Geodynamically active areas in Central Europe determined on the bases of GPS measurements: kinematic models

Lubomil Pospíšil[1] , Jan Hefty[2] and Otakar Švábenský[1]

*Abstract: The region of Central Europe, Adriatic region and Balkan Peninsula were subjects of geo-kinematical monitoring in several projects performed since 1992. Independent GPS epoch-wise observing campaigns took place in several regions and the whole territory is now covered by tens of permanent stations. The long-term observational series from permanent stations generally yield reliable site velocities, however distribution of such stations is not dense enough to provide velocity field with sufficient resolution all over the monitored region. On the other side the epoch-wise campaigns sites are much denser than the permanent ones, however the repeated epoch observations are not very frequent and their referencing is not unique.**

In the paper we shortly describe velocity fields available from various national and regional GPS geo-kinematics projects and an attempt to analyzed and interpret the homogenized the velocity fields in relationship to pozition of the important tectonic zones located in the Central Europe.

Two examples of the complex geodetic and geological-geophysical interpretation from the Bohemian Massif and the Western Carpathians offer next possible explanation and solution for tectonic zones where the geo-kinematics is mostly variable and complicated.

Key words*: Bohemian Massif, geodesy, GPS, geophysics, geodynamics, seismic hazards*

1. Introduction

The most recent studies on the lithosphere of Central Europe (Nemčok et al., 2006, Csontos et al., 1992, Fodor et al., 1999, Cloetingh et al., 2003 and others) mainly based on the complex analysis of geological, geochemical, structural and geophysical data (especially seismic, seismological and magnetotellurical data were used), allowed the creation of the appropriate model of the genesis in the area of the Alps, the Carpathians and the Pannonian Basin for the period from the Late Miocene to the recent.

More complicated situation arises in surveying of the geodynamical conditions for this period in the area of the Bohemian Massif and the boundary areas of the East European Platform.

In the article we deal with the possibility of usage of the comprehensive geodetical, geological, and geophysical knowledge for determination of the critical areas that might from recent point of view (from the geodynamical and mainly seismotectonic point of view) represent major risks for the area of the Central Europe (Fig. 1). On two chosen areas – Diendorf-Čebín tectonic zone (DCTZ) and Muráň-Malcov tectonic zone (MMTZ) – we shortly demonstrate results of the GPS and geophysical analyses, that enable to separate critical locality with possible higher seismic risk.

2. Definition of risk area

The risk areas can be divided into several categories or groups respectively. Each one has different scope and risk degree on the surrounding environment and can be simply divided following way:

A) Category combined with processes related to the Lithosphere/Asthenosphere level
   a. Pos-subduction and subduction areas.
   b. Rift and recent graben.
   c. Continental paleo-sutures.

As a representative of areas where the influence and impingement of processes at the lithosphere/asthenosphere level prevail, in the Central Europe mainly area of the Pannonian Basin and intensive seismoactive Vrancea Area can be mentioned.

In this territory, during late Tertiary the rollback subduction process has been generally accepted (Nemčok et al. 1998a, 2006a). The retreating subducting slab under the advancing Carpathian orogen, the oblique closure of the remnant Carpathian Flysch Basin (rCFB), the progressive change of subduction to collision from west to east along the Carpathian arc drove a scissors-like break-off of the subducting oceanic slab along the Carpathians. The break-off was driven by the weight of the subducting oceanic slab and buoyancy of the attached continental slab. The break-off ran eastwards along the whole Carpathian arc, from the Early Miocene, to its present position in the bend between the East and South Carpathians (Nemčok et al. 1998, 2006).

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[1] *doc. RNDr. Lubomil Pospíšil, CSc., prof. Ing. Otakar Švábenský, CSc.* Institute of Geodesy, Faculty of Civil Engineering, Brno University of Technology Veveří 95, 602 00 Brno Czech Republic, e-mail: pospisil.l@fce.vutbr.cz

[2] *prof. Ing. Jan Hefty, PhD.,* Department of Theoretical Geodesy, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11, 813 68 Bratislava, Slovak Republic, e-mail: jan.hefty@stuba.sk

It can be supposed, that the processes at lithosphere/asthenosphere boundary will continue during next several tenth million years (Székely et al. 2002, Nemčok et al. 1998a) and will be the affecting also recent tectonic condition of this territory (Pospíšil et al., 2012).

B) Category combined with processes related to crustal level are much more actual and dangerous and there are combined with following tectonic features:
   a. transcurrent tectonic zones, separating of blocks and main geological units,
   b. single faults of strike-slip type or reverse fault,
   c. volcano-tectonic areas,
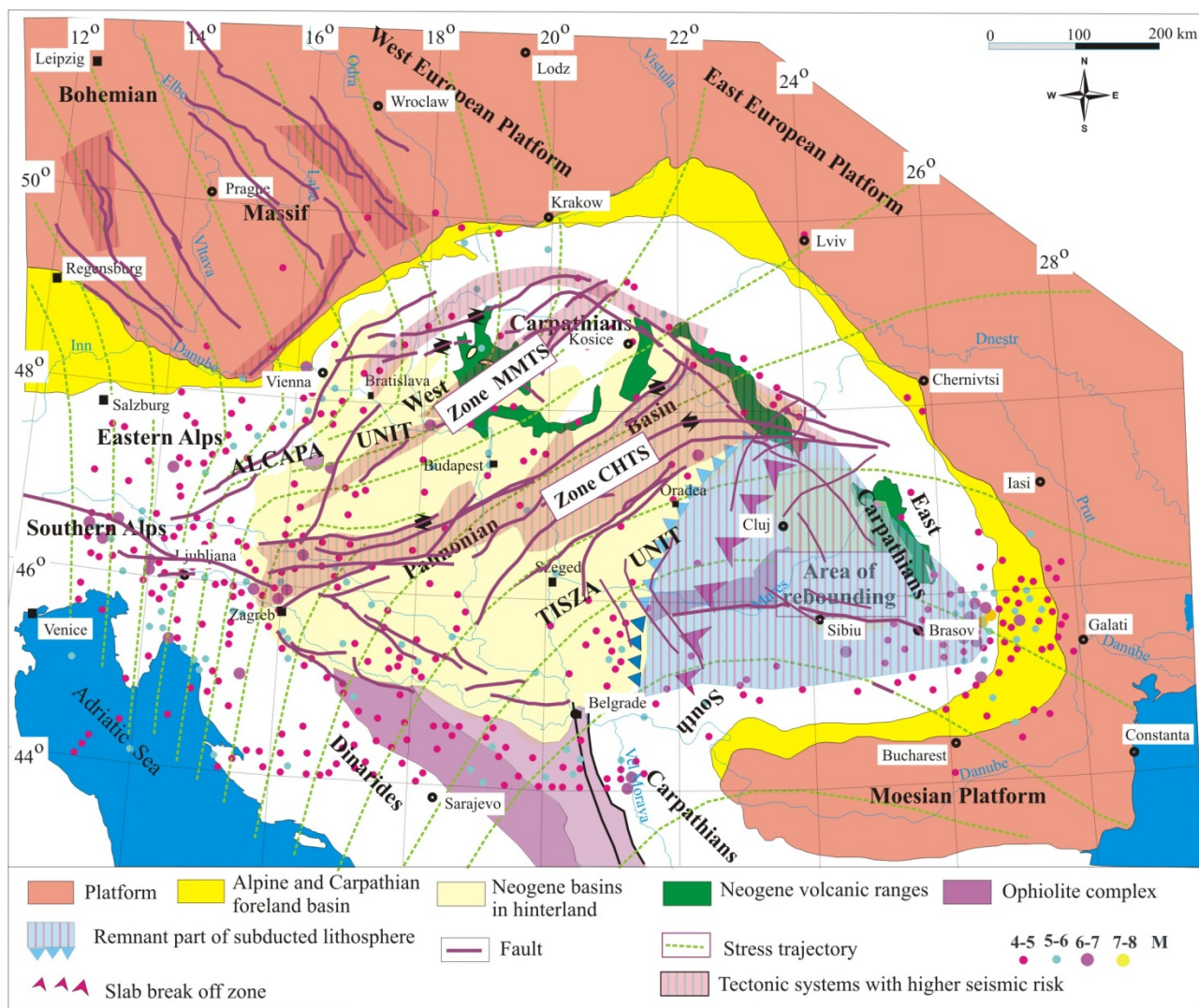   d. surface deformations combined with the stability of rocks massifs.

Fig. 1. *The map of Central Europe with drowned risk areas in Bohemian Massif (BM) and Western Carpathians. Seismological data and stress trajectories are modified after (Zsiros in Pospíšil et al. 2006, Bada et al., 2001, Cloetingh et al. 2003). Area I - Western part of BM (Saxothuringian and Teplá-Barrandian contact zone). Area II – the Sudetic area, Area III – DCTS - zone Diendorf - Čebín tectonic system at eastern margin of BM, Area MMTS – zone of Muráň-Malcov tectonic system, Area CHTS – zone of the Central Hungarian tectonic system.*

Dynamic processes, taking place at upper and middle crustal levels, have a most worldwide distribution. Co-exist; crustal deformations represent the hazards for the settled areas. For example for the Bohemian Massif, first two categories represent the largest risk, on the other hand in Carpathian–Pannonian Area the structure of all fours categories can be found. With regards to Variscan building of the BM and its small Alpine involvement often this both categories can be combined to one.

Already several decades attention of tectonophysicists, seismologists and mainly geodesists specialized on GPS surveying is concentrated to the Western Bohemian region (Kraslice area - e.g. Horálek et al. 2004), on problematic of Hronov–Poříčí fault, to region of Kralický Sněžník Mts (Schenk et al. 2010, Švábenský and Weigel 2004) and Sudetes (Kaplon and Cacon 2009, Kontny et al. 2000; Kaláb et al. 2007 and others). By the 90´s the research of new earthquake foci, evaluation of monitoring networks have been intensively increased and improved.

The fundamental methodology of detection of movement tendencies in BM is based on the utilization of the continental permanent GPS monitoring networks, supplied by annual epoch-wise measuring campaigns. Second one is organized by domestic and international teams of experts from academies and universities. Repeated precise levelling and gravity measurements belong to next used methods (Horálek et al. 2004, Pospíšil et al. 2009, 2010, 2012, Švábenský et al., 2011). Other methods as detail morphological and structural studies or accompanying geotechnical works are completely missing in application of many projects. Local geotechnical and structural researches are exceptional.

Similar situation there is in the Carpathian–Pannonian space. Grenerczy (2002), Grenerczy et al. (2000), Hefty (2007), Hefty et al. (2006, 2005), and others processed complete results from realized GPS campaigns to unified map of movement tendencies in the Carpathian–Pannonian area (Hefty, 2006).

From this reason we started, beginning in year 2002, to build a geodetic, Remote Sensing, and geophysical database at the Brno University of Technology in a form convenient for multidisciplinary studies of the movement tendencies. Recently more than 65 thematic layers are available, including attribute information (e.g. Grav/Mag maps, complex geophysical and geodetic data, recent vertical movements, seismic data, seismotectonic data, wells, etc.). In many localities there are very detailed data incorporated that can be used for any detail analyses up to scale 1:10,000, too (e.g. Diendorf–Čebín Tectonic Zone—DCTZ, Muráň–Malcov Tectonic System—MMTS, Central Hungarian Tectonic System - CHTS).

The geodatabase has been supplied by the horizontal and vertical velocities gained from the region of Central Europe, Adriatic region and Balkan Peninsula (Fig. 2), which were subjects of geo-kinematic monitoring in several projects performed since 1992. Independent GPS epoch-wise observing campaigns took place in several regions and the whole territory is now covered by tens of permanent stations (Hefty 2007, Hefty et al., 2009). The long-term observational series from permanent stations generally yield reliable site velocities, however, distribution of such stations is not dense enough to provide velocity field with sufficient resolution all over the monitored region. On the other side the epoch-wise campaigns sites are much denser than the permanent ones, however, the repeated epoch observations are not very frequent and their referencing is not unique. In the paper we used the homogenized velocity fields available from various national and regional GPS geo-kinematic projects and an attempt to evaluate with regards to geophysical and geological data from two – geologicaly different areas. Important role played data of the recent vertical movements processed for area of the Central Europe by Joó in Pospíšil et al. (2006), Joó et al. (1987) and Vyskočil (1996).

3. Velocity field resulting from GPS reprocessing

The complex analysis based on relevant GPS observations performed on the territory of Slovakia and close territories was performed by the method using the combination of reprocessed homogenized long-term GPS measurements provided by permanent and epoch-wise GPS stations. The input RINEX data are from 55 permanent and 63 epoch-wise GPS stations covering reasonable time span to estimate the geo-kinematical behaviour of the monitored areas. These data originate from one permanent and four epoch-wise GPS networks.

First of all we have to mention that all of the data were reprocessed respecting the rules given by CEGRN (Central European Geodynamic Reference Network) consortium and applied e.g. in (Hefty et al., 2009). The main features of reprocessing realized by Bernese GPS software version 5.0 (Dach et al. 2007) were as follows: Processing at daily intervals (0-24 h UT), celestial reference frame realized by IGS (International GNSS Service) orbits and the corresponding Earth Rotation Parameters since 2006. Before this date the reprocessed global GPS network data were used (Steinberger et al. 2006). The elevation cut off angle of 10° was applied in case of epoch stations and 3° elevation cut off in case of permanent network. Constraints of 0.0001 m were adopted to station positions of the reference point in order to reference the network solutions to the ITRF2005. As concerns the troposphere modelling the Niell mapping function was applied with elevation dependent weighting and station zenith delays were estimated at hourly intervals. Satellite and receiver antenna eccentricities were taken from the IGS05 absolute calibration model and the ocean loading model FES2004 was used.
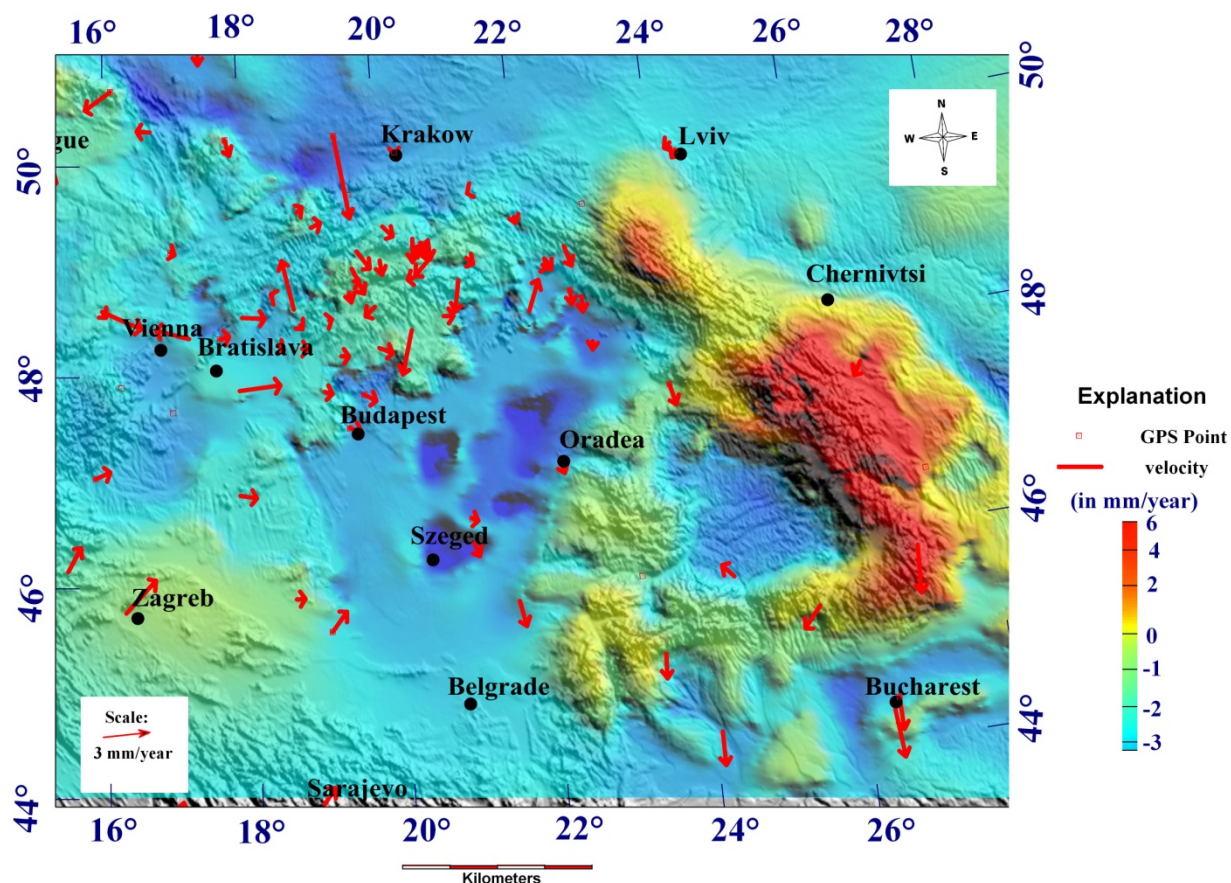
Fig. 2. Area of interest with the location of the GPS station supplied by map velovities vectors (Hefty, 2007, Pospíšil et al., 2012) and Map of Recent Vertical movement (Joó in Pospíšil et al. 2006).

Velocities were estimated by the combination model of CATREF software (Altamimi et al. 2009) based on 7-parameters similarity transformations assuming that for each individual solution and each point we have position at the epoch of observation and velocity expressed in a given reference frame. The estimated parameters represent translations, rotations and scale factor of each individual frame, stations positions expressed at reference epoch and appropriate velocities related to the combined frame. All the input and output data are provided in SINEX format. The datum definition is ensured by minimum constraint approach supposing the minimization of transformation parameters between individual and combined frame. The most delicate procedure of the combination is the discontinuities identification. These phenomena are most commonly caused by antennas manipulations, receiver changes, monumentation modification, random changes, earthquakes etc. Discontinuities are relatively easy to identify in time series of permanent stations but they are almost undetectable in case of epoch-wise points

The estimated horizontal velocities obtained from final combination of the five mentioned networks are shown in Figure 2 (Hefty 2007, Hefty et al., 2009, Pospíšil et al., 2012) for the whole region of interest and in Figure 3 (Pospíšil et al., 2012) focused on the territory of Slovakia. Final combination set contains ITRF2005 related coordinates, velocities and appropriate covariance matrix of 118 stations. The presented velocities were obtained after reduction for APKIM2005d plate motion model which is supposed to be the most representative for the investigated area. As it is visible from the plottings, the orientation, magnitude and accuracy of the velocity vectors is variable and heterogeneous. Magnitude of estimated velocities varies from 1 to 3 mm/year, their uncertainties are from 0.2 to 1.1 mm/year.

When comparing the horizontal velocities obtained from the above mentioned analysis methods we observe a good consistence of both velocity fields at the level under 1 mm/year. Thanks to this conclusion we may use the velocities in Figures 2 as homogeneous and apply them for further analyses.
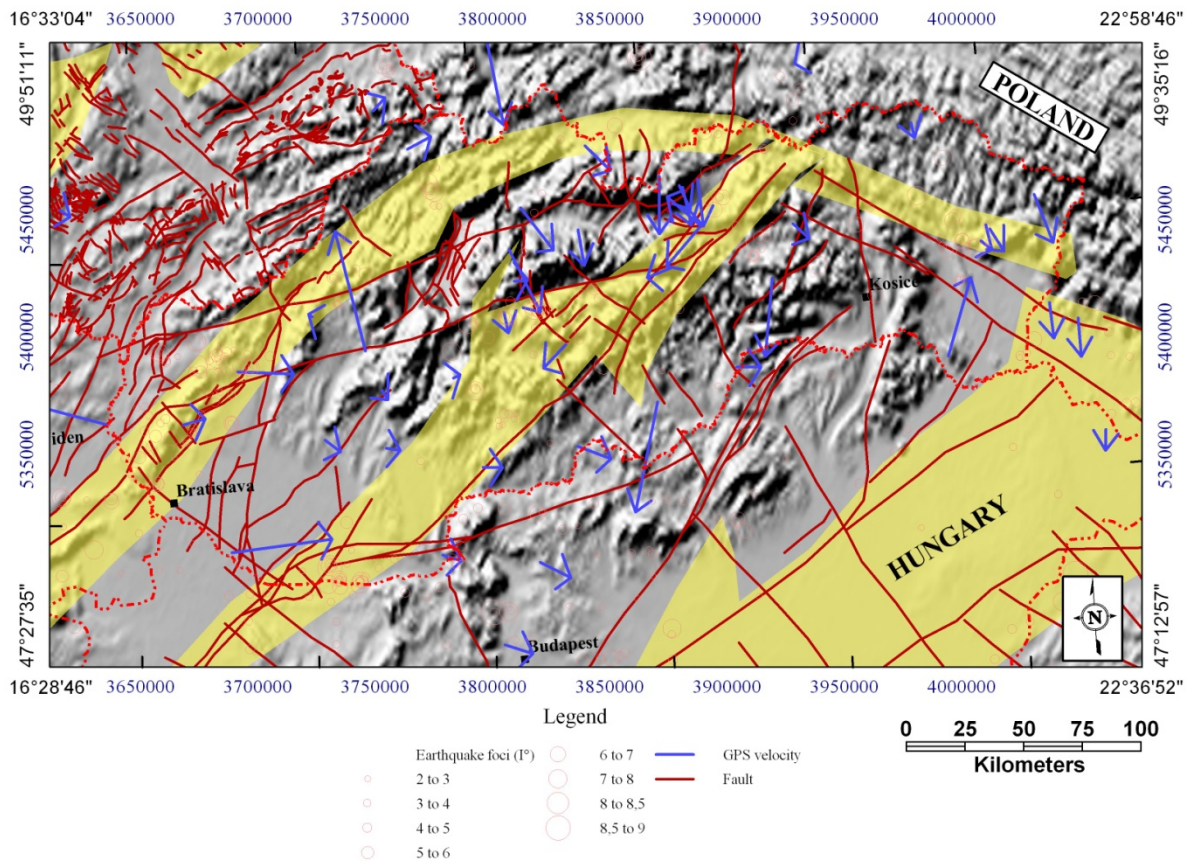
Fig. 3. The estimated horizontal velocities obtained for the whole territory of Slovakia. Yellow bends - risk zones.

4. The recent vertical movements

The vertical movement tendencies are presented in the Map of Recent Vertical Movements (RVM) of the Central European region (Fig. 2), which has been compiled on the basis of published maps and data from several sources. The basic source create the Map of (RVM) constructed by Joó (see in Pospíšil et al. 2006), which represents the 20 years repeated periods of the precise leveling measurements (Jóo et al. 1987, Joó in Pospíšil et al. 2006).

The areas of the West Carpathians and Bohemian Massif were evaluated on the basis of the RVM maps and the results of Vyskočil (1996), Vanko and Vyskočil (1987), Kowalczyk (2006) and Wyrzykowski (1985).

The dominant uplifted tendencies of the vertical movements are observed in the most anomalous triangle area set bound to connecting line of towns Czernovcy, Brasov, and Beograd (Fig. 2). In this area, which comprises the East Carpathians and margin of the East European and Moesian Platforms, the uplift riches to 6–7 mm/yr whereas the Northeastern Carpathians uplifted to 4.4 mm/yr.

For the geodynamic study and analyses of the kinematics in the all Central European region the new map of the recent movement tendencies has been compiled (Fig. 2) on the basis of the all above mentioned RVM data (Joó in Pospíšil et al. 2006, Székely et al. 2002, Vanko and Vyskočil 1987, Kowalczyk 2006) an supplied by the latest results of the velocity vectors gained from the GPS measurements.

5. Examples of analyses geodynamicaly risk areas

It is only a seismotectonically active area of Vrancea that could be delineated -from the point of view of recent dynamics of the lithosphere- as an area of possible occurrence of catastrophic earthquake. It is possible to map with relatively high degree of reliability the first kilometers of the Earth crust in depth but it is hardly possible to exclude some unexpected manifestation or effect caused by processes in deeper parts of lithosphere. From this point of view the whole area of rebounding, i.e. area of triangular shape connecting the Gutii Mts – western margin of Moesian platform – the Vrancea area - may be considered risky (Figure 1). In this area a vast system of tectonic zones occur functioning from Precambrian that are permanently activated during the whole Tertiary up to the recent, evidence of which may be traced in seismological, geodetical and magnetotellurical investigations. Passive margin of the continent in the easternmost curvature of the East Carpathians seems to be still in not balanced position according to the thickness of molasse sediments of the Foredeep (9–13 km). Thus it may be assumed that continuing process of uplift of remaining lithosphere will affect compensation of stress at all depth levels and in this way a spreading of seismic activity just

along these deep-seated fractures and original grabens may occur. Rebounding process may affect relatively shallow sections of lithosphere as well with about as much intensive effects on zones of the Carpathian orogene margins. Then it should necessarily be assumed that intensive earthquakes may occur not only along the compensating fractures but also along detached and overthrusted surfaces, which corresponds with foci mechanisms from the Vrancea area (Nemčok et al. 2006).

From our interpretation of data follows that the zone affected by isostatic compensation of lithosphere (rebounding) is delineated by the area influenced by detachment and break-off of submerged part of the plate. With respect to effusions and a distance of the last intermediate volcanism related to the thickness of bended lithospheric plate (80-100km—Pajdušák et al. 1988, Nemčok et al. 1998) it can be deduced that break-off occurred before 2-0.5 Ma. The area, corresponding with the space of the break-off slab, is laying between the Gutii Mts. – Turnu Severin. Northwest of this zone a thermal soaking of the whole lithosphere may be observed that is connected with high uplifts of the mantle material and distinctive sedimentation of Pannonian–Quaternary. In front of this zone most of material originated by the areal intermediate volcanism of the Late Badenian – Pannonian connected with original subduction is deposited. Anomalous "triangle" of recent active uplift of the area of East Carpathians and the Apuseni Mts should be considered a highly geodynamically risky area. Velocity vectors obtained from GPS tending eccentrically towards the platform margins support these conclusions. During the next phase of investigations this problematic area will be a subject of detailed monitoring.

Deindorf-Čebín tectonic zone

One of the leaved out fault active systems at Southern Moravian can be considered the so called Diendorf - Čebín tectonic zone (DCTZ), that is seismically active in its southern segment (in Austrian). The Waitzendorf fault is a part of the DCTZ, with intensive morphological signs .

The terrain recognizance along the eastern margin of the Dyje Dome confirmed many indications showing evidence of geodynamic activity. The facets, old land slides and rock falls indicate recent activity in the environs of Znojmo area.
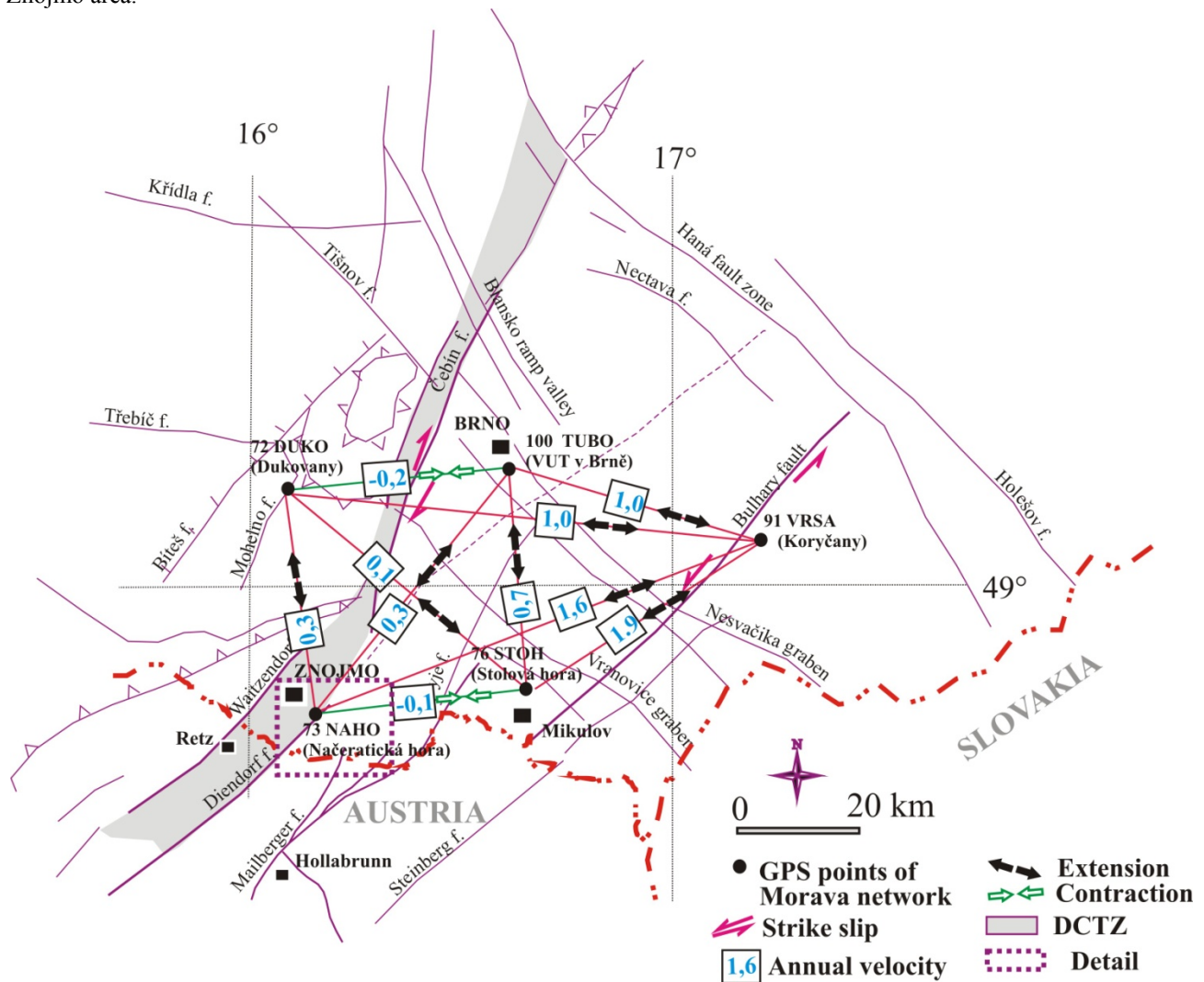

Fig. 4.   The Results of measurements at the Znojmo GPS polygone. Annual velocities were gained from two etaps – in years 2009 and 2010.

The investigation of movement tendencies in the area of the Diendorf-Čebín Tectonic Zone (DCTZ) has been conducted in the transitional part where the Diendorf and Weitzendorf faults are hidden bellow the Neogene sedimentary cover Figure 4). The geodynamic Znojmo Polygon was established in 2009 with the purpose of displacement monitoring in southern part of DCTZ, covering the area of about 3 x 15 km along the Thaya river valley between Znojmo and Slup (Pospíšil et al., 2010). The geodetic monitoring network consists of eight stabilized GNSS points surrounding the Načeratice Hill (NAHO - GPS point of the former Morava Geodynamic Network) which has been chosen as reference point. The distribution of the network points covers both the NE-SW oriented faults – Waitzendorf and Diendorf - in E-W direction.

Three measuring campaigns of GNSS static observations at all points of the Znojmo Polygon have been carried out up to now. The initial (zero) campaign E0 was carried out in October 2009. The Leica SR520 and Leica GX1230 receivers together with Leica AT504GG, AX1202GG and AT502 antennas were used. The measuring scheme included GPS static observations of longer duration (up to 20 hours) at points HRAD and VALT, and the data of permanent station TUBO were utilized. Resting points measurements (UNEM, TASO, KRHO, MICM, DERF, VDJM) were performed in the triplet pattern, which included shorter observations (2 hours) repeated three times in time lag from 6 to 7 hours (Švábenský and Weigel, 2006).

The following (first) campaign E1 was carried out in October 2010, and the (second) campaign E2 was realized in September 2012 after two years pause, both using the same instrumentation and the same observing scheme as in the initial E0 campaign.

The data of all the campaigns 2009, 2010 and 2012 were processed using BSW 5.0 (longer intervals), and LGO 8.1 (shorter triplet intervals –Figure 4), using only GPS data in the first run. Precise ephemerides from CODE in Berne and antenna phase center absolute calibrations were used in processing. Based on previous analyses, expected baseline standard deviations were under 2 mm for longer observation sessions, and under 4 mm for triplet observations. Adjustment results show the actual accuracy level as expected in the three measuring campaigns.

Preliminary results from the GNSS Znojmo Polygon repeatedly confirm the significant movement tendencies in the environs of the Waitzendorf and Diendorf faults. The maximal velocities of –0.6 mm/year between the stabilized Thaya Dome block and the shifted Načeratice Hill block and the velocity of 10mm/year measured between points NAHO and KRHO should receive increased attention in future investigations.
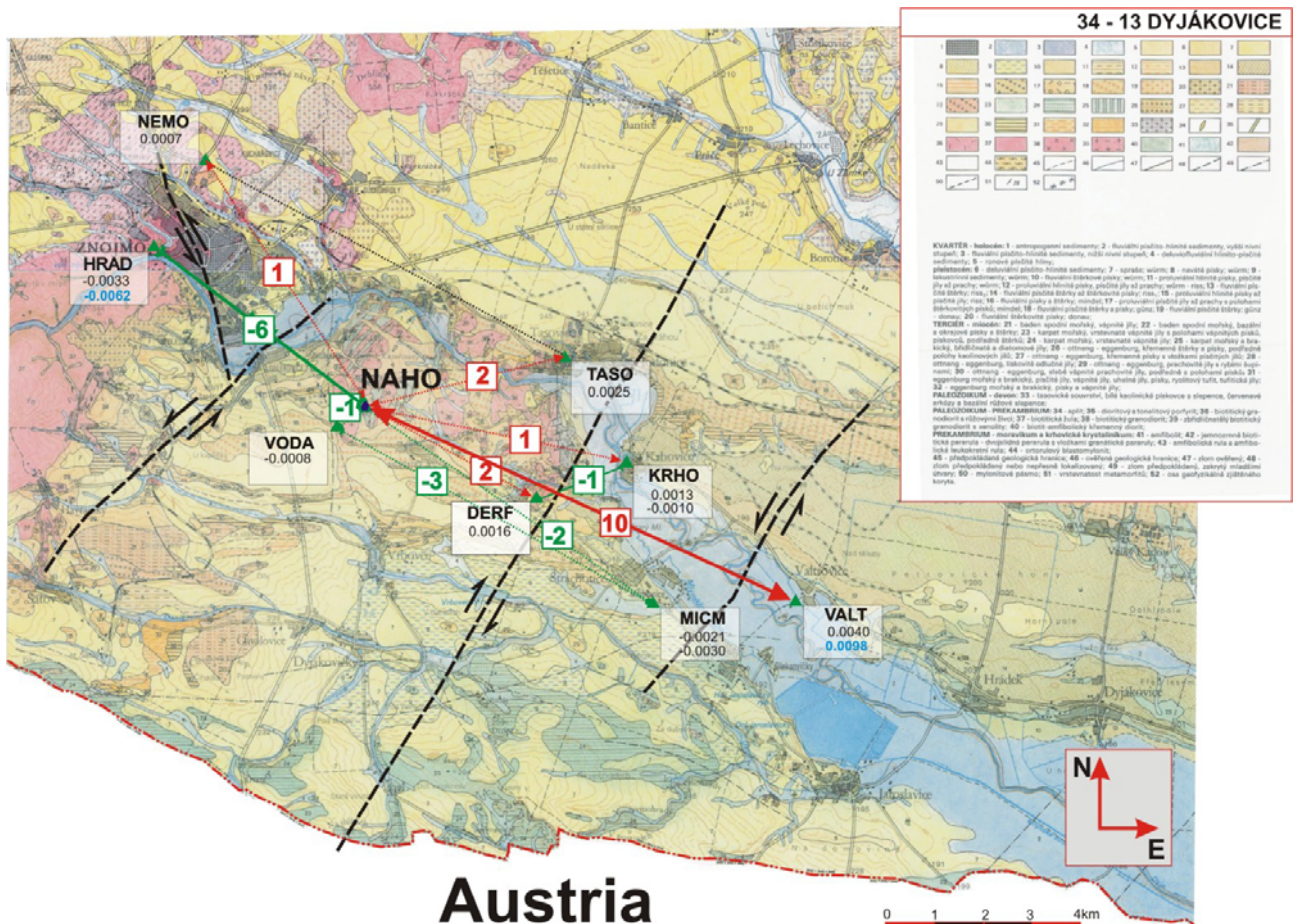

Fig. 5. Detected horizontal movement tendencies and annual velocities in the Morava network area during the 1995 –2010 period (Švábenský et al., 2011). The major faults and movement types are inserted.

The preliminary results were complemented with processed recent data from EPN stations (Hefty, 2007, Hefty et al., 2009), and results from the Morava Network repeated measurement (Figure 5 - Švábenský et al., 2011). Taking into account the distribution of GPS points on the outcrops of crystalline basement in places where low thickness Tertiary units occur, movements at the basement level can be assumed, Brunovistulicum and adjacent Moravo-Silesian and Moldanubian units in this case. The most significant movement in South Moravia was recorded between the points NAHO and VRSA (Vršava near Koryčany) – over 2 mm/year (Švábenský et al., 2011). Even if only preliminary, the results suggest interesting movements near the above discussed faults. Moreover, there is a good agreement with the results gained at the geodynamic Morava Network (Švábenský et al., 2011).

Preliminary GPS positioning results obtained on the territory of South Moravia (Švábenský et al., 2011 – Fig. 5 and 6) have shown relatively intensive movement tendencies between the Bohemian Massif and tectonic units of the Western Carpathians. Particularly tectonic zones the Diendorf-Čebín tectonic zone (DCTZ) and the Bulhary fault play dominant role (Švábenský et al., 2011).

It has been the reason for another GPS monitoring at the Znojmo polygon, where the results have confirmed more detailed changes of movements influenced by the tectonic conditions along the Waitzendorf and Diendorf faults. From the morphological and seismotectonic points of view(Lenhardt et al., 2007) the two faults are among the most important tectonic zones in this territory (Fig. 6).

For the preliminary analysis the movement tendencies the GPS results have been confronted with geomorphological and geophysical data. On the basis of gained results it is possible to suggest the new more detailed GPS measurements and look for a new tectonic model of the area located on the border of the three main tectonic units – The Moldanubian, Moravian and Brunnovistulian units.
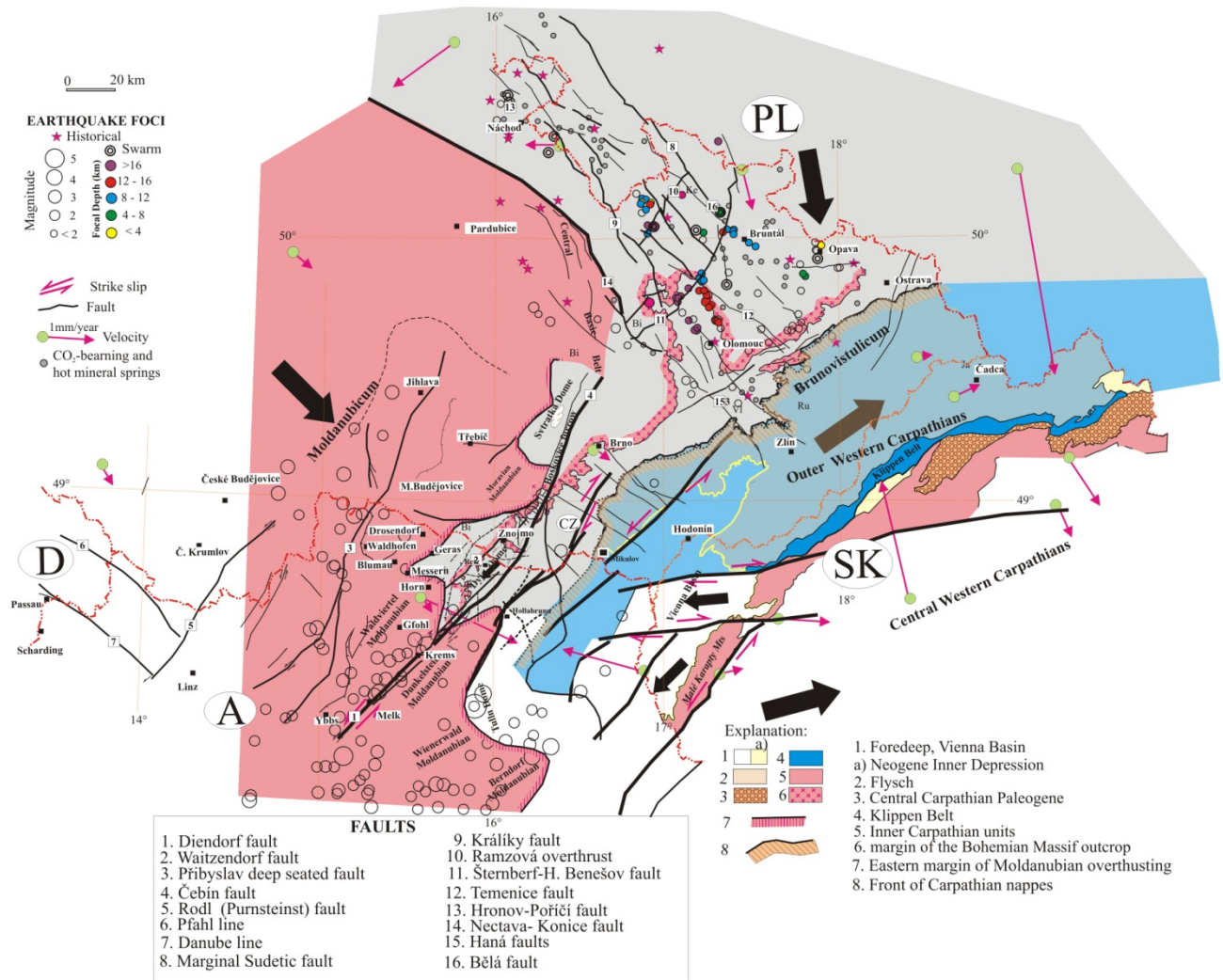

Figure 6. Constructed kinematic model of the Moravian region on the bases of the correlation of the morphotectonic and geophysical data with the results of GPS measurements. Geological explanation after Finger et al., 2000). Sources of magnetic anomalies are processed after K. Šalanský (1995): Explanation: 1 – neovolcanites, 2- paleovolcanites – Upper Paleozoic, 3- paleovolcanites – Lower Paleozoic, 4- paleovolcanites – Upper Proterozoic - Lower Paleozoic, 5- paleovolcanites – Upper Proterozoic, 6- granitoids, 7- granitoids with mafic bodies, 8- mafic intrusive rocks, 9- mafic and ultramafic intrusive rocks, 10- metamorphic volcano-sedimentary complex, 11- amphibolites, 12- serpentinites, 13- skarns, eclogites, calc-silicate rocks, 14- metamorphic rocks, 15- volcano-plutonic complex, 16- undifferentiated. Epicenters of earthquakes for the period from 8.5.1267 to 31.3.2004 (after Lenhardt et al., 2007). The sizes of pink circles are scaled proportionally to the local magnitudes of individual earthquakes. With combination of results from Kralický Sněžník network the basic 3 blocks were determined: Moldanubic block - pink, Sudetic block - gray and Outher Carpathian Flysh - blue.

The Muráň-Malcov Tectonic System (MMTS)

On the basis of structural analyses (Nemčok et al. 1998b), geophysical data (Pospíšil et al., 1993, Hók et al. 2000), and interpretation of Remote Sensing data (Pospíšil et al. 1986) the tectonic setting of Western Carpathians was refined taking in account late Alpine activities (Nemčok et al. 2006a,b, Pospíšil et al. 1993).

This dynamic tectonic system of Western Carpathians and Pannonian basin supplements a broad zone of transcurrent fractures with dominating tectonic zones Muráň-Malcov (MMTS), that can be combined with Raba fault, too (Pospíšil et al., 1993), the ENE-WSW trending faults of Hron and sub-Tatras tectonic boundaries (Pospíšil et al., 1986, Schenk et al., 1989), they have been active from Pliocene up to recent (Decker and Peresson 1996), at the N and the the Balatón line and the Central Hungarian tectonic zone in S dominates whole ALCAPA territory (Wein, 1969, Contos et al., 1992, Czontos and Nagymarosy 1998). These fault zones belong to these most prominent tectonic elements of the area of Western Carpathians and Pannonian Basin.

This line together with forms a wide transcurrent tectonic zone which played an important role during a regression of remnant oceanic lithosphere and intrusion of the Apulian desk to the north.

However, the transcurrent system of Muráň-Malcov (Figure 7 - Pospíšil et al. 1989) - with well pronounced morphological manifestations, including dominant tectonic features, but with minimum seismological response in comparison with above mentioned system belongs to the most important but the most problematic ones from the geodynamical point of view.
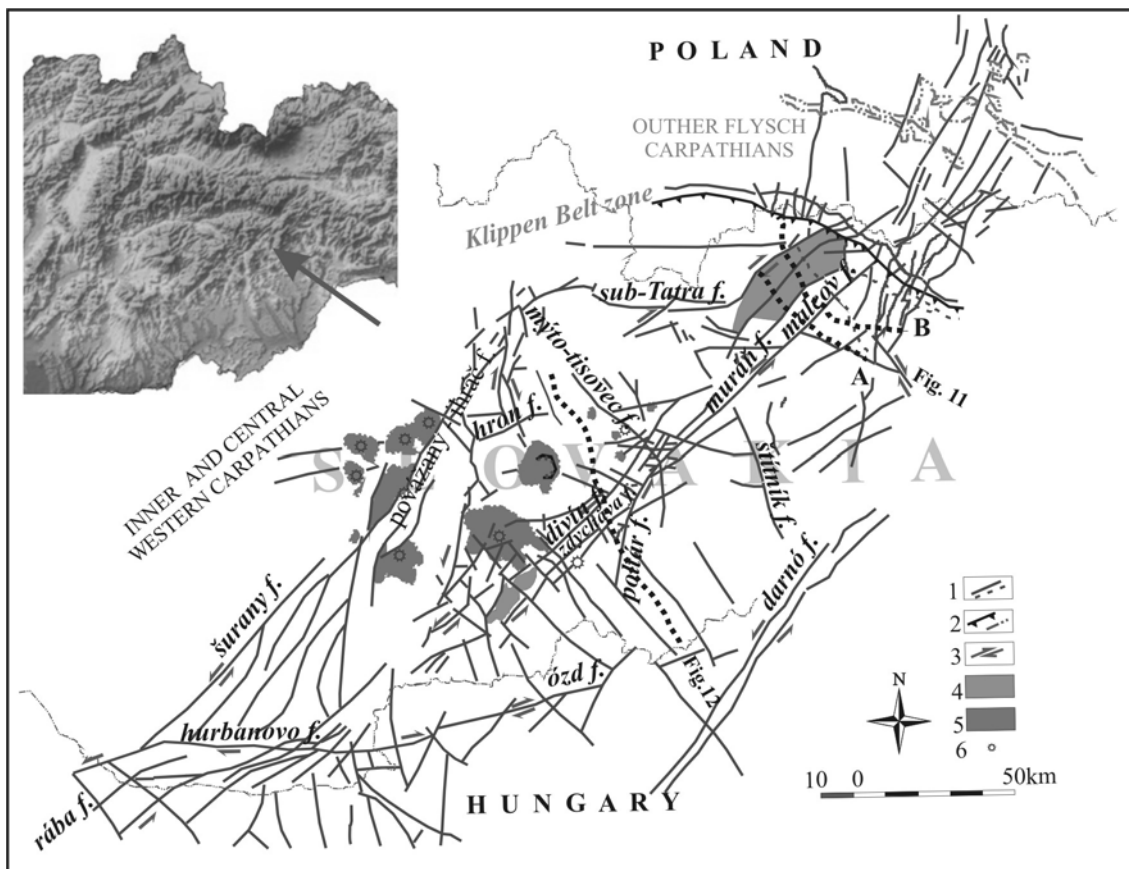

Figure 7. Muráň-Malcov transcurrent fault system and is position within the area of West Carpathians (Pospíšil et al. 1989). Legend: 1-faults, 2- overthrust lines, 3- strike-slip, 4- andesites (age Sarmatian to Panonian), 5 – Modrý Kameň depression (SW) and Levoča Mts graben (Lower to Upper Ottnangian and Paleogene, respectively). B) Morphological character of MMTS in iluminated topo-relief (45° NW)

When interpreting the satellite images of the area of Western Carpathians, everybody pays attention to the prominent manifestation and position of Muráň-Malcov tectonic system (Pospíšil et al. 1989). MMTS can be understood as a fault system composed from two or three main parallel faults NE-SW trending that is interrupted at the surface by transversal faults of WNW-ESE direction accompanied by effusions of young andesites in the area of Tisovec village (Bezák 1988, Pospíšil et al. 1989; Marko 1993, 2002). Beneath volcanites of Tertiary and basin sediments the faults system influences creation of narrow and relatively deep graben structures (Modrý Kameň -Vass 1979, Levočské vrchy Mts. – Pospíšil and Hrušecký 2001).

MMTS zone manifests not only geomorphologically but also in geophysical data by sharp gradients and spatial shift of anomalies (Pospíšil et al. 1989, Pospíšil 2004). E.g. in gravity and magnetic maps it creates 10-20km long zone of anomalies NE-SW trending. Similar features may be observed in geological maps and in

Remote Sensing data. The zone manifest the features of classical transcurrent fault system (a zone along which horizontal shifts of crustal blocks occur) that is accompanied by all extensional and transpressional elements. Horizontal shift – estimated for the period of Upper Tertiary by 40 km (Pospíšil et al. 1989) – is blurred by a distinctive vertical shift along particular branches of the fault system (Figs. 7 and 8). Along the faults system the sinistral component of movements dominated from the origination of the faults system up to recent (Bezák 1988).
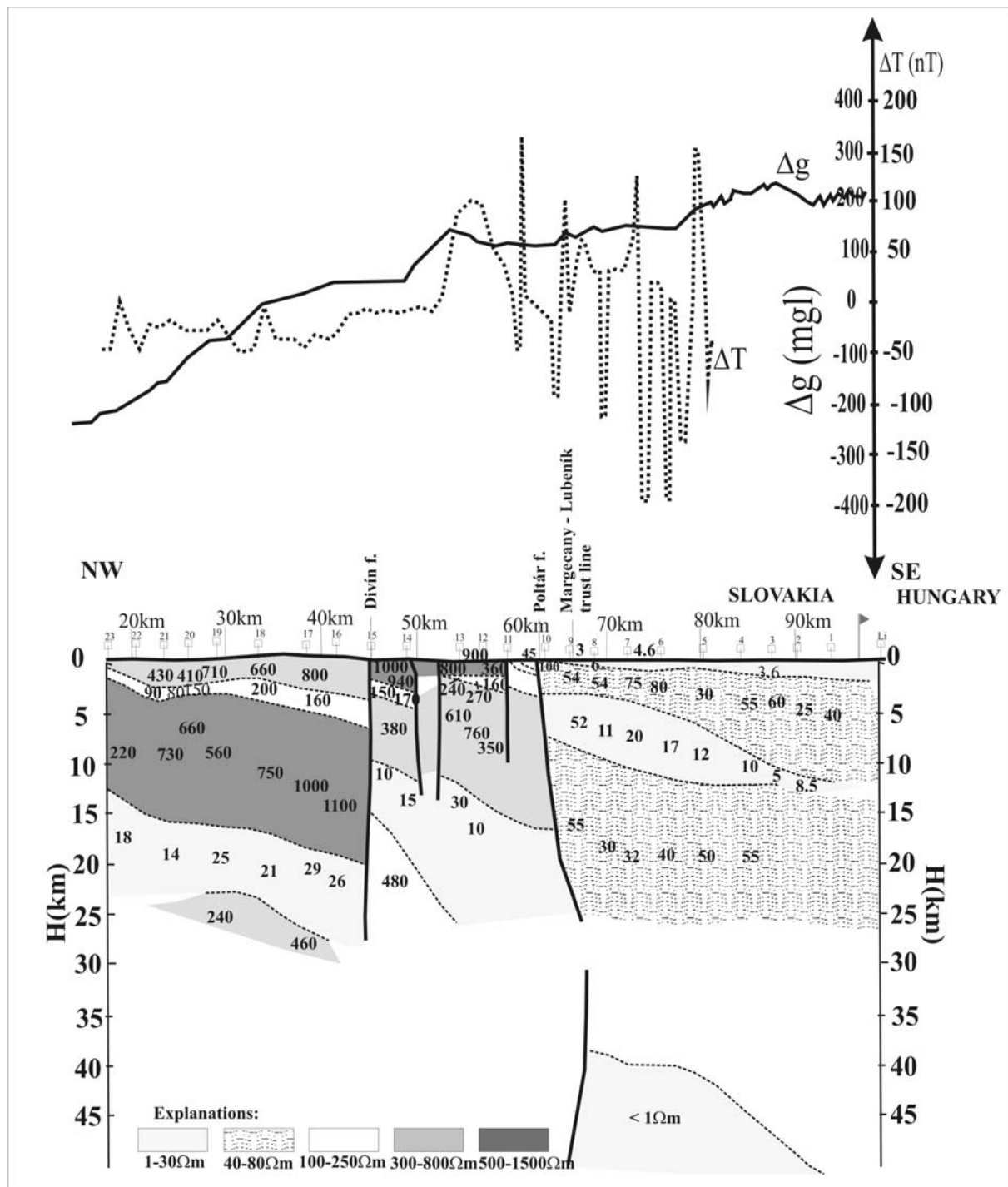

Figure 8. The part of the magnetotelluric profile 2T crossing MMTS – faults Děvín, Muráň and Poltár (youngest) modified after Pospíšil 2004.

The central part of the MMTS is presented in a geophysical cross-section constructed along the line of seismic and magnetotelluric line 2T. Whereas interpretation of seismic data ((Tomek et al. 1989) has not taken in account results of magnetotellurics (Varga and Láda 1988), interpretation of magnetotellurics data (Hajdová and Pícha 1990; Varga and Stanley in Pospíšil 2006) complemented a general picture of geological setting up to

the depth of several tens of km (Fig. 8). Resulting section is convincing enough and documents not only thrust tectonics expressed by several seismic reflexes along the seismic line but also distinctive changes and disruptions of the setting caused by normal faults and by the strike-slip faults as well. In the section presented two boundary faults dominate: the Divín fault at the north and the Poltár fault at the south. Distinctive change in resistivity behind the Poltár fault indicate relations between units of Veporicum (underlying) with alternating zones of high and low resistivities (correlation with reflection zones indicating thrust tectonics?) and Gemericum units (overthrusted) with low resistivities and increased manifestations in magnetic field.

Namely the GPS data obtained in the area of Western Carpathians (Hefty et al., 2009, 2010, Mojzeš et al., 2004) are of extreme value. Even though as for their nature these observations represent permanent measurements with a random choice, at a locality with assumed neotectonic or recent activity a striking concordance and correlation with faults identified on the basis of Remote Sensing and geophysical data have been observed.

The MMTS manifests itself as a significant boundary in terms of a chage and nature of recent motion tendencies (Fig.2 and 9). This phenomenon is obvious even from the course of strain trajectories (Cloething et al., 2003, Generczny et al., 2000) showing a significant change W from the MMTS. Further consequences may be drawn from submitted results. E.g. from the direction and exceeding of the motion tendencies in the eastern Slovakia even beyond the Klippen Belt it may be deduced that regional movements are generated not only at the level of underlying units - at their detachment but also within their basement. Anyway these currently rather speculative deductions have to verified during succeeding field campaigns in future.

Significance of MMTS is observable also from the correlation of movement tendencies and distribution of the earthquake foci. It is evident that the most active focal zones are located in areas of crosing MMTS with regional faults of the ENE-WSW direction. From the neotectonical point of view these faults belongs to the main seismoactive boundaries in the Western Carpathians, (Pospíšil et al., 1993).
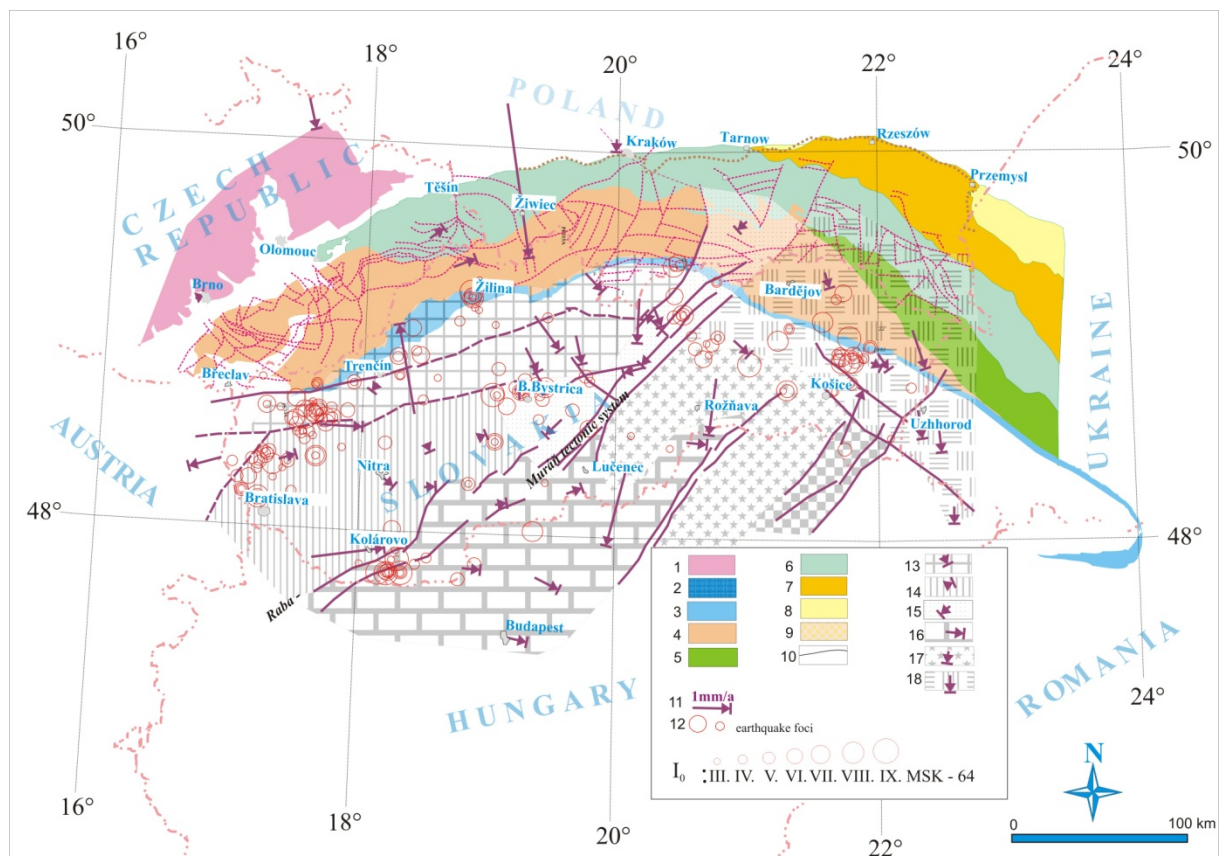

Figure 9. The estimated horizontal velocities obtained for the whole territory of Slovakia and their correlation with earthquake foci, main sutures and faults. Arrows mean the strike slip character of faults with largest risk in the Carpathian-Pannonian territory. The GPS vectors of horizontal velocities (after Hefty et al. 2010) show recent movements of the separated blocks and they are supplied by the Map of epicenters of macro-seismically observed earthquakes of Slovakia for period 1304−1990 (after Labák and Brouček 1996). Explanations: 1 − Crystalline outcrop, 2 − pre-Tertiary outcrop, 3 − Klippen Belt, 4 − Magura unit, 5 − Dukla unit, 6 − Silesia unit, 7 − Skole unit, 8 − Stebnik unit, 9 − Szolnok graben complex (southern part of the figure − not shown here), 10 − fault, 11 − GPS velocity vectors (in mm/a), 12 − earthquake foci (MSK-64 Intensity − I₀), 13−18 − orientation of velocity vectors of different blocks.

6. Seismic hazard analysis – New way for utilization of gps results

Seismic Hazard Analysis (SHA) depends on three types of models: 1) a forecast of all possible earthquake ruptures for the region; 2) a ground-motion model giving the level of shaking for each possible rupture; and 3) an engineering model of structural response given the ground shaking. Current implementations combine models (2) and (3) into what we call an "Intensity-Measure Relationship", or "IMR" for short, which gives the conditional probability that an intensity measure (some functional of ground shaking found by engineers to correlate with damage) will be exceeded at a site given the occurrence of a specified earthquake rupture.

A wide variety of Earthquake-Rupture-Forecast (ERF) and IMR models have been, and will continue to be, developed. This diversity reflects differing opinions about how to best model earthquake processes and building response. Having a variety of viable models is not a conceptual problem for SHA, as the probabilistic formalism includes explicit ways of dealing with differing expert opinion.

GPS data and their interpretation offer next opportunity to utilize the information on geodynamic and kinematic conditionin areas for calculation and SHA (Fig. 10).
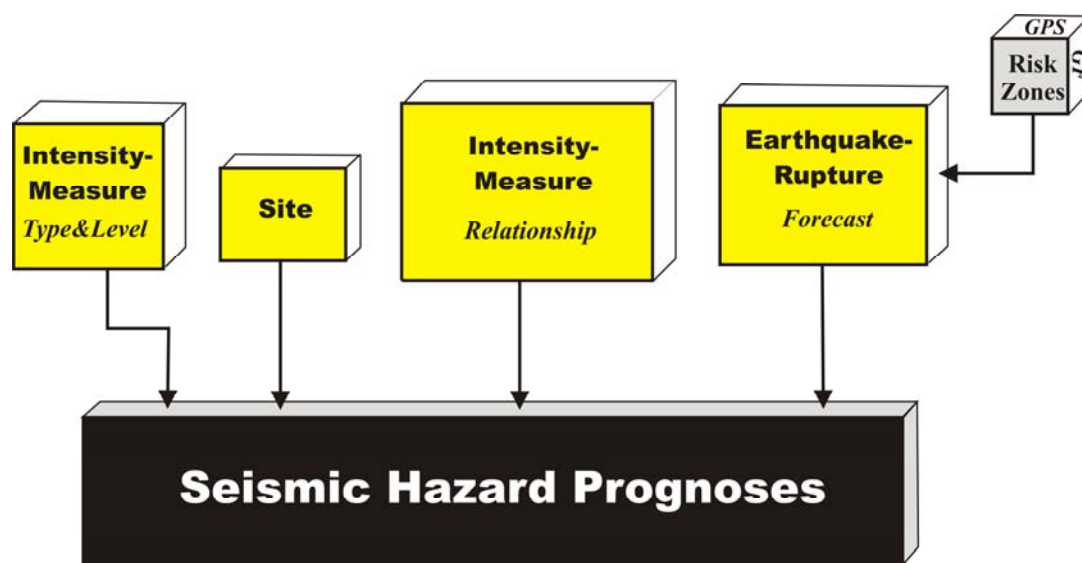

Fig. 10. The Chart definins way for calculation of the Seismic Hazard supplied by block, that is based on the information gained on the basis of GPS and Geophysical-geological studies. Such approach much better enable to do prognoses of the potencial risk combined with the recently active tectonic system.

Developing such a distributed "community-modeling environment" requires having a well-established object-oriented framework (a specification of the various model and data components and the communication protocol for each). Because the different disciplines contributing to SHA often hold different meanings for the same word, also important is establishing a fixed vocabulary. For example, "earthquake" literally means earth shaking, but to some it refers to fault rupture (as in an "earthquake catalog" where no information about ground shaking is contained). Although humans can understand such difference contextually, computers communicating with each other cannot.

Figure 10 shows the basic elements of framework, and the possible computational sequence that takes place inside the "black box". GPS results with geophysical data enables localize also places where seismic activities can be combined with longer time periods (e.g. > 200 years), or are bound to structures which temporarily adjust the environment strain (e.g. Hron boundary). It is possible to consider the MMTS as just such case.

In future period the GPS data for the calculation could be play irreplaceable role with regards to permanent registration and possibility to follow movement tendences and strain conditions in the Earth crust.

7. Conclusions

Joint results of studies of dynamics of the Western Carpathians lithosphere based on geodetical and geophysical data confirm recent activity of some parts of the territory of Carpathians. Recommendations submitted for further refinement of knowledge concerning the recent activity of these areas may help e.g. in the process of choice or evaluation of chosen areas for building deep seated disposal sites, which is currently a task of high priority. For easier and faster updating of databases of observed phenomena it is necessary to

realize a direct connection of particular institutions conducting geodetical, geophysical and seismological observations.

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