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Geologica Macedonica	Год.	Број	стр.	Штип

TABLE OF CONTENTS

Geologica Macedonica	Vol. **36**	No 1	pp. 1–100	Štip 2022
Geologica Macedonica	Год.	Број	стр.	Штип

СОДРЖИНА

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Original scientific paper

GEOMAGNETIC MODEL OF LAKAVICA DEPRESSION

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A b s t r a c t: This paper presents the results from the geomagnetic explorations conducted on the territory of the Lakavica depression (graben) which is located near Štip, in the eastern part of N. Macedonia. According the tectonic regionalization of Macedonia the Lakavica depression is located in the Vardar zone. It is relatively sinked block with orientation NW-SE, between the horst of Serta–Grdeški Mountains and the horst of Bučim block–Smrdeš. From the southwest, the Lakavica depression is limited with the horst of Serta–Smrdeški Mountains along the contrast normal (gravitational) fault. The horst of Bučim block–Smrdeš, which is characterized with very complex morphological structure, limits the Lakavica depression on the northeast. The geophysical–geomagnetic investigations were performed by three proton magnetometers. One was located on the base station and countinuously measured the daily variation, and with other two was measured total vector of the magnetic field. The magnetogram obtained from the magnetometer placed on the base station was used during the process of data processing for elimination of daily variation. The obtained results from the performed geophysical investigations confirmed that Lakavica is a depression sikned between two rised blocks.

Key words: exploration; geomagnetic method; depression; total field

INTRODUCTION

The Lakavica depression is located in eastern Macedonia, along the river of Kriva Lakavica. On the southwest side it is bordered by the mountains of Serta, Gradeška Planina and Plauš, and on the northeast side by the mountains of Plačkovica and Smrdeš. This depression is about 70 km long and up to 7 km wide. It has a northwest–southeast orientation and is bounded by a contrasting normal fault on the southwest side, and is partially tectonically bounded by the northwest side. The Lakavica depression is a relatively lowered block between the Serta Horst – Gradeški Mountain from the southwest and the Bučim block – Smrdeš from the northeast. [Petrov, Stojanova and Mirčovski, 2012].

According to the geotectonic regionalization of Macedonia, the Lakavica depression is located in the Vardar zone, more precisely in its eastern subzone. The geological structure of the wider area of the Lakavica depression is quite heterogeneous, with a predominance of tectonic structures from the so-called Vardar direction (north–northeast–south–southwest). The heterogeneous lithological composition is represented by various rock masses of Precambrian age, Old Paleozoic metamorphic rocks, Jurassic (Mesozoic) basic magmatic rocks and granitoids, Cretaceous sediments, Upper Eocene flysch sediments, and Neogene-Quaternary sediments and volcanites.

In Macedonia, until now, were performed geomagnetic and gravity measurements. Based on these investigations were created map of vertical Z–component of the geomagnetic field and map of Bouguer's anomaly. According that explorations, in eastern part of Macedonia are separated several regional magnetic anomalies which are separated by interspaces with a negative sign.

Geomagnetic measurements presented in this paper showed the geomagnetic model for the Lakavica depression.

GEOLOGICAL AND HYDROGEOLOGICAL STRUCTURE OF THE INVESTIGATION AREA

The wider vicinity of the Lakavica depression, which is an integral part of the Vardar zone, are characterized by a complex lithological structure represented by different rock types (Figure 1) (Petrov and Stojanova, 2015):

– Precambrian rocks,

– rocks from the Paleozoic complex,

– Jurassic igneous rocks,

– Cretaceous sediments,

– Neogene-Quaternary sediments and volcanites.

Precambrian rocks: The Precambrian rocks have a northwest-southeast orientation. From the northwest side they are covered with Neogene and deluvial formations, and to the east-northeast above them lie transgressively Paleogene and Neogene sediments. The Precambrian complex is represented by different types of gneisses, micashists, graphite schists, quartzites, amphibolites, marbles and cipollino marbles.

Paleozoic rocks: The Paleozoic rocks form the eastern edge of the Vardar zone, between the Damjan block and the Bučim block. Several lithostratigraphic series are distinguished in the complex of Old Paleozoic rocks: amphibolite shists and marbles, chlorite-amphibolite shists and shistose-carbonate series with carbonate shists.

Jurassic igneous rocks: The most common rocks from the Jurassic complex are the granitoids (Štip granites) that extend from Štip toward southeast to the mouth of the Madenska river in Kriva Lakavica, with a length of about 20 km and an average width of about 10 km. The granitoids intrude the Precambrian metamorphic complex (gneisses and micashists), as well as the rocks of the Old Paleozoic complex, on which they underwent intense metasomatic changes (in the Damjan region). On the southwest, the granitoids are tectonically bounded by the Precambrian rocks, but this tectonic structure is covered by Paleogene and Neogene sediments along the Kriva Lakavica river. Granitoids are represented by granodiorites, quartzmonzonites and granites.

On the investigated terrain are present serpentinites that appear along tectonic dislocations. They tectonically protruded in the Old Paleozoic rocks and the granitoides. On several places, serpentinites are covered with Neogene sediments from the Lakavica depression.

At the mouth of the river of Madenska in Kriva Lakavica, in the form of an elongated zone with orientation northwest-southeast, there are contact – metamorphic rocks – skarns with a length of about 5 km and a width of about 1 km. They are represented by schistose rocks, amphibole and pyroxene schists, cipollino marbles, marbles, skarns, etc.

Cretaceous: The Cretaceous sediments are separated in the horst of Bučim block – Smrdeš as elongated zone with orientation north-northwest – south-southeast, with a length of 7–8 km and a width of about 1 km. The following facies participate in the construction of the Cretaceous sediments: facies of tuff-flyschoid sediments, facies of marls and slates, facies of limestones and sandstones, facies of conglomerates and facies of andesitic tuffs.

Upper Eocene: The Upper Eocene sediments are mostly present in the southwestern parts of the horst Serta – Gradeški Mountain, in the Lakavica depression, and less in the horst of Bučim block – Smrdeš. According to the lithological composition in the Upper Eocene sediments, the following lithological-stratigraphic series are distinguished: conglomerate flysch, lower zone of yellow sandstones, lower zone of flysch and upper zone of flysch.

Tertiary volcanic rocks: The Tertiary volcanism in the area of the Lakavica depression represents a product of tectonic-magmatical processes which took part in the Vardar zone and on the contact zone with the Serbian–Macedonian massiv. The volcanic complex is presented with pyroclasts, latites, quartzlatites, andesites, trachites and rhyolites.

Pyroclasts: Pyroclasts are present on the right side of the Kriva Lakavica river, in the vicinity of the village of Brest. They occupy the lower parts of the volcanic complex and lie through Upper Eocene sediments, granitoids and Old Paleozoic shists. Above them lie andesites and in some places they intruded them. Pyroclasts are represented by tuffs and tuffites that alternate in both vertical and horizontal direction.

Andesites: The andesites, which include latites, quartzlatites, rhyolites, and trachites, occur in clusters arranged along tectonic structures with orientation northwest–southeast. Andesitic bodies in the shape of necks and dykes occur in the vicinity of the Bučim village, where they intrude in the gneisses (Precambrian complex) and are associated with copper mineralization.

Pliocene sedimentary complex: Pliocene sediments are developed in the Lakavica depression and have orientation northwest–southeast. Their thickness is up to 150–200 mm. In the lithological structure of the Pliocene complex are present: gravels, sands, sandstones which are, tectonically, undisturbed (Dumurdžanov, Petrov et al., 2002).

Quaternary: Quaternary sediments are distributed along the Bregalnica and Kriva Lakavica rivers, as well as along the southwestern edge of the Lakavica depression. They are presented with terraced, alluvial and deluvial sediments.

The Lakavica depression is an elongated structure between the rised blocks of Serta-Konečka Mountain from the southwest and the Bučim block (Plačkovica) from the north-northeast. This structure is relatively long and has a small cross section.

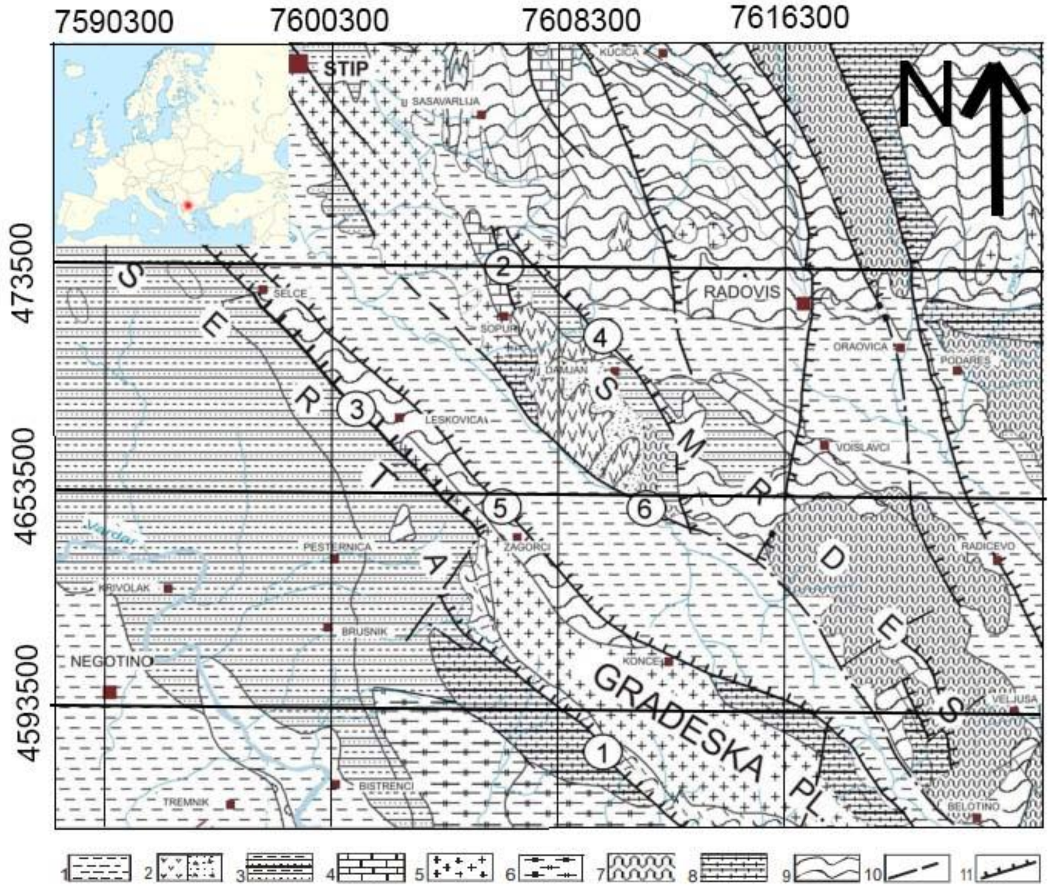


Fig. 1. Geological Map of the wider vicinity of the Lakavica depression (Petrov, Stojanova and Dimov, 2013)
1 – Quaternary and Neogene sediments, 2 – Tertiary volcanic rocks, 3 – Upper Eocene flysch sediments, 4 – Cretaceous sediments, 5 – Jurassic (and older) granitoides, 6 – Jurassic gabbro-diabases, 7 – Lower Paleozoic complex, 8 – Riphean Cambrian complex, 9 – Precambrian complex, 10 – faults, 11 – peels

Hydrogeological characteristics

Regionalization of the terrain from a hydrogeological aspect, is made based on the hydrogeological parameters of the environment (structural type of porosity, degree of water permeability and hydrogeological (HG) function). (SARDICH, 2015).

According to the structural type of porosity, the represented rock masses in the wider vicinity of the investigated area are categorized in the following groups:

Group I – rocks with intergranular porosity, where a boundary (intergranular) type of well is developed. In this group are distinguished the unbound clastic Quaternary alluvial terrace and proluvial sed4iments.

Group II – rocks with karst–fissure porosity, where a karst type of water body is formed. In this group are separated Paleozoic marbles, which appear in the gn3eiss complex as isolated masses with limited sp4reading.

Group III – rocks with crack porosity, where a fissure type of wells is developed. In this group are separated the solid cracked rock masses (andesites, granites, shists), which together form a complex fissure type of well.

Group IV – conditionally waterless, mostly waterproof rocks, and waterless waterproof rocks, in which there is a conditionally waterproof and waterless environment. This group includes solid rock masses (gneisses, serpentinites, quartzmonzonites), with insignificant cracking (shallow below the surface of the terrain), and in depth they are waterproof. These water wells are formed locally and with very limited distribution.

Group V – waterless alternated clastic rocks which are waterproof. Here is distinguished Eocene flysch.

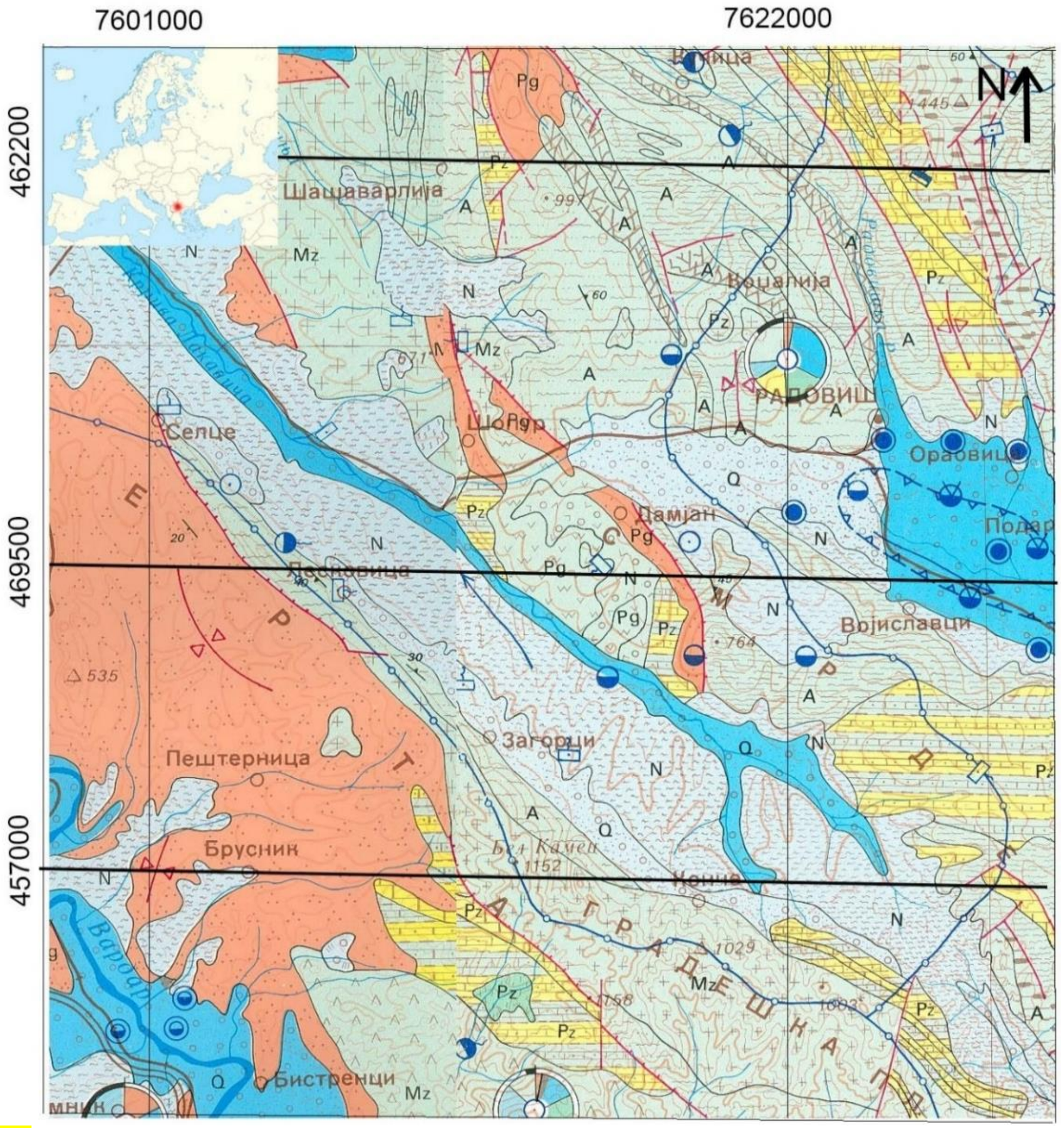


Fig. 2. Cutting of the hydrogeological map of the vicinity of the investigated area (Hydrogeology Map 1:200 000, 1977)

Former geophysical surveys

Former geophysical investigations on the territory of Macedonia were performed in the 50th and 60th years of twentieth century. Based on that exploration were created a map of Bouguer's anomaly and a map of vertical Z-component of the geomagnetic field.

According this data, the Lakavica depression has the following geophysical characteristics: in the area of the Lakavica depression and its surroundings (Figure 3), several maximums and minimums of the Bouguer's anomaly can be seen. The depression itself is clearly defined by two minimums:

$$\Delta g = -10^{-5}\,\mathrm{ms}^{-2}$$

and other minimum is south–southeast with

$$\Delta g = -16\cdot 10^{-5}\,\mathrm{ms}^{-2}.$$

At the edges there are maximums with $\Delta g = 12 \cdot 10^{-5}$ ms^{-2}. Interesting anomalies are near Šopur with $\Delta g = -12 \cdot 10^{-5}$ ms^{-2} and Šašavarlija with $\Delta g = 0$ ms^{-2}, which are outside the depression. The relatively dense arrangement of minimums and maximums from a gravimetric point of view, in such a small space, indicates different rock densities and complex geological and structural construction.

On the map of the vertical component of the magnetic field ΔZ there are a number of anomalies with positive and negative sign, as well as with different intensity (Figure 4). This is another proof of the complex composition of the rock masses. On the part of the depression, the pronounced volcanism in the area of Bučim-Damjan–Borov Dol is strongly felt.

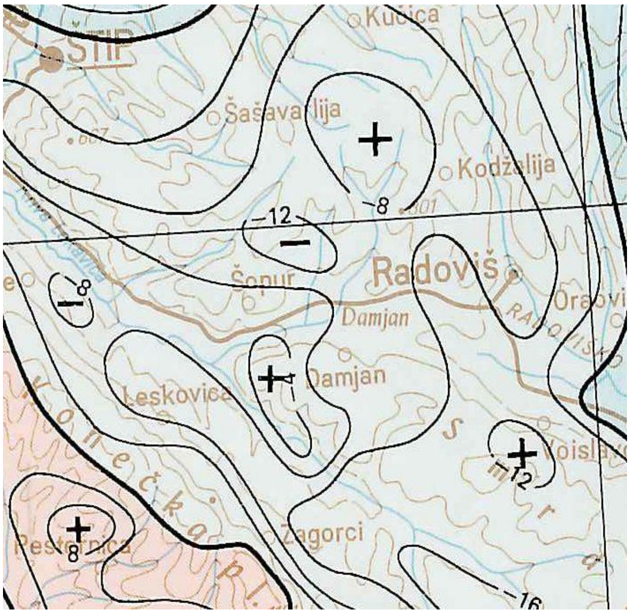


Fig. 3. Part of the Map of Bouguer's Anomalies of the Lakavica depression (Map of the Bouguer's anomalies, 1 : 500 000)

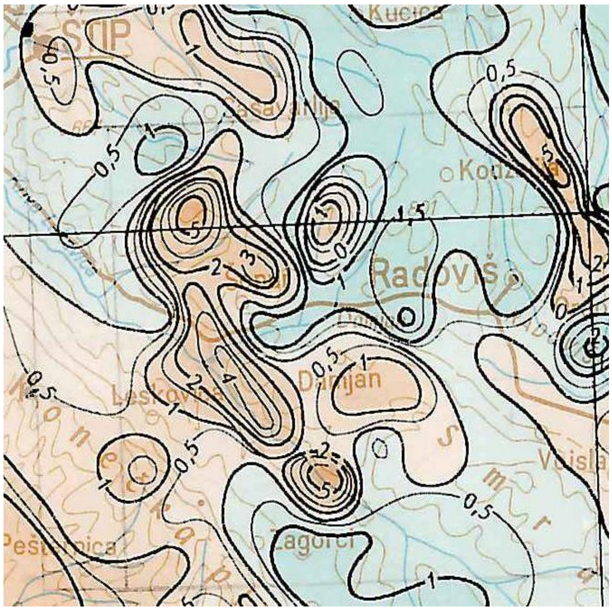


Fig. 4. Part of the Map of the vertical geomagnetic Z-component of the Lakavica depression (Map of the Vertical Z-component 1 : 500 000)

MATERIALS AND METHODS

In order to study the magnetic structures of the field in the Lakavica depression, the total vector of the geomagnetic field was measured along certain profiles with a relatively high density of measuring points.

Based on these field measurements and cabinet data processing, maps of the total magnetic field vector in the depressions were obtained for the first time.

Measurements were performed with proton precession magnetometers Bison and Geometrix. Three magnetometers were used (Delipetrov, T., 2003).

Proton precession magnetometers, also known as proton magnetometers, measure the resonance frequency of protons (hydrogen nuclei) in the magnetic field to be measured, due to nuclear magnetic resonance (NMR) (Auster, 2008).

Because the precession frequency depends only on atomic constants and the strength of the ambient magnetic field, the accuracy of this type of magnetometer is very good.

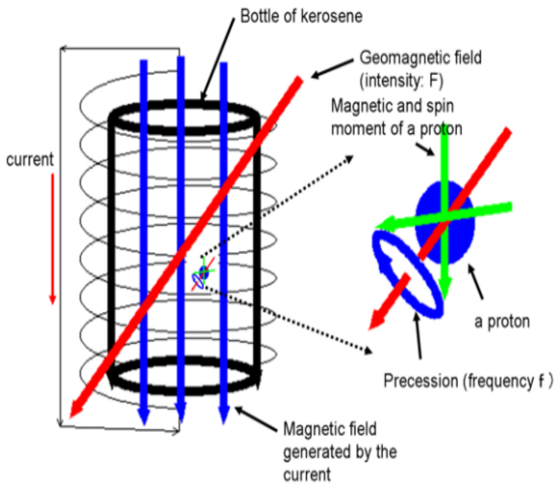


Fig. 5. Sketch of proton precession magnetometer (Magnetometer – Space Instrumentation and Observation (I) syllabus, 2011)

RESULTS AND DISCUSSION

After the performed explorations, or measurements of the total geomagnetic field of Lakavica depression, analysis of the obtained data was made and according the obtained results maps were created (Delipetrov et al., 2000).

A magnetogram is obtained from the instrument placed on the base station, which covers the time interval of the magnetic measurements. This magnetogram is used in the process of processing the measured results to remove the daily variation of the magnetic field. The analysis shows that the measurements were performed on magnetically calm days, i.e. the daily variation is in the interval of several nT.

The mean value of the normal magnetic field of the total vector is in the interval of 46 337 nT.

The other two instruments were used for measurements of the magnetic field on the projected profiles. The measured results are presented in the Tables 2 to 8.

Elimination of the daily variation from the measured result is performed using the following equation:

$$T_i = T_M + (\pm T_{DV}),$$

where:

T_i – value of eliminated daily variation,

T_M – measured values for every point of the magnetic field,

T_{DV} – values of daily variation.

Than, the calculation of the normal field is performed according the equation (Kearey, et al, 2002):

$$T_N = a_1 + a_2\Delta\varphi + a_3\Delta\lambda + {}_4\Delta\varphi^2 + a_5\Delta\lambda^2 + a_6\Delta\varphi\Delta\lambda \ ,$$

where:

$\Delta\varphi = \varphi_1 - \varphi_0$

$\Delta\lambda = \lambda_1 - \lambda_0$

T_N – normal magnetic field

φ_1 – latitude of measurement point

φ_0 – latitude of base station

λ_1 – longitude of measurement point

λ_1 – longitude of base station

$a_1 - a_6$ – coefficients calculated for each profile (Table 1).

Subtracting the normal value of the magnetic field gives the anomalous value of the magnetic field ΔT, given by the formula

$$\Delta T = T_M + (\pm T_{DV}) - T_N = T_i - T_{N.}$$

The obtained maps show the anomalous values of the magnetic field of the factors that are located at different depths, or the magnetic field ΔT gives the summary picture of the researched field, in order to single out the causes of the magnetic anomalies that have local and regional significance. The values of ΔT were filtered:

$$\Delta T = \Delta T_R + \Delta T_{L,}$$

where:

ΔT – total anomaly

ΔT_R – regional anomaly

ΔT_L – local anomaly

With the help of linear regression analysis method, the total value of ΔT is divided into regional ΔT_R – the values of the linear part and ΔT_L – the residues between the linear curve and the results for ΔT. These results are shown on maps for regional and local geomagnetic anomalies.

The method of linear regression analysis is a method that is combined with the current knowledge of the researched field.

Comparing the obtained maps for ΔT_R and ΔT_L with the method of regression analysis, their agreement in defining local and regional anomalous values can be seen.

Further are given results and the model obtained from the processed measurement data which were performed on seven profiles.

On the map, Figure 7, are presented anomalies of the total vector of the geomagnetic field. Strongly expressed is the anomaly between the villages of Suvo Grlo on south and Goračino on north. The values of ΔT are the highest on south-souteast with ΔT = 1675 nT, and decreased toward west to ΔT = 1300 nT, as well as toward the depression axes to values of ΔT = 1400 nT.

On Figures 8 and 9 are shown the maps of regional and local vector of the geomagnetic field on the Lakavica depression.

It is clearly seen that on the map of the regional vector ΔT_R the field is quiet with a numerous isolines that is calmer with a large number of isolines that are not enclosed in the investigation area. The values decrease going towards the axis of depression, so that on this map the depression is clearly defined.

T a b l e 1

Calculated values for coefficients of the elements

Element	a_1	a_2	a_3	a_4	a_5	a_6
H	24312.7	–6.7716	0.94910	–0.009034	–0.0004253	–0.0036940
Z	37955.9	12.8860	3.13740	0.0000060	–0.0014000	–0.0049550
T	45047.09	7.6930	3.14070	–0.004336	–0.0011680	–0.0002080
D	55.695	0.024390	0.197130	0.000465	0.0001057	0.0000139
I	3442.01	96703.0	0.055560	0.000451	–0.0000056	–0.0000019

T a b l e 2.

Data from the measurements of the total vector T for profile I – I'

Station	ϕ_1	λ_1	ϕ_o	λ_o	*Tm* (nT)	*Tn* (nT)	ΔT (nT)	ΔT_R (nT)	ΔT_L (nT)
1	41.7348	22.1594	41.7348	22.1906	46531	45046.744	1490	1434	56
2	41.7025	22.1635	41.7348	22.1906	46542	45046 720	1500	1438	63
3	41.6929	22.1679	41.7348	22.1906	46496	45046696	1453	1441	12
4	41.6879	22.1723	41.7348	22.1906	46510	45046.672	1467	1445	22
5	41.6834	22.1774	41.7348	22.1906	46467	45046.653	1424	1449	–25
6	41.6797	22.1843	41.7348	22.1906	46435	45046.646	1391	1453	–61
7	41.6761	22.1894	41.7348	22.1906	46453	45046.635	1409	1456	–47
8	41.6719	22.1925	41.7348	22.1906	46460	45046.612	1415	1460	–45
9	41.6681	22.1979	41.7348	22.1906	46463	45046.6	1418	1464	–46
10	41.6646	22.2017	41.7348	22.1906	46462	45046.585	1417	1468	–50
11	41.662	22.2067	41.7348	22.1906	46498	45046.58	1455	1472	–16
12	41.6592	22.2102	41.7348	22.1906	46498	45046.57	1455	1475	–20
13	41.6554	22.2136	41.7348	22.1906	46507	45046.551	1463	1479	–16
14	41.6528	22.2174	41.7348	22.1906	46488	45046.543	1443	1483	–39
15	41.65	22.2212	41.7348	22.1906	46624	45046.534	1578	1487	92
16	41.6469	22.2225	41.7348	22.1906	46636	45046.514	1590	1490	100
17	41.6441	22.2256	41.7348	22.1906	46635	45046.502	1588	1494	94
18	41.6422	22.2294	41.7348	22.1906	46640	45046.499	1594	1498	95
19	41.6404	22.2326	41.7348	22.1906	46430	45046.496	1384	1502	–118
20	41.6373	22.2379	41.7348	22.1906	46486	45046.488	1440	1506	–66
21	41.6361	22.2445	41.7348	22.1906	46499	45046.5	1453	1509	–57
22	41.6342	22.2512	41.7348	22.1906	46667	45046.506	1620	1513	107
23	41.6321	22.2571	41.7348	22.1906	46628	45046.509	1581	1517	65
24	41.6302	22.2622	41.7348	22.1906	46532	45046.51	1484	1521	–36
25	41.6279	22.2676	41.7348	22.1906	46612	45046.509	1564	1525	40
26	41.6251	22.2735	41.7348	22.1906	46458	45046.506	1410	1528	–118
27	41.6225	22.278	41.7348	22.1906	46452	45046.501	1404	1532	–128
28	41.6194	22.2824	41.7348	22.1906	46726	45046.49	1678	1536	142

T a b l e 3

Data from the measurements of the total vector T for profile II – II'

Station	ϕ_1	λ_1	ϕ_o	λ_o	*Tm* (nT)	*Tn* (nT)	Δ*I* (nT)	ΔT_R (nT)	ΔT_L (nT)
1	41.6154	22.2786	41.7348	22.1906	46496	45046.448	1448	1461	–14
2	416130	22.2754	41.7348	22.1906	46487	45046.419	1438	1465	–27
3	41.6114	222720	41.7348	22.1906	46573	45046.396	1524	1468	55
4	416090	22.2698	41.7348	22.1906	46512	45046.371	1466	1472	6
5	41.6074	22.2666	41.7348	22.1906	46525	45046.349	1479	1475	4
6	41.6046	22.2638	41.7348	22.1906	46526	45046.318	1480	1478	1
7	41.6022	22.2616	41.7348	22.1906	46523	45046.293	1478	1482	–4
8	41.6003	22.2584	41.7348	22.1906	46522	45046.268	1477	1485	9

T a b l e 4

Data from the measurements of the total vector T for profile III – III'

Station	ϕ1	λ1	ϕo	λo	*Tm* (nT)	*Tn* (nT)	Δ*T* (nT)	Δ*TR* (nT)	Δ*TL* (nT)
1	41.6093	22.2526	41.7348	22.1906	46700	45046.319	1655	1515	137
2	41.6107	22.2594	41.7348	22.1906	46631	45046.351	1586	1513	72
3	41.6133	22.2559	41.7348	22.1906	46535	45046.36	1490	1508	19
4	41.6152	22.2527	41.7348	22.1906	46619	45046.365	1574	1505	70
5	41.617	22.2483	41.7348	22.1906	46580	45046.365	1535	1429	76
6	41.6192	22.2464	41.7348	22.1906	46576	45046.376	1530	1434	36
7	41.6218	22.242	41.7348	22.1906	46578	45046.382	1532	1439	43
8	41.6241	22.2382	41.7348	22.1906	46445	45046.388	1396	1464	33
9	41.6265	22.2348	41.7348	22.1906	46446	45046.396	1397	1479	83
10	41.6302	22.2266	41.7348	22.1906	46473	45046.398	1422	1465	53
11	41.6323	22.2237	41.7348	22.1906	46471	45046.405	1420	1460	50
12	41.6342	22.2212	41.7348	22.1906	46457	45046.412	1403	1455	62
13	41.6356	22.2184	41.7348	22.1906	46470	45046414	1416	1450	44
14	41.6373	22.2162	41.7348	22.1906	46482	45046.42	1427	1445	28
15	41.6399	22.2131	41.7348	22.1906	46483	45046431	1425	1440	22
16	41.6418	22.2108	41.7348	22.1906	46467	45046.438	1428	1435	21
17	41.6441	22.2095	41.7348	22.1906	46481	45046.452	1422	1430	19
18	41.6469	22.2061	41.7348	22.1906	46486	45046.462	1425	1425	11
19	41.6505	22.1979	41.7348	22.1906	46485	45046.464	1423	1421	8
20	41.6521	22.1947	41.7348	22.1906	46477	45046.467	1415	1416	11
21	41.6545	22.1913	41.7348	22.1906	46464	45046.474	1401	1411	20
22	41.6575	22.1878	41.7348	22.1906	46468	45046.487	1405	1406	11
23	41.6604	22.1828	41.7348	22.1906	46483	45046.493	1420	1404	9
24	41.6632	22.1802	41.7348	22.1906	46469	45046.506	1403	1403	4
25	41.6653	22.1764	41.7348	22.1906	46441	45046.511	1325	1401	26

T a b l e 5

Data from the measurements of the total vector T for profile 1 – 1'

Station	ϕ_1	λ_1	ϕ_o	λ_o	*Tm* (nT)	*Tn* (nT)	ΔT (nT)	ΔT_R (nT)	ΔT_L (nT)
1	41.7348	22.1906	41.7348	22.1906	46569	45046.463	1520	1519	1
2	41.6347	22.2363	41.7348	22.1906	46573	45046.43	1524	1525	–1
3	41.6319	22.2326	41.7348	22.1906	46590	45046.404	1540	1531	9
4	41.6291	22.231	41.7348	22.1906	46598	45046.378	1549	1536	12
5	41.6267	22.2288	41.7348	22.1906	46553	45046.358	1504	1542	–39
6	41.6248	22.2269	41.7348	22.1906	46605	45046.336	1556	1548	8
7	41.6229	22.2247	41.7348	22.1906	46612	45046.316	1563	1554	9
8	41.621	22.2228	41.7348	22.1906	46610	45046.296	1561	1560	1

T a b l e 6

Data from the measurements of the total vector T for profile 2 – 2'

Station	ϕ_1	λ_1	ϕ_o	λ_o	*Tm* (nT)	*Tn* (nT)	ΔT (nT)	ΔT_R (nT)	ΔT_L (nT)
1	41.6535	22.2105	41.7348	22.1906	46456	45046.463	1520	1519	1
2	41.6514	22.2073	41.7348	22.1906	46480	45046.43	1524	1525	–1
3	41.6498	22.2039	41.7348	22.1906	46488	45046.404	1540	1531	9
4	41.6479	22.201	41.7348	22.1906	46494	45046.378	1549	1536	12
5	41.6458	22.1988	41.7348	22.1906	46474	45046.358	1504	1542	–39
6	41.6441	22.196	41.7348	22.1906	46467	45046.336	1556	1548	8
7	41.6427	22.1938	41.7348	22.1906	46456	45046.316	1563	1554	9
8	41.6404	22.1909	41.7348	22.1906	46465	45046.296	1561	1560	1

T a b l e 7

Data from the measurements of the total vector T for profile 3 – 3'

Station	ϕ_1	λ_1	ϕ_o	λ_o	*Tm* (nT)	*Tn* (nT)	ΔT (nT)	ΔT_R (nT)	ΔT_L (nT)
1		22.1796	41.7348	22.1906	46490	45046.618	1427	1420	7
2	41.6764	22.1761	41.7348	22.1906	46480	45046.595	1418	1421	–2
3	412.6743	22.1739	41.7348	22.1906	46478	45046.572	1416	1421	–4
4	41.6728	22.1714	41.7348	22.1906	46475	45046.553	1414	1421	–7
5	41.6712	22.1679	41.7348	22.1906	46479	45046.529	1420	1422	–1
6	41.6703	22.1648	41.7348	22.1906	46489	45046.513	1431	1422	9
7	41.6688	22.1607	41.7348	22.1906	46478	45046.488	1420	1422	–3
8	41.6684	22.1563	41.7348	22.1906	46481	45046.471	1424	1423	1

Table 8

Data from the measurements of the total vector T for profile 4 – 4'

Station	ϕ_1	λ_1	ϕ_o	λ_o	*Tm* (nT)	*Tn* (nT)	ΔT (nT)	ΔT_R (nT)	ΔT_L (nT)
1	41.6999	22.1553	41.7348	22.1906	46497	45046.711	1434	1431	3
2	41.6985	22.1522	41.7348	22.1906	46488	45046.69	1424	1430	–6
3	41.6964	22.1484	41.7348	22.1906	46487	45046.662	1423	1429	–6
4	41.694	22.1475	41.7348	22.1906	46499	45046.641	1435	1429	7
5	41.6919	22.1427	41.7348	22.1906	46496	45046.61	1432	1428	5
6	41.6896	22.1402	41.7348	22.1906	46494	45046.584	1428	1427	1
7	41.6867	22.1377	41.7348	22.1906	46488	45046.554	1422	1426	–4
8	41.6837	22.1351	41.7348	22.1906	46489	45046.523	1424	1425	–1

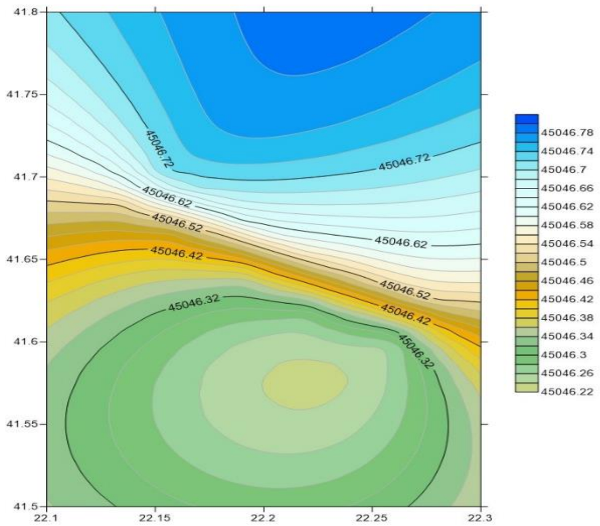


Fig. 6. Map of normal magnetic field T_n of the Lakavica depression

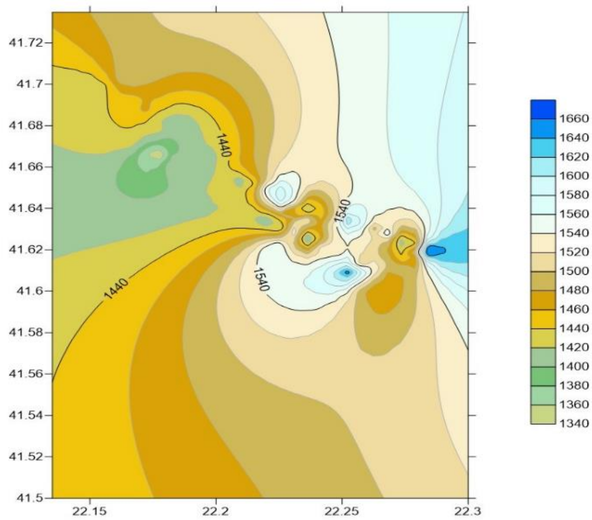


Fig. 7. Map of total magnetic vector ΔT of the Lakavica depression

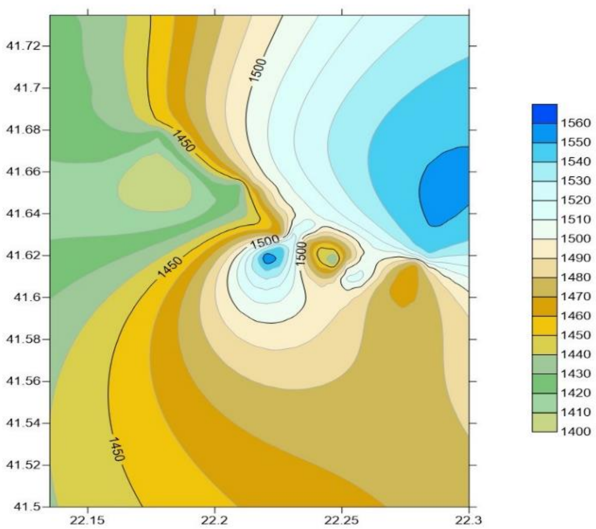


Fig. 8. Map of regional magnetic vector ΔT_R of the Lakavica depression

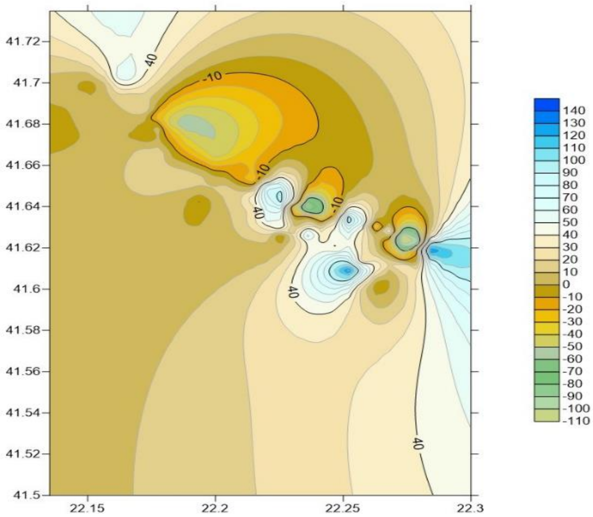
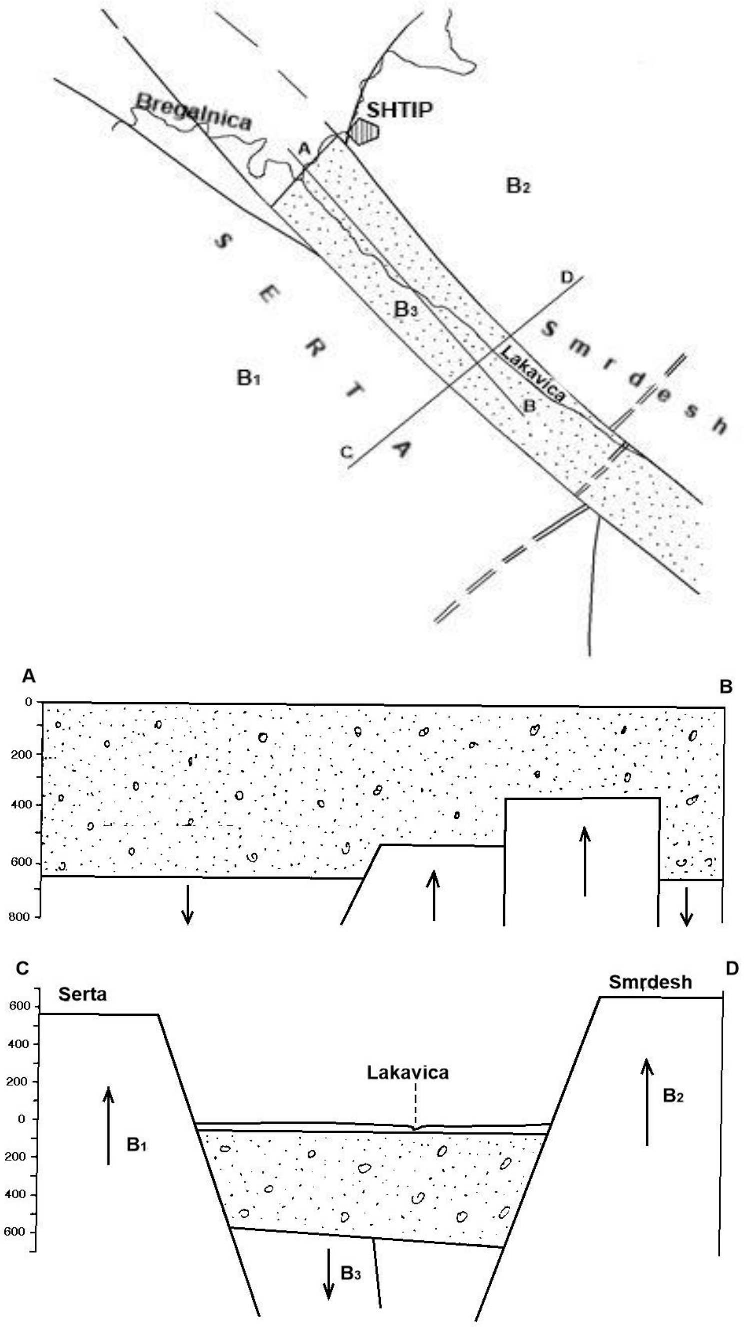


Fig. 9. Map of local magnetic vector ΔT_L of the Lakavica depression

On the map of local anomalies (Figure 9) more strongly expressed maximums and minimums are distinguished. Some of the anomalies can be interpreted as monopoles, but also some anomalies clearly express the magnetic dipole structure with a defined direction of dipping. For complete interpretation of these anomalies, we need additional geomagnetic surveys with higher density of measuring points. Some maximums are with values $\Delta T_L = 100$ nT, and some of the minimums are with values $\Delta T_L = -100$ nT.

Such expressed minimums and maximums show presence of rocks with high magnetic characteristics that can be interesting as mineral raw materials.

Figure 10 shows the geophysical model of the Lakavica depression, obtained from the measured results.



Rising morphostructures
B_1 – Serta
B_2 – Smrdeš

Sinking morphostructures
B_3 – Lakavica depression (graben)

Fig. 10. Geophysical model of the Lakavica depression

Analysis and interpretation of results

Disturbances of the total magnetic field vector in intensity and direction can be caused by different types of magnetic anomalies. An anomaly is often a summary effect of more than one simple magnetic sources, but its appearance, although simple, due to their interaction, is often complex.

If we compare the regional anomalous fields with the geological map of the researched area, it can be noticed that the magnetic anomalies better determine the geological boundaries and deep faults of certain geological structures and give very important information about the internal structure.

The analysis of the maps of the total vector of the magnetic field ΔT gives the possibility to define spaces with more or less magnetism. In order to get a clearer picture of the existing anomalies in depression, the previously mentioned analyses were performed (Delipetrov and Karakašev, 2000).

The map of the regional magnetic field of the depressions ΔT_R gives the influence of the magnetic factors that are deeper in the depressions and their influence is felt in a larger area of the investigated area. When analyzing the map of the regional magnetic field of depressions, it is noticed that the intensity of the magnetic field is the lowest in the central part of the depression.

After filtering the anomalous vector ΔT on a regional ΔT_R and a local ΔT_L component, attempts were made to calculate the depths of the causes of the local magnetic anomalies. The formula was used for that purpose:

$$T = \frac{M}{z^2},$$

where:

T – the intensity of local anomaly,

M – the magnetic moment of local anomaly,

z – the depth of the geological structure.

Defining the depth of dipping of the causes of local anomalies in the depression is a numerical data that defines the relationships of the blocks that make up the base of the sediment complex (bedrock) of depression.

DISCUSSION

This investigation is part of the measurements conducted in the period 1998–2000 for the purposes of the scientific project "Geophysical research and creation of a geophysical model of modern depressions in Eastern Macedonia", funded by the Ministry of science and education of the Republic of N. Macedonia. In this project were measured several depressions: Dojran depression, Strumica depression, Kočani depression, Lakavica depression and Delčevo–Pečevo depression (Delipetrov, 2003; Dumurdžanov and Petrov, 2002; Delipetrov and Karakašev, 1998; 1999; Delipetrov et al., 2000).

CONCLUSION

Investigations of the geophysical characteristics of the Lakavica depression were performed for two geophysical fields: gravity and geomagnetic. This paper presents the results only from geomagnetic measurements. According the obtained results and created maps for the depression, the following conclusions can be presented:

Geographical position of the Lakavica depression is with coordinates $\Delta\lambda$ = 22º21' – 22º08', and $\Delta\phi$ = 41º43' – 41º34'.

The Lakavica depression occupies an area of about 100 km^2. The length of the depression is about 20 km, the width is about 5 km, and the depth is around 700 m.

The geological composition of the depression is represented with different types of rocks. In the horst of Serta–Gradeška Mountain are separated Precambrian gneisses protruded with granites and Eocene sediments, and in the structure of the Bučim block are present granites and volcanic and volcanic -sedimentary Neogene rocks (andesite and tuffs).

The regional gravitational faults that limited the depression are with general orientation northeast -southwest. Within the depression, locally, are determined transverse vertical faults.

The dip of the depression related to the Serta horst is larger, which means that it is asymmetrical graben.

Gravity minimums determine the deepest parts of the depression.

The map of local geomagnetic anomalies reveals the complex structure in the depression itself.

The map of the regional geomagnetic component of the total vector gives the causes lying at greater depths than the depression itself.

The application of regression analysis in the processing of geophysical data is correlated with the conditions of the researched area and has its own physical justification as well as its own verification.

In the field measurements of the geomagnetic field, a bigger disadvantage is the absence of a magnetic observatory in Macedonia and other equipment, which will enable measurement of other geomagnetic components of the field.

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Р е з и м е

ГЕОМАГНЕТЕН МОДЕЛ НА ЛАКАВИЧКАТА ДЕПРЕСИЈА

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Клучни зборови: истражување; геомагнетен метод; депресија; тотално поле

Во овој труд се претставени резултатите од геомагнетните истражувања спроведени на територијата на Лакавичката депресија (грабен) која се наоѓа во близина на Штип, во источниот дел на С. Македонија. Според тектонската реонизација на С. Македонија, Лакавичката депресија се наоѓа во Вардарската зона. Таа претставува релативно потонат блок со ориентација СЗ-ЈИ, помеѓу хорстот Серта – Грдешки Планини и хорстот Бучимски Блок – Смрдеш. Од југозапад, Лакавичката депресија е ограничена со хорстот Серта–Смрдешки Планини по должината на нормалниот (гравитациски) расед. Хорстот Бучимски Блок – Смрдеш, кој се карактеризира со многу сложена морфолошка градба, ја ограничува Лакавичката депресија од североисток. Геофизичките геомагнетни мерења се спроведени со три протонски магнетометри. Едниот беше поставен на базната станица и континуирано ја мереше дневната варијација, а со другите два беше мерен тоталниот вектор на магнетното поле. Магнетограмот добиен од магнетометарот поставен на базната точка беше искористен во процесот на обработката на мерните податоци за елиминација на влијанието на дневната варијација. Добиените резултати од извршените геофизички испитувања потврдија дека Лакавица е депресија потоната помеѓу два издигнати блока.