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Research Article

Shallow Geophysics and Archaeoseismology – Support to Archeology in Bulgaria

Boyko Ranguelov[1, 2] *

[1]*Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria*

[2]*Bulgarian Academy of Sciences and Arts, Sofia, Bulgaria*

***Corresponding author:** Boyko Ranguelov, Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria

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Abstract

An extended review about the performance of the shallow geophysics and archaeoseismology for the archeology studies in Bulgaria is presented. The country is very rich with the archaeological sites, most of them not yet fully disclosed. During the last decade extensive application of various geophysical prospecting methods are performed before and during the archaeological diggings. Magnetometric and gravimetric measurement, electric tomography, radiometry and metal detector measurements are frequently used to solve emerging archeological tasks. The studied targets are of different type – ancient walls, buildings, fortifications and other constructions, necropolis and ovens, ancient metallurgy, metal and non-metal artefacts, tombs and graves, monetary treasures, etc. The archaeoseismology is performed for the documentation of ancient earthquakes, tsunami deposits, and other natural phenomena accompanying strong seismic events. The new discovered seismic effects on the ancient towns and temples, villages and building constructions, churches and bastions, ancient production factories (like salt extraction and masks' productions) are also among the established systematic seismic deformations. The investigated sites helped the scientists for the dating; discovery of new seismic events; multihazard's observed phenomena. The review is accompanied by examples, documented new discoveries and enrichment of the archaeology knowledge. The problems about the application and effectiveness of shallow geophysics and archaeoseismology are also mentioned.

Keywords: Shallow geophysics; Archaeoseismology; Archaeology, Support, Bulgaria

Introduction

Bulgaria is famous country (together with Greece and Italy) with a rich archaeological heritage in Europe. More than 2000 archaeological sites have been discovered, most of them documented but still new ones are appeared especially in the cases of new roads and infrastructures are designed. In such cases new and emergency archaeological diggings must be performed to save the new discovered artefacts and objects. Very frequently unexpected archaeological objects appeared. Thus, all intended construction works must stop until the prospecting is done. The target is to save new artefacts and the documentation of the new discoveries. This needs a lot of efforts and archaeological studies to be performed in a very short time. On the other side – the time deficit needs also very fast prospecting and, in this direction, the shallow geophysics with its advanced technologies and new effective instruments is an extremely valuable tool for recognizing and mapping the possible areas of interest.

The active construction works for roads, buildings and other infrastructure and industrial development are accelerated from year to year. That's why the role of the use of shallow geophysics for archaeological purposes and applications increases very rapidly.

On other side the new regulations performed by European commission needs new and active change of the seismic codes and rules of each seismic prone country. This needs a new approach including archaeo- and paleoseismological studies for the completeness of the seismic catalogues and to add missing ancient seismic events. As the country is located on the east coast of the Black sea and earlier investigations discovered seismic and tsunami effects, thus the need of extended archeoseismological studies also increased.

Due to all these circumstances an extensive application of the shallow geophysics and archaeoseismology during the last decades is performed.

Shallow geophysics as an effective tool was implemented in many cases and reflected at various publications. The new objects have been discovered and described and specialized methodology, fields' measurements and effective prospecting developed and published.

Archaeoseismological studies have been performed during the extensive and especially targeted international expeditions mainly with Russian specialists. The main purpose of these investigations was to establish the methodology, to coordinate the results with the archaeologists and to reveal the obtained results in a new light of interpretations.

Both – shallow geophysics and archaeoseismology findings – are described and explained in the light of the Literature review Paragraph analyzing their effectiveness to new discovered and well-known archaeology sites – Figure 1.

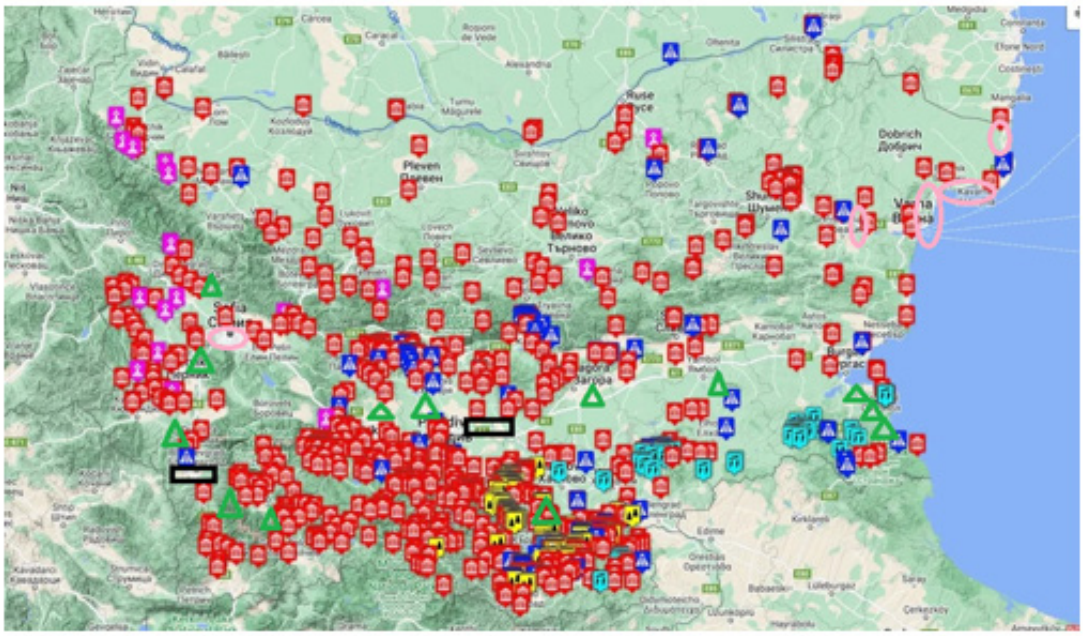

Figure 1: Archeological sites (ancient inhabitant places, tombs, dolmens, necropolis, castles, churches and altars, baths, etc.), paleoseismological diggings (black quadrangles), archaeoseismological investigated areas (magenta ellipses) and shallow geophysics (green triangles) with archeological application executed during last decades in Bulgaria.

Short explanations of the content of the different Projects executed and their achievements are presented. Finally, the gaps are identified in the light of all synthesized information and presented in the paragraph – Gaps and Challenges.

Literature Review, Prospection and Achievements

The literature review is focused mainly in the time interval of the last 20 years. The earlier investigations used primitive technics and methodology and have been revealed in publications (Examp. "Investigations of the solid-state earth physics at the Geophysics Institute (http://www.niggg.bas.bg/wp-content/uploads/2012/01/BGJ/2008/7_statia.pdf)

Starting with the earlier publications [1- 5] the first attempts have been made to connect the archaeological diggings with seismological evidences. Several very clear cases have been explored. The first case was a Cybele temple in Balchik (ancient Dionisopolis) on the Black Sea coast dated 3rd century BC and operated until to 6th century AD. This famous temple discovered occasionally due to the digging works for a private new hotel building revealed clear multihazard event. The reconstruction of this sequence of the natural disasters [1] following each after another in a short time as a remarkable sequence of disasters (strong earthquake -> tsunami ->landslide) destroyed this famous temple indicating clear events' sequence not longer than several

months. This prevented the secondary use of the materials of the temple for next generation of buildings. The extended research and conclusions made were published in Ranguelov and Bojkova [2].

Another very clear evidence of seismic influence to the walls of a bastion dated 4 550 BC is related with the diggings of the archaeological object Provadia-Solnicata [3,4]. An ancient factory of salt production (one of the most valuable products of the ancient society) has been circled by a bastion built by huge stone blocks which was destroyed by a strong earthquake around 4 050 years BC. The source and the power of this event were reconstructed due to the direction of the acted forces and the analogy with similar event documented in 1901 from the known source Shabla-Kaliakra [3]. Thus, this seismic event is the most ancient one with determined time, place and magnitude in Europe. The seismic source has a submarine location near the shore and also generated several well documented strong earthquakes, produced as well as tsunamis [4].

In parallel – the summary of these discoveries was presented to the international auditory combining the knowledge of other foreign authors with the results of the first archaeoseismological studies in Bulgaria [5]. The next large campaign was performed in the time interval 2019-2023 when a complex Bulgarian-Russian Expedition (BRE) investigated extensively many archeological objects located mainly on the Black Sea coast [6-7]. These investigations have been performed together with the similar research on the Russian coastline (ancient Georgippia) [8]. In parallel underwater geophysics was performed to study archaeological heritage for implementation of protective measures [15].

In general, the archaeoseismological studies during the execution of BG-RUS project were targeted to discover and to date the seismic effects of ancient earthquakes [6-14]. The studied archaeological objects have been dated from 5 000 BC to the present days. The special targeted methodology was developed and published in [13]. It includes the measurements of the systematic seismic deformations observed on the excavated structures of the objects. In this way, the direction of the acting seismic forces can be determined, and then the age of the affected structures is assessed and the time of the seismic event determined. Main discoveries were detected in the area of Durankulak site - an island with structures dated from Neolithic era (about 5 000 BC) to the 14th century AD. In the ancient part, the confirmation of the oldest seismic event detected in Provadia-Solnicata was confirmed [11,12]. Several later events dated 3rd c.BC, 6th c.AD, 1444, etc. with their effects on the Roma termi (Roman baths-Varna (ancient Odessos)), early Christian monastery (Djanavara-Varna) as well as other objects [13,14] have been revealed together with several new discovered seismic events with not yet exact dating.

In parallel during the same time a lot of shallow geophysics explorations of the ancient archaeological objects in other parts of Bulgaria have been executed [16]. Starting with ancient metallurgy [17], tombs and graves, walls and bastions, temples and churches, new artefacts and future archaeological objects were detected and studied in details.

Recent underwater archeological studies were strongly supported by different geophysical methods including ray-bathymetry, radar and sonar studies, gravimetry and magnetometry measurements in the sea and on the land [15-18].

Examples and Results

Archaeoseismology

The first example is related to the Cybele temple near Balchik town on the Northern Black Sea shore. As mentioned before the temple exists between two strong seismic events (3rd c.BC to 5th c.AD) The temple destruction started with a fire on the roof, then earthquake occurred (traced of seismic deformations are observed on the preserved parts of the walls and all standing stelas and statues fall on the floor in a same direction). The earthquake triggered tsunami which brings sand and mollusks shells on the floor and buried the artefacts. Then a landslide occurred (the area is famous with the Sarmatian recently active landslides) which preserved the ruins from the secondary use of building's remaining parts. This scenario was reconstructed due to the preserved deposits and clearly expressed sequence on the stratigraphy of layers discovered during the archaeological diggings [1] (Figure 2).

The next example is the Provadia-Solnicata ancient Neolithic salt production factory surviving from 5500 to about 3000 years BC. The discovered destructed bastion by a strong earthquake in 4050 BC probably was constructed by the ancient people to protect the salt reach community who trade this very important product that time. The fallen big stone blocks are due to the seismic effect of the Shabla-Kaliakra seismic source generated a strong earthquake about 4050 BC– Figure 3. The dating was done due to the discovered pottery, and the reconstruction of seismic influence was done by geodesy methods showing the direction to the seismic source. This is the only source located to the NE of the site and its activity is proved by a series of strong earthquakes during the historical time – since 3rd c. BC (well known Bisone case – the case of movement the old Greek colony Bisone - Kavarna town- from the shore to the plateau due to the landslide generated by strong earthquake during 3rd century BC multihazard event [5]) to the present days – last earthquake with magnitude 7.0 occurred 1901.

The example of Cybele temple shows the importance of preservation of the deposited materials to be able to reconstruct the happened events. The usual practice during the archaeology diggings is to remove the filling materials thus eliminating the possibility to reconstruct the paleo environment during the crisis destructed the respective object.

Similar but much more extensive investigations have been done during the Bulgarian-Russian field expeditions on both sides of the Black Sea [6-14]. The results of these expeditions confirmed the ancient earthquakes affected the Durankulak site and revealed new strong seismic events influencing the North Bulgarian Black Sea coast during the time interval from Neolith to the Middle Ages. Something more – clear observations of systematic seismic deformations on the ancient structure to the other side of the sea confirmed earthquakes of Caucasus origin (see for example [8]). The Durankulak archaeological site is rich of systematic seismic deformations generated by earthquakes since Neolith to the Middle Ages – confirmed 40 c. BC, 3rd c. BC and 6th c. AD events and

discovered new ones (Eneolithic - 46-41st c. BC and Medieval – 9th c. AD [11]) – Figure 4, Figure 5. The confirmed and new discovered seismic events to the North Bulgarian Black Sea coast are displayed in [9,11]. Very clear evidence about the seismic effects on the structures are displayed in the Roma termi (Roman baths) constructed in 2-3rd c.AD. The effects of the 6th c. AD strong seismic event (affected as well as Cybele temple) are visible on the entrance (Figure 6) as well as inside the structures of Roma termi.

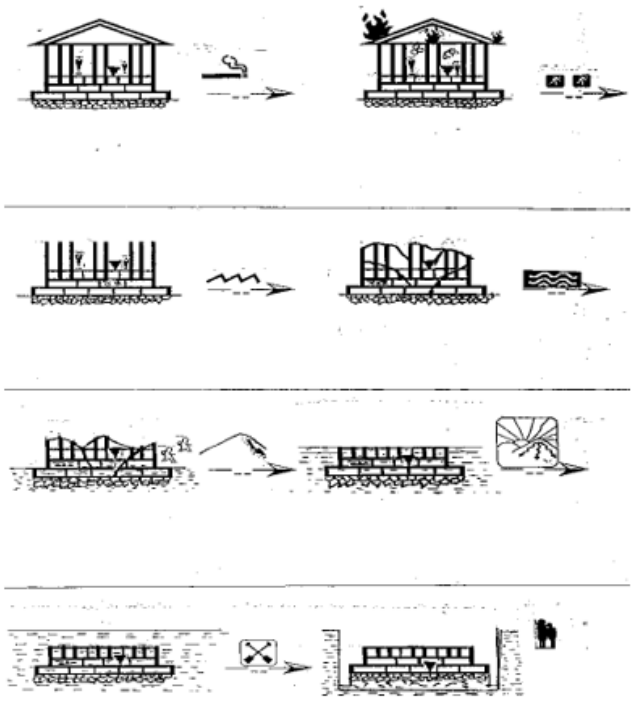

Figure 2: The time sequence reconstruction of the multihazard events affecting Cybele temple (Balchik) – 6th century AD: Fire->earthquake->tsunami->landslide->erosion depositions->digging->recent display (all effects sealed in time and disclosed after archeological digging - detailed explanations in [1]).

Figure 3: In situ bastion's destructed walls *(Provadia-Solnicata) and fallen stones permitting to establish the force direction and power of the ancient earthquake originated from seismic source Shabla-Kaliakra in 4050 BC [2,3].

Figure 4: The seismic deformation on wall of a house built at the boundary between the Stone Age and the Copper Age - Island in Lake Durankulak (4450–4100 B.C.). This north–south wall has been fractured by strong seismic motion acting nearly parallel to the old wall [11]. Effects have been created by a strong earthquake of 4050 BC event.

Figure 5: View of another north-south wall (Durankulak site) from neighboring structure (the same time period as Figure 4.) The seismic force acted E-W [11].

Figure 6: Entrance of the Frigidarium (Roma termi) affected by the strong seismic event. The numbers show azimuths of the cracks (tp.1 and tp.2). The shift of the horizontal stone bar is to the left. The vertical subsidence indicated by white arrow. This data gives the possibility to assess the direction of the seismic force as well as the power of it. Seismic event's source identified same as for the 6th c.AD [9].

There are also many examples of the archaeological sites (especially in Varna region) investigated for seismic influence. The summary of the confirmed and new discovered historical seismic events can be found in [10-14].

In conclusion to the archaeoseismology several new and unknown seismic events have been documented in addition to the well-known by the catalogues (Figure 7).

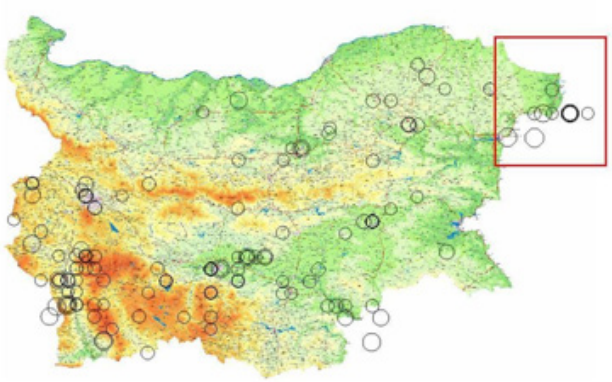

Figure 7: Schema of the seismic events (M>5.0) occurred on the territory of Bulgaria since ancient times to the present days. The new documented earthquakes are located mainly in the red quadrangle [7].

Shallow geophysics

The shallow geophysics has been performed on many sites following different purposes – from search and mapping of huge structures (like walls, buildings, churches, huge production factories (for example salt extraction in Provadia-Solnitsata), bastions, tombs, through metallurgy ovens and wastes, to single minor objects like pottery, marble and metal artefacts. Depending on the size, physical properties contrast and depth different methods have been performed. Very frequently a combination of different geophysical methods sensitive to the different physical properties of the artefacts has been used. Just several examples are presented and performing the field measurements and respective analyses the effectiveness and effective depth penetration of the different shallow geophysical methods has been extracted.

Geophysical prospecting methods have been performed investigating several archeology sites in the area of south Black Sea coast rich of ancient metallurgy – Figure 8. About twenty centuries ago – copper and iron mining and metallurgy was developed in this area. The remains are still visible on the land and ovens buries under it. The ores are rich in copper, iron and even radioactive minerals. The geophysics was performed to map the ovens, eventual deeper ore body, and metallurgy wastes from iron melt pieces [16].

Figure 8: Wastes of ancient metallurgy.

Archeological site – "Disappeared water" – in Bourgas district was studied to discover the ancient metallurgy activity. The electrical tomography detected low resistivity layers interpreted as ore deposits (Figure 9). The ground-penetrating radar (antenna 106 MHz) confirmed the boundary of the mineralization zone (Figure 10).

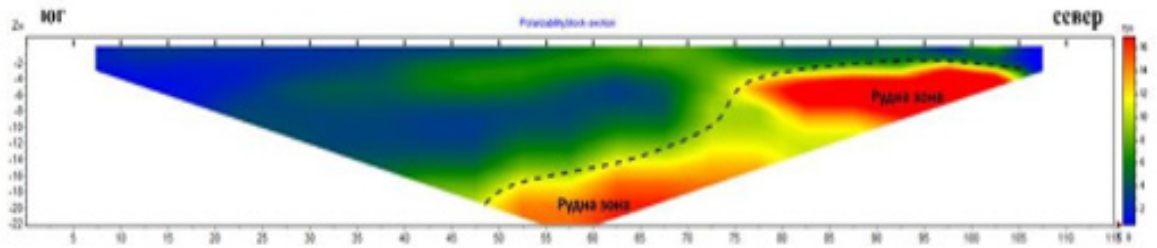

Figure 9: Electro tomography cross-section in the area of "Disappeared water". Red areas indicated ore zones at depths 3-5 and 15-20 meters, probably not reached by ancient people [16].

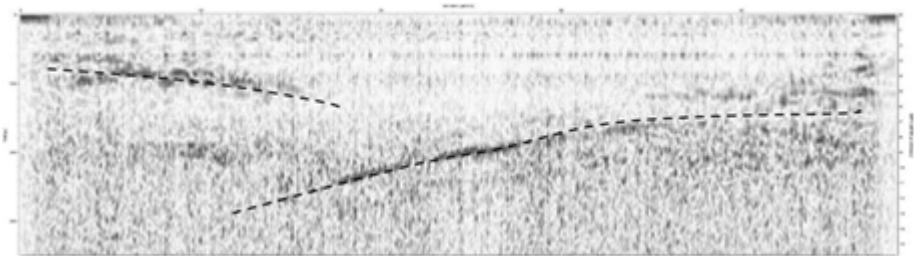

Figure 10: Ground-penetrating radar cross-section confirming electro tomography measurements.

Geomagnetic areal measurements of the vertical gradient $\partial T/\partial z$ shows a mosaic of anomalies reflecting the sparse distribution of the magnetic rich wastes in the same area – Figure 11.

Completely different are anomalies reflecting the old metallurgy furnace – Figure 12, partially visible on the land surface thus confirming the effectivity of the magnetometer measurements in this particular case.

More complicated are the various anomalies at the same archaeological site ant shifted to the SW in about 200 meters. There increased radioactivity was measured - Figure 13., again related to the higher values of magnetic susceptibility – Figure 14.

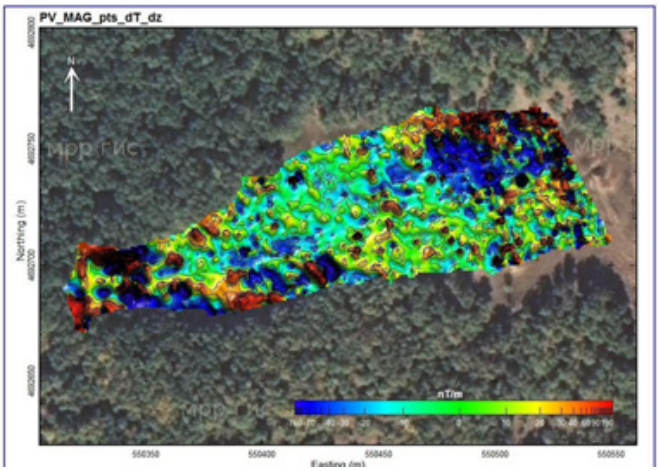

Figure 11: Schema of the vertical magnetic field gradient ∂T/∂z on the map of Disappeared water. Intensive anomalies are related to the iron wastes of ancient metallurgy activity [16].

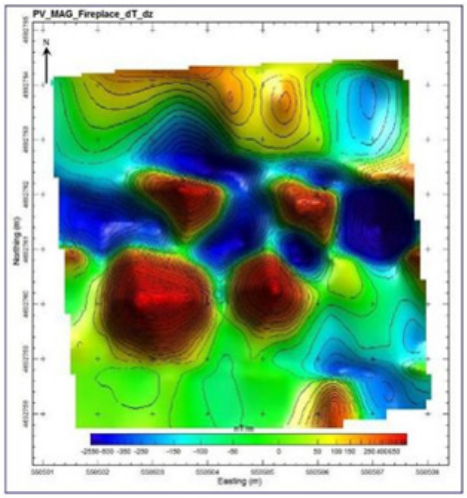

Figure 12: Vertical gradient of magnetic field over the ancient broken metallurgy furnace [16].

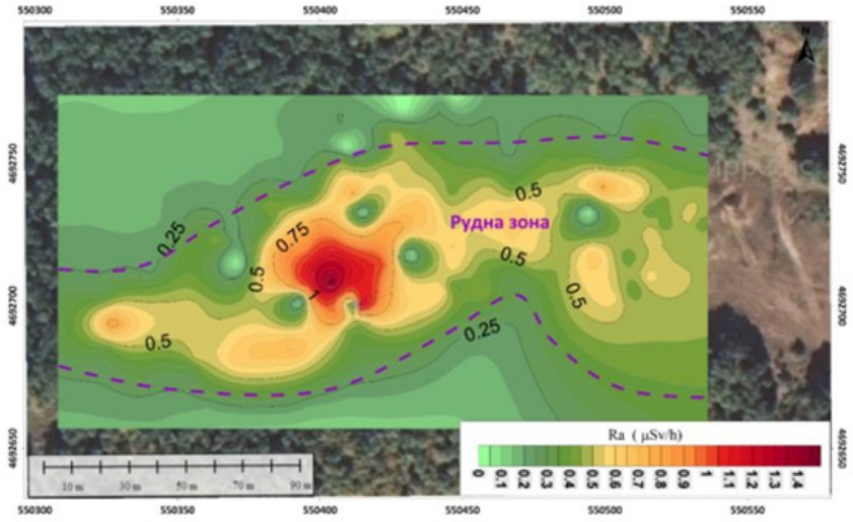

Figure 13: Radioactive anomalies (3-4 times higher than the natural background) due to the U-Th mineralization [16].

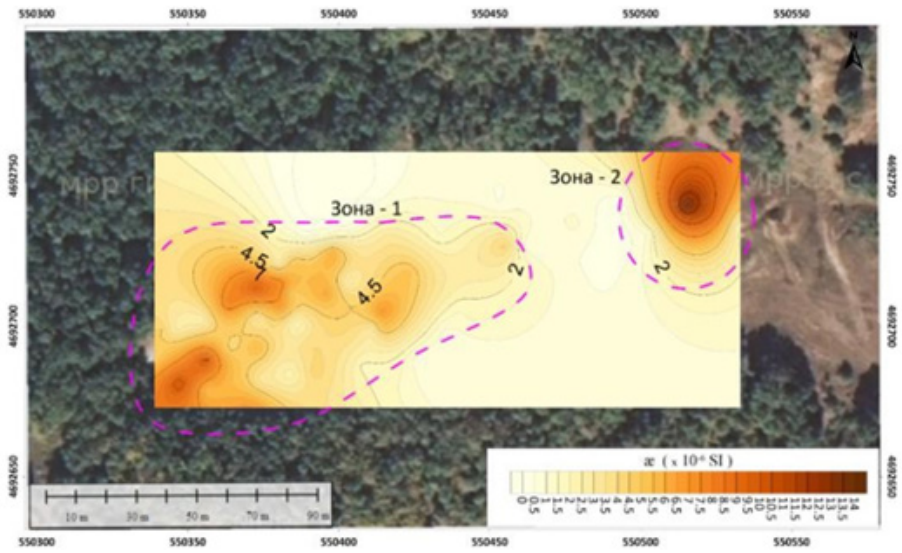

Figure 14: Magnetic susceptibility of the same area as on Figure 13 [16].

All presented examples show the variability of the methods and their applications in a case of shallow geophysics investigation to solve different archeological tasks.

As a result of many similar measurements a rich statistic about the depth penetration of the methods was collected. The summary of their effectiveness for certain conditions a table was created reflecting the comparison between different shallow geophysical methods used for archeometry - Table 1.

Table 1: Typology of searched archaeological sites and objects by different geophysical methods with depth penetration and effectiveness assessment in %(underlined) for each of them

Searched Archeological object Geophysical Method (Depth penetration – [m]) Effectivity (E) in %	Search and mapping of buildings and tombs	Search and mapping of ancient metallurgy and wastes	Search for low density underground spaces	Search for ancient ovens
Gravimetry (~0.2-0.3 g/cm^3 density difference)	(1 ~ 10-100) E – up to 70-80%	(1~10-20) E – up to 80-90%	(1~10-20) E – up to 80-90%	(1~10-20) E – up to 80-90%
Magnetometry (if ferromagnetic minerals are presented)	(1 – 20-30) E – 90-95%	(1 – 20-30) E – 90-95%	(1 – 20) E – 65-70%	(1 – 20) E – 95-100%
Electrothomography (depends on the resistivity)	(1-15) E-40-60%	(1-10) E-60-80%	(1-20) E-80-90%	(1-15) E-60-80%
Ground-penetrating radar (depending on the used antenna)	(1~10-15) E-50-60%	(1-10) E-60-70%	(1-10) E-80-90%	(1~10-15) E-60-80%
Metal detection (if metal artefacts are presented)	(1-5) E~100%	(1-5) E~100%	n/a	(1-5) E~100%
Radiometry (if radioactive minerals are presented)	(1-3) E- 40-50%	(1-2) E- 95-100%	(1-3) E-80-90%	(1-3) E- 40-50%
Magnetic susceptibility (kappametry- if ferromagnetic minerals are presented)	(0.1-0.2) E- 70-80%	(0.1-0.2) E- 80-90%	n/a	(0.1-0.2) E- 90-95%

Identified Gaps and Challenges

It was presented that the country territory is densely populated with the archeological sites and monuments most of them buried under the soils. This is a solid basis for the performance and implementation of the shallow geophysics as a strong tool for effective investigations. The gap could be fulfilled by close cooperation between archeologists and geophysicists. The common enterprises, the multiple purposes teams and firms – private and governmental can provide effective use and to serve for the preventive measure against illegal diggings and vandalism. The rescue archeological diggings could be faster and more effective using geophysical methods for mapping and outlining the threaten sites. This needs much more effective coordination and logistics to preserve the newly discovered artefacts and to protect and reconstruct the rich archeological heritage.

One of the emerging problems (not only in Bulgaria, but elsewhere), is the preservation of the environment of the ancient sites. Very frequently the removal of the sediments during the diggings eliminates the possibility to reconstruct the ancient environment. For example, the clearance of the deposits in the Cybele temple (Balchik case) eliminated the possibility to reconstruct the tsunami influence and source. It was just occasional chance to see the sand deposits. The deposited mollusks on the floor help to be able to decide that it was an ancient tsunami. The coordination and team work by different specialists – archeologists and geophysicists is an essential requirement for fruitful and effective work. To be together during the excavations is an important task and must be solved timely.

Summarizing

i. Special needs of strong cooperation and investigations during the digging works and excavations must be coordinated.

ii. Full documentary (written, movies, photos, photogrammetry, etc.) of the whole process of disclosure of archeological sites and elements in them is important for future reconstructions.

iii. Common interpretation of the observed facts and discovered objects and ancient environment must be performed by all specialists.

iv. Common dating and cross-check (if possible) of the available historical information with the leading role of archeology is essential for better results.

Conclusion

The presented work shows the systematic beginning of archaeoseismological investigations and the seismic (and tsunami) influence to the ancient structures and monuments. Effective use of archaeoseismology data for the confirmation and for new discoveries of known and unknown seismic events and their possible effects on the archeological sites is demonstrated by clear examples.

The shallow geophysical prospecting is illustrated by examples on archeological sites and many results of effective use for the research and discoveries in archeology (especially ancient metallurgy in Bulgaria)

The strong cooperation among different specialists (geophysicists, geologists, archeologists, etc.) during the digging works and excavations is essential for good results of the investigations.

The needs of extended and wider use of geophysics in archaeological investigations, thus increasing the effectiveness of both sciences – geophysics and archaeology is proved by examples.

Wide perspective of geophysical and archaeoseismology methods and equipment for research in known sites and for the new discoveries in promising areas in Bulgaria both – on land and underwater could be assessed effectively. The presented table is a proof for this.

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Conflict of Interest

The authors declare no conflicts of interest.

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