced and remanent magnetization, where the direction of the remanent magnetism could be different from that when the kiln was still functioning due to the viscosity of magnetization. I have cited this example as a point of interest, as the above mentioned manner of determining the declination of thermoremanent magnetization corresponds to the data Marton (1998, 74) cited for the second half of the 2nd and first half of the 3rd centuries.

A relatively strong magnetic anomaly (min = -26 nT/m, max = +23 nT/m) was measured north of the brick kiln in a zone approximately 5 m wide and more than 10 m long (Fig. 38). A refuse pit filled with fragments of brick was discovered during archaeological excavations. A smaller natural depression was supposedly filled with brick,
Fig. 41: Ilovca near Vransko. Pedosequences on gravel and sand. A three-dimensional depiction of the effect of thermoremanent magnetization of the Roman brick kiln.

Sl. 41: Ilovca pri Vranskem. Pedosekvenca na produ in pesku. Tridimenzionalni prikaz učinka termoremanentne magnetizacije antične opekarske peči.

Fig. 42: Ilovca near Vransko. Pedosequences on gravel and sand. The vertical gradient of the magnetic field above the eastern part of the Roman brick kiln in the direction of the profile A-B (Fig. 41).

presumably to level the ground. Considering that it is a deposit of discarded ceramic artifacts, an appropriate interpretation of this structure, in an archaeological context, is as a refuse pit. The depth of the refuse pit in the western profile is 90 cm at most, with a width of 350 cm.

CONCLUSION

The determination that good results for geophysical investigations can be expected only in the instance that various geophysical techniques are applied at each individual archaeological site, as well as diverse types of instruments functioning on the basis of different physical principles, is incontestable. I am thus introducing the concept of anomaly associations in the physical fields, which enable a more precise interpretation of the -points- of targeted objects (e.g. a wall) as well as of surfaces that represent a region serving a particular purpose in the archaeological past (e.g. ruination layers incorporating a layer of tiles = the inside of a house).

I consider the classification of the natural environment into regional system (=pedosequences), first established by Stritar (1990), the most appropriate also for describing the suitability of geophysical investigations subject to the natural circumstances.

Pedosequences on soft carbonaceous rock (marl) (Groblje near Buče) and pedosequences on clays and loam (Čatež along the Sava) are the most suitable for geophysical investigations. Both these types are relatively homogeneous and isotropic mediums. The soil is deep and lacks any thick stony aggregate. The detectability of archaeological remains is very good for all used geophysical techniques.

Pedosequences on noncarbonaceous rock in Slovenia are still, as of yet, poorly investigated. Only one site was researched on flysch stone presenting excellent results from geophysical prospecting (Ajdovščina above Rodik). Results attained on acidulous magmatic rock at similar archaeological sites abroad (Mont Beuvray, France) were less favorable. The resistivity method produced the worst results on these types of pedosequences. This is partly due to the thick layer of Roman ruins and partly the consequence of thick decaying layers with magmatic rock-disintegration. Magnetometry and apparent magnetic susceptibility proved the most useful for detecting industrial workshops (e.g. ironworks) in such surroundings with low susceptibility of the geologic and pedologic background. As architectural remains are usually made of the same stone as the basic geology, the contrast in the magnetic susceptibility is too small to detect individual walls. I believe that the georadar method provides the only prospecting method capable of detecting architectural remains under these types of circumstances.

I base my evaluation of geophysical investigations on pedosequences of hard carbonaceous rock on hill-top settlements that are situated on karstic limestone foundations (Ajdovski gradec near Bohinjska Bistrica, Škocjan. Cvinger near Meniška vas). Due to the large contrast in the magnetic susceptibility between the limestone geologic foundation and the various soils rich with iron minerals, as well as the unlevel topography of the karstic geologic foundation, the so-called -topographic effect- should not be neglected. Geoelectric mapping similar to that on pedosequences of gravel and sand is also used here for determining geologic forms. Magnetometry serves well in these circumstances primarily for detecting objects within industrial workshops with a thermoremanent type of magnetization (e.g. kilns and smelting furnaces) (Cvinger near Meniška vas), smaller deposits of metallurgic refuse products (Ajdovski gradec near Bohinjska Bistrica), architectural remains made of brick and traces of terracing (Škocjan).

The most unfavorable environment for geophysical investigations is on pedosequences of gravel and sand (Ilovca near Vransko). The rapid alternation of sandbanks in such an environment elicits an exceedingly wide range, and also extremely variable, of apparent resistivity. Consequently, the use of the resistivity method is very limited. Better results are usually attained in such environments using magnetometry and georadar. The results from geoelectric mapping are indirectly useful as they serve well for demarcating changes in the geologic foundation; this data is often significant for distinguishing geologic and archaeological information on magnetograms and radar diagrams.

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**Geofizikalna prospekcija v Sloveniji:**

**UVOD**


Sprejemamo pristop, podobnega sestavljanju večkanalnih podatkov o anomalijah v fizikalnih poljih. Pedološke osnove, ki jih je za geoelektrično upornostno metodo uporabimo več različnih geofizikalnih tehnik. Trenutno uporabljamo magnetometrijo s pretočnim gradiometrom in protonskim magnetometrom. V tem kontekstu opredeljuje ta sistem in hkrati to sprejemamo pristop, podobnega sestavljanju večkanalnih podatkov o anomalijah v fizikalnih poljih.)


Upraba pristopa, podobnega sestavljanju večkanalnih satelitskih podatkov v kompozitno slike, pri čemer namestimo satelitskih podatkov omogočamo podatkovne nize arheološke prospekcije. Tak pristop zagotavlja boj izpovedno interpretacijo.
avtor opredeljuje kot orodje za lociranje ali ovrednotenje, njenja razširjena uporaba v začetnih fazah načrtovanja arheoloških raziskav pa jo je ves čas vodila v tej smeri. Isti avtor nadalje ugotavlja, da bi morali možnosti umeščanja geofizikalnih metod v celotni spekter arheoloških analiz obravnavati bolj pogosto in bolje razložen. V tej sicer dobrotavnih in illustrativnih izjav, ki verjetno odraža splošno videnje geofizikalnih raziskav v arheološki stroki, je avtor sprejel nekatere pomembne raziskave, ki so bile narejene na arheoloških materialih in so imela za cilj razumevanje rezultatov geofizikalnih raziskav (glej Carr 1982). Po mojem mnenju lahko z laboratorijsko analizo, rentgensko difraktometrično analizo, donošimo centre določenih aktivnosti v arheološki preteklosti. V ta namen uporabljamo sejalno analizo, rentgensko difraktometrično metodo, diverentno termično analizo in laboratorijske meritve, ki so bile narejene na arheoloških materialih in so imela za cilj razumevanje rezultatov geofizikalnih raziskav (glej Carr 1982). Po mojem mnenju lahko z laboratorijsko analizo, rentgensko difraktometrično analizo, donošimo centre določenih aktivnosti v arheološki preteklosti. V ta namen uporabljamo sejalno analizo, rentgensko difraktometrično metodo, diverentno termično analizo in laboratorijske meritve, ki so bile narejene na arheoloških materialih in so imela za cilj razumevanje rezultatov geofizikalnih raziskav (glej Carr 1982).


Ostala polja so izbrane in urejena tako, da je tabela uporabna tudi za ugotavljanje ocene potenciala geofizičnih raziskav pri odkrivanju različnih tipov arheoloških ostalih v različnih naravnih okoljih. Za opisovanje naravnega okolja sem uporabil razdelitev ozemlja Slovenija na krajinske sisteme (združbe tal, pedosekvence), ki jo je leta 1994 predlagal SDB varstvo (English Heritage Geophysical Survey database, SDB).

Ostala polja so izbrane in urejena tako, da je tabela uporabna tudi za ugotavljanje ocene potenciala geofizičnih raziskav pri odkrivanju različnih tipov arheoloških ostalih v različnih naravnih okoljih. Uporabnost te razdelitve vidim predvsem v tem, da omogoča združevanje podatkov o arheoloških najdiščih s informacijami o naravoslovni podolgovosti ter podatkih o naravnih okoljih v naravoslovni podolgovosti.

Prvi temelje baze podatkov geofizičnih raziskav je po mojem mnenju odpis takšne baze, ki v največjih primerih omogoča dostop do vseh podatkov o arheoloških najdiščih, ki so se v različnih naravnih okoljih v Sloveniji pojavila. V tem primeru je uporaba podatkov o naravoslovni podolgovosti praviloma pomembna za oceno ustreznosti geofizičnih raziskav.

OCENA USTREZNOSTI GEOFIZIKALNIH TEHNIK

V idealnih razmerah narekujejo izbiro najustreznejše geofizične tehnike samo ciljini arheološki objekti, ki jih želimo locirati. Dejansko je tako, da pri geofizični prospekciji ciljini arheološki objekti prispevajo le večji ali manjši del pri odločitvi o najustreznejši geofizični tehniki. V tem kontekstu imenujemo anomalije v fizikalnih poljih, ki so posledica prisotnosti ciljini arheoloških obrednih signalov, vse ostale nepričakovane anomalije v fizikalnih poljih, ki so posledica češčenja drugih faktorjev, pa imenujemo šum. Najustreznejše izbire ne predstavlja geofizična tehnika, pri kateri je pričakovana ampliduta signala največja, temveč tista, pri kateri je največje razmerje signal proti šumu.

Geofizične raziskave običajno izvajamo na terenu, za katerega vsaj približno vemo, kakšen je njegov arheološki potencial, kar se tiče tega tipa arheoloških ostalih, ki jih lahko zaznamo z geofizičnimi tehnikami. Ciljni objekti so običajno različni elementi naselbene strukture (zidovi, ruševinske ploščaste, odpadne jame, stojke, jarki, razne obrtne delavnice, kurišča in stratigrafske sekvence z znaki antropogene dejavnosti).

Oceno ustreznosti geofizičnih tehnik podajam na način, da je v bistvu samo nekoliko prijema in dopolnjenja različica predlog, ki jih je izdelal Bevan (1996a) za predstavitev rezultatov tega tipa raziskave, ki je v bistvu samo nekoliko prijema in dopolnjenja različica predlog, ki jih je izdelal Bevan (1996a) za predstavitev rezultatov tega tipa raziskave. Ti rezultati niso bili objavljeni, so pa načeloma dostopni širši javnosti. Po moji oceni je bivši razlog za majhno število tovrstnih raziskav močen trend, da se za tovrstno raziskavo zaveda večja število ljudi.

Za ilustracijo ocene ustreznosti geofizičnih tehnik v različnih naravnih okoljih je bilo bilo sicer veliko primanjkov, ki jih je tudi v bistvu vključoval, da se je prihajalo do podatkov, ki jih uporabljamo za oceno ustreznosti geofizičnih tehnik. Ti rezultati niso bili objavljeni, so pa načeloma dostopni širši javnosti. Po moji oceni je bivši razlog za majhno število tovrstnih raziskav močen trend, da se za tovrstno raziskavo zaveda večja število ljudi.

PRIMERI GEOFIZIKALNIH RAZISKAV

Za ilustracijo ocene ustreznosti geofizičnih tehnik v različnih naravnih okoljih, ki jih omogočajo različne tehnike, se je bilo prihajalo do podatkov, ki jih uporabljamo za oceno ustreznosti geofizičnih tehnik. Ti rezultati niso bili objavljeni, so pa načeloma dostopni širši javnosti. Po moji oceni je bivši razlog za majhno število tovrstnih raziskav močen trend, da se za tovrstno raziskavo zaveda večja število ljudi.

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Arheološka najdišča, ki jih obravnavam v članku, so sl. 1 raziskav na ostalih arheoloških najdiščih sem izbral tako, da loških najdiščih v strokovni literaturi. Rezultate geofizikalnih dejavnikov predstavljajo resno omejitev za večino geofizikalnih prazgodovinskimi arheološkimi kulturnimi horizonti. Vsi ti za geofizikalne raziskave, kot so na domala vseh podobnih naravnih danosti. Prazgodovinska gradišča v južni Angliji so v gradini in kasnoantičnih utrdb se na te podatke nistan organiziranost naselbin. Pri svojih raziskavah prazgodovinskimi gradišči in kasnoantičnih višinskih utrdb sem izbral tako, da najbolje ilustrirajo nekatere posebnosti krajskega sistema, na katere moramo biti pozorni pri načrtovanju prospekcije. Arheološka najdišča, ki jih obravnavam v članku (sl. 1), so razvrščena glede na geološko-pedološko podlagi: Pedosekvenca na nekarbonatnih kamninah.

- Ajdovščina nad Rodikom (1)
- Pedosekvenca na trdih karbonatnih kamninah
- Ajdovski gradec pri Bohinjski Bistrici (2)
- Skočjan (3)
- Čvijner pri Meniški vasi (4)
- Pedosekvenca na mehkih karbonatnih kamninah
- Groblje pri Bučah (5)
- Pedosekvenca na glinah in Ilovcah
- Grafendorf (Avstrija)
- Velike Malence (6)
- Čatež ob Savi (7)
- Pedosekvenca na prodru in pesku
- Ilovca pri Vranskem (8)

Pedosekvenca na nekarbonatnih kamninah

Ajdovščina nad Rodikom (sl. 2)

arheoloških objektov, kot so npr. feromagnetni železni predmeti in ferimagetni keramični objekti (npr. žgalne peči za kerami-ko, metalske taline peči, opeka, strešniki itd.) (Heathcoe, Aspinall 1981, 61-70; Papamarinopoulos, Tsokas, Williams 1985, 483-490; 1986, 111-112). Območja s termoremanentno magnetizacijo (sl. 5) smo raziskali tudi s protonskima magneto-
rometra Geometrics GSM 819 in GemSystem GSM19 (sl. 7 in 8). Razdalja med merilnimi točkami je bila v obeh smerih enaka, in sicer 1 m oz. 0.5 m.

*Magnetna susceptibilnost*

Navidezno magnetno susceptibilnost smo merili s terenskim instrumentom Kappamerter KT-5 (Geofyzika, Brno). S tem instrumentom merimo susceptibilnost zemljišča samo do globine približno 3 cm. Na ta način ugotavljamo spremen-
ljivost magnetne susceptibilnosti, ki je v glavnem posledica spremembe sibko magnetnih železovih mineralov v bolj ma-
gnetne oblike pri povši pri temperaturi zaradi uporabe ogne.

Magnetna susceptibilnost je sicer samo fizikalna veličina, ki je definirana kot količnik med izmerjeno intenziteto magnetiza-
cije in induciranjo magnetnim poljem, ki je v tem primeru
Zemljino magnetno polje. Glede na to sodijo meritve magnetne
susceptibilnosti enako kot magnetometrija med magne-
tne metode. Meritve magnetne susceptibilnosti različnih materialov,
ki jih isčešmo pri magnetni prospekciji, služijo običajno le kot
pomemben vir informacij o magnetnih lastnostih ciljnih
objektov in medij, v katerem se nahajajo. Meritve magnetne
susceptibilnosti na površjo so se pri geofizikalni prospekciji
v arheologiji uveljavile kot samostojna prospekcijska tehnika
med merilnimi točkami je bila v obeh smerih enaka (2 m).

Zato za takšno (razromera veliko) razdaljo med merilnimi
tockami smo se odločili zaradi prihranka pri terenskem času.

Zelo visok pozitivni gradient na območju 2 (sl. 5 in 6) kaže
na močno termoremanentno magnetizacijo v jugovzhodnem vogalu
območja, ki jo lahko v arheološkem kontekstu interpretiramo kot
žalno oz. talino peč ali kovaško ognjišče. Termoremanentna
magnetizacija je posledica konverzije sibkomagnetnih železovih
mineralov v bolj magnetne oblike pri visokih temperaturah. Glede
na pravilno obliko anomalije sklepam, da gre za dobro ohranjen
objekt oziroma ognjišče ali opeka. Zato je v tem primeru
uporabljena pri interpretaciji magnetometrije. Pri sibkom
susceptibilnosti na površju poslužijo kot pomemben vir informacij o magnetnih lastnostih ciljnih
objektov.

**Georadar**

Pri georadarški raziskavi smo uporabili za glavno merilo
enoto instrument GSM SIR 3. Vse meritve smo opravili z
splošno na prvotnem mestu.

**Arheološki terenski pregled**

Velikost zbiralne enote pri intenzivnem terenskem pregledu
je bila 4 m² (2 x 2 m). Večino površinskih najdb predstavljajo
drobi antiki kerame (strešniki, opeka, lončenina) (za tano
razlago glej Vidrih Perko 1997, 341-358) in različni
tipi odpadnih produktov metalurgije (železarstvo). Površinski
najde smo razdelili v magnetni odlomke (lončenina, opeka,
strešniki) in odpadne produktni metalurgije. Razširjenje teh
dveh tipov najdb smo razredili s pomočjo rezultatov geofizikalnih
raziskav uporabili za opredeljevanje območij različnih aktivnosti (activity areas, use areas) v kasni anti,

**Rezultati prospekcie**

Zelo visok pozitivni gradient na območju 2 (sl. 5 in 6) kaže
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objektov.

Podobno kot s pretočnim gradiometrom (Geoscan FM36)
(sl. 6) smo tudi s protonskim magnetometrom (GemSystem GSM19)
izmerili na isti lokaciji anomalijo z visoko amplitudo
(200 nT), kar prve ugotovitve samo potrjuje (sl. 7). Severozahod-
hodno od pika anomalije (+) je bil izmerjen tudi nižji
kot magnetna anomalija (-). Pri tem moram opozoriti na
to, da je ta anomalija pravzaprav 10° od smeri geografskega
severa proti vzhodu. Močna pozitivna deklinacija kaže na to,
da termoremanentna magnetizacija močno prevladuje nad
inducirano magnetizacijo in je najverjetneje usmerjena v smeri
magnetnega polja v kasni anti, ko so prebivali z ognjišči in
je se je povečalo pod ognjiščem. Taka oblika anomalije kaže na
močan dipolni značaj, ki je posledica tremoremanentne
magnetizacije dobro ohranjenega objekta ostalim, ki je seveda
še vedno na prvotnem mestu.

S protonskim magnetometrom GemSystem GSM19 smo
dodatno raziskali še magnetne anomalije na območjih 6 in 7
(sl. 5 in 8). Podobno kot s pretočnim gradiometrom (sl. 5) smo
tudi s protonskim magnetometrom ugotovili območja z močno
termoremanentno magnetizacijo, ki najverjetneje predstavljajo


ostaline obrtnih delavnic in situ (kovačje?) (sl. 8A: 1), in nekoliko šibkeje magnetne anomalije, ki so najverjetneje rezultat deponije odpadnih produktov metalurgije (sl. 8A: 2). Skoraj popolnoma identično situacijo smo pred tem ugotovili že na območju 2 (sl. 5 in 6). Nižje magnetne anomalije so lahko posledica različno orijentiranih manjših magnetnih dipolov, ki so v tem primeru lahko kosi žlindre. S protonskim magnetometrom GeomSystem GSM 19 smo dobili boljši rezultat predvsem glede geometrije objekta s termoremanentno magnetizacijo na območju B (sl. 8B), ki kaže v tloriso jasen polkrožni presek.

Kot se izkazalo na primeru Ajdovščine nad Rodikom, je za detekcijo zidov pod debelimi ruševinskimi grobljami vode najbolj učinkovita georadarška metoda (sl. 9). Poleg tega smo to metodo uporabili tudi za dokazovanje objektov z močno termoremanentno magnetizacijo, ki se jim na osnovi magnetometrije interpretiral kot ostaline obrtnih delavnic (železarstvo?) in deponije odpadnih produktov metalurgije. Od vseh teh objektov smo dobili zelo jasne radarske odboje. Vse te ugotovitve so seveda zelo pomembne za oceno potenciala geofizikalnih tehnik na kasnoantičnih naseljih, kjer so arhi-tekturne ostaline prekrite z debelimi plastami ruševinskih grobelj. Za proučevanje urbanistične zasnove takšnih naselb in njihove stavbe dediščine je morda najbolj pomembna ugotovitev georadarskih raziskav, da zidovi nič vodno pod vrhom groblje. To pomeni, da se ne moremo izrisati natančno lokacijo tej naselbe, saj pod zrakom ni vidno in se nadaljuje globoko v notranjost naselbine, kjer prečka magnetno anomalijo s termoremanentno magnetizacijo arheoloških objektov.


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nakloni na vzhodni strani najdišča. Sam sem mnenja, da gre za magnetne anomalije, ki so vsota magnetnih polj arheoloških kulturnih plasti in magnetnih anomalij, ki so posledica naravnih dejavnikov. Ker nas pri metalurških aktivnostih zanima predvsem močan termoremanentni tip magnetizacije, sem se odlučil, da prikažem le distribucijo pozitivnih gradientov in sicer tistih, ki so višji od +5 nT/m. V tem primeru so se anomalne območja zelo skrčila, vendar so se vedno zelo številna. Ker gre za razmeroma močne magnetne anomalije, sklepam, da gre za termoremanentni tip magnetizacije odpadih produktov metalurzije oz. manjših oblik, ki vsebujejo termoremanentni tip magnetizacije (odpadni produkti-žlindre). Skoraj vse močne magnetne anomalije so na zunanjem robu izravnanih površin oz. teras. Toc ter avstrija predpostavki, da so izravnane površine oz. manjše terase primeren prostor za bivanje kot tudi za ohranjanje arheoloških kulturnih plasti vendar ne moremo izključiti možnosti, da gre za topografski učinek pregiba pobočja terase, kjer je lahko apnenec blizu površi ali celo izdanja.


Topografske oblike, ki so pomembne za arheološko interpretacijo, so označene na sl. 19. Ugotovil sem naslednje značilnosti:

- Okoli naselbine lahko sledimo izzirati pozitivni topografski obliki, ki predstavljata ostaline pragozdovinskog in/ali kasnoantičnog obzidja. Gre za sklenjeno nasip, ki poteka po zunanjem robu naselbine in je na mnenju Manja terased-terasah- prikazana debole arheološke kulturne plasti.
- Naselbeni kraj so posneti med šibko magnetno apnenčevo geološko podlago, kar kaže podobnost s keramiko pozne bronaste dobe ter ozko etnično in kulturno povezavo med prebivalci istrskih kaštelirjev, ki kažejo podobnost s keramiko pozne bronaste dobe ter ozko etnično in kulturno povezavo med prebivalci istrskih kaštelirjev.


Povsod po naselbi so manjše ali večje izravnave, ki jih imenujem -terase-. Verjetno gre za izravnanje površin terase, da so izravnane površine oz. terase pomembne indikacije za arheološke kulturne plasti.

V naselbi je vodil tudi Neumann, in sicer na mestu, kjer se območje vzdolži z območjem v starejši železni dobi pridobili podatke o rimskodobnih ostalih. Hkrati je izravna površina ali geološka podlaga. Te linije so lahko posledica termoremanentne magnetizacije opeke.

Tudi za georadarsko metodo je potrebno na takšnih površinah raziskovati v arheološki preteklosti. Močna magnetna anomalija (sl. 20 in 21). Na robu platoja, kjer se ter stom bojjujo, smo ugotovili izrazite radarske odboje v obliki hiperbol, ki so lahko posledica večjega kamennega materiala, ki pripada obzidju, ali pa gre za odboje od zakrasele apnenčeve podlage.

Na vrhu naselbe je bil prazgodovinsko gradišče, ki je merilo v obsegu 950 m in je bilo na edini položni strani obdan z obzidjem. Na površini kaštelirja so naselja obdana glistavost podgleda.

Vasi Škocjan je bilo prazgodovinsko gradišče, ki je merilo v obsegu 950 m in je bilo na edini položni strani obdan z obzidjem. Na površini kaštelirja so naselja obdana glistavost podgleda.

**PEDOSEKVENCA NA MEHKIH KARBONATNIH KAMNINAH**

**Groblje pri Bučah** (sl. 28)


**PEDOSEKVENCA NA GLINAH IN ILOVCAH**

**Grafendorf (Avstrija)**


**Območje 1** (od 0 do 7 m). To območje je najbližje ozadju arheološkega najdišča. Na georadarskem profilu so vidni šibki odboji (od 12,5 do 20 m). Na georadarskem profilu so vidni šibki odboji (od 12,5 do 20 m). Na georadarskem profilu so vidni šibki odboji (od 12,5 do 20 m). Na georadarskem profilu so vidni šibki odboji (od 12,5 do 20 m) in negativni gradient vertikalne komponente (od 7 do 12,5 m). Zelo izrazite odboji med 9,5 in 10 m je posledica plitve ležečega zidu. Na istem mestu sta bili izmerjeni tudi visokoupornostna anomalije in negativni gradient vertikalne komponente magnetnega polja. Položaj pikov obeh anomalij natančno ustrezata izrazitemu radarskemu signalu.

**Območje 2** (od 7 na 12,5 m). Zelo izrazit obdobj bi do 10 m je posledica plitve ležečega zidu. Na istem mestu sta bili izmerjeni tudi visokoupornostna anomalije in negativni gradient vertikalne komponente magnetnega polja. Položaj pikov obeh anomalij natančno ustrezata izrazitemu radarskemu signalu.

**Območje 3** (od 12,5 do 20 m). Na georadarskem profilu so bili ugotovljali obdobji od površine do 12,5 m in odboji od nepravilnih oblik, ki potrjujejo domnevo, da gre za obdobje, ki je posledica stratifikacije tal zaradi obstoječih podzemnih izolacij.

**Zgodovina** in **izobraževanje**

**Geophysical prospecting in Slovenia: an overview with some observations related to the natural environment**

**Cvinger pri Meniški vasi** (sl. 26)

Ker so bili rezultati geofizikalnih prospekcij na Cvingerju pri Meniški vasi (sl. 26) že podrobne objavljeni na drugem mestu (Mušič, Oreno 1998, 157-186), v tem članku povzemam samo nekatere ugotovitve, ki so pomembne za ugotavljanje potenciala magnetometrije in magnetne suscep-tibilnosti za detekcijo prazgoščenih izolacij v fizikalnih poljih.

**PEDOSEKVENCA NA MEHKIH KARBONATNIH KAMNINAH**

**Groblje pri Bučah** (sl. 28)


**PEDOSEKVENCA NA MEHKIH KARBONATNIH KAMNINAH**

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**PEDOSEKVENCA NA MEHKIH KARBONATNIH KAMNINAH**

**Groblje pri Bučah** (sl. 28)


**Velike Malence (sl. 32)**

**PEDOSEKENVA NA PRODU IN PESKU**

Ilovca pri Vranskem (sl. 37)

Arheološke podatke, ki so pomembni za ovrednotenje rezultatov geofizikalnih raziskav, so bili izkopani s povsem različnima raziskavam. Posamezne geoelektrične metode so bile sprožene za različne tipov magnetnih anomali. Najvišji posledica magnetnega polja so bili izmerjeni v notranjosti objekta (sl. 35: B in sl. 36), kar kaže na to, da gre za termoremanentni tip magnetizacije opeke (stresnikii?). Negativni gradient potekajo v linijah, ki nakazujejo smer kamnitih zidov (sl. 36).

Arheološke podatke, ki so pomembni za ovrednotenje rezultatov geofizikalnih raziskav, so bili izkopani s povsem različnima raziskavam. Posamezne geoelektrične metode so bile sprožene za različne tipov magnetnih anomali. Najvišji posledica magnetnega polja so bili izmerjeni v notranjosti objekta (sl. 35: B in sl. 36), kar kaže na to, da gre za termoremanentni tip magnetizacije opeke (stresnikii?). Negativni gradient potekajo v linijah, ki nakazujejo smer kamnitih zidov (sl. 36).

**Čatež ob Savi (sl. 34)**
Podobno kot antično najdišče pri Velikih Malenc se tudi ta nobah na podatkih na gлинah in Illovca, v lahko strmen v nekaj točk.


Peč 2 - vzhodna peč (sl. 39: E) je nekaj višje glede na zahodno peč in je bila zapolnjen s fragmenti (keramični)? različnih oblik. Kamnični oboki peči so bili popolnoma uničeni. Na podlagi teviljev je bilo mogoče upotrijeti, da je bila peč zgrajena v sedmih opečih. Na kanal kurišča in centralni del peči je bil do vrha zapolnjen s različnimi kosi opeke. Sicer je bila konstrukcija podobna kot pri sosednji peči. Zidovi, ki obdajajo peč so debeli 100 cm in so ohranjeni do višine 70-90 cm. Vsii struje vseh se zaključujejo v krožno obliko.

Z geoelektrično upornostno metodo elektrodnih dvojčkov so ugotovili v glavnem le položaj prodnih zasipov. Razpon vrednosti navidezne električne upornosti naravnega opeča je na tej podatkih. Tiško, da zajema tudi vse tip arheoloških opečnih. Zaradi tega lahko te izkoriščamo le na podlagi pravilnih oblik anomal. Pri tem so bile le na nekaj mestih izmerjene visokoupopornosne anomalije, ki so podzemno posledica arheoloških opečnih. Vse ostale visokoupopornosne anomalije so podzemni opeči.

Močni pozitivni gradienti vertikalne komponente magnetnega polja so bili izmerjeni nad keramičnimi arheološkimi elementi v notranjosti objekta (sl. 38: B; 39: 40, 41 in 42) z izrazito visokoupopornostjo in termoremanentnim tipom magnetizacije. Najvišja amplituda pozitivnega gradianta
magnetnega polja nad pečjo znaša 82 nT/m (sl. 42). Zidovi so izmerjali predvsem kot zanimivost, ker je takšna deklinacija na smer remanentnega magnetizma zaradi viskozne magnetizacije vsota inducirane in remanentne magnetizacije, pri čemer je tudi smer remanentnega magnetizma zaradi viskozne magnetizacije lahko drugačna, kot je bila v času delovanja peči. Ta primer navaja predvsem kot zanimivost, ker je takšna deklinacija na Madžarskem značilna za drugo polovico 3. st. (Marton 1998, 74).

V arhitekturah elementih notranjosti peči, ki so iz opeke, je ohranjena oz. -zamrznjena- remanentna magnetizacija iz časa, ko so se peč zadnjič ohladila. Deklinacijo (D) termoremanentne remanentnega magnetizma iz časa, zidovi je -30 nT/m. Zgrajeni iz prodnikov z zelo nizko magnetno susceptibilnostjo, magnetnega polja nad pečjo znaša 82 nT/m (sl. 42). Zidovi so izmerjali predvsem kot zanimivost, ker je takšna deklinacija na Madžarskem značilna za drugo polovico 3. st. (Marton 1998, 74).

Severno od opeke peči smo izmerili v pasu, širokem približno 5 m in dolgem več 10 m (sl. 38). Zidovi so izmerjali izmerjali predvsem kot zanimivost, ker je takšna deklinacija na Madžarskem značilna za drugo polovico 3. st. (Marton 1998, 74).

Globina odpadne jame v zahodnem profilu je največ 90 cm, jami je bila nasičena z vodo in v fazi intenzivnega razpadanja. Previsokim temperaturam. Večina keramičnih odlomkov v odpadni kipi je bila uporabljena kot odpadna jama. Jarek je bil zapolnjen Izkopavanja so odkrila, da gre za naravni jarek oz. depresijo, magnetno anomalijo (min = -26 nT/m, max = +23 nT/m).


ZAKLJUČKI

Nesporna je ugotovitev, da lahko pričakujemo dobre rezultate geofizikalnih raziskav le v primeru, ko na istem arheološkem najdišču uporabljamo več različnih geofizikalnih tehnik in tudi več različnih izvedb instrumentov, ki delujejo na drugačnih fizikalnih principih. Na tej osnovi vplivamo koncept združevanja analiz v fizikalnih poljah, ki omogočajo natančnejšo interpretacijo -točkovnih- ciljnih oblik. Ker je zgodovina posameznih arheoloških najdišč, ki so na zakraselih naravnih podlag in deloma iz raziskovanje ogromnešca depresij na Srednji Evropi (Ajdovščina nad Rodikom). Praviloma dobimo v takšnih okoliših s kontrastom v magnetni susceptibilnosti med apnenčevimi kamninskim podlagami in podlaga moramo uporabiti t. -topografski efekt-. Geoelektrično kartiranje podobno kot na pedosekvencah na produ in pesku tudi tukaj uporabljamo za ugotavljanje geoloških oblik. V takšnih okoliših z magnetometrijo učinkovito odkrivamo predvsem objekte obrtnih delavnic (npr. železarstvo). Ker so arhitekturne ostaline praviloma iz kamnin geološke podlaje, na simetralni podlagi in z železovimi mine-rali bogatimi vlagami v naravni okolji. Mag. Branko Mušič Oddelek za arheologijo Filozofske fakultete Univerze v Ljubljani Zavetiška 5 SI-1000 Ljubljana