Seismicity of the Pannonian Basin

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Abstract This article gives a brief summary of the seismic instrumentation used and the monitored results of earthquake activity in Hungary. Despite the Pannonian basin being characterized as a low-to-medium level seismicity region, the risk of destructive earthquake is still a major concern throughout Central Europe. The high population density in the region, and the number of vulnerable industrial facilities eg. nuclear power plants are being among the most sensitive ones regarding public concern.

Keywords Pannonian basin, seismicity, seismic monitoring, seismic hazard

1 Introduction

The Pannonian basin is located between the seismically very active NE Mediterranean sea and the nearly aseismic East European platform. The formation of the Pannonian basin within the Alpine orogenic belt started in the early Miocene and continued with structural inversions up to the late Pliocene-Quaternary period. Presently, there is clear evidence from GPS geodetic observations and seismic monitoring that the Pannonian basin continues to be deformed (Horváth et al., 2004; Grenerczy et al., 2002, 2005; Tóth et al., 2002, 2006; Bada et al., 1998, 1999; Horváth, 1988; Horváth and Cloetingh, 1996).

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The monitoring of seismicity in the Pannonian basin is not only vital for seismic risk assessment, within a densely populated area, but also to gain a better understanding of the geodynamics of the region through extensive geophysical mapping, and seismotectonic modeling and research. Seismotectonic models published in the early 1990s for the Alps and the northern Dinarides predict with some confidence where earthquake may occur (Anderson and Jackson, 1987; Slejko et al., 1989, 1998; Carulli et al., 1990; Favali et al., 1990; Del Ben et al., 1991; Console et al., 1993; Mariucci et al., 1999).

Due to the development in seismic instrumentation, computer equipments and communication technology in the last decades, high quality seismic stations became affordable even for industrial and civil applications. Sensitive local and regional networks have been installed in the Euro-Mediterranean area (Burchfiel et al., 2008; Kotzev et al., 2008) and the number of seismic monitoring stations has been dramatically increased even in seismically less active areas like Hungary.

2 Historical Seismicity

Seismic activity in and around the Pannonian basin can be characterized as moderate. There are significant variations in different tectonic domains (Figure 1) with the Vrancea region, in the southeast Carpathians, having the strongest and most frequent earthquakes – three with magnitudes larger than 6.5 within the last 30 years (1977: Ms7.2; 1986: Ms7.0; 1990: Ms6.7), and magnitudes of 5 on almost a yearly basis (Zsíros, 2003a, b). In the less active Pannonian basin – an area of about 206,117 km^2 – the occurrence of a magnitude 6 earthquake is about once in 100 years, while a magnitude 5 event occurs in average every 20 years.

Distribution of focal depths suggests three depth domains. Shallow focal depths within the top 20 km of the earth's crust occur almost exclusively through the whole region except the Vrancea zone. In the Pannonian basin, the majority of events occur between 6 and 15 km below ground level. Earthquakes of the Vrancea region are characterized by intermediate depths, the strongest ones occur between 70–110 and 125–160 km depths within an almost vertical column. Deeper and shallower events also have been recorded but only with small magnitudes.

In studies of focal mechanism (Tóth et al., 2002), strike-slip and thrust faulting occurs almost exclusively throughout the Southern Alps and the Dinarides. The maximum horizontal stress directions clearly show N–S and NNE–SSW compression related to the ongoing collision of Adria with Europe (Bada et al., 1999; Kotzev et al., 2008).

The seismicity is moderate in the Eastern Alps and the western Carpathians, where focal mechanism findings show that the majority have strike-slip mechanisms with NNW–SSE and N–S directions. The horizontal stresses are the largest and the most frequent, but NE–SW directions are nonetheless occasionally observed.

Focal mechanism results in the Pannonian basin are more diverse although thrust and strike-slip faulting seem to be dominant. NNE–SSW and NE–SW directions of

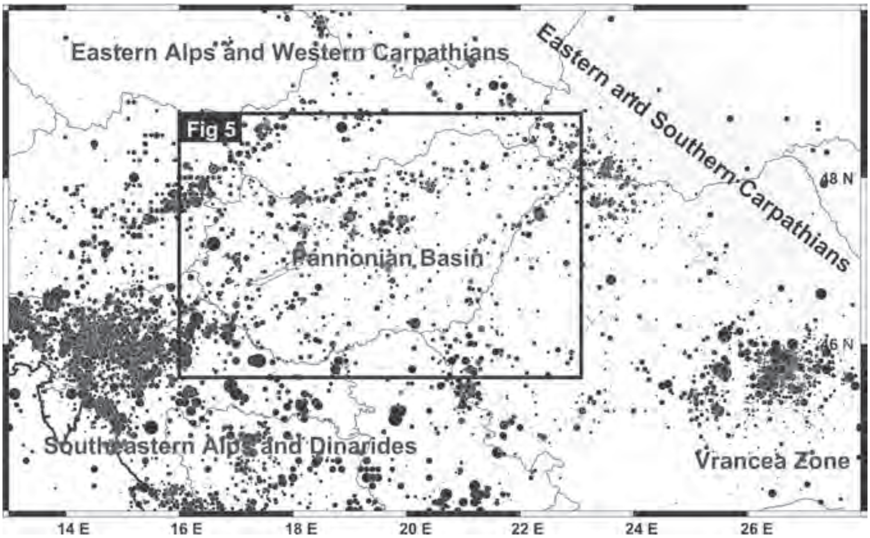

Figure 1 Seismicity of the Pannonian basin and adjacent area (44.0–50.0N; 13.0–28.0E). The regional earthquake database contains more than 22,000 historical and instrumentally recorded events from AD 456 until 2005 (modified from Tóth et al., 2006). Details on the Pannonian basin seismicity are presented in Figure 5

maximum horizontal stresses prevail. However, these features highlight significant differences from those in Western Europe, where the dominant stress directions are perpendicular to those directions. The very few fault-plane solutions from the eastern and southern Carpathians areas indicate thrust faulting along E–W dominant stress axes. Most events in the Vrancea zone are compressional and occur at intermediate depths. Fault-plane solutions of instrumentally recorded large earthquakes show remarkably similar characteristics as they typically strike SW–NE and dip towards NW with the maximum horizontal stress axis characteristically being NW–SE, and in a few cases E–W.

3 Seismic Monitoring

Instrumental seismology is a relatively young science and the first somewhat crude pendulum instruments were installed around the turn of 19th century. The low sensitivity of these mainly ground displacement instruments allowed only for recording of larger magnitude events above M > 4.5 for local ones. The first seismograph station in Hungary became operational in 1902 but did not contribute much to the study of local seismicity (Bisztricsány and Csomor, 1981). Hence, macroseismic observations remained the primary source of earthquake occurrences in Hungary to the end of 1980s.

Both instrumentation and seismic record analysis techniques have improved markedly since the mid-1970s. Digital recording has become commonplace and thus permitting use of sophisticated signal processing techniques even in real time. Previously, poor sensitivity of the seismograph stations effectively "prevented" detection of small magnitude earthquakes. Today the problem is the ambient noise level being due to natural and cultural noise sources which sets a lower signal detection level being roughly equivalent to magnitude 2.0 events. Note this level is most difficult to lower further unless local networks are deployed.

In Hungary, a complete overhaul of the traditional analogue seismograph network was commenced in the early 1990s. 16 stations became operational by 2004 with an approx. station density of 1/6,000 km^2. The new national Hungarian network comprises 4 broadband stations (BB-STS2) and the remaining 12 stations are being equipped with 3-component short period seismometers (LE-3D).

Careful site selection and analysis of the ambient seismic noise was carried out before locating the BB stations in the field. Each of the sites has fairly good geology in terms of competent hard rocks. The seismic vaults are constructed according to well proven local standards and besides advantages taken of pre-existing infrastructure (Figure 2). A high speed TCP/IP internet link is used for remote data access at all

Figure 2 The BB field stations are equipped with STS-2 three component broadband seismometers. Seismic data is distributed in near real time by SeedLink servers running on Linux based PCs

Figure 3 The SP field stations each consist of a three component short period seismometer located in a pit, with a digital recorder and time signal receiver housed nearby in a heat insulated steel container building

the BB sites. The stations are equipped with STS-2, three component, broadband seismometers and the seismic data are distributed in near-real-time by SeedLink servers running on inexpensive Linux based PCs.

Each SP field station consists of a three component short period seismometer located in underground pits with a digital recorder and time signal receiver housed nearby in a heat insulated steel container building (Figure 3). The seismometers used are the LE-3D three directional compact size high sensitivity 1 Hz geophones. The digital acquisition system is the Lennartz MARS-88 recorder that uses 20 bit AD converters sampling the data 62.5 times per second. The recorder also performs signal detection by its internal STA/LTA algorithm.

Both event records and continuous data are stored on rewritable magneto-optical disks. This in turn are collected and transferred to the data centre in Budapest on a weekly basis.

The predicted detection capability of the network (Table 1) at average noise conditions (with $S/N > 10$ at four stations) is equivalent to 1.5–2.0 M_L (Figure 4) so it is unlikely that any felt events would remain undetected in most of Hungary. In other words, 10 years of national network recording have now confirmed its design goal capability.

4 Recent Seismicity

Earthquake activity in the Pannonian basin can be characterized as distributed intraplate seismicity. However specific tectonic structures cannot be identified because incomplete in seismotectonic and geological information does not allow us to determine which fault is associated with a specific earthquake (Figure 5). This is particularly true for events below magnitude 4. For large historical earthquakes, the difficulty mostly stem from inaccurate hypocenter locations.

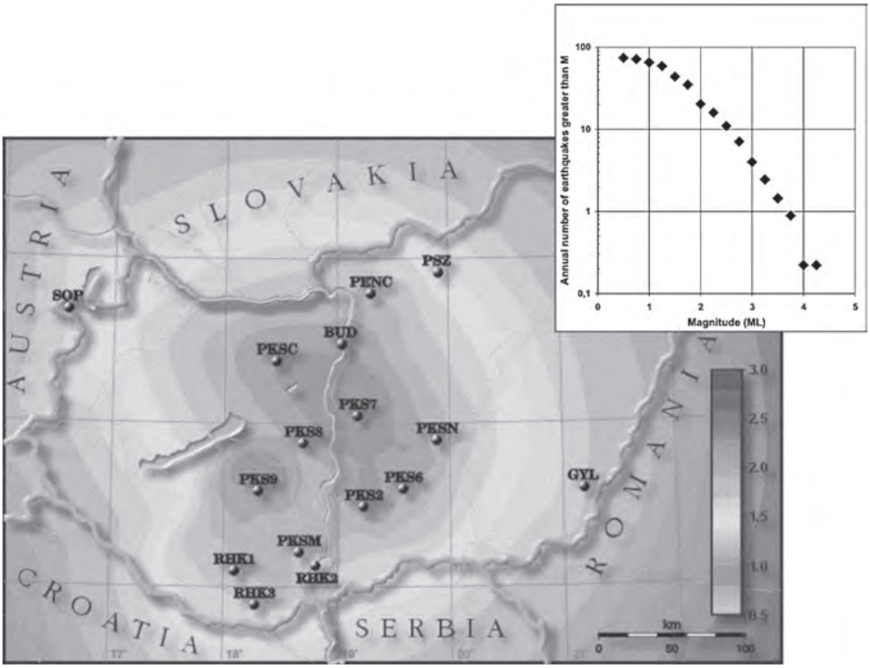

Figure 4 Predicted and observed detection capability of the Hungarian seismograph network. Contour values are local Richter magnitudes (M_L). Criteria for calculation: signal to noise ratio greater than 10 at minimum four stations at average noise conditions. The insert shows the magnitude recurrence curve for Hungary for the recording period 1995–2004

During the 10-year period 1995–2004, the Hungarian seismographic network located some 700 earthquakes within the Pannonian basin and adjacent areas as shown in Figure 5. This total includes two earthquakes of M_L 4; 61 earthquakes of M_L 3; and 249 earthquakes of M_L 2. Out of the mentioned 700 earthquakes 60 were reported felt. Focal depth is also important whether an earthquake would be felt or not and naturally shallow events favor “human detection”. These recorded earthquakes are mostly shallow with about 80% in the upper crust that is 6–15 km depth.

Obviously, earthquakes can occur in almost any part of the Pannonian basin, although certain areas have a higher likelihood of occurrence than others. The most earthquake prone areas are the Komárom – Mór – NE of Balaton belt (47.4–47.8N; 18.2E); the Danube bend region (47.8N; 19.0E); the locality of Eger (47.9N; 20.4E) and the area of Jászberény (47.5N; 20.0E). The Vienna basin, in eastern Austria and the northeastern part of Croatia are also relatively active (Markušić, 2008).

The outcome of high sensitivity monitoring over the last 10 years (Tóth et al., 2004) shows that there are in average 4 and 30 earthquakes of magnitude 3 and 2 respectively. The information of magnitude recurrence in the low magnitude range (M_L 2–4) is a very important contributor for the seismotectonic modeling (Bada et al., 2006).

Figure 5 Historical and recent seismicity of the Pannonian basin (Figure 1 insert; 45.5–49.0N; 16.0–23.0E). Grey dots show epicenter distribution of historical (456–1994) earthquakes while black dots represent recent (1995–2004) well located earthquakes. Lines illustrate neotectonic active structures after Horváth et al. (2005)

5 Earthquake Recurrence and Seismic Hazard

In assessing the seismic risk in areas where the extent of faulting in the crustal interior is unknown, the current practice is to represent the temporal occurrence of earthquakes as a Poisson process. For a "complete catalogue" all fore and aftershocks must be removed from the earthquake catalogue, and all earthquakes above a lower bound magnitude (the threshold magnitude M_0) are presumed to be included.

For identifying main shocks, space and time filters are applied - see Table 2. Dieterich (1994) proposed that the aftershock duration T generally increases with the inferred recurrence time of the main shock T_r such that $T \approx T_r/20$. Stein and Newman (2004), following studies in New Madrid zone, Missury USA, put forward the hypothesis of much longer aftershock duration periods for low seismicity intraplate settings. The explanation here is in terms of higher earthquake stress drops and larger normal stresses on intraplate faults. This in turn has a major impact on the assessment of seismic risk in areas of low seismic activity.

The Hungary case; based on empirical weighting, and also on our professional judgment, we used a magnitude-dependent space and time filter to identify main shocks in the catalogue detailed in Table 3.

A simple comprehensiveness test based on "magnitude recurrence fit" shows that our catalogue is complete since 1500 for magnitude $M_0 \geq 6.4$, since 1600 for magnitude

Table 1 The Hungarian seismograph network, the individual stations, their geographical locations, instrumentation and lithologies

Code	Lat (N)	Long (E)	Elev (m)	Site rock	Station type (1)	Sensor type (2)	Record (3)	Org. (4)
BUD	47,4836	19,0239	196	Dolomite	3C BB 3C SP	STS-2 LE-3D	D - C D - E	GGKI GR
PENC RHK4	47,7905	19,2817	250	Alluvium	3C SP	LE-3D	D - E	GGKI-GR
PKS2	46,4920	19,2131	106	Sand	3C SP	LE-3D	D - E	GR
PKS6	46,5998	19,5645	120	Sand	3C SP	LE-3D	D - E	GR
PKS7	47,0473	19,1609	95	Mud	3C SP	LE-3D	D - E	GR
PKS8	46,8787	18,6765	135	Rhyolite tuff	3C SP	LE-3D	D - E	GR
PKS9	46,5870	18,2789	240	Loess	3C SP	LE-3D	D - E	GR
PKSG	47,3918	18,3907	200	Dolomite	3C SP	LE-3D	D - E	GR
PKSM	46,2119	18,6413	170	Granite	3C BB	STS-2	D - C	GGKI
PKSN	46,8972	19,8673	110	Sand	3C SP	LE-3D	D - E	GR
PSZ	47,9184	19,8944	940	Andesite	3C BB	STS-2	D - C	GGKI
RHK1	46,0948	18,0720	297	Limestone	3C SP	SS-1	D - E	GGKI
RHK3	45,8885	18,2521	420	Limestone	3C SP	LE-3D	D - E	GR
RHK5	47,6983	19,0822	213	Limestone	3C SP	LE-3D	D - E	GR
RHK6	47,6741	19,2488	157	Sand	3C SP	LE-3D	D - E	GR
SOP	47,6833	16,5583	260	Gneiss	3C BB	STS-2	D - C	GGKI

(1) 3C – three component seismometer; SP – short period seismometer; BB – broad band seismometer
(2) STS-2 – Streckeisen broad band seismometer; LE-3D – Lennartz three directional 1 Hz geophone; SS-1 – Kinemetrics 1 Hz seismometer
(3) D – digital; C – continuous recording; E – event recording
(4) GGKI – Geodetic and Geophysical Research Institute, HAS; GR – GeoRisk Earthquake Research Institute Ltd

Table 2 Space and time windows used for filtering out the aftershocks and foreshocks in the Hungarian catalogue. In the vicinity of radius **R** of the magnitude **M** main earthquake, all shocks with **M′< M** are regarded as aftershocks or foreshocks conditioned on their origin time differences being less than **T** or **T′** respectively

Magnitude	R (km)	T (day)	T′ (day)
MM ≤ 1.8	5	1	1
1.9 ≤ MM ≤ 2.7	10	2	1
2.8 ≤ MM ≤ 3.3	15	5	1
3.4 ≤ MM ≤ 4.0	20	30	2
4.1 ≤ MM ≤ 4.7	25	130	4
4.8 ≤ MM ≤ 5.4	30	260	10
5.5 ≤ MM ≤ 6.1	35	650	15
6.2 ≤ MM	40	850	30

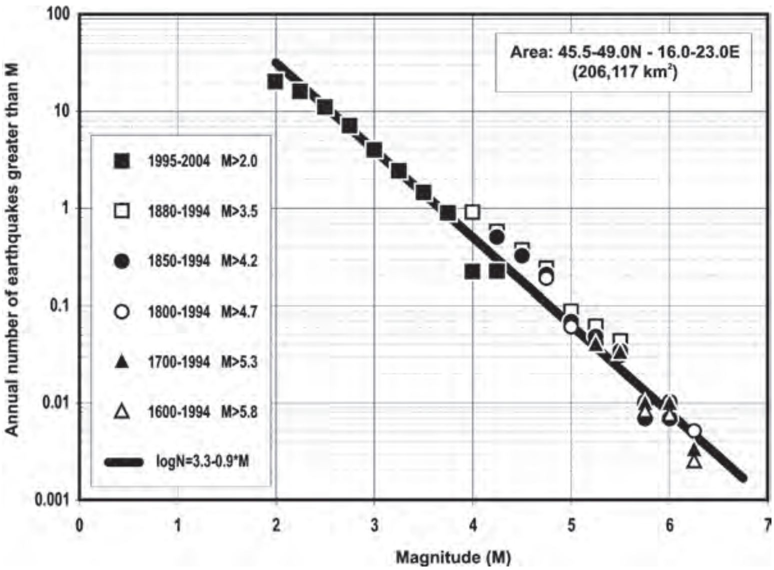

Figure 6 Magnitude recurrence curve for Pannonian basin earthquakes

$M_0 \geq 5.8$, since 1700 for magnitude $M_0 \geq 5.3$, since 1800 for magnitude $M_0 \geq 4.7$, since 1850 for magnitude $M_0 \geq 4.2$, and since 1880 for magnitude $M_0 \geq 3.5$ for the whole Pannonian region related to the human detection threshold mentioned previously.

The probability of earthquake occurrence as a function of magnitude is generally represented by an exponential distribution, as proposed by Gutenberg and Richter (1944): $log\mathbf{N} = \mathbf{a} - \mathbf{bM}$, where **N** is the annual number of earthquakes with magnitude equal or greater than **M**. From the Pannonian basin dataset, we find that **a** = 3.3 and **b** = 0.9 in the 2.0 ≤ **M** ≤ 6.3 magnitude range (Figure 6).

Using the methodology described in slejko (1998) and particularly in Tóth et al. (2006), seismic hazard maps for the whole Pannonian region were computed. The map shown in Figure 7 depicts the mean PGA with a 90% probability of non-exceedance in 50 years.

Table 3 Completeness test results for the Pannonian region earthquake catalogue

The catalogue is complete	for magnitude
Since 1500	$M_0 \geq 6.4$
Since 1600	$M_0 \geq 5.8$
Since 1700	$M_0 \geq 5.3$
Since 1800	$M_0 \geq 4.7$
Since 1850	$M_0 \geq 4.2$
Since 1880	$M_0 \geq 3.5$

Most of the Pannonian basin has a relatively low seismic risk, with less than 1 m/s^2 expected PGA; however, there are some areas of potential greater risk in the range of 1–2 m/s^2. These are Komárom, northeast of Lake Balaton, east of Budapest, the south-western part of Hungary.

6 Conclusions

To understand how tectonic stress and strain propagates from plate boundaries into continental areas has been a major problem for a long time (Ziegler et al., 1995, 2002. Due to its unusual tectonic environment, the Pannonian basin is an excellent natural laboratory for in-depth investigations here. Stress accumulations and recent deformations in the Pannonian basin are governed by the interaction of plate boundary and intraplate forces being the dominant source of compression. Adding to the complexities is the counterclockwise rotation and N–NE directed indentation of the Adria microplate (also known as "Adria-push"- see also Kotzev et al., 2008). A combination of buoyancy forces associated with elevated topography and lithospheric heterogeneities in the adjacent orogens that result in a complex pattern of ongoing tectonic stresses and deformation activities being projected far into the Pannonian basin.

Observed earthquake activities indicate that current deformation is mainly concentrated in the contact zone between Adria and the Alpine–Dinarides orogen (Figure 1) and some of the movement is transferred into the Pannonian basin resulting in a complex stress/strain pattern. Deformations here may occur whenever the stress exceeds the local shear strength of any given rock mass so neither earthquakes nor other forms of deformation are restricted to block boundaries. Hence a more distributed seismicity pattern as expected is observed (Figure 5), with an added feature of the hot and weak extended Pannonian lithosphere being its characteristic reactivation under relatively low compressional stresses (Lenkey et al. 2002).

Using GPS measurements, Grenerczy et al. (2002) found the largest crustal velocities (1.5–2 mm/year northward) in the Pannonian region in the SW; in the Alpine–Adriatic collision zone. Inside the Pannonian basin itself, the typical velocity was about 1.0–1.5 mm/year directed eastward. Grenerczy at al. (2005) and Kotzev et al. (2008) also concluded that the Alps, Dinarides, and Pannonian basin, take up the shortening caused by the Nubia/Adria convergence. On this basis, we claim ourselves that the Western and Northern Carpathians are no longer active thrust fronts; and now can be considered parts of a stable, and rigid, European Platform.

Figure 7 Seismic hazard in the Pannonian basin region. Expected peak ground acceleration in m/s^2 (10% probability of exceedance in 50 years, 475-year return period)

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References

Anderson, H. A., Jackson, J. A., 1987. Active tectonics of the Adriatic region. *Geophys. J. R. Astron. Soc.,* 91: 937–983.

Bada, G., Gerner, P., Cloetingh, S., Horváth, F., 1998. Sources of recent tectonic stress in the Pannonian region: inferences from finite element modelling. *Geophys. J. Int.,* 134: 87–102.

Bada, G., Horváth, F., Gerner, P., Fejes, I., 1999. Review of the present-day geodynamics of the Pannonian basin: progress and problems. *J. Geodynamics*, 27: 501–527.

Bada, G., Grenerczy, Gy., Tóth, L., Horváth, F., Stein, S., Cloetingh, S., Windhoffer, G., Fodor, L., Pinter, N., Fejes, I., 2006. Motion of Adria and ongoing inversion of the Pannonian basin: Seismicity, GPS velocities and Stress Transfer (to appear in a special GSA volume).

Bisztricsány, E. Csomor, D., 1981. 75 years of seismological research in Hungary, Acta Geodaet., Geophys. et Montanist. *Acad. Sci. Hung. Tomus,* 16 (2–4): 423–434.

Burchfiel, B.C., King, R.W., Nakov, R., Tzankov, T., Dumurdzanov, N., Serafi movski, T., Todosov, A., Nurce, B., 2008. Patterns of Cenozoic Extensional Tectonism in the South Balkan Extensional System. In E.S. Husebye (ed.). Earthquake Monitoring and Seismic Mazard in Balkan Countries. Springer publishing, Berline, 3–18.

Carulli, G. B., Nicolich, R., Rebez, A., Slejko, D., 1990. Seismotectonics of the Northwest External Dinarides. *Tectonophysics*, 179: 11–25.

Console, R., Di Giovambattista, R., Favalli, P., Presgave, B. W., Smriglio, G., 1993. Seismicity of the Adriatic microplate. *Tectonophysics*, 218: 343–354.

Del Ben, A., Finetti, I., Rebez, A., and Slejko, D., 1991. Seismicity and seismotectonics at the Alps-Dinarides contact. *Bollettino di Geofisica Teorica ed Applicata*, 33: 155–176.

Dieterich, J. H., 1994. A constitutive law for rate of earthquake production and its application of earthquake clustering. *J. Geophys. Res*. 99(2): 2601–2618.

Favali, P., Mele, G., Mattietti, G., 1990. Contribution to the Study of the Apulian Microplate Geodynamics. *Memorie della Società Geologica Italiana*, 44: 71–80.

Grenerczy, G., Fejes, I., Kenyeres, A., 2002. Present crustal deformation pattern in the Pancardi Region: Constraints from Space Geodesy. In *Neotectonics and surface processes: the Pannonian basin and Alpine/Carpathian system*, S. Cloetingh, F. Horváth, G. Bada, A. Lankreijer (eds.). *EGU St. Mueller Special Publication Series* 3: 65–77.

Grenerczy, G., Sella, G., Stein, S., Kenyeres, A., 2005. Tectonic implications of the GPS velocity field in the northern Adriatic region. *Geophys. Res. Lett*, 32 (16), L16311.

Gutenberg, J., Richter, C. F., 1944. Frequency of earthquakes in California. BSSA; 34: 185–188.

Horváth F., 1988. Neotectonic behaviour of the Alpine-Mediterranean region. In *The Pannonian Basin - A study in basin evolution*, L. H. Royden, F. Horváth (eds.). AAPG Memoir, 45: 49–51.

Horváth, F., Cloetingh S., 1996. Stress-induced late-stage subsidence anomalies in the Pannonian basin. *Tectonophysics*, 266: 287–300.

Horváth, F., Bada, G., Szafián, P., Tari G., Ádám A., Cloetingh S., 2004. Formation and deformation of the Pannonian basin constraints from observational data. In *European Lithosphere Dynamics*, D.G. Gee, R. Stephenson (eds.). *Geol. Soc. London Spec. Publ*.

Kotzev et al., 2008. Crustal Motion and Strain Accumulation in the South Balkan Region Inferred from GPS Measurements. In E.S. Husebye (ed.). Earthquake Monitoring and Seismic Hazard in Balkan countries. Springer Publishing, Berline, 19–43.

Lenkey, L., Dövényi, P., Horváth, F., Cloetingh, S.A.P.L., 2002. Geothermics of the Pannonian basin and its bearing on the neotectonics. In *Neotectonics and surface processes: the Pannonian basin and Alpine/Carpathian system*, S. Cloetingh, F. Horváth, G. Bada, A. Lankreijer (eds.). EGU St. Mueller Special Publication Series, 3: 29–40.

Mariucci, M.T., Amato, A., Montone, P., 1999. Recent tectonic evolution and present stress in the Northern Apennines (Italy). *Tectonics*, 18: 108–118.

Markušić, S., 2008. Seismicity of Croatia. In E.S. Husebye (ed.) Earthquake Monitoring and Seismic Hazard in Balkan countries. Springer Publishing, Berline, 81–98.

Slejko, D., Carulli, G. B., Nicholic, R., Rebez, A., Zanferrari, A., Cavallin, A., Doglioni, C., Carraro, G., Castaldini, D., Iliceto, V., Semenza, E., Zanolla, C., 1989. Seismotectonics of the eastern Southern-Alps: a review. *Bollettino di Geofisica Teorica ed Applicata*, 31: 109–136.

Slejko, D., Peruzza, L, Rebez, A., 1998. Seismic hazard maps of Italy. *Ann. Geophys*., 41: 183–214.

Stein, S., Newman, A., 2004. Characteristic and Uncharacteristic Earthquakes as Possible Artifacts: Applications to the New Madrid and Wabash Seismic Zones. *Seismol. Res. Lett.ers*, 75 (2): 173–187.

Tóth, L., Mónus, P., Zsíros, T. Kiszely, M., 2002. Seismicity in the Pannonian Region – earthquake data. In *Neotectonics and surface processes: the Pannonian basin and Alpine/Carpathian system*, S. Cloetingh, F. Horváth, G. Bada, A. Lankreijer (eds.). *EGU St. Mueller Special Publication Series*, 3: 9–28.

Tóth, L., Mónus, P., Zsíros, T., Kiszely, M., 2004. Micro-seismic monitoring of seismoactive areas in Hungary. Studi Geologici Camerti, Special Issue: Proceedings of the workshop COST Action 625 "Active faults: analysis, processes and monitoring".

Tóth, L., Györi, E., Mónus, P., Zsíros, T., 2006. Seismic Hazard in the Pannonian Region. In: Pinter, N., Grenerczy, Gy., Weber, J., Stein, S., Medak, D. (eds.), The Adria Microplate: GPS Geodesy, Tectonics, and Hazards. Springer Verlag. *NATO ARW Series*, 61: 369–384.

Ziegler, P. A., Cloetingh, S., Van Wees, J.D., 1995. Dynamics of intra-plate compressional deformation: the Alpine foreland and other examples. *Tectonophysics*, 252: 7–59.

Ziegler, P. A., Bertotti, G., Cloetingh, S., 2002. Dynamic processes controlling foreland development - the role of mechanical (de)coupling of orogenic wedges and forelands, in Bertotti, G., Schulmann, K., and Cloetingh, S. (eds.), Continental collision and the tectono-sedimentary evolution of forelands. Katlenburg-Lindau, Germany, European Geosciences Union. *St. Mueller Special Publication Series*, 1: 17–56.

Zsíros, T., 2003a. Earthquake activity and hazard in the Carpathian basin I. *Acta Geod. Geoph. Hung*., 38 (3): 345–362.

Zsíros, T., 2003b. Earthquake activity and hazard in the Carpathian basin II. *Acta Geod. Geoph. Hung.*, 38 (4): 445–465.