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HUNGARIAN NATIONAL REPORT ON IASPEI 2007–2010

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Introduction

The present report has been compiled by Z Wéber, the current national correspondent for the International Association of Seismology and Physics of the Earth's Interior (IASPEI). Scientists working along one or more lines of IASPEI have been asked to send their contributions for this compilation. The individual reports are presented below with only minor changes, if any, under the names of the original contributors.

1. Observational seismology

1.1 Developments in the Hungarian Seismological Station Network since 2007

(Péter Mónus)

There have been only minor changes in the seismological station network in Hungary during the period of 2007–2010. At present, 14 seismological stations are in operation in Hungary operated by two different institutions: Geodetic and Geophysical Research Institute (GGRI) and GeoRisk Earthquake Research Institute Ltd. The list and main parameters of these stations can be found in Table I. Seven of these 14 stations (BEHE, BUD, PKSM, PKST, PSZ, SOP and TRPA) have real-time data access.

Six broadband stations have been installed in Hungary so far. All these stations have Streckeisen STS-2 very broadband seismometers and EarthData PS-6-24 digitizers. At all the stations Linux PCs are used as data acquisition units with SeisComP software running on them. All stations have Internet connection for data transfer. The average data latency at these stations is below 10 s.

The national station network has been extended beyond the political borders creating a "virtual" network of seismic stations. The larger pool of data provided by this extended or virtual network helps to have faster and more accurate earthquake locations and parameter determinations. At this moment, 71 stations from several countries and agencies are used to extend our national station network.

Table I. Seismic stations

Code	Location	Lat. N	Long. E	Elev. m	Station type (1)	Sensor type (2)	Recording equipment (3)	Recording (4)
BEHE	Becsehely	46.4704	16.7757	298	3C BB	STS-2	PS-6-24+ SeisComP PC	D – C
BUD	Budapest	47.4836	19.0239	196	3C BB	STS-2	PS-6-24+ SeisComP PC	D – C
CSKK	Csókakő	47.3631	18.2605	320	3C SP	SS-1	MARS-88/MC+ SeisComP PC	D – C
PKS2	Kecel	46.4920	19.2131	106	3C SP	LE-3D	MARS-88/OC	D – E
PKS6	Bócsa	46.5998	19.5645	120	3C SP	LE-3D	MARS-88/OC	D – E
PKS7	Kunszent-miklós	47.0473	19.1609	95	3C SP	LE-3D	MARS-88/OC	D – E
PKS9	Tamási	46.5870	18.2789	240	3C SP	LE-3D	MARS-88/OC	D – E
PKSG	Gánt	47.3918	18.3907	200	3C SP	LE-3D	MARS-88/OC	D – E
PKSM	Mórágy	46.2119	18.6413	170	3C BB	STS-2	PS-6-24+ SeisComP PC	D – C
PKSN	Nyárlőrinc	46.8972	19.8673	110	3C SP	LE-3D	MARS-88/OC	D – E
PKST	Tés	47.2590	18.0343	473	3C SP	LE-3D	MARS-88/MC+ SeisComP PC	D – C
PSZ	Piszkéstető	47.9184	19.8944	940	3C BB	STS-2	PS-6-24+ SeisComP PC	D – C
SOP	Sopron	47.6833	16.5583	260	3C BB	STS-2	PS-6-24+ SeisComP PC	D – C
TRPA	Tarpa	48.1304	22.5391	113	3C BB	STS-2	PS-6-24+ SeisComP PC	D – C

(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 SS-1 short period seismometer
(3) MARS-88 – Lennartz electronic digital data logger
PS-6-24 – Earth Data digitizer
SeisComP – GEOFON Seismological Communication Processor
(4) A – analogue; D – digital; C – continuous recording; E – event recording

The data centre of the Hungarian Seismological Station Network is located in Budapest. SeisComP Ver. 2 is used for data acquisition and SeisComP3 performs some automatic tasks. At the data centre a SeedLink server is operated. Real-time data from broadband stations can be accessed through this server. Real-time data are provided to international data centres (ORFEUS, GEOFON) and some partner institutions. AutoDRM service is also available (autodrm@seismology.hu). A kind of live seismograms are generated in every 10 minutes and published on the website of the Seismological Observatory (www.seismology.hu). Seismogram readings (phase data) and the results of our automatic location system are disseminated by means of e-mail.

The series of Hungarian Earthquake Bulletin (Tóth et al. 2007, 2008, 2009, 2010) gives a brief summary of the seismic instrumentation used and the monitored results of present day earthquake activity in and around Hungary.

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2. Seismicity and earthquake hazard

2.1 Seismicity of the Pannonian Basin

(László Tóth)

The Pannonian Basin is located between the seismically very active NE Mediterranean sea and the nearly aseismic East European platform. Seismicity in the Pannonian Basin is relatively low comparing to the peripherals and the distribution of earthquake epicentres shows a rather scattered pattern at the first glance. It is particularly difficult to decide whether the epicentres occur at isolated places or along elongated zones however, at several single places earthquakes occur repeatedly. For example, near to Eger (47.9N; 20.4E) at least sixteen earthquakes with more than fifty greater aftershocks occurred over a time interval of some 70 years. Komárom and Mór area (47.4–47.8N; 18.2E), Jászberény (47.5N; 20.0E), Kecskemét (46.9N; 19.7E) and Dunaharaszti (47.4; 19.0E) 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 surface 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 (Tóth et al. 2008).

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2.2 Seismicity and earthquake hazard of the Bánát region and Kecskemét area, Hungary

(Tibor Zsíros)

In recent years, the seismicity and earthquake hazard of the Bánát region and Kecskemét area have been studied (Zsíros 2007, 2009). In the seismic source zone of Bánát, more than 600 earthquakes are known since 1773. Among them, six events with magnitude of 5.0–5.7 measured on the surface magnitude scale. The macroseismic reinterpretation of the April 2, 1901 earthquake yields epicentral intensity of VII on the European Macroseismic Scale, and a focal depth value of 12 km. Based on empirical relations, the maximum rupture area is estimated as 50–55 km^2 and the maximum displacement along the fault is about 16 cm in the Bánát seismic zone due to the $M_S = 5.7$ event occurred on July 12, 1991. The average recurrence that we may expect an earthquake of M $\geq$ 3.4 every 1 year, an earthquake of M $\geq$ 4.3 every 10 years and an earthquake of M $\geq$ 5.3 every 100 years in the studied source zone. The probabilistic seismic hazard assessment predicts 1.3–2.1 m/sec^2 peak ground accelerations, and 6.7–7.3 maximum (theoretical) earthquake intensity values with 10% chance of exceedance for an exposure time of 100 years in the region.

In the small seismic source zone of Kecskemét, 203 earthquakes are known between 1739 and 2006 and about 90 percent of them have a magnitude value not more than 3.0. However, the strongest event on July 8, 1911 has 5.6 surface-wave magnitude. Concerning the latter earthquake, the maximum (epicentral) intensity of I = VIII (EMS) was observed in the area enclosed by Kecskemét, Katonatelep and Hetényegyháza locations. The quake caused significant damage to buildings (I $\geq$ VI EMS) on about 6 thousand square kilometres and was felt (I $\geq$ III EMS) on some 85 thousand square kilometres. The focal depth is estimated as 11 km directly from the individual intensity data points. During the earthquake, liquefaction (sand crater) occurred in the epicentral area and some electromagnetic effects were also observed. Studying the source dimensions we can conclude that the rupture area is between 40 and 67 square kilometres and the maximum displacement along the fault can be estimated to 14–20 centimetres for the Kecskemét earthquake of July 8, 1911. A probabilistic seismic hazard assessment predicts 1.1–1.5 m/cm^2 peak ground accelerations and 6.6–7.1 maximum (theoretical) earthquake intensity values with 10% chance of exceedance for an exposure time of 100 years in the studied area.

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2.3 Earthquake hazard investigations at the Eötvös Loránd Geophysical Institute of Hungary (ELGI)

(Péter Tildy)

The new European building standard (Eurocode) contains a separate volume for earthquake resistance design (EC 8) among other sophisticated rules and processes for structural design. The requirements of this regulation generate a number of new issues for the geotechnical-geophysical practice, like (V_S^{30} based) soil classification of sites. As Eötvös Loránd Geophysical Institute of Hungary (ELGI) has a strong tradition in development of a variety of geophysical applications, the institute obviously was involved into this task.

Our recent activity is mainly focused onto soil classification and mapping of dense populated areas of Hungary — Budapest and its vicinity. Three fundamental questions have been arisen in the beginning: where, with what kind of method, and how? First of all the number and place of measurement places needed to specify to characterize a relatively large area — in our case a district of Budapest (with a territory about 5–15 km^2). In our case detailed geologic data are available at Budapest, making it possible to pre-classify the investigated area, and to delineate areas with similar mechanical properties in order to reduce the amount of measurement points.

The V_S^{30} values are obtained by multi-channel analysis of surface waves (MASW). In order to have homogeneous V_S^{30} data, repeatable, standardised active measurement and data processing system was developed. The measurement system was "sharpen" (optimize), to records with strong low frequency content, so it contain low frequency vertical geophones and a special surface wave source ("kangaroo") operated with cartridges. The dispersion curves are obtained by f-k transform of the records, and inverted using a Genetic Algorithm (GA) with the core of Thomson-Haskell method. As a result the shear wave velocity profile of the investigated sites is obtained. In the last 4 years Eurocode 8 based soil classification maps were completed of 2 district of Budapest.

A number of practice-induced methodological problems have been raised during the mapping. One of the most important is the awkward operation of our seismic source. The "kangaroo" is very effective low frequency surface wave generator but its operation is very loud and isn't safe enough in the city, that's why it had to be replaced. Because of the insufficient low frequency content of the hammer source, parallel active and passive measurements were applied to obtain reliable dispersion curves without disruption of everyday city life. The combined method was used in Józsefváros (the VIIIth district of Budapest).

Soil classification measurements were applied in Dinar, Turkey, too, to create a new soil classification map of the region. Surface seismic measurements were carried out at 50 locations mostly in Dinar city and its surroundings. In possession of a detailed shear wave velocity map of Dinar City, the results show that there is a correlation between the V_S^{30} values and the damage distribution of the region caused by the Dinar earthquake (1995, $M_S = 6.1$). In addition to the low V_S^{30} values, the likely causes of the damage were investigated, and it is observed that one of the major factors for high levels of damage is 3D variations of geological structures.

As a next step a deeper investigation were made for obtaining the shear-wave velocity profiles of the whole sedimentary basin. These profiles were estimated from the inversion of the microtremor horizontal-to-vertical spectrum based on surface waves from seismic noise at each site using a genetic algorithm. A new relationship between the thickness of basin sediment and the main peak frequency in the horizontal-to-vertical spectral ratios was derived. This relationship allows a zonation of the Dinar region, which is consistent with previous studies and can be importantly used for the seismic hazard evaluation of the region.

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2.4 Deterministic seismic hazard assessment

(Katalin Gribovszki, Péter Varga)

Deterministic seismic hazard computations were performed along four different profiles across the downtown of Budapest (Gribovszki et al. 2010). Synthetic seismograms were computed by the “hybrid technique”. By applying the hybrid technique it is possible to take into account the focal source, the path and the site effect together. Four independent computations have been performed using the same seismic source but different profiles. The parameters of the seismic source were adopted from the parameters of the well-known 1956 Dunaharaszti earthquake. The focal mechanism and the homogeneous and heterogeneous parts of the profiles are known from geophysical and geological data of the investigated area.

As the results of the computations, PGA (peak ground acceleration) grid maps of the downtown of Budapest for the three different components came into existence. Furthermore, spectral acceleration (response spectra, SA) and RSR charts of the synthetic seismograms for the four different profiles were created. The PGA grid maps show that the maximal PGA values are situated at the eastern (Pest) part of the downtown, and their values are 50–200 cm/s^2.

For the downtown of Budapest a special seismic risk map have been prepared. This special seismic risk map were created on the basis of the difference between the maximal amplitude frequencies of SA of synthetic seismograms and the building’s eigenfrequencies at every 0.1 km^2 of the downtown. In order to determine the building’s eigenfrequencies, microseismic noise measurements were performed at

6 different buildings in the downtown. The special seismic risk map shows that the buildings situated at the hilly western section of the downtown have higher seismic risk than the ones at the flat eastern part.

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2.5 Probabilistic Seismic Hazard Assessment (PSHA)

(László Tóth)

The unsolved problem of classical earthquake prediction, especially in moderate seismicity regions (Horváth and Tóth 2009), give emphasis to different methodologies of seismic hazard analysis. Seismic Hazard Analysis is a methodology that estimates the likelihood that various levels of earthquake-caused ground motion will be exceeded at a given location in a given future time period. Probabilistic method of seismic hazard assessment (PSHA) has evolved over the past decades into the generally preferred method to estimate earthquake-caused ground motion at critical facilities especially in moderate seismicity regions. By incorporating recurrence information and input variability, this method provides a more complete evaluation of hazard than deterministic method does.

Seismic hazard for single sites and hazard maps for the whole Pannonian region (44.0–50.0N; 13.0–28.0E) have been investigated (Bus and Tóth 2007, Tóth et al. 2009). The hazard assessment was carried out using a probabilistic approach by incorporating a wide range of parameter values and viable interpretations that were consistent with the data. Alternative interpretations were described by branches of a logic tree. Each branch was weighted according to the ability of that interpretation to explain the available data. The resulting seismic hazard map describes expected shaking with a 475-year return period in terms of peak ground acceleration. Furthermore, some important contributors to seismic risk are also highlighted, and a liquefaction hazard map is presented for the territory of Hungary (Győri et al. 2007).

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2.6 The magnitude of the maximum expected earthquake for the Pannonian Basin

(Zoltán Bus)

In Hungary, on average 4–5 earthquakes of magnitude M = 2.5–3 are felt by the public in each year. Events with significant damages occur in every 15–20 years, while strong, severely damaging earthquakes (M = 5.5–6) happen characteristically in every 40–50 years. The strongest known event which affected the present day territory of Hungary occurred near Komárom in 1763 with a magnitude of around 6.3.

The knowledge of the maximum earthquake magnitude (M_{max}) plays an important role in determining the level of seismic hazard for a given area. Bus and Tóth (2007) in their work aimed to compute the M_{max} based exclusively on the data of the available Hungarian earthquake catalogues. The M_{max} and its uncertainty have been estimated by a maximum likelihood method using the procedure of Kijko and Sellevoll (1992). The resulting $M_{max} = 6.4 \pm 0.3$ value is in good agreement with the known geophysical and geological properties of the territory of Hungary, i.e. the thinned, hot lithosphere beneath the inner part of the Pannonian Basin does not allow the accumulation of the strain needed to the occurrence of very large, destructive earthquakes.

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2.7 Statistical properties of earthquakes

(Márta Kiszely)

The Carpathian Basin is situated in the territory between the Mediterranean area, which is seismically one of the most active regions, and the Carpathian Mountains belt. The temporal variations of seismicity have been investigated on the example of three seismo-tectonically different regions: the Carpathian Basin, the Vrancea region and the Dinarides. The seismicity has been analyzed since 1900 in order to investigate the existence of diurnal periodicities using hodographs. There are two different diurnal distributions opposing each other: maximum early morning dominates until the year 1963, followed by a period of time when earthquakes seem to occur more often around 13h local time mainly concerning the weak $M_L < 3.2$ events. The midday maximum in the number of minor events may be caused by the inclusion of quarry blasts, but the diurnal geomagnetic variations correlate well with diurnal changes in earthquake activity. The spatial and temporal fractal structures of earthquakes were analyzed using the box counting method. The regions were divided into different size r of a square box and were counted the minimum number $N(r)$ of boxes necessary to cover all the data. The recurrence times of earthquakes are shown to be a clustering process and are much higher in the Carpathian Basin. The earthquakes in these regions have self-similar structures. The slope of $\log N - \log r$ function for Carpathian Basin breaks at about 20 km, which divides the range into two bands. This breaking at about 20 km maybe connected to the intrinsic weakness of the Carpathian Basin lithosphere (Kiszely 2007, Kiszely 2009). The number of earthquakes has a diurnal periodicity, more earthquakes happen at night due to daytime increase in the noise level (Kiszely 2010).

The diurnal magnetic variations, commonly known as Sq variations are generated in the Earths ionosphere, and show some tens of nT maximum in the magnetic components. The shape and amplitude depend on the geographic latitude and season. It has been pointed out that diurnal geomagnetic variations correlate well with diurnal changes in earthquake activity. The variations of magnetic field may trigger earthquakes, or around the moment of earthquakes disturbances in them can be observed. In some cases precursor may appear before the earthquake in the sign of magnetic intensity. This correlation has been tested in the 100 km vicinity of Nagycenk. In this region 96 small earthquakes occurred in the last 14 years, and were only 4 events which magnitude reached or exceeded $M = 4$. The minutely observed horizontal geomagnetic intensity data (averaged for months) shows a daily periodicity, and the maximum intensity is reached in June and July. The distribution of earthquakes between the years 1995 and 2008 shows a maximum in summer. (The calculated monthly distribution of earthquakes depends on aftershocks, and the time window.)

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2.8 Spatial and temporal distributions of earthquakes

(László Tóth)

The temporal fluctuations of the 1880–1994 seismicity recorded in the Pannonian Basin were investigated (Telesca and Tóth 2010) by means of the Fano Factor and Allan Factor methods, which allow us to estimate the power spectrum for point processes. Up to our knowledge, this is the first scaling analysis performed on earthquake series spanning for almost one century. Our findings point out a presence of two temporal regimes in the analyzed seismicity, which is characterized by quasi-Poissonian behaviour for low to intermediate timescales for up to about 1/2 years, and by scaling behaviour for higher timescales with scaling exponent around 0.3–0.4, indicating a rather high time-clustering of the events. Furthermore, the Allan Factor shows the presence of a periodicity at about 2.23 years for events with magnitude larger or equal to 3.5.

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2.9 The discrimination of earthquakes and quarry blasts

(Márta Kiszely)

In seismology it is a universal problem to discriminate the seismic events from quarry explosions, to purge earthquake catalogs of unwanted explosions. The Vértes Hills are an interesting region in Hungary where the earthquake activity occurs in the vicinity of quarries. Both natural and artificial seismicity is observed here. The blasting activities in quarries, mines represent a significant problem for ensuring the accuracy and completeness for catalogues of small ($M_L < 3$) events. It has been found that the spectral analysis and the correlation of spectra proved to be successful in the discrimination. One type of blast and five types of earthquakes are identified based on the correlation analysis of spectra of S-phases on the horizontal component. The result of the correlation analysis is that most of the spectra of the blasts were very similar. Correlation analysis has also showed that the big part of earthquakes could be classified into 5 groups. Earthquakes of each group concentrated on different places on the map (Kiszely 2009).

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. The diurnal distribution shows a maximum about noon. In our bulletin the contamination may affect 15% of the earthquakes assuming that the classification was wrong, and the daily peak is caused by blasts. 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. The comparison of the diurnal distribution of earthquakes occurring on weekends and on weekdays indicate the contamination of the Hungarian Earthquake Bulletin with data from quarry blasts (Kiszely 2010).

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2.10 Visualization of earthquakes on maps

(Márta Kiszely)

Pődör and Kiszely (2010) give a brief overview of the difficulties in the cartographic representation of large data sets like earthquakes data catalogue of Hungary and adjacent region. The Hungarian Earthquake Catalog contains about 25 000 earthquakes dated from 456 A.D. till the present. Systematic earthquake data collection in the Carpathian Basin started in the nineteenth century. Officially organized collection and evaluation of earthquake data started in 1881. Visualizing the dataset of the Catalog on maps raised several problems, because the dataset is large, the symbolization of all the data on one map is very complicated. Another problem is the data quality, as data gathered in different way two hundred years ago and today. Nowadays scientists gather instrumental and macroseismic earthquake data and also deal with definition of earthquake focal parameters, too. Concerning the determination of exact location of the epicenters is also not uniform throughout the whole Catalog. Pődör and Kiszely made an attempt to find the optimal visualization technique for representing the data of the Hungarian Earthquake Catalog, and made an effort to combine the traditional cartographic sign system and the possible visualization techniques offered by modern GIS software.

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2.11 Paleoseismology

(Katalin Gribovszki, Győző Szeidovitz, Péter Varga)

Speleothems with high height/diameter ratio (H/D > 40) have been found in Bulgarian caves:

— in the Snezanka and Eminova caves, situated in Rodope Mountain Massif, South Western part of Bulgaria (Szeidovitz et al. 2008) and;

— in the Varteshkata and Elata caves, situated in Western part of Balkan Mountain Range, North-West Bulgaria (Gribovszki et al. 2008).

The examination of these speleothems allows estimating an upper limit for horizontal peak ground acceleration generated by paleoearthquakes.

The density, the Young's modulus and the tensile failure stress of the samples originating from broken speleothems have been measured in laboratory, while the natural frequency of speleothems was determined by *in situ* observations.

Based on a simple mechanical model, the value of the upper limit horizontal ground acceleration resulting in failure and the theoretical natural frequency of speleothems were assessed by theoretical calculations using mechanical parameters — the density, the Young's modulus and the tensile failure stress — of the samples originating from broken speleothems from each investigated caves.

The ages of the samples taken from the investigated stalagmites have been determined by alpha spectrometry.

According to our modeling results, the investigated speleothem has not been excited by a horizontal acceleration higher than:

- 0.90 g in case of Snezanka cave,
- 0.60 g in case of Eminova cave,
- 0.14 g in case of Varteshkata cave, and
- 0.33 g in case of Elata cave during the last few thousand years.

These results can serve to improve the present seismic risk policy for karst regions, too (Gribovszki et al. 2008, Szeidovitz et al. 2008).

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2.12 Historical seismology

(Péter Varga)

The first scientific tools of earthquake investigations were provided by isoseismic maps. Varga (2008a) presents a historical development of these maps from the first scientifically documented seismic event, the Calabrian earthquake (1783), through the first earthquake map which consists isoseismal lines (completed by P Kitaibel and A Tomcsányi, professors of Pest — today Budapest — University in 1814) till the birth of isoseismal maps in their present-day sense connected to the first intensity scales by Rossi (1874), Forel (1881), Forel-Rossi (1883) and Mercalli (1897).

One of the most significant physical characteristics of earthquakes is the energy they radiate. Probably this is the reason why this problem attracted the attention of scientists at the very beginning of the development of modern seismology. Presumably Mendenhall (1886, 1887) and Kövesligethy (1897) were the first scientists who estimated the energy of earthquake waves. Later on such famous seismologists as Reid (1912), Galitzin (1915), Klotz (1915), Jeffreys (1923), Sieberg (1923) dealt with solution of the problem. Our present knowledge in this field is based on study of Gutenberg and Richter (1956) (Varga et al. 2010).

The parallelisms and common roots of the development of two important fields of earth sciences, geodesy and seismology is discussed by Varga (2009, 2010), Varga and Denis (2010). The connection is based on the fact that for early seismology the effective rigidity observed by earth tidal observations was of first order importance. The common interest in the study of rheological properties of the Earth remains hitherto. In addition, seismology and geodesy used similar instruments observing directly accelerations due to gravitational forces or inertial accelerations due to ground deformations.

The Heligoland explosion after WW II was the first internationally synchronized experiment to study the Earth's crust and upper mantle by artificially generated elastic waves. This event created tradition and had an important influence on the studies of the Earth's inner structure (Varga 2008b).

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2.13 The 200-year anniversary of the Mór M5.4 earthquake in Hungary

(Márta Kiszely)

Although catastrophic earthquakes are rare in the Pannonian Region there is a long history of earthquakes that have caused substantial damage, one of the biggest being on the 14th January 1810 at Mór at 18 h local time, the intensity of the quake reached the VIII degree, $M_L = 5.4$ on the Richter scale. There were some casualties, too. Heavy damages in buildings were caused in Mór and Isztimér, and in the narrow strip of the Mór-graben. The earthquake caused panic in Buda and Wien, and was felt in Sopron, Debrecen and Baja. The area is active at present, too, small shocks burst out from time to time mostly in the environment of Mór, the earthquakes can be connected to known geological structure, i.e. to the Mór-graben (Fodor et al. 2007, Kiszely 2009, Kiszely 2010).

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3. Seismological theory

3.1 Estimating source time function and moment tensor of weak local earthquakes

(Zoltán Wéber)

Linear inversion of three-component waveform data for the time-varying moment tensor rate functions (MTRFs) is a powerful method for studying seismic sources (Wéber 2005, 2006). After finding the MTRFs, however, we should try to represent an earthquake by just one moment tensor and one source time function (STF), if possible. This approach is particularly justified when dealing with weak local events. Unfortunately, extraction of a moment tensor and STF from the MTRFs is essentially a nonlinear inverse problem.

We have introduced an iterative Lp norm minimization technique to retrieve the best moment tensor and STF from the MTRFs obtained by waveform inversion (Wéber 2008, 2009). In order to allow only forward slip during the rupture process, we impose a positivity constraint on the STF. The error analysis, carried out by using Monte Carlo simulation, allows us to estimate and display the uncertainties of the retrieved source parameters. On the basis of the resulting moment tensor uncertainties, the statistical significance of the double-couple, compensated linear vector dipole, and volumetric parts of the solution can be readily assessed.

Tests on synthetic data indicate that the proposed algorithm gives good results for both simple and complex sources. Confidence zones for the retrieved STFs are usually fairly large. The mechanisms, on the other hand, are mostly well resolved. The scalar seismic moments are also determined with acceptable accuracy. If the MTRFs cannot resolve the complex nature of a source, the method yields the average source mechanism. If the subevents are well separated in time, their mechanisms can be estimated by appropriately splitting the MTRFs into subintervals.

The method has also been applied to some local earthquakes that occurred in Hungary. The isotropic component of the moment tensor solutions is insignificant, implying the tectonic nature of the investigated events. The principal axes of the source mechanisms agree well with the main stress pattern published for the epicentral regions.

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3.2 Spectral estimation of source parameters for local earthquakes in the Pannonian Basin

(Bálint Süle)

Dynamic source parameters are estimated from P-wave displacement spectra for 18 local earthquakes ($1.2 < M_L < 3.7$) that occurred in two seismically active regions of Hungary between 1995 and 2004 (Süle 2010). Although the geological situation of the two area is quite different, their source parameters can not be separated. The source dimension ranges from 200 to 900 m, seismic moment from $6.3 \cdot 10^{11}$ to $3.48 \cdot 10^{14}$ Nm, stress drop from 0.13 to 6.86 bar and the average displacement is less than 1 cm for all the events. The scaling relation between seismic moment and stress drop indicates a decrease in stress drop with decreasing seismic moment. A linear relationship of $M_w = 0.71\ M_L + 0.92$ has been obtained between local magnitude and moment magnitude.

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3.3 Problems related to seismology and inner structure of the Earth

(Péter Varga)

In the frame of a German-Hungarian project (supported by DFG and HAS) and a collaboration with Italian scientists, we have analysed the global distribution of seismic events for magnitudes M $\geq$ 7.0, which release about 90% of the elastic energy of plate tectonics, using the Centennial Catalogue (CC). In this catalogue that extends from 1900 to April 2002 all available magnitudes for each earthquake have been reduced to a common, reliable value. Thus completeness is practically ensured for magnitudes $M_w \geq 7.0$. The CC has been updated by us to September 2007 by adding all the events with $M_w \geq 7.0$ from the USGS/NEIC global catalogue. This extended global catalogue contains 1719 events with $M_w \geq 7.0$ (Riguzzi et al. 2010).

If the assumption is made that the global seismicity with $M_w \geq 7.0$ is stable during the whole 20th century, we conclude that geographical coordinates and focal depths are of sufficient accuracy since the beginning of the 20th century, but the magnitudes are determined with sufficient accuracy only since the middle of 20th century.

The global earthquake catalogue of seismic events with $M_w \geq 7.0$, for the time interval from 1950 to 2007, shows that the depth distribution of earthquake energy release is not uniform. The 90% of the total earthquake energy budget is dissipated in the first ~30 km, whereas most of the residual budget is radiated at the lower boundary of the transition zone (410–660 km), above the upper-lower mantle boundary. The upper border of the transition zone at around 410 km of depth is not marked by significant seismic energy release. This points for a non-dominant role of the slabs in the energy budged of plate tectonics (Varga 2009, Varga et al. 2010).

The analysis of the global energy household of the Earth shows that energy income ($(0.94-1.15)\cdot 10^{22}$ J/year) composed by accretion ($5.4\cdot 10^{21}$), core formation ($3.3\cdot 10^{21}$), radioactive decay ($(0.6-1.9)\cdot 10^{21}$) and tidal friction ($(0.12-0.9)\cdot 10^{21}$) is in quasi equilibrium with energy expenditure ($1.3\cdot 10^{22}$ J/year) composed by conducted heat ($1.8\cdot 10^{21}$), convection heat ($4.6\cdot 10^{21}$) and global tectonic momentum ($7.7\cdot 10^{21}$). We have arrived to a conclusion that the effect due to tidal despinning influences the plate tectonic process through westward mantle flow (Varga 2008, Riguzzi et al. 2010).

The energy balance can be disturbed significantly by minor processes acting at global scale. From this point of view the effect of tidal triggering of earthquakes is discussed by the study of tidal stress tensor components expressed in spherical system of coordinates. Tidal friction influences through the despinning of the axial rotation the geometrical flattening. Present day accuracy of the length of day variations is not sufficient yet to detect spin variation generated by the greatest earthquakes. The polar motion is probably more sensitive to earthquakes and then there is a chance to detect the polar displacements generated by seismic events (Varga and Denis 2010).

The statistical comparison of temporal variation of earth magnetic and astronomical data shows close correlation of geomagnetic dipole momentum M_0 and ΔLOD (Length Of Day), what shows that there is a close relationship between variations of axial speed and core processes. It should be mentioned that the time-correlation is somewhat closer when the centred geomagnetic dipole is used for statistical modelling (Varga et al. 2007). At the same time significant fit was found between ΔLOD and all the components describing the eccentric geomagnetic dipole (M_0, orientation and eccentricity) too (Varga et al. 2008). The connection of geomagnetic field and the LOD was investigated in geological time-scale too. A significant ΔLOD was found which coincides in time with the geomagnetic Mesozoic low. The reason of this coincidence is enigmatic (Schreider et al. 2008).

Enceladus, one of Saturn's moons, shows significant volcanic activity identified by the Cassini spacecraft. We applied geophysical methods to study anomalic volcanic activity of this small heavenly body. Due to the inhomogeneity within Enceladus, 85% of the tidal energy is generated in a volume that contains just 39% of its mass. In time intervals of 3.0×10^8 and 5.3×10^8 years the temperature increase in the relative depth range $0.70 <= r/a_E <= 0.90$ is approximately 270° and 370° Kelvin, respectively (Varga et al. 2009).

We proposed the combined use of geodetic strain rate data and the seismic moment data set determined for past seismic events. This combination represents a new and independent approach to estimate future seismic activity. Using a modified version of Kostrov's (1974) equation and the catalogue of seismic moments, the minimum return period of the strongest earthquakes of a source area is estimated. It was found that the return periods in a given source zone in case of earthquakes $M_w \geq 9.0$ are of the order of some hundred years. For the large and medium earthquakes the expected Δt is well above some 10^3 years (Varga 2011a, 2011b).

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4. Deep structure of the Pannonian Basin

(István Kovács, János Kiss, Endre Hegedűs)

4.1 Active and passive seismic experiments in the wider Carpathian-Pannonian region

Following the successful CELEBRATION 2000 seismic experiment, new international seismic campaigns were organised in the particular time period (2007–2010, Carpathian Basins Project, ALPASS-DIPS) to get a deeper insight into the structure of lithospheric units building up the area. In addition, the processing and geological interpretation of the massive CELEBRATION 2000 dataset has been also progressing resulting in the publication of several papers in prestigious international journals. Special attention was paid to place the seismic sections such that major geological boundaries on the surface are crossed, and entire lithospheric units are covered. The aim was to cover all the important geological units including the ALCAPA, Tisza-Dacia, Western Carpathians, Bohemian Massif, Eastern Alps, Southern Alps and Dinarides. The Eötvös Loránd Geophysical Institute of Hungary (referred to as ELGI hereafter) contributed to these international efforts with providing instruments, setting-up and operating seismic stations, processing data and taking part in the geological interpretations with special respect to the Pannonian Basin. ELGI has had, and has been involved by, many major international partners in lithospheric research over the years: University of Leeds (Leeds, UK), University of Zagreb (Zagreb, Croatia), Vienna University of Technology (Vienna, Austria), Institute of Geophysics, Polish Academy of Sciences (Warsaw, Poland), University of Helsinki (Helsinki, Finland).

It seems that major lithospheric units could be identified on the seismic sections as these are generally characterised by distinct velocity distribution and Moho thickness. In the majority of the seismic sections abrupt changes in the depth of the Moho and lithosphere-asthenosphere boundary (LAB) coincide with major tectonic features on the surface (e.g., suture zones, fault zones, depressions). In many sesismic sections mantle reflectors were identified in 50–60 km depth roughly following the topography of the Moho. The seismic section could be also utilised as proxies to locate previous subduction zones in the area, which are important to reveal the geodynamic processes responsible for the present day geology of the area.

The Alp01 profile crossed the Eastern Alps in NNW-SSE direction and indicated gradual thickening of the lithosphere toward the south indicating the southward subduction of the European platform beneath Adria plate. The maximum lithospheric thickness is 47 km close to the boundary between the Eastern and Southern Alps. Alps02 is oriented in WEW-ESE direction from the Eastern Alps to the the Pannonian Basin through the Internal Dinarides. The section revealed an abrupt change in MOHO depth between the Internal Dinarides and the Pannonian Basin (Brückl et al. 2007)

The CEL10/Alps04 profile transects the Alps from the Southern Alps to the Bohemian Massif through the Molasse basin in a NE-SW direction. The lithospheric thickness decreases gradually from 42–44 km beneath the Alps to 38–40 km beneath the Bohemaian Massif (Grad et al. 2009).

The S04 profile investigated a NW-SE section stretching from the Bohemian Massif to the Pannonian Basin. The study found that there is an abrupt change in the Moho topography and crustal structures beneath major tectonic features such as the Pieniny Klippen Belt (separating the European platform from ALCAPA) and the Middle Hungarian Zone (dividing the ALCAPA and Tisza-Dacia units). The crust thickens gradually from ∼25km underneath the Pannonian Basin to 32–22 km beneath the Bohemian Massif. Mantle reflectors at 50–60 km depth were detected beneath the Western Carpathians and the Pannonian Basin (Hrubcova et al. 2010).

A detailed regional seismic study (Oeberseder et al. 2011) in the junction of the Eastern Alps, Western Carpathians and Little Hungarian Plain also identified reflectors in the upper mantle in 50–60 km depth, and the Moho depth reduces rapidly when entering the Pannonian Basin.

The Alp07 profile was investigated by both active and passive seismic experiments utilising analysis of receiver functions and integrating gravity analysis (Sumanovac et al. 2009). The Alp07 sections stretches from Istria through the Dinarides to the Pannonian Basin in a WSW-ENE direction. The Moho deepens towards the Dinarides from the Pannnonian Basin, reaching the maximum of ∼40 km depth. Three major lithospheric units were identified: the Dinaridic, the transitional and the Pannonian, which all have their distinct geophysical signatures. In the transitional zone signatures referring to the presence of subduction remnants (basaltic rocks) were identified. This zone coincides surprisingly well on the surface with the location of the Sava fault and the associated ophiolitic fragments.

Janik et al. (2010) investigated 8 seismic sections covering the stable European platform, Western Carpathians and Pannonian Basin. The Moho thickness decreases from 25 km beneath the Pannonian Basin to ∼45 km under the Western Carpathian and European platform. The ALCAPA appears to be slightly thicker in terms of Moho depth than the neighbouring Tisza unit. Mantle reflectors at 50–60 km depth beneath the Pannonian Basin and Western Carpathians were identified dipping gently towards the north. The geophysical features support the idea that soft collision took place between the ALCAPA unit and the stable European platform with only moderated degree of convergence.

A detailed re-interpretation (Posgay et al. 2009) of the Pannonian Geotraverse-1 (PGT-1 for short) brought new interesting results into the light, suggesting that some faults can penetrate the entire lithosphere, and irregularities at the depth of both the Moho and LAB can be correlated against surface features as the Middle Hungarian Zone. The ALCAPA and Tisza units appear to be distinct units at lithospheric scale and show distinct geophysical features (e.g., distinct amplitudes in the units may be reflecting the different petrological features of these units).

Dando et al. (2010) processed the first results of the Carpathian Basins Project (i.e., a broad band seismic network covering mainly the western part of the Pannonian Basin in NW-SE direction from the edge of the Bohemian Massif to the Serbo-Macedonian Massif crossing perpendicular the Middle Hungarian Zone, which separates the ALCAPA and Tisza units). The tomography showed an E-W oriented sublithospheric structure stretching from the Eastern Alps towards the Carpathians. The tomography also identified geophysical signatures implying mantle down welling beneath the Pannonian Basin which in turn results in compressional forces in the surroundings which may be responsible for the folding and emerging of the Carpathian arc.

Beyond the Carpathian-Pannonian region the ELGI took part in a seismic experiment on the Fennoscandian Shield in Finland (HUKKA 2007) which managed to reveal so far unknown tectonic boundaries separating lithospheric units with different age and tectonic history.

4.2 Investigation of the lithosphere using xenoliths and experimental petrology

The ELGI in cooperation with the Australian National University (Canberra, Australia) contributed to an experimental petrology project (Green et al. 2010) that aimed at reinvestigating the water-saturated solidus of the fertile upper mantle combined with Fourier-transform infrared (FTIR) spectroscopy. The study revealed that the amphibole (pargasite) is the most important water (OH-) bearing mineral in the upper mantle and its breakdown and melting at 3 GPa or ~ 1050°C causes an abrupt weakening in the lithosphere. This process main explain the global presence of a low velocity zone at $\sim$100 km depth. The study demonstrated that the water capacity of the fertile upper mantle is about $\sim$180 ppm after a small degree of partial melting, which is in line with independent estimates for the MORB mantle.

Falus et al. (2008) (in collaboration with the University of Montpellier, France) studied mantle xenoliths from the Persanyi Mts. (Eastern Carpathians) to arrive to the conclusion that anisotropy patterns in the studied xenoliths likely to be the consequence of convergence driven belt-parallel flow. The silicate minerals show water concentrations similar to areas affected by contemporaneous subduction.

By Kovács et al. (2010) was concluded that an eastward oriented asthenospheric flow originating from the Alpine collision belt could be responsible for seismic anisotropy directions in the Carpathian-Pannonian region and deformation patterns in mantle xenoliths from the ALCAPA block. This asthenospheric flow may be, in addition, a new driving force explaining the mainly Miocene extrusion and extension of lithospheric units.

4.3 Examination of the changes occurring in gravity Bouguer anomaly after the isostatic corrections in Hungary

The Bouguer-anomaly map shows an integrated image of the geological structures of the studied area which depends on the density distribution of the rocks. It means that Bouguer anomaly map gives a summarized gravitational effect of all formations to be found from the surface until a depth of several tens of kilometres.

For several decades the Bouguer anomaly map has been used as an essential base map in geological prospecting for raw materials and thermal water, in geothermal exploration and geological mapping or in other words in applied geophysics. Despite this practice there is a special part of the gravity anomaly field what we have not dealt up to now with, though it may have an effect on geological interpretations.

There is some regional isostatic based root and antiroot effects in the Bouguer anomaly map of Hungary. Using the Airy-Heiskanen local isostatic compensation we tried to minimise effects of these (Moho level) changes.

The different depths of the Moho in Central-Europe is determined by different crust thicknesses of the Carpathian Basin and its surrounding mountains (Alps, Carpathians and Dinarides) which are connected to the isostatic antiroots of the deep sedimentary basins and isostatic roots of the mountain regions.

Using isostatic corrections we can get a more useable Bouguer anomaly map, which reflects more accurate the known near surface geological construction.

4.4 Gravity, geomagnetic, magnetotelluric and seismic modelling and interpretation along regional profiles

There are some regional/country-size geophysical profiles, where gravity, magnetic, seismic, and sometimes magnetotelluric data were already available, for example along the CEL7 and CEL8 lines of CELEBRATION 2000 international lithospheric research program.

Interpretation of deep and regional profiles, having first-arrival seismic tomography data is not a simple problem. Control borehole data are available only from the uppermost 5 km. Other geophysical measurements could provide useful additional data to the geological interpretation, but only magnetic and gravity data are available, which cover the whole area of Hungary. Along the CEL7 seismic profile the ELGI and the MTA GGKI carried out magnetotelluric measurements with the point density of the seismic measurements. By now, due to seismic and magnetotelluric measurements we have got a data base, which is appropriate not only for lithosphere studies.

The basement depth, the upper crustal structures, the places of magmatic intrusions and other information are important elements of the Earth's crust. The geological interpretation of the tomographic sections of deep seismic profiles takes an interesting turn because of the comparison with potential field data.

The elements of geological construction can be determined in a much more reliable way from the joint interpretation of seismic, magnetotelluric, gravity and geomagnetic measurements, than from individual measurements.

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5. Geodynamics and tectonophysics

5.1 Modeling thermal mantle convection

(Attila Galsa, László Lenkey and Bálint Süle)

In order to study the nature of the thermal convection occurring in the Earth's mantle, numerical calculations have been carried out in which the physical properties of mantle plumes have been investigated in highly viscous thermal convection depending on the Rayleigh number (Ra). Boussines approximation was applied in a three-dimensional Cartesian domain filled with isoviscous, purely bottom-heated fluid with infinite Prandtl number. In order to monitor the dynamical behaviour of plumes, an automatic plume detecting routine (PDR) was developed based on the temperature between the plume and its surroundings (Galsa and Lenkey 2007).

It was established that as the convection becomes more vigorous with increasing Rayleigh number, the average cross-sectional area of an individual plume decreases (appr. $\sim Ra^{-2/3}$), the vertical velocity in plumes increases ($\sim Ra^{2/3}$), while the average temperature in plumes is independent of Ra. It means that the volume and the heat transport in an individual plume is independent of the Rayleigh number. The number of plumes forming in the box increases ($\sim Ra^{1/3}$) which is in accordance with the scale analysis using the energy balance and the conservation of momentum. Furthermore, the Rayleigh number influences the temporal behaviour of the average surface heat flow (Nusselt number – $Nu_0(t)$) and the heat advected by plumes ($Tw_p(t)$). The characteristic frequencies of $Nu_0(t)$ and $Tw_p(t)$ increase by $\sim Ra^{2/3}$ in agreement with the rate of increase of the vertical velocity in plumes. The characteristic frequencies of $Nu_0(t)$ and $Tw_p(t)$ are between the frequency corresponding to the time necessary for a plume to rise from the bottom to the top of the layer and the frequency of a whole convective cycle. The time series of $Tw_p(t)$ contain larger amplitudes and higher frequencies than $Nu_0(t)$. It was assumed that the heat in the top thermal boundary layer (TBL) propagates by conduction and using $Tw_p(t)$ as an input at the bottom of the top TBL the amplitude and the frequency of the heat flow series on the surface was calculated. It corresponds very well to the amplitude and the frequency of the observed $Nu_0(t)$. The correlation analysis between the time series of the surface Nusselt number and the heat advected by hot plumes showed that the time delay between the time series is equal to the time of the heat propagation by conduction through the TBL. The correlation between time series $Tw_p(t)$ at different depths demonstrated well that the main heat transfer mechanism in plumes is advection.

Another main goal was to speed up and automate the run of codes calculating the characteristics of thermal convection. In collaboration with the MTA SZTAKI Application Porting Centre a new method was developed to port the NMMC3D (numerical modeling of mantle convection in 3D) code on the SEE-GRID-SCI Infrastructure parallel system. The applied tool (P-GRADE grid portal) supported effectively the parameter studies in which the effect of the Rayleigh number and the viscosity distribution was investigated on the mantle plume characteristics and surface manifestation. Simple depth-dependent (including asthenosphere, lithosphere and D" layer) and a depth- and temperature dependent viscosity profiles were studied while the Rayleigh number varied in the range of $10^5 - 10^7$ (Kozlovszky et al. 2010).

It was established that the low viscosity layer just above the core-mantle boundary (D" layer) increases the heat flow from the core and heats the mantle. A high viscosity lithosphere near the surface has similar effect on the thermal structure of the Earth's mantle, since it reduces the outward heat flux. However, a low viscosity astenosphere below the lithosphere facilitates the heat transport toward the surface, thus it cools the convecting system. Using depth-dependent viscosity profiles (viscosity increased exponentially with depth) the heat transport is moderated especially in the deeper region of the mantle, since the higher viscosity slows down the flow velocity. On the other hand, if the viscosity depends on the temperature (viscosity exponentially decreases with the temperature), the heat transport from the Earth's core is more efficient, which has an opposite effect on the global temperature structure. As a consequence, the temperature-dependent viscosity decreases the temperature anomaly between the mantle plume and its surroundings; additionally, the increasing Rayleigh number intensifies this effect. In conclusion, the low viscosity zone above the core-mantle boundary (D" layer), the high viscosity layer below the surface (lithosphere), the depth- and temperature-dependent viscosity as well as the high Rayleigh number characterizing the mantle push the flow system in the direction of having a moderate plume temperature excess (200–300 K) as it is in the Earth's mantle.

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5.2 Lithospheric evolution in the Pannonian Basin

(Endre Dombrádi and Frank Horváth)

We presented a new compilation of data on the present-day stress pattern in the Pannonian Basin, and its tectonic environment, the Alpine-Dinaric orogens. Extensional formation of the basin system commenced in the early Miocene, whereas its structural reactivation, in the form of gradual basin inversion, has been taking place since Pliocene to recent times. Reconstructed compression and associated horizontal contraction are mainly governed by the convergence between Adria and its buffer, the Alpine belt of orogens. The resulting contemporaneous stress field exhibits important lateral variation resulting in a complex pattern of ongoing tectonic activity. In the Friuli zone of the Southern Alps, where thrust faulting prevails, compression is orthogonal to the strike of the mountain belt. More to the southeast, intense contraction is combined with active strike-slip faulting constituting the dextral Dinaric transpressional corridor. Stresses are transferred far from Adria into the Pannonian Basin, and the dominant style of deformation gradually changes from pure contraction through transpression to strike-slip faulting. The importance of late-stage inversion in the Pannonian Basin is interpreted in a more general context of structural reactivation of backarc basins where the sources of compression driving basin inversion are also identified and discussed. The state of recent stress and deformation in the Pannonian basin, particularly in its western and southern part, is governed by the complex interaction of plate boundary and intra-plate forces. The counterclockwise rotation and north-northeast-directed indentation of the Adriatic microplate appears to be of key importance as the dominant source of compression ("Adria-push"). Intra-plate stress sources, such as buoyancy forces associated with an elevated topography, and crustal as well as lithospheric inhomogeneities can also play essential, yet rather local role (Bada et al. 2007).

The role of lithospheric folding in the Quaternary inversion of the Pannonian Basin was investigated by a series of analogue models. To this aim, build-up of stresses due to intraplate compression in the hot and weak Pannonian lithosphere, changes in the style of deformation and related surface processes were modelled. The primary response of the lithosphere to compression appears to be deformation in the form of large-scale folding. As a consequence of the folding, differential crustal motions occur, affecting present-day surface morphology and landscape processes. The analogue experiments examined folding mechanisms of the hot Pannonian lithosphere characterised by extremely low strengths except for a thin layer of brittle upper crust. Modelling results confirmed the existence of a large wavelength (350–400 km) component of deformation accounting for large-scale vertical crustal motions. The amplitude of folding is sufficient to generate the amount of observed uplift and subsidence. Our analogue models, supported by the results of stress analyses, suggest that despite the low rate of convergence between the Adriatic microplate ("Adria-push") and the European plate, the weak Pannonian lithosphere has been an efficient transmitter of compression during the basin inversion. Crustal thickness variations are of key importance in governing regional deformation pattern and influence the timing and extent of the basin inversion. Effects of alternating strong and weak units in the brittle crust were also examined by means of two series of conceptual models, in which the order of thin and thick crustal blocks was opposite. Strain localisation in the brittle crust was strongly controlled by the moderate initial thickness variations. The concept gives a plausible explanation for the presence of anomalous rates of uplift and subsidence and multi-wavelength folding inside the basin. Models taking into account horizontal movements due to lateral extrusion were constructed with an oblique face of the indenter. This kinematic boundary condition resulted in a complex internal structure of the folded layers. The presented analogue experiments, together with previous numerical modelling studies, demonstrate the link between large-scale lithospheric folding and topography evolution in the Pannonian Basin system (Dombrádi et al. 2010).

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5.3 Crustal deformation

(Zoltán Bus)

The seismicity and the associated seismic hazard in the central part of the Pannonian Region is moderate. However, the vulnerability is high, as three capital cities are located near the most active seismic zones. By Bus et al. (2009) two seismically active areas, the Central Pannonian and Mur-Mürz zones, have been considered in order to assess the style and rate of crustal deformation using Global Positioning System (GPS) and earthquake data.

The data of continuous and campaign GPS measurements obtained during the years 1991–2007 have been processed. Velocities relative to the stable Eurasia have been computed at GPS sites in and around the Pannonian Basin. Uniform strain rates and relative displacements were calculated for the investigated regions. GPS data confirm the mostly left lateral strike slip character of the Mur-Mürz-Vienna basin fault system and suggest a contraction between the eastward moving Alpine-North Pannonian unit and the Carpathians.

The computation of the seismic strain rate was based on the Kostrov summation. The averaged unit norm seismic moment tensor, which describes the characteristic style of deformation, has been obtained from the available focal mechanism solutions, whereas the annual seismic moment release showing the rate of the deformation was estimated using the catalogues of historical and recent earthquakes.

The results reveal that in the Central Pannonian zone the geodetic strain rate is significantly larger than the seismic strain rate. Based on the weakness of the lithosphere, the stress magnitudes and the regional features of seismicity, it is suggested that the low value of the seismic/geodetic strain rate ratio can be attributed to the aseismic release of the prevailing compressive stress and not to an overdue major earthquake. In the Mur-Mürz zone, although the uncertainty of the seismic/geodetic strain rate ratio is high, the seismic part of the deformation seems to be notably larger than in the case of the Central Pannonian zone. These results reflect the different deformation mechanism, rheology and tectonic style of the investigated zones.

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5.4 Seismotectonics

(László Tóth)

Seismicity in the Pannonian Basin and surrounding East Alpine-Dinaric orogens indicates that deformation is mainly concentrated along Adria's boundaries where pure contraction (thrusting in Friuli and the southeastern Dinarides), often in combination with transform faulting (dextral transpression in the central Dinarides), is predominant (Bada et al. 2007, Bus et al. 2009). Tectonic stresses and deformation are transferred into the Pannonian Basin, resulting in a complex pattern of ongoing tectonic activity (Tóth and Mónus 2009). From the margin of Adria toward the interior of the Pannonian Basin, the dominant style of deformation gradually changes from pure contraction, through transpression, to strike-slip faulting. Shortening in the basin system, documented by earthquake focal mechanisms (Tóth et al. 2009), global positioning system (GPS) data, and the neotectonic habitat, has led to considerable seismotectonic activity and folding of the lithosphere. As Bada et al. (2007) concluded the state of recent stress and deformation in the Pannonian Basin is governed by the interaction of plate-boundary and intraplate forces, which include the counterclockwise rotation and N-NE-directed indentation of the Adria microplate ("Adria-push") as the dominant source of compression, in combination with buoyancy forces associated with differential topography and lithospheric heterogeneities.

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6. Other IASPEI related activities

6.1 Impact structure studies in Hungary

(Tamás Bodoky)

In the last few decades geoscientists has gradually realized the significance of collisions of extraterrestrial bodies with Earth and an intensive research was started to discover traces of impacts and study their geological features and their effect on their neighbourhood (French 1998).

In Hungary there are no any known traces of possible impacts on the surface, but there are rather dense geophysical data systems covering the entire country and so to find craters hidden below the surface one can make use of their geophysical signature usually differing well from those of the adjacent areas (Pilkington and Grieve 1992, Bodoky 2004). Consequently we have investigated the national geophysical data bases and basic maps looking for characteristic signatures of hidden impact structures. Up to now three interesting locations have been chosen for study, on the first study area, on the so called "Magyarmecske area", the investigations have been carried out and are finished already, thus we report activities and results on that area.

A more or less circular high-amplitude telluric conductivity anomaly (CA) is located at Magyarmecske, in south-western Hungary (Nemesi et al. 2000). Several attempt were made to interpret the anomaly and to find its geologic reason, but none of them could provide a geologic model answering all the questions arisen in connection with the anomaly (Ádám 1980, Nemesi et al. 1985, Ádám et al. 1990, Nemesi et al. 2000).

If the geology in the close vicinity of the Magyarmecske telluric CA is summarized from the point of view of geophysics, then a rather simple three layer model is obtained. The deepest layer is the old crystalline basement, which is overlain by thick Carboniferous sedimentary formations making up the second layer, while the uppermost (third) layer is formed by the Neogene sediments covering the area (Baranyai and Jámbor 1963, Kassai 1983, Barabás and Barabásné Stuhl 1998, Jámbor 1998, Szederkény 1998). Nemesi et al. (1985, 2000) indicated that the anomaly is linked to a funnel-like depression of the basement, and inferring from data of the boreholes of the wider surroundings, that it is in all probability filled with a thinly-layered Carboniferous meta-anthracite sequence responsible for the conductivity anomaly. They mention that the depth of the high-velocity seismic refraction basement and that of the high-resistivity geoelectric basement differ significantly from one other; the difference can be as large as 2 km in the centre of the anomaly. On the other hand, the seismic velocities of the refracting basement decrease by 15–20% in the area of the anomaly (Nemesi et al. 2000). Concerning the interpretation of the Magyarmecske telluric CA, several questions have arisen (Majoros 2000).

We studied the geology of the area of the anomaly and its neighbourhood, and collected and reinvestigated all available geophysical data previously measured here. Those data include gravity, magnetic and telluric conductivity maps, magnetotelluric and vertical electrical soundings, seismic refraction data, seismic reflection profiles and the morphology (even the paleo-morphology) of the surface (Bodoky et al. 2004, 2006, 2007).

Geologic and geophysical data of the study area confirm the earlier interpretation, which attributes the Magyarmecske telluric CA to graphitized Carboniferous coal beds (Ádám 1980); there is no evidence pointing to any other possibility. However, if this is accepted, then the manner in which graphitization occurred, and the reason for its only occurring at this location, require explanation.

Based on the described geophysical signature of the studied area the conclusion was reached that the geologic-geophysical phenomenon known in Hungarian literature as the "Magyarmecske telluric conductivity anomaly" can be better explained as an impact structure. It might have originated through a cosmic body impacting the surface of the Carboniferous formations. As a consequence of the impact a single-ring complex crater was formed, with an outer diameter of 6–8 km. The projectile hit the surface of the Carboniferous sequence and the impact's extreme heat and extreme pressure graphitized the coal beds within it. Thus graphite is connected only to the impact structure, or perhaps only to its inner zones, i.e. to the crater fill and to the fractured and brecciated zone. The impact theory is also supported by the decrease of refraction velocities on the telluric CA. There is probably no any funnel-like depression at the Carboniferous-crystalline interface, but the fractured zone does penetrate the crystalline rocks and the electrical "high-resistivity basement" indicates its base (Bodoky et al. 2004, 2006, 2007).

It is concluded that, in order to explain the origin of the Magyarmecske telluric CA, the most complete answer can be obtained with the impact theory; however, without further geologic and mineralogical evidence, the anomaly itself should only be classified as a "possible impact structure" (http://omzg.sscc.ru/impact/english.html) (Bodoky et al. 2007).

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