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DEFINING THE LEVEL OF SUBSURFACE WATER WITH ELECTROMAGNETIC (VLF) AND ELECTRICAL RESISTANCE (VES) METHODS

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A b s t r a c t: The purpose of the investigations presented in the paper is the determination of the level of underground water for a geologically researched area. On the basis of the geological data are determined the vertical faults and contacts that can be assessed as accumulating areas with possible presence of exploitable amount of underground water.The geophysical approach is based on the preliminary geological investigations as well as the measurable physical parameters, and ultimately is reduced to the application of methods that records electromagnetic waves with very low frequency (VLF) and geoelectrical investigations performed with the method of vertical electrical sounding. The geophysical surveys are applied in stages where the VLF method initially is used as a prospective investigation obtained through three profile lines (positioned transverse of the assumed fault zones), whereas the electrical resistance research is used as an investigative method to define the depth to the assumed water bearing structure. The VLF surveys are obtained through evaluation of the electromagnetic field and filtering the obtained data through different determined depths and are performed with the instrument WADI. The electrical investigations are performed with the instrument TERRASAS 1000.

Key words: vertical electrical sounding; electromagnetic waves; geological faults

INTRODUCTION

The very low frequency methods utilizes the magnetic components of the electromagnetic field generated by military radio transmitters that use the VLF frequency band (15 – 30 kHz) (Tabbagh, A., 1991). The electromagnetic investigations presented in the paper are based on the generator stationed at Bordeaux, France, that is operating on frequency of 15.1 kHz. When the electromagnetic field from a VLF transmitter passes through a conductive body, as a result of the principle of induction secondary currents will grow up in the body (Beamish D., 1994). These secondary currents will in turn generate a magnetic field – a secondary field – which will try to repel the primary field. Only a body with a low electrical resistivity and a minimum size can generate secondary fields (Inan, 2010). The VLF methods detect the ratio between the vertical and horizontal components. Because the primary field from the transmitter is horizontal, the normal reading of the instruments will be zero even in the presence of horizontal lying conducting layers. The VLF anomaly appears only in presence of steep conductors. The original VLF anomaly is characterized with a maximum (to the left) and minimum to the right of the conductor (Oskooi and Pedersen, 2006). The original anomalies can be filtered to show the part of the resulting field which are in phase with the primary field from the VLF transmitter (Karlık and Kaya, 2001). In a complicated geology with existence of several conductors often it is impossible to distinguish between separate anomalies (Inan, 2010). The filtering method is an effective tool for converting the complex kind of anomaly to a much more attractive anomaly with a single peak right above the conductor.

The geoelectrical investigations are based on registering the changes on the electrical field that depending of its nature can be classified as natural or induced field. The electrical changes directly depend from the conductive characteristics of the under surface structure (Краев, 1965). The underground complex is modeled with identification of the resistance, through correlation of the obtained data with the conductive properties of the geological materials that are found on site (Reynolds, 1997). The electrical resistivity mehods usually are performed with two current electrodes, A, B (set outwards), through which electrical current is conducted in the investigated area, and two potential electrodes, M, N (usually set inwards), that measure the difference in the potential of the conducted electrical field. The geoelectrical methods are usually performed with conducting direct current through the investigated area.

Through the method of Vertical Electrical Sounding (VES) the structural shapes and the geological structure in the investigated area is researched through depth (Slimak, 1996). This investigations are performed with Schlumberger symmetrical alignment of the measuring dispositive. Through the investigations the potential electrodes (M, N) are either fixed or moved very little, whereas the current electrodes (A, B) are successively distanced from the center of the measuring composition for each new measurement, thus increasing the penetrating depth of the electrical field (Delipetrov, 2003). For each measurement is determined the current (I) that is conducted through the surface, and the potential difference (ΔV) between the electrodes (M, N), as well as the distance of each electrode from the center of the measuring dispositive (Prem V. Sharma, 2004). These three parameters are input values through which is calculated the apparent electrical resistance for each investigated depth bellow the center of the measuring alignment. The apparent electrical resistance for linear measuring dispositive composed from two current and two potential electrodes is defined with the equation (Todd, 2004):

$$\rho_s = \frac{2\pi}{\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}} \cdot \frac{\Delta V}{I}.$$

The ρ_s value determines the distribution of potential on the surface of a homogeneous half area (Jakosky, 1960). The expression is used for determination of the specific electrical resistance meaning that regardless of the structure of the investigated area, each environment is treated as a homogeneous layered environment (Dey, and Morrison, 1979). The scientific justification for complementary usage of the presented geophysical methods while resolving the presented matter is based on several facts:

- The presence of underground water in a geological complex where is propagated an electrical and electromagnetic field results with anomalous values on the investigated physical parameters.
- Through a process of singular and complex interpretation of the registered anomalies is determined the presence of the underground water, the terrain location as well as the depth in the investigated area.
- The electrical anomalies (with the applied method) represents the influence of the underground water through horizontal propagation of the electrical field, where as the electromagnetic investigations register anomalies with vertical propagation of the electromagnetic field.

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS OF THE INVESTIGATED AREA

The basis of the wider surroundings of the investigated field is built up of granite, specifically from adamellites. On the north site the granites are covered with basalt series from late Eocene. The granites are intrusive massifs with Jurassic age and is characterized by large cracks and partial surface putrefaction. They are mainly exposed to the surface and are rarely covered with diluvium. From hydrogeological aspect they are attached to the hydrogeological collectors with fissure porosity. According to the engineering geological features they belong to the group of tightly attached rock masses, with the ratio of strength classifying them in the II category of very healthy rocks.

The Eocene sediments are products of deposition in an aqueous medium. They are built of layers of sandstones that convert into conglomerates and clay layers. Are characterized with reddish color, quite decayed, cracked and modified. According to the findings of the performed investigative drilling the following zones are separated in depth of the granite (Rakičević et al., 1985b):

0 – 12 meters – Surface part degraded and altered granite with a number of cracks filled with clay and grus. This area is anhydrous and represents the conduction zone of the collector.

12 – 32 meters – Middle part, solid and cracked granite where the cracks are larger and not filled, making this area a hydrogeological collector – reservoir zone of the collector.

>32 meters – Basalt area, less cracking and represents hydrogeological insulator.

On Figure 1 is shown the geological structure of the wider surroundings of the investigated area (Rakičević et al., 1985a) presented with its position from the basic geological map (BGM) of Macedonia. The geological map is complemented with legend that represents every lithological structure of the area. From the geological and hydrogeological characteristics of the researched area is concluded that up to 32 meters depth the presence of geothermal potential is not possible, but do not rule out the possibility that the deeper parts of the investigated area presents favorable conditions for the accumulation of geothermal and hydrothermal fluids. These reasons confirms the necessity of additional geophysical surveys for accurate determination of the hydrothermal potential of the research area.

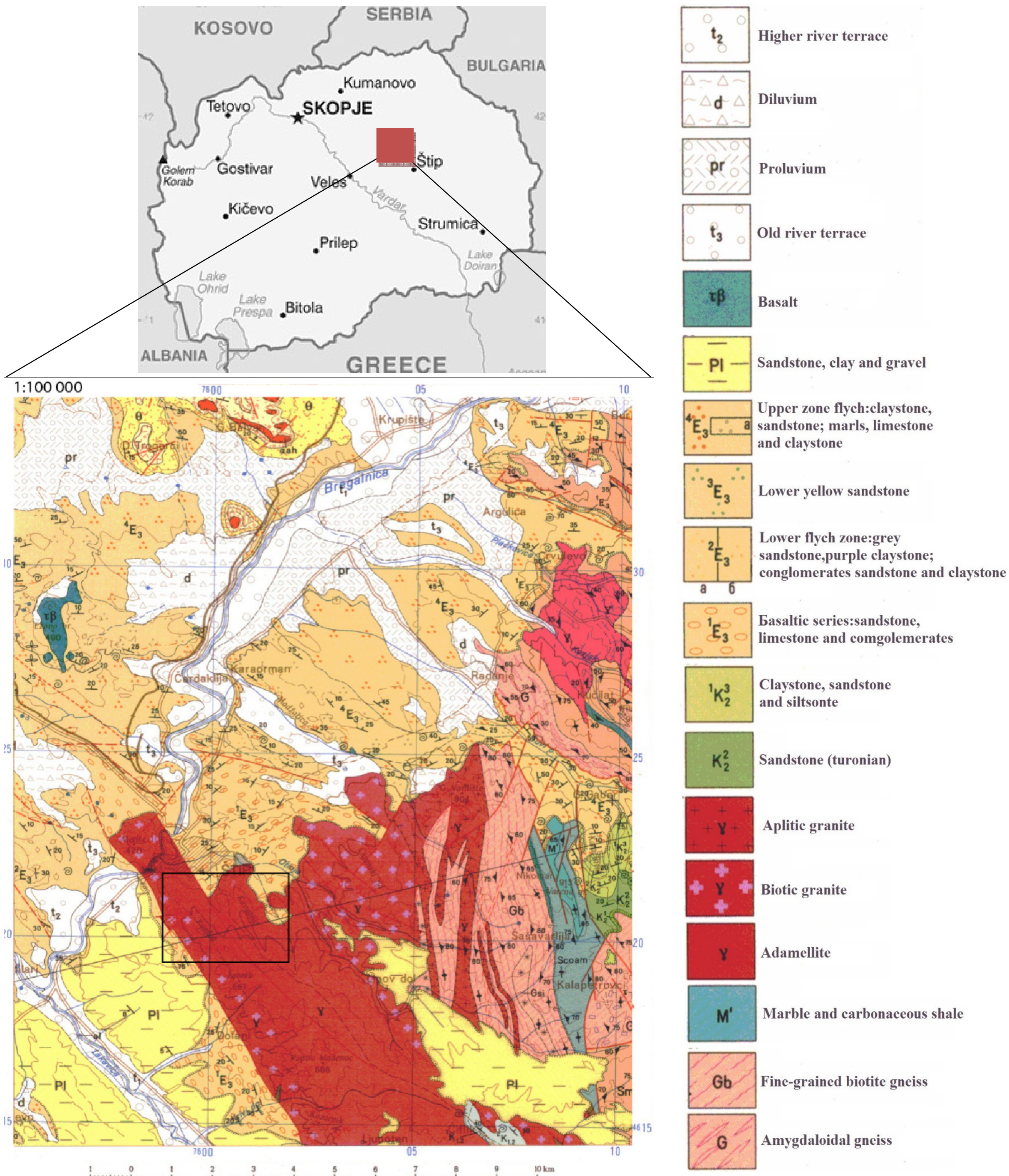

Fig. 1. Geological map 1:100 000, for the locality "Mazgi", Štip, from BGM – 1, sheet Štip

PROPSPECTIVE ELECTROMAGNETIC INVESTIGATIONS

Initially is approached with prospection of the wider surroundings, the hills that are around the site and also the areas which pass through the determined regional faults. Along the propagation of these fault zones presumably is possible the circulation of fluids. The general prospection is performed with the method of registration of electromagnetic waves with very low frequency (VLF) across three profile lines with a total length of 2500 meters. The trajectory of the profile lines is determined on the basis of the defined geological faults. They are cross cutting them in order to accurately determine their terrain position. With qualitative analysis and interpretation from the obtainned data is determent the exact location of the fault zones, their decline and the impact they have on the immediate area of investigation. On Figure 2 are shown the prospective profile lines of the VLF investigations as well as the defined fault zones (Military Geographic Institute, Belgrade, 1971).

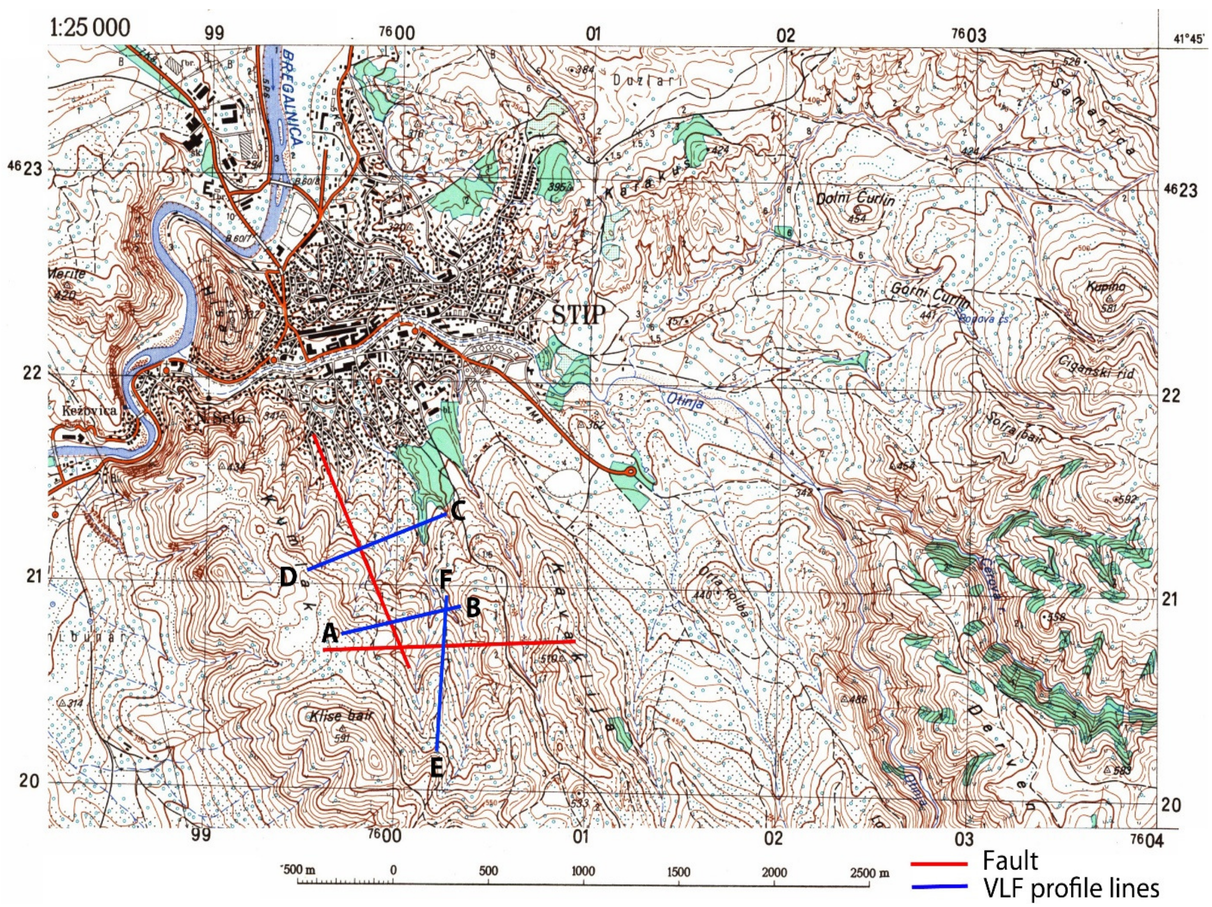

Fig. 2. Topographic map 1:25 000 for the locality "Mazgi", Štip, with field position of prospective VLF electromagnetic investigations

On the following diagrams are shown the investigations performed with the VLF method (Beamish 1994, 1998). With this method the investigated area is widely researched through three profile lines where two of them are parallel to each other (AB ad CD) and the other is cross cutting them – EF. On the following figures (3a,b,c,d,e,f,g) are shown the prospective VLF diagrams with the original obtained data as well the filtered data for depths of 50, 100, 200, 250, 300 and 400 meters. Each VLF measurement constructs two curves (real and imaginary). The real component registers the presence of conductive bodies in the investigated area where as the imaginary anomalies represents the presence of mineral ore bodies (Kuo, 1993; Bosch and Müller, 2001).

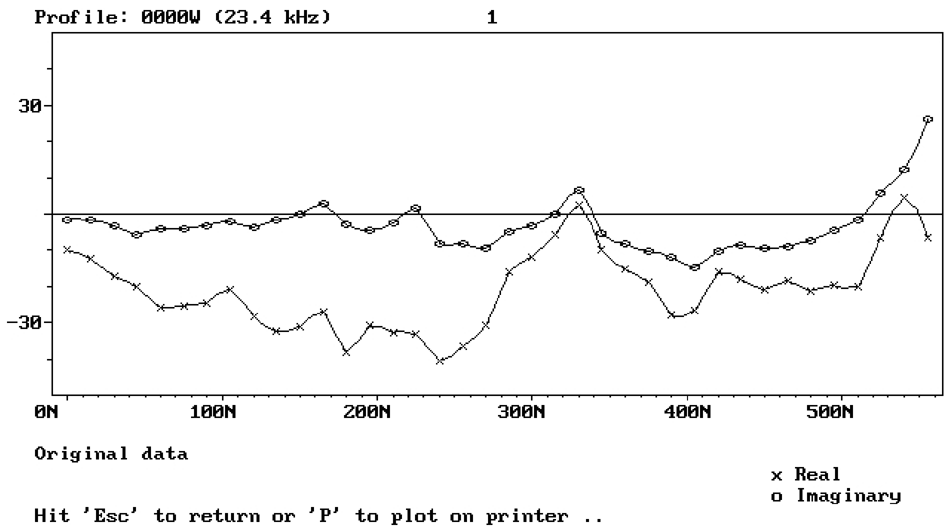

Fig. 3a

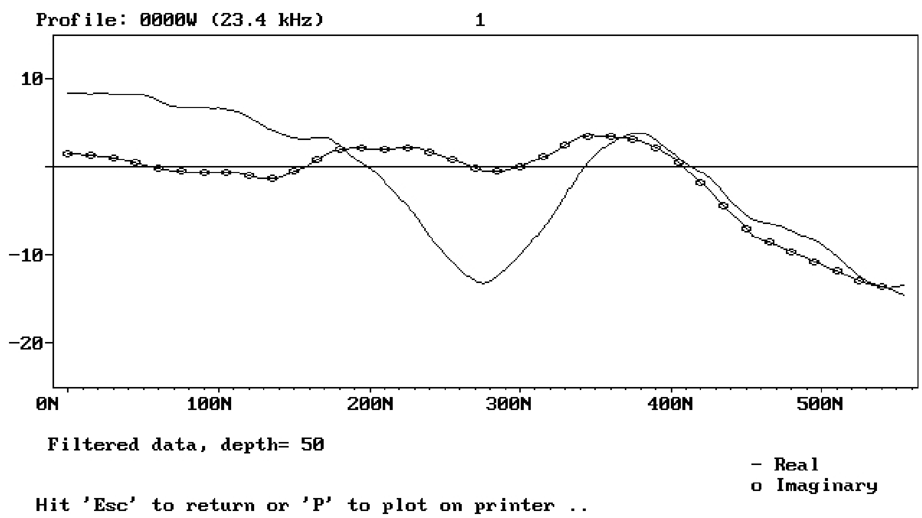

Fig. 3b

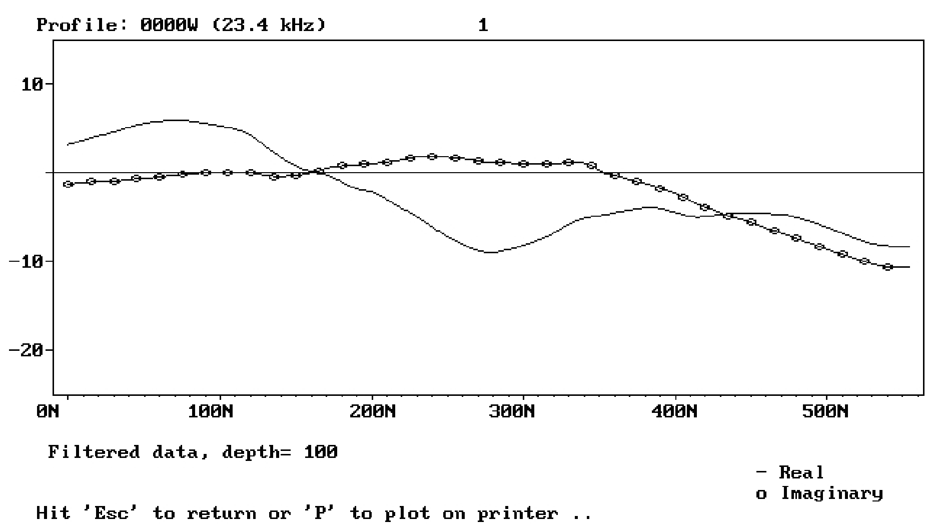

Fig. 3c

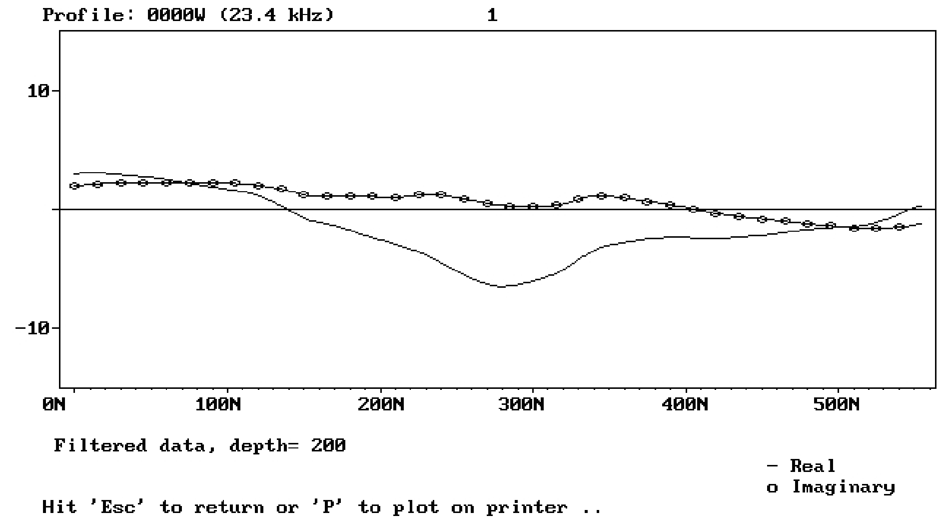

Fig. 3d

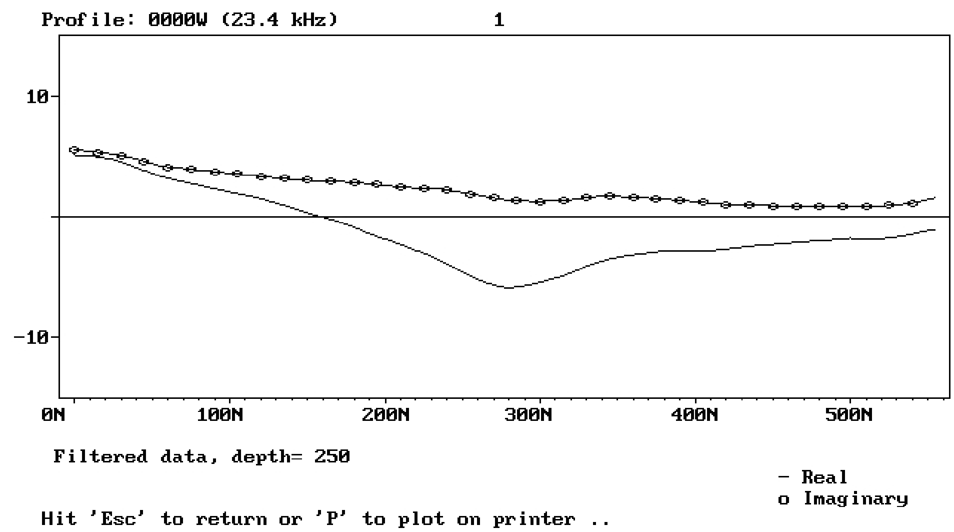

Fig. 3e

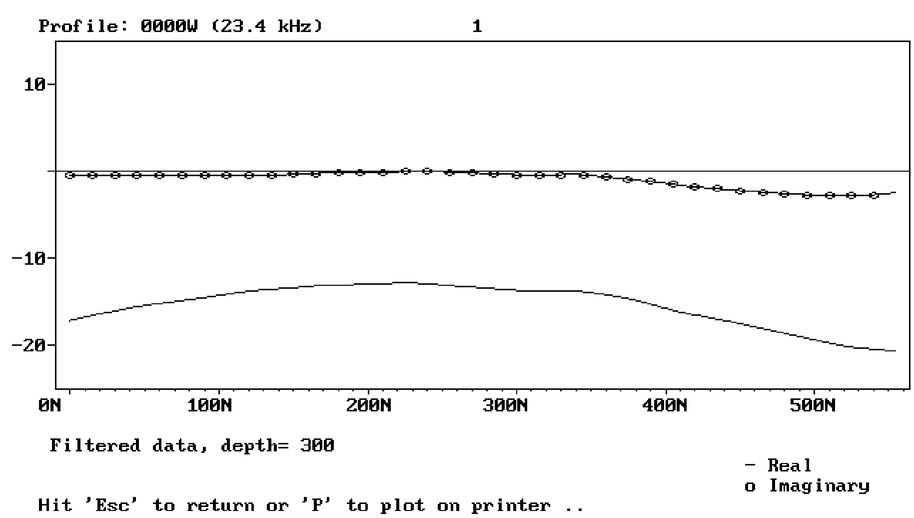

Fig. 3f

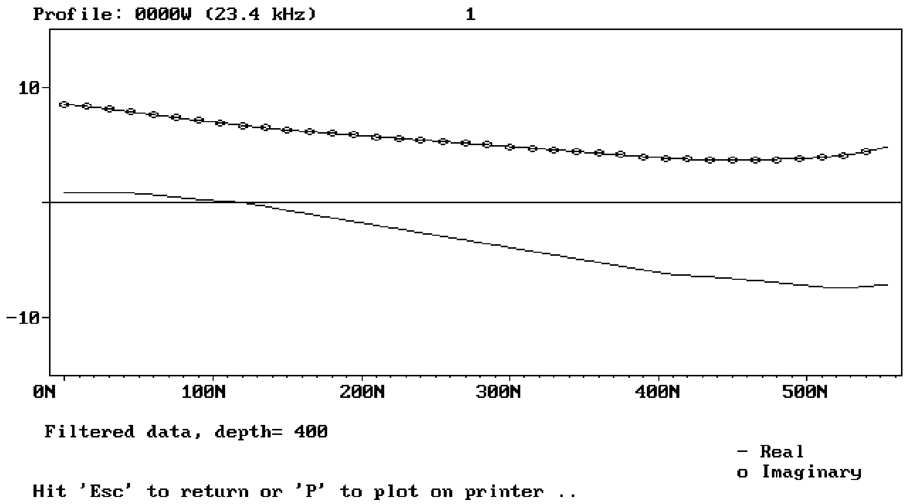

Fig. 3g

Figs. 3a,b,c,d,e,f,g. VLF data for profile line AB (original and filtered data)

The first presented profile line (AB) has a total length of 550 m and it is analyzed for six different depths. On the original data for the profile line are registered several anomalies. The depths of the recorded conductive bodies is determined with adequate filtering of the original data (Tronin, 2004).

With qualitative interpretation of the filtered depth of 50 meters in the real component is detected anomaly along the profile line between 200 and 400 meters. The registered anomaly is presented with lower intensity in the filtered curves for 100 and 200 meters. The remaining filtered curves for depth of 250, 300 and 400 m does not register any anomalies which indicates that the presence of water-bearing structures in those depths is unlikely (Pedersen, 1998). The following figures (4a,b,c,d.e,f,g) presents the original and filtered data for the profile line CD.

The profile line CD has a total length of 900 m, is parallel with the profile line AB and its original data is filtered through the same six depths as the profile line AB. From the filtered depth for 50 meters, along the profile line are registered two anomalies (from 100 to 500 meters and from 600 to 950 meters). The detected anomalies with reduced intensity are registered for depth of 100 and 200 m. The remaining filtered curves (250, 300 and 400 m) do not register anomalies from which can be concluded that in these depths there is no presence of conductive structures. On the figures (5a,b,c,d.e.f,g) are shown the original as well as filtered data for the profile line EF.

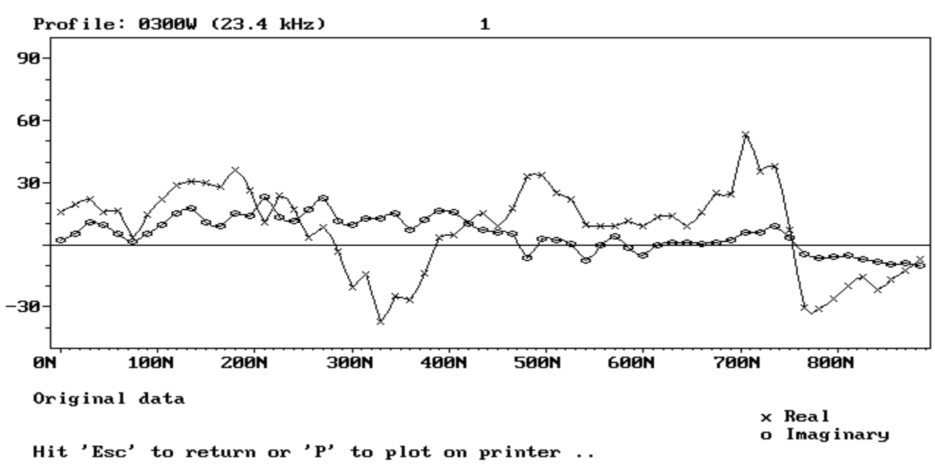

Fig. 4a

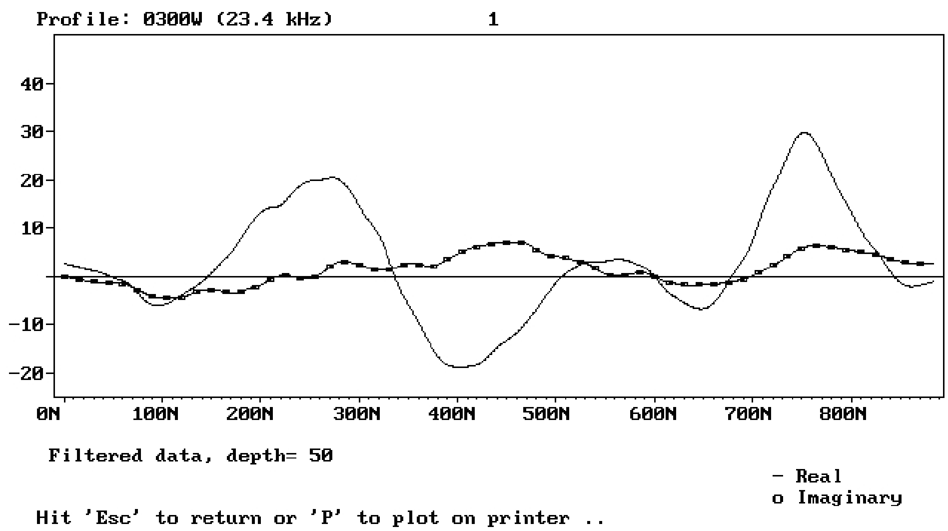

Fig. 4b

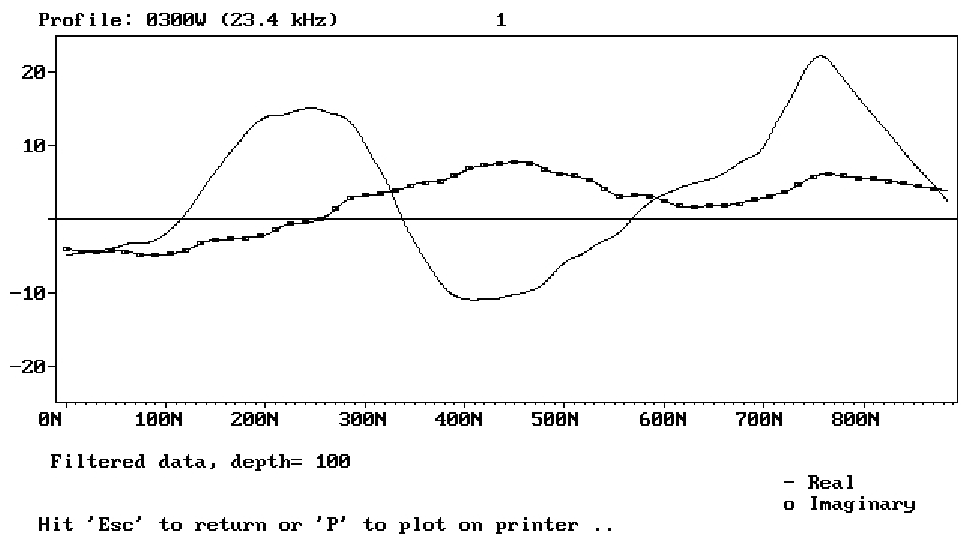

Fig. 4c

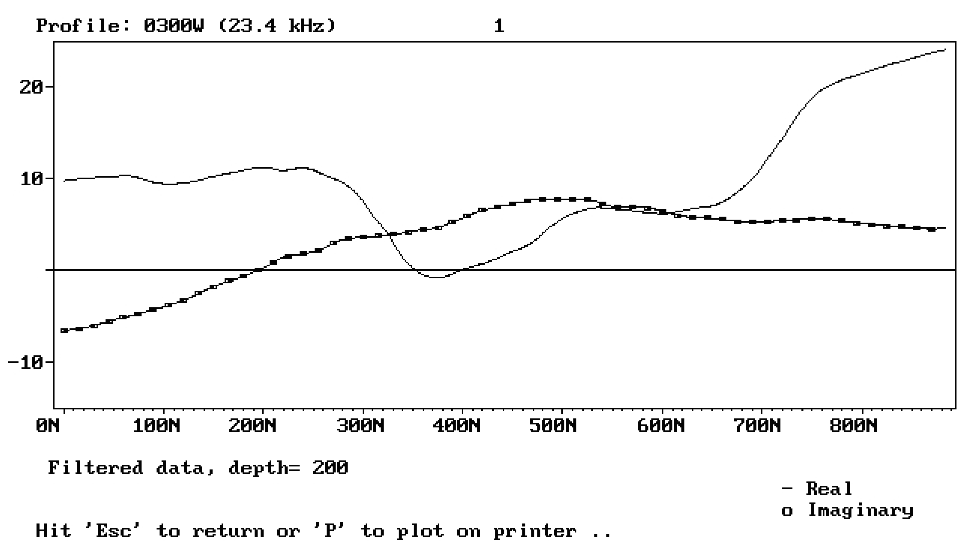

Fig. 4d

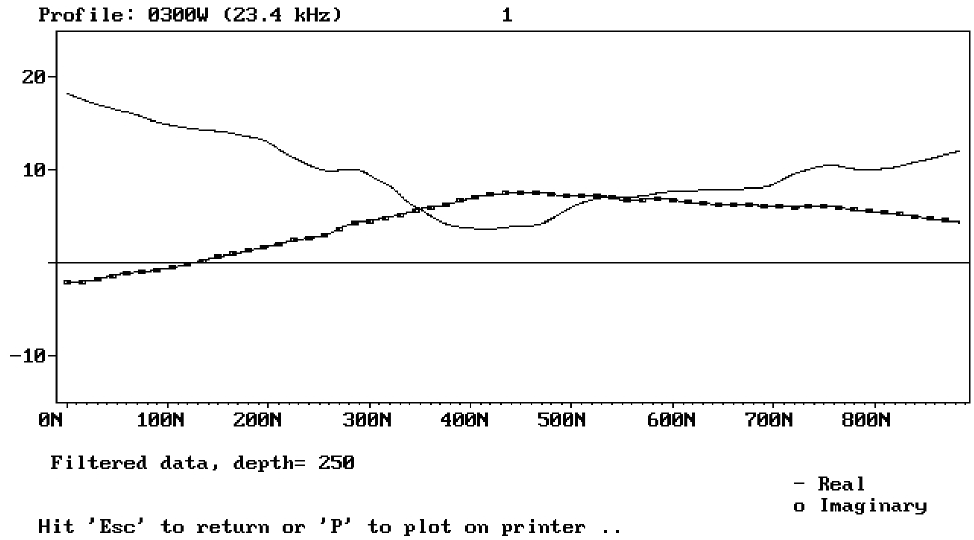

Fig. 4e

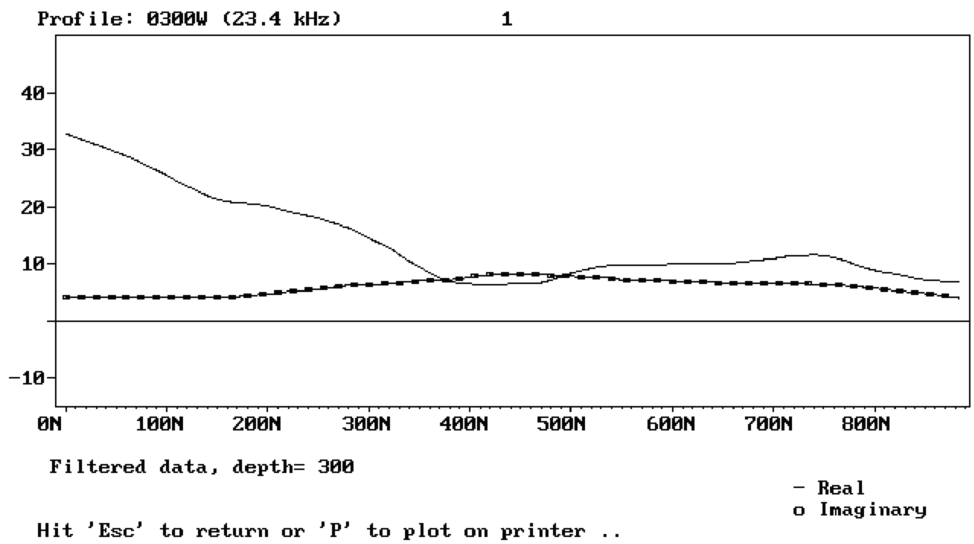

Fig. 4f

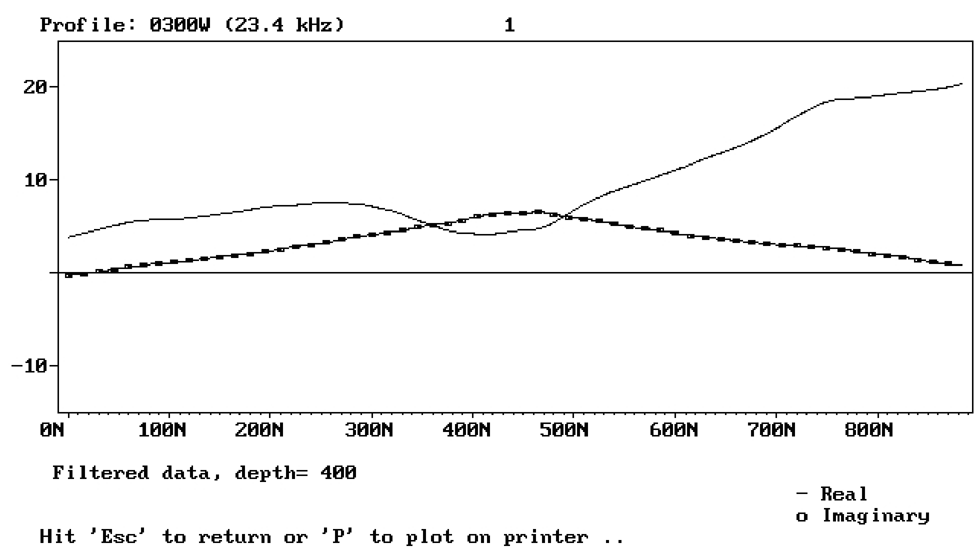

Fig. 4g

Figs. 4a,b,c,d,e,f,g.. VLF data for profile line CD (original and filtered data)

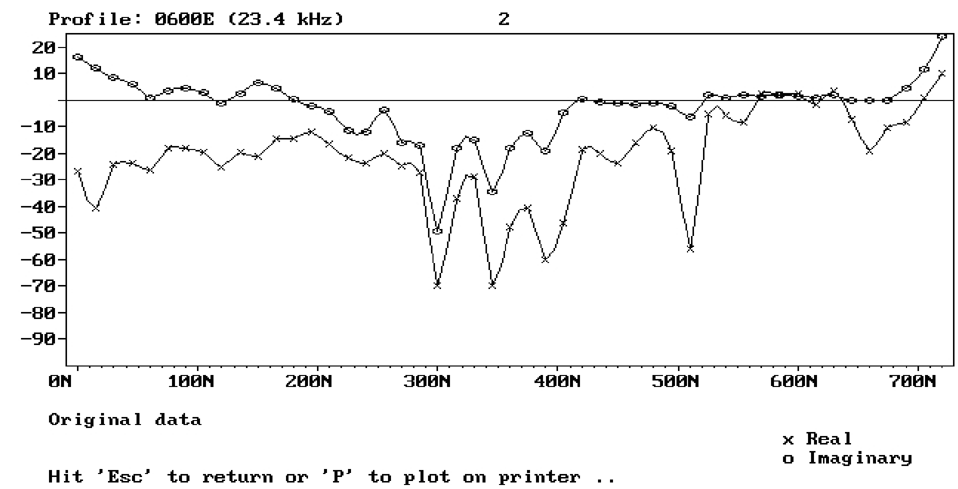

Fig. 5a

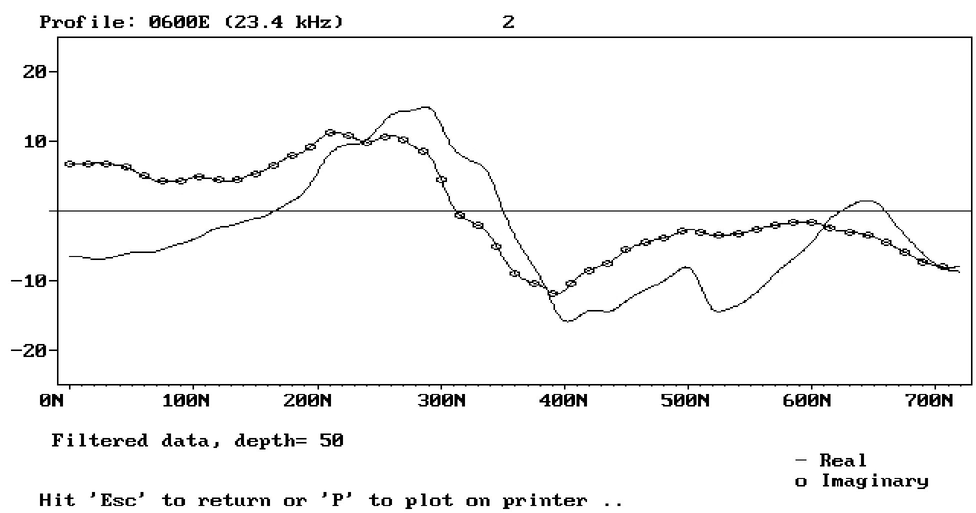

Fig. 5b

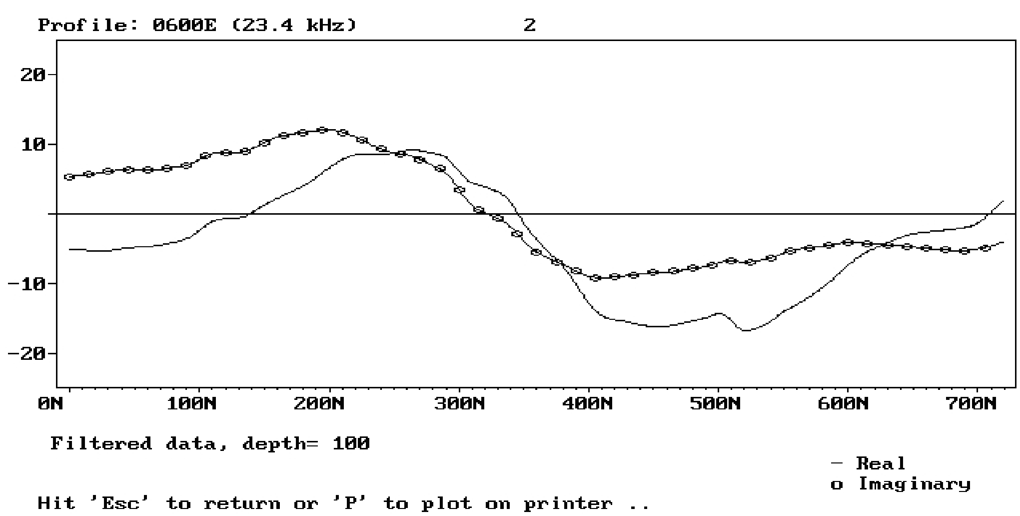

Fig. 5c

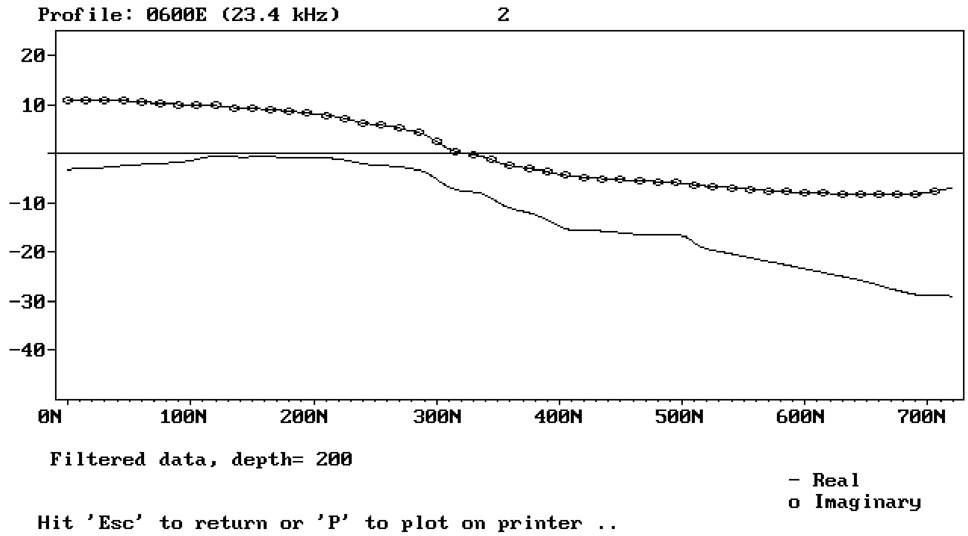

Fig. 5d

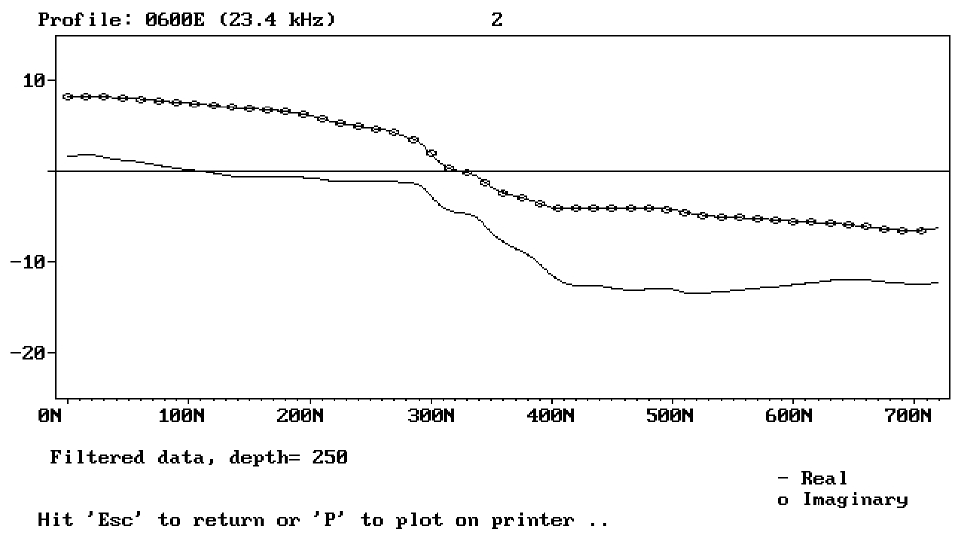

Fig. 5e.

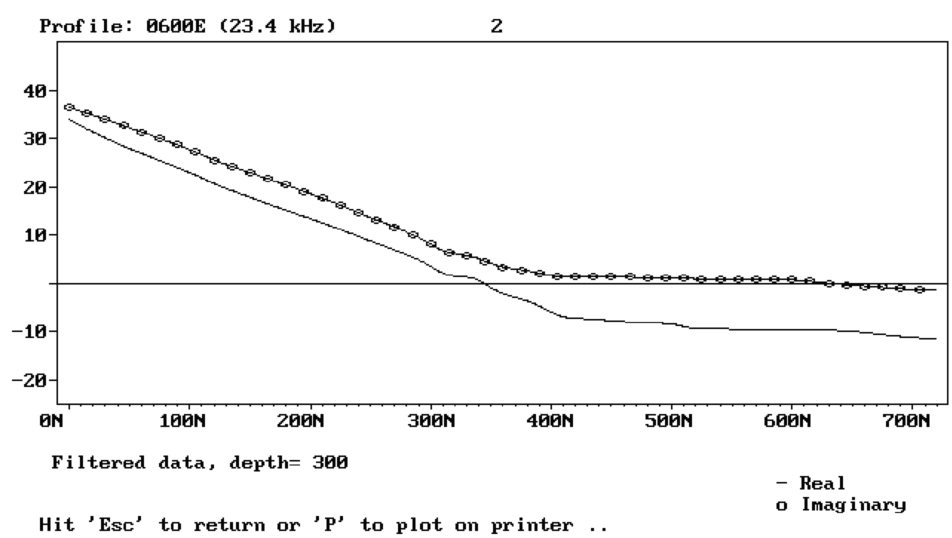

Fig. 5f

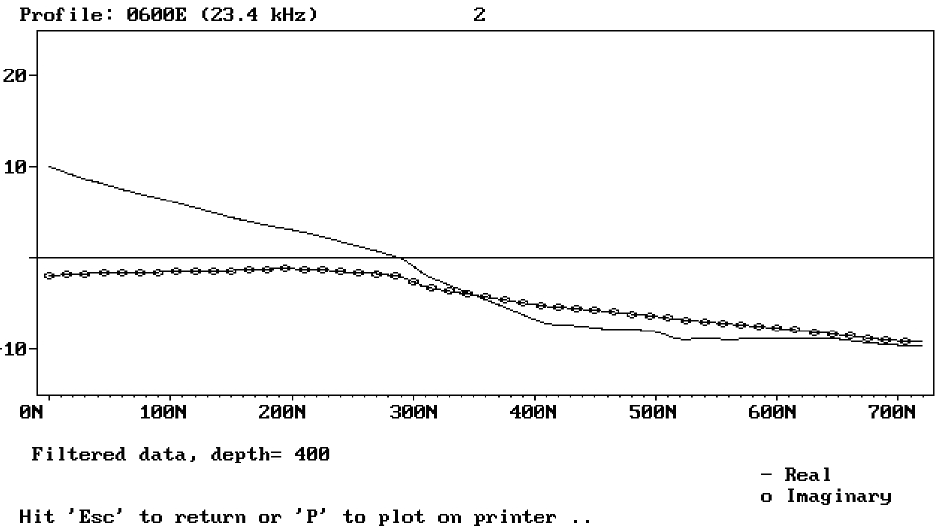

Fig. 5g

Figs. 5.a,b,c,d,e,f,g. VLF data for profile line EF (original and filtered data)

The profile line EF is positioned transverse to the two parallel profile lines and has a length of 730 meters. The obtained original curve is additionally filtered through six different depths in order to selectively determine the presence of the conductive structures in the investigated area. From the real component of the filtered curve for 50 m depth is registered anomaly along the profile line positioned from 100 to 700 m. This anomaly with reduced intensity is also registered in the filtered curve for 100 meters investigated depth. On the remaining curves (200, 250, 300 and 400 meters) are not registered anomalous values, from which the presence of conductive bodies in depths greater than 200 meters is ruled out

With the interpretation of each curve of the electromagnetic investigations the geophysical prospecting of the field is finished. The results of the electromagnetic investigations determine the geologically confirmed fault zones and are used as etalons for the application of the investigative geophysical methods.

GEOELECTRICAL INVESTIGATIONS

The investigative geophysical survey is represented with the method of geoelectrical sounding. This method is performed with two profile lines which are mutually perpendicular. The geoelectrical sounding is used for specifying the water bearing structures. The positioning of the sounds is determined on the basis of the defined vertical faults determined through the obtained geological data for the regional surrounding of the investigated area as well as the results from the VLF investigations (Romano, 2002). With the electrical surveys a predetermined field position is evaluated in cross section.

The total length of each profile lines is 800 meters, or separately each profile segment has a length of 400 meters. The geoelectrical sounding is done with a logarithmic distribution of electrodes where the value of AB/2 (half the distance between the current electrodes) varies from 10, 15, 20, 30, 40, 60, 80, 100, 150, 200, 250, 300 and 400 meters (Kirsch and Ernstson, 2006). On Figure 6 is shown the geometric alignment of the vertical electrical sounding along with their starting position and the investigation wells positioned on the basis of the interpreted data. (Military Geographic Institute, Belgrade, 1971).

The results of the vertical electrical sounding are presented through curves that represent the dependence of the measured apparent electrical resistance and the depth of propagation of the electrical field (Orenella and Mooney, 1966). On the Figure 7 graphically are presented the AB and A'B' curves obtained directly from the software (Ipi2Win) used for interpretation of the geo-electrical investigations. The diagrams presents curves of apparent electrical resistance (produced from the terrain data), as well as curve of specific electrical resistance modeled on the basis of the entry data (Barker, 1990).

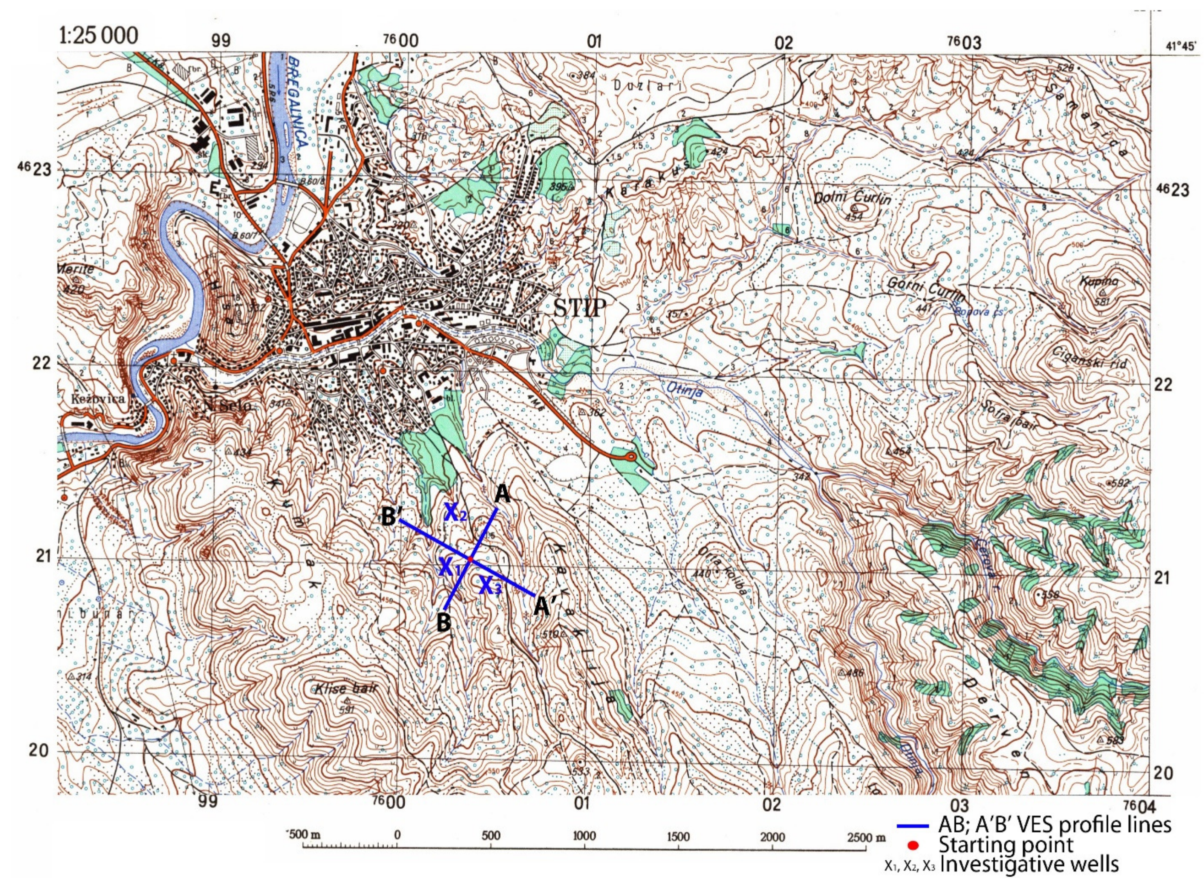

Fig. 6. Topographic map 1:25 000 for the locality "Mazgi", Štip, with field positions of geoelectrical investigations (vertical electrical sounding method)

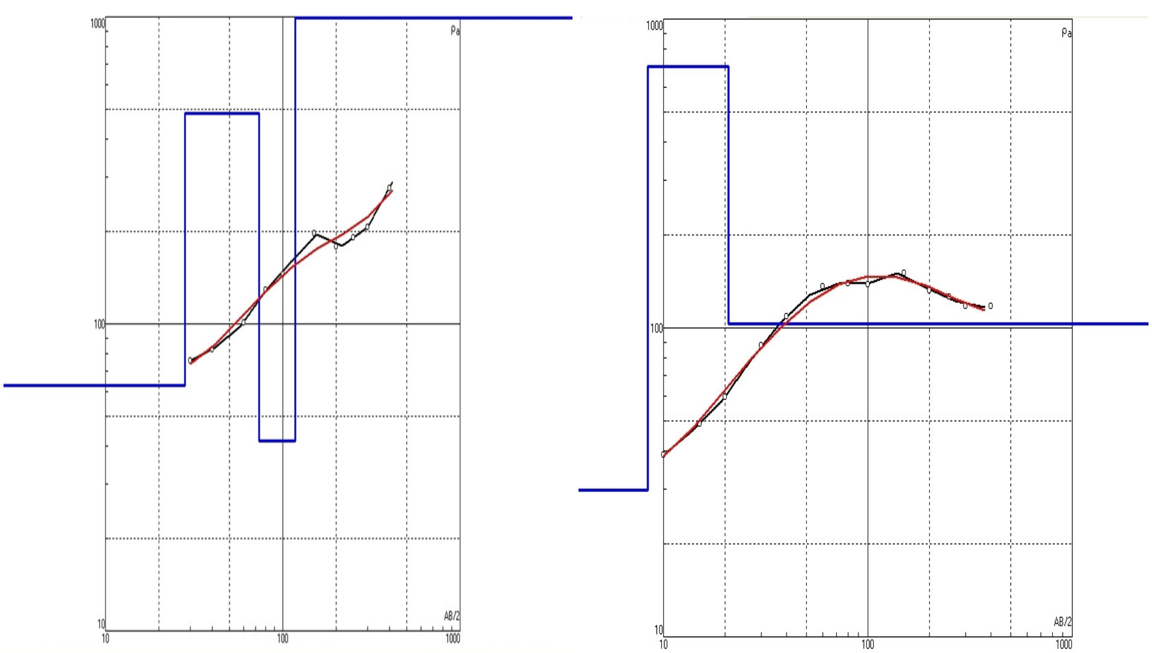

Fig. 7. Curve of apparent electrical resistance for the profile lines AB and A'B'

The apparent electrical resistance (shown with grey and red color) obtained with any electrical resistance method is given with the equation 1, and depends from the accumulated electrical resistance as well as the positioning of the current and potential electrodes. The real electrical resistance (shown with blue color) is calculated from the apparent resistance and represents the specific electrical resistance for each geological composition with different electrical characteristics.

The diagrams have bilogarithmic presentation of the data on which on the abscissais shown the data for the depth of the investigated area, whereas on the ordinate the data for the registered apparent and specific electrical resistance (depending on the analyzed curve). From the diagram is determined the form of the curve, the values for the registered electrical resistance for given depth as well as the defined anomalies. On the basis of the physical principles of the vertical electrical sounding the resistance anomalies suggest presence of conductive bodies in the subsurface structure. The anomalies are interpreted depending on its form, intensity as well as the depth of its registration and with correlation of the defined regional geological data. The both curves present rapid decrease of the registered apparent and real electrical resistance around depth from 110 until 130 meters. With qualitative analysis of the presented electrical anomalies and the geological defined vertical faults, the most perspective water accumulated zone is located in depth from 100 to 150 m. This zone is set for investigative drilling with terrain positions based on the trajectory of the electrical surveys presented on Figure 6.

COMPLEX INTERPRETATION OF THE GEOPHYSICAL INVESTIGATIONS

Both methods are interpreted independently but in order to have complete picture for the investigated subsurface structure it is important to construct conclusion based on complex interpretation from the geophysical as well as the geological data. The exact positioning and drilling depth of the investigated well is determined from the interpreted curves of the vertical electrical soundings as well as the defined anomalies on the filtered depths from the electromagnetic investigations (Никитина 1984). With the VLF investigations is determined the vertical presence of conductive bodies, whereas with the VES investigations are determined the horizontal conductive variations of the geological complex. Thus the data from both geophysical investigations are taken as complementary and because of that the complete conclusion of the geophysical investigations is that the defined area that is set for investtigative drilling has water accumulating potential determined with both geophysical investigations, and the interpreted results are in correlation with the geological data for the research area.

CONCLUSION

The conducted geophysical survey provides a good opportunity for mutual correlation of the obtained data as well as constructing an appropriate and reliable model of the water – bearing structures for a specific investigative area. On the basis of the elaborated facts and scientific principles can be concluded that with the application of the presented geophysical methods through the obtained results is determined the optimal field position of the measuring point as well as the depth to the water bearing structures. In the presented researches on the basis of the geophysical investigations is determined the anomalous zone for investigative drilling. The results of the investigative exploitation well on the given location confirmed the data obtained from the applied geophysical measurements.

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Р е з и м е

ДЕФИНИРАЊЕ НА НИВОТО НА ПОДЗЕМНА ВОДА СО КОРИСТЕЊЕ НА ЕЛЕКТРОМАГНЕТНИ (МНФ) И МЕТОДИ НА ЕЛЕКТРИЧЕН ОТПОР (ВЕС)

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Клучни зборови: вертикално електрично сондирање; електромагнетни бранови; раседи

Целта на презентираните истражувања во овој научен труд претставува определување на нивото на подземна вода во геолошки истражуван простор. На основа на геолошките податоци се определени регионални вертикални раседи и контакти за кои се смета дека имаат потенцијал да бидат акумулирачки средини со возможно присуство на искористлива количина подземна вода. Геофизичкиот пристап се базира на прелиминарни геолошки испитувања, како и на мерливите физички параметри, е редуциран на примена на методи кои регистрираат електромагнетни бранови со многу ниска фреквенција (МНФ), како и на геоелектрични испитувања изведени со методот на вертикално електрично сондирање (ВЕС). Геофизичките истражувања се вршени во фази, каде што електромагнетните испитувања се користени иницијално како проспективни истражувања изведени преку три профилни линии (позиционирани напречно на претпоставените раседни зони), додека пак методите на електричен отпор се применети за дефинирање на длабочината до претпоставените водоносни структури. Електромагнетните истражувања се базираат на регистрирање на електромагнетно поле и филтрирање на податоците преку различни определени длабочини и се изведени со инструментот WADI. Електричните истражувања се базирани на регистрирање електричен отпор во геолошкиот комплекс за различни длабочини и се изведени со инструментот TERRASAS 1000.