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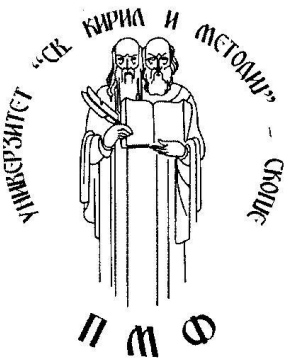

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ANALYSIS OF GEOPHYSICAL MODELS ON THE TERRITORY OF THE REPUBLIC OF MACEDONIA

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Abstract. This paper presents the models which are defined on the basis of /different geophysical parameters. Each one from these models through the prism of appropriate geophysical parameter provides a clear insight on the basic composition in the region of the Republic of Macedonia. Analysis of data from the presented models indicates a high degree of correlation. The accordance of the models created on the basis of surface observations (geological mapping) with the models made with geophysical methods is of particular importance. Geophysical models are made on the basis of measurements of adequate fields. The data from geophysical measurements results mainly from inner structure of surveyed area.

1. INTRODUCTION

The territory of the Republic of Macedonia as a part of the Alpian orogen in the Balkan region is characterized with a very complex structure, where the massive structure segments are isolated – the zones which are characterized with different geological features, different relief and different thickness of the Earth's crust. A lot of those elements have an impact at the geotectonic stage – the new geological history, because a number of structures are reactivated and there are also the new forms connected with the seismicity.

A lack of the synthesis in the relation to the structure elements from first order (zones), with the relief i.e. geophysical parameters, gives conditions for solving of this problem. The basic geophysical models of the territory of the Republic of Macedonia are made for accomplishing of this aim. They are subject of analysis of this paper.

Both, the geological maps and the data from the geophysical and seismological investigations, which are obtained in the last thirty years are used during the solution of this problem. The modern methods of mathematical modelling with help of computer technology are applied for solution of the correlation between the parameters from different fields. The computer modelling of the data for the territory of the Republic of Macedonia is made for the first time and the same procedure can be use in the analog investigations.

The analysis of the presented models should be defining the degree of correlation of the models made on the basis of geophysical fields. They are reflection of the internal structure and neotectonic model which is made on the basis of the surface manifestations of the terrain.

2. NEOTECTONIC MODEL

Information offered by many authors (Arsovski at al. 1975) helped to compile Fig. 1 and give the regional tectonic setting of the Republic of Macedonia.

The Republic of Macedonia belongs to the Dinaride and the Rhodope system. The part of Macedonia west of the Presevo - Zletovo - Strumica - Dojran line belongs to the Dinaride system and east of the line is part of the Macedonian massif which, with the Ograzden massif, joins the Rhodope system.

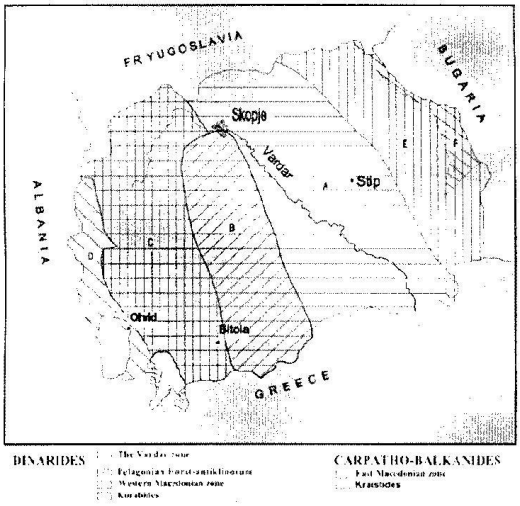
The Macedonian massif in this part of the Alpine orogeny is a geological anticline zone, or mid - position massif that separates the Dinarides from the Carpatho - Balkanides. In the area bordering Bulgaria east of the Berovo - Pehcevo line, elements of the Carpatho - Balkanides have been forced as a wedge into the old Rhodope massif, known as Strumica zone (Kraistides) separating the Rhodope and the Eastern Macedonian massif.

The territory of Macedonia, west of the Presevo - Zletovo - Strumica - Dojran line belongs to the Dinaric system. Four zones have been distinguished: the Vardar zone, the Pelagonian horst - anticlinoriums, the Western Macedonian zone, and the Korabides.

These zones represent individual structural facies units with their own geological evolution.

The structural zones are characterized by their own geological evolutions which can be seen from various lithological complexes that differ in composition, age, and dislocation.

Different types of rocks (metamorphic, intermediary to igneous), from Precambrian to Cenozoic are present.



DINARIDES: A – Vardar zone, B - Pelagonian horst - anticlinoriums, C – Western Macedonian zone, D – Korabides; KARPATHO-BALKANIDES: E – Eastern Macedonian zone, F – Kraistide zone

Fig. 1. Tectonic reonization of the territory of the Republic of Macedonia

Recent tectonic processes divided the territory of the Republic of Macedonia into three zones based on the geological and geophysical characteristics in order to provide better modelling.

- Western Macedonia, which includes Korabides, Western Macedonian zone and Pelagonian horst - anticlinoriums
- Vardar zone,
- Eastern Macedonia, which involve the Eastern Macedonian massif and Kraistides.

In this manner the area is structurally modelled into two blocks of uplift (Western Macedonia and Eastern Macedonia) and one block of subsidence (The Vardar zone).

The Vardar zone is a tectonic rift of very complex structural characteristics, only one part of this zone passes through Macedonia. In the territory of Macedonia the zone is 60 to 80 [km] wide. It is separated from the surrounding rocks by deep faults that cut the Earth's crust. The most common rocks, in terms of their age, are Precambrian, Paleozoic and Mesozoic complexes. The depressions are filled with paleogene and neogene sediments. The Vardar zone as a block of subsidence divides the Karpato – Balkanides in the east from the Dinarides in the west.

The Western Macedonian zone is mainly built of carbonaceous rocks which is specific lithological composition of the Dinarides. In terms of their age, the Paleozoic, Mesozoic and Neogene complexes are the most common rock types. The Pelagonian horst, which according to its composition is closer to the Eastern Macedonian zone, because of the recent tectonic processes is separated and becomes a part of Western Macedonia.

The Eastern Macedonian zone is built of dislocated complexes of Precambrian and Riphean Cambrian rocks. The morphostructures of uplift in eastern Macedonia are present as mountainous massifs 1600 - 1800 m high and the depressions are present as grabens oriented east - west.

3. GRAVIMETRICAL MODEL

The gravimetric field or the values of Bouguer anomaly in the territory of the Republic of Macedonia vary within $-80 \cdot 10^{-5} < \Delta g < 30 \cdot 10^{-5}$ ms^{-2}.

As a magnetic anomalies, also the gravimetrical field is result of the complex effect of the structures, theirs different rock mass, density and thickness. The observed analogy between those two fields in one region is a good parameter for the common ground origin.

Analysis of the gravimetric model (Fig. 2) indicate that the Western – Macedonian zone generally have negative value of the Bouguer anomaly. If it is take in consideration that the value of Bouguer anomaly depends from the density of the rock mass:

$\Delta g>0$ for $\rho>2{,}67$ g/cm^3

$\Delta g=0$ for $\rho=2{,}67$ g/cm^3

$\Delta g<0$ for $\rho<2{,}67$ g/cm^3

The model clearly shows that the Western – Macedonian zone is build mainly from the rocks with lower density of 2,67 g/cm3, which is correlated with the density of carbonate rocks. Those rocks are wide distributed on the surface and generally made the interiority of the same zones.

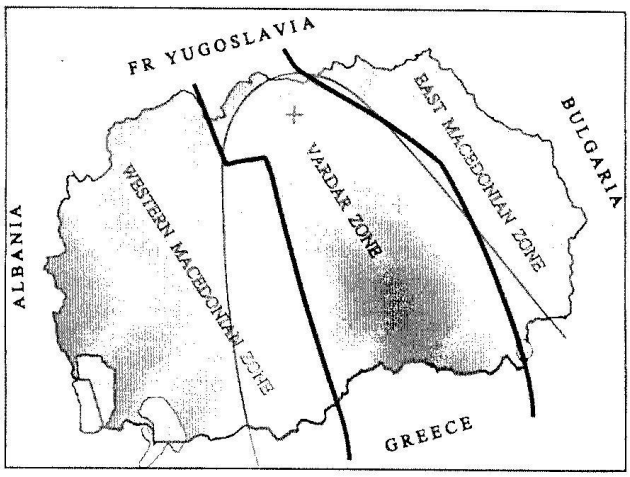


Fig. 2: Gravimetrical field of the territory of the Republic of Macedonia

Analysis of the Pelagon shows that this part is separeted with average value of Bouguer anomaly $\Delta g \approx 0$, which means the different deep structure in relation with the Western – Macedonian zone. The positive value of the Bouguer anomaly is caused because of two reasons, the first is Moho – discontinuity and the second, the density of the rocks which are components of the Vardar zone mainly with the density of $\rho \geq 2{,}67$ g/cm^3.

4. GEOMAGNETIC MODEL

Regional magnetic anomalies presents multicomponent anomaly fields which are the reflection of different structures in the Earth's crust. The magnetic field should be understood like integral impact of the deep buried and surface magnetic sources.

The magnetic field in the Western Macedonian zone is fairly stable. The Z-component values of the magnetic field are mostly negative with a small number of positive local anomalies. This is consistent with the geological composition of the zone. The Z-component values are within $-2 \cdot 10^{-5}$ nT $< Z < +2 \cdot 10^{-5}$ nT. The areas of positive magnetic anomalies are connected with local intrusions of magmas through the thick carbonaceous complex of low negative field values (Fig. 3).

The magnetic field of the Vardar zone is characterized by rapid changes of positive and negative anomalies. However, the large numbers of negative local anomalies are also characteristic. The value of Z-component varies widely from $-10 \cdot 10^{-5}$ nT $< Z < +15 \cdot 10^{-5}$ nT. The magnetic field is in correlation with the geological structures comprising the Vardar zone. It is the best justification of the unstable nature of the zone intersected by deep faults along which various magma types penetrated and generate the magnetic field.

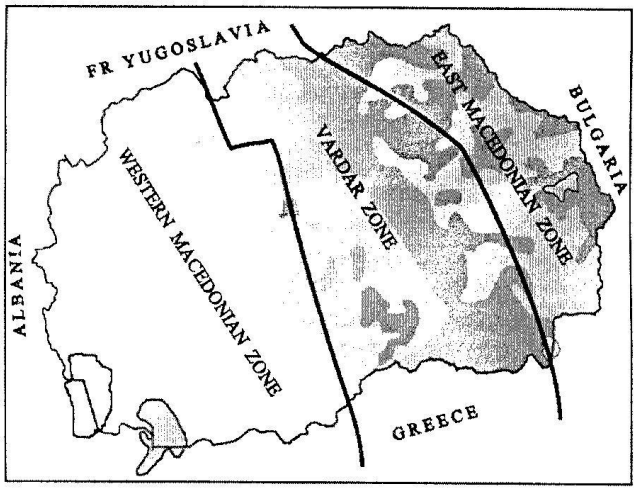


Fig . 3: Geomagnetic field of the territory of the Republic of Macedonia

The magnetic field in Eastern Macedonia is characterized by pronounced maximums and minimums. In the first zone the negative values were dominant, in the second the positive ones, whereas both positive and negative values are present in the zone. In terms of the magnetism, the eastern zone is equal to the Vardar zone indicating to its complex geological composition. The Z-component values vary within $-10 \cdot 10^{-5}$ nT < Z < $+15 \cdot 10^{-5}$ nT.

5. GEOTHERMAL MODEL

The geothermal field in the territory of the Republic of Macedonia increases from west to east reaching its maximum in the Vardar zone and gradually decreases in the area of Eastern Macedonia. The thermal flux in the Western Macedonian zone is within 40 and 60 [mW/m2] . In the Vardar zone it is from 80 to 120 [mW/m2], whereas in the Eastern zone from 80 to 100 [mW/m2] . Analysis of the geotherms in the zones indicate that the average temperature in the Western zone amounts to 20°C to 1000 [m] in depth. In the Vardar zone and the Eastern Macedonian zone the temperature amounts to 70oC. The increased temperature is due to higher Moho discontinuity and the pronounced young volcanism.

The existence of a big number of the thermal sources on the territory of the Republic of Macedonia indicates for the fields with the enlarged geothermal energy. Until now, a number of locations are investigated in details on this territory with respect to the geothermal characteristics. In the vicinity of Kocani, Strumica, Gevgelija and other localities the detail geothermal investigations defines the geothermal sources with the economic importance and today they are in service. Driven by the economical interest of particular regions, they are more

detail investigated, but it's not done much in the plan of preparation of the thermal flux in the Republic of Macedonia. Regional geothermal characteristics on the territory of Macedonia are expected features and with accordance with the data obtained with the newest geophysical investigations. The map of density of thermal flux for the territory of Macedonia is presented in this paper, although there are a lot of approximations. The data for the temperature and the density of the thermal flux are corrected of the temperature balance, while the thermalgraphic correction is excluded. The underground temperature can be seen clearly by regional means going from West (the border with Albania) to the East, the temperature achieve the maximum value on the part of Vardar zone and decrease the value going towards Macedonian – Bulgarian border (Fig. 4). Typical geotherms presented on the Fig. 5 gives the following results for the depth of H=1000 m, for Dinarides the temperature is about 20°C, for Vardar zone is about 60°C and for Eastern Macedonian zone is about 70°C. From this point of view it should be eliminate the local anomalies which have its minimum of small regions.

Generally taken the temperature zones on the territory of Republic of Macedonia can be correlated with the follows tectonic units:

Table 1 – Correlation between the tectonic and temperature zones

Zone	**Tectonic unit**
Low temperatures: < 50 mW/m^2	Korabides
Medium temperature: 50 - 80 mW/m^2	Western Macedonian Zone, Pelagonides
High temperatures: > 80 mW/m^2	Eastern Macedonian Zone

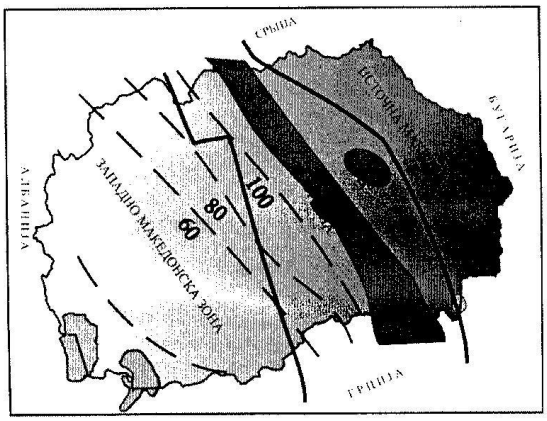


Fig. 4: Geothermal field of the territory of the Republic of Macedonia

The boundaries of the regions with equal density of thermal flux are taken to be aproximative.

It can be concluded that the zones with the maximum values of the density of the thermal flux in the Serbo – Macedonian Massif and Vardar Zone are overlaid mainly with the reduced thickness of the Earth's crust, while the low values of the density of the thermal flux are obtained in regions with the increase thickness of the Earth's crust (Korabides). From all these

facts the conclusion is that the main but not the only source of the anomaly geothermal field is the spreading of the astenosphere, i.e. temperature anomaly field is reciprocical with the respect of the thickness of the Earth's crust. At the same time these regions represent labile zones accessible of the often break and forming of the deep dislocations which cut the whole Earth's crust. The magmata penetrated along these deep faults on the Earth's surface or its vicinity. This occurrence is especially present in the Vardar zone and Serbo – Macedonian Massif, and it's conformed by the magnetic investigations. In this way the deep faults with the length of few hundred kilometers have the function of the supply channels of the convection heat. This method of heating of the geological formations is verified with the fact that the biggest natural sources of the territory of the Republic of Macedonia are found in the regions with Tertiary magmatic activity. The temperature increasing of the Granite mass in the Serbo – Macedonian massif and the Vardar zone can be explain with the decay of radioactive elements in the Granite plutons.

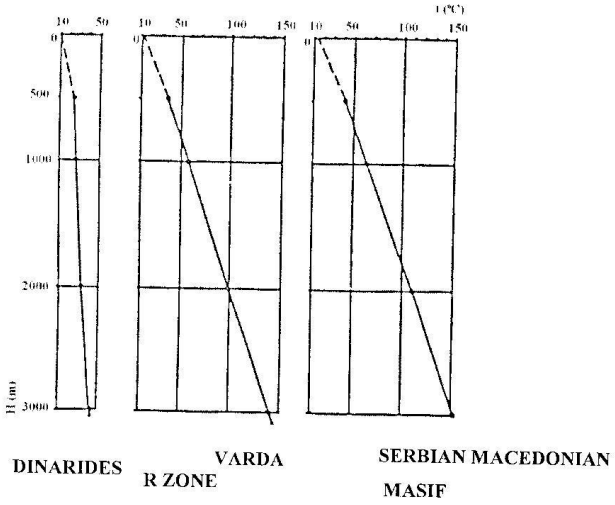


Fig.5: Typical geotherms in the individual zones

6. STRUCTURAL MODEL

The correlation carried out for the depth of Moho discontinuity (M) is made of deep structure of the territory of the Republic of Macedonia. The activities include the analysis of:

M=f (p); p – Geophysical parameter

M=a+bg; g – Bouguer anomaly

M=a+bv; v – Velocity of the neotectonic movements

Table 2 gives the correlation of the coefficients from those investigations. The analysis shows that the Western zone is a block of the highest numerical values and the most stable block in the model. With approval to those investigations, the internal structure of the Vardar zone indicates higher homogeneity and stability in relation to Eastern Macedonian Zone. The

earlier investigations define the eastern Macedonian Zone as a block with high degree of dynamics. However, the most pronounced young volcanism and present movements of the territory of Eastern Macedonia are the reasons for correlation coefficients M=a+bR to be from inverse type. The analysis of the geophysical fields justifies the structural model suggested for the territory of the Republic of Macedonia. (Fig. 6).

Table 2 – Correlation coefficient of the linear dependence M=f(p)

	Western Macedonian Zone	**Vardar zone**	**Eastern Macedonian Zone**
Height relief (R)	-0.44	-0.65	0.18
Bouguer anomaly	0.87	0.47	0.25
Velocity of neotectonic movements (V)	-0.63	-0.46	-0.66

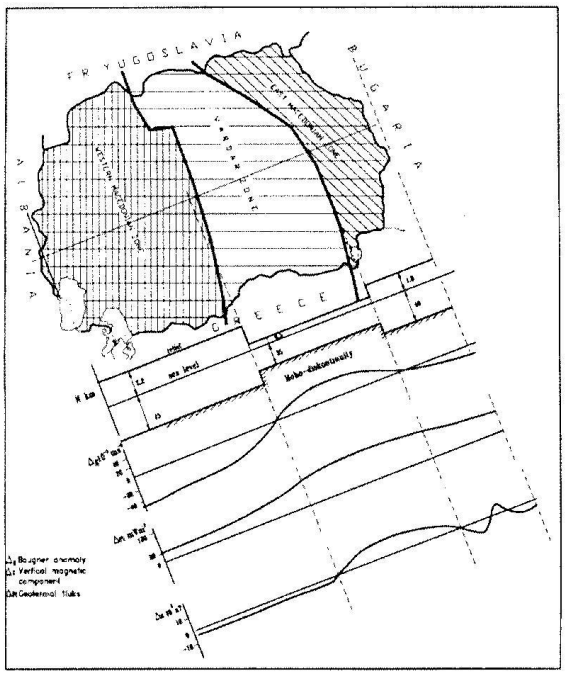


Fig. 6: Structural model for the area of the Republic of Macedonia

7. CONCLUSION

- Presented models have high degree of correlation;
- Above all the geophysical models are reflection of the region subsurface;
- The neotectonic model is compiled on the basis of the surface features of the investigation terrain
- The Western Macedonian block is homogenous;
- The Vardar zone is a complex structure, specially its internal parts;
- The Eastern Macedonian zone shows high degree of dynamics and this block isn't in topographical correlation with the Moho – discontinuity;
- The territory of the Republic of Macedonia is structurally modelled into two blocks of uplift (Western Macedonia and Eastern Macedonia) and one block of subsidence (The Vardar zone);
- The correlation of all models indicates an connection of the internal with the surface structure of the investigation terrain.

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