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SEISMOTECTONICS OF THE PANNONIAN BASIN

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ABSTRACT

From earthquakes that occurred between 1763 and 1984 in the Pannonian Basin, maps were prepared by means of a computer. These maps show the epicentral density, the magnitude density and the densities of the epicentral intensities and of the seismic energy in the form of isolines. In the energy map, individual events are overemphasized. The other seismic maps show a close relationship with tectonics. A low temperature at a depth of 1 km is very closely correlated with an increased occurrence of earthquakes: a main chain of anomalies extends along the Transdanubian Central Range up to the Bükk Mountains. It is intersected by a chain Komárom–Esztergom–Budapest–Kecskemét–Hódmezővásárhely. Individual anomalies are found at the mouth of the Mura river near Pecs. Two tectonic hypotheses on the formation of the Pannonian Basin are discussed.

Zusammenfassung

Aus den zwischen 1763 und 1984 aufgetretenen Erdbeben des Pannonischen Beckens wurden mit einem Rechner Karten hergestellt. Diese Karten zeigen die Epizentrendichte, die Magnitudendichte und die Dichten der Epizentralintensitäten und der seismischen Energie in Isoliniendarstellung. Bei der Energiekarte werden Einzelereignisse überbetont. Die anderen seismischen Karten zeigen einen engen Bezug zur Tektonik.

Niedrige Temperatur in 1 km Tiefe korreliert sehr eng mit erhöhter Bebenhäufigkeit: eine Hauptkette von Anomalien folgt dem Transdanubischen Mittelgebirge bis zum Bükk-Gebirge. Diese wird gekreuzt von einer Kette Komárom–Esztergom–Budapest–Kecskemét–Hódmezővásárhely. Einzelanomalien sind an der Mur-Mündung und bei Pecs. Es werden zwei tektonische Hypothesen zur Entstehung des Pannonischen Beckens erörtert.

1. INTRODUCTION: COMPUTATION OF THE SEISMIC MAPS

It is the objective of the present paper to represent the seismic activity of the Pannonian Basin in map form, in such a way that subjective elements are excluded as much as possible, and to consider the correlation with the tectonic evolution of the basin. A preliminary version of the catalogue by Zsiros et al. (1988) forms the data basis for the paper. In the catalogue, 2745 earthquakes are listed. For any one earthquake, the following data are provided: consecutive number, focal time, geographic latitude and longitude of the epicentre in degrees, focal depth in km, magnitude, epicentral intensity according to MSK-64 (see Sponheuer, 1965), nominal class of accuracy of the determination of the epicentre, i.e., σ_i, geographic designation of the epicentre, accuracy of the intensity, literary source. According to the error of the determination of the epicentre, the earthquakes have been divided into five groups: $\sigma_i = 5$ km; $\sigma_i = 10$ km; $\sigma_i = 20$ km; $\sigma_i = 50$ km; $\sigma_i =$ unknown. Only earthquakes of the more precise three classes have been used in the computation of the maps. Consequently, a large portion of the older historical earthquakes has been omitted, and only earthquakes taking place between 1763 and 1984 have been taken into account. To enable comparisons, this overall period has been subdivided into two epochs of equal length: the first epoch ranges from 1763 to 1873, the second one from 1874 to 1984. As has been set out in greater detail by Walzer et al. (1988), the following formula applies to the density flow of a variable g_i or, in other words, the time-normalized density of the variable g_i:

$$s_g(Q) = \frac{1}{T}\sum_i g_i \frac{1}{2\pi\sigma_i^2} \exp\left(\frac{-d_i^2}{2\sigma_i^2}\right) \qquad (1)$$

d_i is the distance, in km, between any one point Q of the investigated region and the point Q_i of the i-th earthquake, which point is given as epicentre in the catalogue. σ_i is the error of the determination of the epicentre, in km, which error is also given in the catalogue. A centrosymmetric normal distribution was assumed. T is the period studied, expressed in years. Fundamental considerations of formula (1) can be found in Ullmann and Maaz (1966). Twelve maps have been computed for the Pannonian Basin: the (time-normalized) epicentral density s_1 which results from (1) with $g_i = 1$; the (time-normalized) magnitude density s_M, with g_i being replaced by the magnitude M_i of the i-th earthquake, which magnitude is always positive in the catalogue; the (time-normalized) intensity density s_I, with g_i being replaced by the epicentral intensity of the i-th earthquake listed in the catalogue; finally, the (time-normalized) energy density s_E. The densities s_1, s_M, s_I and s_E were in each case computed for the entire period 1763 to 1984, the first epoch and the second epoch. For a computation of the energy density s_E, the seismic energy E_i (in erg), which was computed from the magnitude M_i of the i-th earthquake with the help of a formula by Båth and Duda (1964), was substituted for g_i in formula (1):

$$\log E_i = 12.24 + 1.44\, M_i \qquad (2)$$

log is the logarithm to base 10. For a computation of s_E, $\sigma_i + R_i$ was substituted for σ_i, with $R_i = (\frac{3}{4\pi} V_i)^{1/3}$ in km. V_i has been taken from

$$\log V_i = 9.58 + 1.47\, M_i \qquad (3)$$

TABLE I.
THE SCALING VARIABLE N FOR THE COMPUTED SEISMIC DENSITIES

epoch	S_1	S_M	S_I	S_E
1763-1873	4	3	3	-14
1874-1984	4	3	3	-13
1763-1984	4	4	3	-14

V_i is the volume of the i-th earthquake in cm^3. Scaling is performed for all densities, whereupon the numbers plotted in the maps have to be multiplied by 10^{-N} (see Table I). On the map plane, the portion of the spheric surface of the earth defining the Pannonian Basin was mapped with the help of a Lambert's conformal conic projection. For the purpose of the construction of lines of constant seismic density (optionally s_1, s_M, s_I or s_E) we have to assume that the plane image of the region studied is covered by a square grid. The functional values of the seismic densities are computed in the grid points Q so that each function is represented by a matrix of values. To construct the level lines, points of the functional value in question are sought on the grid lines and diagonals through interpolation. These points can eventually be used for plotting closed curves of constant density. The level values have been predetermined according to the problem posed and to the range of values of the functions.

2. THE TECTONIC UNITS OF THE PANNONIAN BASIN

The Pannonian Basin consists of four tectonic units striking WSW-ENE (Balla, 1984, p. 319):

a) A northern unit, situated to the northwest of the Rába line. It is characterized by very large depths of the pre-Tertiary basement (Kilényi and Rumpler 1984), by negative regional Bouguer anomalies, if a low-pass filter with a cut-off frequency of 20 km is used (Meskó 1983), by a Mohorovičić discontinuity at a depth of 25 to 27.5 km. This latter property is common to the Great Hungarian Plain, which consists of the third and fourth units. The northern unit, which essentially consists of the Little Hungarian Plain and Danube Lowland, has only slightly increased values compared with average heat flow values (Dövényi et al., 1983; Stegena and Horváth, 1984).

b) The Bakony-Bükk unit. It is characterized by a chain of positive Bouguer anomalies, by normal temperatures at depths of 1 km and 2 km, i.e., negative temperature anomalies compared with the entire Pannonian Basin (Dövényi et al., 1983), by a low heat flow relative to the basin, by high horizontal geothermal gradients for the depth of 1 km (Stegena, 1979). The depth of the Mohorovičić discontinuity ranges between 31 to 37 km for the Transdanubian Central Range. This special partial region is distinguished by a crustal electrical conductivity anomaly (Ádám, 1984).

c) The Mid-Hungarian Belt which is separated from the afore-mentioned Bakony-Bükk unit by the Balaton line in the west and by the Hernád line in the east. It is characterized by a narrow belt of deep pre-Tertiary basement (Kilényi and Rumpler, 1984), by high temperatures and a high heat flow (Dövényi et al., 1983). The Szolnok-Marmaros flysch belt is the tectonic boundary which, at least to the east of the Tisza, separates the Mid-Hungarian Belt from the

d) Mecsek-Apuseni unit. The homogeneity of this last unit is not wholly apparent. A kinematic and paleomagnetic analysis shows that a more than rectangular rotation of this unit, in a clockwise direction, has been taking place for 22 Ma, whereas the Mid-Hungarian Belt, bordering on the unit to the north, rotated at the same time by 30° in a counterclockwise direction (Balla, 1986). This means that the position of the afore-mentioned tectonic units of the Pannonian Basin relative to one another is of quite recent origin.

The two units c) and d) together form the Great Hungarian Plain, the temperature gradient of which is about double that of the normal global value (Horváth et al., 1979). If we leave aside a narrow strip, which extends in a straight line from Budapest via Kecskemét to Hódmezővásárhely (see maps by Dövényi et al., 1983), the Great Plain is characterized by high heat flow and high temperatures. The depth of the Mohorovičić discontinuity is low (Čermak, 1979), the thickness of the basalt layer amounts to 6 to 9 km only, and the entire lithosphere, too, is thin (70 km), so that one can speak of a bump of the asthenosphere (Bisztricsány, 1974; Stegena et al., 1975).

3. RESULTS AND DISCUSSION

Figure 1 shows the epicentral density of the second epoch. It goes without saying that this illustration is particularly meaningful, because the earthquake material collected here is in all probability almost complete. A chain of positive anomalies located on the Bakony-Bükk unit is especially noticeable: I to IV and VII. Anomaly I is located to the north of Zalaegerszeg, II in the vicinity of Várpalota and Mór, III near Dunaharaszti, IV near Eger, VII near Csap. Apart from these, greater positive anomalies of the epicentral density are found only at Komárom (VIII) and at Kecskemét (V). All of these regions are characterized by temperatures at a depth of 1 km, which lie below 50°C, that is, significantly below the average value for the Pannonian Basin. The historical material from the first epoch is probably less complete. Figure 2, however, also shows a pattern which is roughly similar to that of Figure 1. If one wishes to attach greater importance to the stronger earthquakes, the magnitude density of the second epoch proves to be suitable (see Fig. 3). In this case, too, the recent seismic activity of the Bakony-Bükk unit and of anomalies V and VIII is clearly evident. It turns out that even positive anomalies of s_M, which are still smaller, are connected to small temperature lows: the

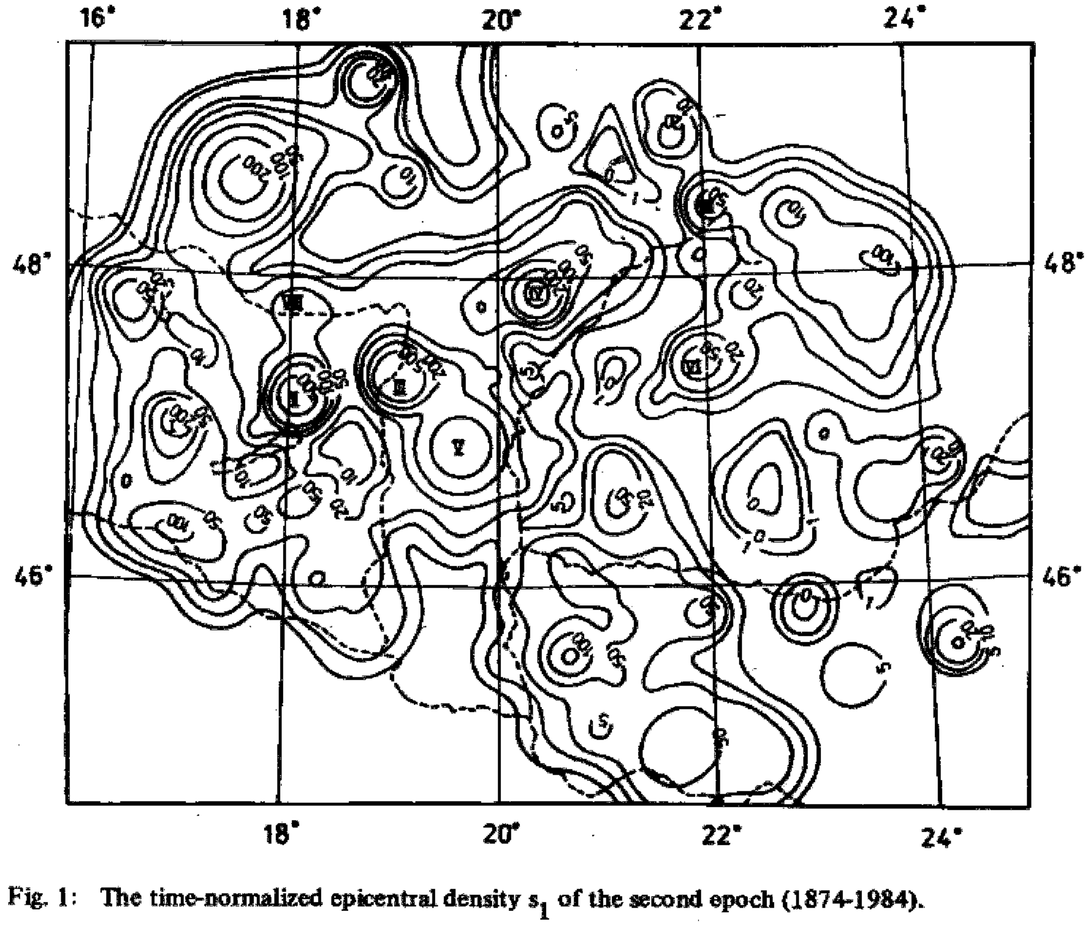


Fig. 1: The time-normalized epicentral density s_1 of the second epoch (1874-1984).

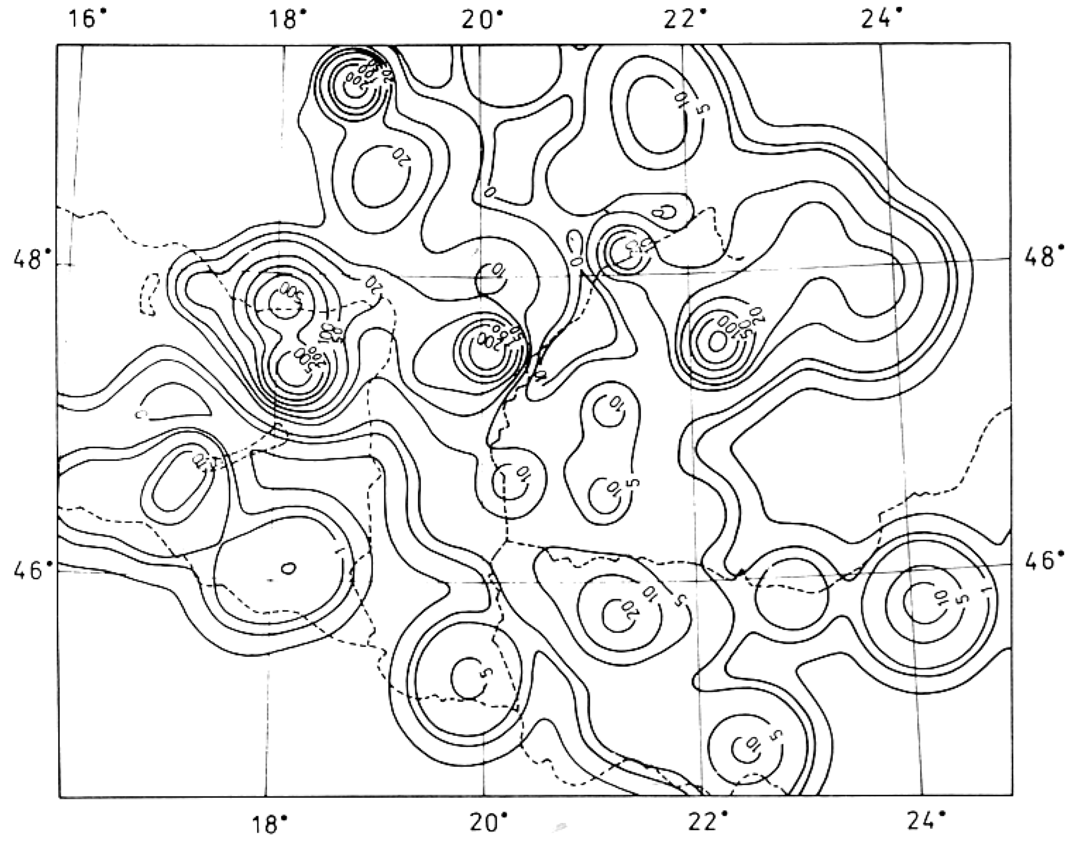


Fig. 2: The time-normalized epicentral density s_1 of the first epoch (1763-1873).

anomaly of Pecs and the one situated at the point where the Mura (Mur) flows into the Dráva (Drau) can also be found on the map of geoisotherms at 1000 m depth by Dövényi et al. (1983).

In Figure 4, the distribution of the positive magnitude density anomalies for 1763 to 1984 has been compared with the positive anomalies of the heat flow. It is obvious that earthquakes avoid zones with a high heat flow. Even more noticeable is the coupling of the magnitude density of the entire period under study to regions exhibiting a low temperature (see Fig. 5). Just as the anomalies of low temperatures at a depth of 1 km form two lines, which intersect north of Budapest, the positive magnitude density anomalies form a cross with corresponding angles: anomalies I, II, III, IV, VII extend along the Transdanubian Central Range, Mátra and Bükk Mountains, while VIII, III and V extend perpendicular to this. A possible interpretation of this phenomenon is that mechanical stresses tend to build up in those parts of the crust in which the effective viscosity is high. In contrast to this, stresses in the warmer parts of the crust can decrease through slow creep.

The formation of the Pannonian Basin has already been explained in terms of plate tectonics at an early date (Stegena et al., 1975; Boccaletti et al., 1976). Judging from

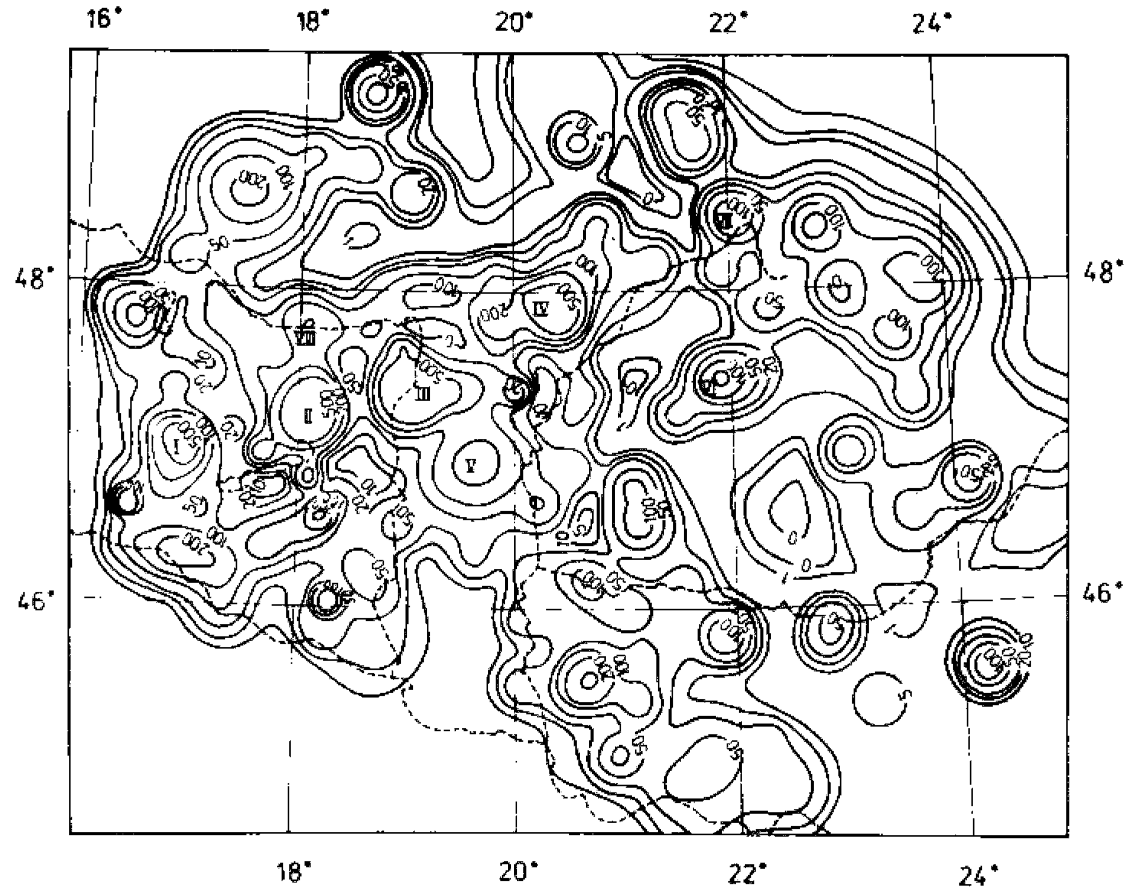
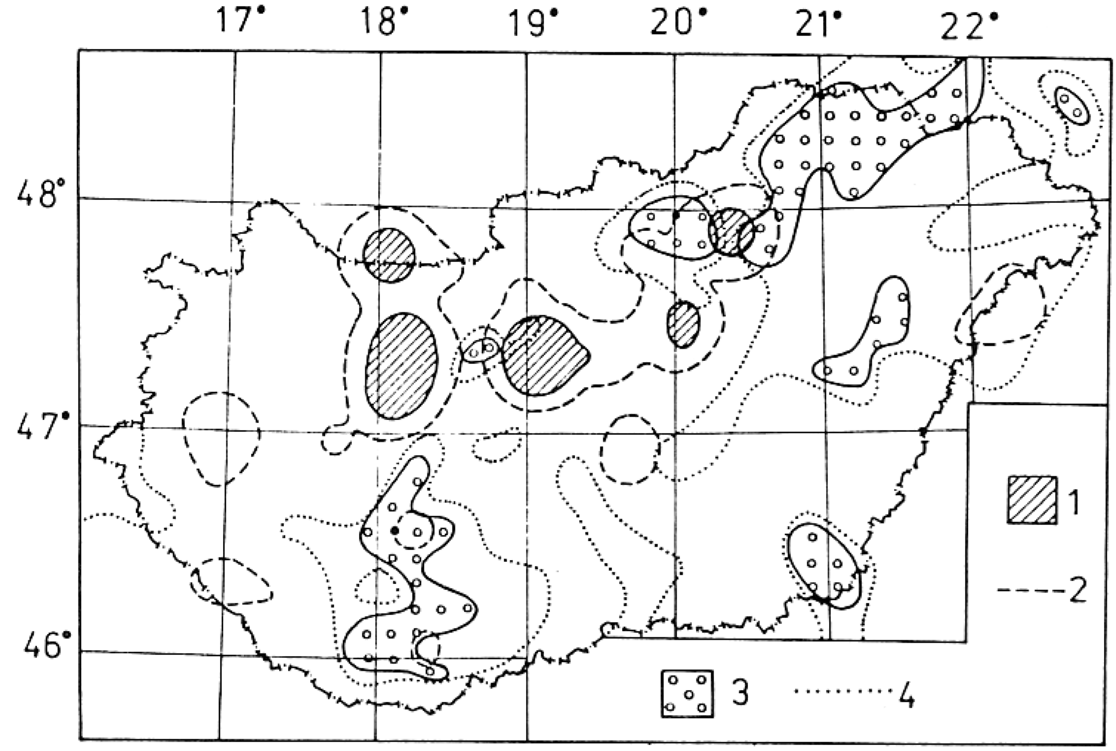


Fig. 3: The time-normalized magnitude density s_M of the second epoch (1874-1984).

the joint occurrence of ophiolites, flysch and of calc-alkaline volcanites, the latter being partly distributed in a chain-like manner, in the Carpathian region, it seems reasonable to assume that there is an old lithospheric plate boundary, whose activity was fully developed in the Miocene and which is at present still active only near Braşov. During the Miocene, compression prevailed in the Pannonian Basin and, starting from the Pliocene, with decreasing subduction, extension prevailed. In northern Hungary and in Slovakia, calc-alkaline volcanism is followed by alkaline-basaltic volcanism. According to Balla (1984), the northward migration of the volcanism is due to a gradual bending down of the subduction slab of the European plate.

Some also argue that the formation of the Pannonian Basin cannot be explained in terms of the plate theory. According to them, this theory is not suitable for explaining the volcanism of the Great Hungarian Plain. Moreover, alkali basalts could also exist independently of island arcs (Lexa and Konečný, 1974). 15 to 20 Ma elapsed between active subduction and volcanism, whereas these phenomena could be observed simultaneously on island arcs. The Carpathian Arc is enclosed from the Bohemian Mass right into the Walachia by a closed solid frame, so that formation of the Pannonian Basin can be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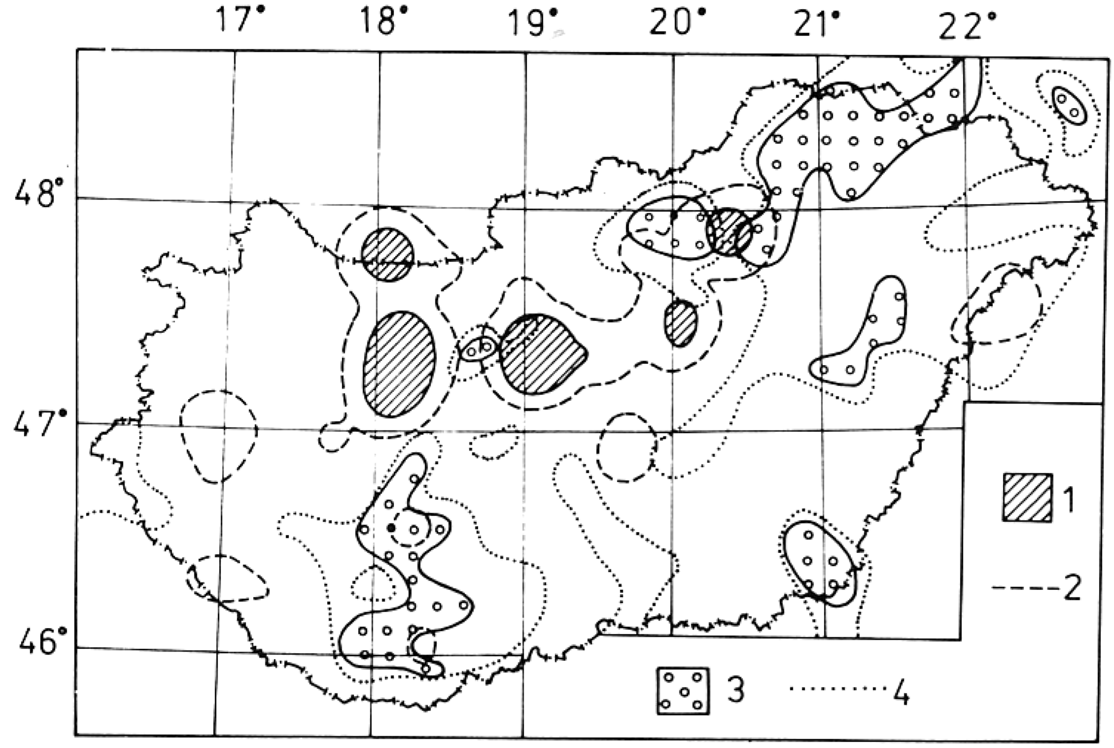
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more easily explained by the existence of a rising hot mantle diapir. Artyushkov et al. (1983) tried to explain the formation of the Tyrrhenian Sea and later also of the Pannonian Basin not in terms of back-arc spreading, but by gabbro-eclogite transition in the lower crust. The rate of this transition strongly increases with temperature. Eclogite is also formed there through fluid inflow into the lower crust (Sobolev, 1978). The eclogite then sinks to the bottom in the hot asthenosphere, thus bringing about the formation of basins, such as the Pannonian, Pontic, Tyrrhenian and South Caspian Basins.

4. CONCLUSIONS

From a modern earthquake catalogue, maps of the Pannonian Basin were plotted in an objective manner by means of a computer. These maps show lines of equal density of the epicentres, the seismic magnitude, the epicentral intensity and seismic energy. From the new seismic maps thus obtained, the authors cannot draw a direct conclusion in favour of one or another tectonic hypothesis. However, the positive seismic anomalies show good agreement with the negative temperature anomalies and also partly with the positive Bouguer anomalies. Obviously, mechanical stresses can more easily accumulate in the cooler parts of the earth's crust, because they cannot readily release these stresses through solid-state creep on account of their higher effective viscosity. The distribution of the geophysical fields can be well understood by the tectonic structuring of the Pannonian Basin into four units striking WSW-ENE described in Section 2. Since the history of these units, derived on the basis of the plate theory and paleomagnetism, enables good comprehension of the present geophysical situation, the authors favour an interpretation of the evolution of the Pannonian Basin in terms of mantle convection theory (Walzer, 1988).

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Fig. 4: A comparison of the magnitude density s_M with the heat flow. 1–hatching denotes $s_M > 500$ for earthquakes taking place between 1763 and 1984 (this work); 2–$s_M = 100$ for earthquakes taking place between 1763 and 1984 (this work); 3–heat flow greater than 100 mW/m^2; 4–heat flow equal to 90 mW/m^2. 3 and 4 according to Dovényi et al. (1983).

Fig. 5: A comparison of the magnitude density s_M with the temperature at a depth of 1 km.
1–magnitude density $s_M > 100$, computed for 1763 to 1984 (this work);
2–temperature $T \leqslant 50^\circ C$;
3–temperature $T = 60^\circ C$;
4–temperature $60^\circ C < T < 70^\circ C$;
5–temperature $T \geqslant 70^\circ C$.
Temperature at 1 km depth according to Dovényi et al. (1983).

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