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SEISMIC ACTIVITY OF THE PANNONIAN BASIN AND COMPARISON WITH OTHER GEOPHYSICAL FIELDS

Uwe WALZER*, Richard MAAZ* and László TÓTH**

From the earthquakes taking place in the Pannonian Basin from 1763 till 1984, seismic maps were constructed by means of a computer. The maps with lines of equal epicentral density and magnitude density are particularly closely related to the tectonic units of the basin striking WSW–ENE. Maxima in the afore-said seismic maps are linked with minima in the map of the temperature at a depth of 2 km. The distribution of the epicentral and magnitude density maxima also exhibits a relationship with the heat flow minima and, to a somewhat lesser extent, with the maxima of the horizontal geothermal gradient and with the positive regional Bouguer anomalies.

Keywords: seismicity maps, epicenters, magnitude density, temperature, crust, Pannonian Basin, seismology

1. Introduction

The aim of this paper is to present the seismic activity of the Pannonian Basin with the help of maps in a manner as objective as possible. The relationship between this distribution and geophysical fields of a different type and the geology is to be investigated. It is clear that, from a given seismological catalogue, seismological fields can be derived in various manners. The maps with lines of equal seismic energy per unit of time and area are governed by a few high-energy earthquakes.

Consequently, they need not necessarily be in agreement with a map (which unfortunately cannot be prepared) of the same type, which would be applicable, e.g. for a more recent geological period, such as the Holocene or the Quaternary. For this reason, maps with lines of equal density of the seismic epicentres are more important for comparison with tectonic maps because the epicentres are less randomly distributed. However, if one wants to attach greater importance to the stronger earthquakes, it is possible to introduce the magnitude or the epicentral intensity as a weighting factor. The maps were constructed with the help of a computer, and the isolines were printed by means of a plotter.

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* Central Institute of Physics of the Earth of the Academy of Sciences of the GDR, Burgweg 11, DDR-6900 Jena, German Dem. Rep.
** Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, Seismological Observatory, Meredek u. 18, H-1112 Budapest, Hungary
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2. Computation of fields of seismic activity

The catalogue of all known earthquakes in the Pannonian Basin by ZSIROS et al. [1988] forms the data base for the seismological part of the paper. It contains 2745 seismic events. With respect to the historical earthquakes, it is based mainly on RÉTHLY [1952]. The parameters of some historical earthquakes have, however, been re-estimated. The catalogue prepared by ZSIROS et al. [1988] contains for each earthquake the focal time, geographical latitude and longitude of the epicentre, the focal depth—computed according to the Kövesligethy formula [see SPONHEUER 1960], the magnitude, the epicentral intensity on the MSK–64 scale [see SPONHEUER 1965 and WILLMORE 1979], the error of the determination of the epicentre σ_i, the geographic designation of the epicentre, the error of the intensity determination and the literature source. According to the error of the determination of the epicentre, the earthquakes have been formally categorized in five classes: $\sigma_i = 5$ km, $\sigma_i = 10$ km, $\sigma_i = 20$ km, $\sigma_i = 50$ km, $\sigma_i =$ undetermined. Only earthquakes of the first three categories have been used in the computation of the maps so as not to adversely affect the accuracy of the maps. Since the catalogue obviously contains only a small portion of the earthquakes that took place in earlier centuries and as the determination of the intensities is also unreliable for these periods, only the earthquakes which took place between 1763 and 1984 have been used for constructing the maps. The 111 years between 1763 and 1873 have been denoted as the first epoch and the 111 years between 1874 and 1984 as the second epoch. The maps have been constructed for the entire period, that is for the period from 1763 to 1984, and for both epochs.

The maps have been constructed in the following manner: Let Q be any point in the area studied, Q_i the point indicated in the catalogue as the epicentre of the i-th earthquake. Let d_i be the distance $\overline{QQ_i}$, σ_i the scattering of the epicentre given in the catalogue—a centrosymmetric normal distribution being assumed. Thus, the epicentre with the probability density

$$P_i(Q) = \frac{1}{2\pi\sigma_i^2} \exp\left(\frac{-d_i^2}{2\sigma_i^2}\right) \tag{1}$$

is located at point Q. This position function P_i, whose integral over the entire area is 1, constitutes the epicentral density of earthquakes, whereas

$$S_1(Q) = \sum_i P_i(Q) \tag{2}$$

is the epicentral density of all earthquakes. Let T be the investigated period during which the earthquakes have taken place. In this case,

$$s_1(Q) = \frac{1}{T} S_1(Q) \tag{3}$$

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

Table I. The scaling variable N for various seismic fields

I. Táblázat Az N skála változó értéke különböző szeizmikus terekre

Таблица I. Переменные значения шкалы N при различных сейсмических полях

is the time-normalized epicentral density or, in other words, the epicentral density flow. Hence, the dimension of s_1 is $\mathrm{km}^{-2} \cdot \mathrm{a}^{-1}$. In addition, a scaling was performed according to which the numbers printed in the maps have to be multiplied by $10^{-N} \cdot N$ is given in *Table I.* The following equation

$$s_g(Q) = \frac{1}{T}\sum_i g_i P_i(Q) \qquad (4)$$

is a generalization of s_1, with $g_i > 0$. The magnitude M_i of the i-th earthquake, which magnitude is always positive in the above catalogue has, for example, been used as g_i. The time-normalized magnitude density $s_M(Q)$ thus created causes stronger earthquakes to become more distinctly evident on the map than does the epicentral density s_1. The situation is similar with s_I, with the epicentral intensity serving as the weighting factor. The dimension and scaling of s_M and s_I are the same as those for s_1. In none of the cases was normalization by means of $\sum_i g_i$ used. If the energy of the earthquake is substituted for g_i, one obtains the time-normalized energy density s_E with the dimension $\mathrm{erg} \cdot \mathrm{km}^{-2} \cdot \mathrm{a}^{-1}$. The equations developed by BÅTH and DUDA [1964] were used:

$$\log E = 12.24 + 1.44M \qquad (5)$$

$$\log V = 9.58 + 1.47M \qquad (6)$$

where log is the logarithm to base 10; E the seismic wave energy in erg; M the magnitude, which is equivalent with the Gutenberg–Richter magnitude; and V the earthquake volume in cm^3. The last of these is identified with the total aftershock volume. In the computation of s_E, $\sigma_i + R$ was substituted for σ_i, with $R = \sqrt[3]{3/4\pi}\; V$ in km. ULLMANN and MAAZ [1969] have considered in greater detail the computation of seismic fields, while BÅTH [1981] provides an up-to-date survey of problems of the earthquake magnitude. The density functions s_1, s_M, s_I and s_E have been plotted in an isogram for both epochs and for the overall period from 1763 to 1984 within a polygon with the following vertices:

17	20	23	26	26.5	22	16	λ in degrees longitude east
49	49.5	49	47	45.5	44.59	46.37	φ in degrees latitude north

On the map plane, the afore-said spherical polygon was mapped with the help of a Lambert's conformal conic projection. This made possible an exact comparison with the International Tectonic Map of Europe [Schatsky et al. 1964]. To facilitate comparison with other maps, the network of parallels and meridians was used in our illustrations, and the rivers Danube, Dráva, Tisza and Maros as well as Lake Balaton and the Neusiedler See were drawn with broken lines.

3. Seismic fields and comparisons with other geophysical fields

Figure 1 shows the (time-averaged) density of the seismic epicentres. One can notice an almost linear chain of highs extending approximately WSW–ENE: I located approximately at Csehi to the north of Zalaegerszeg; II Várpalota–Mór; III Dunaharaszti; IV Eger; VII Csap. It is noticeable that this chain of epicentral highs lies directly to the north of the Balaton line on the Bakony–Bükk Unit [Balla 1984] and also runs parallel to its strike. V Kecskemét, VI Érmellék and VIII Komárom are further significant areas with a high epicentral density. Other highs (e.g. in Slovakia) have not been numbered. The magnitude density in *Fig. 2* shows the afore-said chain of highs even more distinctly: further maxima located on this line are observed in addition to the above five maxima. The question we ask now is to what extent the results depend on the time interval in which the earthquakes took place. Figure 2 shows s_M for the entire period, *Fig. 3* for the second epoch, *Fig. 4* for the first epoch. It can be seen that Fig. 2 is similar to Fig. 3. With regard to Fig. 4, this has been computed only from historical earthquakes taking place between 1763 and 1873, it also shows the afore-said chain of anomalies.

A strongly negative correlation is found between the epicentral density (for the entire period investigated) s_1 and the temperature at a depth of 2 km (see *Fig. 5*). $s_1 > 100$ and $T > 120°$ C have been drawn separately. The aforementioned chain of epicentral highs striking WSW–ENE is located at its western and central parts in the cooler region. Likewise, the high IV in the eastern part is located on the temperature low in the Bükk Mts. The seismic high V also lies in a temperature minimum. Obviously, stresses that have seismic effects can more easily build up in cooler, less ductile portions of the crust. This effect is well known from solid-state physics. It is, however, only a supposition that the correlation between the positive epicentral density anomalies and the negative temperature anomalies could be partially explained by it. The largest warm regions in the Pannonian Basin also strike WSW–ENE. They are located on the Mid-Hungarian Belt [see Balla 1984, p. 319], that is, to the south of the seismic chain of anomalies. This belt is possibly linked to a high position of the asthenosphere [Pospíšil and Vass 1984, p. 359]. According to a kinematic analysis performed by Balla [1984], this is the suture between two blocks. The southeastern domains rotated in a clockwise direction by 100°, the northwestern block rotated counter-clockwise by 30°.

Earlier paleomagnetic investigations led to similar conclusions: In the Early Miocene, the Transdanubian Range rotated by 35° in a counter-clockwise direction [Márton and Márton 1983] whereas South Transdanubia rotated by 60° or more in a clockwise direction [Márton 1981]. To the south of Lake Balaton and to the south of Székesfehérvár, the Balaton line is characterized by an electric conductivity anomaly [Varga 1979, Ádám 1985], alongside which special heat flow anomaly can also be found [Dövényi et al. 1983]. It constitutes the continuation of the Periadriatic lineament which separates the Southern Alps from the metamorphosed Eastern Alps. The Periadriatic lineament in the Gail valley and in the Karawanken mountains is also characterized by a conductivity anomaly and an increased heat flow [Ádám et al. 1984].

Walzer et al. [1989] studied the correlation between the heat flow and seismic magnitude density in the Pannonian Basin. They also found a negative correlation, which was, however, not quite as distinct as that between the temperature at a depth of 2 km and the epicentral density. Somewhat less recognizable are the correlations between the epicentral density and magnitude density (this work), on the one hand, and the maxima of the horizontal geothermal gradient according to Stegena [1979], on the other hand. Here, too, there is an anomaly chain, oriented WSW–ENE, which determines the overall picture. But the pronounced seismic anomalies II and VIII are clearly situated outside the maxima of Stegena's map. Anomaly V also lies on a maximum of the map of the geothermal gradient. A relationship between the distributions cannot be denied. If one compares the survey of the most important thermal springs in Mesozoic carbonates [Dövényi et al. 1983, p. 38] with modern maps of seismic activity (Figs. 1 to 3), it becomes evident that these springs are located without any exception at the edge of seismic highs: Spring regions of 67, 17 and 9 MW at the edge of I, those of 100 and 6 MW at the edge of VIII, a spring region of 35 MW at the edge of III, those of 42 and 20 MW at anomaly IV, a spring region of 15 MW (Harkány) at the edge of an unnumbered magnitude density anomaly in the southern part of Transdanubia.

Whereas there is a very close relationship between regions with a low temperature and earthquake regions, the relationships with the field of gravity are only loose. At any rate, the largest positive regional Bouguer anomalies [Meskó 1983], which were obtained by means of a low-pass filter with a cut-off frequency of 20 km and of 45 km, coincide with our seismic anomaly chains I, II, III, IV. The remaining anomalies are not clearly associated with seismic highs. Understandably, the correlation between the negative regional Bouguer anomalies, which were obtained by means of a low-pass filter with a cut-off frequency of 20 km [Meskó 1983], and the largest depths of the pre-Tertiary basement [Kilényi and Rumpler 1984] is very close, as can be shown by directly projecting the maps on one another.

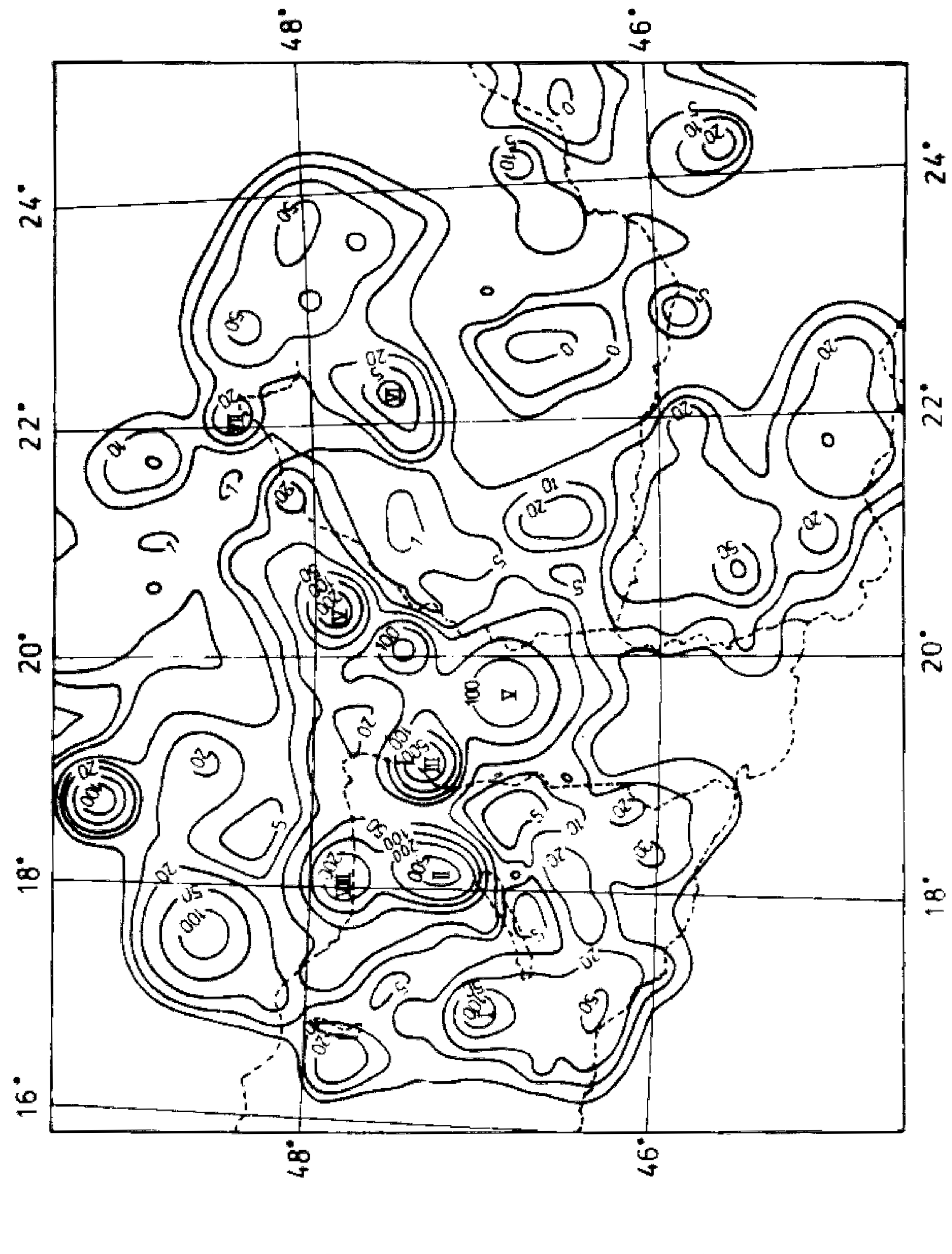

Fig. 1. Time-normalized epicentral density s_1 for the period 1763–1984

1. ábra. Időre normált epicentrum-sűrűség eloszlás s_1 az 1763–1984 időszakra

Рис. 1. **Распределение плотности эпицентров s_1, отнесенное ко времени, для периода 1763–1984**

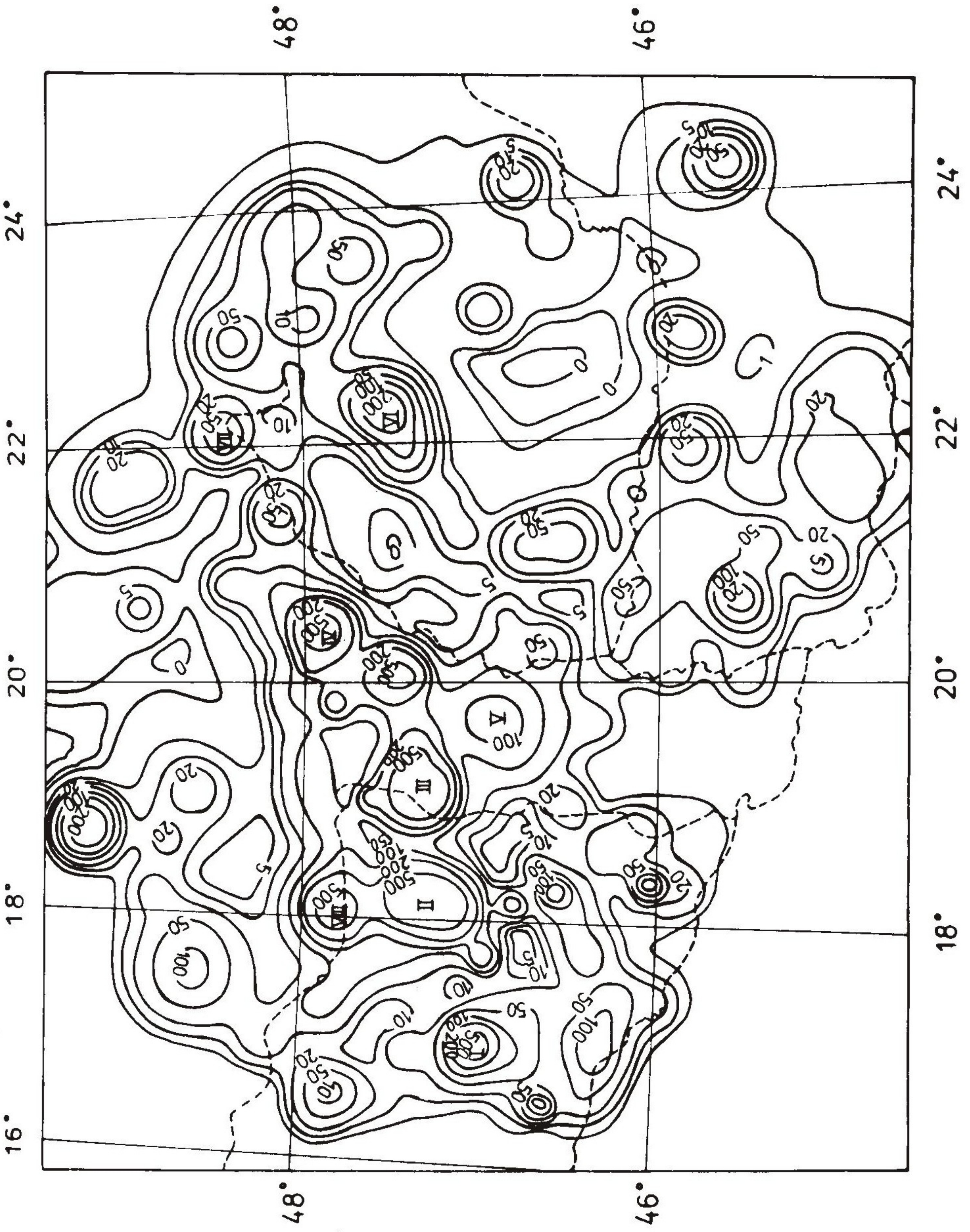

Fig. 2. Time-normalized magnitude density s_M for the period 1763–1984

2. ábra. Időre normált magnitúdó-sűrűség eloszlás s_M az 1763–1984 időszakra

Рис. 2. Распределение плотности магнитуд s_M, отнесенное ко времени, для периода 1763–1984

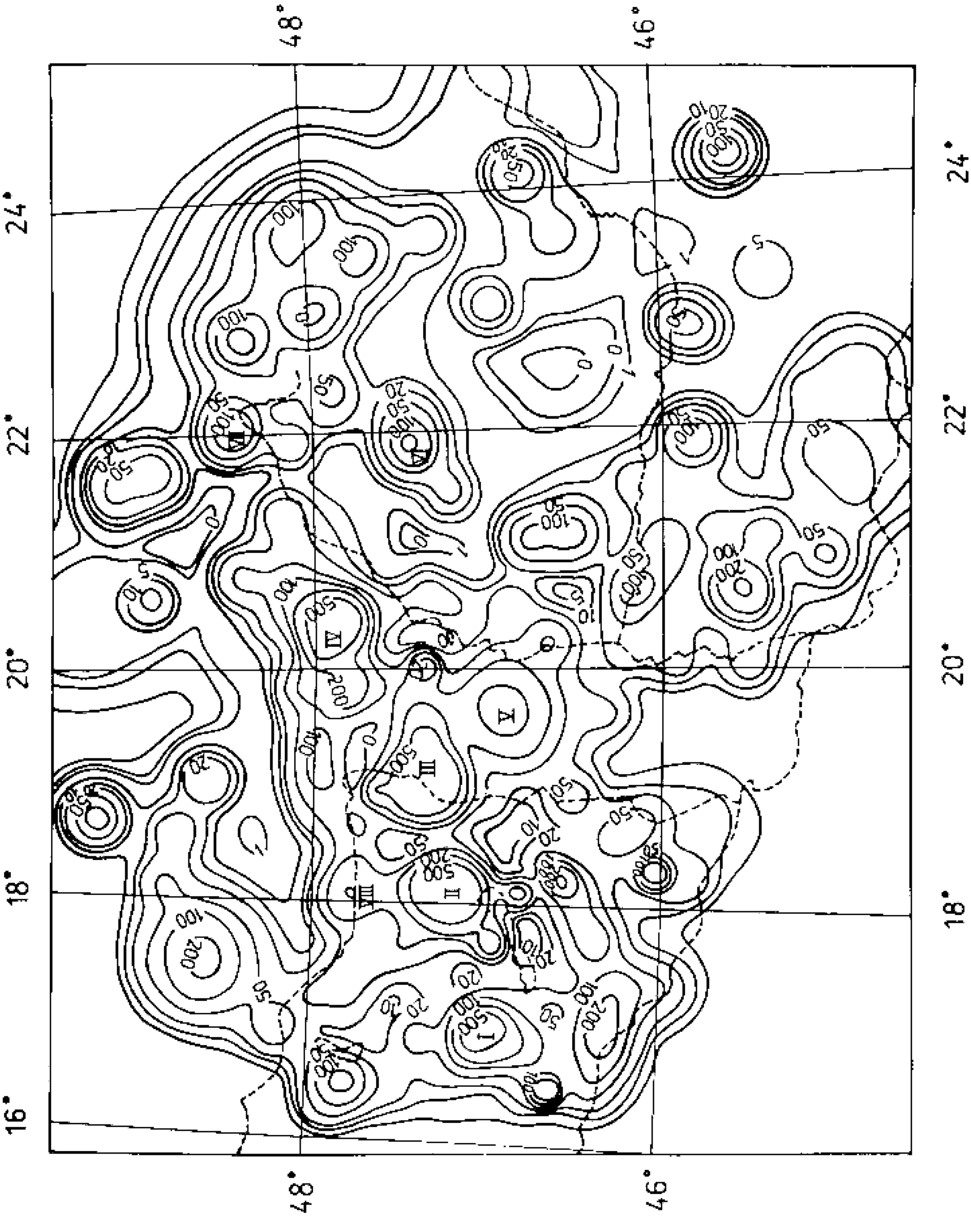

Fig. 3. Time-normalized magnitude density s_M for the second epoch (1874–1984)

3. ábra. Időre normált magnitúdó-sűrűség eloszlás s_M a második vizsgált időszakra (1874–1984)

Рис. 3. Распределение плотности магнитуд s_M, отнесенное ко времени, для второго периода (1874–1984)

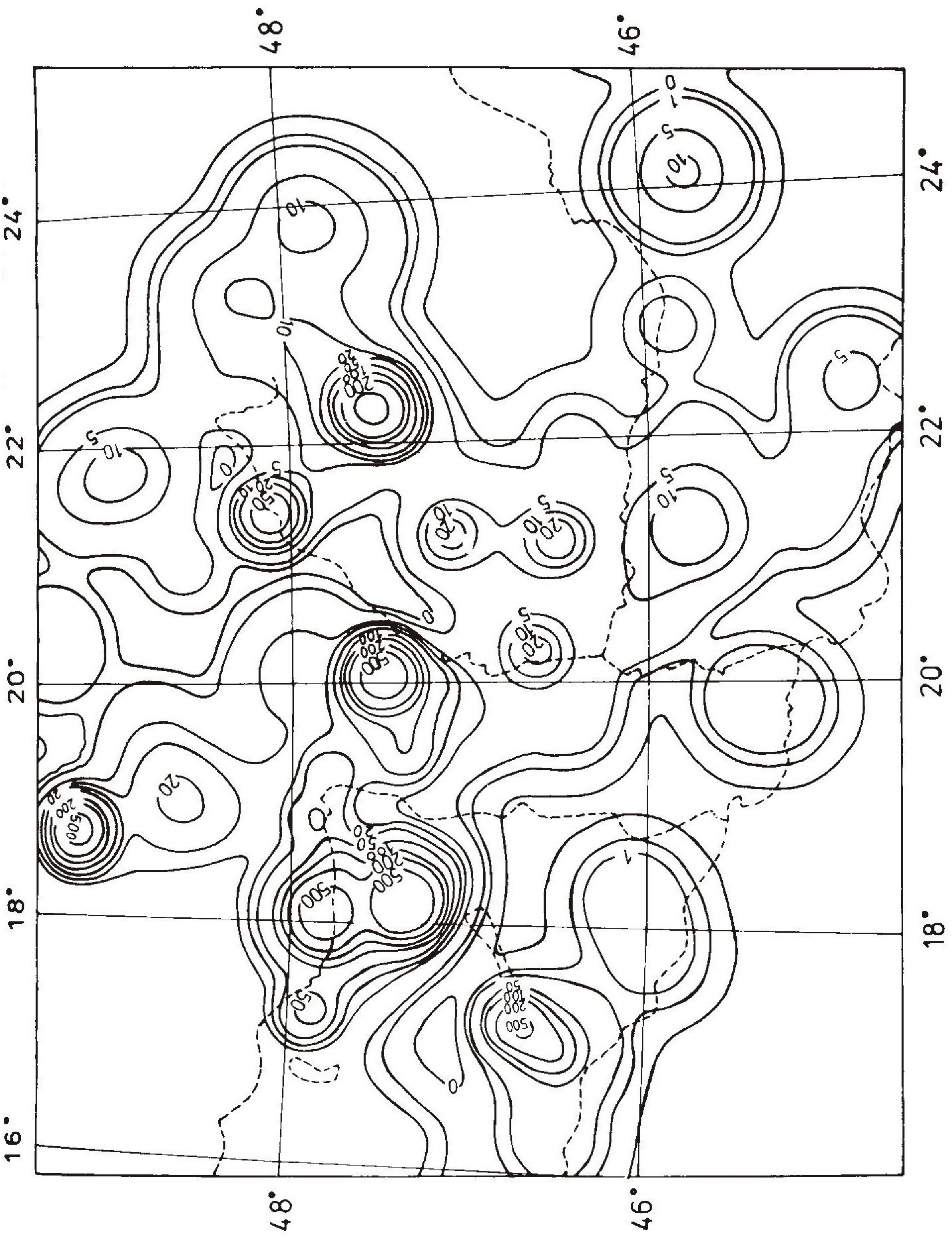

Fig. 4. Time-normalized magnitude density s_M for the first epoch (1763–1873)

4. ábra. Időre normált magnitúdó-sűrűség eloszlás s_M az első vizsgált időszakra (1763–1873)

Рис. 4. Распределение плотности магнитуд s_M, отнесенное ко времени, для первого периода (1763–1873)

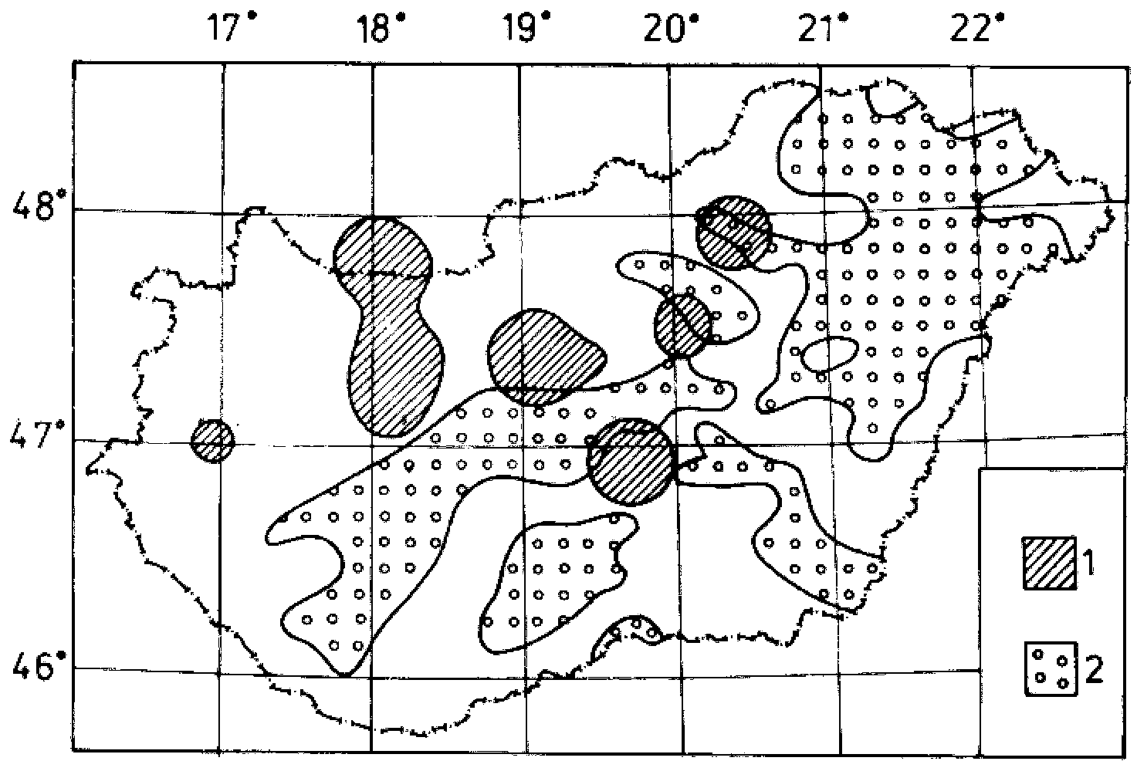

Fig. 5. Comparison of regions with high epicentral density s_1 with regions of high temperature. It can be seen that the seismic activity occurs preferably in those regions of the Pannonian Basin which are less hot

1 $s_1 > 100$ for earthquakes between 1763 and 1984; 2—$T > 120$°C at 2 km below the surface [Dövényi et al., 1983, p. 14]

5. ábra. A nagy s_1 epicentrum-sűrűségű területek összehasonlítása nagy hőmérsékletű területekkel. Látható, hogy a szeizmikus aktivitás főként a Pannon medence kevésbé meleg területein jelentkezik

1 — $s_1 > 100$ területei az 1763 és 1984 közötti földrengésekre; 2— $T > 120$ °C, a felszín alatt 2 km mélységben. [Dövényi et al. 1983]

Рис. 5. Сопоставление районов с высокой плотностью эпицентров s_1 с районами высоких температур. Можно заметить, что сейсмичность приурочена ва основном к менее нагретым районам Паннонской впадины

1 районы $s_1 > 100$ по землетрясениям 1763–1984 гг.; 2 $T > 120$ °C на глубине 2 км [Dövényi et al. 1983]

It is remarkable that the chain of positive anomalies with the WSW–ENE orientation is very pronounced on our epicentral and magnitude density maps, while the same cannot be said of the published maximum intensity maps. Whereas the positive anomalies V, II, VIII and IV (in this order) are the most important ones on the maximum intensity map of Simon [1930]; V, VIII and, to a lesser extent, IV and III are dominant in Bisztricsány et al. [1961]. In Zsíros and Mónus [1984, p. 442], V and III are dominant. These differences are certainly due to a varying degree of the completeness of the material as well as to different methods used.

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A PANNON MEDENCE SZEIZMIKUS AKTIVITÁSA ÉS EGYÉB GEOFIZIKAI MÉRÉSEKKEL VALÓ ÖSSZEHASONLÍTÁSA

Uwe WALZER, Richard MAAZ és TÓTH László

A Pannon medencében 1763 és 1984 közt kipattant földrengések adataiból számítógépes szeizmicitás térképet szerkesztettünk. A medence NyDNy–KÉK csapású tektonikai egységei szoros kapcsolatot mutatnak az epicentrum-sűrűség és magnitúdó-sűrűség izovonalaival. Az említett szeizmikus térképek maximumait 2 km mélységben felvett hőmérséklettérképek minimumaival korreláltuk. Az epicentrum- és magnitúdó-sűrűség maximumok eloszlása a hőáram minimumokkal is összefüggést mutat, és valamivel lazább kapcsolatot a horizontális geotermális gradiens maximumokkal, valamint a pozitív regionális Bouguer anomáliákkal.

СЕЙСМИЧНОСТЬ ПАННОНСКОЙ ВПАДИНЫ В СОПОСТАВЛЕНИИ С ДРУГИМИ ГЕОФИЗИЧЕСКИМИ ДАННЫМИ

Уве ВАЛЬЦЕР, Рихард МАЦ и Ласло ТОТ

По данным землетрясений, имевших место в Паннонской впадине за период 1763–1984 гг., с помощью ЭВМ составлена карта сейсмичности. Тектонические единицы ЗЮЗ–ВСВ простирания в Паннонской впадине обнаруживают тесную связь с изолиниями плотности эпицентров и магнитуд. Максимумы на этой карте сейсмичности скоррелированы с минимумами на картах температур на глубине 2 км. Распределение максимумов плотности эпицентров и магнитуд обнаруживает связь также и с минимумами теплового потока, и несколько более слабую — с максимумами горизонтальных геотермических градиентов, а также с положительными региональными аномалиями Буге.