Archaeo-geophysics Laboratory

Dept. of Physics, Sofia University, James Bourchier 5, Sofia 1164, Bulgaria,
YYShopov@phys.uni-sofia.bg,

Dr. Yavor Shopov- supervisor

Members:
Dr. Diana Stoykova
Dr. Ludmil Tsankov
Dr. Milen Tsekov
Valentin Vasilev

Introduction Archaeological Geophysics lab of Department of Physics of Sofia University is the only one in Bulgaria which develops new geophysical methods and equipment for study of archaeological objects and their dating (Shopov et al., 1993, Dermendjiev et al, 1996). This lab has equipment and specialists for using of broad range of archaeogeophysical methods. Here we demonstrate possibilities of these techniques for solving of various archaeological tasks.

Archaeogeophysical Methods This lab uses following archaeogeophysical methods for exploration and non- destructive investigation of archaeological objects:

I. Radar Methods

1. **Ground penetrating radar (GPR)** – This method was developed by NASA to study the lunar ground. Introduction of these space technology to archaeology makes GPR the most powerful archaeogeophysical technique (Conyers, 2004), but interpretation of GPR data is most complicated and requires very complex data computing. It is the most complicated and complex archaeogeophysical technique. GPR allows registration of so fine archaeological objects that are hard to see by eye and can be missed during archaeological excavations (Conyers, 2004).

Advantages: a. GPR is the only archaeogeophysical method which allows preparation of 2D slices (maps) of underground objects from various depths under the surface without their excavation (Conyers et al., 2004), (fig.1).

b.It is the only archaeogeophysical method which allows preparation of 3D reconstructions of the precise shapes and depths of underground objects (Conyers et al., 2004), (fig.2).

c.It allows precise determination of depths of the underground objects under the surface.

d.It allows visualization of the underground objects as radar images in real time during the measurements.

e.It allows simultaneous geophysical exploration and archaeological excavation of the registered anomalies.

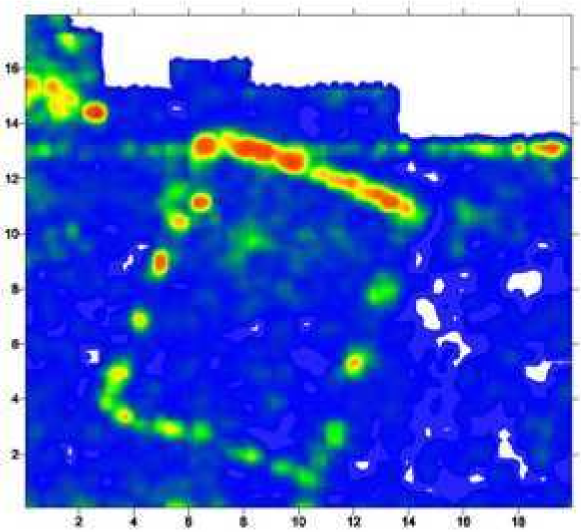

Fig.1. Amplitude Slice Map 100-150 cm. under the surface demonstrating foundations of a building and a possible Roman water line (up) by (Conyers et al., 2004).

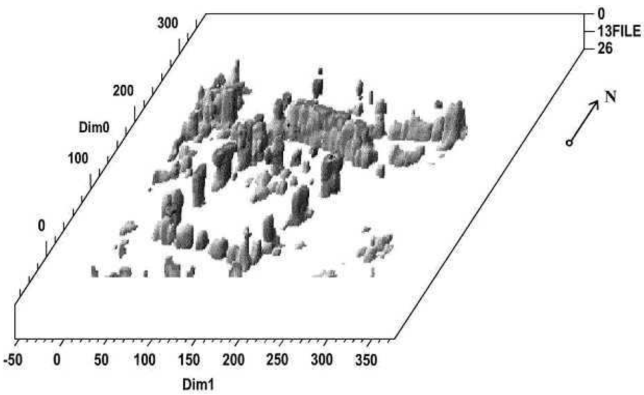

Fig.2. Three- Dimensional Rendered Surface of the foundations of the building on fig.1 constructed from Amplitude Slice Maps like this on fig.1 from various depths under the surface. (Conyers et al., 2004). Even separate stones are visible.

f.It has highest resolution from all geophysical techniques.

g.It can be used for scanning of vertical walls and localization of unhomogeneities in it.

h.Registered signal can undergo further computing for extraction of invisible details from the raw scan and graphic display of the results.

i.It allows fast scanning of large area. It is effective for large scale exploration with high horizontal resolution.

j.It allows connecting of different archaeological excavations by GPR exploration of the space between them.

k.GPR exploration can be done through ice, asphalt, concrete etc. (Archaeological Geophysics lab website, 2007).

l.On rough terrains can be done step-by-step measurements which allows deeper penetration of the radar signal.

Disadvantages: a. Interpretation of the signal is extremely complicated (Conyers, 2004) and requires years of experience of GPR studies of archaeological sites.

b.Very high cost of the equipments.

c.It can not be used in conductive environment (like sea water) or salty soils.

d.Limited penetration depth which depend on the soil humidity. Usually it varies from 1 meter in wet soil to 17 m in buildings (Archaeological Geophysics lab website, 2007)

e.Archaeological applications of GPR require an expert of very unusual training in specific fields of geophysics, geology and statistical physics. Experience in other GPR applications can not be applied on archaeological sites and experts on them can not be easily trained in archaeological applications of GPR

GPR applications in archaeology (Archaeological Geophysics lab website, 2007) are nondestructive localization and mapping of cultural layers in following buried archaeological objects:

-tombs and burials

-tunnels, catacombs, mud- huts and underground channels

-walls of buildings

-fire places

-metal and ceramic artifacts and coatings

-cavities and defects in buildings

-caves, bunkers, caverns and karstic futures

-underground reservoirs and buried pipes.

Nondestructive stratification of:

-sediments, river and lake deposits;

-soil layers including ancient arable lands;

-water table;

-faults and land slides.

Nondestructive study and monitoring of archaeological objects, cultural heritage and underground communications.

Experimental part

Calibration Experiments: Large numbers of calibration experiments were made inside the building of Department of Physics of Sofia University (fig.3) and surrounding grounds with known underground communications (pipes, canals, tunnels, etc) before the start of the field GPR measurements. They demonstrated that this equipment works perfectly on open ground and inside buildings and visualize all known futures of the studied terrains (fig.3, 4). It can work 17 meters deep in dry environment (fig.4). This depth is 70 % deeper than the claims of the producer of this GPR unit and antenna.

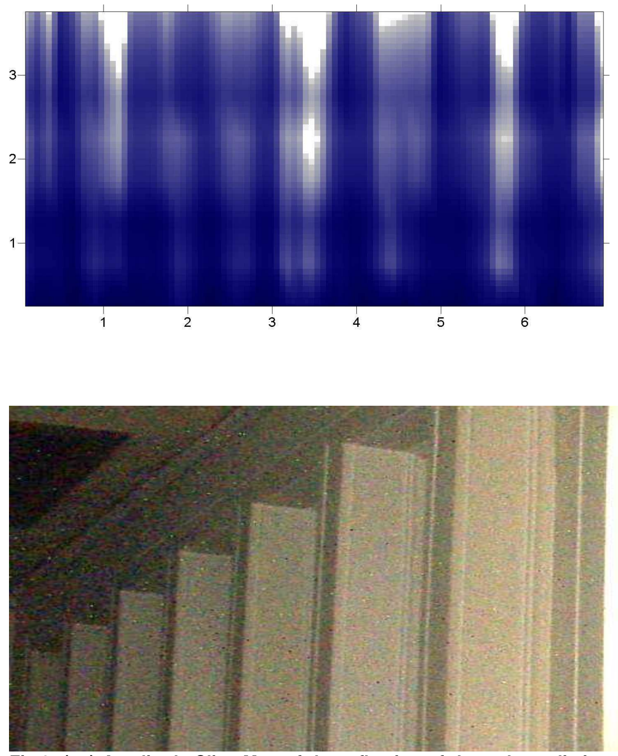

Fig.3. (up) Amplitude Slice Map of the reflection of the radar radiation from the concrete bars on the ceiling of the 4-rd floor measured on 35-62 cm depth through the concrete foundation of the 5th floor, by Y. Shopov & D. Stoykova. Dimensions of X and Y axis are in meters.
(Down) Photo of the same concrete bars on the ceiling of the 4-rd floor of building "B" of Dept. of Physics of Sofia University scanned by GPR.

Fig.4. (up) Amplitude Slice Map of the reflection of the radar radiation from the two concrete bars supporting the ceiling of the basement measured on 17,11- 17,38 meters depth from the 5th floor through five concrete foundations with total thickness of 3.25 meters by Y. Shopov & D. Stoykova.
(Down) Photo of the same concrete bars on the ceiling of the basement (-1-st floor) of building "B" of Dept. of Physics of Sofia University scanned by GPR.

GPR measurements of Bulgarian archaeological sites.

First GPR measurements on Bulgarian archaeological site (fig.5) were made in 2007 in the tomb "Golyamata Kosmatka" (Shopov, in press). 60 scans of the walls and floor of the tomb were measured with resolution varying from 1,3 to 1,7 cm. Four groups of 5 parallel scans each were measured on the walls of the tomb on height from 0 to 250 cm. They were summed in a 3D data base. Then it was sliced in 15 slices (fig.6) of 20 nanoseconds (corresponding to a thickness of 75 cm if the radar beam pass through soil but to 3 m through air)

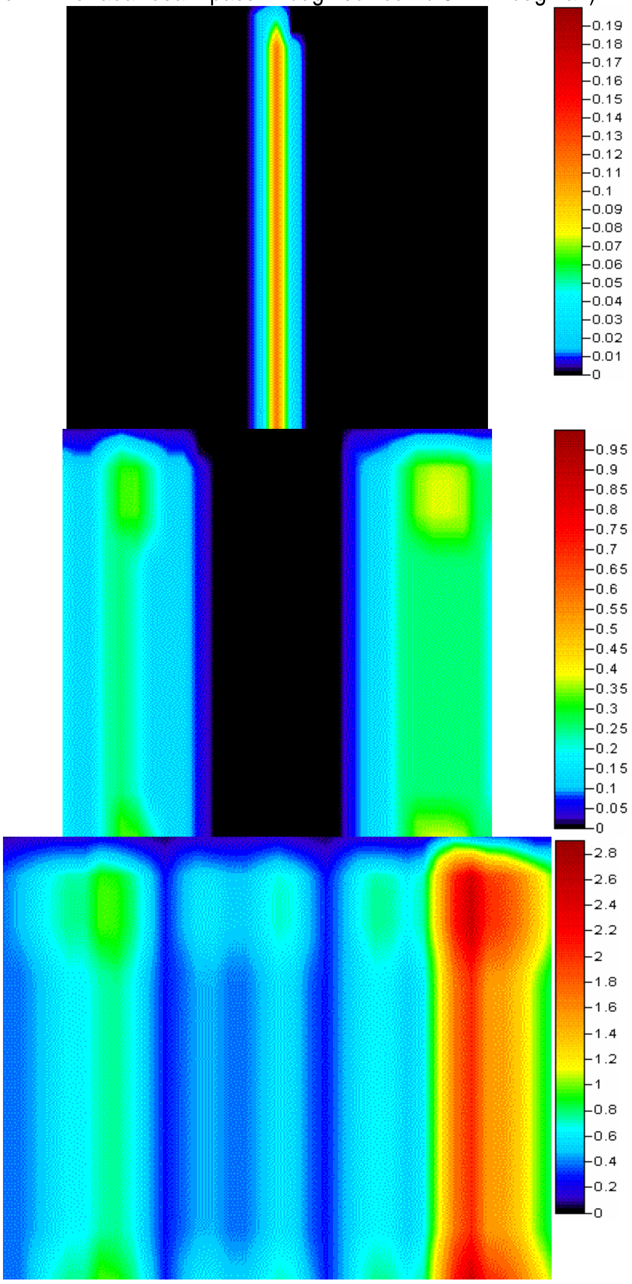

Fig.5. Vertical Amplitude Slice Maps of the intensity of the radar radiation reflected by objects around the tomb "Golyamata Kosmatka"(fig.6) measured through the wall of its round camera. (Up) A vertical slice 100-150 cm behind the wall of the camera. External wall of another unknown round building is intersected In the middle of the scans. (Middle) A vertical slice 150-225 cm behind the wall of the camera. In the beginning and the end of the scans are intersected external walls of the other round building. (Down) A vertical slice 450-525 cm behind the wall of the camera. In the beginning and the end of the scans are intersected external walls of the other round building. Three vertical structures between them can be internal columns. Color codes of the intensity of the reflected radar radiation are given to the right.

Obtained slices have resolution of 0.1 m. in horizontal, but 0.5m. in vertical direction. Scanned tomb camera was round, so obtained slices are segments of a circle (fig.6). So obtained 2D maps looks as prints of cylindrical seals (fig.5). They demonstrate that second unexcavated camera is located behind the west wall of the tomb. It is twice bigger than the camera in the excavated tomb.

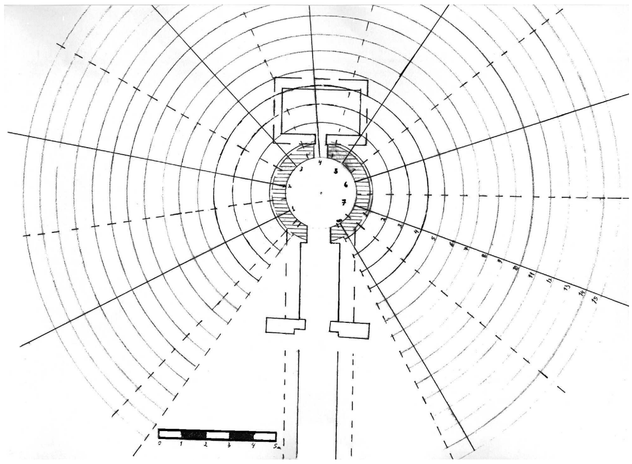

Fig. 6. Scheme of the tomb, distribution of the radar radiation during its scanning and positions of the 15 slices of 20 nanoseconds each (corresponding to a thickness of 75 cm if the radar beam passes through soil but to 3 m through air). It was unusually complicated because all important scans are vertical due to the great depth of the tomb, which makes impossible to measure it from the surface of the mound by GPR .

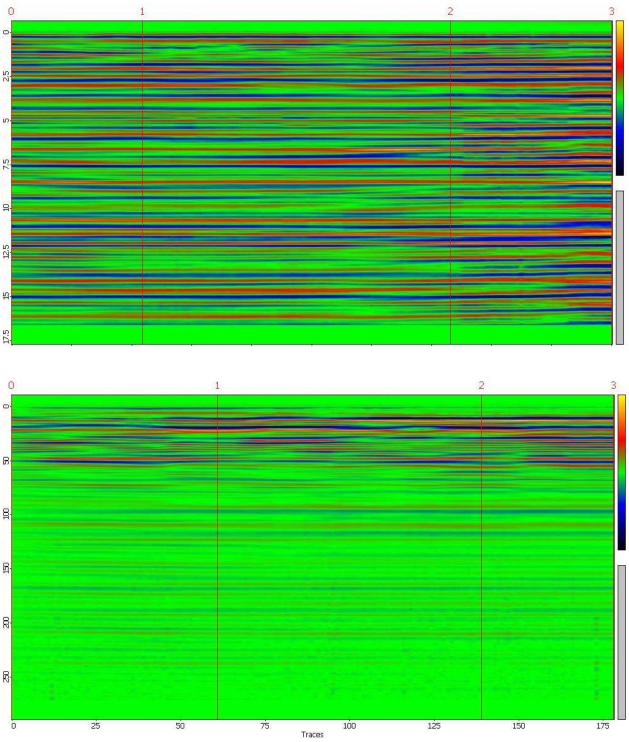

Fig. 7.A (up) A scan of the walls of the vestibule of the tomb 0- 50 cm above the floor suggesting that the radar radiation penetrates trough homogeneous material et least 16 meters in all directions. Fig. 7.B (down) A scan of the walls of the vestibule of the tomb 200- 250 cm above the floor. It demonstrates that the radar radiation penetrates through the granite wall of the tomb in the homogeneous soil filling of the mound outside the tomb wall.

Scans of the walls of the tomb in the lowest scanning position suggest that the radar radiation penetrates trough homogeneous material (Fig. 7.A) at least 16 meters in all directions. Material of the walls is granite. It means that the whole tomb is embedded at least 50 centimeters deep in a granite square at least 35 meters in diameter. This does not mean that the square is circled. It can be extended in all directions but radar radiation can not reach its edges. The soil filling of the mound is detected through the granite wall of the tomb (Fig. 7.B) everywhere at over 50 cm above the floor.

GPR measurements of prehistoric archaeological sites. Prehistoric sites are the most difficult archaeological objects for archaeogeophysical survey due to lack of metal objects in them. Most of the artifacts have the same chemical composition and physical properties as the surrounding ground. Especially stone artifacts have same properties as stones aground. So GPR is the most appropriate archaeogeophysical technique for survey of Neolithic settlements (fig.8) and is the only one usable for survey of Paleolithic sites.

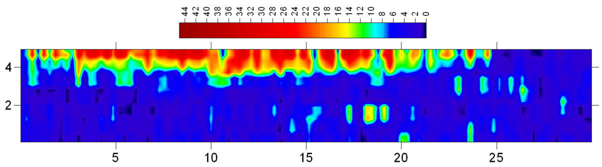

Fig.8. Amplitude Slice Map, 252– 261.5 cm under the surface of an archeological site in south Bulgaria demonstrating foundations of a possible stone wall (up) of a potential Neolithic building measured by Y.Shopov, A. Petrova, D. Stoykova and V. Vasilev. Dimensions of X and Y axis are in meters.

GPR is most suitable geophysical technique for solving of most of the tasks of archaeological exploration. Before its development it was considered impossible to locate underground objects like plastic, terracotta, concrete and asphalt. GPR became the main technique for localizing and mapping of non-conductive, non-metal and non-magnetic objects. It can be used even for exploration of under-water objects in fresh water basins (Archaeological Geophysics lab website, 2007).Therefore in the last years it is the main focus of work of Archaeological Geophysics lab of Sofia University.

II. Electrical resistivity methods.

2. Electrical profiling. It measures profiles of the electric resistivity (fig.9). It allowed deepest geophysical exploration of a Bulgarian archaeological site at 19 meters below the surface (Shopov, 2007) but such measurements can be done even on 40 m. depth. It is most appropriate for searching of tombs, caves, tunnels or bunkers.

3. Vertical Electrical Probing- detects the same objects as electrical profiling serving for determination of the depth of the detected anomalies.

4. Electrical tomography (continuous electrical probing)- allows visualization of anomalies of the electric resistivity and of the objects creating it.

Although its great depth of operation these methods are extremely slow, laborious and expensive, have many limitations and interferences. So now Archaeological Geophysics lab abandons these methods except of Vertical Electrical Probing which sometimes can help GPR for determination of the depth of the detected anomalies.

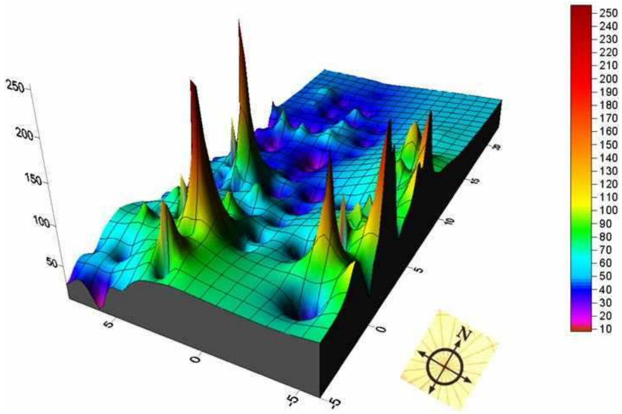

Fig.9 Map of the electric resistivity of Omurtag tomb. Vertical axis is in units of Omh/m. (Shopov, 2007)

III. Induction methods- use military technologies for location of mines.

5. Pulse induction- Allows localization of large metal objects on depth up to 6 meters. Its equipment emits powerful electromagnetic pulses and measures the inducted current in the underground objects between the pulses (Aittoniemi et al., 1986). It works through walls and stones. It allows very fast scanning and high precession of localization of the objects, but it doesn't allow precise determination of the depth of the anomalies. Underground cables, rebar or metal nets mask objects and make impossible its use.

6. Electromagnetic Induction- Allows precise localization of small metal objects and determination of the metal building them by its conductivity (Gardiner, 1967). Works on shallow depth which varies from 0.3 up to 1 meter depending on the size of the found object. Its equipment emits electromagnetic field and measures the inducted current in the underground objects passing between its coils. It doesn't allow determination of the depth of the anomalies. Underground cables, rebar or metal nets mask objects and make impossible its use.

Due to the limitations of each method in some cases is necessary to use several methods and apparatus to solve a specific task.

All geophysical explorations are non- destructive and harmless for the archeological objects unlike of the coring which damage the object in some degree.

Acknowledgements. We express special thanks to V. Mutafov, A. Koichev and M. Purvin for their help in the terrain measurements, to Dr. D. Gergova, G. Kitov and K. Leshtakov for the helpful data, discussions and providing of technical support on their excavation sites. We thank to Hydroloc Ltd. for providing of their equipment for field research. We thank to prof. G. Tenchov for the discussions.

References:

.Aittoniemi et al. (1986) US Pattent 4,605,898, 7p.

.Archaeological Geophysics lab website, (2007) www.phys.uni-sofia.bg/bul/departments/ucsrt/agpl/index.html

.Conyers L. B. (2004) *Ground- penetrating radar for archaeology.* Altamira press, Oxford, 201p.

.Dermendjiev V., Shopov Y. Y., Buyukliev G. N. (1996) High-Precision Method of Cave Deposits Dating and an Implication for Archeometric Study. - *Physical and Chemical Techniques (PACT) Journal,* **45, IV.7**, pp. 307-312

.Gardiner F. G. (1967) US Pattent 3, 355,658, 4p.

.Kitov G., Purvin M., Shopov Y. Y. (2008) GPR exploration of the mound Golyamata Kosmatka near Shipka village. *Archeological findings and excavations (AOR)* for 2007., pp.291-292 (in Bulgarian)

.Shopov Y. Y, Dermendjiev V, Buyukliev G. (1993) A New Method for Dating of Natural Materials with Periodical Macrostructure. B. Patent 51012 from v.8 1, 1990, *Patent office bulletin*, 1993, 1, p.20-21 (in Bulgarian)

.Shopov Y. Y. (2007) Electrical profiling of the Omurtag tomb.- *Avant-garde Research of Ancient Bulgarians*, v.1, pp. 57-58; *Archeological findings and excavations (AOR)* for 2006. (in Bulgarian)

.Shopov Y. Y., (2008) Potential and limitations of the Archaeogeophysical techniques: in "Along the Path of the Past"- Jubilee book in honour of 65-th anniversary of Dr.George Kitov. Edited by D.Dimitrova, IK Aros pp. 204-209

.Shopov Y., Diana Stoykova, A. Petrova, Valentin Vasilev, Ludmil Tsankov (2008) Potential and limitations of the archaeo-geophysical techniques. - Geoarchaeology and Archaeomineralogy (Eds. R. I. Kostov, B. Gaydarska, M. Gurova). Proceedings of the International Conference, 29-30 October 2008 Sofia, Publishing House "St. Ivan Rilski", Sofia, pp. 320-324.

.Shopov Y. Y. (2009) The secret of the success of Dr. Georgi Kitov. Avi Tohol, v.31, pp.3-4 (in Bulgarian)