GEOTHERMAL MODEL OF EARTH'S CRUST AND LITHOSPHERE FOR THE TERRITORY OF YUGOSLAVIA# : SOME TECTONIC IMPLICATIONS##

MIHAILO G. MILIVOJEVIĆ

*Faculty of Mining and Geology, Beograd, FR Yugoslavia**)*

Summary: *Deep sounding seismic data along nine profiles and measured values of the terrestrial heat flow were used to construct a geothermal model of the crust for the territory of Yugoslavia. The obtained data indicate that the lowest temperatures (250 - 350 °C) at the crust base are in the region of the Outer Dinarides and the highest (900 - 1000 °C) in the region of the Pannonian Basin and the Serbian-Macedonian Massif. The difference is associated with the changing heat flow which reaches the Earth's crust from the upper mantle. Based on the crustal temperature distribution, an approximate lithospheric thickness was estimated for the first time for the entire territory of Yugoslavia. It is largest under the Outer Dinarides, where it is up to 260 kilometres, and smallest under the Pannonian Basin and the Serbian-Macedonian Massif, only 40 - 50 kilometres.*

1. INTRODUCTION

The physical and tectonic states of the Earth's crust and upper mantle are largely controlled by terrestrial heat flow. For this region, the knowledge of the heat flow and temperature distribution in the crust and upper mantle can provide useful data on the physical composition and dynamics of the lithosphere.

The effects of terrestrial heat flow on the geotectonic evolution of the crust on the territory of Yugoslavia could not have been studied earlier because geothermal investigations began only a few years ago. The first map of the terrestrial heat-flow density for Yugoslavia was prepared (Ravnik et al. [1]) as late as in 1987. That is why the territories of Yugoslavia and Albania, Portugal and partly Spain were shown blank on the first heat-flow density map of Europe (Čermák and Rybach [2]).

The knowledge about the distribution of heat and temperature fields in the crust and the upper mantle was acquired by preparing the heat-flow density map of Yugoslavia. Interpretations of these field values led to new indications, corroboration and to some old data concerning the regional dynamics of the crust and the entire lithosphere during the Mesozoic and the Cenozoic, as well as its present condition.

Before the separation of Slovenia, Croatia, Bosnia and Herzegovina and Macedonia.

Presented at the International Meeting on Terrestrial Heat Flow and the Structure of Lithosphere, Bechyně Castle, Czech Republic, September 2 - 7, 1991.

*) Address: Laboratory of Geothermal Energy, Faculty of Mining and Geology, Djusina 7, 11000 Beograd, FR Yugoslavia

2. GEOTECTONIC FEATURES

All earlier tectonic concepts of Yugoslavia can be divided into two principal groups. One is based on the theory of synclines and bilateral orogeny, and the other on the theory of new global tectonics. The only common point of the two theories is the complexity of crustal geology and tectonics in Yugoslavia. The complexity is the result of the joining or collision of two orogenic alpine arcs which belong to the eastern Alpine orogenic belt. One arc is made up of the Eastern Alps, Carpathians and Balkanides, and the other is composed of the Dinarides, Hellenides and Albanides, with the Pannonian and Serbian-Macedonian intermontane massif between them (Sikošek [3]).

Concepts of the geotectonic pattern of the Yugoslavian territory have developed parallel with the general evolution of geotectonic ideas in the world. The first ideas about the geotectonic framework of Yugoslavia were given by Kossmat [4] and Kober [5], and were based on the bilateral orogeny concept. The idea was accepted by national geologists (Petković [6]) before the Second World War; after the war, a number of concepts was developed that interpreted principal tectonic features on the territory of Yugoslavia as large thrust sheets. A long dispute ensued among the national geotectonicists, between the defenders of this concept and those against it.

The theory of new global tectonics and plate tectonics (Dewey et al. [7]) was soon accepted by national geologists, and today many models for different regions are based upon it: Dimitrijević [8], Karamata [9], Grubić [10], etc.

The principal geotectonic units in Yugoslavia are: Carpatho-Balkanides of eastern Serbia, Serbian-Macedonian Massif, Yugoslavian Dinarides, part of the eastern Alps, part of the Pannonian Basin, Dacian Basin-Yugoslavian part of the Mesian Platform, intermontane molasse basins, and the Adriatic Basin (Grubić [11]) (Fig. 1).

The Carpatho-Balkanides occupy eastern Serbia. Their geology and tectonic pattern are very complex.

The Serbian-Macedonian Massif is a crystalline core-area dividing the Dinarides from the Carpatho-Balkanides. The Massif is composed of highly crystalline metamorphic rocks and granite intrusions. These rocks are Proterozoic in age and the thickness of the complex is about 16 kilometres (Milivojević [12]). The Yugoslavian part of the Dinarides is the largest geotectonic unit. Its geological boundary is distinct only against the Serbian-Macedonian massif, while gradual and indistinct against other geotectonic units. The general features of the Dinarides are the great thickness of Paleozoic and Mesozoic rocks and a high degree of tectonic transport. In the regionalisation of the Dinarides on national territory, the Dinarides are divided into two larger zones: the Inner and the Outer Dinarides.

The eastern Alps on this territory are in northern Slovenia. The dominant rocks of the Alps there are gneiss and micaceous schist of indefinite age, Paleozoic metamorphic rocks, Mesozoic sedimentary and magmatic rocks, and Neogene clastics.

The territory of Yugoslavia covers the southern part of the Pannonian Basin. It was formed in processes of faulting and differential rising and setting in its basement and marginal Dinarides, eastern Alps, and the Carpathians. The geological conditions of the basinal paleorelief is highly heterogeneous and largely belongs to the Dinarides. The

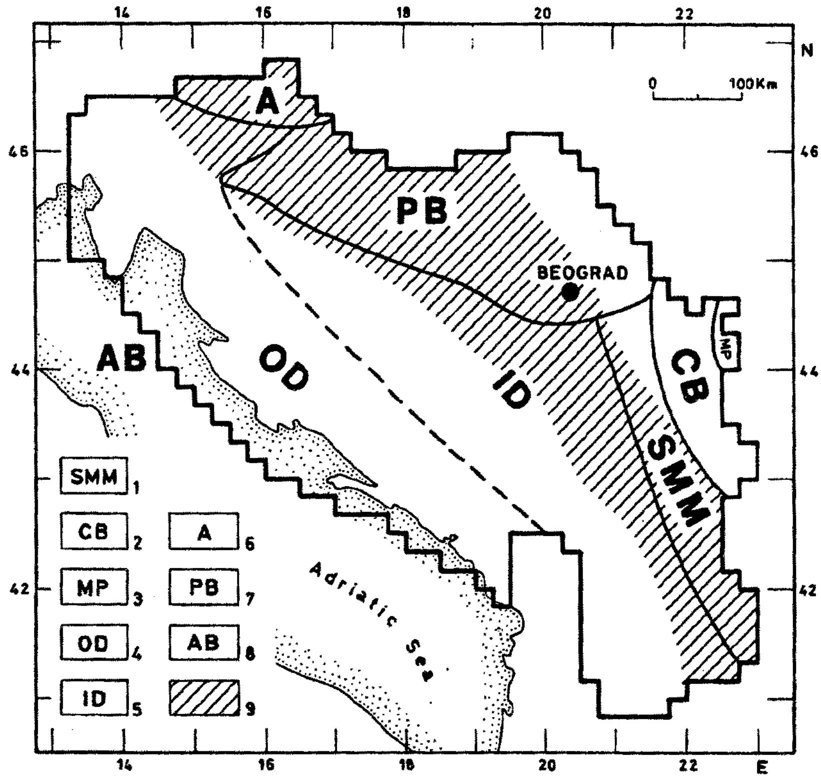

Fig. 1. Map of geotectonic units in Yugoslavia [11] (1-Serbian-Macedonian Massif; 2 - - Carpatho-Balkanides; 3 - Mesian Platform; 4 - Outer Dinarides; 5 - Inner Dinarides; 6 - Alps; 7 - Pannonian Basin; 8 - Adriatic Basin; 9 - Zone of Neogene magmatic activation).

thickness of Neogene and Quaternary sediments in it amounts to six kilometres (Dragašević et al. [13]).

The Dacian Basin, which forms the western margin of the Mesian Platform, covers a small and eastwardmost part of Yugoslavia (Fig. 1). It is filled with Neogene sediments up to two kilometres in thickness, over a basement of Paleozoic metamorphic rocks, Mesozoic sedimentary and ultramafic rocks.

The Adriatic Basin is situated between the Balkanic and Apenninic peninsulas. At its base, Paleozoic rocks lie under a thick complex of Mesozoic carbonate rocks from 3·5 to 6 kilometres thick (Grubić [11]) and very thick Neogene and Quaternary deposits, up to eleven kilometres, SE in the basin where the sea depth is the greatest (Dragašević et al. [13]).

3. GEOTHERMAL MODEL OF THE CRUST AND THE LITHOSPHERE

The data base for geothermal estimates presented in this paper included: geological model of the crust, its thickness and geological composition; heat field distribution in the subsurface; heat conductivity of rocks and concentration of radiogenic elements (U, Th, K).

3.1 Crustal thickness and composition

The thickness and composition of the crust were explored by seismic sounding in Yugoslavia from 1964 to 1984. They were made along nine profiles, total length of about 5000 kilometres, that included Yugoslavia in the group of countries of relatively highly marked composition and density of this part of the globe. The results, in the form of depths of the Mohorovičić discontinuity, are shown in Fig. 2 (Dragašević et al. [14]). According to these authors, the regional boundaries in the crust, the basement and Mohorovičić discontinuity, are reliable identifications. Another boundary, very

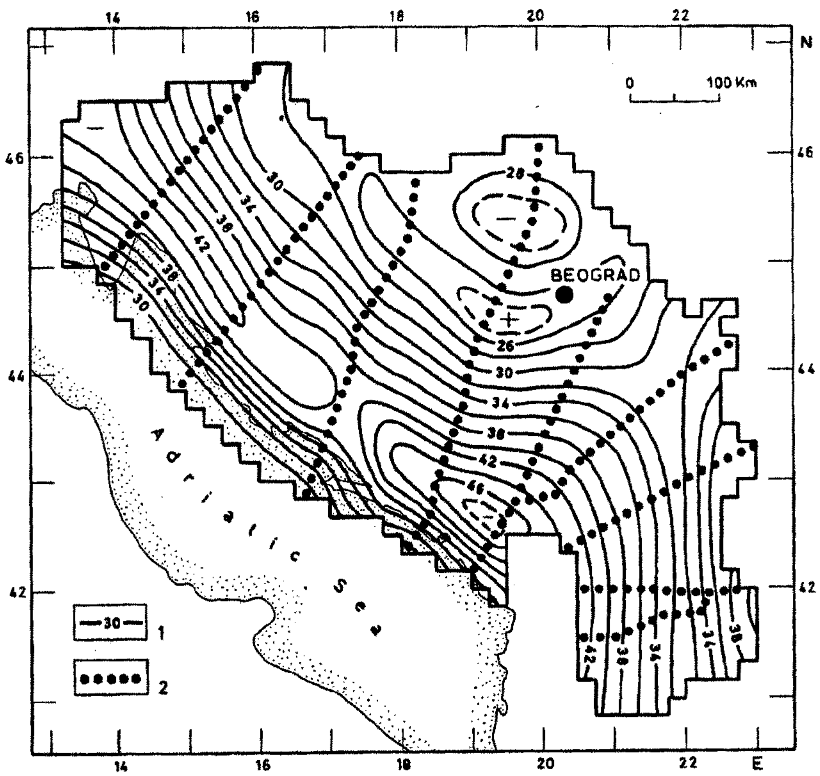

Fig. 2. Map of depths [km] of the Mohorovičić discontinuity for the territory of Yugoslavia based on the original map of Dragašević et al. [14]. (1 - isoline of the crustal thickness; 2 - DSS profile).

important for geothermal considerations, such as the Conrad discontinuity, was not identified by the methods used by the authors mentioned; they proposed additional investigation to provide the answer to the question of its existence. However, there are opinions that the Conrad discontinuity is present under a large part of Yugoslavia - the Yugoslavian part of the Pannonian Basin and its southern margin, and a part of the Inner Dinarides (Roksandić [15]).

A general assumption, based on the data given by Roksandić [15], was that the crust under the Pannonian Basin included all three "layers", in Yugoslavia and Hungary alike (Ottlik et al. [16]), the thickest being the "granite layer". According to Roksandić [15], the "granite layer" and "basalt layer" in the Inner Dinarides have similar thicknesses, but in the Outer Dinarides, the "basalt layer" is thicker than the "granite layer". The thicknesses of the "granite layer", "basalt layer" and "sediment layer" in the mentioned and other geotectonic units, used in the temperature estimate model, are given in Table 1.

Very important for geothermal estimates is the identification of the "sediment layer". Its greatest thickness, about 18 kilometres was located in the south near the Adriatic coast. In continental Yugoslavia, the "sediment layer" has the greatest thickness about 13 kilometres in the Outer Dinarides, which decreases inland from the Adriatic coast to the Pannonian Basin, or from the Outer to the Inner Dinarides. In the Pannonian Basin, it is up to six kilometres thick in the Sava depression.

Within the "sediment layer", "sublayers" of Tertiary, Mesozoic, Paleozoic and pre-Paleozoic rocks are distinguished. In other words, the model was calibrated to the "base of sediments" (Dragašević et al. [13]), because the thickness, lithological composition and temperature field in the sediment layer are well known from the avaliable geological, geophysical and geothermal data.

3.2 Heat flow

The first map of the terrestrial heat-flow density of Yugoslavia was prepared in 1987, using data of 138 land and 13 sea boreholes (Ravnik et al. [1]). The geographic density of holes is not uniform: it is the greatest in the Pannonian Basin and the lowest in the

Table 1. Thickness (km) of Earth's crust "layers" by geotectonic units of Yugoslavia.

Geotectonic unit	"Sediment layers"	"Granite layer"	"Basalt layer"
Pannonian Basin	1·8 - 6·5	13 - 17	7 - 14
Serbian-Macedonian Massif	0·5 - 3·5	14 - 17	8 - 20
Mesian Platform	3·0 - 4·5	12 - 14	16 - 18
Outer Dinarides	5·0 - 13·0	9 - 15	16 - 25
Inner Dinarides	1·0 - 5·5	13 - 18	9 - 24
Alps	1·0 - 4·5	15 - 17	8 - 15
Karpatho-Balkanides	2·5 - 4·5	13 - 16	10 - 21

Dinaridic mountains (Fig. 3). Most of the holes were drilled for oil and gas exploration. The acquired data are considered representative as 37 of boreholes less than thousand metres deep, while 55 boreholes were deeper than three thousand metres.

The original 1987 map of heat-flow densities was revised for the central area of Serbia and Macedonia, based on new drilling data from the period 1987 - 1989, and on a reinterpretation of the old data (Milivojević [12]). Figure 3 shows the new data for central Serbia and the data of the 1987 map for the rest of Yugoslavia.

3.3 Thermal conductivity and radiogenic heat

Knowledge of the thermal conductivity of the content of radiogenic elements in crustal rocks is very important and essential for geothermal models and estimates. However, the actual values of these parameters throughout the depth of the Earth's crust

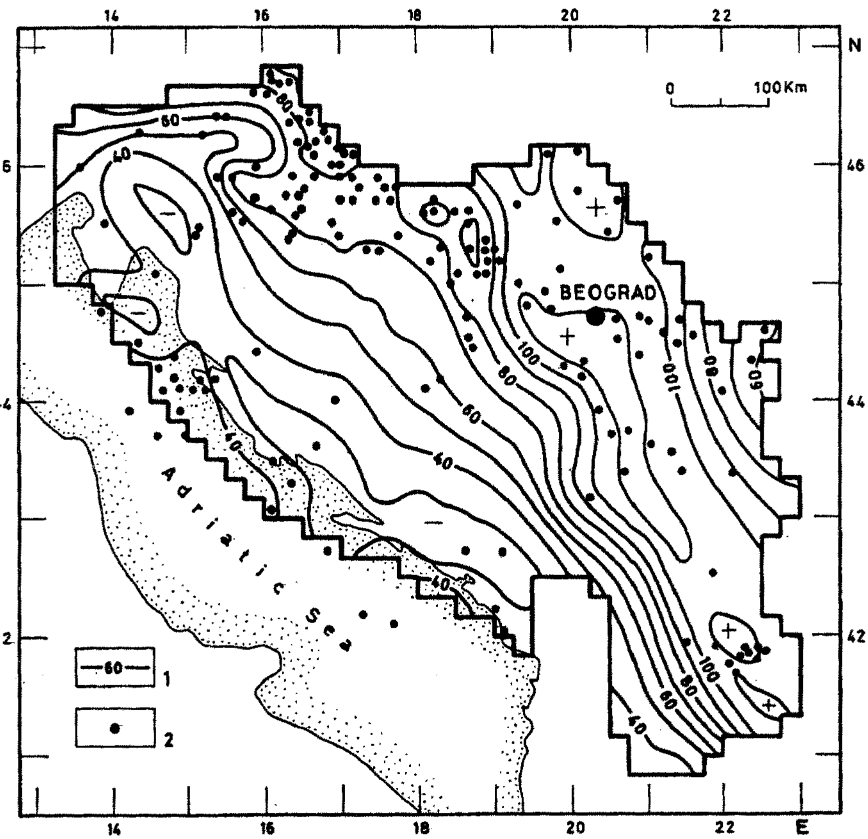

Fig. 3. Map of the heat-flow density for Yugoslavia based on the original maps of Ravnik et al. [1] and Milivojević [12] (1 - isoline of the heat-flow density; 2 - observation point of heat-flow density)

will never be learned, because rocks cannot be assayed from great depths of several kilometres. Accurate values are available only to the depths reached by drilling deep exploratory structural, geothermal or oil wells. For greater depths, down to the Mohorovičić discontinuity, data on the physical state of the crust and its likely geological and structural features have been obtained by various indirect methods. This general approach or method was also used in our models (Stromeyer and Hurtig [17]).

Thermal conductivity and radiogenic elements were assayed on samples of all lithological types and ages but Quaternary, for central Serbia. The samples were collected only from fresh rocks on the surface and, of course, from drill-holes. Also specific heat and density were determined. Since 1981, a catalogue and a data bank have been formed of thermo-physical properties of rocks, first of the kind in Yugoslavia. The values of mean thermal conductivities and radiogenic heats of different rock types approximated those of similar rocks outside Yugoslavia (Milivojević [12]). These, and the data of earlier researchers (Čermák [18,19] Horvath et al. [20]; Kutas [21]; Ottlik et al. [16]; Stromeyer and Hurtig [17]; etc.) sumarized in Table 2, constituted the data base for the model of thermal conductivity and the model of geothermal energy generation in the process of decay of radioactive elements.

Thermal conductivity and radiogenic heat distribution models were constructed in relation to depth, because the lithology and crustal thickness were different in each field for which the estimate was made.

3.4 Crustal and lithospheric temperature estimates

To estimate the temperature values through the crustal and upper mantle or in the lithosphere on the territory of Yugoslavia, the following linear differential equation was used

$$-\nabla(K\nabla T) = A, \qquad \nabla = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right) \tag{1}$$

which describes the mechanism and process of conductive, steady, heat transmission, in which T is temperature, K is thermal conductivity, and A is the amount of heat generated

Table 2. Basic parameters used in estimates on geothermal models.

Calculated and physical layers	Thermal conductivity [W/m K]	Radiogenic heat generation [10^{-6} W/m^3]
"Sediment layer"	1·2 - 2·6	0·3 - 1·0
"Granite layer"	2·7	2·4
"Basalt layer"	2·1	0·1 - 0·5
Subcrustal part of upper mantle	2·5	0·01
Upper mantle depth interval > 120 km	2·5	0·04

in a unit volume of rock mass. In the one-dimensional approximation the equation will become:

$$A(z) + \frac{d}{dz}\left[K(T)\frac{dT}{dz}\right] = 0 \qquad (2)$$

for calculation of temperature. Integrating this equation yields the known relation:

$$q_0 = q_M + \int_0^{z_M} A(z)\,dz \qquad (3)$$

between the measured density of terrestrial heat flow $q_0 = -K(dT/dz)$, geothermal or radiogenic heat generation at depth $A(z)$ and the density of geothermal flow q_M at depth z, or at the Mohorovičić discontinuity. Since the values $A(z)$ and $q(z)$ are not known, their determination based only on subsurface measurements of q_0 is a problem of inversion (Stromeyer and Hurtig [17]).

Temperature $T(z)$ and lithospheric thickness were calculated using the T - MOHO 87 v. 1.02 computer program, developed for this purpose (Milivojević [12]; Milivojević and Martinović [22]). The territory of Yugoslavia was divided into 872 oblong fields of latitude 15 and longitude 10, i.e. 20 × 18 km.

Estimates were made for the solution of equation (2) under boundary conditions $T = T_0$ and $q = K(dT/dz)$ (Čermák and Haenel [23]): (1) $A(z) = A_0$, $K(T) = K_0$ in the "sediment layer" in the layer model, and (2) $A(z) = A_0 \exp(-z/D)$, $K(T) = K_0/(1 + \alpha T)$, on the expotential model (Lachenbruch [24]) for the "granite layer", the "basalt layer" and upper mantle, where α (0·001 for the "granite layer" and - 0·00025 for the upper mantle) is the coefficient of heat conductivity variation in rock dependent on temperature, and D ($D = 10$ km) is the parameter describing the distribution of radiogenic heat through the crustal depth (Čermák [18]).

4. RESULTS AND DISCUSSION

The heat field on the territory of Yugoslavia, although not studied uniformly and in detail, is largely the result of radiogenic heat production and tectonic-magmatic activity.

The neotectonic and seismic activities are very high over a large part of the national territory, also characterized by positive geothermal anomalies. The source of these processes, their mutual relation and that to geothermal anomalies have not been identified. Data interpretations of the heat-flow density map and the crustal thickness map give plausible information on the likely sources of the mentioned processes and the physical condition of the upper mantle subsurface. The heat-flow density map (Fig. 2) shows its high positive anomalies over northern and eastern Yugoslavia. The anomalies were identified in the manner used by Bodri and Bodri [25]; they were found in the Pannonian Basin, in central Serbia and eastern Macedonia, coincident with the zone of Neogene magmatic activation (Figs. 2 and 3). In other words, the obtained values

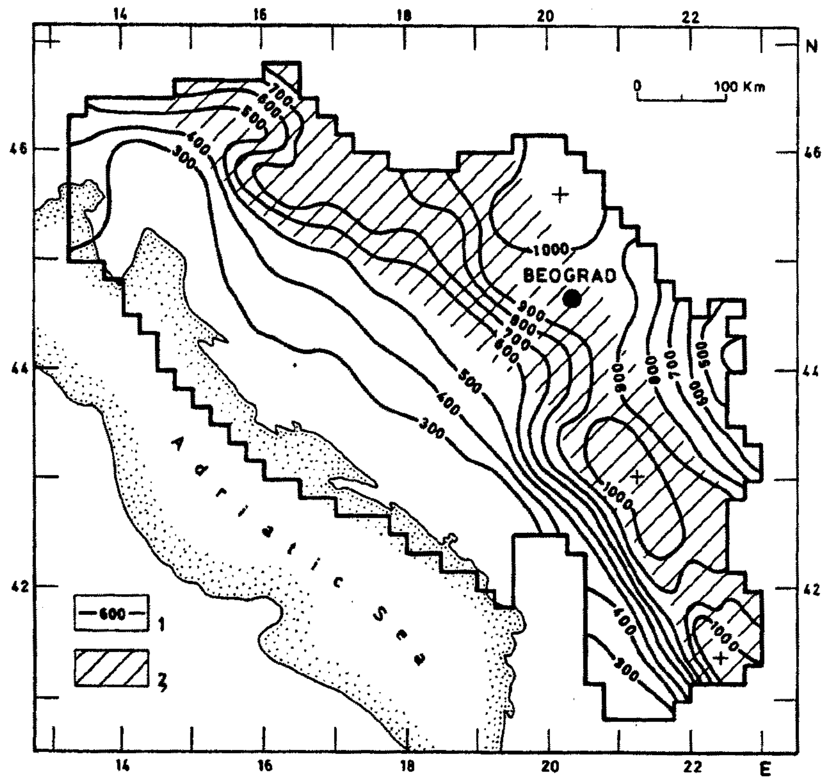

Fig. 4. Map of temperatures [°C] at the Mohorovičić discontinuity for Yugoslavia. (1 - isolines of temperatures; 2 - zone of Neogene magmatic activation).

showed a high heat-flow density at the Mohorovičić discontinuity in areas of recent tectonic activity, and a low density in areas of earlier tectonic activity, or in regions of the cooled crust depression into the upper mantle (Dragašević [14]), such as the case of the Outer Dinarides.

The temperature relations at the Mohorovičić discontinuity within the mentioned geothermal anomaly are very interesting (Fig. 4). In the domains of the Pannonian Basin and the Serbian-Macedonian Massif, temperatures are about 900 °C on average. This is an indication of contemporary geothermal activity in these domains. It can be understood either as the southern extension of the Pannonian geothermal anomaly or as the northern extension of the geothermal anomaly of the Neogene magmatic activation. The similarities in the geology of the basement and margin of the Pannonian Basin in Hungary and Yugoslavia suggest that the geothermal anomaly zone in Yugoslavia was an extension of a similar zone in Hungary, Fig. 5 (Milivojević [26]).

The proposed geothermal model provided the first data on the lithospheric thickness for Yugoslavian territory. The assumed upper boundary of the high electrical

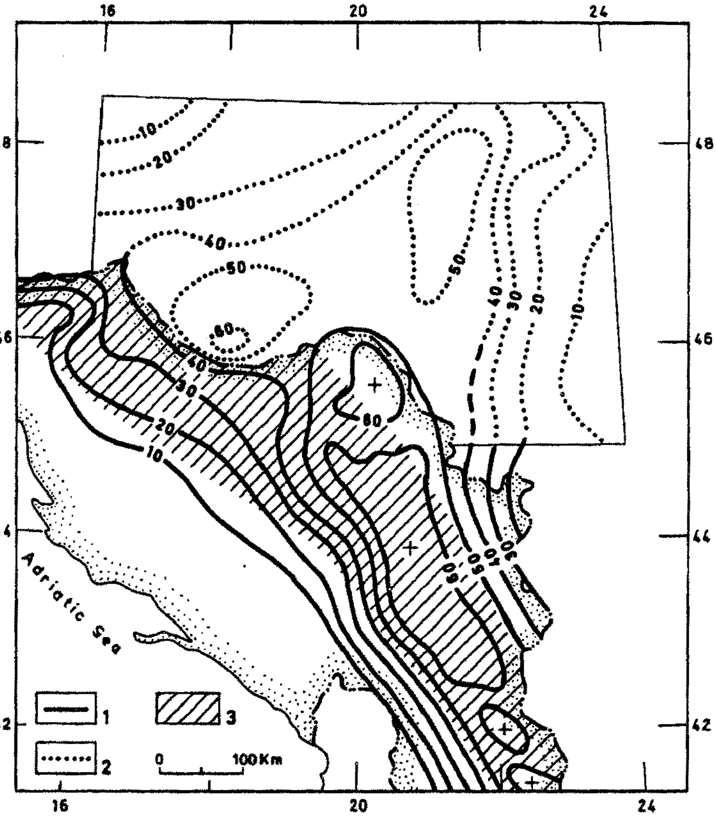

Fig. 5. Positive anomalies of terrestrial heat-flow density [mW/m^2] for the Pannonian Basin in Hungary and Romania (Bodri and Bodri [25]) and Yugoslavia (Milivojević [26]), and for the zone of Neogene magmatic activation. (1 - isolines for Yugoslavia; 2 - isolines for the Pannonian Basin in Hungary and Romania; 3 - zone of Neogene magmatic activation).

conductivity zone was located at a depth where the model temperatures reached those of rock melting. In other words, model-supported deep temperature estimates were used in a tentative estimate of the mean lithospheric thickness. In this connection, the data given by Yoder and Tilley [27] and Chapman and Pollack [28] were used. A map of approximate lithospheric thicknesses, based on these estimates, is shown in Fig. 6.

Smiljanić and Mužijević [29] tried to determine the lithospheric thickness at several points of the national territory using experimental induction measurements of the Earth's electromagnetic field. Some of these data are in agreement with our results. A relatively good correlation of results was accomplished using the formula developed by Adam [30] based on magnetotelluric explorations of the electric conductivity boundary and high electric conductivity layer locations in the upper mantle.

The lithospheric thickness calculated on our model is the smallest (only 40 - 50 km) in the Serbian-Macedonian Massif region, slightly higher (40 - 80 km) in the Pannonian

Basin, 40 - 200 km in the Inner Dinarides, 160 - 180 km in the Mesian platform; 60 - - 100 km in the Alps; 70 - 160 km in the Carpatho-Balkanides, and the highest 160 - - 260 km in the Outer Dinarides. These values indicate the smallest lithospheric thickness in the domain of the most recent tectonic activity, such as the Pannonian Basin and its margin, and the zone of magmatic activation.

Zones of positive geothermal anomalies have important geotectonic implications. They express well the old subduction zones: the eastern part of the Pannonian Basin under the Carpathians, central and eastern Serbia under the Serbian-Macedonian Massif, and a likely zone of an old subduction in the boundary area of the Dinarides and the Pannonian Basin. These processes were interpreted for the Pannonian Basin by Stegena et al. [31], for the Dinarides by Dimitrijević [8] and Karamata [9], and for the Carpatho-Balkanides by Grubić [10].

The mentioned subduction zones are inactive at present. They are indicated, however, by the present lithospheric thickness determined on our model. The subduction of the Dinarides ceased before that of the Mesian Platform, but because the lithospheric thickness under the subduction zones in the Pannonian Basin and western part of the

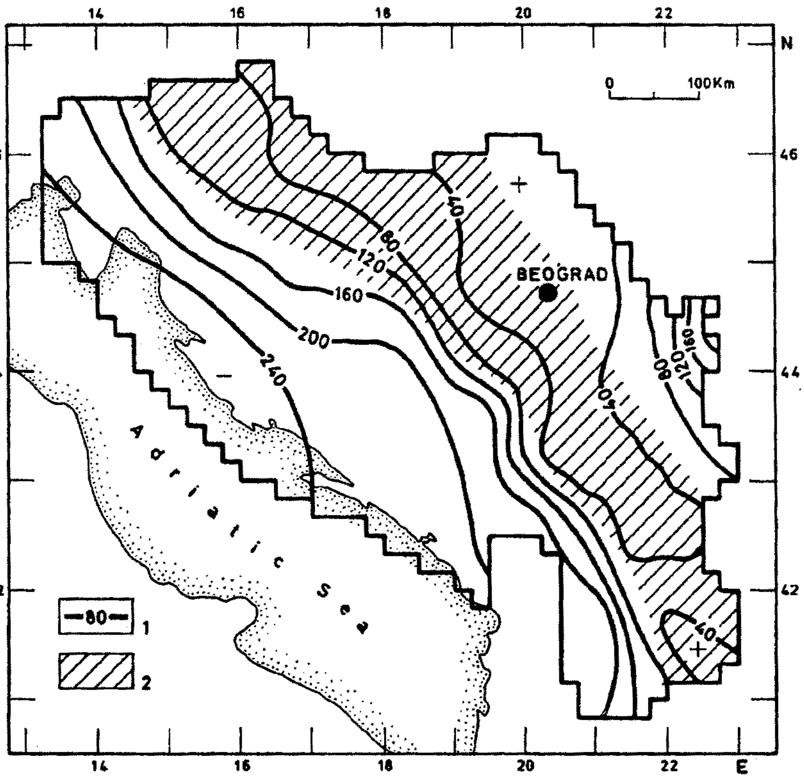

Fig. 6. Map of lithospheric thickness [km] for Yugoslavia. (1 - isolines of lithospheric thickness; 2 - zone of Neogene magmatic activation)

Serbian-Macedonian Massif was not uniform, it is at present nearly equal or slightly smaller in the eastern part.

The Serbian-Macedonian Massif has a relatively small width as compared to that of the Dinarides and the Mesian plate that subducted beneath it. Molten parts of the descending plates and produced magma led to the formation of granitoid intrusions in the Serbian-Macedonian Massif and to the thinning out of its basalt layer due to earlier melting, or subcrustal erosion, as was the case in the Pannonian Basin. It is in this connection that the elevated position of the Mohorovičić discontinuity can be explained as equivalent to an early melting in the regions of Serbia and Macedonia (Figs. 2 and 6).

Some thirty granitoid intrusions, ranging in age from ten to thirty million years, are situated in the zone of Neogene magmatic activation which, as mentioned earlier, coincides with the zone of small lithospheric thickness. Strong earthquakes occur in the areas of many of these intrusions. In the two zones of high positive anomalies of heat flow, between the "granite" and "basalt layers" of the crust, high temperatures of 600 - - 700 °C affect the mechanical properties of rocks which become plastic. These zones reach a depth of 13 - 17 km. The plastic state of rocks in these zones cause instability of the solid rocks overlying them and thereby the occurrence of earthquakes (Milivojević [12]). Typical examples of the mentioned zones, which are also zones of increased electric conductivity in the crust (Adam [30]), are the Kopaonik and Rudnik earthquake areas, where earthquakes have intensities of 9 - 10 on the MKS scale.

5. CONCLUSIONS

This paper is an attempt at elucidating the lithospheric thickness and temperature field in the crustal basement using a geothermal model for the territory of Yugoslavia. Since these parameters are largely relative to the heat-flow values, future revisions and corrections of the heat-flow density map will provide for corrections of the model. Corrections of the heat flow are expected, in our opinion, to be the greatest for the Outer Dinarides, because they are composed of a very thick complex of Mesozoic carbonate rocks. The limestone karstification depth in this complex exceeds 3000 metres; therefore, the amount of convective geothermal energy with cold vadose water is very large. This is the source of very low values of heat flow in most of this geotectonic unit, which are about 30 mW/m^2; values of the actual heat-flow density must be higher, because in our model, for the given crustal thickness, they are at the limit of reality. True values will be found in the impermeable basement of the carbonate rocks complex.

Acknowledgements: My thanks are due to the referees for their critical reading of the manuscript and the valuable suggestions; to Dr V. Čermák for useful advice; to Mr. M. Martinović for computer processing the data, and to Mrs. D. Pilić for translating the paper into English.

Received: 6. 1. 1992
Revised: 24. 4. 1992

References

[1] D. Ravnik, S. Kolbah, K. Jelić, M. Milivojević, N. Miošić, S. Tonić: Geothermal Atlas of Europe-Yugoslavia (Geothermal regime in Yugoslavia). Unpubl. Rep., Fed. Geol. Inst., Beograd, 1987, 22 pp.

[2] V. Čermák, L. Rybach: Terrestrial Heat Flow in Europe. Springer-Verlag, Berlin, 1979, 328 pp.

[3] B. Sikošek: Geology and Tectonic Regions of Yugoslavia. Acta Seizmologica Yugoslavica, No 2-3, Beograd, 1975, 8-13.

[4] F. Kossmat: Geologie der Zentralen Balkanhalbinsel. Die Kriegsschauplatze, 1914-1918. Geol. dargest., H. 12, Berlin, 1924 (in German).

[5] L. Kober: Die Grossgliederung der Dinariden. Centralbl. f. Min. eto. Abt. B., Stuttgart, 1929, 425-437 (in German).

[6] V. Petković: Tectonic Structure of Eastern Serbia. Glas SANU, knj. 14, Beograd, 1930, 56-76, (in Serbian).

[7] J. F. Dewey, W. C. Pitman III, W. B. F. Ryan, J. Bonnin: Plate tectonics and the evolution of the Alpine system. Geol. Soc. Amer. Bull., **84** (1973), 3137-3180.

[8] M. Dimitrijević: The Dinarides: A Model Based on the "New Global Tectonics". In: S. Janković (Editor), Metallogeny and Concepts of the Geotectonic Evolution of Yugoslavia. Rud.-geol. fak., Beograd, 1974, 119-151, (in Serbian).

[9] S. Karamata: Plate Tectonics in Tethys-type Regions Applied to Yugoslavia. X jubil. Kongr. geol. Jugosl., knj. I, stratigr., paleontol., mineral., sedimentol., i tektonika, Budva, 1982, 549-566, (in Serbian).

[10] A. Grubić: Eastern Serbia in the Light of the New Global Tectonics and This Models Effect on Tectonic Interpretation of the Recent Alpide Branch. In: S. Janković (Editor), Metallogeny and Concepts of the Geotectonic Evolution of Yugoslavia. Rud.-geol. fak., Beograd, 1974, 153-180 (in Serbian).

[11] A. Grubić: An Outline of Geology of Yugoslavia. 26th Internat. Geological Congress, Paris. Guide book, 1980, 49 pp.

[12] M. Milivojević: Assessment of Geothermal Resources of Serbia Exluding Autonomous Provinces. Doctoral thesis, Rud.-geol. fak. Beograd, 1989, 459 pp, (in Serbian).

[13] T. Dragašević, B. Andrić, P. Joksović: Explanation for Prognostic Map of Depth Position of Geological Elements of Yugoslavia, 1::500 000. Fed. Geol. Inst., Beograd, 1990, 82 pp. (in Serbian).

[14] T. Dragašević, B. Andrić, P. Joksović: Structural Map of Mohorovičić Discontinuity of Yugoslavia. Scale 1:500 000. Fed. Geol. Inst., Beograd, 1990.

[15] M. Roksandić: Use of Geophysical Data in Explaining Tectonic Pattern and Evolution of the Dinarides. Glas CCXCII SANU, Odelj. prir.-matem. nauka, knj. 38, Beograd, 1974, 61-95.

[16] P. Ottlik, J. Galfi, F. Horvath, K. Korim, L. Stegena: The Low Entalpy Geothermal Resource of the Pannonian Basin, Hungary. In: L. Rybach and P. Muffler (Editors), Geothermal Systems: Principles and Case Histories. John Wiley & Sons, New York, 1981, 221-246.

[17] D. Stromeyer, E. Hurtig: Parameter Estimation for Steady-state Heat Conduction Model. In: R. Haenel and M. Gupta (Editors), Results of the First Workshop on Standard in Geothermics. E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart, 1983, 88-93.

[18] V. Čermák: Heat flow Map of Europe: Brief Summary of the Geophysical Implications. Travaux Geophysiques XXIX, N° 562, Prague, 1981, 295-314.

[19] V. Čermák: Regional pattern of the lithospheric thickness in Europe. In: V. Čermák and R. Haenel (Editors), Geothermics and geothermal energy. E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart, 1982, 1-10.

[20] F. Horvath, L. Bodri, P. Ottlik: Geothermics of Hungary and the Tectonophysics of the Pannonian Basin "Red Spot". In: V. Čermák and L. Rybach (Editors), Terrestrial Heat Flow in Europe. Springer Verlag, Berlin, 1979, 309-315.

[21] R. Kutas: A Geothermal Model of the Earth's Crust on the Territory of the Ukraninian Shield. In: V. Čermák and L. Rybach (Editors). Terrestrial Heat Flow in Europe. Springer Verlag, Berlin, 1979, 206-217.

[22] M. Milivojević, M. Martinović: Computers Applications in Geothermal Investigations: some Characteristical Examples. In: S. Vujić (Editor), Application of Mathematical Methods and Computers in Geology, Mining and Metallurgy. Com. for appl. of mat. meth. and comput. in geol., min. and metall. & FMG, Beograd, 1991, 275-286.

[23] V. Čermák, R. Haenel: Geothermal maps. In: R. Haenel, L. Rybach and L. Stegena (Editors), Handbook of Terrestrial Heat-Flow Density Determination. Kluwer Academic Publishers, Dordrecht, 1988, 261-297.

[24] H. Lachenbruch: Crustal Temperature and Heat Production: Implication of the Linear Heat Flow Relation. J. Geophys. Res., **75** (1970), 3219-3300.

[25] L. Bodri, B. Bodri: Geothermal model of the heat anomaly of the Pannonian Basin. In: V. Čermák and R. Haenel (Editors), Geothermics and geothermal energy. E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart, 1982, 37-43.

[26] M. Milivojević: Geothermal anomaly of the Pannonian Basin and its Association with the Geothermal Anomaly of Serbia. In: S. Karamata (Editor), Geodynamic Evolution of The Pannonian Basin, SASA, Acad. Conf., Vol. LXII, Beograd, 1991, 355-365.

[27] S. Yoder, C. Tilley: Origin of Basalt Magmas and Experimental Studies of Natural and Synthetic Rock Systems. J. Petrol., **3** (1962), 342-532.

[28] D. Chapman, H. Pollack: Regional geotherms and lithospheric thickness. Geology, **5** (1977), 265-268.

[29] N. Smiljanić, R. Mužijević: Relationship between Regional Distribution of Electrical Conductivity and Heat Flow in Yugoslavia. In: Investigation Problem of Geothermal Energy Resources with a Particular Reference to the Place and Part of Geophysical Methods. Komitet za geofiz. SITRGMJ, Beograd, 1987, 43-62, (in Serbian).

[30] A. Adam: Geothermal effects in the formation of electrically conducting zones and temperature distribution in the earth. Phys. Earth Planet. Inter., **17** (1978), 21-28.

[31] L. Stegena, B. Geczy, F. Horvath: Late Cenozoic Evolution of the Pannonian Basin. Tectonophysics, **26** (1975), 71-90.