50 Years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, part I, Geology and Geophysics, Sofia, 2003, pp.403-407

EULER DECONVOLUTION OF MAGNETIC ANOMALIES OVER THE BASALTIC BODIES IN NORTHERN BULGARIA

Peter Stavrev[1], Daniela Gerovska[2], Marcos J. Araúzo-Bravo[3]

[1] University of Mining and Geology "St. Ivan Rilski", Sofia 1700, stavrev@mgu.bg
[2] Kyushu University, Fukuoka 812-8581, Japan, daniela@mine.kyushu-u.ac.jp
[3] Burgos University, Burgos 09006, Spain, marara@dali.eis.uva.es

ABSTRACT
Euler deconvolution of magnetic anomalies over basaltic bodies along the Suhindol-Svishtov line in Northern Bulgaria was implemented. Original algorithms and programs for 3D Euler deconvolution using differential similarity transformations of the magnetic field was applied. This allowed simultaneous estimation of the singular point coordinates and the structural index, without requiring input data about the magnetization vector and the shape of the causative bodies. Thus, estimates of the depth range and the main features of the morphology of a number of basaltic bodies along the line of the paleovulcanic centers and their periphery were obtained. Most of the sources are vertical pipelike intrusions (volcanic necks) to the south and lenticular bodies to the north and along the periphery. The depth range of the massive bodies varies from several hundred meters to two kilometers.

INTRODUCTION

The basaltic bodies along the line Suhindol – Svishtov are the only manifestation of volcanic activity with outcrops at the surface in the typically platform setting of Central Northern Bulgaria. The interest towards these formations is supplied by the information they carry about the geologic structure and development of the Moesian platform in its southern part, as well as by the possibility to use them for the production from them of valuable construction material.

The presence of a number of natural outcrops of the basalts and quarries for their output had allowed comparatively detailed studies of their geologic characteristics and physical properties. Information about location, mineral composition, chemical constitution, magnetic properties and paleomagnetism of the basalts can be found in G. Bonchev 1904, Mavrudchiev *et al.* 1971, Jovchev *et al.* 1971, Nozarov *et al.* 1981, Bogdanov *et al.* 1983. Nevertheless, the information about the depth distribution of the basaltic bodies is scarce, and the published estimates of the source depths are of qualitative character (Nozarov *et al.* 1981).

In this article we present results from the application of one direct method for interpretation of magnetic anomalies with possibilities to give numerical estimates for both the depth and shape of the basaltic bodies. The method does not require a previously assumed geometrical and magnetic model and input data for the absolute value and direction of the magnetization vector.

GEOLOGICAL AND GEOPHYSICAL DATA

Fifteen separate basaltic bodies are exposed at the surface between the towns of Suhindol and Svishtov, along a line with azimuth 16° and length 35 km. Their size varies from 200 m to 1 km, forming in some places upland. The basalts are dark-colored and dense rocks, composed primarily of olivine and pyroxene, and belong to the sodium-alkaline type of the basalt-basanitic formation (Mavrudchiev *et al.* 1971, Bogdanov *et al.* 1983). The content of ferromagnetic components is comparatively high, from 6 up to 10%, represented mainly by titanomagnetite (Nozarov *et al.* 1981). The alignment of a number of outcrops along a single line is interpreted as a manifestation of a buried fault along which the magmatic material intruded (Mavrudchiev *et al.* 1971, Jovchev *et al.* 1971). The solidified formations are of subvolcanic type, volcanic necks, and rarely dikes.

The magnetic and paleomagnetic characteristics of the rocks were studied from a number of oriented specimens, collected from natural and man-made outcrops of basaltic bodies (Nozarov *et al.* 1981). The magnetic susceptibility varies from 0.016 SI to 0.046 SI, which determines comparatively high values of the induced magnetization. The natural remanent magnetization is high, with Königsberger ratio between 2 and 26. The normal magnetization is prevailing but for three of the outcrops in the southern part a reverse remanent magnetization was measured. The varying ratios of the vectors of induced and remanent magnetization create diversity in the effective magnetization directions. Paleomagnetic studies estimated the age of the basalt products as Pliocene-Pleistocene, and the depth of the magnetic chambers to be 50 km.

The contrast between the magnetic properties of the basalts and the embedding them nonmagnetic sediments (sandy and clay loam, marl and limestone) is a reason for an intense manifestation of the basalts in the magnetic field. The magnetic anomalies in the area are measured with a middle-scale survey of the vertical component Z. Here they are presented with the calculated modulus T_a of the anomalous magnetic vector (Fig. 1). In the figure, the intense anomalies with amplitude greater than 100 nT are located over and around the outcropping basalts. The contour pattern is isometric with maxima of the anomaly values over the outcrops at the Varcha area, Butovo-yug and Chervena. The anomalies from the same line at Ovcha Mogila, Varbovka, Tashladzhik and Cherna Mogila have an average intensiveness of the maxima between 100 nT and 250 nT.

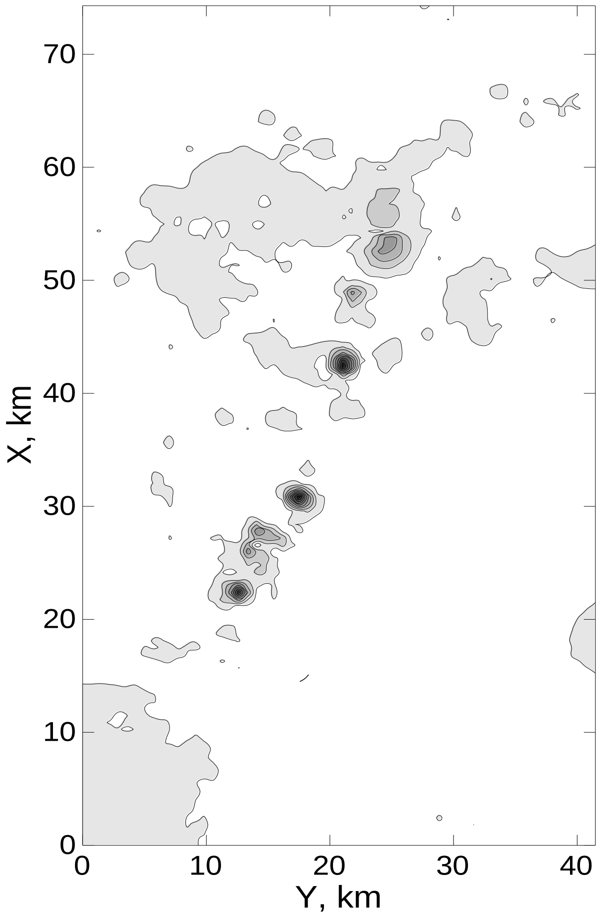

Figure 1. Map of modulus T_a, nT, of the anomalous magnetic vector, calculated from the measured component field Z.

Around these outcrops, at a distance of up to 15-20 km, several low intense magnetic anomalies with extrema below 100 nT can be observed. Their sources are probably buried relics from the area of outflow of the low viscous basaltic lavas. The magnetic anomalies reflect the joint effect of the magnetic bodies. Compared with the outcrops of these bodies, the magnetic anomalies T_a with their maximum and pattern give more information about the location and the shape of the massive intrusive body in plan view and depth. Inverse magnetic problems are posed and solved (see Dimitrov and Stavrev 1986) for obtaining such type of information. Their solutions determine the geometric and magnetic parameters of the source of the magnetic anomaly.

STUDY METHOD

The available information about the anomalous field and its sources in the area of interest advocates the use of direct method of solving of inverse problems. One of the effective direct methods, widely applied, is that of 2D or 3D Euler deconvolution. The latter name was suggested by Reid et al. (1990) but the approach was first proposed by Solovev (1960) and later independently developed in 2D by Thompson (1982). For sources of magnetic field *A* with one singular point $M(x_0,y_0,z_0)$ in the presence of a constant background *B*, Euler's homogeneity equation can be written as

$$\left(x-x_0\right)\frac{\partial A}{\partial x}+\left(y-y_0\right)\frac{\partial A}{\partial y}+\left(z-z_0\right)\frac{\partial A}{\partial z}=N\left(B-A\right), \quad (1)$$

where (x,y,z) are the coordinates of the observation point, N=-n, where n is degree of homogeneity, and N is a coefficient, called structural index (Thompson 1982). The structural index depends on the geometry of the source. For a homogeneous point source N = 3, for a linear source (line of dipoles or poles, and for a homogeneous cylinder, rod, etc.) N = 2, for extrusive bodies (thin layer, dike, etc.) N = 1, for a contact, vertex of a block and a pyramid with a big height N = 0.

The unknown coordinates (x_0, y_0, z_0) are estimated by solving a determined system of linear equations (1) using a prescribed value for N with the least squares method. A solution with a minimum standard deviation is found through using different tentative values for N. The standard deviation should be below a given value, for example less than 15% to 25%, (Reid *et al.* 1990), the estimated source depth z_0. The window size and the respective number of the observation points, for which the system of linear equations is formed taking the data of a grid or a profile, are also parameters in the solving the inverse magnetic problem.

Here we apply one improvement of the Euler deconvolution method, which allows linearisation of the system of equations with N as an unknown, and in the presence of a constant, as well as of a linear background (Stavrev 1997). The problem is solved using a differential similarity transformations (DST) of the component $A(x,y,z)$ of the anomalous magnetic intensity. DSTs are functions of the following type (Stavrev, 1981)

$$S[A]=(u-3)A+(a-x)\frac{\partial A}{\partial x}+(b-x)\frac{\partial A}{\partial y}+(c-z)\frac{\partial A}{\partial z}, \quad (2)$$

where u is a parameter with values ranging from 0 to 3, so that $(u-3)$ = - N in eq.(1), (a,b,c) are the coordinates of a point C, chosen for a center of the geometric similarity. When the similarity center $C(a,b,c)$ coincides with the singular point $M(x_0,y_0,z_0)$, then $S[A]$ = 0 at all observation points. In the presence of a linear background Φ, a linear function $S[A + \Phi]$ = $S[A]$ + $S[\Phi]$ is obtained, since Φ has constant derivatives in eq.(2). On the bases of these properties, the problem is reduced to obtaining a linear distribution of the DST of the observed field $F = A + \Phi$. For the purpose, the residual dispersion of the linear regression for the F data is minimized. The operations are implemented within the limits of a given window along the data grid of a map or a profile. The quality of the result for the unknowns x_0, y_0, z_0 and N is estimated according to two criteria: (a) the relative standard deviation (as mentioned above), and (b) the value of N, which should be between 0 and 3, and with a standard deviation less than a given value, related to the desired degree of approximation (Stavrev 1997).

This described approach we implemented with the developed by Gerovska and Araúzo-Bravo (2003) computer program for Euler deconvolution with unprescribed structural index. Along a data grid, windows of a given size are formed around each grid point. The window center is moved consecutively from point to point along rows and columns. Thus, the scheme of sliding and overriding windows is implemented. The obtained acceptable solutions for x_0, y_0, z_0 and N for sets of neighboring windows are statistically processed. Groups of results related to each separate source are formed with calculation of the mean value and a confidence interval for each estimated parameter.

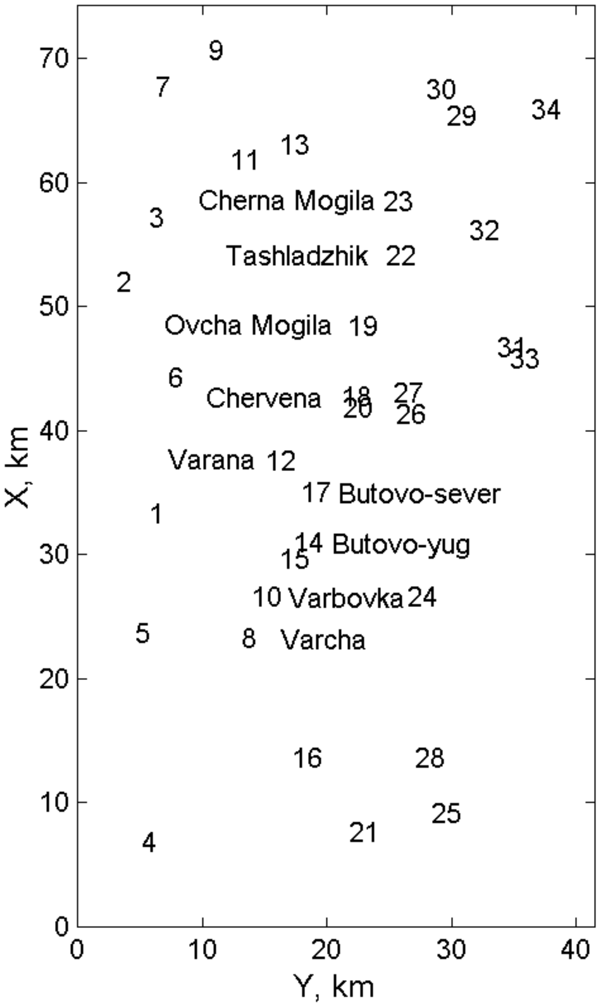

Figure 2. Indices of the formed Euler deconvolution solution clusters, corresponding to the basaltic bodies along the Suhindol-Svishtov line. The indices are used to find the corresponding statistical results for the clusters in Table 1.

RESULTS

Three-dimensional Euler deconvolution of the anomalous magnetic field over an area of 3000 km^2 (Fig. 1) over outcropping and possibly covered basaltic bodies along the Suhindol-Svishtov line was carried out.

According to the width of the anomalous magnetic field manifestations and the initial estimates for the depths of internal points of the bodies, the half width of the window is determined to be 3.2 km. Thus, one window includes 121 data grid points, from which solution for the 4 unknowns x_0, y_0, z_0 and N is obtained.

In Fig. 2, in a plan view of the map of the magnetic field, the numbers of the detected 34 clusters of solutions for the location of sources of magnetic anomalies of different intensiveness are presented. Their horizontal location and the depth with the ovals showing the confidence intervals of the obtained values are given as a graph in Fig. 3, and numerically in Table 1. The analysis of the obtained results gives us the opportunity to interpret the pattern of the anomalous magnetic field, outlining the following line characteristic points.

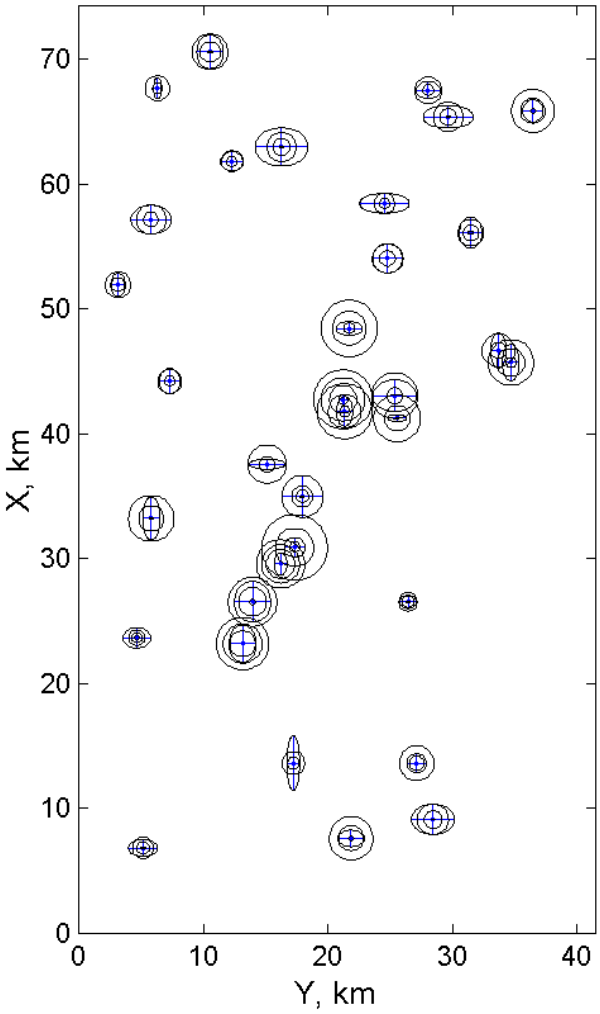

Figure 3. Plan view of the estimated location of the center of gravity of the Euler deconvolution solution clusters with confidence intervals, depicted as concentric circles for the depth and ellipses of confidence for the horizontal position.

The highly intense magnetic anomalies at Varcha, with number 8 in Fig. 2, at Butovo-yug with numbers 14-15, and at Chervena with numbers 18 and 20, have similar values for the depth z_0 and the structural index N. The depth to the internal similarity point of the bodies is within the interval 650 m and 860 m, mean value 760 m, and the structural index N is between 1.56 and 2.51, mean value 2.22. The latter speaks of a widened column-like shape of the basaltic bodies, most probably volcanic necks. According to the pattern and the intensiveness of the anomalies, these are vertical and sub-vertical massive bodies with depth to the bottom at least twice z_0, i.e. at least 1.5 km.

The anomalies with middle range intensiveness can be subdivided into two groups according to the results of the Euler deconvolution. The first group includes the anomalies at Varbovka, number 10, and at Ovcha Mogila, number 19. The depth z_0 is respectively 570 m and 670 m, and the structural index 1.87 and 1.99. From the values of *N*, we can conclude that the shape of the bodies is column-like. The body parameters are close to those of the previously described ones for the intense anomalies, but the body mass is either smaller or their shape is less elongated in depth. The second group of results is related to the bodies at Tashladzhik (number 22) and at Cherna Mogila (number 23). There, the depths z_0 are considerably shallower, 310 m and 200 m, and the values of the structural index are smaller 0.66 and 0.30, respectively. Such indices are typical of thin layers and dikes (*N* = 1), or of thicker layer shaped bodies and contacts with upper vertices close to the surface (*N* = 0). For intermediate values of *N* the body shape can be estimated as lenticular or parallelepiped with various thickness. In the studied case, it is probable that there exists preserved material in the craters of the two close paleovulcanos in the northern part of the Suhindol-Svishtov line.

Table 1. Estimated coordinates singular points and structural indices with their confidence intervals of the basaltic sources of the anomalous magnetic field along the Suhindol-Svishtov line. The estimation is for a window of 11×11grid points at ground level. Column $No_{sol.}$ shows the obtained number of solutions for one source. The confidence intervals are calculated for 95% confidence.

Index	$No_{sol.}$	x_0 , *km*	y_0 , *km*	z_0 , *km*	*N*
1	42	33.24±1.67	5.81±0.68	0.50±0.41	0.56±0.68
2	11	51.95±0.88	3.13±0.57	0.27±0.23	0.60±0.63
3	59	57.17±1.13	5.78±1.60	0.29±0.30	0.61±0.70
4	6	6.84±0.66	5.15±1.16	0.26±0.16	0.22±0.37
5	11	23.66±0.80	4.65±1.09	0.21±0.09	0.19±0.27
6	48	44.21±1.02	7.29±0.85	0.20±0.27	0.38±0.75
7	5	67.68±0.78	6.30±0.29	0.21±0.27	0.41±0.52
8	76	23.21±1.46	13.14±1.09	0.78±0.26	2.40±1.11
9	8	70.60±1.34	10.53±1.08	0.40±0.30	0.84±0.86
10	44	26.56±1.61	13.94±1.45	0.56±0.42	1.87±1.34
11	8	61.84±0.75	12.30±0.92	0.20±0.22	0.56±0.78
12	17	37.58±0.41	15.11±1.42	0.31±0.45	0.85±1.17
13	77	62.99±1.51	16.27±2.08	0.33±0.24	0.83±0.83
14	68	30.91±0.78	17.32±0.82	0.76±0.55	2.21±1.76
15	20	29.60±0.87	16.19±0.50	0.77±0.19	2.50±0.39
16	11	13.65±2.17	17.21±0.51	0.23±0.22	0.44±0.86
17	16	35.00±1.67	17.94±1.63	0.25±0.17	0.56±0.71
18	14	42.77±0.41	21.20±0.36	0.86±0.32	2.42±1.03
19	39	48.45±0.55	21.70±1.03	0.67±0.45	1.99±1.52
20	15	41.82±1.17	21.33±0.64	0.65±0.44	1.56±2.31
21	10	7.61±0.66	21.85±1.04	0.49±0.38	0.93±0.96
22	89	54.05±1.14	24.78±1.24	0.31±0.27	0.66±0.71
23	7	58.47±0.78	24.53±1.96	0.19±0.21	0.30±0.66
24	6	26.55±0.52	26.42±0.64	0.23±0.13	0.34±0.44
25	62	9.13±1.18	28.43±1.70	0.34±0.27	0.74±0.83
26	5	41.27±0.26	25.54±0.74	0.50±0.44	0.39±1.05
27	8	43.07±1.26	25.35±1.75	0.32±0.59	0.61±0.78
28	6	13.64±0.73	27.12±0.79	0.28±0.40	0.57±0.87
29	31	65.39±0.88	29.65±1.99	0.33±0.26	0.84±0.61
30	8	67.52±0.68	28.05±0.94	0.22±0.31	0.73±0.83
31	33	46.68±1.39	33.68±0.61	0.33±0.33	0.69±0.83
32	30	56.11±1.23	31.46±0.90	0.30±0.21	0.63±0.62
33	54	45.73±1.43	34.68±0.67	0.55±0.35	1.12±0.65
34	37	65.87±0.91	36.45±0.81	0.49±0.37	1.37±1.03

At the periphery of the outcropping basalt bodies, where magnetic anomalies of low intensiveness are observed, the results indicate, without exceptions, comparatively shallow depths z_0 and small structural index values *N*. From the marked 20 anomalies (Figures 2, 3 and Table 1), depths within the interval 200 - 500 m, mean value 320 m, and structural indices ranging from 0.19 to 1.12, mean 0.64, were obtained. These results could be interpreted as reflecting the presence of thin to thicker buried remains of lava flows, filling the deeper forms of the paleorelief.

CONCLUSION

The results from the interpretation of the anomalous magnetic field in the region along the Suhindol-Svishtov line using the Euler deconvolution method with unprescribed structural index show in practice the possibilities for estimation of the depth and the shape of the causative bodies with a minimum of required information about the geometry and the magnetization of the bodies. The obtained results are in correspondence to the geologic idea for neck shaped basaltic bodies in the paleovulcanic craters. Besides, the magnetic data interpretation marks bodies from the outflow of basaltic lava.

The source depth and shape estimates can effectively serve as approximations for the construction of magnetic models of the basaltic bodies in the studied area. For the purpose, more detailed and precise magnetic surveys over and around the source outcrops should be done.

REFERENCES

Bogdanov, B. (chief editor) *et al*., 1983. Magmatism and metallogeny of the Carpatian Balkan zone. BAN, Sofia, 300 p., (in Russian).

Bonchev, G., 1904. The basalt in Bulgaria. - *Period. sp. na Balgarskoto knizh. d-vo*, 45, 161-190, (in Bulgarian).

Dimitrov, L., Stavrev, P., 1986. Magnetic methods in geophysics. – Publishing house VMGI, Sofia, 434 p, (in Bulgarian).

Jovchev, J. (editor in charge) *et al*., 1971. Tectonic structure of Bulgaria. - Tehnika, Sofia, 558 p, (in Bulgarian).

Solovev, O. A., 1960. A method of magnetic interpretation using the vertical and horizontal gradients of Za. – Proc. IGG Siberian Br. Acad. of Sc., 1, 15-19, (in Russian).

Stavrev, P., 1981. Similarity transformations of the gravity and magnetic anomalies.- Bulgarian Geophysical Journal., VII, 3, 95-106, (in Bulgarian).

Gerovska, D., Araúzo-Bravo, M., 2003. Automatic interpretation of magnetic data based on Euler deconvolution with unprescribed structural index. - Computers & Geosciences, (in press).

Mavrudchiev, B.D., Moskovski, S.N., Nozarov, P.B.,1971. On the origin and evolution of Plio-pleistocene basalt magmatites in Bulgaria. - Comptes Rendus de l'Acad. bulg. des Sci., 24, 12, 1683-1687.

Nozarov, P., Petkov, N., Kropacek, V., Krs, M., 1981. Application of magnetism and palaeomagnetism to petrogenetic studies of basalts, northern Bulgaria. - Journal of Geophysical Science, Applied Geophysics, volume 13, 61-81.

Reid, A.B., Allsop, J.M., Granser, H., Millet, A.J., Somerton, I.W., 1990. Magnetic interpretation in three dimensions using Euler deconvolution. - Geophysics, 55, 80-91.

Stavrev, P., 1997. Euler deconvolution using differential similarity transformations of gravity or magnetic anomalies. - Geophysical Prospecting, 45, 2, 207-246.

Thompson, D.T., 1982. EULDPH – a new technique for making computer assisted depth estimates from magnetic data. - Geophysics, 47, 31-37.

Recommended for publication by Department Applied Geophysics, Faculty of Geology and Prospecting