

STATISTICAL ANALYSIS OF EARTHQUAKES AND QUARRY BLASTS IN THE CARPATHIAN BASIN – NEW PROBLEMS AND FACILITIES

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Abstract. Presently thirteen seismological stations work in Hungary and hundreds of small earthquakes are detected yearly. The magnitude of 80% of the detected seismic events is $M_L \leq 2.0$. If we compare this to the situation fifty years ago, when the catalogued events contained only the earthquakes that people felt, we understand that today in Hungary an important revolution is taking place in seismology. In this paper we investigate the statistical features of earthquakes and blasts in the Carpathian Basin and adjacent regions ($16^\circ\text{-}23^\circ\text{E} - 44.5^\circ\text{-}49^\circ\text{N}$). Three different methods were performed using data from the period 1995.01.01-2009-08.31 to investigate the existence of periodicities in the seismic events. A midday maxima is verified in the cases of earthquakes and blasts, and we found that there are fewer events on weekend and more during the summer. The increased number of earthquakes around 12 h (MET) might be attributed to the inclusion of quarry blasts among the earthquakes, however natural process might also contribute in triggering instability in a fault approaching the failure threshold around midday. Monthly variations in the distributions of seismic events might not be of physical origin, but connected to the changing sensitivity of the instruments during the seasons. The comparison of the diurnal distribution of earthquakes occurring on weekends and on weekdays indicates the contamination of the Hungarian Earthquake Bulletin with data from quarry blasts.

Key words: earthquake, blast, seismicity, Carpathian Basin, diurnal, hodograph

1. INTRODUCTION: Poisson or not Poisson

The goal of this study is to investigate the statistical features of seismic events in the Carpathian Basin and adjacent regions ($16^\circ\text{-}23^\circ\text{E} - 44.5^\circ\text{-}49^\circ\text{N}$) for the period 1995.01.01-2009.08.31. Three different calculations were performed to investigate the diurnal, weekly and monthly distribution of events.

A comprehensive database is at disposal from 1995, when the first truly broadband digital stations were installed in Hungary. The new network has a detection capability $M_L=2$ at average noise level of the Carpathian Basin (Tóth et al. 2002). From 1995 small $M_L \leq 2$ quarry blasts were detected regularly, and the problem of discrimination between earthquakes and quarry blasts was born. The diurnal distributions of the earthquakes in the Carpathian region show a significant and stable peak at 12h (MET), and minimums at 8h and 18h, also there are

more earthquakes during summers, and less on weekends.

The simplest model for earthquake occurrence is a time-independent Poisson model, in which the probability that an earthquake will occur in an interval of time starting from now does not depend on when "now" is, because the Poisson process has no "memory". However, the earthquake catalogues contain foreshocks and aftershocks too. The parameters of earthquakes (time, location, depth, fault mechanism) are estimated from different detections and may be flawed. An earthquake catalogue needs to be complete it should not miss any event. However, vast number of small seismic events was not detected in the past and even today many go undetected.

Earthquakes are one of the most interesting phenomena whose every aspect displays fractal statistics and whose dynamics is possibly chaotic and show extra properties (Mandelbrot 1982, Smalley et al. 1987). For examples the Gutenberg-Richter (1944) frequency-magnitude law of

earthquake states that the total number of earthquakes that are larger or equal than magnitude M is proportional to 10^{-bM} . Therefore, a graph of the log of the number of quakes greater or equal to a given magnitude versus the given magnitudes is a straight line. The value of b seems to vary from area to area, but worldwide it seems to be around $b=1$.

The temporal distribution of earthquakes at different scales shows different pattern. For examples the Vrancea seismic region contains an isolated cluster of events beneath the Carpathian Arc Bend in Romania. The study of Enescu et al. (2005) revealed two distinct scaling regimes. At small scales (minutes-hours) they have found a clear nonhomogeneous, multifractal pattern. The temporal distribution of events shows Poisson (random) behavior only at large scales. Faenza et al. (2009) investigate the cluster properties of the seismicity of Central-Europe between 1960 and 2004. Their analysis shows that clustering dominates the $M>4$ earthquake activity in the first two years, subsequently the events tend to occur as Poisson random events.

The temporal and diurnal pattern of the earthquake occurrence is an unresolved problem and has a long history. Scientists have been long searching for a relation between earthquakes and the Moon's orbiting (Schuster 1897, Emtner 1997), and between Earth's local magnetic field and the number of earthquake occurrences. Recent observations connected the regular diurnal variations of the Earth's magnetic field, commonly known as S_q -variations or "magnetic quiet-day solar daily variations" with the diurnal distribution of earthquakes. Duma and Ruzhin (2003) analysed this geodynamic process of changing earthquake activity with time of day as a triggering affect, and have found correlation in the daily distribution of earthquakes and S_q -variations in several region of the Earth. Duma's (2006) presentation deals with details of the electromagnetic model. His model builds on the mechanic 'Lorentz forces' and torques which are generated by the regularly induced electric ('telluric') currents in the Earth's lithosphere in presence of the Earth's main magnetic field. The model's capability to fit the observed seismic performance of several strong earthquake regions in the three time-domains: diurnal, seasonal, long term. This was demonstrated for active earthquake regions in Asia (Japan, Taiwan, China, Sumatra), in the USA (California) and in Europe (Italy, Austria, Greece), even for earthquake activity with event magnitudes $M>6$.

Ulbrich et al. (1987) made statistical investigations on diurnal and annual periodicity of

local earthquakes in Central Europe. Their detailed investigation led to the conclusion that the periodicities are not of physical origin, they must be attributed to the sensitivity of macroseismic observation varying with season and time of day.

Seasonal variations of earthquakes are suspected in Japan (Omori 1902, Heki 2003). They suggested that in snow load regions occur more $M>7$ earthquakes in spring and summer than in autumn and winter. Ohtake & Nakahara (1999) found a significant seasonality in the occurrence time of past great earthquakes ($M>7.9$) in the north-western margin of the Philippine Sea plate. They found that change in the atmospheric pressure may trigger an earthquake. Similar connection have been found by Gao et al. (2000) in the distribution of earthquakes (mostly $M<3$) and the yearly fluctuation of barometric pressures in Southern California.

Can the human activity disturb the diurnal distribution of earthquakes, and it is possible to reveal new features of the small events? The daily and monthly cycles coincide with natural periods, but the weekly one must be attributed to anthropogenic events. Zotov (2007) revealed with statistical analysis of the world catalogue of earthquakes ($M\leq 5$) the so-called weekend effect. The number of earthquakes has a seven day variation with a Sunday maximum, supposedly related with industrial activity. The contamination of bulletins by quarry blasts is problematic in Europe (Gündüz et al. 2008, Gulia 2009) and in other regions (Wiemer & Baer 2000).

Several diurnal distributions of earthquakes from different regions of the World are listed in figure 1: (Gündüz et al. 2009 (a), Duma and Rhuzin 2003 (b, c), Atef et al. 2009 (d)). The histograms of diurnal distribution show periodicity. There are more events in the nightly period than in the work hours, except the data of Turkey.

To sum up the reasons of the daily periodicity maybe:

- contamination the catalogue with explosions (Fig. 1a)
- geodynamic processes as a triggering affect (Fig. 1b-c)
- lower level of the industrial noise at night (Fig. 1d)

In this article three different statistical calculations were used to analyze the small earthquakes distribution in the Carpathian Basin.

- Histograms: conventional Khi-Square Test
- Hodograph: Schuster test
- FFT

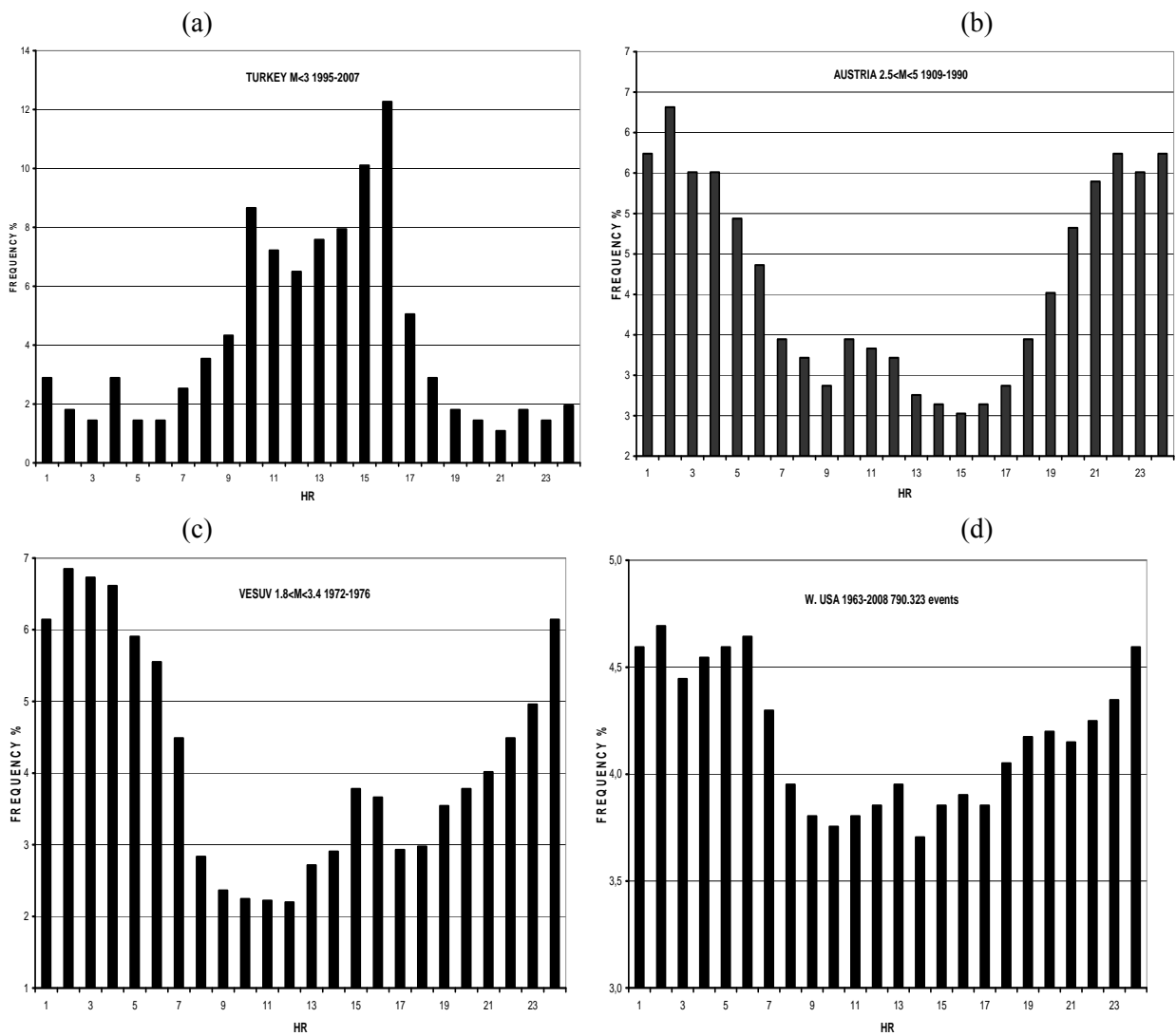


Figure 1, Diurnal distribution of earthquakes in several regions of the World

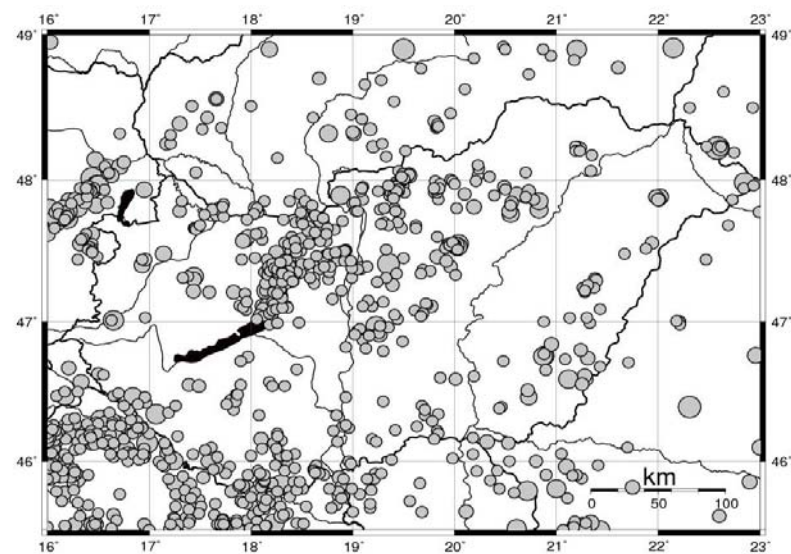


Figure 2, Map of the earthquakes in the Carpathian Basin (1900-2009). The size of the circle is proportional to magnitude of the earthquake.

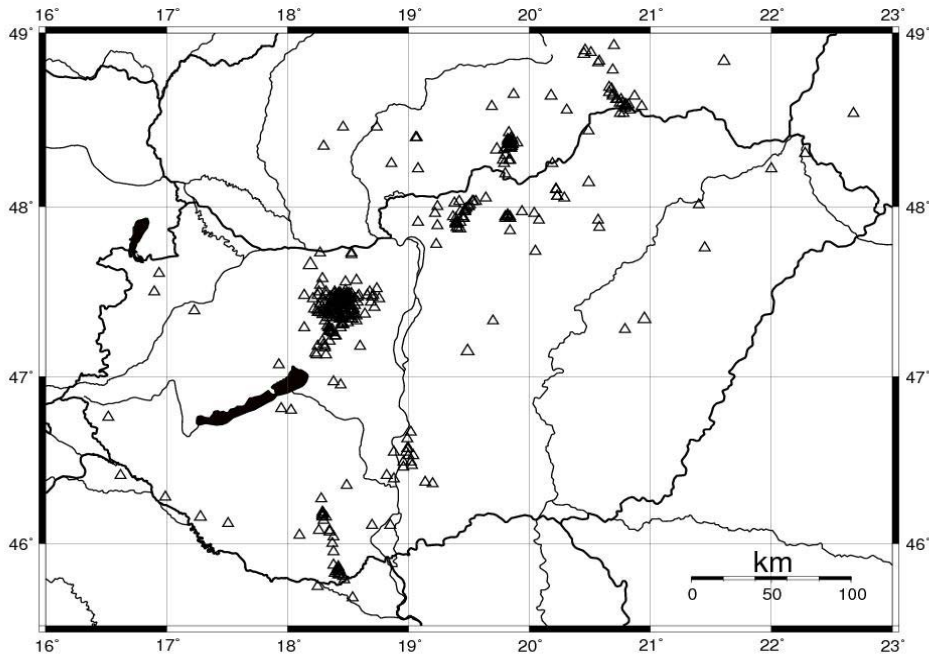


Figure 3, Map of the blasts in the Carpathian Basin (1998-2009)

2. DATA

Data from the Hungarian Earthquake Bulletin for the period of 1995 to 2009 (Tóth et al., 1995-2009) was used in our analysis (Fig.2; Fig.3). The Bulletin contains about 1030 earthquakes from 1995 to 2009.08.31 and about 400 quarry blasts from 1998 to 2009.08.31 77% of the earthquakes and 96% of the blasts have magnitude less or equal to $M_L=2$.

The epicenters of the earthquakes and blasts coincide in most cases.

The diurnal, monthly and weekly distribution of events (Fig. 4-6) shows interesting features. There is a significant peak about midday and minimums at 6h and 18h (MET). The monthly distribution of earthquakes shows maxima between May and October, and more quarries were detected during the summer. The weekly distributions show more events on weekdays.

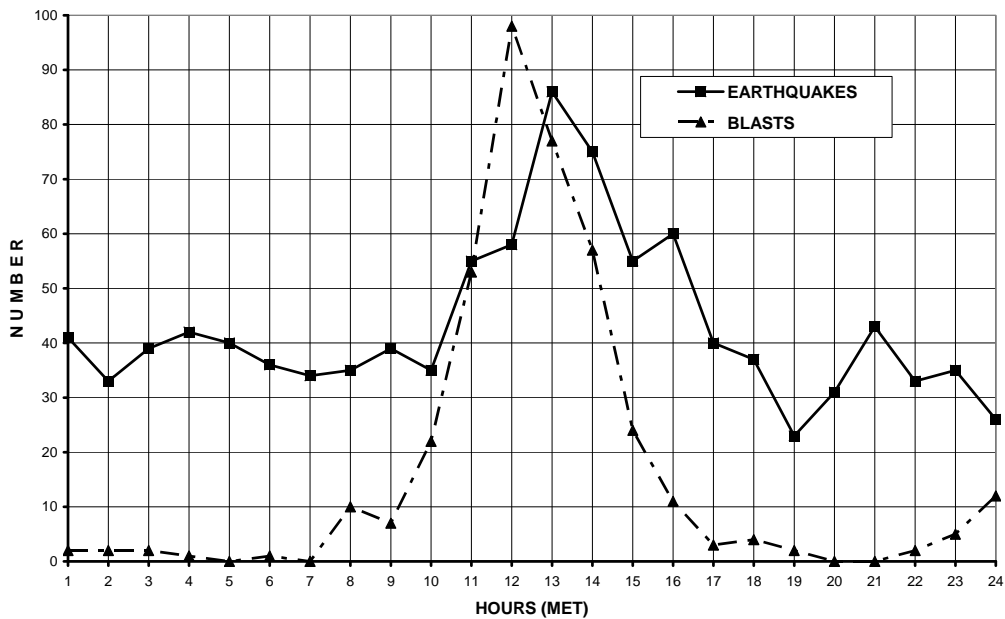


Figure 4, Diurnal distribution of seismic events, in the calculations we used Middle Europe Time

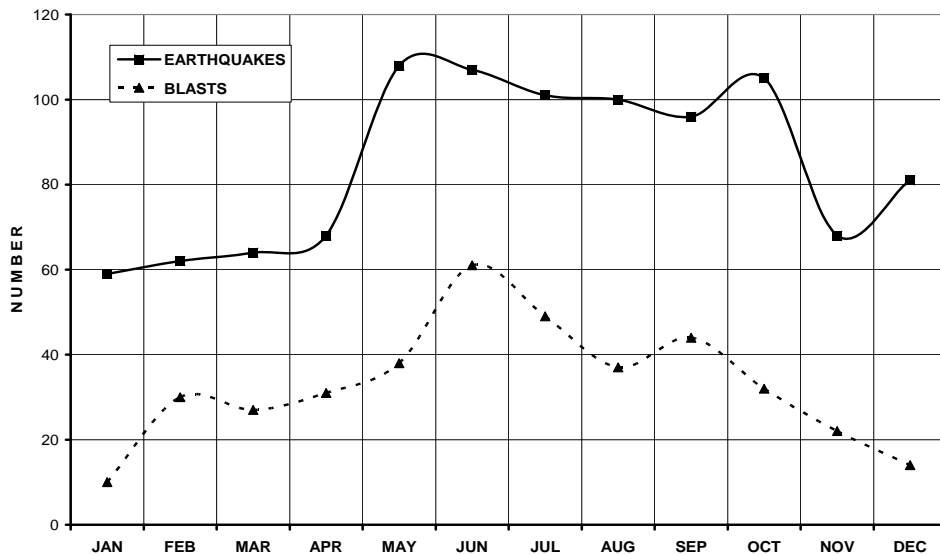


Figure 5, Monthly distribution of seismic events

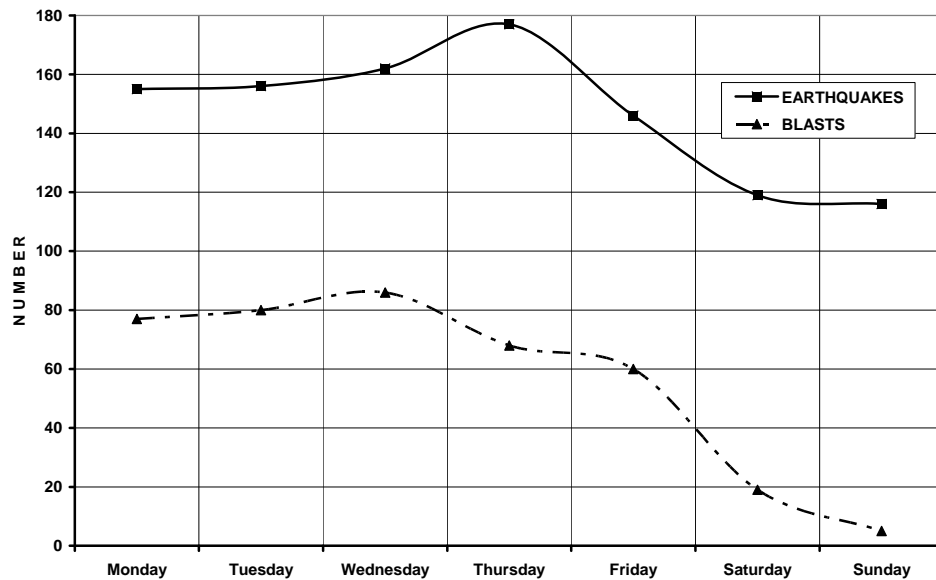


Figure 6, Weekly distribution of seismic events

The human activities can also influence the sensitivity of the instruments and lead to diurnal and weekly periodicities. The detection capability is better at night, and at weekend. More earthquakes can be detected on weekends than on weekdays and more events at night.

The large number of detected seismic events from April to October, in the case of quarry blasts, is evident; the mines work in higher activity during this period. The reason for the low number of detected earthquakes during the winter might be connected to the lower power state of the solar cells powering the seismological stations.

There are several methods to discriminate earthquakes from blasts in Hungary (Kiszely 2001,

2009), however since each region has its own distinctiveness, the categorization of small events is always ambiguous. Therefore, the data of the earthquakes might be contaminated with data from the blasts, and vice versa. The midday peak includes about 15% of the earthquakes.

There is a simple idea on how to control the contamination of the data of the earthquake bulletin by quarry blast data. Comparison of the diurnal distribution of weekend and weekday earthquakes is presented in figure 7. Here we see that on weekends the midday peak is missing, and in general more seismic events are detected during the night. The reason for this is the low level of the industrial noise in the given period.

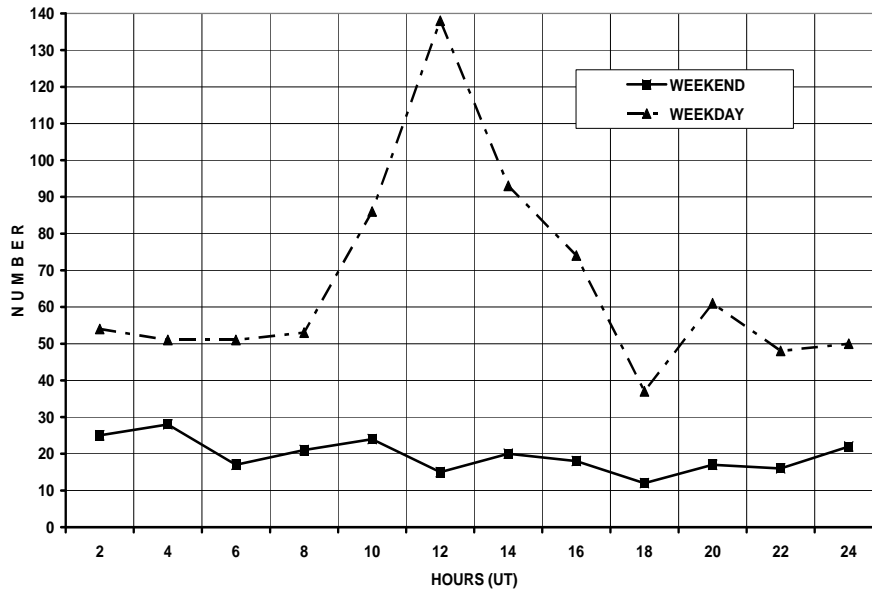


Figure 7, Diurnal distribution of earthquakes on weekends and on weekdays

3. STATISTICAL CALCULATIONS

Conventional Khi-Square test was performed on daily, weekly and monthly sets of data in order to see whether our data is significantly different from random events or not. The tests have failed in every case. The Schuster-test (Schuster, 1897) based on a random walk model is specially designed for investigations of phase distributions.

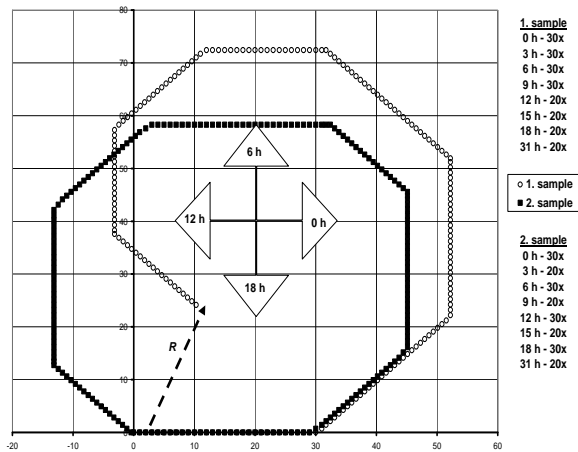


Figure 8, Examples for hodographs

Each earthquake corresponds to a unit vector, of which orientation is determined by the phase angle. (e.g. for the diurnal distribution 24 hours correspond to 360°). The sum of all vectors is a hodograph. The origin is the starting point of the vector sequence. The distance between the origin and the end of this vector sequence is R , which measures the periodicity. In figure 8 we show two examples for hodographs. The examples shown

contain the same number of events, except that the hourly numbers are different. In the first example from the beginning to the end of the hodograph there is a relatively large distance (R), this indicates periodicity in the data set. In the second example, however, the hodograph makes almost perfect a circle (R is small), indicating that there is no preferred phase in the data set. According to Schuster's test using N events the probability for the resultant distance to be larger than R is: $p = \exp(-R^2/N)$

We rejected the null hypothesis when p is found to be less than or equal to 1%. For these examples the Khi-Square Test gives the same results. The Khi-Square Test does not take into account any possible the grouping of events. Therefore, any ordering of the groups, out of which four contains 30 events and the other four 20 events, would be equivalent for the purpose of this test. In contrast, the result of Schuster's test differs considerably in the two samples, and reveals periodicity.

In figure 9 and figure 10 we show the diurnal (in LT) and monthly hodographs for earthquakes and blasts. In the case of the monthly graph the hodograph makes one circle every year. In all cases R is so large that Schuster's test indicates periodicity and thus failed the null hypothesis.

The time between the adjacent events (in hours) were regarded in the calculations. The coefficient of variation V is the ratio of the standard deviation to the mean. For random (Poisson) distribution of interval times $V=1$. For quasi periodic events $V<0$, and $V>1$ indicates that the events have been occurred in clusters.

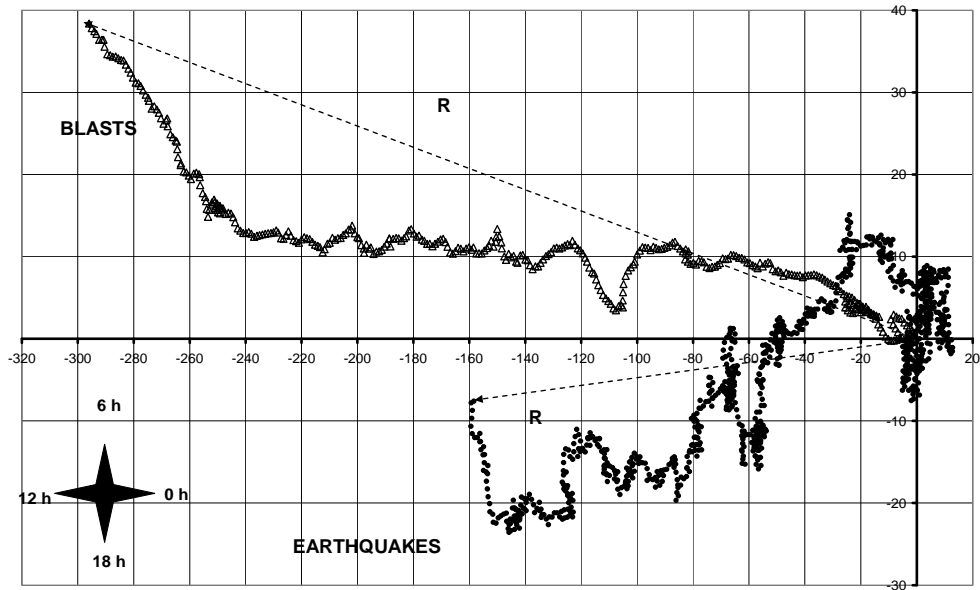


Figure 9, Diurnal hodograph of earthquakes and blasts

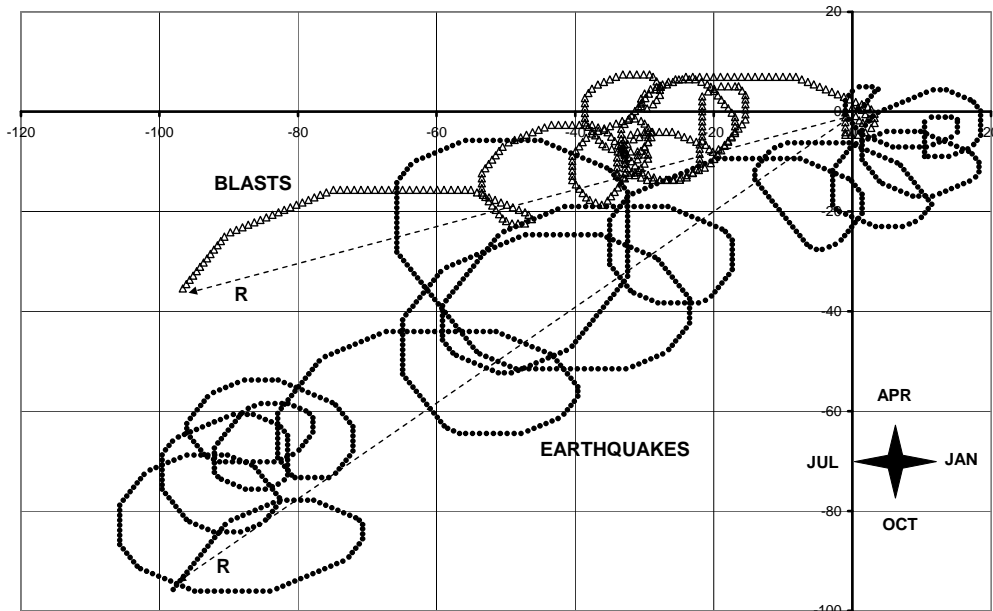


Figure 10, Monthly hodograph of earthquakes and blasts

Table 1. Statistical calculations regarded to time between adjacent events

Categories	Number	Mean between adjacent	Maximum between adjacent	Standard Deviation	Coeff. Variation: V
EARTHQUAKES	1031	124	2208	182.4	1.46
BLASTS	395	242	3840	441	1.83

The statistical calculations are listed in the table 1. The $V > 1$ for earthquakes and blasts indicate deviation from Poisson process.

The statistical calculations for diurnal weekly and monthly distribution of events are listed in the table 2. The Khi-square tests earthquakes are

accepted in the case of weekend earthquakes – there is no periodicity - but failed in the case of other categories. The contamination of catalog by blasts may be determined by looking at the weekend distribution of earthquakes.

Table 2. Statistical calculations for diurnal weekly and monthly distribution of events

CATEGORIES	MEAN	STANDARD DEVIATION	KHI-SQUARE TEST	SCHUSTER TEST
DIURNAL EA.	42,9	14,3	fail	<< 1%
BLASTS	16,4	26	fail	<< 1%
WEEKLY EA.	147,2	22,4	fail	<< 1%
WEEKLY BL.	56,4	31,7	fail	<< 1%
MONTHLY EA.	85,9	19,7	fail	<< 1%
MONTHLY BL.	32,9	14,3	fail	<< 1%
EA ON WEEKENDS	9,7	3,3	accept	-
EA ON WEEKDAYS	33,2	14,2	fail	-

4. SPECTRA OF EARTHQUAKES AND BLASTS

Finally, to reveal periodicity in our data set we utilized Fast Fourier Transformation (FFT). The

occurrence times of seismic events have been calculated in hours from 2007.03.24. The number of earthquakes was calculated every five hours successively. The resulting 4096 data point of the FFT covers about 2 years and four months.

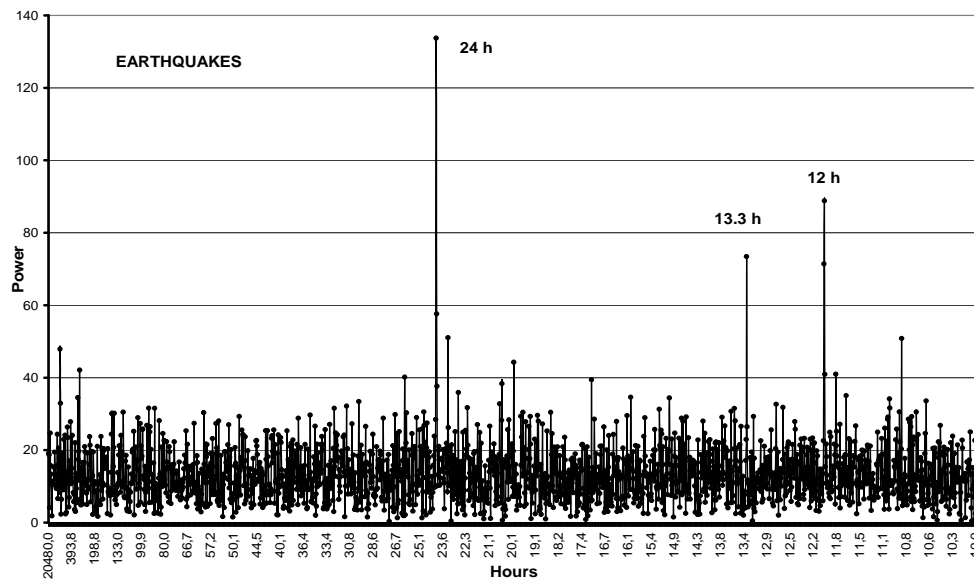


Figure 11, Power spectrum of the earthquakes for the period 2007.03.24-2009.07.

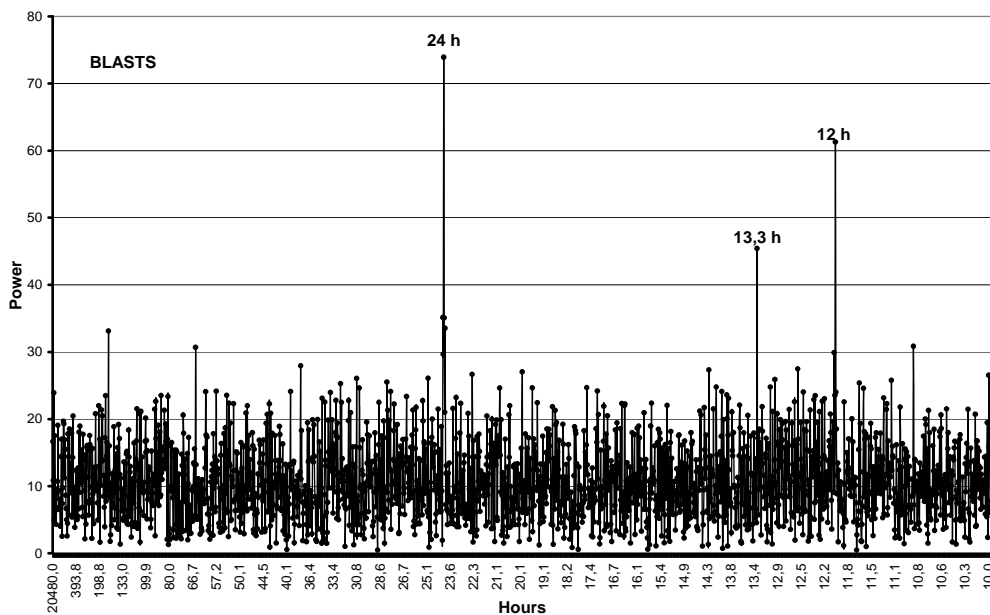


Figure 12, Power spectrum of the blasts for the period 2007.03.24-2009.07.04

About 160 earthquakes and 120 blasts occurred in this period. The time variations in the numbers of these events were calculated and are pictured in figure 11 and figure 12. Three different peaks are seen. The peak at 24 h is realistic, but the peaks at 12h and 13.3h are the result of the selected $\Delta t=5h$ sampling interval. The power of spectra is low however this calculation was only used to point out the potential of using FFT in seismology.

5. CONCLUSIONS

Many studies have been devoted to the daily periodicity of seismic events, and these have been made mostly in the seismic active regions. There is less statistical casework for other regions. A comprehensive database is at our disposal for the period starting 1995 when the first truly broadband digital stations were installed in Hungary. In the last 13 years the majority of detected events were small $M_L \leq 2$. The data in the Hungarian Earthquake Bulletin is contaminated with data from blasts, and vice versa. In the Hungarian Earthquake Bulletin 27% of the investigated seismic events are earthquakes and the remaining 73% are quarry blasts. The misclassified blasts may modify the diurnal, weekly and monthly distributions of earthquakes. In our bulletin the contamination may affect 15% of the earthquakes assuming that the classification was wrong. To obtain information about the hourly distribution of quarry blasts may not be possible, since these events have not been reported regularly and the hypocenter calculation is not precise in the case of $M \leq 2$ events.

Three different statistical calculations demonstrated the diurnal, weekly and monthly periodicity of earthquakes and blasts in the Carpathian Basin and adjacent regions. These results show significant deviations from the Poisson distribution for small $M < 1.8$ events.

Certainly there is a variation in the sensibility of the seismic instruments during the summer and the winter also there is a diurnal and weekly cycle of traffic-cultural noise. Opposite this fact, more earthquakes have been detected in the middle of the day, about at noon, and less, then the mean on weekend. This fact and the comparison of the diurnal distribution of earthquakes on weekends and those on weekdays indicate the contamination of the bulletin by quarry blasts.

The question remains very topical: Do the distributions of small earthquakes show natural affect in the Carpathian Basin?

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