

GEODYNAMIC PATTERN OF THE WEST BOHEMIA REGION BASED ON PERMANENT GPS MEASUREMENTS

VLADIMÍR SCHENK AND ZDEŇKA SCHENKOVÁ

*Centre for Earth Dynamics Research, Institute of Rock Structure and Mechanics,
Academy of Sciences of the Czech Republic, Prague^a*

ZUZANA JECHUMTÁLOVÁ

Institute of Geophysics, Academy of Sciences of the Czech Republic, Prague^b

S u m m a r y : *In West Bohemia in the period of 2003 - 2005 five permanent GPS stations were established to detect local movement trends. Their mutual position changes were determined from time series of GPS observations and were associated with seismic, gravity, and geo-scientific data related to the geodynamics of the West Bohemian region. Knowledge of local physical processes based on spatial and time earthquake occurrences, focal mechanisms of main events, stress and strain fields set up a tool for recent seismotectonic analyses. The permanent GPS measurements bring independent effective phenomenon, direct monitoring of site movements. The movements detected by our GPS stations evidenced WSW-ENE extension with subsiding trends in the western part of the Cheb Basin and the Smrčiny Mts. Besides, there were monitored dextral movements along the Mariánské Lázně tectonic fault zone (MLF). A comparison of results with previous data formed a presumption that an antithetic stress pattern has to exist inside the inner part of the MLF tectonic zone. This antithetic stress can explain the coexistence of dextral and sinistral movements on individual tectonic elements in the West Bohemian area.*

K e y w o r d s: GPS data, horizontal and vertical velocities, West Bohemia, earthquake swarm area

1. INTRODUCTION

The western part of the Krušné hory Mts. and adjoining Vogtland are regions that are characteristic for the occurrences of the earthquake swarms. The first written document on a swarm dates back to 1198. Since that, other historical occurrences of the swarm activities were reported repeatedly in irregular cycles of several decades (*Kárník et. al., 1987*). Even if the first seismograms were registered as early as in 1903, the first complete instrumental swarm seismograms exist since 1962. In winter period during 1985-86 some events of the intensive earthquake swarm were macroseismically felt in distances bigger than 100 km. The strongest event was in December 21, 1985 and had a magnitude of 4.6 with dynamical impact corresponding to epicentre intensity of 6° to 7° MSK.

A local seismic network WEBNET was established in 1994 with the aim to monitor the West-Bohemian earthquake swarm activity. Since that, the network has been permanently and is still upgraded (*Horálek et al., 2000*). At the moment, it operates 13 seismic stations that allow monitoring the swarm events from $M_L \approx 0.5$ or even below this level. A continuous

^a Address: V Holešovičkách 41, CZ – 182 09 Prague 8, Czech Republic; fax: +420 284 680 105,
e-mail: schenk@irsm.cas.cz

^b Address: Boční II/1401, CZ – 14131 Prague 4, Czech Republic; fax: +420 272 761 549, e-mail: zs@ig.cas.cz

monitoring of the local seismicity enabled detection of the earthquake swarms in 1994, 1997, 2000, 2004, 2007. It was ascertained that the swarm foci are clustered in space and time in several areas; on the Czech side they are found near Nový Kostel, Kopaniny, Skalná, Kraslice and Lazy villages, on the German side they are in the vicinity of Klingenthal, Plauen and Marktredwitz. The focal depths are in range of 4 to 16 km, usually not more than 10 km.

The western part of the Bohemian Massif is known for the following geophysical and geological phenomena: distinct negative gravity anomaly (*Švancara et al., 2000*), higher heat flow (*Čermák et al., 1996*), Quaternary volcanism active till the Holocene (*Wagner et al., 1998*), abundant occurrence of juvenile carbon dioxide waters, rich CO₂ emissions, anomalies of mantle-derived He and geothermal springs (*Heinicke and Koch, 2000; Weise et al., 2001*). All these phenomena clearly manifest a high potential of recent dynamic activities in this region and give a chance to reveal other original relations among them.

2. GPS DATA IN WEST BOHEMIA REGION

In 1994, the Geophysical Institute, Academy of Sciences of the Czech Republic, v.v.i., started to carry out the repeated GPS measurements in West Bohemia (the Czech part of the studied area) in a network covering an area of about 1000 km² (*Mrlina, 1997, 2000; Mrlina et al., 2003; Špičák et al. 1997, 1999*). Unfortunately, the applied system of GPS measurements (only few hours of registrations, no identical antenna applications in one site during GPS campaigns, etc.) did not allow any detection of the systematic velocity trends among individual network sites.

Similarly, in 1994, the Institute for Planetary Geodesy, Technical University of Dresden, established a local geodetic network with the dimensions of 30-35 km in all directions (*Wendt and Dietrich, 2003*) operating in Vogtland (the German part of the studied area). The results of five GPS campaigns carried out in the network during 1994 to 2001 indicated that a deformation process was non-linear in time and was in relation to the seismic activity. To improve the surface deformation determinations, there were installed two permanent GPS stations, Grünbach (GRNB) and Neustadt (NEUS), in the northern part of Vogtland. Unfortunately, the obtained results have not been published, yet.

In 2003, the Institute of Rock Structure and Mechanics (IRSM), Academy of Sciences of the Czech Republic, v.v.i., established two GPS permanent stations MARJ and POUS (*Schenk et al., 2004*) in West Bohemia. The GPS antenna of the station MARJ is situated on the unused reinforced chimney of one-storey building in Mariánská village near Jáchymov town. The station is based in the Karlovy Vary granitic pluton, i.e. at the eastward wing of the seismoactive Mariánské Lázně tectonic zone. The antenna of the station POUS was installed at the roof of a massive 4-storey concrete panel-house in Poustka village near Františkovy Lázně town, which is based in the Smrčiny (Fichtengebirge) granitic pluton. Contrary to the MARJ station, this station is situated at the opposite westward wing of the same tectonic zone with the aim to indicate possible regional movement pattern of the whole West Bohemian area. There were studied site stabilities of both stations for the period of 2003-2007 and there was not observed any seasonal variations and/or effects of building construction subsidence. The third permanent station VACO has been operating since 2004 in Vacov village near Vimperk town and is located in the opposite side of the shear zones of the Bavarian Pfahl contrary to the German station Wetzell (WTZR). In 2005, these three stations were included to the European permanent network EPN.

In 2005, in West Bohemia, two other GPS permanent stations LUBY and KYNS were established in towns Luby and Kynšperk-Kolová, respectively. Both antennae are sited at the

roofs of weight-carrying building walls to ensure their position stability. Figure 1 shows the positions of the permanent stations.

The permanent GPS stations MARJ and VACO are equipped with Ashtech Z18 receivers and Ashtech choke ring antennae with snow domes. Four other stations KYNS, LUBY, POUS and VACO are equipped with Topcon GB-1000 receivers and Topcon CR3 GGD antennae to monitor both American NAVSTAR and Russian GLONASS satellite system signals. The receivers register the signals on PC hard disks with 5° elevation mask and with the sampling rate of 1 second. The permanent stations MARJ and POUS registered from 2003 till May 2005 and station VACO from 2004 till 2005 with the sampling interval of 30 seconds. To avoid problems with some electric power failures, each station is equipped with a spare battery, which is able to power the equipments for at least 24 hours. After storing the data on the internal PC hard disk, they are transmitted automatically to the operational IRSM data centre (OC IRS) by GPRS or WiFi connections (Kottbauer *et al.*, 2003). Hourly RINEX data are available in the OC IRS within 1-2 minutes after each hour (Mantlik *et al.*, 2005). Before GPS data processing by the Bernese GPS Software version 5.0 (Hugentobler *et al.*, 2005), hourly data pass a routine TEQC check procedure (Estey *et al.*, 1999). In case that any antenna is changed or replaced, corrections to its new position are introduced. The Earth rotation parameters, precise satellite orbits and clock data are collected for GPS data processing from the CODE centre where both the NAVSTAR and the GLONASS GNSS system ephemerides are available. Information about all registered data is available on-line at <http://geonas.irsm.cas.cz>.

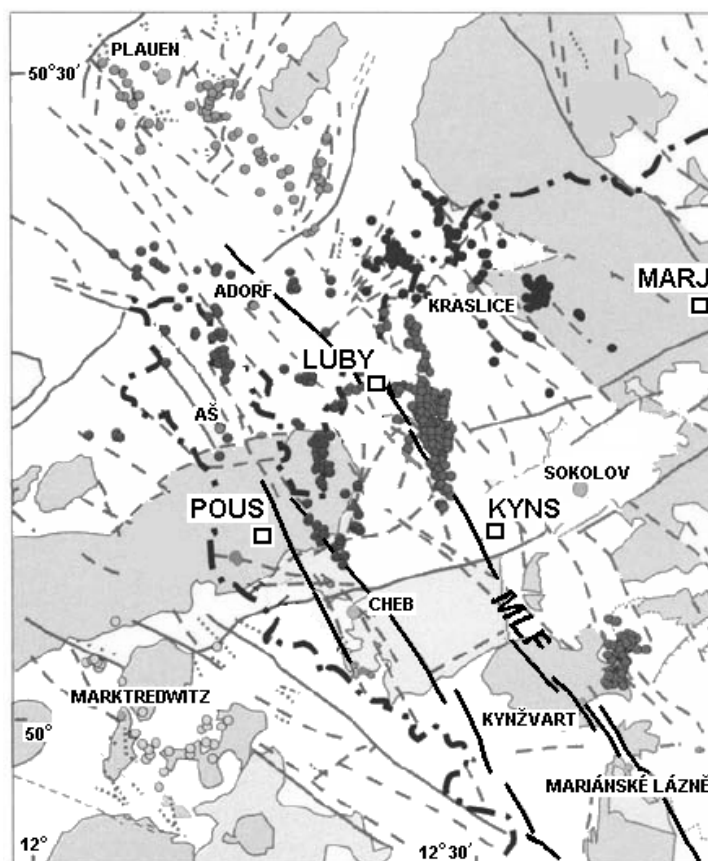


Figure 1. Location of four GPS permanent stations KYNS, LUBY, MARJ and POUS in West Bohemia; ● - earthquake epicentres, black line – main fault, grey line – faults, grey dashed line – expected faults, MLF - the Mariánské Lázně fault system, base map from Heuer (2006)

After standard data processing by the Bernese GPS Software version 5.0 where the ITRF2000 coordinate system was applied, the obtained time series of absolute horizontal and vertical site components of all permanent stations passed further additional inspections. The random outliers were eliminated and the values affected by snow covers of the antennae were removed too. The GPS antennas at the MARJ and VACO stations are shot by web cameras in 5-minute intervals (*Grácová et al., 2007*). Then, the corrected time series were used for a determination of individual site velocity components (Fig. 2).

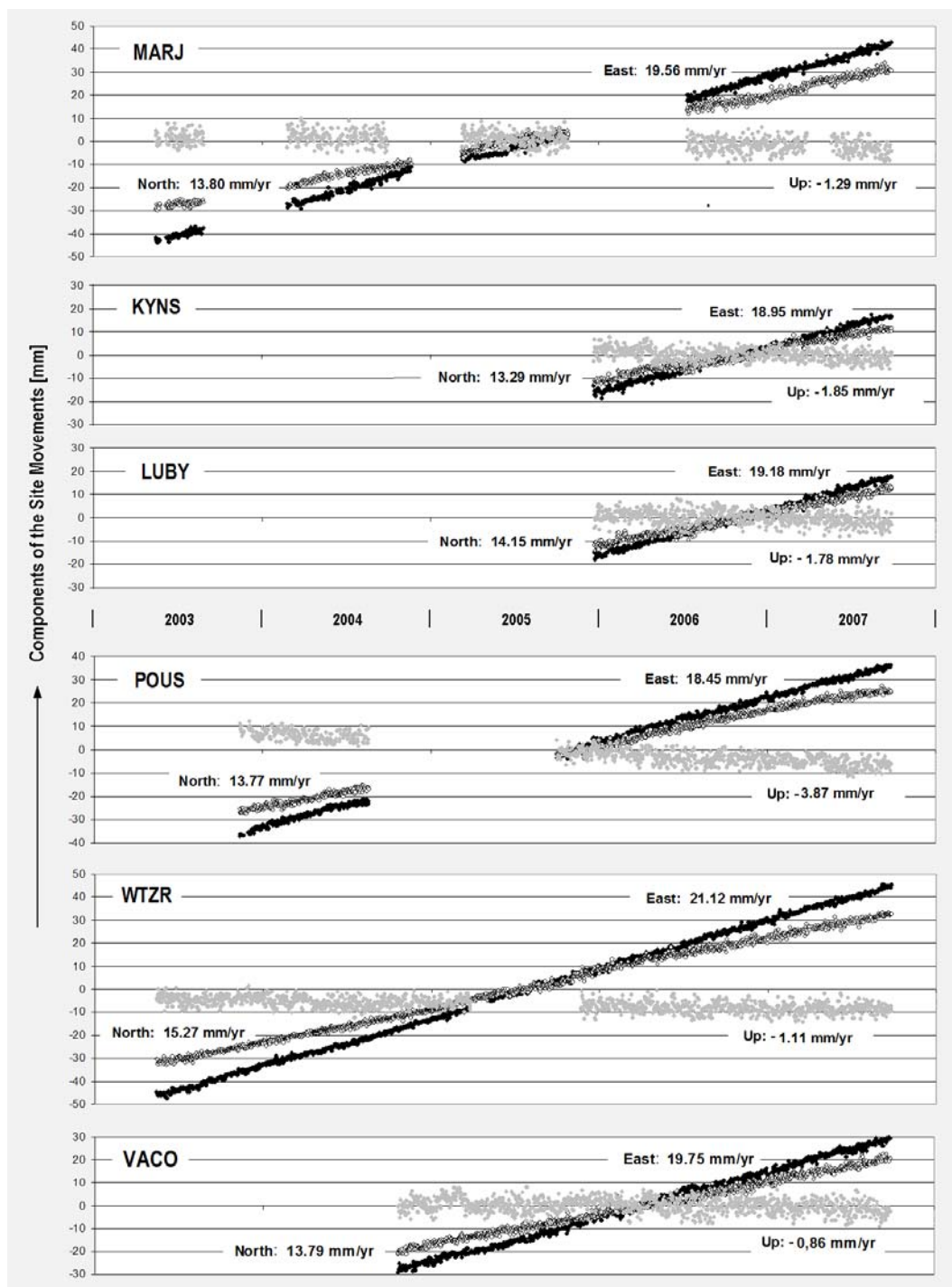


Figure 2. Site movements of the permanent GPS stations located in West Bohemia; black points –east components, empty points –north components and grey points – vertical components.

3. ANNUAL SITE VELOCITIES

Horizontal and vertical site velocities detected by six permanent GPS stations MARJ, POUS, VACO, LUBY, KYNS and WTRZ located in the western part of the Bohemian Massif (Fig. 2) were mutually analyzed to assess quantitative velocity trends among the main geologic structures of the area. Table 1 summarizes the annual absolute and relative site velocities for the east and north horizontal and vertical components together with standard and probability errors of absolute velocities. For each component its median was calculated to determine the relative site velocities among the sites. The median seems to be more reliable than the mean value because of small number of sites and because it only depends on the relative position of the values in the component data set. The use of the median is also supported by the distinct vertical velocity of the site POUS and the horizontal velocity of the site WTZR. The Table 1 shows that the standard errors of velocity determinations of the KYNS and LUBY stations, operated for 2-year period only, are twice or three times higher than the errors of other stations but they are already in acceptable limits for the movement pattern analysis of the West Bohemian area presented below. The evaluated errors confirm that the longer the observation time series the smaller the errors and that the horizontal velocity errors are smaller than the errors of the vertical velocities.

Table 1. Annual velocities of six permanent GPS stations and error evaluations

GPS site	East component				North component				Vertical component			
	absolute	relative	err_{stand}	err_{prob}	absolute	relative	err_{stand}	err_{prob}	absolute	relative	err_{stand}	err_{prob}
	[mm/year]			[%]	[mm/year]			[%]	[mm/year]			[%]
MARJ	19.56	0.19	0.03	0.09	13.80	0.0	0.03	0.14	-1.29	0.25	0.08	4.13
KYNS	18.95	-0.42	0.07	0.23	13.29	-0.51	0.09	0.48	-1.85	-0.31	0.19	6.85
LUBY	19.18	-0.19	0.07	0.26	14.15	0.35	0.09	0.42	-1.78	-0.24	0.23	8.87
POUS	18.45	-0.92	0.02	0.09	13.77	-0.03	0.03	0.13	-3.87	-2.33	0.06	1.12
WTZR	21.12	1.75	0.02	0.05	15.27	1.47	0.02	0.09	-1.11	0.43	0.05	2.73
VACO	19.75	0.38	0.04	0.14	13.79	-0.01	0.04	0.20	-0.86	0.68	0.11	8.62
<i>median</i>	<i>19.37</i>				<i>13.80</i>				<i>-1.54</i>			

The standard errors err_{stand} [mm/sec] of the absolute velocity components have not exceed 0.1 mm/year except two vertical components related to KYNS and LUBY stations for that they are 0.19 mm/year and 0.23 mm/year, respectively. The probabilistic errors

$$err_{prob} [\%] = 67.45 * (err_{stand} / velocity\ value) ,$$

of the absolute horizontal velocity components have not exceed 0.5% and for the absolute vertical components are lower than 9%. The difference between the probabilistic errors of the horizontal and vertical components corresponds to the differences between absolute values of the horizontal (tens millimetres) and the vertical (millimetres) velocity components. Both standard errors and probabilistic ones represent a good precision of the velocity determination from the permanent GPS station observations.

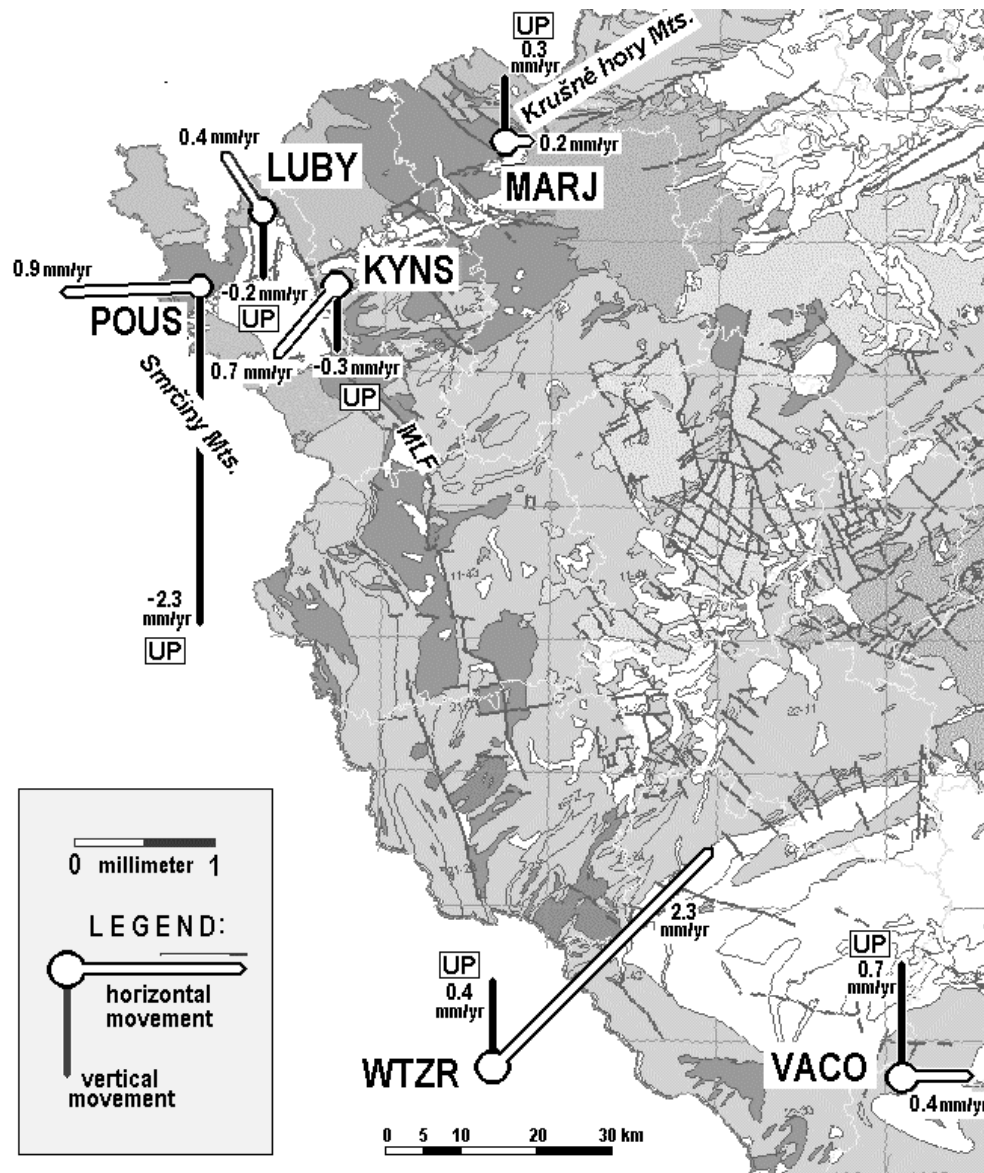


Figure 3. Annual horizontal and vertical site relative velocities in [mm/year] for six GPS permanent stations.

4. DISCUSSION OF RESULTS

The relative site velocities determined from six permanent GPS measurements represent the first long-term systematic investigations in the West Bohemian area (Fig. 3). Movement trends extend significantly the present knowledge of the regional geodynamics of West Bohemia. The main interest has been the detection of recent movements along the Mariánské Lázně fault (MLF) zone. The following movement pattern and trends were found:

- dextral horizontal velocities of 0.6 ± 0.1 mm/year along the western boundary of the MLF zone,
- regional horizontal extensions round 1.1 ± 0.1 mm/year between structural blocks of the Krušné hory Mts. (Erzgebirge) and the Smrčiny Mts. (Fichtelgebirge), especially in the area of the Cheb (Eger) Basin,

- c) relative subsiding trends of 2.6 ± 0.1 mm/year in the western part of the Cheb Basin and the Smrčiny Mts. with respect to remaining part of the area under study and
- d) shortening horizontal trends up to 1.9 ± 0.1 mm/year in the SW-NE direction in the area of the Český Les Mts. and the Šumava Mts. (Oberpfalz and Bavarian Forests).

The dextral movements indicated from GPS data along the MLF tectonic zone reach in total the pronounced velocity value of 1 mm/year. In the southwestern part of the Bohemian Massif the dextral trends were identified also on the Bavarian/Pfahl fault (*Kaiser et al., 2005; Behm et al., 2007*) and on the Danube fault (*Behm et al., 2007; Finger et al., 2007*). This regional movement pattern supports the existence of the dextral movements determined along the Mariánské Lázně fault system (MLF). General trend of the dextral faults can be explained only by the recently active movement source in this area: by the Adria plate motion acting through the East and Central Alpine areas northward with a slight anticlockwise rotation.

There are also estimations that along the MLF zone the movements have sinistral character. These opinions are partly rooted in focal mechanism solutions of microearthquake swarms occurring in the main seismic zone in the West Bohemia region, in the Nový Kostel zone, and partly on the existence of so called Regensburg-Leipzig-Rostock lineament permeating through this area (*e. g. Bankwitz et al., 2003; Heuer et al., 2006*) where sinistral movements are expected, too. Geologically the existence of this lineament could be probably linked to the deep lithospheric structure of the area assembled during Variscan. The assumption of sinistral movements on this lineament, which is located between the Krušné hory Mts. and Smrčiny Mts. units, corresponds well with our findings that the area between both units is under extension.

The seismotectonic models based on 1985-86 earthquake swarm data assumed both extensional trends in the seismoactive West Bohemian area (*Antonini, 1988*) and an existence of a lamella-like rock setting inside the Nový Kostel seismic zone (*Grünthal et al., 1990*).

The model delivered by *Antonini (1988)* presumed also subsiding trends in westward direction. Earthquake focal mechanisms observed for March 1991 events near Bad Elster (*Wirth et al., 2000*) on the western marginal part of the MLF tectonic zone supported the subsiding trends expected in this area. The mechanisms related to movements originated on normal faults with the WSW slips located between the Cheb Basin and the Smrčiny Mts. All the observations mentioned above fit well to movement trends detected by the GPS investigation.

The registered velocities, based on GPS data, still detect the regional extension between the Krušné hory Mts. and the Smrčiny Mts. together with subsiding trends. It is evident that such phenomena have to be accompanied by changes in regional stresses. The indicated conditions – dextral movements along the MLF zone, extensions together with subsidence in this zone – correspond to the state where an antithetic stress conditions can originate inside the MLF tectonic zone. Such stress conditions allow a mutual coexistence of the dextral movement trends along the MLF tectonic zone and the sinistral trends on a lamella rock setting inside the MLF zone, like in the Nový Kostel swarm zone, to be clarified (*Twist and Moores, 1992*).

The shortening trends in the SW-NE direction in the area of the Český Les Mts. and the Šumava Mts. (Oberpfalz and Bavarian Forests) seem to be joined to regional pattern of stress field observed in Central Europe, the origin of which is linked to the Alps movements northward.

In 2003 we started to monitor the GNSS signals on our GPS permanent stations, which enabled simultaneous correlations of station position changes with recorded earthquake

swarms. But there have not been observed any pronounced or even regular position changes. Nevertheless, in February 2004 there was detected a certain positive correlation between station positions and relatively minor swarm activity (*Schenk et al., 2007*). The most west swarm events of the Nový Kostel zone occurred in a few-day period. Focal positions of the events were in depths of 13 to 14 km; see earthquake catalogue on web pages of the Institute of Geophysics, Academy of Science of the Czech Republic. These events are deeper than the common swarm depths of 6 to 10 km originated in the seismoactive Nový Kostel zone and are located close to the west boundary of the MLF. At the moment, this certain correlation with GPS regional movement pattern is still under study and verification.

5. CONCLUSIONS

Permanent GPS observations realized within a few years on six sites in West Bohemia detected local movement trends. Their correlations with other data related to geodynamics of this area brought new ideas on how to explain the recent physical processes. They confirmed previously expected existence of extending WSW-ENE movement trends accompanied by subsiding in the western part of the Cheb Basin and the Smrčiny Mts. Furthermore, they detected dextral movements along the Mariánské Lázně fault zone in that area. When we compared the results with former results and assumed the presence of an antithetic stress pattern for the MLF tectonic zone then we can clarify the recent coexistence of dextral and sinistral movements on individual tectonic elements inside the MLF tectonic system. Even if these results extended recent knowledge, it is evident that they should be additionally proved by further measurements.

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