

## STATISTICAL INVESTIGATIONS OF LOCAL EARTHQUAKES IN THE CARPATHIAN BASIN AND SURROUNDING AREA

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The Carpathian Basin is situated in the territory between the Mediterranean area, which is seismically one of the active regions and the Carpathian Mountains belt. The temporal variation of seismicity is investigated on the example of three seismo-tectonically different regions: the Carpathian Basin, the Vrancea region and the Dinarides. The seismicity is analyzed since 1900 in order to investigate the existence of diurnal periodicities using hodographs. There are two different diurnal distributions opposing each other: maximum early morning dominates until the year 1963, followed by a period of time when earthquakes seem to occur more often around 13h local time mainly concerning the weak  $M_L < 3.2$  events. The midday maximum in the number of minor events may be caused by the inclusion of quarry blasts, but the diurnal geomagnetic variations correlate well with diurnal changes in earthquake activity. Duma and Rhuzin (2003) suppose that the current vortices induced by Sq variations in the lithospheric layer, flowing across the horizontal component of the geomagnetic field generate a torque which can be added to the tectonic loading stress (which have a maximum about noon) and may help trigger instability in a fault approaching the failure threshold.

The spatial and temporal fractal structures of earthquakes were analyzed using the box counting method. The regions were divided into different size  $r$  of a square box and were counted the minimum number  $N(r)$  of boxes necessary to cover all the data. The recurrence times of earthquakes are shown to be a clustering process and are much higher in the Carpathian Basin. The earthquakes in these regions have self-similar structures. The slope of  $\log N - \log r$  function for Carpathian Basin breaks at about 20 km, which divides the range into two bands. This breaking at about 20 km maybe connected to the intrinsic weakness of the Carpathian Basin lithosphere.

**Keywords:** Carpathian Basin; diurnal variation; earthquake; fractal; hodograph; seismicity

## 1. Introduction

The aim of this study is to investigate the existence of diurnal periodicities of the occurrence time of seismic events in the Carpathian Basin and adjacent regions in Dinarides and Vrancea. The temporal variation of seismicity is studied in these seismo-tectonically different areas. For that purpose, we used the data of the Hungarian Earthquake Catalogue ranging in time from 1900 to 2003 (Zsíros 2000, personal supplements till 2003). The recurrence times of earthquakes are shown to be a clustering process in the Carpathian Basin (Bodri 1999).

The hodographs of diurnal distributions show a difference before and after 1962–1963 years in both the Carpathian Basin and Dinarides databases. Before 1963 there were more earthquakes in the early morning, and after 1963 more earthquakes were detected during afternoon in the Carpathian Basin. The event times are tested against the null hypothesis (earthquakes occur according to the Poisson process in time) by using the Schuster's test (Schuster 1897).

Using the box-counting method the fractal structures of the spatial and temporal distributions of earthquakes epicenters were examined.

## 2. Data

The Carpathian Basin is bounded on the north to the east by the Carpathian mountain belt and on the west by the eastern Alps and on the south by the Dinarides. The area is tectonically rather complicated. The seismicity in the Carpathian Basin is more moderate compared to the peripherals, and the distribution of earthquakes epicenters shows a rather scattered patterns. The development of the Carpathian mountain belt and the Carpathian Basin is attributed to collision between the Eurasian Plate and the African Plate between the Paleocene and Middle Miocene (Horváth 1984, 1988, Royden and Horváth 1988). Several authors basically agree that present-day deformation in the Carpathian Basin system is continuing and is controlled by the northward movement and counter-clockwise rotation of the Adriatic microplate relative to Europe (Bada 1999, Bada et al. 1998, 1999, Gerner et al. 1999). In the Carpathian Basin the crustal structure is relatively simple. Beneath the sedimentary layer, two almost homogeneous crustal layers are observed, and the Moho lies at depths of only 24–25 km (Grad et al. 2006).

Due to the relative motion of Adria, no plate convergence can explain the recent tectonic evolution of the Apennines, which appears to have been entirely controlled by passive subduction processes. Slab sinking is still an active process in the northern Apenninic Arc, where a mobile axial belt characterized by strong shallow earthquakes, and the region is bordered by compressional and extensional active belts, respectively along the Adriatic and the Tyrrhenian margins of the mountain chain (Herak 1995, Slejko et al. 1999). The thickness of Moho varies between 40 and 50 km.

The Vrancea region is characterized by at least three tectonic units in contact: the East European plate, Intra-Alpine and Moesian subplates. The strongest seismic activity of Romania concentrates at intermediate depths (60–200 km) in an old,

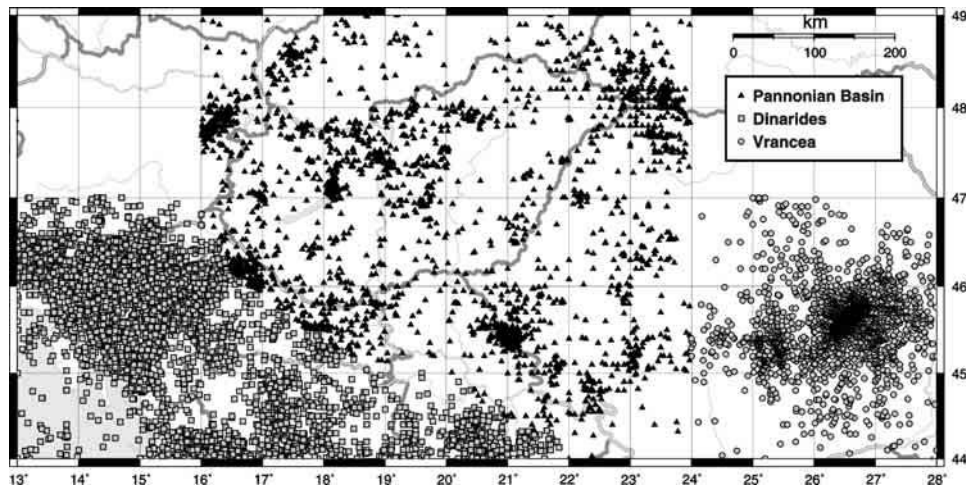


Fig. 1. Distribution of earthquakes epicenters in the Carpathian Basin and its surroundings. The region is divided into three parts. The earthquake database of the regions contains 19,000 events from 1900 until 2003

almost vertical subducting slab. For this region the historical records of subcrustal earthquake occurrences are fairly more than a millennium (Purcaru 1979). A deep seismic sounding survey was performed in 2001 in south-eastern Romania. Recent uplift observed in the Vrancea zone, likely coupled with contemporaneous rapid subsidence in the foreland. The Moho lies at the depth of about 40 km (Panea et al. 2005).

A comprehensive earthquake catalogue has been compiled, listing historical and instrumentally recorded earthquakes throughout the Carpathian Basin. The catalogue contains more than 20,000 events, and is considered to be complete for earthquakes larger than  $M_L 6.4$  since 1500, and for earthquakes larger than  $M_L 3.5$  since 1880, and for earthquakes larger  $M_L 3.2$  since 1900.

The region is divided in three parts (Fig. 1). These are the Carpathian Basin (4361 earthquakes), the Vrancea region (4024 earthquakes) and the Dinarides (10620 earthquakes) ranging in time from 1900 to 2003.

The yearly variation of the number of events in the Carpathian Basin for events  $M_L > 3.2$  (Fig. 2a) shows no linear trend. The dashed line indicates the slope of regression line fitted to this. The cumulative earthquake frequencies versus magnitude in the investigated three regions (Fig. 2b) prove the completeness, too.

The magnitude-depth distribution (Fig. 3) indicates that shallow hypocentral depth within the top 20 km of the earths crust is principal in the entire region except for the Vrancea zone where intermediate depth seismicity (from 70 to 160 km) is governing. Many focal depth values were estimated from macroseismic data (Zsíros 1989, 1996). In the Carpathian Basin area the majority of events happen between 6 and 15 km depths, in the Dinarides region between 1 and 22 km below the surface. In the Vrancea region strong earthquakes occur either between 5 and 25 km or 70 and 160 km depth. There is a lack of data of microearthquakes  $M_L < 2$ .

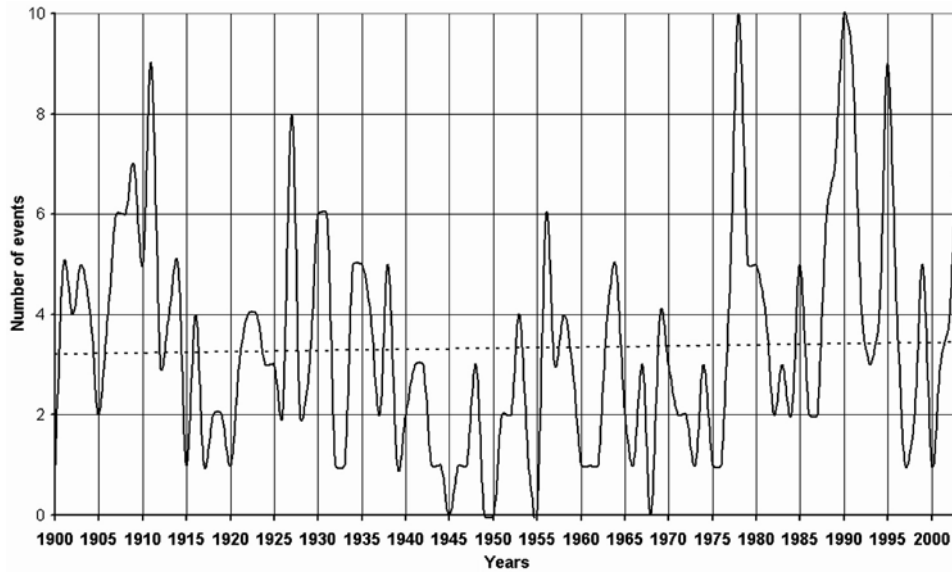


Fig. 2a. Number of events per years in the Carpathian Basin for events  $M_L > 3.2$ . Dashed line indicates the slope of regression line fitted to data. There is no linear trend

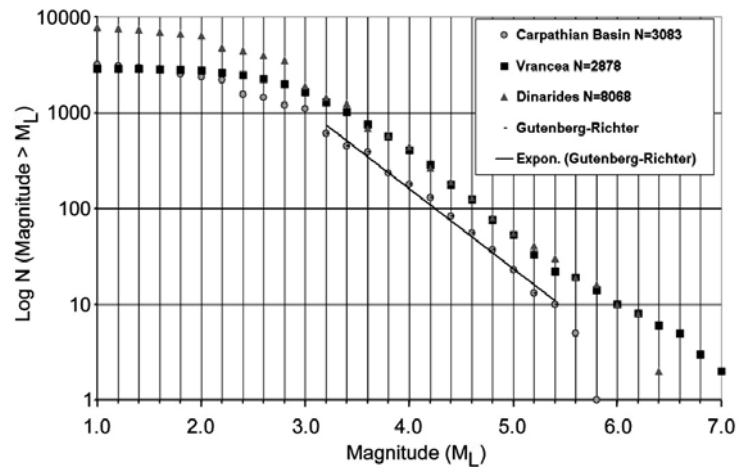


Fig. 2b. The cumulative earthquake frequency versus magnitude in the investigated three regions with regard to all data. Data set is no complete for magnitude below  $M_L < 3.2$

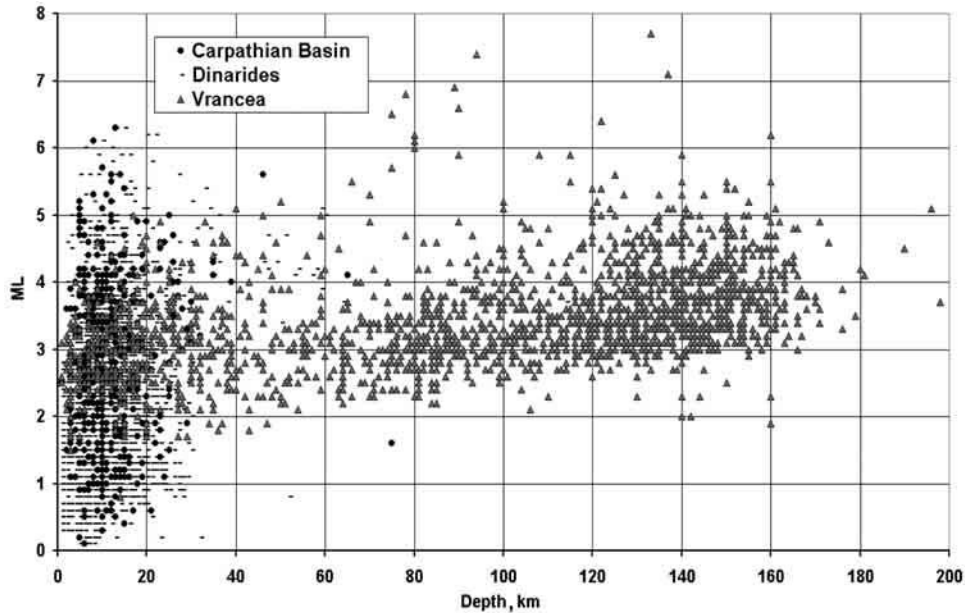


Fig. 3. The magnitude-depth distribution of earthquakes in the three regions with regard to all data. In the Carpathian Basin majority of events occur primarily between 6 and 15 km below surface and most occur between 6 and 9 km. In the Vrancea region strong earthquakes occur either between 5 and 25 km or between 70 and 160 km depth. The Dinarides region is typical with shallow shocks

### 3. Methods

The occurrence times of an earthquake corresponds to a phase with respect to a given periodicity, each event is assigned to a phase (e.g. for the diurnal wave 24 hours correspond to  $360^\circ$ ), which is determined by its location within this period (the hour within a day, a day within the year). The event times are tested with the Schuster's test (Schuster 1897). The Schuster's test based on a random walk model is specially designed for investigations of phase distributions.

Each earthquake corresponds to a unit vector, its orientation is determined by the phase angle. The sum of all vectors is a *hodograph*. This graphical representation is a powerful tool for control and interpretation of the statistical results. The origin is the starting point of the vector sequence. The distance between the origin and the end of this sequence is  $R$ , measured in multiples of the unit length (Fig. 4).  $R$  is small when there is no preferred phase in the data, and is large when a periodicity is realistic. Using  $N$  events the probability for the resultant distance to be larger than  $R$  is, according to Schuster's test:

$$p = \exp(1 - R^2/N).$$

We reject the null hypothesis when  $p$  is found to be less than or equal to 1%, equivalent to a significance level of  $1 - p = 99\%$ . Schuster's test only uses the values of  $R$  and  $N$ . It does not take into account whether the vector sequence (and

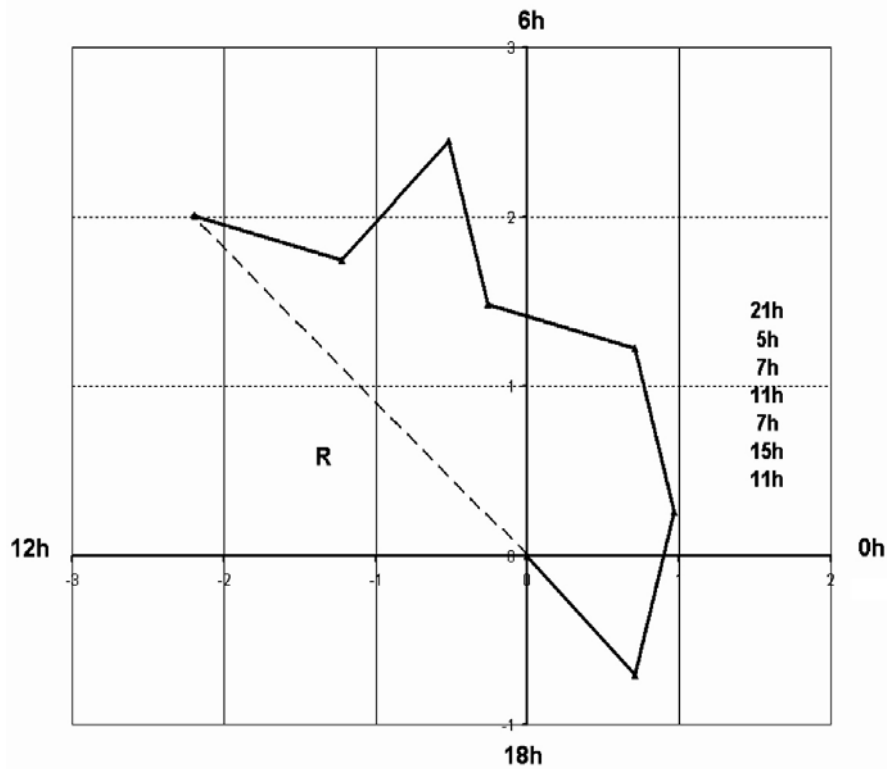


Fig. 4. Hodograph consists of  $N = 7$  unit vectors. The first data is 21h corresponding to  $315^\circ$ . The sum vector of  $R = 3$  units is represented by the broken line

therefore the statistical significance) is influenced by any effects. But such effects can be appear in the hodograph, which, in this way, proves to be a valuable tool for identifying effects within the data influencing, and reveal the changes with time.

The catalogue contains foreshocks, mainshocks and aftershocks mixed. The mainshocks and aftershocks were analyzed separately.

#### 4. Results and discussion

##### *The diurnal periodicity*

Different cumulative diurnal hodographs are calculated using the main events in the catalogue (Fig. 5a) and main events with  $M_L > 3.2$  are only included (Fig. 5b). The right hand direction corresponds to 0h, the up corresponds to 6h the left hand to midday and down to 18h. The Pannonian and Dinarides hodographs show similar trends. There are two parts of vector sequences opposing each other: a maximum at early morning dominates until the year 1963, followed by a period of time when earthquakes seem to occur more often around afternoon and midday in the case of Carpathian Basin and Dinarides databases. There are more earthquakes in the afternoon from beginning to end in the Vrancea region. Using the  $M_L > 3.2$  events,

happen more earthquakes at night in the Carpathian Basin and Dinarides (Fig. 5b). There are less earthquakes around midday in the Vrancea region, and in the latest part of hodograph dominating events occur in the daytime.

The events were separated for mainshocks and aftershocks with special routine (Fig. 6). Aftershocks usually occur near their mainshock. The rate of aftershocks dies off quickly, the decrease is proportional to the inverse of time since the mainshock. This simply means that the second day after the mainshock has about one-half and the tenth day about one-tenth of the number of aftershocks on the first day. Aftershocks can continue for weeks to months. The mainshocks of the Carpathian, Vrancea and slightly the Dinarides regions have a midday maximum and this appear in the case of aftershocks in the Vrancea region. There is secondary maximum at aftershocks in early dawn. The diurnal distributions were analyzed with two aspects.

Dividing into two parts of Carpathian, Dinarides and Vrancea databases (between years 1900–1963 marked with squares, and between years 1964–2003 signed with triangles) the diurnal distributions of earthquakes are displayed in Fig. 7 (all data were used). The two time intervals have different diurnal distributions in the Carpathian Basin and Dinarides. A tendency toward midnight dominates until about the year 1963, followed by a period of time when earthquakes seem to occur more often around midday. There is no significant periodicity in the Vrancea region.

The events  $M_L > 3.2$  are signed with triangles, and the events  $M_L < 3.2$  are signed with squares in Fig. 8. All data were used that had magnitude determination. The  $M_L < 3.2$  events show an midday maximum in the Carpathian Basin and Vrancea zone, and there is a slightly maximum in the Dinarides. The earthquakes of Dinarides show that the occurrence of events is more frequent around midnight. Maybe the midday maximum in the number of minor events is caused by the inclusion of quarry blasts, which have not been marked in the catalogues. In the earliest years before the instrumental registrations there are more recorded earthquakes during the quiet night. There is a possible lack of completeness of weaker events at daytime.

Nowadays there are more detected  $M_L < 3.2$  events in each region and these show a midday maximum about the same time especially regarding the main events. The diurnal distributions of these datasets show a significant and stable peak at 13h local time. Ulbrich et al. (1987) made statistical investigations on diurnal periodicity of local earthquakes in Central Europe. The detailed investigation led to the conclusion that the distributions are not of physical origin but have to be attributed to the sensitivity of macroseismic observation varying with season and time of day.

Lipovics (2001) has found similarity between the diurnal distribution of geomagnetic variations recorded in Tihany (Hungary) and diurnal distribution of earthquakes (within 300 km radius to Tihany and  $M_L > 3.5$ ). It has recently been pointed out that diurnal geomagnetic variations correlate well with diurnal changes in earthquake activity. This correlation has been shown to be global and a model to explain this possible correlation has also been proposed by Duma and Ruzhin (2003). This model claims that the current vortices induced by Sq variations in the

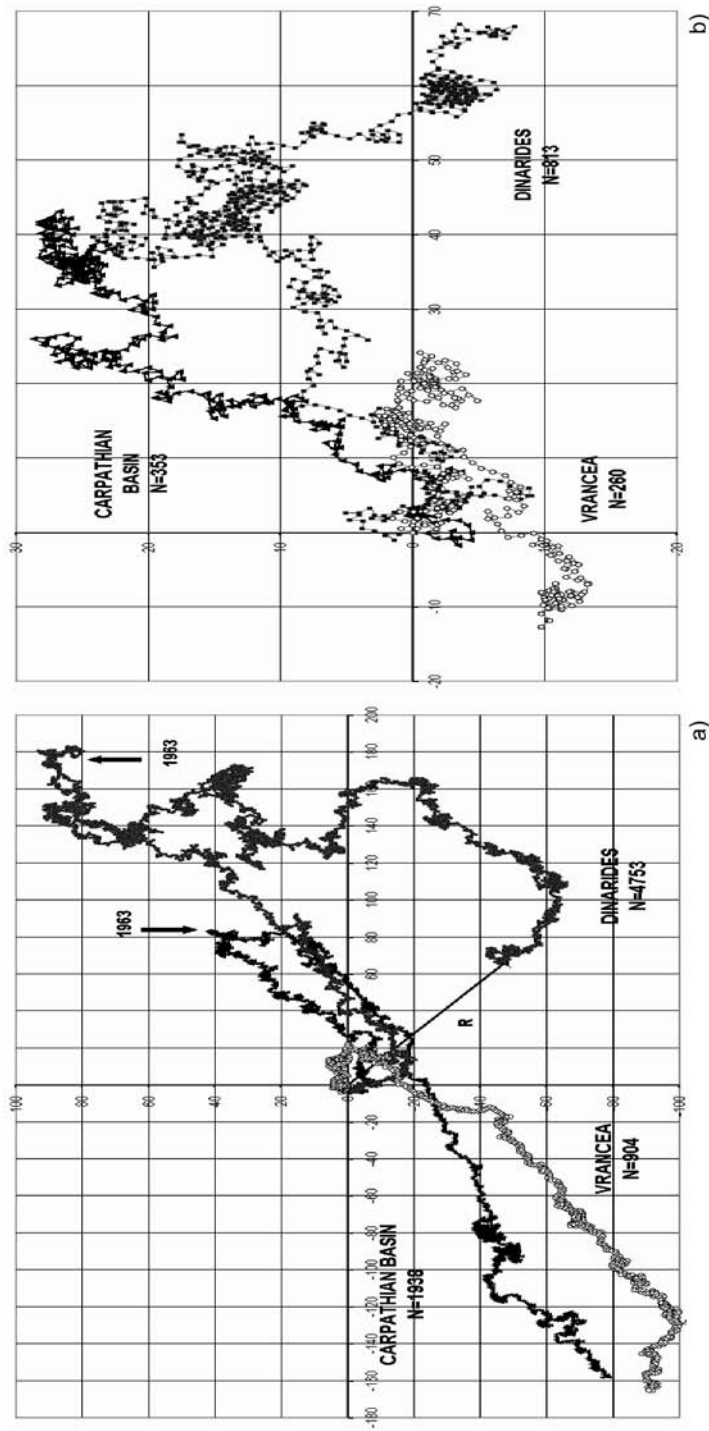


Fig. 5. a) Diurnal hodographs for every main events. The right hand direction corresponds to 0 h, up corresponds to 6 h the left to midday and down to 18 h. The diurnal hodographs of the Carpathian Basin and Dinarides clearly show a significant difference in the vector sequence. There are more earthquakes in the Vrancea region from beginning to end. The thick line signed with  $R$  is used in calculations of Schuster's test. The vector sequence changed opposed to each other in the year 1963. b) Diurnal hodographs for  $M_L > 3.2$  main events

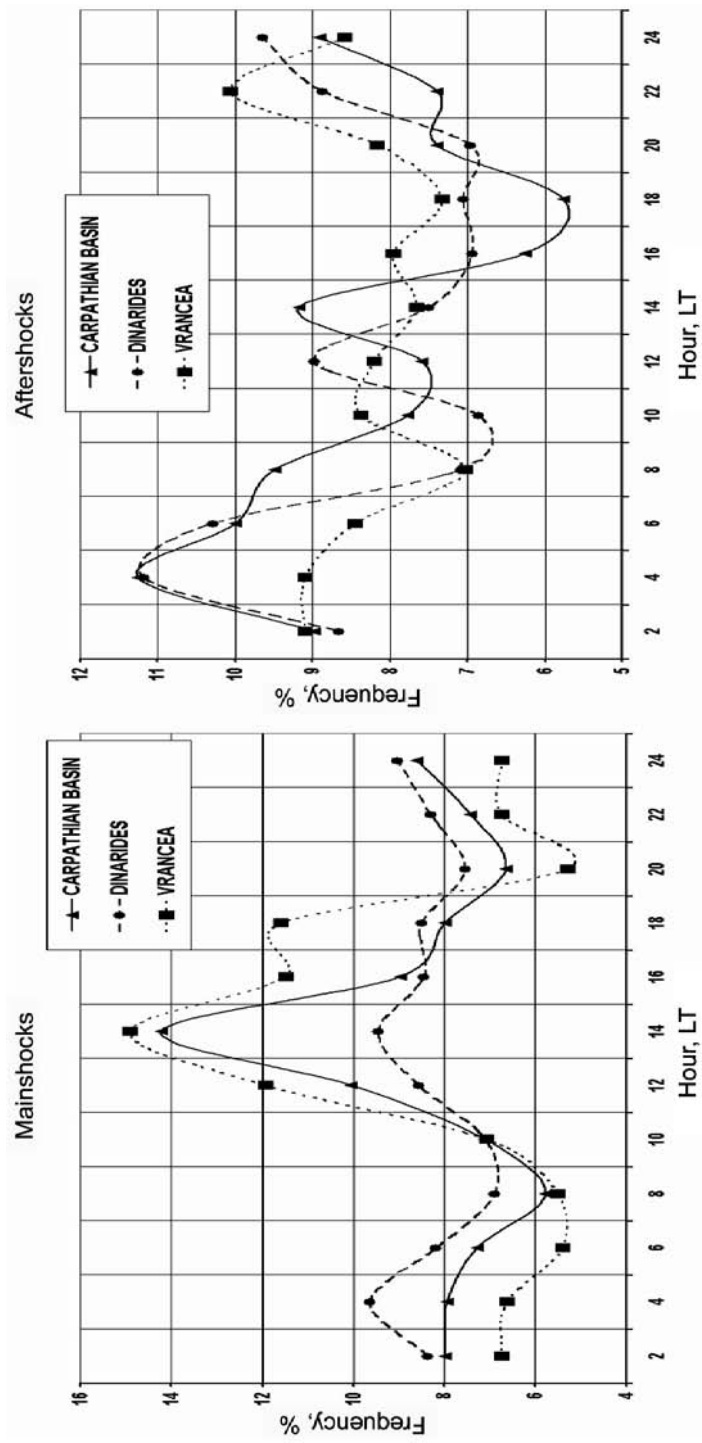


Fig. 6. The diurnal distributions of Carpathian Basin, Dinarides and Vrancea earthquakes. The mainshocks and the aftershocks are plotted separately, and grouped over two hours

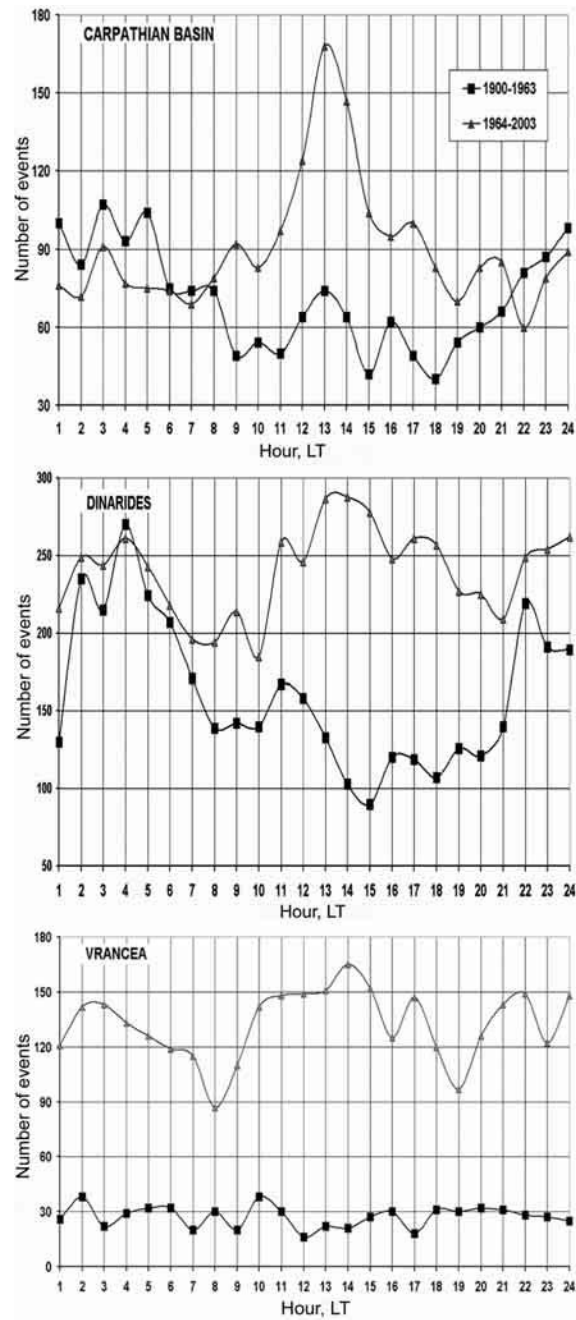


Fig. 7. Diurnal distributions of Carpathian Basin, Dinarides and Vrancea earthquakes. Data are marked with squares between years 1900–1963 and with triangles between years 1964–2003. All data were used. The two time intervals have different diurnal distribution in the Carpathian Basin and Dinarides. A midnight maximum dominates until the year 1963, followed by a period of time when earthquakes seem to occur more often around midday. There is no significant periodicity in the Vrancea region

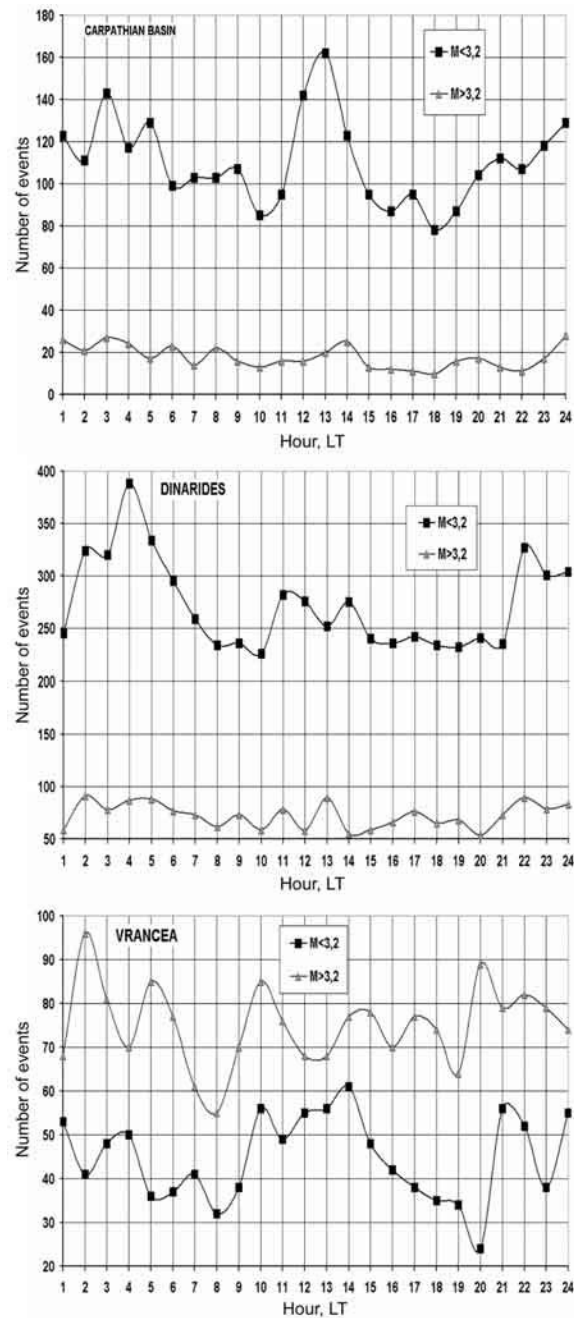


Fig. 8. Diurnal distributions of Carpathian Basin, Dinarides and Vrancea earthquakes. Data  $M_L < 3.2$  are signed with squares and  $M_L > 3.2$  with triangles. All data were used that had magnitude determination. The  $M_L < 3.2$  events show an midday maximum in the Carpathian Basin and Vrancea zone. There is a slightly maximum in the Dinarides at midday and an more determined around midnight

lithospheric layer, flowing across the horizontal component of the geomagnetic field generate a torque which can be added to the tectonic loading stress and may help trigger instability in a fault approaching the failure threshold. If the Duma-Ruzhin mechanism is indeed the underlying process, then statistical analysis indicates that this kind of earthquake triggering is relatively rare, but still there's a distinct probability that more earthquakes will tend to occur during the hours of higher Sq intensities at midday. The clustering of earthquake occurrences as a function of the hour-of-day are also observed recently.

The midday maximum in the number of minor events is maybe caused by the inclusion of quarry blasts, which have not been marked in the catalogues (supposing that every mine works in the same time at 13h local time). The better and accurate determination of focal depth could help to distinguish the quarry blasts. There are several method for discriminate the earthquakes from blasts in Hungary (Kiszely 2001).

### 5. Statistical confirmation

Testing against the uniformly distributed hypothesis the Schuster's test is calculated the diurnal and seasonal distribution of these regions.

The null hypothesis of randomly distributed earthquakes can be rejected with a significant level of  $(1 - p)$ . Using  $N$  events,  $p = \exp(-R^2/N)$ . The value of  $R$  changes with the number of data:  $N$ . The databases ranging in time from 1900 to 2003. This is calculated and graphically represented in Figs 9, 10. The horizontal axis shows the serial number of earthquakes in the database and the vertical axis indicates the calculated  $p$ . The thick horizontal line indicates the  $p = 1\%$ . We accept the null hypothesis when the value is above this line ( $1 - p = 99\%$ ), in the cases of Carpathian Basin and Vrancea region, and is rejected in the case of Dinarides region.

### 6. The fractal approach of earthquakes

#### *Temporal distribution*

An earthquake is a fractal process of the crust, both its microscale and macroscale features. There are several kind of scale invariance or fractal features in the earthquake phenomena which are given in a power law form the magnitude-frequency distribution, the spatial distribution of hypocenters, the frequency of aftershock occurrences and so on, just as Poisson statistics model purely random process, fractal statistics model process that exhibit scale-invariant properties. Mandelbrot (1982) developed the concept of fractal geometry and dimension. An important characteristic of fractal structure is its scale independence.

To study the temporal statistics of earthquakes occurrence, Smalley et al. (1987) applied the concept of fractal or scale-invariant clustering to seismicity. Supposing there is a temporal distribution of  $N$  earthquakes occurring in the time interval  $t_0$  (between years 1900–2003). The number of earthquakes is determined by the study of the area (Fig. 2b). The natural period of earthquakes for the overall data is then  $t_0/N$ .

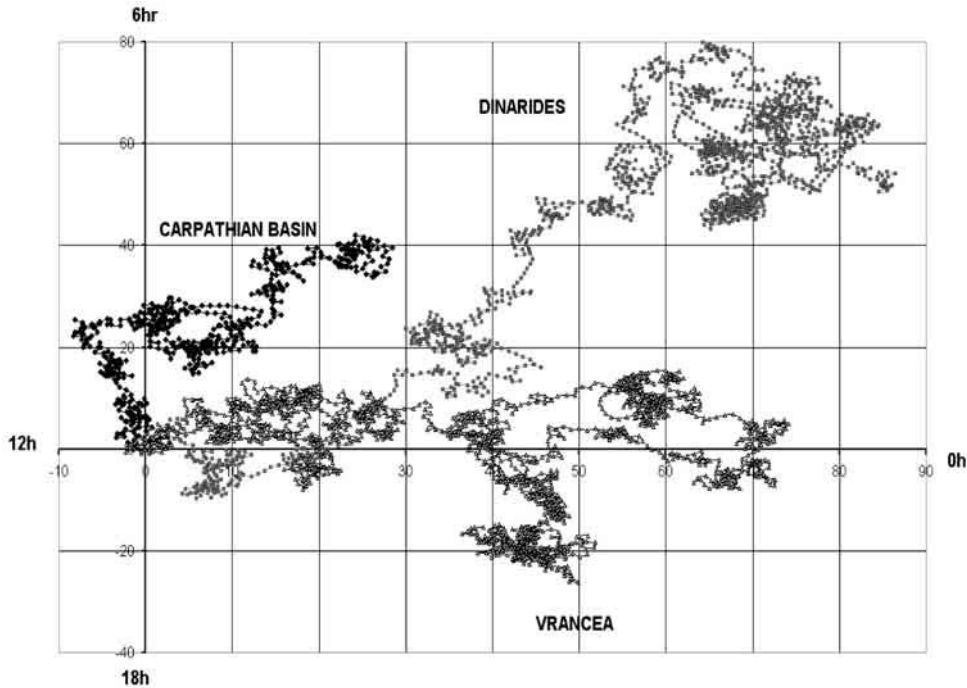


Fig. 9. Diurnal hodographs of earthquakes  $M_L > 3.2$  ranging in time from 1900 to 2003

In order to analyze the available data, the interval  $t_0$  was divided into a series of smaller  $t$  intervals and used the box-counting method (Mandelbrot 1982). The fraction  $x(t)$  of the intervals in which at least an earthquake occurred was calculated, i.e., the fraction of nonempty boxes, as a function of the interval length  $t$ . If the temporal distribution is fractal, the number of nonempty intervals should be  $t^D$ , then the fraction  $x(t)$  of the intervals in which an earthquake occurred, is:  $x(t) \propto t^{1-D}$ .  $D$  is the fractal dimension. A linear relation of  $\log x(t)$  versus  $\log t$  is obtained within the time interval 400 to 1600 hours, which indicates that power-law dependence exist in the temporal distribution of the earthquakes. The fractal dimension is obtained from the slope of the linear relation (Fig. 11).

The value of  $D$  and natural period for different regions and different magnitude ranges and some statistical characteristics of the data sets are listed in Table I and Table II. Young et al. (1998) find that three regions, northern China, mainland China and southern California show nearly the same fractal dimension  $D = 0.3$  for Northern China and the mainland of China, and  $D = 0.4$  for southern California.

The Carpathian Basin has a lower value about  $D = 0.3$ ; the Dinarides and Vrancea region have nearly the same fractal dimension  $D = 0.5 - 0.7$ . The value for Carpathian Basin can be interpreted in the frames of a simple self-organised criticality model, and the Dinarides and Vrancea region need more complex model including a regional driving force (Brown et al. 1991).

The degree of temporal clustering of earthquakes can be estimated by the co-

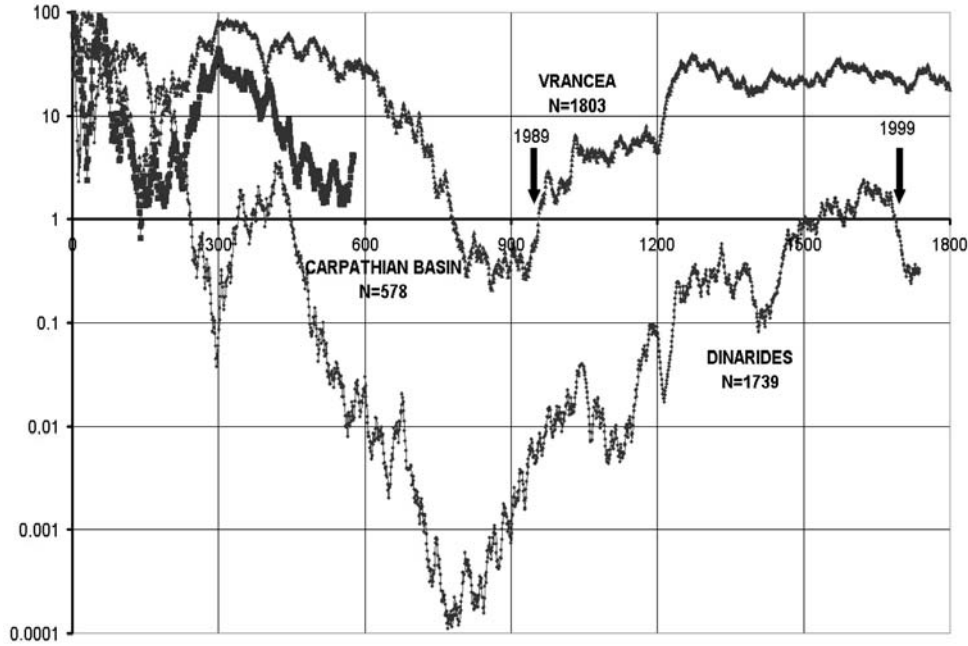


Fig. 10. Schuster's tests of diurnal distributions of earthquakes  $M_L > 3.2$ . We reject the null hypothesis when  $p$  is less than or equal to 1%, equivalent to a significance level of  $1 - p = 99\%$ . The thick horizontal line indicates the  $p = 1\%$  corresponding to significance level 1%. We accept the null hypothesis when the value is above this line. We accept the null hypothesis in the cases of Carpathian Basin and Vrancea region from year 1989 (signed with arrow), and reject in the case of Dinarides from year 1999

**Table I.** The fractal dimensions and scaling ranges of each region (1900–2003)

Region	Magnitude range	Number of ea.	Fractal dimensions	Scaling range (h) (logt)	Natural period (h)
Carpathian Basin	$3.2 < M_L$	579	0.36	3 – 3.8	1594
	$3.6 < M_L$	247	0.31	3 – 3.8	3727
Dinarides	$3.2 < M_L$	1737	0.7	3 – 3.6	519
	$3.6 < M_L$	747	0.68	3 – 3.6	1205
Vrancea	$3.2 < M_L$	1803	0.67	3 – 3.6	500
	$3.6 < M_L$	1144	0.51	3 – 3.6	788

efficient of variation. This is an attribute of a distribution: its standard deviation divided by its mean. High values of coefficient of variation denote clustered activity, while low values represent quasiperiodic occurrence of events. The case coefficient of variation = 1 corresponds to a random Poisson process. The recurrence times of earthquakes are much higher in the Carpathian Basin. Bodri (1999) have calculated the coefficient of variation in the Carpathian-Pannonian region together with Vrancea region and have found similar values.

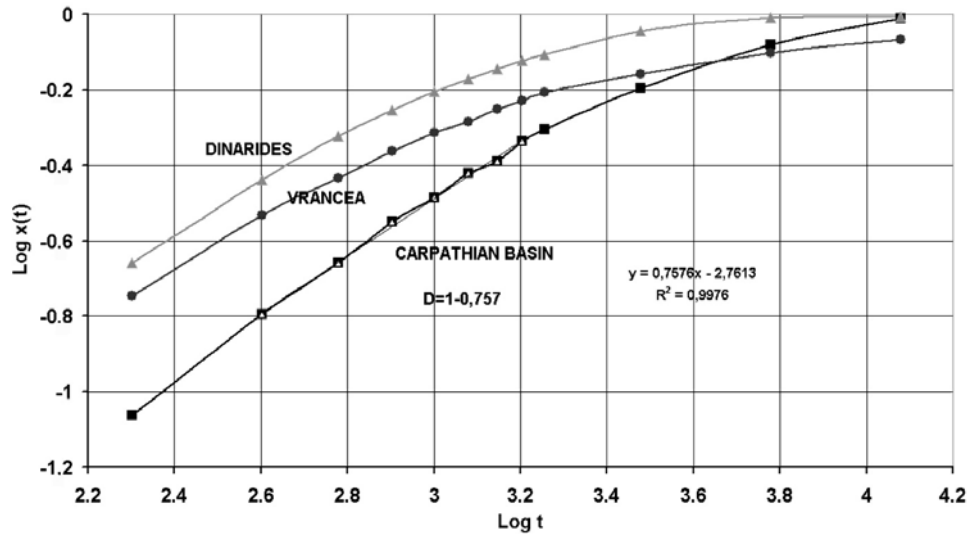


Fig. 11. A linear relation of  $\log x(t)$  versus  $\log t$  is obtained within the time interval 400 to 1600 hours, which indicates that power-law dependence exist in the temporal distribution of the earthquakes.  $D$ , the fractal dimension is calculated from the slope of the linear relation and regarding the events between the  $3 < M_L < 4$  magnitude range

**Table II.** The recurrence interval and coefficient of variation distribution of each region (1900–2003)

Region	Magnitude range	Number of ea.	Coeff. of variation	Mean recurrence times (h)
Carpathian Basin	$2.8 < M_L$	1150	1.68	807
	$3.2 < M_L$	579	1.47	1600
Dinarides	$2.8 < M_L$	3790	1.93	216
	$3.2 < M_L$	1737	1.69	518
Vrancea	$3.5 < M_L$	1233	1.56	730
	$3.2 < M_L$	1803	1.39	500
	$4 < M_L$	664	1.71	1360

### *Spatial distribution*

Several studies suggested (e.g. Matsumoto et al. 1992, Lei et al. 1993) that many geological systems, such as faults and the spatial distribution of earthquakes epicenters, statistically obey a power law distribution by which a fractal dimension can be defined.

Imagine a line of finite length  $L$ , consisting of uniformly distributed points. Cover the line with a minimum number of squares  $N(e)$ , with sides of length  $e$ . If the sides of the squares were reduced by half, twice as many squares would be required to cover the same line. The number of squares  $N(d)$  of size  $d$  required to cover the surface is proportional to  $1/d^2$ . If a  $D$ -dimensional object were used in

place of the line, a relationship of  $N(e) = 1/ed$  is observed, where  $d$  is the capacity or box-counting dimension for non-integer  $d$ .

Using the box-counting method the fractal structures of the spatial distributions of earthquakes epicenters were examined, too. The regions were divided into different size  $r$  of a square box and were counted the minimum number  $N(r)$  of boxes necessary to cover all the data. The relation between  $N(r)$  and  $r$  is obtained. If the distribution is fractal,  $N(r)$  versus  $r$  obeys a power law distribution. The  $N(r)$  versus  $r$  relation in a double logarithm co-ordinate will be a line, and the slope of the line gives the box-counting or capacity fractal dimension (Lei et al. 1993), what is a geometric measure of complexity. Figure 12 shows the box-counting method for Vrancea region. The calculated fractal dimensions are: 1.49 for Dinarides; 1.34 for Vrancea region. Since the record for earthquakes of magnitudes less than  $M_L 3.2$  is not complete, only the earthquakes of  $M_L \geq 3.2$  were selected. The slope of  $\log N - \log r$  for Carpathian Basin breaks at about 20 km, which divides the range into two bands. Since  $\log N - \log r$  is linear in both bands, two fractal dimensions corresponding to the two bands are obtained: 0.33 and 1.05 (Fig. 13).

Lei and Kusunose (1999) examined the fractal structures of the spatial distribution of three geological systems in Japan, namely those of earthquakes epicenters, the active faults and rivers. They results show that, in scale range from 1 to 100 km, all geological systems have a common characteristic scale of about 13 km, which divides the spatial distribution into two bands: smaller fractal dimension: 1.1 at smaller scale  $r < 13$  km, and larger fractal dimension: 1.6 at larger scale  $r > 13$  km (where  $r$  is the box size). In both bands, the three systems obey a power law distribution, and have a band-limited fractal structure. Since the characteristic scale of about 13 km is in agreement with the depth of the brittle-ductile transition zone of the crust, Lei and Kusunose suggest that it is a common feature of the heterogeneity of the crust. The common feature in their data, that the slope of  $\log N - \log r$  breaks about 13 km, that corresponds to the depth to the transition zone from unstable friction to the stable friction of the crust (Sholz 1990).

## 7. Conclusions

These investigations have shown that it is advisable to use hodograph for displaying fluctuations of a periodicity that would otherwise remain undetected. The detailed study leads to the conclusion that the weak earthquakes show a diurnal periodicity. The rate of detected weak events changed from 1960s years, (Figs 4, 6) from this time there are more detected weak events in the Pannonian and Dinarides regions. Events before 1963 generally contribute to midnight maximum, while the later events show the opposite tendency. The midday maximum in the number of minor events is maybe caused by the inclusion of quarry blasts. It has recently been pointed out that diurnal geomagnetic variations correlate well with diurnal changes in earthquake activity. This correlation has been shown to be global and a model to explain this possible correlation has also been proposed yet.

Using the box-counting method the fractal structures of the temporal and spatial distributions of earthquakes epicenters were examined, too. The earthquakes in

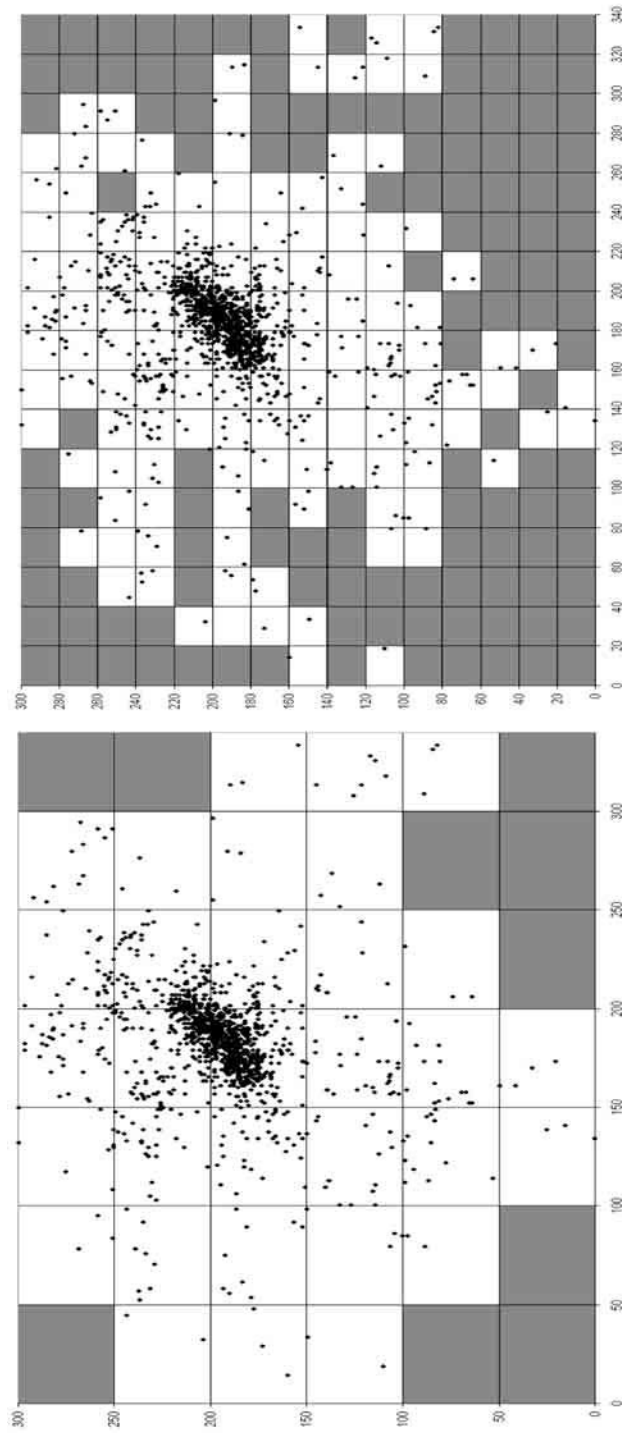


Fig. 12. The box counting method for Vrancea region ( $r = 50$  km, 20 km).  $N(r)$  = the number of boxes that cover all the epicenters

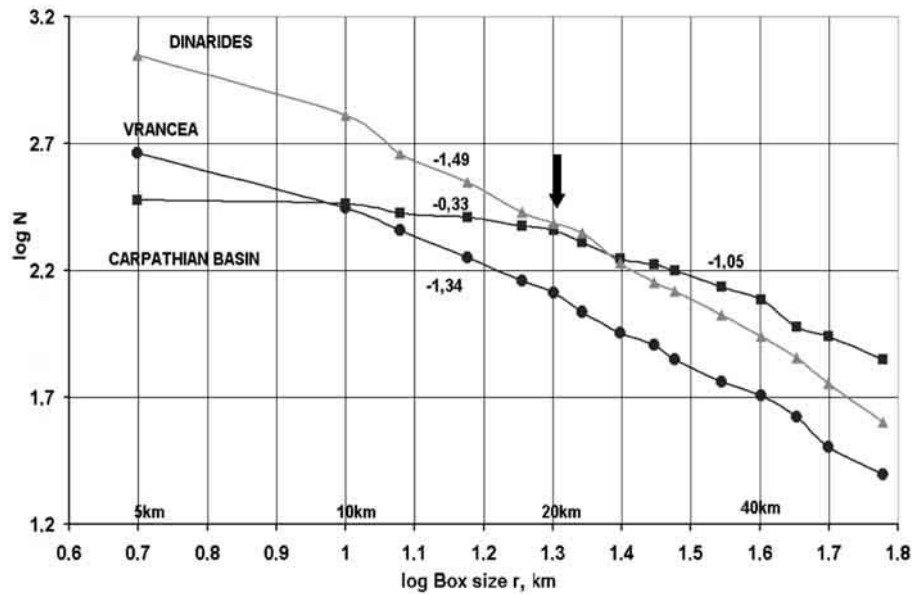


Fig. 13.  $N(r)$  versus  $r$  relation in a double logarithmic co-ordinate is a line. The slope of the line gives the fractal dimension. The slope of  $\log N - \log r$  breaks at 20 km (signed with arrow) at Carpathian Basin, which divides the range into two bands

these regions have self-similar structures, in other words fractal structures. The recurrence times of earthquakes are much higher in the Carpathian Basin. The slope of  $\log N - \log r$  function for Carpathian Basin breaks at about 20 km, which divides the range into two bands, so two fractal dimensions corresponding to the two bands are obtained. Maybe this breaking at about 20 km is connected to the intrinsic weakness of the Carpathian Basin lithosphere. The extreme weakness of the lithosphere caused that the Moho is laying here at depths of only 24–25 km (Grad et al. 2006). The depth of Moho varies between 40 and 50 km beneath the Dinarides and is about 40 km beneath the Vrancea zone.

## References

- Bada G 1999: Cenozoic stress field evolution in the Pannonian Basin and the surrounding orogens. PhD Thesis, Vrije Universiteit Amstredam
- Bada G, Cloetingh S A P L, Gerner P, Horváth F 1998: *Geophys. J. Int.*, 134, 87–101.
- Bada G, Horváth F, Fejes I, Gerner P 1999: *J. Geodynamics*, 27, 501–527.
- Bodri B 1999: *Magyar Geofizika*, 40, 12–23.
- Brown S R, Scholz C H, Rundle J B 1991: *Geophys. Res. Lett.*, 18, 215.
- Duma G, Rhuzin Y 2003: *Natural Hazards and Earth System Sciences*, 3, 171–177.
- Gerner P, Bada G, Dövényi P, Cloething S, Onescu M, Müller B 1999: In: Geological Society Special Publications, Vol. 156, 269–294.
- Grad M, Guterch A, Keller G R, Janik T, Hegedűs E, Vozár J, Slaczka A, Tiira T, Yliniemi J 2006: *J. Geophys. Res.*, 111, B03301, doi:10.1029/2005JB003647

- Herak M 1995: Archives of the Andrija Mohorovicic Geophysical Institute, Zagreb
- Horváth F 1984: *Ann. Geophys.*, 2/2, 147–154.
- Horváth F 1988: *AAPG Memoir*, 45, 49–51.
- Kiszely M 2001: *Acta Geod. Geoph. Hung.*, 36, 439–449.
- Lei X, Kusunose K 1999: *Geophys. J. Int.*, 139, 754–762.
- Lei X, Nishizawa O, Kusunose K 1993: *Geophys. J. Int.*, 115, 79–84.
- Lipovics T 2001: The effect of geodynamic processes on the variation of the geomagnetic field (in Hungarian), Diploma Thesis (in Hungarian). Eötvös Loránd University, Budapest
- Mandelbrot B 1982: The fractal geometry of nature. W H Freeman and Company, San Francisco, California
- Matsumoto N, Yomogida K, Honda S 1992: *Geophys. Res. Lett.*, 19, 357–360.
- Panea I, Stephenson R, Knapp C, Mocanu V, Drijkoningen G, Matenco, Knapp J, Prodehl K 2005: *Tectonophysics*, 410, 293–309.
- Purcaru G 1979: *Phys. Earth Planet. Inter.*, 18, 274–287.
- Radulian M, Vaccari F, Mândrescu N, Panza G F, Moldoveanu C L 2000: *Pure Appl. Geophys.*, 157, 221–247.
- Royden L H, Horváth F 1988: *Am. Assoc. Petr. Geol. Memoir*, Vol. 45
- Schuster A 1897: In: Proceedings of the Royal Society of London, 61, 455–465.
- Sholz C H 1990: Cambridge University Press, Cambridge
- Slejko D, Camassi R, Cecic I, Herak D, Herak M, Kociu S, Kouskouna V, Lapajne J, Makropoulos K, Meletti C, Muco B, Papaioannou C, Peruzza L, Rebez A, Scandone P, Sulstarova E, Voulgaris N, Zivcic M, Zupancic P 1999: *Annali Geofis.*, 42, 1085–1108.
- Smalley R F, Chatelain J D, Turotte D L, Prevot R 1987: *Bulletin of Seismological Society of America*, Vol. 77, 1368–1381.
- Stanica D 2001: IAGA-IASPEI, 2001 Abstracts Volume, Hanoi, Vietnam, 21–22.
- Tóth L, Mónus P, Zsíros T, Kiszely M 2000: GeoRisk, Budapest
- Tóth L, Mónus P, Zsíros T, Kiszely M 2001: GeoRisk, Budapest
- Tóth L, Mónus P, Zsíros T, Kiszely M 2002a: EGU Stephan Mueller Special Publication Series, 3, 9–28.
- Tóth L, Mónus P, Zsíros T, Kiszely M 2002b: GeoRisk, Budapest
- Tóth L, Mónus P, Zsíros T, Kiszely M 2003: GeoRisk, Budapest
- Tóth L, Mónus P, Zsíros T, Kiszely M 2004: GeoRisk, Budapest
- Ulbrich U, Ahorner L, Ebel A 1987: *J. Geophys.*, 61, 150–157.
- Young C, Ling C, Zhaojun L, Ro-Shan W 1998: *Bull. Seismol. Soc. America*, Vol. 88, 89–94.
- Zsíros T 1989: *Gerlands Beitr. Geophys.*, 98, 146–154.
- Zsíros T 1996: *Acta Geod. Geoph. Hung.*, 31, 115–125.
- Zsíros T 2000: Seismicity and seismic hazard of the Carpathian Basin: Hungarian earthquake catalogue (456–1995) (in Hungarian), Seism. Obs., Geod. Geoph. Res. Inst. of HAS, Budapest