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Horizontal gravity gradients and earthquake distribution in Hungary

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The distribution of the maximum horizontal gravity gradients shows very often a linear pattern. If the topographic features of the basement were formed by horizontal and/or vertical block movements then this linear pattern marks faults. The structural lineaments based on geophysical data are, however, insufficient for making a proper judgement about the seismic hazard of a region: seismological data are indispensable. With the help of structural lineaments a relationship can be found between scattered earthquake epicentres, individual source regions can be delineated, and their relationships clarified. To study these relationships, a gravity lineament map of Hungary was constructed, based on the Bouguer anomaly map, and applying the maximum gradient method. The gradients were corrected for basin effect. This lineament map was correlated with the distribution of historical earthquakes and the earthquakes registered between 1995 and 1998 by the Microseismic Monitoring Network (MMN) of Hungary's Paks Nuclear Power Plant. Former investigations had indicated a correlation between high gradients and the epicentres of historical earthquakes. An even more striking correlation was found between the epicentre distribution of earthquakes recorded by the MMN and belts of high horizontal gravity gradients.

Keywords: gravity surveys, lineaments, earthquakes, Microseismic Monitoring Network, Hungary

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1. Introduction

Earthquakes originate as a consequence of stress and strain in the lithosphere. The source of these stresses is the movement of continental and oceanic plates, and their collision and subduction. High-magnitude lithospheric earthquakes concentrate in such collision zones, the so-called active plate margins (e.g. the western coast of America, Japan, etc.). Hungary, however, is far from any active plate margins. Her earthquakes with low-magnitude ($M_0 \leq 6$) and shallow focal depths (≈ 10 km), meaning they originate within the basement, belong to the so-called intra-plate category.

The composition and structure of the basement of the Pannonian basin is extremely complex, consisting of different plate fragments drifting and accreting during the late Mesozoic and early Tertiary. It is a difficult task to determine which of the different structural lines are linked with earthquakes: the intra-fragment ones, or those separating these fragments, or the faults transversing the present basement. Maybe this is why some earth scientists believe that there is no connection between the structural system of Hungary and its earthquake distribution. The truth is that even now the tectonism of Hungary is not known to the extent that an unambiguous relationship could be found between structure and earthquake occurrence.

Another difficulty in studying the correlation between earthquake distribution and geological structure is that there is no instrumental earthquake recording dating back further than the beginning of the 20th century. The records of historical earthquakes based on building damage can be regarded more-or-less exact since the time of the Komárom earthquake of 1763. Because of the moderate seismicity of Hungary this not much more than 200-year old history of earthquakes means that there is insufficient evidence to enable the exact regularity of the seismicity of Hungary to be identified.

In this respect, Hungary is not unique, as the eastern regions of the USA have similar problems: moderate seismicity, low-magnitude earthquakes not causing faults on the surface, etc. The increasing volume of data, however, confirms that generally speaking seismicity concentrates in the reactivated zones of Palaeozoic and Mesozoic deformations [HILL 1987]. In regions characterized by moderate and scattered earthquakes, the seismic hazard of an area can be assessed only by the seismologists' accumulated experience.

2. Analysis of data

Earthquake data for our analysis were taken from the catalogue compiled and updated by a team of the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences [ZSÍROS et al. 1988]. This catalogue contains some 5000 items of data going as far back as 456 AD. The relative frequency of historical earthquakes for 20-year intervals are presented in *Fig. 1.* It can be seen that the number of recorded events grew

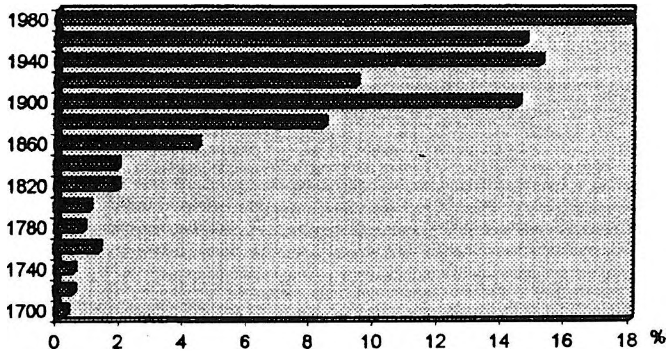

Fig. 1. Relative frequency of historical earthquakes for 20-year intervals
1. ábra. A történelmi rengések 20-éves idő intervallumokra számított relatív gyakorisága

considerably after 1860 which, however, does not mean that the seismic activity of Hungary increased from that time, but refers to the uncertainty concerning the characteristics of historical earthquakes. Before instrumental recording, an earthquake had to fulfil the following criteria to get recorded: population to observe the quake and regard the observed event to be so important that they would report it to the authorities who would then record it. Taking into account the above criteria it can be concluded that only a small proportion of the historical earthquakes were registered. It is evident that in a more advanced society more earthquakes are recorded (e.g. literacy is an essential factor). Since the beginning of the 20th century, owing to the starting of regular instrumental registration, the number of recorded earthquakes has been increasing significantly. The ever growing sensitivity of seismographs is also leading to more and more registered events.

There is a similar or even greater uncertainty in the locations of epicentres. Historical earthquakes are generally designated as being linked to the nearest large settlement, but it does not mean that the highest relative damage occurred in the given settlement. The quality of the buildings should also be taken into consideration. There is also no guarantee that the epicentre was near to a settlement. We can take into account as well that the effect of an earthquake is much less frightening in the country than in a town. Based on the above considerations it is evident that the reliability of epicentre determination depends on the spatial distribution of settlements.

The compilers of the above-mentioned catalogue tried to categorize the earthquakes according to the reliability of epicentre location. The relative distribution of the different categories is presented in *Fig. 2*. It can be

a	b	c
A	±5	5%
B	±10	35%
C	±20	33%
D	±50	5%
E	u.	22%

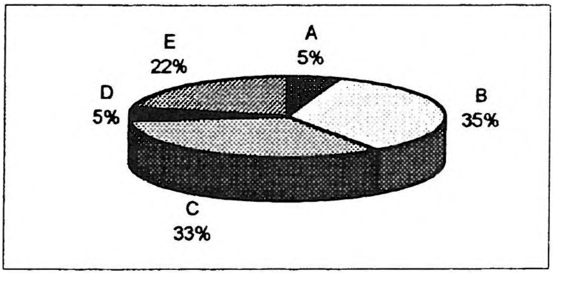

Fig. 2. Categorization and relative distribution of historical earthquakes based on the reliability of their epicentre location
a — category, b — accuracy of epicentre determination in km, c — relative distribution
2. ábra. A történelmi rengések kategorizálása az epicentrum meghatározási pontossága szerint és ezen kategóriák relatív gyakorisága
a — kategória, b — az epicentrum meghatározási pontossága km-ben, c — relatív gyakoriság

seen that the uncertainty is rather high. That phenomenon has to be taken into consideration if we try to find an empirical correlation between geological structure and earthquake distribution, otherwise we may reach wrong conclusions. To avoid large errors we included into our investigations only those quakes the locations of which are categorized as A and B; in other words their epicentre locations are known better than ±10 km. Only 40% of the historical earthquakes fell in these categories.

Bouguer anomalies reflect the integrated effect of subsurface masses, thus they contain all information which can be deduced from mass effects. In basin areas, where the high-density basement is overlain by young, loose sediments, the topographical changes of the basement present themselves in a horizontal plane as density contrasts. If the topographic features of the basement were formed by horizontal and/or vertical block movements then the lineaments mark faults. Above a fault, where an abrupt density change exists, the horizontal gradient has a local maximum. This phenomenon is utilized in determining structural lineaments. The maximum gradients show very often a linear pattern. These gravity lineaments can be used for detecting structural lines taking part in the shaping of basement topography. Although they do not provide any direct information on the age of these structural lines, they are very useful pointers in seismotectonic studies.

3. Correlation

For studying the correlation between gravity lineaments seen in the map and the earthquake distribution we plotted all historical earthquakes whose epicentres are known to an accuracy at least ±10 km. The radii of the circles are proportional to the respective accuracy in the scale of the map (*Fig. 3*).

From this map we can conclude that at some places epicentres are concentrated along lineaments belonging to known structural lines (e.g. Kapos line, the south-western and the north-central part (Jász region) of the Central Hungarian dislocation zone). At other places the linear pattern can be recognized in the epicentre distribution (e.g. Komárom–Berhida, Rajka–Zirc) but one cannot see their equivalent in the gravity lineament map nor in the known geological structure. As gravity lineaments indicate the locations of sharp density contrasts, if earthquakes occur along such lineaments their cause must be attributed to some sort of fault even if it is not yet identified. Those earthquakes, however, which show a linear pattern but do not coincide with any gravity lineament are caused by such stress zones which are not linked with linear density contrast, proving that stress zones do not necessarily occur along geological boundaries.

As the epicentre determination of historical earthquakes is unreliable, in the next step we decided to use those data which were registered by the Microseismic Monitoring Network (MMN) of Paks Nuclear Power Plant, in 1995–98. The siting and the sensitivity of the recording seismographs allow us to recognize earthquakes of magnitude 1–2.5, and to determine the hypocentre with an accuracy of 1–5 km [TÓTH et al. 1996, 1997, 1998]. A preliminary analysis for 1995–96 has already been published [SZABÓ–PÁNCSICS 1997]. The reliability of this data set is comparable to that of the lineaments, thus their relationship is worth studying. The lineament map computed from the Bouguer anomalies and corrected for basin effect [SZABÓ–PÁNCSICS, a separate paper in this volume] seemed the best for comparison; in this map we plotted the epicentres of earthquakes recorded by the MMN, in 1995–98 (*Fig. 4*). *Figure 5* contains all locations and names used in the analysis below.

Moving from west to east on this map, we find the following:

— The earthquakes in the north-western corner of the map, on Austrian territory, confirm the activity of the Muhr–Mürz line, determined formerly by historical earthquakes.

— The earthquakes near Veszprémvarsány and Lébény lie in the Rajka–Zirc earthquake zone — delineated by historical earthquakes — along gravity lineaments intersecting perpendicularly that zone. This Rajka–Zirc zone has up till now evaded attention because it consists of small quakes ($I_0 \leq 5$ MSK-64) and its direction is nearly perpendicular to the known structural lines. Nevertheless its existence is supported by the latest results of the DANREG project [NEMESI et al. 1997]. One of the most outstanding results of its geophysical investigations was the detection by magnetotellurics of the Rába–Hurbanovo–Diósjenő dislocation zone.

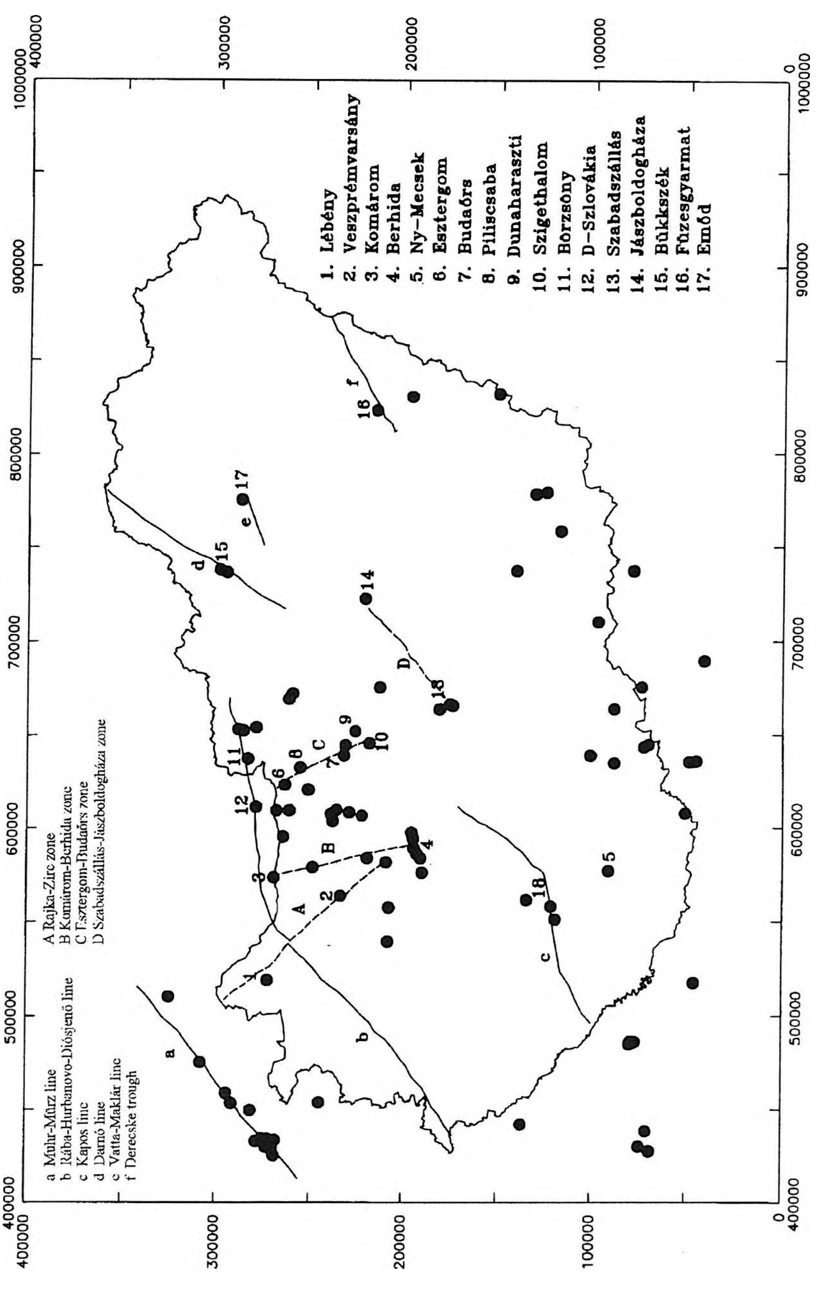

Fig. 5. Map showing the epicentres recorded by MMN from 1995 to 1998 and the structural lines mentioned in the text
5. ábra. Mikroszeizmológia Megfigyelő Hálózat által 1995–1998-ban regisztrált földrengések epicentrumai és a szövegben említett szerkezeti vonalak helyszínrajza

The magnetotelluric curves recorded on the N, and NW side of this zone sharply differ from those recorded on the S, and SE side, thus reflecting different geology. Based on the magnetotelluric survey, the tectonic zone can be located with high reliability. From our point of view it is of outstanding importance that in the Rába line, 5 km to the southwest from Győr, a strike-slip fault of about 6–7 km shift can be recognized which coincides with a part of the Rajka–Zirc earthquake zone.

— The earthquakes in the area of Berhida mark the activity of the southern termination of the Komárom–Berhida zone which is regarded as the most active seismic zone of Hungary. The gravity lineaments reflecting this zone are not very distinctive; they can be traced only intermittently.

— The focal depth of the earthquake in the western Mecsek Mts. is 1 km, thus it is most probably an event linked with the mining activity there.

— The two earthquakes at the two opposite ends of the Esztergom–Budaörs lineament — limiting the outcropping Mesozoic blocks of the Pilis–Buda hills in the west — are worthy of attention. The odd thing about it is that both ends set off on the same day, on 4 May 1995, calling attention to its activity. The earthquake of Piliscsaba in 1997, supports the activity of this zone.

— The two earthquakes at Dunaharaszti and Szigethalom are indications that the area is still under stress after the big earthquake of 1956. Another possibility, is that they are related to the Esztergom–Budaörs line.

— The earthquakes of the Börzsöny Mts. and of South Slovakia are most probably connected with the Hurbanovo–Diósjenő line.

— The earthquakes at Szabadszállás–Jászboldogháza occurred along a definite lineament of NE–SW direction, indicating its activity. Historical earthquakes suggest the continuation of this lineament further to the NE from Jászboldogháza.

— The earthquakes near Bükkszék refer to the activity of the Darnó line. The Darnó line is manifested by a strong gravity lineament, too.

— The 7 earthquakes occurring within two days in the area of Füzesgyarmat are marked with the mean value of their co-ordinates, because of their big errors. They coincide with the junction of two definite lineaments and mark, most probably, the activity of the Derecske trough.

— The earthquake in the neighbourhood of Emőd marks the activity of the Vatta–Maklár trough, well known from seismics.

— The two earthquakes along the Kapos line support the activity of this well-known tectonic line.

4. Relationship between earthquake distribution and gravity gradients

The geological-geophysical investigation of epicentral areas of historical earthquakes of $I_0 \geq 6°$ (MSK-64) intensity led to the finding of a correlation between the horizontal gradients of the gravity field and earthquake distribution [SZABÓ Z. 1990]. It seemed advisable to carry out a similar investigation for the earthquakes registered by the Microseismic Monitoring Network. In *Fig. 6* we have plotted those areas where horizontal gradients, computed from Bouguer anomalies, exceed 15 E (1.5 mGal/km), as well as the earthquake epicentres. We have found that 84% of earthquake epicentres coincide with high gradient belts. The importance of this correlation increases if we take into consideration that these high-gradient zones represent only 24 % of the area of Hungary.

5. Closing remarks

Because of the high number of gravity lineaments the probability of an earthquake coinciding with one of them is 50 %. In spite of this real problem we consider that the lineaments with their definite characteristics provide a sound basis for tracing the active zones. Good examples for this are the Esztergom–Budaörs and the Szabadszállás–Jászboldogháza lineaments discussed above. The earthquakes in both cases coincide with definite lineaments. The high correlation between high-gradient belts and epicentre distribution supports this statement.

Despite there being a degree of uncertainty in our findings, it should be taken into consideration that in areas of low to medium activity the possibility of identifying a correlation between seismic zones and geological structure is a world-wide problem. Doubtless the correlation of gravity lineaments and distribution of earthquakes has provided encouraging results in delineating active zones. The earthquakes to be registered in the future will increase the reliability of this method.

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Horizontális gravitációs gradiensek és a földrengéseloszlás kapcsolata Magyarországon

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A horizontális gravitációs gradiensek maximális értékei igen gyakran vonalas elrendeződést mutatnak. Amennyiben a medencealjzat domborzatát törések menti kiemelkedések, süllyedések

illetve elmozdulások alakították, akkor a gradiensek alapján kijelölhető lineamensek is a törések hatását tükrözik. A geofizikai adatokból szerkesztett lineamensek azonban önmagukban nem elegendők egy-egy terület földrengés veszélyességének megítéléséhez, ehhez szükség van szeizmológiai ismeretekre is. A lineamensek segítségével kapcsolatot találhatunk az egyes, látszólag szórtan elhelyezkedő földrengés epicentrumok között, ezáltal lehetővé téve az egyes forrásterületek körülhatárolását és a különböző forrásterületek közötti összefüggések tisztázását. A Boguer-anomália térkép alapján, a maximális gradiens módszer segítségével, kijelöltük a gradienseket, melyeket javítottunk a medenceüledékek hatásával, majd megszerkesztettük a lineamens térképet. A lineamensek számos helyen korrelálnak a történelmi földrengéseloszlással, illetve a Paksi Atomerőmű Mikroszeizmológiai Megfigyelő Hálózata (MMH) által 1995–98-ban regisztrált földrengésekkel.

ABOUT THE AUTHORS

Zoltán Szabó, for a photogprah and biography, see this issue, p. 27.

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