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Seismicity in the Pannonian Region – earthquake data

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Abstract. A comprehensive earthquake catalogue has been compiled, listing historical and instrumentally recorded earthquakes throughout the Pannonian Region bounded by 44.0–50.0 N latitude and 13.0–28.0 E longitude. The catalogue contains more than 20 000 events ranging in date from 456 AD to 1998 and is considered to be complete for earthquakes larger than M 6.4 since 1500, for earthquakes larger than M 4.7 since 1800 and for magnitudes greater than 3.5 since 1880. In combination with the stress data derived from 190 focal mechanism solutions for individual earthquakes these data provide a relatively strong basis for evaluating seismic sources and seismotectonic models both within and surrounding the Pannonian Basin. The most active parts of the area are the Carpathian and Dinaric tectonic belt and the Vrancea region in the Southeast Carpathians. Seismicity in the Pannonian Basin is more moderate compared to the peripheral areas, however distribution of the total seismic energy release indicates current deformation in the basin area as well. Shallow hypocental depth within the top 20 km of the earth's crust is principal in the entire region except for the Vrancea zone where intermediate depth seismicity (from 70 to 160 km) is governing. In the Pannonian Basin area the majority of events occur between 6 and 15 km. Focal mechanism solutions show that strike-slip and thrust faulting are almost exclusive in the Southern Alps and in the Dinarides. In the Eastern Alps and Western Carpathians focal mechanism solutions present exclusively strike-slip character. In the Pannonian Basin, thrust and strike-slip faulting seem to be dominant, while earthquakes in the Vrancea area occur in a compressive regime with thrust tectonics.

1 Introduction

Within plate tectonic theory, deformation and consequently seismicity is concentrated along the boundaries of rigid plates. For that reason seismicity is one piece of information essential for understanding current tectonics. On the other hand, the extension of plate tectonics to a regional or local scale is a more complicated task and should be performed with great care. Not only because almost 10% of all earthquakes occur within plate interiors globally, but also as plates continue to move, plate boundaries change over geologic time and weakened boundary regions become part of the interiors of the plates. These zones of weakness within the continents can cause earthquakes, either in response to stresses that originate at the edges of the plate or in response to local gravitational stresses.

Nevertheless, the study of the recent tectonics requires input data from the seismic activity of the area: if existing tectonic features are active in the present, or were active in the recent past, this necessarily should be reflected in current seismicity. Earthquakes represent the sudden release of slowly accumulated strain energy and hence provide direct evidence of active tectonic processes. However, low and moderate seismicity at intraplate areas generally precludes reliable statistical correlation between epicenters and geological features.

The Pannonian Basin and surrounding orogens (referred as "Pannonian Region") are located in the northern sector of the central Mediterranean region. The Pannonian Basin is bounded on the north to the east by the Carpathian mountain belt, on the south by the Dinarides mountain belt and on the west by the Eastern Alps. The area is tectonically rather complicated and has been studied intensively over the last twenty years. Development of the Carpathian mountain belt and the Pannonian Basin is attributed to collision between the Eurasian Plate and the African Plate between the Paleocene and Middle-Late Miocene (Horváth, 1984, 1988; Royden, 1988). Different authors basically agree that present-day deformation in the Pannonian Basin system 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).

The aim of this study is to document the latest results in understanding the seismicity of the Pannonian Region, based on available earthquake-related information, epicentral and depth distribution, energy release, magnitude recurrence and stress data derived from focal mechanism solutions.

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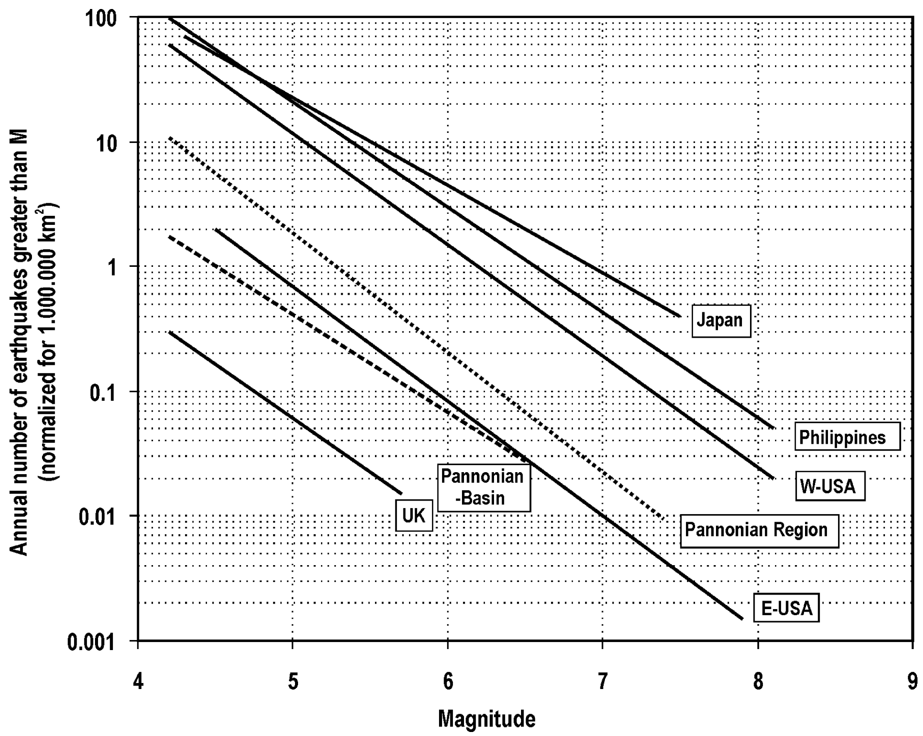

Fig. 1. Seismic activity rate of the Pannonian Region compared to other seismic regions of the world. To be comparable, magnitude recurrence curves have been normalized to a uniform area of 10^6 km^2. Sources – UK: Ove Arup & Partners (1992); eastern USA: Atkinson (1989); Pannonian Region and Pannonian Basin: present study; western USA: Atkinson (1989); Greece: Tsapanos (1988); Philippines: Ove Arup & Partners (1990); Japan: Tsapanos (1988).

2 From early earthquake lists to a comprehensive earthquake data base

Although very strong (M>7) or catastrophic earthquakes are rare in the Pannonian Region, there is a long history of earthquakes which have caused substantial damage. The first earthquake record from the area dates back to 456 AD when a quake hit Savaria, a town of the Roman Empire (now Szombathely, Hungary) and severely affected large areas (Pleidell, 1934).

Systematic earthquake data collection in the region started in the nineteenth century when the great part of the studied area administratively belonged to Hungary and Austria. A detailed seismological report written by Kitaibel and Tomtsányi (1814) on the great Mór earthquake of 14 January 1810, M 5.4, is the first published paper which contains intensity distribution map with isoseismals. Officially organised collection and evaluation of earthquake data started in 1881. The first seismograph stations were established in 1901, and regular observations started the next year. By the end of 1914, ten seismological observatories had been set up in Hungary at the following locations: Budapest, Fiume (Rijeka), Kalocsa, Kecskemét, Kolozsvár (Cluj-Napoca), Ógyalla (Hurbanovo), Szeged, Temesvár (Timisoara), Ungvár (Uzhgorod), Zágráb (Zagreb). The First World War stopped this progress which had gotten off to a good start. The most important regional catalogue of historical earthquakes was published by Réthly (1952) listing approximately 800 well-documented events with references.

The first modern computer-based earthquake catalogue with some 5000 entries was compiled by Zsíros et al. (1988) with the aim of providing a complete revision of the previous lists, a re-evaluation of historical documents and a recalculation of hypocentral data, intensity and magnitude. This work led to a comprehensive catalogue of earthquakes (Zsíros, 2000a) that has been compiled for the Pannonian Region bounded by 44.0–50.0 N latitude and 13.0–28.0 E longitude using various input sources and integrating several local catalogues. More than one and half millennium of historical and instrumental earthquake data, from 456 AD to 1998, give a reasonable quantitative value, indicating moderately active seismicity of the area. The list consists of more than 20 000 events drawn from over 1400 different scientific and scholarly sources, local catalogues, annual bulletins and individual event reports. By its nature, an earthquake catalogue can be neither complete nor without errors, especially if it goes back to historic (pre-instrumental) times. Particularly for periods prior to the 1800s, reporting of earthquakes is not homogeneous in space or time. Because publications mainly list those earthquakes that have caused death or damage, the number of reports is dependent on the written history available for a particular region, as well as on the rate of development of population centers and related structures. Therefore, it is misleading to use the number of earthquakes in an

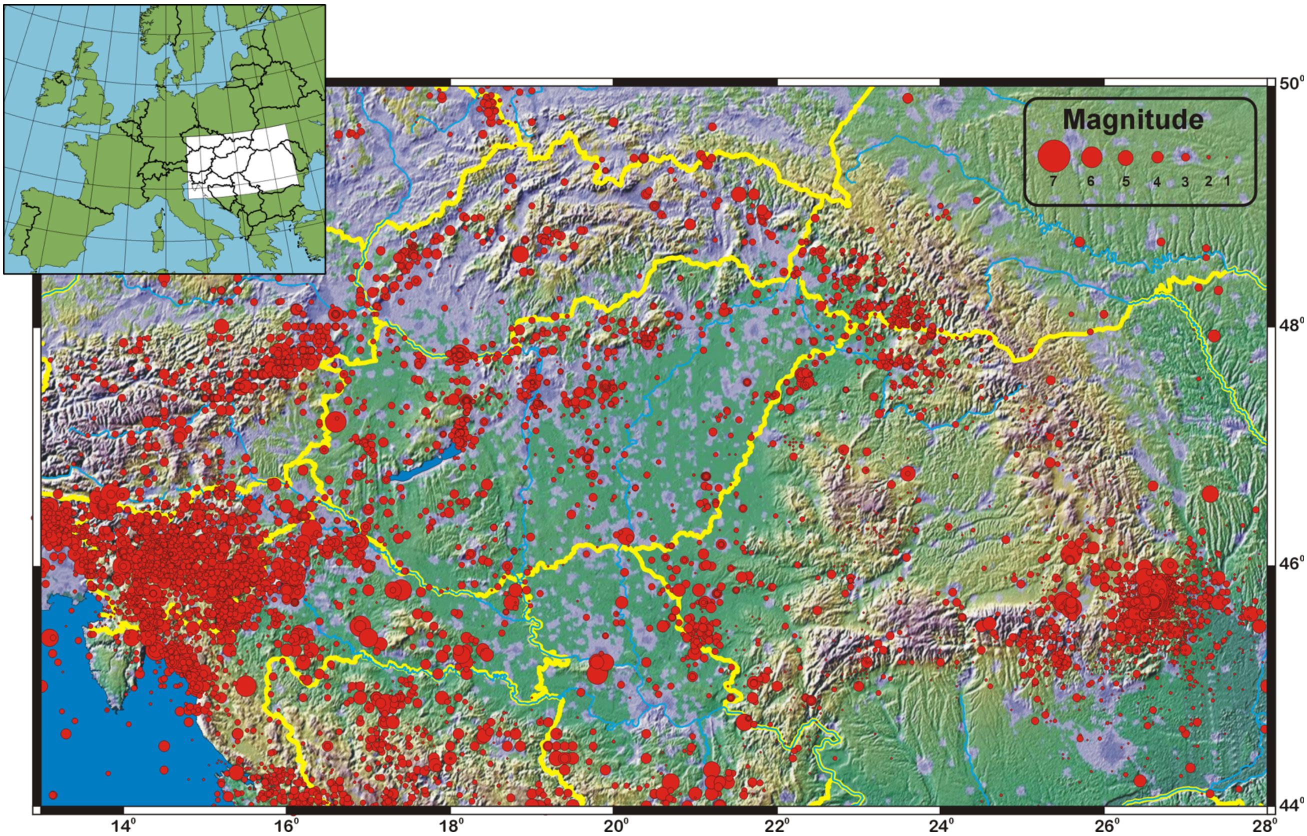

Fig. 2. Distribution of earthquake epicenters in the Pannonian Region (44.0–50.0 N; 13.0–28.0 E). The earthquake database of the region contains more than 20 000 historical and instrumentally recorded events from 456 AD until 1998. Events are excluded from the map if the epicenter accuracy is less than 50 km. Size of circles are proportional to the calculated magnitudes.

incomplete catalogue to suggest statistically that there has been an increase in seismic activity for any time period. The present regional catalogue is considered to be complete for earthquakes larger than M 4.7 since 1800.

The catalogue shows significantly more earthquakes in the Carpathian and Dinaric tectonic belt than within the Pannonian Basin itself where the spatial distribution of epicentres is rather diffuse. Based on all events, the seismic activity can be characterised as moderate. Figure 1 shows the activity rate of the Pannonian Region and the Pannonian Basin compared to those of a few other seismic regions of the world.

The first focal mechanism solution for the study area was published by Csomor (1966) for the 1956 Dunaharaszti earthquake. Mónus et al. (1988) presented fault plane solutions for six larger earthquakes in the Pannonian Basin. Tóth et al. (1989) published a well constrained solution for the Berhida (Hungary) earthquake of 1985 based on 88 observations. Gangl (1975) studied five focal solutions from the Vienna Basin. For larger Vrancea earthquakes a number of focal mechanism solutions have been published by different authors (e.g. Fara, 1964; Ritsema, 1974; Oncescu, 1987). Gerner (1995) catalogued earthquake focal mechanism solutions for the whole Pannonian Region, partly collected from literature and partly based on new calculations. In the framework of the international World Stress Map Project (Müller et al., 1997), different types of stress information, together with focal mechanism solutions, have been stored in a standardised manner. Even for smaller magnitude local earthquakes, regular focal mechanism computation has been started and published in annual bulletins (Tóth et al., 1999) since 1995. Until the end of 1998, altogether 190 carefully revised solutions are available for different earthquakes in the focal mechanisms database for the studied area.

From P-wave displacement spectra of high-quality digital seismograms of 12 recent (1995–1997) local earthquakes, Badawy et al. (2001) estimated dynamic source parameters such as seismic moment, stress drop, fault length and relative displacement.

3 Energy release

The Pannonian Region is situated in the territory between the Mediterranean area, which is seismically one of the most active regions in the world, and the East European Platform which can be treated as nearly aseismic. The first impression that the earthquake epicenter distribution map (Fig. 2) of the entire catalogue suggests is that there are significantly more earthquakes in the Carpathian and Dinaric tectonic belt than within the Pannonian Basin. Within the Pannonian Basin

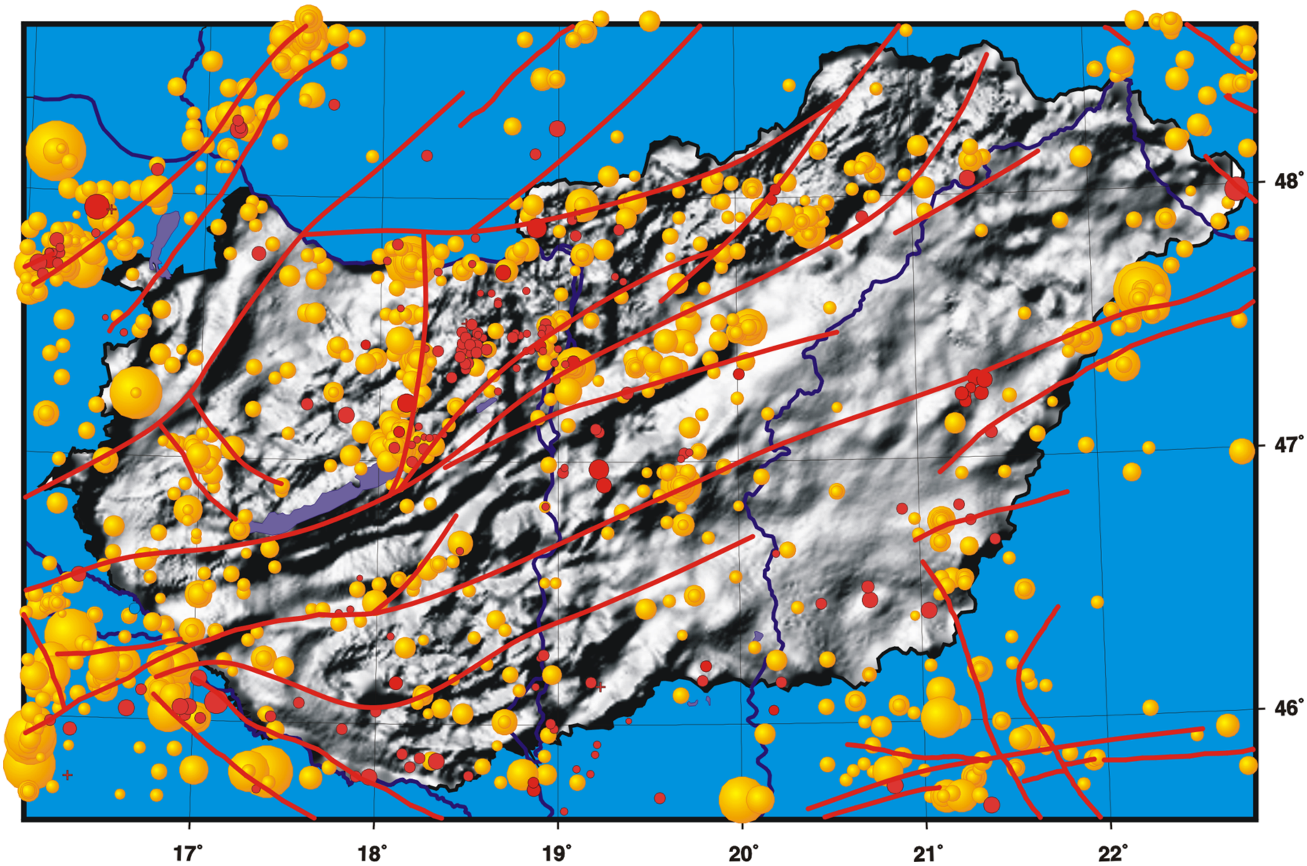

Fig. 3. Historical (456 AD – 1994) and recent (1995–1998) seismicity in and around Hungary (45.5–49.0 N; 16.0–23.0 E) plotted on Bouguer anomaly map. Yellow bubbles show historical events mostly based on macroseismic effects while solid red circles indicate latest epicentral locations measured since high sensitivity digital networks came into operation. Heavy lines show tectonic lineaments as defined by F. Horváth and G. Bada, (personal communication).

there also appears to be significant differences in seismicity among different geographical domains.

Along the western edge of the Pannonian Basin and in the Eastern Alps and Dinarides some well-defined zones of seismic activity can be recognized. Within the Dinaric area, seismic lineaments can be recognized running parallel with the Adriatic coast. These are connected by the very active NE-SW trending Medvednica zone near Zagreb. A linear seismic source zone in the Eastern Alps, the Mur-Mürz-Zilina line, strikes northeast into the southern Vienna Basin and extends as far as the Little Carpathians.

The seismicity of the Vrancea region in the Southeast Carpathians is characterized by an amazingly narrow epicentral region (Oncescu, 1984). The epicentral area is confined to about 20×60 km, where strong earthquakes (M>6) occur quite frequently.

Seismicity in the Pannonian Basin is more moderate compared to the peripherals and, at first glance, the distribution of earthquake epicenters shows a rather scattered pattern. It is particularly difficult to decide whether the epicenters occur at isolated places or along elongated zones. Csomor and Kiss (1959) have noted that at several individual locations earthquakes occur repeatedly. For example, near Eger (47.9 N; 20.4 E) at least sixteen earthquakes with more than fifty significant aftershocks occurred over a time interval of some 70 years. Komárom and Mór area (47.4–47.8 N; 18.2 E), Jászberény (47.5 N; 20.0 E), Kecskemét (46.9 N; 19.7 E) and Dunaharaszti (47.4; 19.0 E) also produced significant activity over a certain, but limited period of time. Moderate seismicity does not necessarily mean moderate size of earthquakes: reports of major earthquakes often refer to heavy building damage, liquefaction (e.g. 1763 Komárom earthquake, M 6.2; 1911 Kecskemét earthquake, M 5.6) and sometimes the possibility of fault rupture (e.g. 1834 Érmellék earthquake, M 6.2). These observations indicate that magnitude 6.0–6.5 earthquakes are possible but not frequent in the Pannonian Basin. Bisztricsány (1978) has illustrated the difficulty in constructing any meaningful geographical pattern of epicentral distribution when the statistical significance of the data is so low. Using only historical and early instrumental data, it really has been very challenging to find strong correlation between known tectonic structures and earthquakes. The recent high quality earthquake observations and locations may change this situation (Tóth et al., 1996, 1997, 1998a, 1999). Preliminary comparison of historical seismicity with recent events shows that the recent earthquakes, in

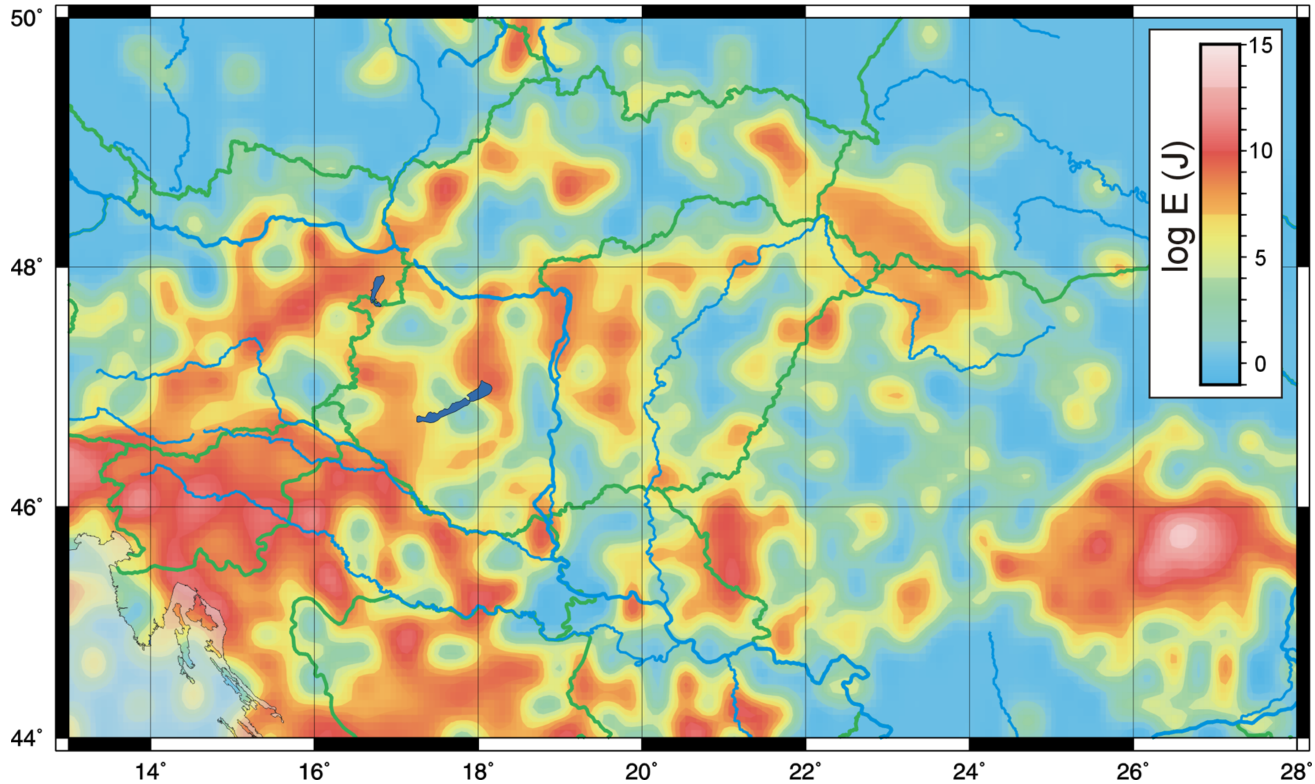

Fig. 4. Spatial distribution of the total seismic energy release in the Pannonian Region. Most dynamic deformation has been taking place in the Dinarides and the Vrancea zone; but rather intense deformation has been taking place in the Pannonian Basin as well.

general, lie near to clusters of historical activity. Only a few events are exceptions, in that they appear to be unassociated with historical activity. However, clusters of stronger present day activity have been detected in the north-eastern part of the Transdanubian Mountain Range, close to the NE coast of lake Balaton and at the bend of the Danube above Budapest (Fig. 3).

The spatial distribution of the total seismic energy release shows (Fig. 4) that the most forceful deformation has been taking place in the Dinarides and the Vrancea zone. However, the deformation occurring in the Pannonian Basin has been considerably more intense than in the rest of the surrounding orogenic belts. The same conclusion was drawn earlier by Gerner et al. (1999). Repeated computation based on our comprehensive data set has confirmed this, and further highlights ongoing tectonic activity in the Pannonian Basin.

4 Focal depth

Less than 20% of the earthquakes – some 3700 – in the catalogue have depth information. Many focal depth values were estimated from macroseismic data (Zsíros, 1989, 1996), and, whilst being the best information currently available, have considerable uncertainty associated with them. It should also be noted that the focal depth determinations from instrumental data are also rather uncertain. The situation has improved since high sensitivity digital networks came into operation, and typical error associated with depth determination has been reduced to about 2–4 km (Tóth et al., 1998b).

Distribution of focal depths suggests three depth provinces where more than 80% of all events have taken place (Fig. 5). Shallow depth within the top 20 km of the earth's crust is almost exclusive in the whole region except the Vrancea zone in the Eastern Carpathians. In the Pannonian Basin area, the majority of events occur primarily between 6 and 15 km below ground level, with many occurring between 6 and 9 km.

The earthquakes in the Vrancea region are characterized by intermediate depth seismicity. Strong earthquakes occur either in the 70–110 km or 125–160 km depth domains within an almost vertical column. Deeper and shallower events have been recorded, but only with small magnitudes. Levels of low seismicity lie adjacent to the depth interval of the strong events between 40 and 70 km and beneath 160 km.

5 Magnitude

Instrumental seismology is a young science. The first calibrated instruments to measure seismic waves travelling through the earth and allowing direct measure of earthquake magnitude did not appear until the late 1800s. But, because of the insensitivity of these early instruments they were able to record only large magnitude events.

Richter developed the first magnitude scale for local earthquakes (M_L) in 1935 using the logarithm of the amplitude

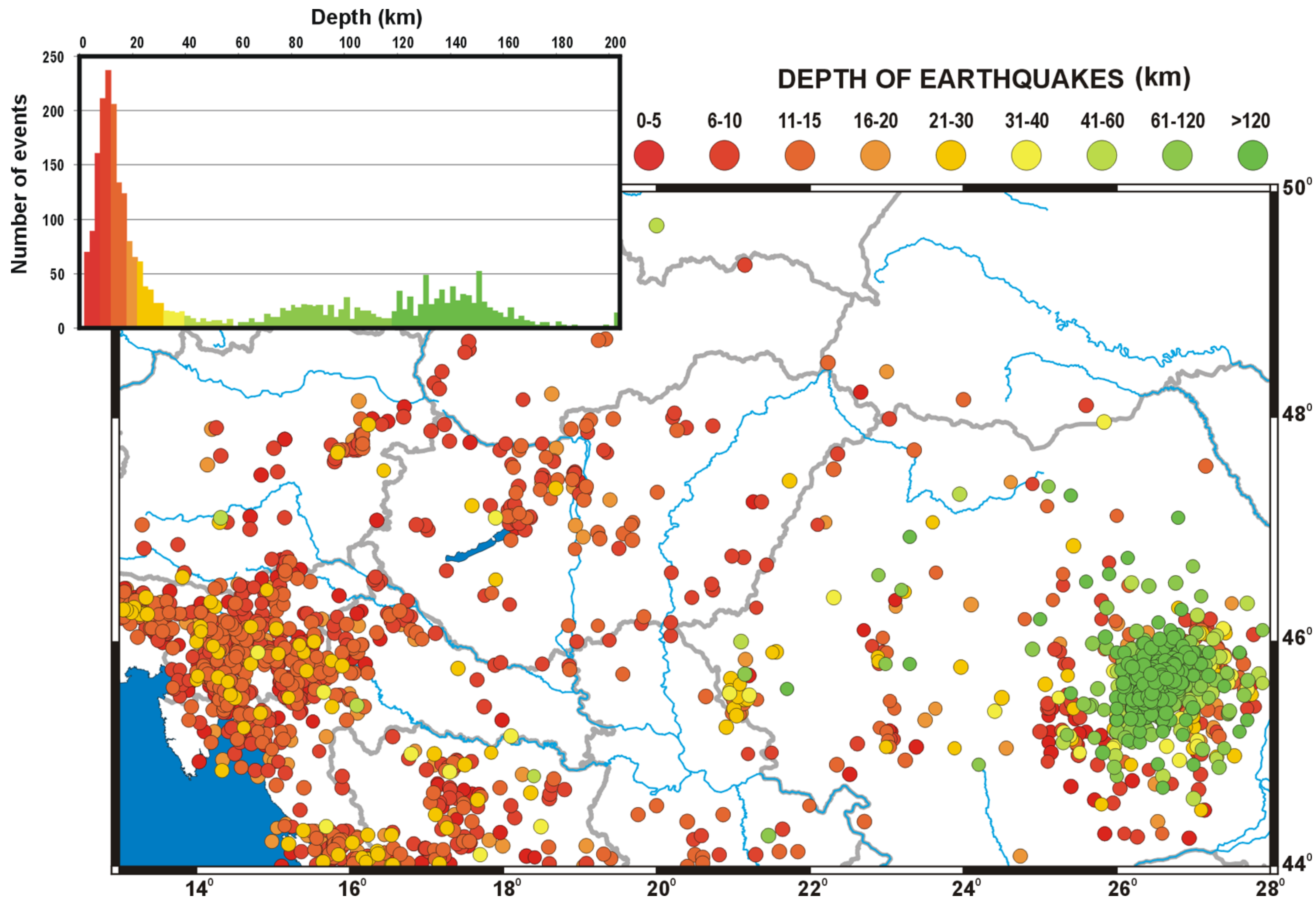

Fig. 5. Hypocenter depth distribution of earthquakes in the Pannonian Region and its surroundings (44.0–50.0 N; 13.0–28.0 E). More than 80% of all earthquakes occur in three different depth provinces. Shallow depth (6–15 km) in the upper crust is almost exclusive in the whole region except the Vrancea zone in the Eastern Carpathians, where intermediate depth seismicity is definitive; strong earthquakes occur either in the 70–110 km or 125–160 km depth domains.

of waves recorded by seismographs. Owing to the narrow dynamic range of early seismographs, it was often impossible to measure the maximum amplitude of strong seismic movements, and the magnitude determination by duration was a useful and simple way of overcoming this problem. Bisztricsány (1958) proposed the use of the duration of the surface-wave train for the determination of magnitude and obtained the following formulae for Wiechert seismographs at the Budapest station, for shallow and deeper shocks respectively:

$$M_D = \left\{ \begin{array}{l} 2.12 \log(F - eL) + 0.0065\Delta + 2.66 \\ 1.58 \log(F - eL) + 0.0020 + 0.0007\,h + 4.02 \end{array} \right\}$$

where F and eL are the end and commencement times in minutes of the recorded surface waves, Δ is the epicentral distance in degrees and M_D is the duration magnitude. The method has been adopted at many seismological stations (Willmore, 1979).

In order to estimate the magnitudes for historical earthquakes relationships have been developed by Zsíros (2000b) between "macroseismic" magnitude (M) and epicentral intensity (I_0).

For the whole Pannonian Region (with the exception of the Vrancea area):

$$M = 0.68\,(\pm 0.02)\,I_0 + 0.96\,(\pm 0.07)\log h - 0.91\,(\pm 0.10)$$
$$\{n = 514,\ I_0 = III - X,\ M = 0.6 - 6.2,\ h = 1 - 65\}$$

For the Vrancea section:

$$M = 0.52\,(\pm 0.02)\,I_0 + 0.55\,(\pm 0.11)\log h - 1.18\,(\pm 0.20)$$
$$\{n = 514,\ I_0 = II - IX,\ M = 2.4 - 7.3,\ h = 1 - 200\}$$

where M is magnitude, I_0 epicentral intensity, and h is focal depth in km. Number of observations (n), intensity, magnitude and depth intervals are listed in brackets.

Statistical relations have been developed between different magnitudes

$$M_S = 1.03\,(\pm 0.02)\,M - 0.20\,(\pm 0.10)$$
$$\{n = 186,\ M_S = 2.0 - 7.0,\ M = 2.0 - 6.8\}$$

$$M_S = 0.97\,(\pm 0.05)\,M_B + 0.04\,(\pm 0.24)$$
$$\{n = 127,\ M_S = 2.5 - 7.0,\ M_B = 2.1 - 6.4\}$$

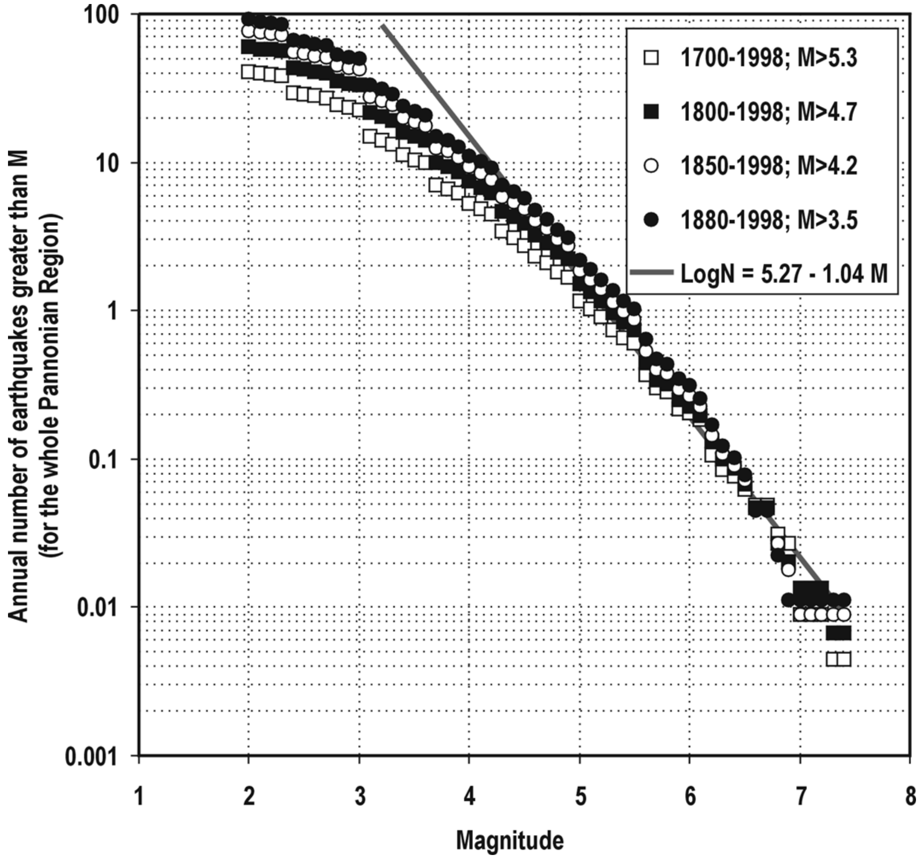

Fig. 6. Magnitude recurrence relationship for the whole earthquake data set (44.0–50.0 N; 13.0–28.0 E) in the conventional form proposed by Gutenberg and Richter (1949). The annual number (expressed as a log to the base 10) of earthquakes greater than magnitude M is plotted as a function of that magnitude.

$$M_S = 0.86\,(\pm 0.06)\,M_L + 0.57\,(\pm 0.27)$$
$$\{n = 97,\, M_S = 2.0 - 7.0,\, M_L = 2.0 - 6.6\}$$

$$M_S = 1.21\,(\pm 0.11)\,M_D 1.23\,(\pm 0.52)$$
$$\{n = 27,\, M_S = 2.3 - 6.9,\, M_D = 2.8 - 6.5\}$$

$$M_B = 0.59\,(\pm 0.05)\,M_L + 1.75\,(\pm 0.22)$$
$$\{n = 259,\, M_B = 2.6 - 6.4,\, M_L = 2.1 - 6.6\}$$

$$M_B = 0.90\,(\pm 0.08)\,M_D + 0.20\,(\pm 0.32)$$
$$\{n = 160,\, M_B = 2.6 - 6.3,\, M_D = 3.2 - 6.5\}$$

$$M_L = 1.14\,(\pm 0.02)\,M_D 0.69\,(\pm 0.06)$$
$$\{n = 894,\, M_L = 0.8 - 5.5,\, M_D = 1.4 - 5.6\}$$

where M, M_S, M_B, M_L, and M_D are “macroseismic” magnitude, surface wave magnitude, body wave magnitude, local magnitude and duration magnitude, respectively. Number of observations (n) and magnitude intervals are listed in brackets.

Instead of using a single intensity value I_0 for magnitude estimation, Ambraseys and Melville (1982) proposed to plot areas within isoseismal IV (A_{IV}) against instrumental surface wave magnitudes (c). For those Pannonian Basin earthquakes where both of the above parameters exist, Ove Arup & Partners (1995) performed a linear regression analysis and concluded that:

$$M_S = 0.97 \log A_{IV} + 0.90\,(\sigma = 0.29)$$

A simple linear regression between measured surface wave magnitudes (M_S) and epicentral intensity (I_0) for the whole catalogue events, where both M_S and I_0 exist, gives:

$$M_S = 0.74 I_0 - 0.28\,(\sigma = 0.30)$$

The estimated macroseismic magnitude (M) and surface wave magnitude (M_S) values, calculated either directly from I_0 or though A_{IV}, are generally quite similar, but tend to deviate somewhat at higher values.

To estimate the completeness of the catalogue in different time intervals, magnitude regression has been carried out for all reported events and is displayed in Fig. 6. The catalogue is considered to be complete for earthquakes larger than M 6.4 since 1500, for earthquakes larger than M 5.8 since 1600, for earthquakes larger than M 4.7 since 1800 and for earthquakes larger than M 4.2 since 1850. For magnitudes greater than 3.5 the catalogue appears to be well de-

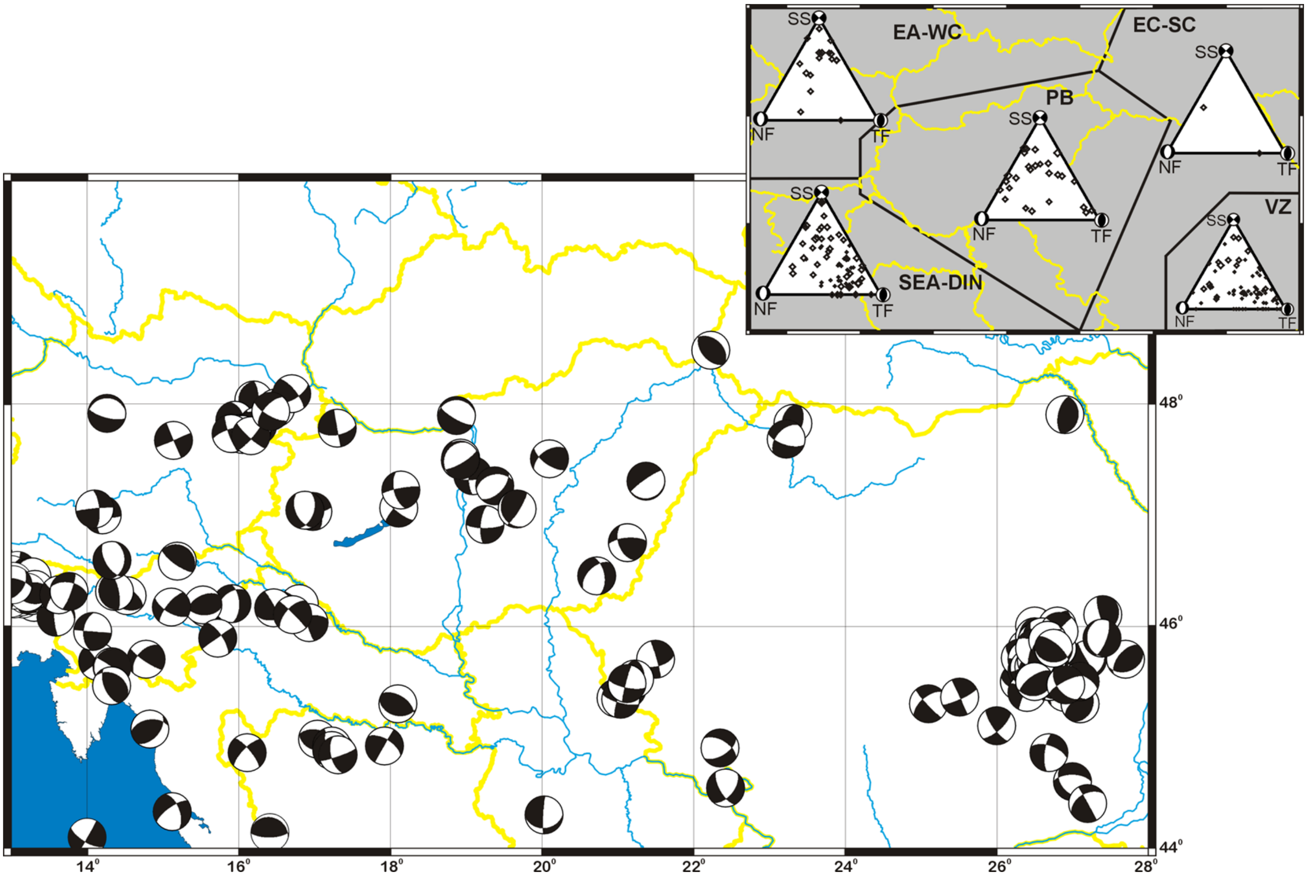

Fig. 7. Focal mechanism solutions for the Pannonian Region. Lower hemisphere stereographic projection is displayed with the compressional quadrants darkened for each mechanism. Summary of solution types such as strike-slip (SS), normal (NF) or thrust fault (TF) are shown in triangle diagrams for each tectonic domain. PB: Pannonian Basin; VZ: Vrancea zone; SEA-DIN: Southeastern Alps and Dinarides; EA-WC: Eastern Alps and Western Carpathians; EC-SC: Eastern Carpathians and Southern Carpathians.

fined since 1880. The conventional logarithmic relation between the annual number of earthquakes N and the magnitude M proposed by Gutenberg and Richter (1949) results in:

$$\log N = 5.27\,(\pm 0.11) - 1.04\,(\pm 0.02)\,M$$
$$\{\text{for } M = 3.5 - 7.3\}$$

Based on the magnitude recurrence parameters, altogether the Pannonian Region can be characterized as a seismically reasonably active area with significant variation of seismicity among different tectonic domains. The seismicity rate of the Vrancea region in the Southeast Carpathians is rather high, where strong (M>6) earthquakes occur quite frequently, with typical ground displacements of 30 cm and peak accelerations on the order of 0.3 g. Within the last two decades three events were detected with magnitudes larger than 6.5, while magnitude 5.0 earthquakes occur on an almost yearly basis.

In the seismically less active Pannonian Basin area, according to observations since 1880, the return period of magnitude 6 earthquake is about 20 years, while magnitude 5 events occurs every 3.6 years on average. Based on recordings for the last 4 years, the average annual number of magnitude 3 earthquakes is 2.3, whilst of magnitude 2 events it is 8.6 (Tóth et al., 1998b).

6 Focal mechanisms

Describing the type of fault, associated movement and main stress directions for a given earthquake focal mechanism solutions provides valuable information for understanding the current stress regime and construction of tectonic models of an area. The double-couple origin of earthquake motions divides the area around the earthquake focus into quadrants revealing different directions of motion. Two planes separate the quadrants, the real fault plane and an indistinguishable auxiliary plane. The object of finding an earthquake focal mechanism is to describe the orientations of these planes. Although there have been attempts to derive focal mechanism information of major historical earthquakes, a reliable fault plane solution inevitably requires good quality records at several seismograph stations with azimuthally good coverage.

Until early 1990s only limited good quality earthquake data were available to yield reliable focal mechanism solutions in the studied area, due to the relatively low frequency of larger earthquakes, on one hand, and to the rather poor station coverage, on the other. In the Pannonian Basin the situation was even worse – only a few earthquakes were strong

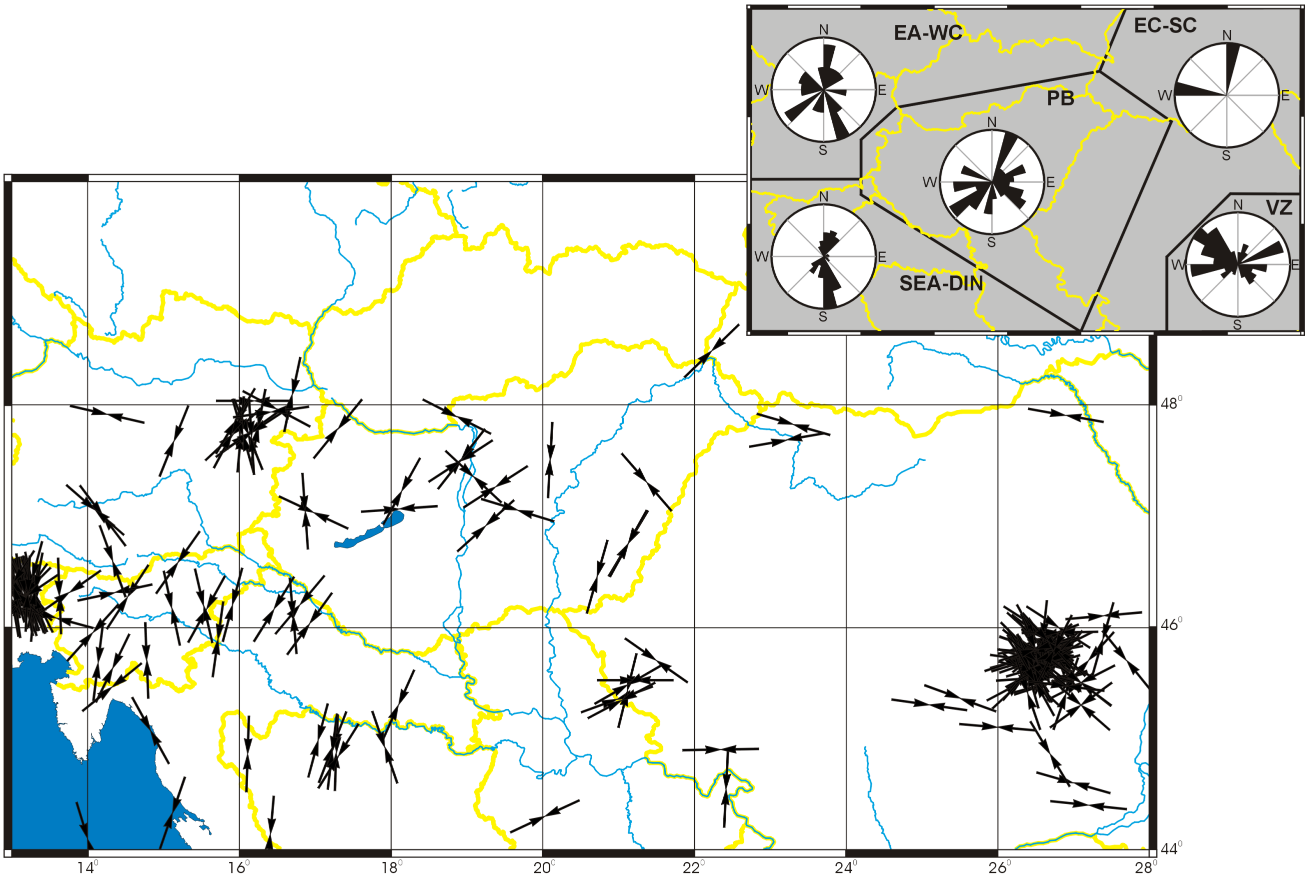

Fig. 8. Maximum horizontal stress directions (S_{HMAX}) derived from earthquake focal mechanism solutions in the Pannonian Region. Rose diagrams show distribution of directions weighted by a quality factor in each tectonic domain. The applied weighting factors are 1, 1, 0.8, 0.7 and 0.3 for classes A, B, C, D and E, respectively. PB: Pannonian Basin; VZ: Vrancea zone; SEA-DIN: Southeastern Alps and Dinarides; EA-WC: Eastern Alps and Western Carpathians; EC-SC: Eastern Carpathians and Southern Carpathians.

enough to product focal mechanism solutions. During the last decade, with the installation of sensitive local seismic networks in various countries (e.g. Tóth et al., 1998b), the situation has changed substantially. Nowadays, magnitude 2–3 earthquakes are good candidates, and magnitude 4 events usually result reliable focal mechanism solutions.

In the Pannonian Basin area Csomor (1966) published the first focal mechanism solution for the 1956 Dunaharaszti earthquake. Using P-wave polarity readings from 10 inadequately distributed stations with 282° azimuthal gap he concluded strike-slip mechanism with nearly vertical nodal planes striking N-S and E-W. Repeated computation based on 26 more soundly distributed arrivals by Mónus et al. (1988) resulted basically in the same nodal planes, but a NW-SE principal stress axis instead of the NE-SW given earlier. Tóth et al. (1989) published a well constrained solution for the Berhida (Hungary) earthquake of 1985, m_B 4.7, based on 88 observations and concluded nearly pure strike-slip character with E-W principal stress axis. Gangl (1975) studied five focal solutions from the Vienna Basin. For larger Vrancea earthquakes a number of focal mechanism solutions have been published by different authors (e.g. Fara, 1964; Ritsema, 1974; Oncescu, 1987).

Gerner (1995) catalogued earthquake focal mechanism solutions for the Pannonian Region, partly collected from the literature and partly based on new calculations. In the framework of the international World Stress Map Project (Müller, 1997), different types of stress information, together with focal mechanism solutions, have been stored in a standardised way. Even for smaller magnitude local earthquakes, regular focal mechanism computation has been started and published in annual bulletins (Tóth et al., 1999) since 1995.

The data set of focal mechanisms used in the present study consists of those collected and catalogued from literature by Gerner (1995), new solutions for events from 1980 to 1993 by Gerner et al. (1999) and latest solutions for mainly Pannonian Basin events from 1995 to 1998 by Tóth et al. (1996, 1997, 1998, 1999).

Until the end of 1998, altogether 190 different carefully revised and qualified solutions are available in our focal mechanisms database for the studied area bounded by 44.0–50.0 N latitudes and 13.0–28.0 E longitudes. The parameters of focal mechanisms are given by orientation of nodal planes and main axes (angles of strike, dip and rake) followed the convention by Aki and Richards (1980). Using the Zoback and Zoback (1991) definition for quality designation (A, B, C, D or E, where A is better quality than E) 1, 4, 26, 24 and 45% of the database entries have been ranked to classes A, B, C, D and E, respectively.

To summarize and display similarity or diversity of focal mechanisms in a tectonic unit triangle diagrams developed by Fröhlich (1992) have been used. This diagram displays the fractional portions of thrust-faulting, strike-slip faulting and normal faulting of each focal mechanism. Based on apriory seismicity and seismotectonic information, five regions (the Southeastern Alps and Dinarides, Eastern Alps and Western Carpathians, Pannonian Basin, Vrancea zone and Eastern and Southern Carpathians) have been selected in the studied area to characterize faulting mechanisms (Fig. 7).

Largest horizontal stress directions S_{HMAX} have been calculated using P, B and T axes of fault plane solutions (Fig. 8). Azimuth of P axes have been taken as the largest horizontal stress directions, if the plunge of P is less than 35° from horizontal. Otherwise azimuth of T+90° or B is used, depending on the plunge of B and T axes according to Zoback (1992). Directions of largest horizontal stresses are summarized for each of the seven tectonic regions on rose diagrams using a quality dependent weighting factor (1, 1, 0.8, 0.6, and 0.2 for classes A, B, C, D and E, respectively).

In the Southern Alps and in the Dinarides, seismicity is rather high, and quite a number of fault plane solutions are available. Strike-slip and thrust faulting is almost exclusive in this region. The maximum horizontal stress direction obviously shows N-S and NNE-SSW compression what can be explained by the collision of the Adriatic micro plate with Europe.

Moderately active seismicity is observed in the Eastern Alps and Western Carpathians. Focal mechanism solutions are available mostly from the Vienna Basin area, presenting exclusively strike-slip character. The NNW-SSE and N-S directions of the largest horizontal stresses are most frequent, but NE-SW direction has also occurred.

In the Pannonian Basin, the picture that can be inferred from the relatively few available focal mechanism solutions is more diffuse, however thrust and strike-slip faulting seem to be dominant. The NNE-SSW and NE-SW directions of maximum horizontal stresses are typical, highlighting significant differences from the Western European tectonic domain where the dominant stress direction is exactly perpendicular to this.

Very few fault plane solutions are available from the area of the Eastern and Southern Carpathians indicating thrust faulting mechanisms and E-W dominant stresses.

Most of the events in the Vrancea area occur in a compressive regime with thrust tectonics at intermediate depth. The fault plane solutions of the large, instrumentally recorded earthquakes show a remarkably similar character. They typically strike SW-NE and dip to the NW. The horizontal stress component characteristically displays NW-SE and, in fewer cases, E-W directions.

7 Dynamic source parameters

Dynamic source parameters derived from P-wave displacement spectra of 12 earthquakes (M_L range from 2.4 to 5.0) in the Pannonian Basin (Badawy et al., 2001) indicate rather low value of corner frequency ranging between 2.5 and 10 Hz. The seismic moments range from 1.5×10^{20} to 1.3×10^{23} dyne cm, stress drops from 0.25 to 76.75 bar, fault length from 0.42 to 1.7 km and relative displacement from 0.05 to 15.35 cm. The relatively small values of stress drops can be attributed to the low strength of crustal materials in the Pannonian Basin.

8 Conclusions

A comprehensive earthquake catalogue has been developed, listing of more than twenty thousand historical and instrumentally recorded earthquakes throughout the Pannonian Region bounded by 44.0–50.0 N latitude and 13.0–28.0 E longitude. The catalogue is considered to be complete for earthquakes larger than M 6.4 since 1500, for earthquakes larger than M 5.8 since 1600, for earthquakes larger than M 4.7 since 1800, for earthquakes larger than M 4.2 since 1850 and for magnitudes greater than 3.5 since 1880.

Epicenter distribution map of the catalogue suggests that the most active parts of the area are the Carpathian and Dinaric tectonic belt and the Vrancea region in the Southeast Carpathians. Seismicity in the Pannonian Basin is more moderate compared to the peripherals, and the distribution of earthquake epicenters shows a rather scattered pattern – however, at several individual locations earthquakes occur repeatedly.

Distribution of focal depths suggests three depth provinces where most of the events have taken place. Shallow depth within the top 20 km of the earth's crust is almost exclusive in the whole region except the Vrancea zone in the Eastern Carpathians. In the Pannonian Basin area, the majority of events occur primarily between 6 and 15 km below ground level. The earthquakes of the Vrancea region are characterized by intermediate depth seismicity. Strong earthquakes occur either in the 70–110 km or 125–160 km depth domains.

Inferred from focal mechanism solutions, strike-slip and thrust faulting are almost exclusive in the Southern Alps and in the Dinarides, with the maximum horizontal stress directions being N-S and NNE-SSW. In the Eastern Alps and Western Carpathians focal mechanism solutions exhibit an exclusively strike-slip character; with NNW-SSE and N-S directions of the largest horizontal stresses most frequent. In the Pannonian Basin, thrust and strike-slip faulting seem to be dominant, with NNE-SSW and NE-SW directions of maximum horizontal stresses. The very few fault plane solutions available from the Eastern and Southern Carpathians indicate thrust faulting mechanisms and E-W dominant stresses. Strong earthquakes in the Vrancea area occur in a compressive regime with thrust tectonics. The horizontal stress component demonstrates NW-SE and E-W directions.

Table 1
List of major (M≥5.5) earthquakes in the Pannonian Region (44.0-50.0N; 13.0-28.0E) from 456 A.D. until 1998. References for each events can be found in Zsíros (2000) where 1453 different sources are listed.

No	Date			Time			Location			Depth	Magnitude	Intensity		Name
	yy	mm	dd	h	m	s	Lat (N)	Long (E)	Q	km	M	EMS		
1	456	09	07				47.24	16.62	na		6.3	9.0	> +/- 1	Savaria
2	567	00	00				45.60	15.30	>+/-50km		6.3	9.0	na	Croatia
3	984	00	00				47.00	19.00	>+/-50km		5.6	8.0	> +/- 1	Hungary
4	1000	01	00				46.06	14.51	>+/-50km		5.6	8.0	na	Ljubljana
5	1038	08	15				47.00	19.00	>+/-50km		5.6	8.0	> +/- 1	Hungary
6	1091	00	00				45.70	26.60	>+/-50km		5.9	7.0	na	Vrancea
7	1092	07	06				48.00	21.00	>+/-50km		5.6	8.0	> +/- 1	Hungary
8	1097	00	00				45.60	15.30	>+/-50km		6.3	9.0	na	Croatia
9	1100	00	00				47.00	18.00	>+/-50km		5.6	8.0	> +/- 1	Dunántúl
10	1107	02	12	03			45.70	26.60	>+/-50km		5.9	7.0	na	Vrancea
11	1122	10	00				45.70	26.60	>+/-50km		5.6	6.5	na	Vrancea
12	1126	08	08				45.70	26.60	>+/-50km		5.9	7.0	na	Vrancea
13	1196	02	13	07			45.70	26.60	>+/-50km		6.4	8.0	> +/- 1	Vrancea
14	1201	05	04	14			47.10	14.20	na		6.6	9.5	na	Murau
15	1230	05	10	07			45.70	26.60	>+/-50km		6.7	8.5	> +/- 1	Vrancea
16	1267	05	08	02			47.51	15.45	>+/-50km		5.6	8.0	na	Kindberg
17	1279	04	24	19			45.93	13.40	>+/-50km		5.6	8.0	na	Friuli
18	1287	06	23				47.00	19.00	>+/-50km		5.6	8.0	> +/- 1	Hungary
19	1323	00	00				45.20	14.70	>+/-50km		6.3	9.0	na	Croatia
20	1327	00	00				45.70	26.60	>+/-50km		6.4	8.0	na	Vrancea
21	1343	06	30				44.00	15.00	>+/-50km		6.3	9.0	na	Croatia
22	1348	01	25				46.50	13.45	<+/-20km		6.6	9.5	na	Villach
23	1366	06	03				50.00	13.00	>+/-50km		5.6	8.0	na	Bohemia
24	1386	00	00				44.20	17.70	>+/-50km		6.3	9.0	na	Bosnia
25	1389	08	20	11			46.43	13.18	>+/-50km		5.6	8.0	na	Moggio Udinese
26	1418	04	07				44.00	15.00	>+/-50km		6.3	9.0	na	Croatia
27	1443	06	05				48.60	18.86	<+/-20km		5.6	8.0	+/- 1	Zólyom
28	1444	08	04				46.26	20.15	na		5.6	8.0	> +/- 1	Szeged
29	1446	10	10				45.70	26.60	>+/-50km		6.7	8.5	na	Vrancea
30	1459	05	20				46.30	16.30	na		6.3	9.0	na	Croatia
31	1471	08	29	11			45.70	26.60	na		6.4	8.0	> +/- 1	Vrancea
32	1473	08	29				45.60	26.00	na		5.9	7.0	> +/- 1	Barcaság
33	1502	03	26	13			45.80	16.10	na		6.3	9.0	na	Croatia
34	1505	00	00				45.00	15.50	na		6.3	9.0	na	Croatia
35	1510	00	00				46.10	14.50	na		6.3	9.0	na	Croatia
36	1511	03	26	14			46.10	14.00	na	15	7.0	10.0	na	Idrija-Cerkno
37	1511	06	26	21			46.00	14.03	na		5.6	8.0	na	Idrija
38	1511	08	08				46.00	14.00	na		6.3	9.0	na	Idrija-Cerkno
39	1516	11	24	12			45.70	26.60	na		6.9	9.0	na	Mt. Háromszék
40	1523	06	09				45.70	26.60	na		5.9	7.0	na	Mt. Háromszék
41	1543	00	00				45.70	26.60	na		5.9	7.0	na	Mt. Háromszék
42	1545	07	19				45.70	26.60	na		6.4	8.0	na	Mt. Háromszék
43	1556	01	24				48.00	15.00	>+/-50km		5.6	8.0	> +/- 1	Western Hungary
44	1561	02	12				47.50	19.05	na		5.6	8.0	> +/- 1	Pest-Buda
45	1569	08	17	05			45.70	26.60	na		6.4	8.0	na	Mt. Háromszék
46	1571	04	10	07			45.60	26.00	na		5.9	7.0	> +/- 1	Barcaság

Table 1 (Cont.)

47	1571 05 19	17	45.60	26.00	na		5.9	7.0	> +/- 1	Barcaság
48	1574 08 14		45.40	14.10	na		5.6	8.0	na	Croatia
49	1578 04 01		45.70	26.60	na		5.9	7.0	na	Mt. Háromszék
50	1585 01 01		47.50	16.30	>+/-50km		5.6	8.0	> +/- 1	Western Hungary
51	1590 08 10	20	45.70	26.60	na		6.7	8.5	na	Mt. Háromszék
52	1590 09 15	23	48.28	16.11	<+/-20km		6.3	9.0	na	Katzelsdorf
53	1590 09 22		45.60	26.00	na		5.9	7.0	> +/- 1	Barcaság
54	1595 04 21	11	45.60	26.00	na		6.4	8.0	> +/- 1	Barcaság
55	1596 04 16		45.70	26.60	>+/-50km		5.6	6.5	na	Vrancea
56	1598 11 22	02	45.70	26.60	na		5.9	7.0	na	Mt. Háromszék
57	1599 08 04		45.70	26.60	na		5.9	7.0	na	Mt. Háromszék
58	1599 10 01	08	47.76	18.12	>+/-50km		5.6	8.0	> +/- 1	Komárom
59	1604 05 03	03	45.70	26.60	na		6.4	8.0	na	Mt. Háromszék
60	1605 12 24	15	45.70	26.60	na		6.4	8.0	na	Vrancea
61	1606 01 13	02	45.70	26.60	na		6.2	7.5	na	Mt. Háromszék
62	1613 11 16	11	49.22	18.74	>+/-50km		5.6	8.0	> +/- 1	Zsolna
63	1620 11 08	13	45.80	26.60	na		6.7	8.5	na	Vrancea
64	1620 12 00		45.70	26.60	na		6.2	7.5	na	Vrancea
65	1628 06 17	18	45.97	15.48	<+/-20km		5.6	8.0	na	Krsko-Brestanica
66	1637 02 01	01 30	45.70	26.60	na		6.2	7.5	na	Vrancea
67	1640 00 00		45.90	15.60	<+/-20km		6.3	9.0	na	Brezice
68	1645 06 28		45.60	15.40	na		5.6	8.0	na	Croatia
69	1648 00 00		44.98	14.90	na		5.6	8.0	na	Croatia
70	1650 04 19		45.70	26.60	>+/-50km		5.9	7.0	na	Vrancea
71	1660 02 08	01	45.70	26.60	na		5.6	6.5	na	Vrancea
72	1666 02 00		45.70	26.60	na		5.6	6.5	na	Mt. Háromszék
73	1681 08 19	01	45.70	26.60	na		6.4	8.0	> +/- 1	Vrancea
74	1689 03 10		45.97	14.85	na		5.6	8.0	na	Slovenia
75	1689 05 10	03	45.97	14.85	<+/-20km		5.6	8.0	na	Temenice
76	1690 12 04	15 45	46.60	13.80	<+/-20km		5.9	8.5	na	Villach
77	1697 03 15		45.63	15.46	na		5.6	8.0	na	Croatia
78	1699 02 11		45.65	15.32	<+/-20km		5.6	8.0	na	Metlika
79	1701 06 12	00	45.70	26.60	na		6.2	7.5	na	Vrancea
80	1711 10 11	01	45.70	26.60	na		5.9	7.0	na	Mt. Háromszék
81	1721 01 12		45.30	14.40	na		6.3	9.0	na	Croatia
82	1730 00 00		45.70	26.60	na		6.4	8.0	> +/- 1	Vrancea
83	1738 06 11	10	45.70	26.60	na	109	6.7	8.5	na	Vrancea
84	1739 02 04		44.00	21.30	na		6.3	9.0	na	Svetozarevo
85	1739 12 20	15 24	45.19	19.81	na		5.6	8.0	na	Ledinci
86	1740 04 05	20	45.70	26.60	na		5.6	6.5	na	Mt. Háromszék
87	1746 12 07	01	45.60	26.00	na		5.9	7.0	> +/- 1	Barcaság
88	1757 07 08	03	45.83	17.39	na		5.6	8.0	na	Mt. Bilo
89	1763 06 28	04 30	47.76	18.12	<+/-20km		6.3	9.0	+/- 1	Komárom
90	1768 02 27	01 45	47.82	16.20	<+/-10km		5.6	8.0	na	Bécsújhely
91	1778 01 18	05 45	45.70	26.60	na		5.9	7.0	+/- 1	Háromszék
92	1778 11 08	19 30	46.20	16.80	na		5.6	8.0	na	Croatia
93	1784 03 18		46.02	25.59	na		5.9	7.0	+/- 1	Miklósvár
94	1786 02 27	03	49.70	18.50	na	38	5.7	7.5	na	Silesia
95	1786 12 03	16	49.67	19.86	na	42	5.7	7.5	na	Poland
96	1787 01 18		45.70	26.60	>+/-50km		5.9	7.0	na	Mt. Háromszék
97	1788 10 20		46.38	13.02	na		5.9	8.5	na	Tolmezzo
98	1788 11 22	10 30	45.20	19.90	na		5.6	8.0	> +/- 1	Serbia

Table 1 (Cont.)

99	1790	01	26	07	30		46.42	13.02	<+/-20km		6.3		9.0	na	Tolmezzo
100	1790	00	00				46.40	13.00	<+/-20km		5.9		8.5	na	Tolmezzo
101	1790	04	06	20			45.70	26.60	na	74	6.4		8.0	na	Vrancea
102	1793	12	08	18			45.70	26.60	na		6.4		8.0	na	Mt. Háromszék
103	1794	02	06	12	18		47.38	15.09	na		5.6		8.0	na	Leoben
104	1802	01	03	06	30		45.40	14.30	na		5.6		8.0	na	Croatia
105	1802	10	26	11	25		45.70	26.60	na		7.2		9.5	na	Mt. Háromszék
106	1812	03	05	12	30		45.70	26.60	na		5.9		7.0	na	Mt. Háromszék
107	1813	02	01				45.70	26.60	na		5.9		7.0	> +/- 1	Mt. Háromszék
108	1821	02	09	01	30		45.70	26.60	na		5.6		6.5	na	Mt. Háromszék
109	1821	11	17	13	45		45.70	26.60	na		5.6		6.5	na	Vrancea
110	1829	11	26	02	40		45.70	26.60	na		6.4		8.0	+/- 1	Vrancea
111	1834	10	15	06	30		47.53	22.31	<+/-10km	13	6.3		9.0	+/- 1	Érmellék
112	1835	04	21	20	30		45.70	26.60	na		5.9		7.0	na	Vrancea
113	1838	01	23	19	30		45.70	26.60	na		6.9		9.0	na	Mt. Háromszék
114	1838	02	10	03	55		45.70	26.60	na		5.9		7.0	> +/- 1	Mt. Háromszék
115	1858	01	15	19	15		49.22	18.74	<+/-10km		5.6		8.0	+/- 1	Zsolna
116	1862	10	16	01	11		45.70	26.60	na		5.6		6.5	na	Mt. Háromszék
117	1868	11	13	07	45		45.70	26.60	na		6.2		7.5	na	Mt. Háromszék
118	1868	11	27	21	35		45.70	26.60	na		5.9		7.0	na	Mt. Háromszék
119	1869	01	10	19	30		45.70	26.60	na		5.9		7.0	> +/- 1	Vrancea
120	1870	03	01	19	57		45.33	14.44	na		5.6		8.0	na	Fiume
121	1872	01	23	21	10		45.70	26.60	na		5.9		7.0	> +/- 1	Mt. Háromszék
122	1878	09	23	20	20		45.00	14.90	na		5.6		8.0	na	Croatia
123	1880	11	09	06	33	53	45.82	15.98	<+/-20km	13	6.3		9.0	+/- 1	Zágráb
124	1880	12	25	15	30		45.70	26.60	na		5.9		7.0	na	Vrancea
125	1893	04	08	13	46		44.12	21.36	<+/-20km	15	6.3		9.0	+/- 1	Serbia
126	1893	05	20	20	42		44.30	21.20	na		5.6		8.0	na	Serbia
127	1893	08	17	14	35		45.70	26.60	na	108	5.9		7.0	na	Vrancea
128	1893	09	10	03	40		45.70	26.60	na		5.6		6.5	na	Vrancea
129	1894	03	04	06	35		46.07	26.65	na		5.9		7.0	na	Mt. Háromszék
130	1894	08	31	12	20		45.70	26.60	na		5.9		7.0	na	Mt. Háromszék
131	1895	04	14	22	17	30	46.11	14.50	<+/-20km	22	6.2		8.5	na	Ljubljana
132	1895	06	21	10			44.10	20.10	na		5.6		8.0	> +/- 1	Serbia
133	1903	09	13	08	02	41	45.12	26.54	na		6.1	+	6.5	na	Mt. Háromszék
134	1904	02	06	02	49		45.70	26.60	na	75	5.7	+	6.0	na	Vrancea
135	1905	12	17	22	16	33	45.82	15.98	<+/-20km	7	5.6	+	7.5	na	Zágráb
136	1906	01	02	04	26	36	45.92	16.10	<+/-20km	10	6.1	+	8.0	na	Zágráb
137	1906	01	09	23	05		48.59	17.46	<+/-20km	10	5.7	+	8.0	+/- 1	Jókő
138	1906	10	16	23	25		46.60	27.40	na		5.5	+	5.0	na	Moldavia
139	1908	10	06	21	39	48	45.50	26.50	na	78	6.8	+	8.0	na	Mt. Háromszék
140	1909	01	13	00	45		45.00	13.00	na		5.6	+		na	Adriatic
141	1909	10	08	09	59	7	45.48	16.09	<+/-20km	12	6.0	+	8.5	na	Vratecko
142	1911	07	08	01	02		46.91	19.69	<+/-20km	12	5.6	+	8.0	+/- 1	Kecskemét
143	1912	05	25	18	01	42	45.70	27.16	na	80 +	6.0	+	7.0	na	Moldavia
144	1912	05	25	20	15		45.70	27.16	na	80 +	6.2	+	6.0	na	Moldavia
145	1912	05	25	21	15		46.01	27.29	na	80 +	6.0	+	5.0	na	Moldavia
146	1913	03	14	03	40		45.60	27.39	na		5.6	+	5.0	na	Vrancea
147	1916	01	26	07	37	54	45.44	24.54	na		6.4	+	9.0	+/- 1	Mt. Fogaras
148	1916	03	12	03	23	59	45.10	14.81	na	12	5.8	+	8.0	na	Croatia
149	1917	01	29	08	22	55	45.90	15.57	<+/-20km	5	5.6	+	8.0	na	Brezice
150	1917	07	11	03	23	55	45.70	26.60	na		5.5	+	6.0	na	Mt. Háromszék

Table 1 (Cont.)

151	1918	11	06	19	26	8	46.17	14.37	<+/-10km		5.5	+	5.0	na	Slovenia
152	1922	03	24	12	22	14	44.40	20.40	<+/-10km	6	6.0	+	9.0	na	Serbia
153	1926	01	01	18	04	3	45.77	14.37	<+/-20km	13	5.6	+	7.5	na	Cerknica
154	1927	05	15	02	47	22	44.14	20.50	<+/-10km	9	5.9	+	9.0	na	Rudnik
155	1928	03	27	02	32	30	46.35	13.00	na		6.0	+	9.0	na	Friuli
156	1929	11	01	06	57	25	45.90	26.50	na	160 +	6.2	+	6.5	na	Háromszék
157	1934	03	29	20	06	51	45.80	26.50	na	90 +	6.6	+	8.0	na	Vrancea
158	1934	11	30	02	58	16	44.10	14.00	na		5.6	+		na	Croatia
159	1935	09	05	06	00		45.80	26.70	na	150 +	5.5		6.0	na	Vrancea
160	1939	09	05	06	02	0	45.90	26.70	na	115 +	5.9	+		na	Vrancea
161	1940	06	24	09	57	27	45.90	26.60	na	115 +	5.5	+	5.5	na	Mt. Háromszék
162	1940	10	22	06	36	57	45.76	26.42	na	122 +	6.4	+	7.0	na	Háromszék
163	1940	11	10	01	39	7	45.77	26.73	na	133 +	7.3	+	9.0	na	Mt. Háromszék
164	1940	11	11	06	34	16	46.00	26.80	na		5.6	+	6.0	na	Mt. Háromszék
165	1940	11	19	20	27	12	46.00	26.50	na		5.7	+	6.0	na	Mt. Háromszék
166	1943	04	28	20	46	50	45.80	27.10	na	66 +	5.5	+	6.0	na	Moldavia
167	1945	03	12	20	51	47	45.60	26.40	na	125 +	5.6	+	6.0	na	Mt. Háromszék
168	1945	09	07	15	48	26	45.90	26.50	na	75 +	6.5	+	7.5	na	Vrancea
169	1945	12	09	06	08	46	45.70	26.80	na	80 +	6.1	+	7.0	na	Vrancea
170	1946	11	03	18	46	59	45.60	26.30	na	140 +	5.5	+	6.0	na	Mt. Háromszék
171	1947	10	17	13	25	20	45.70	26.60	na		5.8	+		na	Mt. Háromszék
172	1948	05	29	04	48	58	45.80	26.50	na	140 +	5.9	+	6.5	na	Mt. Háromszék
173	1950	06	20	01	18	49	45.69	26.72	na	160 +	5.5	+	6.0	na	Vrancea
174	1956	01	12	05	46	9	47.37	19.07	<+/-10km	14 +	5.6	+	8.0	+/- 1	Dunaharaszti
175	1960	02	17	15	32	50	45.57	14.25	<+/-20km		5.5	+	6.0	na	Il. Bistrica
176	1960	10	13	02	21	25	45.70	26.40	na	160 +	5.5	+	6.0	na	Mt. Háromszék
177	1964	04	13	08	30	29	45.26	18.14	na	27	5.6	+	8.0	na	Croatia
178	1968	05	30	18	15	47	45.40	17.00	na		5.8	+		na	Croatia
179	1969	10	27	08	10	58	44.85	17.22	<+/-10km	14	5.9	+	8.0	na	Bosnia
180	1974	04	17	01	31	34	45.94	21.19	<+/-10km	46 +	5.6	+	6.0	na	Varjas
181	1976	05	06	20	00	12	46.27	13.25	na	20 +	6.2	+	9.5	na	Friuli
182	1976	09	11	16	35	1	46.30	13.32	<+/-10km	9 +	5.6	+	9.0	na	Friuli
183	1976	09	15	03	15	19	46.27	13.15	<+/-10km	16 +	5.9	+	9.0	na	Friuli
184	1976	09	15	09	21	18	46.25	13.20	<+/-10km	21 +	5.8	+	8.5	na	Friuli
185	1977	03	04	19	21	54	45.77	26.76	<+/-5km	94 +	6.1	+	9.0	na	Vrancea
186	1981	08	13	02	58	13	44.85	17.33	<+/-5km	16 +	5.5	+	8.0	na	Bosnia
187	1986	08	30	21	28	36	45.54	26.31	<+/-5km	137 +	6.6	+	8.0	na	Mt. Háromszék
188	1990	05	30	10	40	6	45.85	26.66	<+/-5km	89 +	6.7	+	8.0	na	Mt. Háromszék
189	1990	05	31	00	17	48	45.81	26.77	<+/-5km	90 +	5.9	+		na	Vrancea
190	1991	07	18	11	56	31	44.90	22.41	<+/-5km	12 +	5.5	+	8.0	na	Orsova

Focal depth usually derived from intensity distribution, + indicates network determination
M - magnitude for historical events estimated from intensity, + indicates instrumental value (Zsíros, 2000)

Table 2
Focal mechanism solutions for the Pannonian Region (44.0-50.0N; 13.0-28.0E). The parameters of focal mechanisms are given by orientation of 1st nodal plane (angles of strike, dip and rake) and P and T axis (angles of azimuth and plunge) followed the convention by Aki and Richards (1980). Quality definition is given by quality designation (A, B, C, D or E, where A is better quality than E) as defined by Zoback and Zoback (1991). Source of data: No. 1 – 162 collected and catalogued from literature by Gerner (1995), new solutions for events from 1980 to 1993 by Gerner et al. (1999); latest solutions for mainly Pannonian Basin events from 1995 to 1998 (No. 163 – 190) by Tóth et al. (1996, 1997, 1998, 1999)

No.	Date	Time	Lat (N)	Long (E)	Plane 1			P axis		T axis		Qual.
					Srike	Dip	Rake	Azim	Plunge	Azim	Plunge	
1	1928.03.27	8:32:31	46.42	13.03	298	67	148	351	4	258	38	D
2	1929.11.01	6:57:21	45.90	26.60	171	60	106	249	14	116	70	E
3	1934.01.29		45.70	26.50	71	62	-146	287	43	197	1	E
4	1934.03.24		45.80	26.50	73	61	-145	289	44	199	1	E
5	1934.03.29	20:06:48	45.80	26.50	200	66	129	263	12	157	52	E
6	1934.11.30	2:58:19	44.10	14.00	30	88	-22	343	17	77	14	D
7	1935.07.13	0:03:46	46.00	26.50	33	90	-90	303	45	123	45	E
8	1935.08.13		45.70	27.70	220	58	74	321	12	92	72	E
9	1938.03.27	11:16:24	46.20	16.80	310	80	90	40	35	220	55	D
10	1940.06.24	09:17:__	45.90	26.60	220	58	94	307	13	143	76	E
11	1940.10.22	6:36:57	45.80	26.40	223	61	87	315	16	125	74	E
12	1940.11.10	1:39:07	45.80	26.70	224	62	75	325	16	104	69	E
13	1940.11.11	6:34:17	46.00	26.80	216	56	94	303	11	140	78	E
14	1945.03.12		45.70	26.80	223	56	-83	159	78	308	11	E
15	1945.09.07	15:48:22	45.90	26.50	224	60	93	312	15	141	75	E
16	1945.12.09	6:08:45	45.70	26.80	134	63	-115	3	63	242	15	E
17	1948.05.29	4:48:55	45.80	26.50	196	48	84	290	3	54	85	E
18	1950.05.01		45.50	26.30	317	49	69	62	2	160	74	E
19	1950.06.20	1:18:47	45.90	26.50	260	90	-110	151	42	9	42	E
20	1952.06.03	5:53:22	45.70	26.80	10	54	67	116	6	224	71	D
21	1954.10.01	13:30:__	45.50	27.10	60	70	-101	313	63	158	24	D
22	1955.02.01	21:22:__	45.50	26.30	347	61	134	47	6	310	52	E
23	1956.01.12	5:46:08	47.35	19.09	85	73	160	133	2	42	26	B
24	1956.04.18	12:52:__	46.10	27.40	162	77	74	265	30	53	55	C
25	1956.11.05		46.50	13.08	280	90	-179	145	1	55	1	E
26	1957.12.23	23:38:__	45.40	26.90	7	56	-112	228	70	112	8	C
27	1959.04.26	14:45:16	46.46	13.00	304	76	-161	168	23	75	3	C
28	1959.05.31	12:15:43	45.70	27.20	149	84	-106	42	48	253	37	E
29	1959.05.31	23:38:__	45.89	27.39	20	70	-80	307	64	102	24	D
30	1959.06.26	13:44:40	45.86	26.53	80	60	141	137	2	45	48	E
31	1960.01.04	12:21:__	44.60	27.00	271	60	-118	133	63	21	11	C
32	1960.01.26	20:27:04	45.80	26.80	332	58	88	63	13	237	77	E
33	1960.10.13	2:21:25	45.70	26.40	343	50	90	73	5	253	85	E
34	1961.11.18	03:18:__	45.50	26.70	165	87	90	255	42	75	48	E
35	1962.02.27	21:34:__	45.70	26.40	358	80	78	98	34	254	54	E
36	1962.08.30	7:46:00	45.50	26.70	345	65	94	72	20	264	70	E
37	1962.11.09	2:14:52	45.80	26.70	132	47	-108	328	77	234	1	E
38	1963.01.14	18:33:24	45.70	26.60	326	54	-90	236	81	56	9	E
39	1963.02.14	13:18:57	44.33	15.12	235	70	-35	193	39	289	8	D
40	1963.05.19	10:00:08	46.27	14.53	304	60	91	33	15	217	75	C
41	1963.12.02	6:49:05	48.03	16.20	0	70	90	90	25	270	65	D
42	1964.04.13	08:29:59	45.30	18.10	302	55	101	24	10	247	77	B
43	1964.06.30	12:29:59	47.73	15.92	92	90	-1	47	1	137	1	D
44	1964.10.27	19:46:09	47.85	15.95	245	80	-42	196	36	301	20	D
45	1965.01.10	02:52:25	45.80	26.60	348	50	98	72	5	306	82	E
46	1966.09.04	01:29:29	45.77	26.63	5	90	-106	260	43	110	43	E

Table 2 (Cont.)

No.	Date	Time	Lat (N)	Long (E)	Plane 1			P axis		T axis		Qual.
					Srike	Dip	Rake	Azim	Plunge	Azim	Plunge	
47	1966.10.02	11:21:45	45.77	26.50	5	50	90	95	5	275	85	E
48	1966.10.15	06:59:19	45.60	26.40	134	84	93	221	39	48	51	E
49	1966.12.14	14:49:59	45.72	26.39	165	48	90	255	3	75	87	E
50	1966.12.29	06:30:02	45.54	26.48	158	63	65	266	15	27	63	E
51	1967.01.29		47.91	14.26	105	71	-84	25	63	190	26	D
52	1967.02.27	21:00:42	44.86	26.69	187	71	-32	145	36	239	8	D
53	1968.01.06	10:23:50	45.76	26.46	160	67	-44	118	47	219	10	E
54	1968.02.09	13:22:54	45.61	26.42	220	62	68	326	14	90	66	E
55	1968.10.20	23:15:04	45.81	26.59	129	60	73	231	13	3	70	E
56	1968.11.20	01:51:15	45.65	26.60	345	80	91	74	35	257	55	E
57	1969.01.15	08:46:29	45.62	26.55	344	55	106	62	8	300	74	E
58	1969.04.12	20:38:41	45.30	25.10	137	83	-31	90	26	188	16	C
59	1969.06.01	23:20:29	47.00	14.20	94	78	159	143	6	50	23	C
60	1969.10.26	15:36:51	44.87	17.28	228	88	12	2	7	94	10	D
61	1969.10.27	2:55:34	44.98	17.04	285	50	90	15	5	195	85	D
62	1969.10.27	08:10:58	44.92	17.23	246	90	-1	201	1	291	1	B
63	1969.12.31	13:18:33	44.88	17.23	160	70	-128	28	50	277	16	C
64	1970.07.10		47.90	26.90	193	61	94	280	16	113	74	D
65	1971.07.18	16:18:22	45.71	26.31	131	58	43	252	2	345	51	E
66	1972.01.05		47.80	16.25	145	80	169	191	1	101	15	D
67	1972.04.16	00:03:31	45.53	26.44	55	74	105	133	28	346	58	E
68	1972.04.16	10:10:03	47.73	16.12	205	90	-20	158	14	252	14	C
69	1972.04.16	11:04:44	47.73	16.02	235	77	26	5	8	100	27	D
70	1973.08.20	15:18:__	45.70	26.50	26	78	71	132	31	274	53	E
71	1973.10.23	10:50:__	45.70	26.50	117	56	70	222	9	338	71	E
72	1973.12.12	0:02:38	47.05	14.10	264	87	160	311	12	218	16	C
73	1974.06.20	17:08:28	46.16	15.57	81	89	-40	29	28	134	26	E
74	1974.06.20	17:08:47	46.20	15.91	358	58	-120	210	64	110	10	C
75	1974.06.20	22:26:31	46.19	15.53	240	51	66	347	3	87	71	C
76	1974.07.17	05:09:__	45.80	26.50	82	72	109	158	24	18	59	E
77	1975.02.08	08:21:__	45.10	26.00	144	74	21	275	3	7	26	C
78	1975.03.07	04:13:__	45.90	26.60	237	83	31	6	16	104	26	C
79	1976-1979		46.30	13.25	87	63	98	171	18	14	71	A
80	1976.05.06	19:59:06	46.27	13.31	86	72	104	165	26	17	61	E
81	1976.05.06	20:00:11	46.27	13.27	77	70	103	157	24	7	63	E
82	1976.05.07	0:23:50	46.26	13.32	87	70	121	154	19	35	54	E
83	1976.05.08	3:10:06	46.26	13.19	83	59	95	170	14	7	76	E
84	1976.05.09	0:53:45	46.21	13.30	101	56	99	185	10	40	77	C
85	1976.05.10	4:35:52	46.24	13.15	72	63	94	159	18	352	71	E
86	1976.05.11	22:44:01	46.24	13.04	95	63	107	172	17	38	67	C
87	1976.06.08	12:14:38	46.30	13.24	102	61	127	167	9	63	57	E
88	1976.06.26	11:13:47	46.26	13.13	90	71	119	158	21	36	54	E
89	1976.07.14	5:39:34	46.34	13.29	103	63	128	167	10	62	55	E
90	1976.09.11	16:31:11	46.28	13.21	82	61	113	155	13	35	66	E
91	1976.09.11	16:35:02	46.27	13.26	77	76	98	161	31	358	58	E
92	1976.09.12	19:53:28	46.30	13.21	89	66	98	173	20	14	68	E
93	1976.09.13	18:54:46	46.29	13.20	97	65	127	161	12	54	54	E
94	1976.09.15	03:15:19	46.30	13.19	46	59	63	155	10	268	65	E
95	1976.09.15	4:38:54	46.29	13.16	52	80	101	133	34	335	53	E
96	1976.09.15	09:21:19	46.32	13.13	61	68	61	172	18	292	57	E
97	1976.09.15	9:45:57	46.29	13.29	102	63	135	162	7	63	50	E
98	1976.09.15	19:31:11	46.29	13.18	98	62	115	170	14	51	64	E
99	1976.10.01	17:50:__	45.70	26.50	334	48	80	71	3	178	82	E
100	1977.03.04	19:21:54	45.80	26.80	238	76	106	315	29	168	56	E
101	1977.03.05	00:00:__	45.30	27.10	106	86	37	234	22	336	28	D

Table 2 (Cont.)

No.	Date	Time	Lat (N)	Long (E)	Plane 1			P axis		T axis		Qual.
					Srike	Dip	Rake	Azim	Plunge	Azim	Plunge	
102	1977.04.03	3:18:14	46.29	13.16	142	60	100	225	14	77	73	E
103	1977.07.16	13:13:31	46.31	14.36	348	72	90	78	27	257	63	C
104	1977.09.16	23:48:08	46.25	13.00	92	72	106	170	25	25	60	E
105	1978.02.20	12:13:34	46.44	13.27	95	90	-80	15	44	175	44	E
106	1978.04.03	10:49:46	46.29	13.17	145	57	117	216	8	107	66	E
107	1978.04.23	11:23:04	46.08	13.59	175	81	-72	105	51	250	33	D
108	1978.06.22	02:33:__	46.75	21.13	355	79	-144	222	33	121	16	C
109	1978.06.22	2:57:54	46.75	21.13	266	70	42	29	12	130	43	C
110	1978.10.02	20:28:52	45.70	26.70	316	56	93	44	11	236	79	E
111	1979.03.06	13:46:06	46.40	13.02	293	52	76	33	6	151	77	D
112	1979.03.08		47.82	23.31	24	50	102	106	5	349	80	C
113	1979.03.30		47.68	23.22	108	65	-47	64	50	170	8	C
114	1979.04.18	15:19:20	46.33	13.31	315	61	143	11	2	280	46	E
115	1979.05.31	07:20:06	45.60	26.40	233	80	65	344	31	116	49	E
116	1979.06.19	10:03:15	46.28	13.20	83	72	-53	33	49	146	19	E
117	1979.08.14	18:58:58	46.32	13.04	8	82	43	133	23	238	36	D
118	1979.09.11	15:36:54	45.60	26.50	12	77	86	105	32	277	58	E
119	1980.03.25		47.50	20.10	125	66	137	183	9	84	47	C
120	1980.12.08	19:51:__	44.40	27.20	331	89	45	96	29	205	31	E
121	1981.06.28	06:16:27	45.68	14.14	52	90	-1	7	1	97	1	C
122	1981.07.18	00:03:__	45.70	26.40	92	89	135	147	29	38	31	E
123	1981.08.13	02:58:11	44.84	17.31	71	83	-31	24	26	122	16	B
124	1982.05.16	04:03:__	45.40	26.40	206	81	-15	161	17	253	4	E
125	1982.06.05	17:54:12	45.70	14.78	124	80	140	178	20	77	35	C
126	1982.07.01		48.48	22.23	140	50	96	226	5	87	83	C
127	1983.01.25	07:34:__	45.70	26.70	323	58	131	25	5	288	56	E
128	1983.02.21	18:03:__	45.30	27.10	234	63	108	311	16	178	67	C
129	1983.02.26	00:57:__	45.62	26.43	258	89	110	329	41	187	42	E
130	1983.04.14	14:52:14	47.67	15.14	67	90	-1	22	1	112	1	D
131	1983.04.24	06:56:__	45.68	26.66	155	66	98	239	21	80	68	E
132	1983.08.05	15:50:50	45.95	14.07	95	90	-39	42	26	147	26	E
133	1983.08.25	23:57:__	45.63	26.49	258	80	107	333	33	188	52	E
134	1983.12.20	08:26:47	46.30	13.21	247	54	52	3	2	97	60	C
135	1984.10.25	13:58:53	45.63	14.33	302	89	-96	206	45	38	44	E
136	1984.11.30	22:25:__	45.69	26.52	245	53	128	310	1	218	61	E
137	1985.08.01	14:35:03	45.80	26.50	200	76	150	252	10	156	31	E
138	1985.08.15	04:28:47	47.06	18.11	224	76	-163	88	22	356	1	B
139	1986.02.09	17:51:38	46.37	13.02	279	63	128	343	10	238	55	C
140	1986.04.27	00:04:__	45.50	27.10	30	47	79	128	2	228	82	C
141	1986.04.27	00:47:__	45.50	27.10	294	62	-115	161	64	42	13	C
142	1986.08.30	21:28:35	45.50	26.50	235	66	82	331	21	131	68	E
143	1986.11.25	13:59:42	44.14	16.41	89	70	83	185	25	348	64	C
144	1986.12.16	06:22:49	45.07	14.83	41	50	61	151	1	243	68	C
145	1988.11.29	1:23:38	45.70	21.50	344	85	-32	296	26	35	18	C
146	1989.01.26	09:42:57	47.03	16.98	77	78	-147	303	32	205	13	C
147	1989.01.27	02:55:03	47.04	16.87	155	50	-121	358	67	266	1	C
148	1989.08.18	7:26:25	45.95	26.82	223	85	169	269	4	178	11	C
149	1990.05.30	10:40:06	45.87	26.67	236	63	101	318	17	168	70	E
150	1990.05.31	00:17:47	45.80	26.75	309	69	106	27	22	244	63	E
151	1991.04.27	18:44:53	46.58	15.19	125	75	90	215	30	35	60	C
152	1991.07.12	10:42:21	45.35	20.98	125	80	40	250	19	354	35	C
153	1991.07.14	23:59:31	45.43	21.12	175	57	-123	30	62	288	7	D
154	1991.07.18	11:56:30	44.90	22.35	58	57	-137	270	52	179	1	B
155	1991.07.19	01:27:33	45.34	21.04	199	77	-163	63	21	332	3	C
156	1991.08.14	23:26:__	45.52	21.22	6	46	98	90	1	351	84	C

Table 2 (Cont.)

No.	Date	Time	Lat (N)	Long (E)	Plane 1			P axis		T axis		Qual.
					Srike	Dip	Rake	Azim	Plunge	Azim	Plunge	
157	1991.09.01	01:16:03	45.47	26.91	242	74	-143	107	37	7	12	B
158	1991.09.17	03:02:01	44.54	22.42	150	65	-139	10	46	273	7	D
159	1991.12.02	08:49:40	45.48	21.12	194	85	-162	60	16	327	9	C
160	1992.02.21	20:50:32	45.46	14.32	156	60	110	231	13	107	68	D
161	1993.05.23	17:19:23	45.36	25.51	335	90	-10	290	7	20	7	C
162	1993.06.01	19:51:10	46.16	16.46	332	84	129	32	28	277	38	D
163	1995.09.12	22:14:05	47.22	18.14	260	81	30	29	14	127	27	C
164	1995.09.18	8:26:10	47.89	18.87	120	75	-80	44	59	202	29	D
165	1996.01.09	1:07:22	47.96	16.49	169	72	27	298	5	31	31	C
166	1996.03.28	6:31:22	46.91	19.25	90	75	-20	47	25	138	3	C
167	1996.09.29	21:45:53	47.30	21.37	235	81	-95	139	53	329	36	C
168	1996.10.03	22:41:00	46.17	15.11	219	72	27	348	5	81	31	D
169	1996.12.03	0:30:57	47.73	16.10	355	80	-120	234	47	109	29	D
170	1997.01.27	0:46:13	44.86	16.11	320	75	-160	183	25	92	3	D
171	1997.03.08	18:53:39	45.89	15.72	235	90	-20	188	14	282	14	D
172	1997.03.30	4:18:04	47.75	16.17	285	90	-25	237	17	333	17	D
173	1997.05.10	19:29:14	48.09	16.70	321	72	153	12	5	279	31	D
174	1997.05.30	19:28:20	47.72	16.05	310	75	-140	176	38	74	15	C
175	1997.06.03	21:01:59	47.73	15.90	160	80	160	208	7	115	21	D
176	1997.06.17	13:33:45	46.45	20.72	350	55	-130	201	58	107	2	C
177	1997.07.16	20:43:31	47.78	17.30	170	90	-150	39	21	301	21	D
178	1997.09.04	1:45:39	47.71	16.16	132	80	-170	356	14	266	0	D
179	1997.11.27	10:40:56	47.26	19.38	45	55	-110	264	72	149	8	D
180	1998.01.18	7:30:08	46.03	16.93	165	80	150	216	13	119	28	D
181	1998.02.26	12:09:22	44.92	17.92	210	90	-30	161	21	259	21	D
182	1998.03.11	11:33:28	47.93	16.42	120	70	-30	78	35	172	5	D
183	1998.04.12	10:55:36	46.28	13.63	130	85	160	178	10	84	18	C
184	1998.04.15	22:42:11	46.31	13.76	20	80	-140	249	35	145	19	D
185	1998.05.08	4:06:54	47.51	18.93	155	55	130	218	2	124	58	D
186	1998.05.27	12:35:45	46.10	16.71	315	85	-150	183	24	85	17	D
187	1998.06.02	20:46:50	46.59	14.33	150	60	-110	19	68	254	13	C
188	1998.06.28	12:19:40	47.49	18.92	60	75	-80	344	59	142	29	D
189	1998.07.05	3:43:12	47.05	19.67	32	80	107	107	33	322	52	D
190	1998.09.29	22:14:52	44.30	20.03	183	85	-120	65	42	298	33	D

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