Дефинисање археолошких објеката на локалитету Кремените њиве применом Ојлерове 3Д деконволуције на магнетометријске податке

Весна Цветков, Илија Васиљевић, Бранислав Сретеновић, Весна Дамњановић

Дефинисање археолошких објеката на локалитету Кремените њиве применом Ојлерове 3Д деконволуције на магнетометријске податке | Весна Цветков, Илија Васиљевић, Бранислав Сретеновић, Весна Дамњановић | Књига апстраката 17. Конгрес геолога Србије, Врњачка Бања 17-20. мај | 2018 | |

http://dr.rgf.bg.ac.rs/s/repo/item/0005710

17. Конгрес геолога Србије 17th Serbian Geological Congress	Књига апстраката Book of Abstracts	736-741	Врњачка Бања, 17-20. мај 2018. Vrnjačka Banja, May 17-20, 2018.

DEFINISANJE ARHEOLOŠKIH OBJEKATA NA LOKALITETU KREMENITE NJIVE PRIMENOM OJLEROVE 3D DEKONVOLUCIJE NA MAGNETOMETRIJSKE PODATKE

Vesna Cvetkov[1], Ilija Vasiljević[2], Branislav Sretenović[1], Vesna Damnjanović[1]

[1)] Univerzitet u Beogradu, Rudarsko-geološki fakultet, e-mail: vesna.cvetkov@rgf.bg.ac.rs
[2)] NAFTAGAS-Naftni servisi d.o.o. Novi Sad, pogon seizmički servisi

Ključne reči: Ojlerova 3D dekonvolucija, magnetometrijski podaci, određivanje položaja i dubine arheoloških objekata.

UVOD

Sredinom četrdesetih godina XX veka, za potrebe arheoloških istraživanja počinju da se koriste geofizičke metode. Prvobitno su u upotrebi bila merenja specifične električne otpornosti, da bi pedesetih godina u upotrebu ušla i magnetometrija. Učestala upotreba geofizičkih metoda u arheologiji podstakla je razvoj tehnike istraživanja, obrade podataka i interpretacije rezultata, što je dovelo do nove discipline, poznate pod imenom Arheološka geofizika. Najveća prednost Arheološke geofizike je što je nedestruktivna, a sa povećanjem brzine i rezolucije merenja troškovi ispitivanja i iskopavanja su se znatno umanjili. Upotreba magnetometrije u arheološkoj prospekciji omogućava da se za relativno kratko vreme dobiju podaci o veličini lokaliteta i približnoj poziciji objekta (zidovi, podovi kuća, rovovi).

Arheološki lokalitet Kremenite njive se nalazi u naselju Barajevo u blizini Beograda (Srbija). Primenjena magnetometrijska ispitivanjima trebalo je da pruže informacije o dimenzijama i najverovatnijim dubinama na kojima se nalaze arheološki objekti, čije prisustvo je pretpostavljeno na osnovu ranijih arheoloških rekognosciranja. U tu svrhu korišćena je Ojlerova 3D dekonvolucija (O3DD) na magnetometrijskim podacima. Da bi se dobili što bolji ulazni parametri prvo je izvršeno testiranje O3DD na sintetičkim modelima.

METODE

Magnetometrija se zasniva na merenju magnetnog polja Zemlje. Jedinica je Tesla [T], ali kako je ova jedinica velika za primenu, u geofizici i u arheologiji, se koristi nanotesla [$nT = 10^{-9}T$]. Dva tipa magnetizacije se mere istovremeno magnetometrijom: indukovana i remanentna magnetizacija (u arheologiji je naročito značajna termoremanentna magnetizacija). Obzirom da je magnetno polje Zemlje sveprisutno, magnetno polje ispod instrumenta može biti pojačano ili umanjeno poljima, koja izazivaju arheološki objekti kao što su: ognjišta i spaljene kuće, jame ispunjene ulomcima keramike ili velike cele posude, uklanjanje ili akumulaciju površinskog sloja zemljišta, konstrukcije od kamena (temelji kuća ili popločane ulice), gvozdeni artefakti (koji su najmagnetičniji i najlakše se detektuju ovom metodom). U nekim slučajevima, savremeni metalni ostaci predstavljaju veliki problem u magnetometrijskim ispitivanjima, dok nekad, ako su oni cilj istraživanja, ovo predstavlja veliku prednost.

Magnetometrijska ispitivanja arheoloških lokaliteta mogu biti izvedena na dva načina. Prvi, pri kom se meri totalno magnetno polje Zemlje pomeranjem jednog senzora, i drugi, kada se meri gradijent magnetnog polja i izvodi se pomeranjem para senzora. Tačnije, obe metode zahtevaju korišćenje dva senzora. Ako se jedan senzor pomera po istražnom području, drugi senzor mora biti na baznoj tački i on meri dnevne varijacije magnetnog polja Zemlje. Dnevne varijacije, koje su obično intenziteta od 50–100 [nT] se uklanjaju tako što se podaci sa bazne tačke oduzmu od onih prikupljenih na istražnom području.

Važan parametar magnetometrijske interpretacije je definisanje dubine na kojoj se nalazi uzročnik magnetskih anomalija. Procena dubine bazira se na analizi jedne izolovane magnetske anomalije ili više magnetskih anomalija. Za procenu dubine na onovu jedne izolovane magnetske anomalije najčešće se koriste grafički postupci: pravilo polovine širine i postupak tangenti koji iako znatno unapređeni u odnosu na prvobitne grafičke postupke (Eppelbaum, 2015), pružaju orijentaciono oko $\pm$25 % informacije o dubini uzročnika magnetskih anomalija (Isles & Rankin*,* 2013). Poslednjih godina razvijen je algoritam koji omogućava brzu procenu dubina do uzročnika anomalije na osnovu O3DD magnetskih podataka nad mrežom (gridom) podataka, koristeći Ojlerovu relaciju homogeniteta koja povezuje polje (magnetno ili gravitaciono) i njegove gradijente po pravcima (*x, y* i *z*) sa pozicijom izvora uz pomoć stepena homogeniteta (*N)*. Stepen homogeniteta predstavlja meru opadanja intenziteta magnetskog polja sa rastojanjem od uzročnika anomalija. Za jednostavne modele se tumači kao strukturni indeks (Thompson, 1982) i definiše vrstu mete korišćene u proceduri O3DD (Reid i dr, 1990).

U radu su na sintetičkim modelima testirane Standardna i Locirana O3DD sa različitim strukturnim indeksima. Na podatke je primenjena redukcija na pol, iako je teorijski O3DD neosetljiva na magnetsku inklinaciju, deklinaciju i remanentnu magnetizaciju (Bastani & Kero, 2004). Razmatran je model oblika prizme, konačne debljine, na manjoj i većoj dubini zaleganja, kao i model na kome je prikazano više tela na različitim dubinama, koja se nalaze u sredini koja ima različitu vrednost magnetske susceptibilosti u odnosu na zadata tela. Za formiranje sintetičkih modela korišćene su izmerene vrednosti zapremiske magnetske susceptibilnost arheoloških uzoraka ($2{,}735\cdot10^{-3}$ SI) i okolnog zemljišta ($0{,}996\cdot10^{-3}$ SI) sa lokaliteta Kremenite njive. Izmerena vrednosti prirodne remanetne magnetizacije uzoraka crne cigle je $1{,}818\cdot10^{-7}$ [T], a crne cigle sa narandžastim uklopcima $66{,}02\cdot10^{-7}$ [T].

Magnetometrijska ispitivanja su izvedena u dva navrata 2012. i 2013. godine (Vasiljević, 2013) instrumentom GSM-19 Overhauser gradiometer (GEM Systems Inc. Canada, Ontario). Sam instrument dozvoljava rad na više načina, a prilikom akvizicije podataka je korišćen u tzv. „walk-mod“ (walking gradiometer) sa vertikalnim rastojanjem između sondi od 0,84 [m]. Rastojanje donje sonde do površine terena iznosilo je 1 [m]. Rastojanje između profila je bilo 0,5 [m], a interval uzorkovanja 0,5 [s]. Pomoću integrisanog GPS uređaja snimljene su pozicije mernih tačaka u WGS84 geografskom sistemu i vreme uzorkovanja koje je bilo potrebno za korekciju dnevnih varijacija sa čitanja sa donje sonde, s obzirom da se u svim primerima u raspoloživoj literaturi za Ojlerovu 3D dekonvoluciju koristi vrednosti totalnog magnetnog intenziteta (TMI). Ukupna površina ispitanog lokaliteta iznosi 2827 [m^2].

REZULTAT I DISKUSIJA

Testiranje Standardne i Locirane O3DD na sintetičkim podacima pokazalo je da i jedna i druga metoda uspešno određuju dubine do uzročnika. Kod plitkih uzročnika, obe metode daju dobre rezultate, s tim što Locirana O3DD daje tačne pozicije ivica uzročnika dok je kod Standardne metode oblast obuhvaćena rešenjima nešto šira.

U slučaju dubljih uzročnika, za preciznije određivanje dubina bilo je potrebno promeniti vrednost strukturnog indeksa. Standardna O3DD je računanjem dobro uokvirila sam uzročnik anomalija, dok su kod Locirane metode temena dobro obuhvaćena rešenjima, a ivice nisu bile dobro definisane. Nešto bolji rezultat za Lociranu O3DD je dobijen kada su podaci prvo redukovani na pol.

Kod modela na kome se nalazi više tela različitih dubina pokazano je da se bolji rezultati sa obe metode postižu nakon redukcije na pol. Time se postiže da granice svih uzročnika anomalija budu jasnije definisane, a dubine do njih bolje procenjene. Promenom nivoa osetljivosti za detekciju pikova nad mrežom analitičkog signala, postignuto je da se računanje O3DD vrši samo na mestima maksimuma u mreži analitičkog signala. Takav način detekcije pikova možemo da koristimo za procenu dubine do gornje površine uzročnika anomalija.

Na osnovu rezultata testa nad sintetičkim podacima, za proračun dubine do uzročnika magnetskih anomalija na lokalitetu Kremenite njive izabrana je Locirana O3DD sa dva nivoa detekcije pikova sa strukturnim indeksom 0,5 za koji se smatra da najviše odgovara kontaktima (Ried i dr. 1990). Korišćen je normalan nivo detekcije pikova, kojim su obuhvaćene samo maksimalne vrednosti u mreži analitičkog signala (sve susedne ćelije mreže imaju nižu vrednost). Time je postignuto da se pored definisanja dubina do kontakta prikaže i procena dubine na mestima maksimalnih vrednosti u analitičkom signalu. Mesta kontakata nisu jasno izdvojena, što je imajući u vidu da su objekti- uzročnici anomalija nepravilni, kao i različite dubine do njihovog zaleganja, bilo za očekivati. Opseg dubina do kontakata varira od oko 0,2 [m] u severoistočnom delu, preko 0,5 [m] u centralnim delovima do između 0,2 i 0,5 [m] na jugozapadnom delu anomalijske zone.

ZAKLJUČAK

U radu je prikazana primena O3DD, kojom je moguće dati brzu procenu dubina do uzročnika anomalija na velikoj površi. Opravdanost upotrebe metode na podacima prikupljenim na istražnom području data je testom nad sintetičkim podacima. Iako je testom bilo moguće jasno odrediti ivice uzročnika anomalija, nad podacima sa lokaliteta Kremenite njive one nisu jasno naglašene. Imajući u vidu da su tela koja su uzročnici anomalija nepravilnog oblika, takav rezultat nije iznenađenje. Izuzetak predstavlja jedino rezultat u jugoistočnoj anomalijskoj zoni. Tu su pozicije Ojlerovih rešenja prilično dobro okonturile ivice uzročnika anomalija. Očekivane dubine do gornje granice uzročnika anomalija su između 0,4 i 0,6 [m].

Sam izbor metode O3DD se svodi na subjektivnu procenu. Obe metode daju dobre rezultate, s tim što kod velikih setova podataka upotreba Standardne O3DD može biti veoma hardverski zahtevna, dok Locirana O3DD, osim što daje preciznije definisane ivice uzročnika, ima za prednost i manju hardversku zahtevnost. Procena dubine do gornje površine objekta O3DD može poslužiti za dalja arheološka i geofizička istraživanja na ovom lokalitetu.

ZAHVALNOST

Ovaj rad je finansijski podržan od strane projekta osnovnih istraživanja Ministarstva prosvete, nauke i tehnološkog razvoja, Republike Srbije (projekat br. OI 176016).

DEFINITION OF ARCHAEOLOGICAL OBJECTS ON THE LOCATION KREMENITE NJIVE USING EULER 3D DECONVOLUTION ON MAGNETIC DATA

Vesna Cvetkov[1], Ilija Vasiljević[2], Branislav Sretenović[1], Vesna Damnjanović[1]

[1)] University of Beograde, Faculty of Mining and Geology, e-mail: vesna.cvetkov@rgf.bg.ac.rs
[2)] NAFTAGAS-Oilfield services d.o.o. Novi Sad

Key words: Euler 3D deconvolution, magnetic data, determination of the position and the depth of archaeological objects.

INTRODUCTION

In the mid-forties of the XX century, for the purpose of archaeological research geophysical methods began to be used. Initially, measurements of specific electrical resistance were used, while in the fifties also started the magnetic measurements for the same purpose. The frequent use of geophysical methods in archeology has encouraged the development of the techniques of research, data processing and interpretation of results, which led to a new discipline, known as Archaeological Geophysics. The greatest advantage of Archaeological Geophysics is that it is non-destructive, and with the increase in speed and measurement resolution, the costs of the investigation and excavation have decreased considerably. The use of magnetic measurements in archaeological prospecting allows to obtain the data on the size of the site and the approximate position of the objects (walls, floors of houses, trenches) in a relatively short time.

The archaeological site of Kremenite njive is located in the settlement Barajevo near Belgrade (Serbia). Applied magnetic investigations were supposed to provide information on the dimensions and most probable depths on which archaeological objects are located, whose presence is assumed on the basis of earlier archaeological research. For this purpose Euler 3D deconvolution (O3DD) was used on magnetic data. In order to get the best input parameters, O3DD testing was first performed on synthetic models.

METHODS

Magnetic measurements are based on the measurement of the Earth's magnetic field. The unit is Tesla [T], but as this unit is great for application, in geophysics and in archeology, nanotesla is used [nT = 10-9T]. Two types of magnetization are measured at the same time by magnetic measurements: induced and remanent magnetization (the thermoremanent magnetization is particularly significant in archeology). Since the Earth's magnetic field is ubiquitous, the magnetic field below the instrument can be amplified or diminished by the fields arising from archaeological objects such as: fireplaces and burnt houses, pits filled with fragments of ceramics or large whole containers, removal or accumulation of the surface layer of soil, stone structures (foundations of houses or paved streets), iron artefacts (which are the most magnetic and easiest detected by this method). In some cases, modern metal residues pose a major problem in magnetic investigations, while sometimes, if they are the goal of the research, this is a great advantage.

Magnetic investigations of archaeological sites can be carried out in two ways. The first, in which the total magnetic field of the Earth is measured by moving one sensor, and the other, when the magnetic field gradient is measured and is performed by moving the sensor pair. More precisely, both methods require the use of two sensors. If one sensor moves over the investigated area, the second sensor must be at the base point and it measures the daily variations of the Earth's magnetic field. Daily variations, which intensities are usually 50-100 [nT], are removed by subtracting data from the base point from those measured in the investigated area.

An important parameter of the interpretation of magnetic measurements is defining the depth at which the source of magnetic anomalies is located. The depth estimation is based on the analysis of an isolated magnetic anomaly or multiple magnetic anomalies. For the estimation of the depth based on an isolated magnetic anomaly, most commonly graphic procedures are used: the half-width rule and the tangents procedure, which, although significantly improved compared to the original graphic procedures (Eppelbaum, 2015), give about $\pm$25% information on the depth of the source of magnetic anomalies (Isles & Rankin, 2013). In recent years, an algorithm has been developed that enables a rapid estimation of the depths to the source of the anomaly based on O3DD magnetic data over the grid of data, using Euler's homogeneity relation that links the field (magnetic or gravitational) and its gradients along the directions (x, y and z) with the source position by the degree of homogeneity (N). The degree of homogeneity is the measure of the decrease of the intensity of the magnetic field with the distance from the source of the anomaly. For simple models, it is interpreted as a structural index (Thompson, 1982) and defines the type of targets used in the O3DD procedure (Reid et al., 1990).

In this work, the Standard and Located O3DD with different structural indexes were tested on synthetic models. On the data the reduction to the pole was applied, although theoretically O3DD is insensitive to magnetic inclination, declination and remanent magnetization (Bastani & Kero, 2004). A model of a prism of definite thickness which lies on shallower and deeper depth was considered, as well as the model on which are shown several bodies at different depths, in an environment with different magnetic susceptibility values compared to the specified bodies. The measured volume magnetic susceptibility of archeological samples ($2.735\cdot10^{-3}$ SI) and surrounding soil ($0.996\cdot10^{-3}$ SI) from site Kremenite njive were used for creating the synthetic models. The measured value of the natural remanent magnetization of black brick sample is $1.818 \cdot 10^{-7}$ [T], and black brick with orange inclusions is $66.02 \cdot 10^{-7}$ [T].

Magnetic investigations were carried out on two occasions in 2012 and 2013 (Vasiljević, 2013) with the GSM-19 Overhauser gradiometer (GEM Systems Inc. Canada, Ontario). The instrument itself allows the work in several ways, and during data acquisition the so-called "walk-mod" (walking gradiometer) was used with vertical distance between sensors of 0.84 [m]. The distance of the lower sensor to the surface of the terrain was 1 [m]. The distance between the profiles was 0.5 [m], and the sampling interval was 0.5 [s]. Using the integrated GPS device, the measurement points were measured in the WGS84 geographic system and the sampling time required to correct the daily variations from the readings from the lower sensor, since in all cases in the available literature for Euler's 3D deconvolution the values of the total magnetic intensity (TMI) are used. The total area of the surveyed site is 2827 [m^2].

RESULTS AND DISCUSSION

Testing Standard and Located O3DD on synthetic data has shown that both methods successfully determine the depths to the sources. For shallow sources, both methods give good results, except that O3DD Locator gives the exact positions of the edges of the source, while with the Standard Method the area covered by solutions is somewhat broader.

In the case of deeper sources, it was necessary to change the value of the structural index for a more accurate determination of the depth. The Standard O3DD well outlined the source of the anomalies, while with the Located method the apexes were well covered by solutions, and the edges were not well defined. A slightly better result for the Located O3DD was obtained when data was first reduced to the pole.

For models with multiple bodies of varying depths, it is shown that better results with both methods are obtained after reduction to the pole. This ensures that the boundaries of all the sources of anomalies are more clearly defined, and the depths are better estimated. By changing the sensitivity level for detecting peaks over the analytical signal network, it has been achieved that O3DD calculation is only performed at the maximum points in the analytical signal network. Such a method of detection of peaks can be used to estimate the depth to the upper surface of the source of anomalies.

Based on the results of the test on synthetic data, for the calculation of the depth to the source of the magnetic anomalies at the site Kremenite njive the Located O3DD was selected with two levels of peak detection with a structural index of 0.5 considered most suitable for contacts (Ried et al., 1990). A normal level of detection of peaks was used, which included only the maximum values in the analytical signal network (all adjacent cells of the network have a lower value). In this way, besides defining the depth to the contact, the depth estimation at the places of the maximum values in the analytical signal is also shown. The contact points are not clearly separated, which was to be expected bearing in mind that the objects, the sources of the anomalies are of irregular shape, as well as different depths of dipping. The range of the depths to the contacts varies from about 0.2 [m] in the northeastern part, over 0.5 [m] in the central parts to between 0.2 and 0.5 [m] in the southwestern part of the anomaly zone.

CONCLUSION

The paper presents the application of O3DD, which enables the rapid estimation of depths to the sources of anomalies on a large surface. The justification of using the method on data collected in the investigated area was made by testing on synthetic data. Although it was possible to clearly determine the edges of the sources of anomalies by the test, on the data from the site Kremenite njive they are not clearly emphasized. Bearing in mind that the bodies that are the source of the anomalies are of irregular shape, such a result is not a surprise. The exception is the only result in the southeastern anomalous zone. Here the positions of Euler's solutions have quite well outlined the edges of the sources of anomalies. Expected depths to the upper boundary of the sources of anomalies are between 0.4 and 0.6 [m].

The choice of the O3DD method itself is reduced to a subjective estimation. Both methods give good results, except that with large datasets the use of Standard O3DD can be highly hardware demanding, while the Located O3DD, in addition to providing more precisely defined edges of the sources, has the advantage to be less hardware demanding. The depth estimation to the upper surface of the objects by O3DD can be used for further archaeological and geophysical research at this site.

ACKNOWLEDGMENT

This study was supported by the Serbian Ministry of Education, Science and Technological Development, (project No. 176016).

LITERATURA / REFERENCES

Bastani, M., Kero, L., 2004. Test of the analytical signal technique and Euler deconvolution on Fosmark data. P-04-283, Swedish Nuclear Fuel and Waste Management Co., Stockholm, Swedish. 51 pp.

Eppelbaum, L., 2015. Quantitative Interpretation of magnetic anomalies from thick bed, horizontal plate and intermediate models under complex physical-geological environments in archaeological prospection, Archaeological Prospection, 23 (2), 255–268.

Isles, D. J., Rankin, L. R., 2013. Geological Interpretation of Aeromagnetic Data. The Australian Society of Exploration Geophysicists. 357 pp.

Reid, A., Allsopt, J., Granser, H., Milletts, A., Somerton, I., 1990. Magnetic interpretation in tree dimension using Euler deconvolution. Geophysics, 50 (1), 80–91.

Tomphson, D., 1982. A new technique for making computer-assisted depht estimates from magnetic data. Geophysics, 47(1), 31–37.

Vasiljević, I., 2013. Definisanje arheoloških objekata na lokalitetu Kremenite njive primenom geofizičkih ispitivanja. Univerzitet u Beogradu, Rudarsko-geološki fakultet, Master rad. 45 pp.