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ORIGINAL PAPER

MOVEMENT TENDENCIES IN THE MORAVIA REGION: KINEMATICAL MODEL

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ABSTRACT
The Moravia territory has been the subject of geokinematic investigation within scope of several realized research projects and repeated GPS campaigns since 1992. The monitoring has been concentrated on all the Moravia region as well as on particular areas of interest concerning the eventual possible geodynamic changes (Králický Sněžník Massif, Diendorf-Čebín Tectonic Zone (DCTZ) and others).
At present time all the territory is covered by several tenths of permanent and epoch GNSS stations. Long observation time series at permanent stations alone are not sufficient for delivering the regional velocity field of sufficient density. On the other hand, epoch stations are more densely spread but periods of repeated observations are less frequent and often the data processing is not homogeneous.
In the paper the preliminary kinematic model is briefly described which gives for the first time the general view of movement tendencies at the region of Moravia. On base of long-term monitoring it shows that the Southern Moravia region is more active then it was supposed.

KEYWORDS: Moravia, geodesy, GPS, geophysics, kinematic model

1. INTRODUCTION

The most recent studies on the lithosphere of Central Europe (Csontos et al., 1992; Fodor et al., 1999; Cloetingh et al., 2003; Nemčok et al., 2006 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 geodynamical 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 (BM) 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 kinematical boundaries for the area of the Central Europe (Figure 1). On the Moravia area – we shortly demonstrate results of the GPS and geophysical analyses, that enable to present preliminary kinematic model of area, that can be in futuree period to be used for prognostication of localities with possible higher seismic hazards.

2. GEOLOGICAL CHARACTERISTIC OF AREA

The Variscides on the SE margin of the Bohemian Massif belong to the most complicated structures in the whole Europe. This complexity is caused not only by the composition of orogene, which went through complicated evolution during the last 300 Ma, but also by its overlay by younger sediments, too. Part of Variscides is hidden under autochtonous Permo-Carboniferous deposits and Cretaceous sediments, or can be dropped on the SE slopes of the Bohemian Massif under Jurassic and Tertiary complexes. Complications arise by virtue of the overlapping of Variscides arc of BM by the Carpathian arc of Alpine Orogen. The Variscan units, with NE vergency of their are overlaid by Alpine-Carpathian nappes with NW vergency and cover the Brunno-Vistulian foreland. Complexes of Brunnia and Vistulian recognized in the basement are generally connected into one unit – Brunnovistulicum (e.g. Dudek, 1980).

All these complications implicate, that the trace of the Variscides under the sediments and Alpine nappes is uncertain and can be interpreted from borehole and geophysical documentation only (Dudek, 1980; Jiříček, 1991; Batík, 1999; Adámek, 2005; Schulman et al., 2005; Wessely, 2006). All these studies resulted in several theories about the structure of the hidden part of the Variscides towards

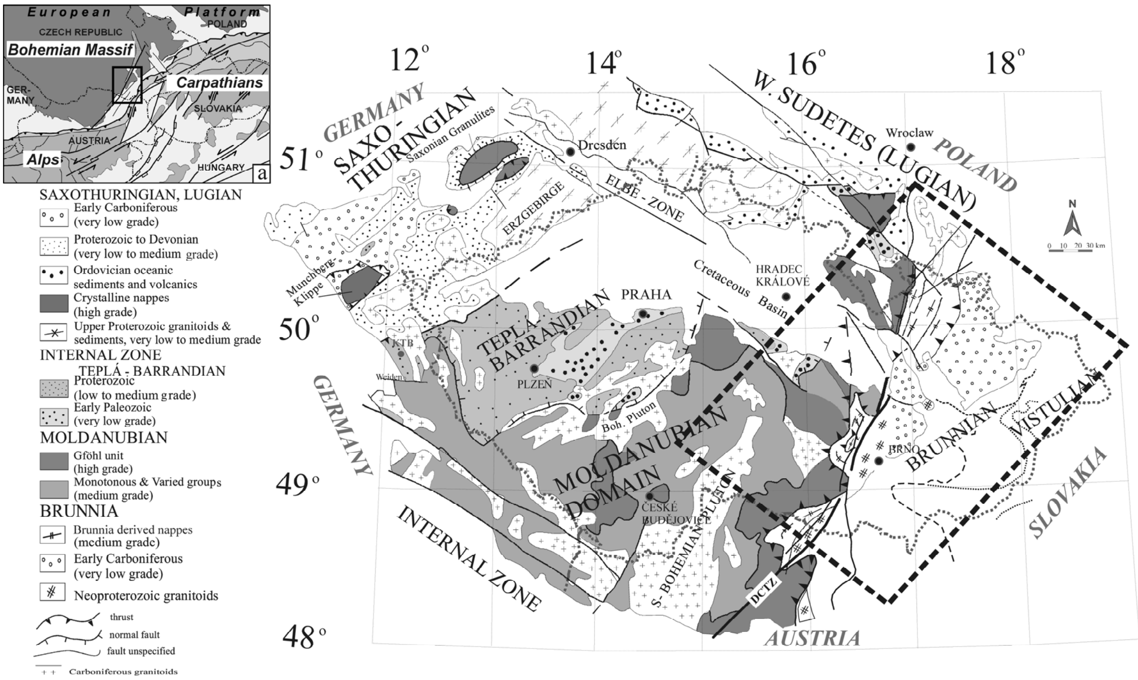

Fig. 1 Geotectonic setting of the Bohemian massif (after Matte et al., 1990, modified by authors). The – Dotted line - area of interest (Moravia).

the remaining, uncovered part of the BM. Unfortunately, the opinions vary. In addition, considerable difficulties arise in segregation of Variscan nappes and faults, which gave way to more universal concept of Variscan units (belts and blocks). The one who drew attention to their uncertainty, unrealistic and hazy definitions, which cannot be sufficient for investigation of hydrocarbons, was for example Jiříček (1991). On the opposite side the latest models and interpretation of the Variscan structure, based on dating, paleomagnetic, structural and seismic data offer Oncken (1997); Finger et al. (2000); Edel et al. (2003), Schulman et al. (2005). All these models of Central Germany Crystalline ridge (CGCR), Rhenohercynicum and Sub-Variscan Molasse, have been adopted as a basis for the whole Northern Variscides. In the area of Bohemian Massif, the Variscides are divided into many structural zones and opinions about their tectonic correlations diverge. The Elbe zone, as the most problematic in BM, can significantly influence and evoke the rupture of Variscan zone. Instead of such result the Mid-German Crystalline Rise (MGCR) is expanding through Poland to Moravia only in the form of the outer Rhenohercynian and Sub-Variscan molasse, overthrust on the Bruno-Vistulian foreland (Havlena, 1976; Dudek, 1980).

Remobilised part of this foreland is described as Moravosilesian. Another study, however, does not exclude that he Moravian and eventually part of Brunnia unit belong to the CGCR (Stille, 1951; Ellenberger and Tamain, 1980).

For correlation and interpretation of geophysical data it is very misleading and troublesome. The results of the last decade (e.g. Vrána and Štědrá, Eds., 1997 – western part of BM) can offer us additional possibilities of solutions, which must be discussed and analyzed using geophysical data to avoid creation of popular hypotheses and models. From the point of view of this paper and specification of observed polygons we concentrate on the questions of the Moravian zone, which is parallelly flanking the whole Diendorf-Čebín Tectonic Zone (DCTZ) (Fig. 2).

For solving of the tectonics in Moravia the geophysical data can play a significant role, mainly GRAV/MAG Data, Remote Sensing and well chosen reflex-seismic profiles. Some of tectonic zone were analyzed in detail. For example we can imagine the DCTZ as a tectonical system, which was in recent form created in Tertiary, but its origin and its main role was taken in the end of Variscan orogeny and in the Mesozoic period. Unfortunatelly, this activity is not possible to be confirmed in the recent.

From the geological point of view it is convincible, that ductile to brittle ductile Moldanubian overthrust representing the sutury created by the collision of two microcontinents, which can be describe on base of the structural and geochemical data (Schulman et al., 2005). But the brittle fault system is wholly different (including the eastern marginal fault of Boskovice graben and the Diendorf fault), created during younger Variscides and repeately reactivated after Variscan period, which is yet generated as the most of transcurrent faults in the detachment level of some "undermoldanubian" unit (Moravicum, Brunnia unit).

Both structures mentioned are still spatially coinciding at present time, in the geophysical fields we can find out many typical signs and symptoms, but they have a whole different genesis. For the perception of function and importance of DCTZ such possibilities of interpretation must be taken into consideration, which are in accordance with the results of the 8HR seismic reflection profile (Pospíšil et al., 2004, 2010) in the space under the Foredeep and Flysh Belt of the Western Carpathians. There, in the depth from 5 to 7 km, the significant reflexes are detected, typical for the sedimentary complexes, which are interpreted as possible devonian complex shifted by the Brunnia unit or its part (Pospíšil et al., 2004; F. Hubatka – oral comunication).

From the geophysical data, based on the knowledge of physical features of rocks and its demonstration in the magnetic and gravity field, we are able to speak about another versions of solution connected to domatic uprise of Moravicum and Brunnia unit in its domes (Dyje, Tulln, Svratka), but this really exceed the scope of this paper.

TECTONIC SETTING

Description of the Cenozoic to Recent tectonic pattern in the Moravia is presented from north to south.

The mountain range stretching from the Krkonoše to the Jeseníky Mountains (the Sudetes) was already dry land in the Cenozoic and was subjected to intensive erosion and transport of the weathering products.

East of the Velké Vrbno Dome, the important Ramzová tectonic line is situated with the Branná Group of probably Devonian age (Middle Paleozoic, around 380 million years) behind it (Don and Opletal, 1996). The crystalline series of the Snieźnik metamorphic unit in the west are separated from the Cretaceous sediments (Upper Cenomanian, around 95 Ma old) of the Nysa-Kłodzka Trough by a fault structure which locally has the character of a reverse fault.

At the end we have to mention the area of Lądek-Zdrój and Bruntál, where basaltic lavas poured out on the gravels deposited at the Tertiary-Quaternary boundary (Birkenmayer et al., 2002).

The tectonic connection between the Boskovice graben with the Diendorf fault system is key for understanding of Tertiary to recent tectonic proceses in area between Moldanubian, Saxothuringian and Brunnovistulian units. With this zone are combined next problems, e.g existance of para Moravicum. Under this unit R. Jiříček (1991) describes the most problematic unit, placed between Dyje and Brno Massif. This interpretation, that is not at all generally accepted, has many indices in geophysical data. From the first one it is separated by the Diendorf fault, by the Miroslav fault, from the second one it is continuation DCTZ through Central ultrabasic band near Svitavy town (Fig. 2).

At first place the Hollabrunn, Krhovice and Miroslav crystalline complexes represent it there. In its deep basement there is evolved the Brunnia unit, which granitoides rise to the surface under Wienerwald flysch in the Tulln Dome and in Dyje Dome (second one Jiříček does not consider!?). Its cover was detected in the northern part of Miroslav horst, too. The Moldanubian to the south from the Dyje Dome, lines wide zone, elongated in the N-S direction in more than 100 km. In the common view the Hollabrunn unit represents deep crystalline synclinorium between Dyje and Brno granitoides. Diendorf fault runs in the geological chart to the NE to Langelois, dividing the Krhovice foreland and limiting from west the Miroslav crystalline complex. Behind, we can observe its connection to the eastern fault of Boskovice graben. Because the Permo-Carboniferous sediments are the lower situated block against the Brno Massif, many authors with the subsidence and strike-slip tectonics connect the Diendorf fault (Fig. 2).

Analogical situation is placed in the eastern direction with the Miroslav fault; on its depressed western block are permocarboniferous and crystalline complexes. The granitoids creaate the higher Brno block. After Jiříček (1991), this fact gives to the Miroslav crystalline complex rather depressed structure than the horst character. The fact, that on the depressed Dyje block we can find granitoids, which occur on the Miroslav or Krhovice upper block under the methamorphites, there have been long discussed question about the connection of the Diendorf fault with the horizontal displacements, steep overthrusts of Hollabrunn crystalline complex or Dyje Massif in opposite vergency.

Zone between Eggenburg and Znojmo is dissected by next important fault system - Waitzendorf fault. This fault is crossing the Thaya Dome, cuts mainly complexes of Brunnia, only on the SW margin of Dome crosses the Moravian unit. In the zone between Diendorf and Weitzendorf faults there exist many subsidiary parallel and oblique, N-S orientated faults (Roštínský and Rötzel, 2005).

This tectonic “pattern” of faults strongly influenced segmentation of area during the Oligocene-Early Neogene period (Roštínský, 2003), while the actual altitudial contrast between the higer elevated crystalline terrain of the Massif and the lower sedimentary relief of the Foredeep is likely of the Late Miocene-Quaternary age (Roštínský, 2003).

What concerns of the recent geodynamical activity, unclear situation is in the Moldanubian unit, where along main faults the earthquake foci were registered, too (Fig. 4). Mylonitic fabrics developed within conjugate wrench ductile shear and fault systems in the Southern Bohemian Massif display both dextral (NW-SE-trending systems) and sinistral (NE-SW-trending systems) shear senses. Contrasting temperature conditions of deformation can be observed in the different shear zones (Brandmayr et al.,1995). Temperatures above 650 °C were reached in the Pfahl shear zone. Shearing under greenschist facies conditions took place in the Rodl and Danube shear zones. Brittle deformation dominated in the Vitis and Diendorf shear zones. After Brandmayr et al. (1995), 4°Ar/39Ar dating of various size fractions of muscovite formed and/or deformed during mylonitization yield ages of ca. 287 Ma (the NW-SE-trending system) and ca. 288-281 Ma (the NE-SW-trending system). The shear zones are interpreted as a late Variscan conjugate system. 4°mr/39mr age spectra of fine-grained newly grown sericite or rejuvenation of ages give evidence for post-Variscan reactivation of the shear zones. Brittle deformation within the shear zones was probably associated with maintenance of very high fluid pressure during Variscan deformation. Foreland deformation during the Alpine orogeny also played a significant role, leading not only to the development of the České Budějovice Graben but also to local reactivation of the shear zones at higher crustal levels.

During Alpine orogeny, the Bohemian Massif comprised a northern tectonic foreland. An Alpine stress field have been established which was probably very similar to that maintained in the Variscan. As a result, Variscan shear zones likely were locally reactivated at higher crustal levels. Reactivation of the shear zones supports interpretation of a pattern of shear deformation extending into Middle Europe and explained by Alpine N-S striking convergence (Stackebrandt and Franzke, 1989).

3. GEOPHYSICAL DATA AND REMOTE SENSING DATA

Although the analysis of remote sensing data has not been the subject of a project goal random analysis of selected parts of the Bohemian Massif showed that the majority of fractures, which focus on GPS campaigns (Sudetic Marginal fault, Diendorf-Čebín tectonic zone, Waitzendorf fault, Bulhary fault etc.) has a number of morphological characters and elements that prove to recent dynamics of these interfaces.

Therefore, for purposes of analysis and interpretation of physical tendencies set of geophysical maps was compiled. These maps were also used for their verification. In addition, this interface was often traceable on aerial or satellite images.

From these data, we then proceeded to compile a simplified map of faults with recent exhibition. We are aware that in the future it will be necessary for the Bohemian Massif to define unified process of methodology**.** Simplified map of major fault zones in combination with selected geophysical and geodetic data (magnetic data, the earthquake foci, horizontal and vertical velocities, etc.) is shown in Figures 3 and 4.

4. LEVELING DATA

In general, geodetic methods in kind of repeated determination of position or elevation serve as the source of information on movements at the Earth`s surface. For such analyses results of at least two measurements must be available at identical geodetic points (benchmarks). Geodetic terrestrial methods are obviously separated into different methods for determination of the horizontal and vertical components of geodetic point movement. The studies of recent crustal movements by means of geodetic methods have been initiated in the Research Institute of Geodesy, Topography and Cartography since 1955.

The repeated leveling measurement were used for the first estimation of vertical movements at the Czechoslovak territory by Kruis (1959) and later by Vyskočil (1966). Unfortunately the older leveling networks (benchmarks) from the end of 19th century and the first half of 20th century had very low accuracy for this purpose. In period 1939 – 1960 the new Czechoslovak Uniform Leveling Network was built up on the whole state territory. This state network consisted of four orders (I – IV) and some basic leveling stations with the fundamental point Lišov for Czech part of the network. On this point the calculation of heights was started in Adriatic Vertical System. The 1st Czechoslovak repeated leveling was carried out in the period 1961 - 1970 and the 2nd Czechoslovak repeated leveling in the period 1974 – 1980. The heights of all points were newly determined in Baltic vertical System – After Adjustment.

In Figure 5 the differences of heights for two repeated measurements are shown. The first measurement was provided in 1948 a the second one in 1969/1978 – time gap is approximately 20-30 years. The I order leveling line OZ_{16} leads from the Znojmo town to the east and intersects the faults. The heights of points (benchmarks) near the faults indicate very well their changes the vertical movements along the faults.

5. GPS DATA

New criteria for kinematic**s** - Velocity field resulting from GPS reprocessing

The complex analysis based on relevant GPS observations performed on the territory of Czech Republic and 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 (Hefty, 2007). The input RINEX data were from 55 permanent and 63 epoch-wise GPS stations covering reasonable time span to estimate the geo-kinematical behavior 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 data were reprocessed respecting the rules given by CEGRN (Central European Geodynamic Reference Network)

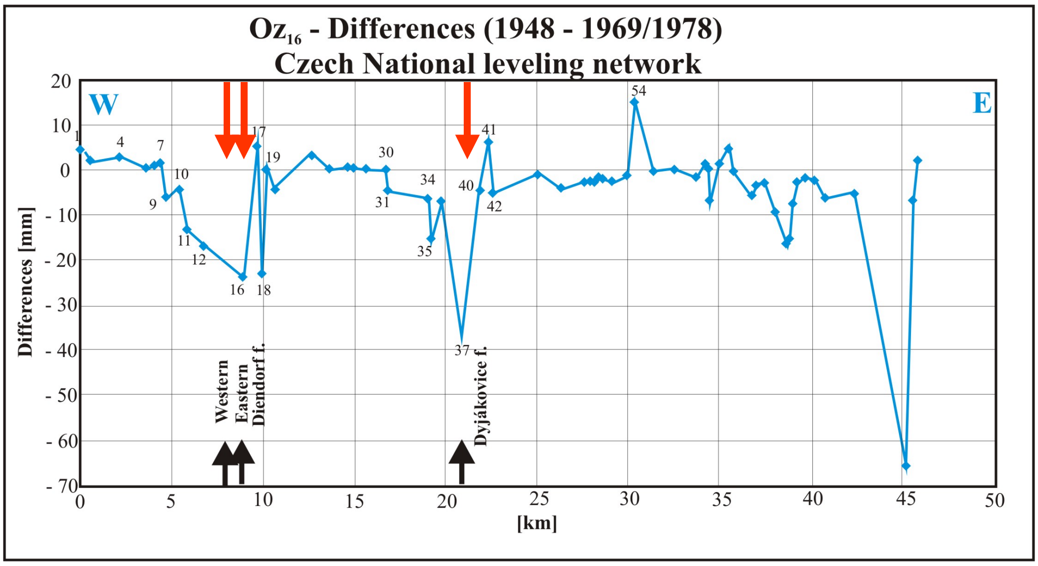

Fig. 5 Repeated leveling along the line Oz_{16} of Czech National leveling network. Location of profile is in Figure 6.

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.

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 identified 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 five mentioned networks are shown in Figure 4 (Hefty, 2007; Hefty et al., 2009; Pospíšil et al., 2012) for the Moravian part and surrounding. 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 plotting, the orientation, magnitude and accuracy of the velocity vectors are 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 Figure 3 as homogeneous and apply them for further analyses.

Namely the GPS data obtained in the area of the Western Carpathians (Hefty et al., 2009, 2010; Mojzeš et al., 2004) are extreme valueable. 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.

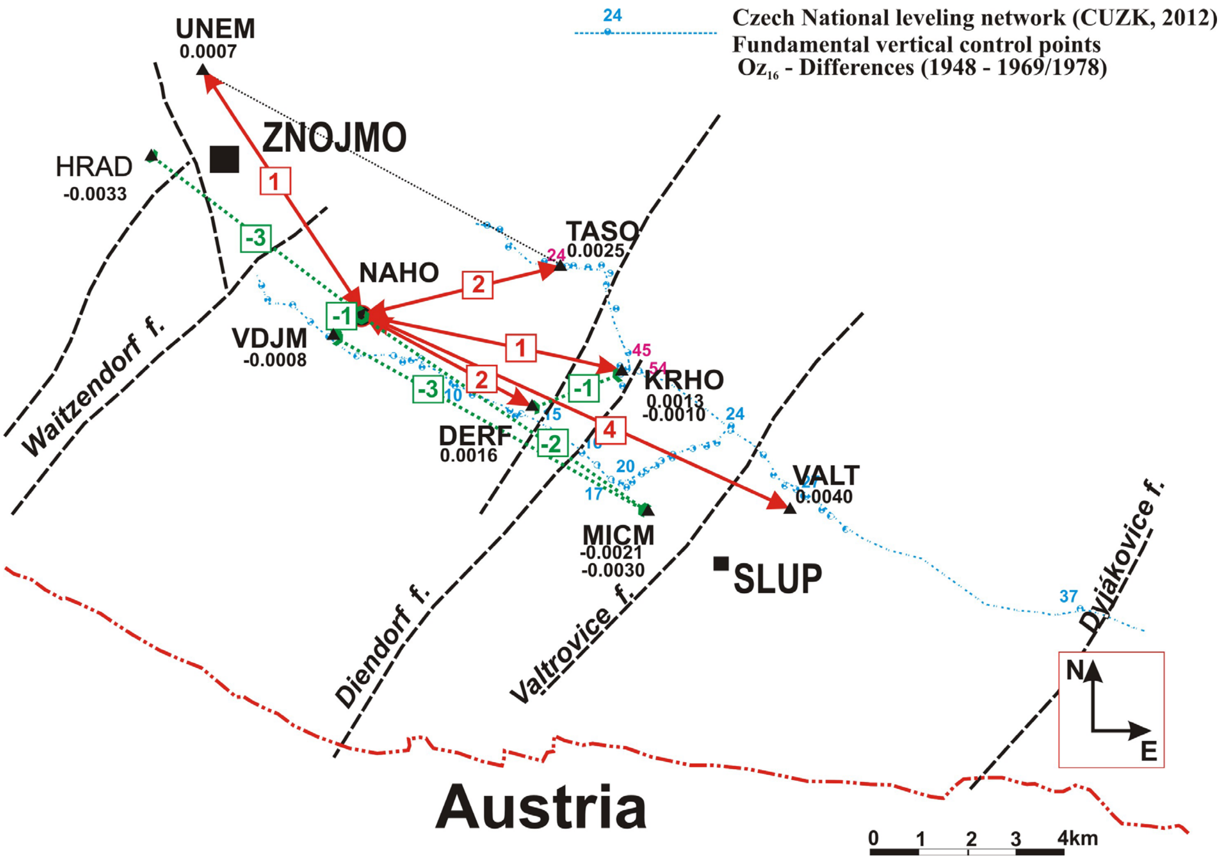

Fig. 6 The first results of GPS measurements at the Znojmo GPS Polygon. Preliminary annual velocities were gained from period 2009 - 2012. Lines with larger dots document benchmarks of the Czech national leveling network that was used for checking of the vertical velocities.

6. EXTENSION AND CONTRACTION BASED ON THE GPS DATA

A. DIENDORF-ČEBÍN TECTONIC SYSTEM

One of the leaved out fault active systems at Southern Moravia is the so called Diendorf - Čebín Tectonic Zone (DCTZ), that is seismically active in its southern segment (in Austria). The Waitzendorf fault is a part of the DCTZ, with intensive morphological signs. Along the eastern margin of the Dyje Dome there are many indications showing evidence of geodynamic activity. The facets, old land slides and rock falls indicate recent activity in the environs of Znojmo area.

Preliminary GPS surveying results on the South Moravian territory indicated relatively intensive movement tendencies between the Bohemian Massif and tectonic units of the Western Carpathians. Particularly tectonic zones the DCTZ (Figure 6) and the Bulhary fault play dominant role (Švábenský et al., 2011). The investigations in the area of the DCTZ has been conducted in the transitional part where the Diendorf and Waitzendorf faults are hidden bellow the Neogene sedimentary cover (Figure 6). The geodynamic Znojmo Polygon was established in 2009 with the purpose of displacement monitoring in southern part of the DCTZ along the Thaya river valley between Znojmo and Slup. The geodetic monitoring network consists of eight epoch GNSS points surrounding the Načeratice Hill (local reference station NAHO - GPS point of the former Morava Geodynamic Network). The distribution of the network points covers both the NE-SW oriented faults – Waitzendorf and Diendorf - in E-W direction (Pospíšil et al., 2010).

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 continuous GPS static observations at points HRAD and VALT, while the points UNEM, TASO, KRHO, MICM, DERF, VDJM were observed in the triplet pattern (Švábenský and Weigel, 2005). 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

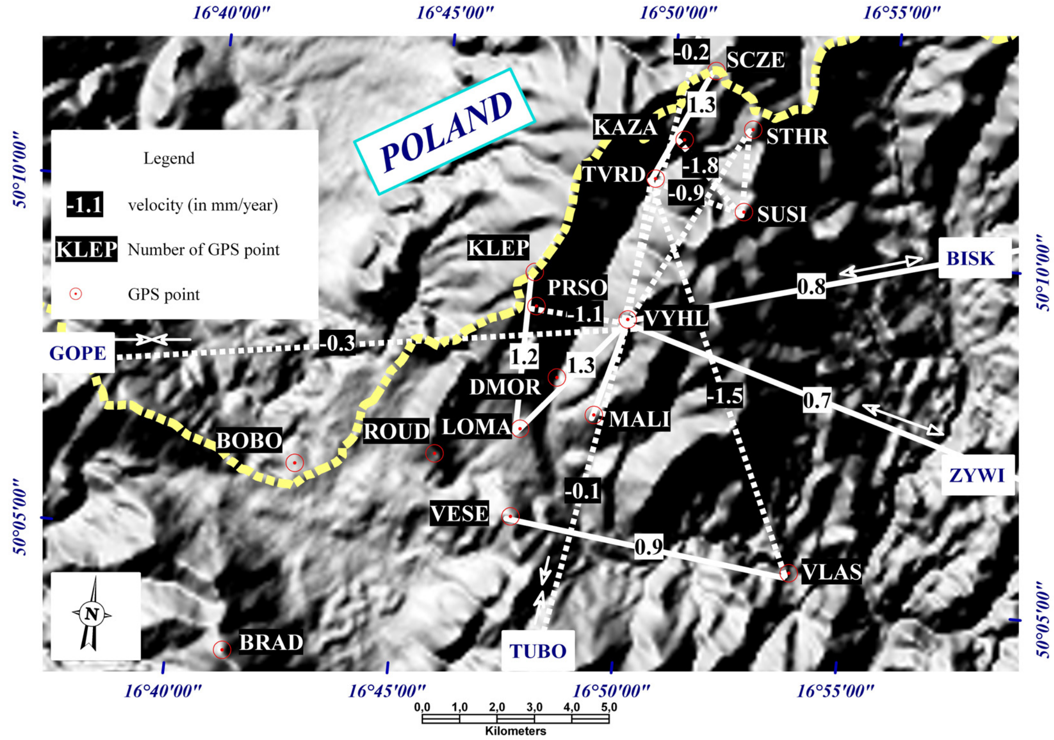

Fig. 7 The results of the GPS measurements and their correlation with morphological data. Mutual movement tendencies are related to the point VYHL. Extensions appear in respect to the points ZYWI and BISK – almost 1 mm/year, while in respect to the points WROC and GOPE there are only insignificant compressions (-0.2 – 0.3 mm/year).

campaigns 2009, 2010 and 2012 were processed using BSW 5.0 (longer intervals), and LGO 8.1 (shorter triplet intervals).

Preliminary results from the GPS Znojmo Polygon repeatedly indicate the significant movement tendencies in the environs of the Waitzendorf and Diendorf faults. The maximum velocities of –0.6 mm/year between the stabilized Thaya Dome block and the shifted Načeratice Hill block and the velocity of >5 mm/year measured between points NAHO and VALT should receive increased attention in future investigations.

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 (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).

B. KRÁLICKÝ SNĚŽNÍK AND SURROUNDING AREA

Measurements in the Local Geodynamic „Sněžník“ Network (LGSN) have started in 1992. The network was established in Králický Sněžník Massif, in cooperation with Department of Geodesy and Photogrammetry AU Wroclaw (now Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences), and Institute of Geodesy, Brno University of Technology, for the purpose of monitoring the upper lithosphere movement in the area. The network spreads out on both sides of the state border in the Králický Sněžník Mt. area. It is also used for experimental testing of various geodetic measuring technologies, and since 1994 it also has served in the Czech part for field practices of the BUT students. The LGSN layout and particular results were published e.g. in (Cacoń et al., 1996; Švábenský and Weigel, 1999; Cacoń et al., 2004; Švábenský et al., 2012).

The measuring campaigns have carried out on a yearly basis in the first half of May since 3rd campaign in 1994 (exceptions were first two campaigns 1992 and 1993 in September). The basic

Table 1 Baseline Time Series - from TUBO.

TUBO	BBYS	SPRN	LINZ	CFRM	CVSE	CHOD	CKRO	CSUM	CBRU	CDAC	CPAR	CSVI	BISK	WROC	GOPE	ZYWI	TRF2
velocity (mm/y)	-0.3	-0.7	-0.2	-0.4	0	-0.1	-0.1	0	0.2	-0.3	0	0.2	-0.2	-0.3	-0.2	0.2	0.4

Table 2 Baseline Time Series - individual processing.

baselina	BRVS	FRBI	FRBR	FRKR	FRVS	FRZY	HOKR	HOVS	KRBR	KRSV	KRVS	PAGO	PASU	PASV	SUBR	SUBI	SUSV
velocity (mm/y)	-1.1	-2.2	-1.5	-1.3	-0.6	-0.3	-0.8	-1.4	-1.1	-1.3	-0.6	-0.2	-0.7	-0.6	-0.2	-0.2	-0.7

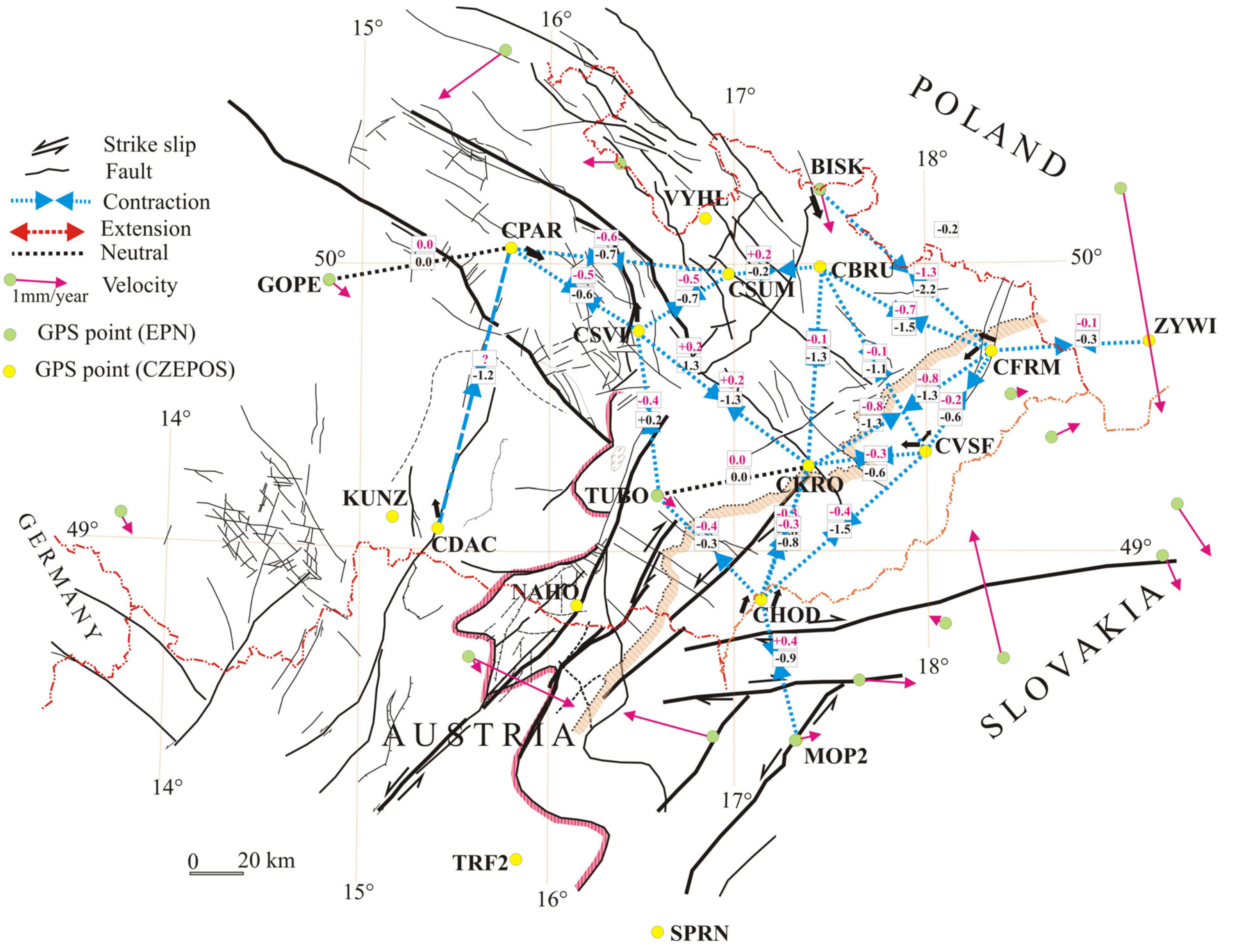

Fig. 8 Images of the major movement tendencies among the chosen GPS points in Moravian parts of CZEPOS network. Arrows near point indicated supposed its direction. The regional character of movements can be observed from data Hefty, 2007; Hefty et al., 2009 (arrows).

observation mode has been 24 hours since 1997, but at some points the amount of observations was in many cases greater (e.g. at the central point VYHL, which was regularly observed in more sessions). Since 2004 the network has been measured with the instrumentation of the Institute of Geodesy only (Švábenský et al., 2012). Network data from the period 1997 – 2011 had been used for the analyses, together with data from selected surrounding EPN stations. All the data obtained within the Czech part of LGSN were reprocessed using the Bernese software ver. 5.0 (and for some computations also the Leica LGO ver. 8.1), employing the unified processing strategy. Preliminary velocity estimations evaluated from the baseline time series are shown in Figure 7, detailed information was presented in (Švábenský et al., 2012).

The GPS points are situated directly on the complexes of the Śnieżnik – Gieraltów Unit, where faults mostly of direction NW-SE dominate (Fig. 7). To make possible the evaluation of movement tendencies in so small area the velocities of baseline changes between the VYHL point and the surrounding EPN stations (WROC, ZYWI, BISK, TUBO and GOPE). Resulting movement trends between VYHL and single EPN stations are displayed in Figures 7, 8 and 9, and in Table 2. While in respect to the stations WROC, GOPE and TUBO a lower compressive movement not greater than -0.3 mm/year is showing in respect to stations BISK and ZYWI there is appearing extensive of 0.7 mmm/year.

C. PERMANENT NETWORKS WITHIN MORAVIAN TERRITORY

To get more detailed view on possible movement tendencies over the whole Moravian territory the data from selected stations of Czech national permanent GNSS network CZEPOS were evaluated. The CZEPOS network has started to operate since May 2005. The data from stations CDAC, CPAR, CFRM, CSVI, CSUM, CBRU, CVSE, CKRO, CHOD, together with data from selected surrounding EPN stations BISK, GOPE, WROC, TUBO, ZYWI, MOP2, KUNZ were processed. The data of two 48 hours epochs per year - first in Spring (May), second in Autumn (September,October) - over the period 2005 – 2012 were processed using the Bernese software ver. 5.0 (and for some computations also the Leica LGO ver. 8.1), employing the similar unified processing strategy as above.

First information about velocities of the baseline changes between the permanent network stations was gained by simple superposing of linear trend upon the single baseline time series over the period analysed. It must be said that the CZEPOS stations quality in respect to displacement monitoring is not very good due to mounting of antennas on roofs of buildings. On the other hand, advantageous is the identical instrumentation and the same antenna type at all stations. Evaluation period had to be shortened to 2005 – 2011 in some cases due to jumps in the time series caused by complete antenna change in CZEPOS network (in first half of 2012 the original LEIAT504 antennas with LEIS radomes were replaced by new LEIAR25.R4 antennas with LEIT radomes). Together with antenna change also the receivers were upgraded to Leica GRX1200+GNSS type that is capable of tracking the signals of more contemporary GNSS.

The evaluation results are presented in the following tables. In Table 1 the estimated preliminary velocities stemming from analysis of baselines going from TUBO station (star) are shown. Table 2 shows the estimated preliminary velocities evaluated on base of single baseline processing between stations less than 100 km distant. The resulting velocity values enabled to form first ideas about the main movement tendencies within the Moravia territory (Fig. 8).

7. RESULTS

The analysis of the results of GPS measurements at the points of the Kralický Sněžník (Švábenský et al., 2012), Morava (Švábenský et al., 2011) and Znojmo (Pospíšil et al., 2012) networks is based on comparison of movement tendencies with the the results gained at netvork CEGRN Hefty, 2007, Hefty et al., 2010). All set of information about horizontal movement tendencies has been confrontated with geomorphological and geophysical available data. A distinct tectonic pattern constructed on the geodetical results indicates good correlation with geophysical anomalies (magnetic, gravity anomalies, earthquake foci etc.).

Relative displacements between interior LGSN points evaluated in period of 15 years were therefore limited to a comparable velocity level – if the computed velocities were under 0.7 mm/year then they were not considered.

Preliminary GPS positioning results obtained on the territory of South Moravia (Švábenský et al., 2011) have shown relatively intensive movement tendencies between the Bohemian Massif and tectonic units of the Western Carpathians. Particularly 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 (Švábenský et al., 2011). The movement tendencies, obtained on the bases of the GPS results and repeated levelling measurement (Vyskočil, 1996), are confronted with geomorphological and geophysical data through GIS. This not only allows permanent database and the results complement and perambulate, but whenever refined to include more interdisciplinary interpretations. For these purposes the pilot Kinematic model for the Moravian region was constructed (Fig. 9). The obtained preliminary results seems to be an area located approximately between Kralický Sněžník Massif and the south Dyje Dome as passive block with pushing of a Moldanubian block from the west. The area of the Flysch Carpathians in the east tends to move to the NE different velocities. It coinsides with velocity vectors determined by Hefty (2007) and Pospíšil et al. (2012 – Figure 9). These conclusions are based on 10 to 15 year period of repeated measurements. It is expected that in the coming years, the results will be continuously improved.

On the basis of gained results it is possible to suggest the new more detailed GPS measurements and

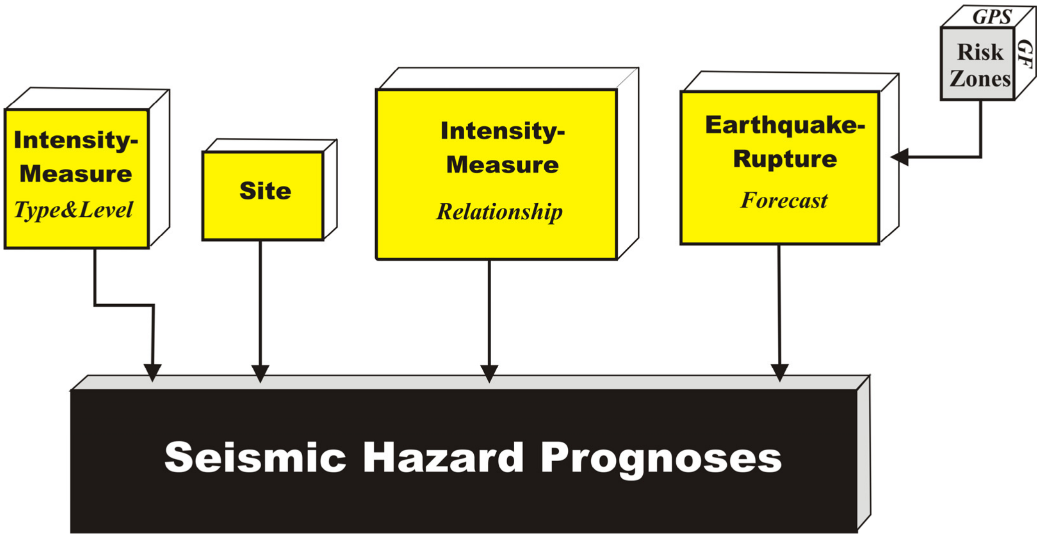

Fig. 10 The Chart defines way for calculation of the Seismic Hazard supplied by block, that is based on the information gained on the basis of GPS and geophysical-geological studies. Such approach much better enable to do prognoses of the potential risk combined with the recently active tectonic system.

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.

8. CONCLUSION AND RECOMMENDATION - NEW WAY FOR UTILIZATION OF GPS RESULTS

One weak place in research geodynamical phenomena in the BM is Seismic Hazard Analyses (SHA). 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 it is usually 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.

GPS data and their interpretation offer next opportunity to utilize the information on geodynamic and kinematic condition in areas for calculation and SHA (Figure 10). Paralely with geological works, Remote Sensing and morphological analyses with the GPS velocities and their evaluation can be identified the most active tectonic features that can be used in SHA models. Paradoxly such approach in our condition is not used, yet, even though the results of the permanent GPS measurements and many campaigns are available.

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 enable to 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. Hronov – Poříčí fault system, Diendorf fault, Hron boundary, Muráň Malcov tectonic zone – MMTS in Slovakia (Švábenský et al., 2011; Pospíšil et al., 2012).

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

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 Moravian territory. 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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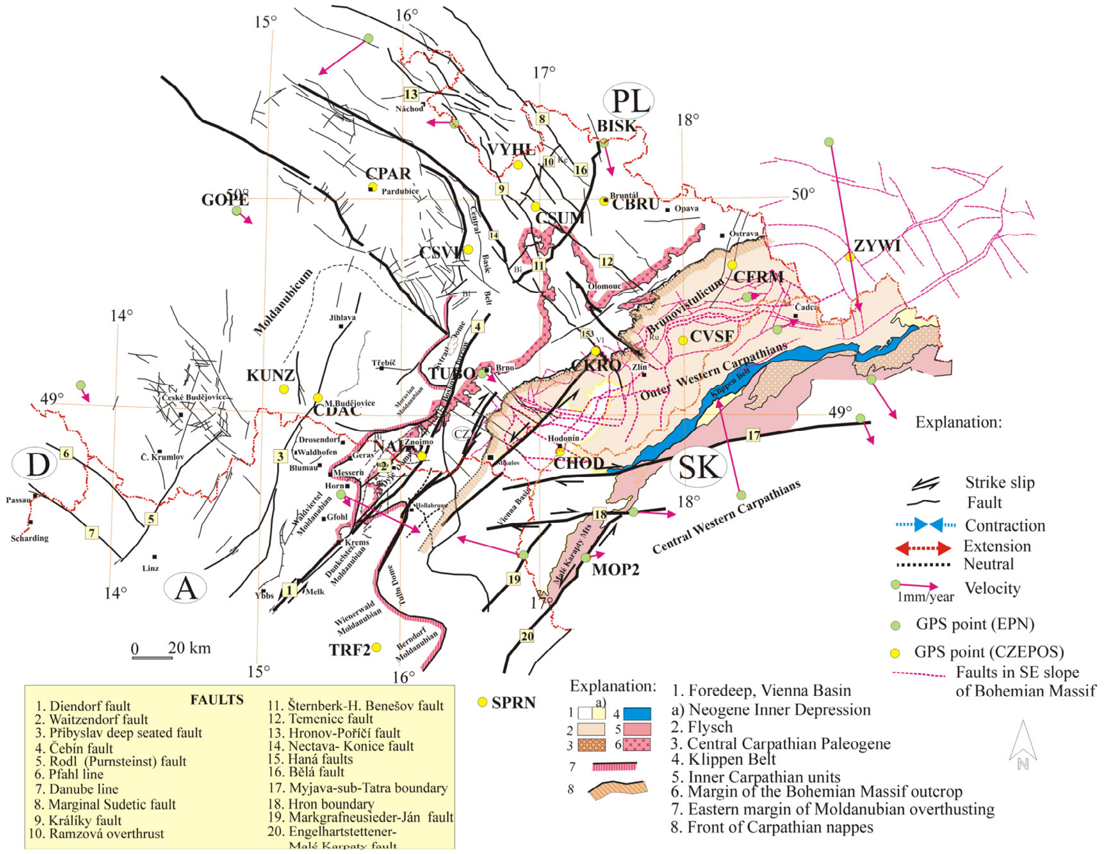

Fig. 2 Main fault in Moravia and surrounding. Heavy lines represent the main tectonic zone interpreted also on the base of Remote Sensing and geophysical data. We considered to be active during Tertiary to Recent and played main role in kinematics of tectonic pattern (Malkovský, 1979; Pospíšil et al., 2010, 2012)

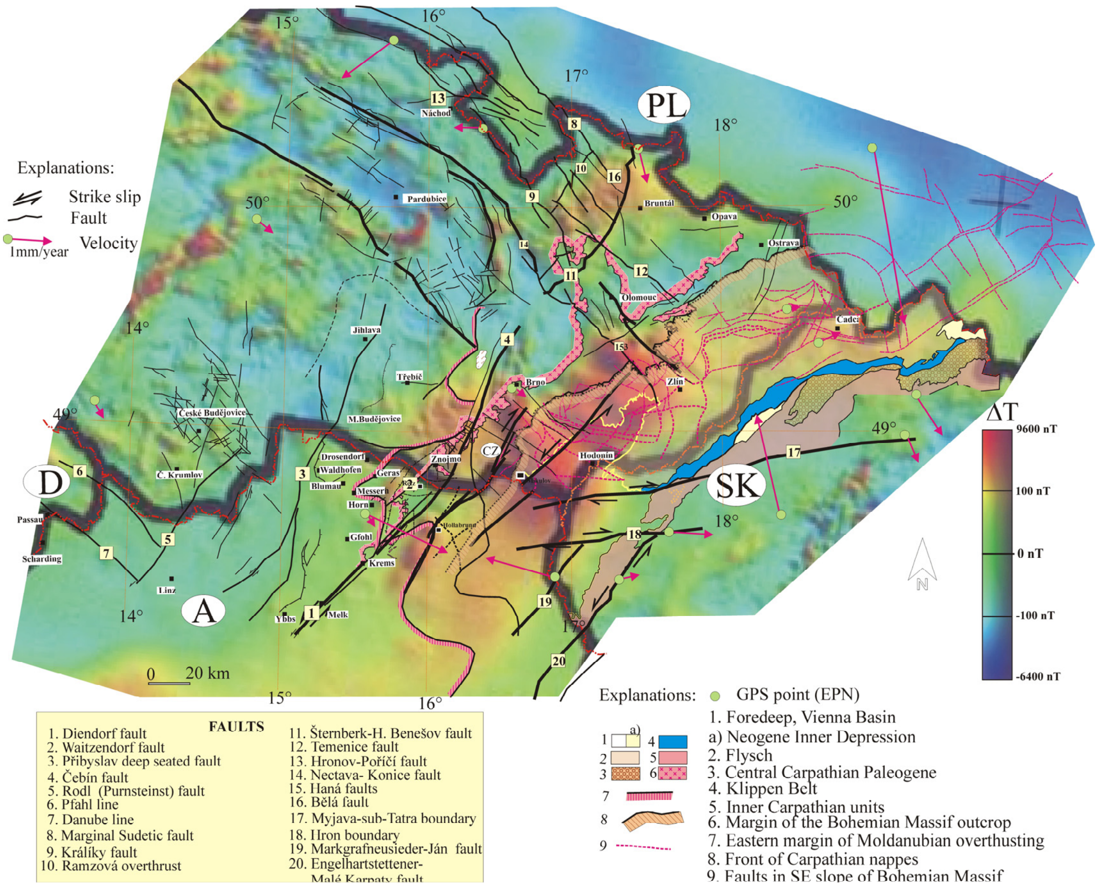

Fig. 3 Magnetic map - example of geophysical map conveniant for verification and mapping of horizontal movement tendencies along tectonic zones.

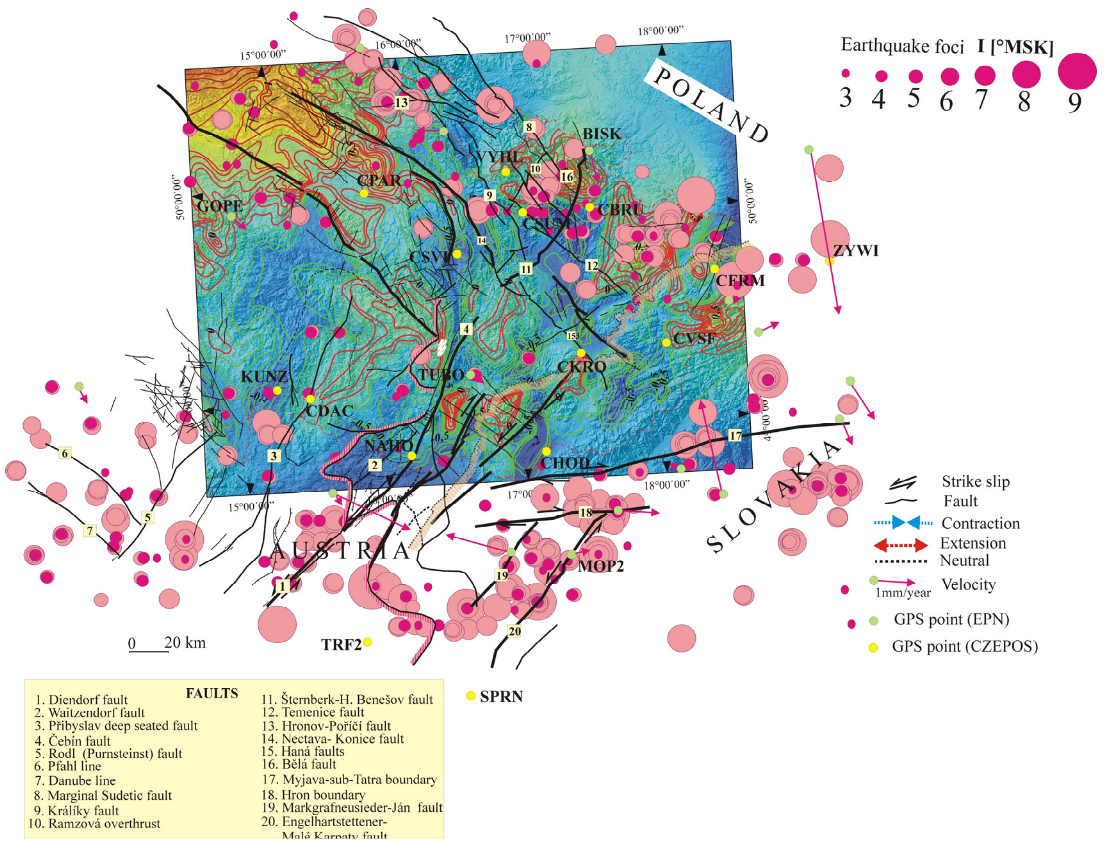

Fig. 4 For the geodynamic study and analyses of the kinematics in all Central European region the new map of the recent movement tendencies (RMT) has been compiled and an supplied by the latest results of the horizontal velocity vectors gained from the GPS measurements (Pospíšil et al., 2012). Figure demonstrates the chosen part of map RMT and the supposed neotectonically active faults for Moravia and surrounding regions. Even though the historical earthquake foci (Schenková et al., 1979) don't enable to verify precisely the activity along single interpreted boundary, they can be used for estimation and localization of such places.

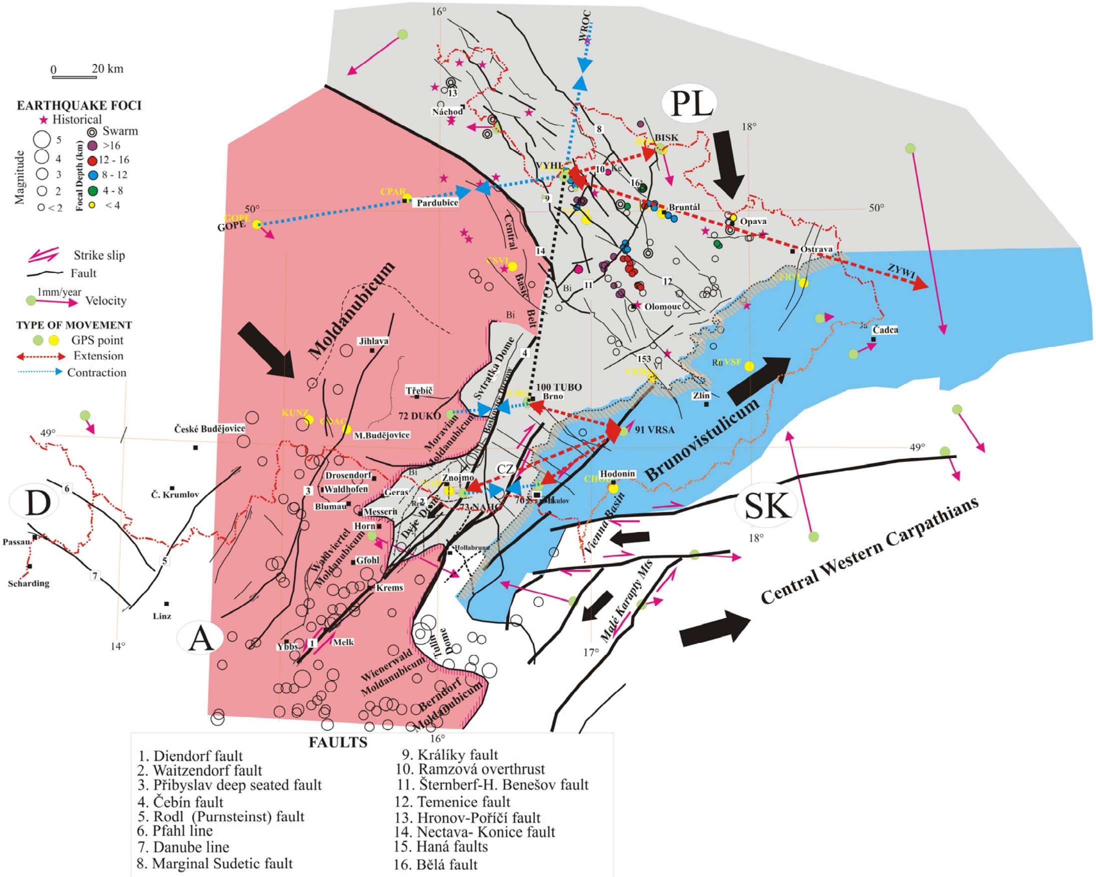

Fig. 12 Constructed kinematic model of the Moravian region on the bases of the correlation of the morphotectonic and geophysical data with the results of GPS measurements. Epicenters of earthquakes for the period from 8.5.1267 to 31.3.2004 - after Špaček et al., 2006, other after Lenhardt et al., 2007). The sizes of black circles are scaled proportionally to the local magnitudes of individual earthquakes. With combination of results from Kralický Sněžník and polygon Znojmo networks the basic 3 blocks were determined: Moldanubic block - red, Sudetic block - gray and Beskyde block, represented by the Outher Carpathian Flysh - blue.