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UTILIZATION OF ARCHIVE GEOPHYSICAL DATA FOR GEODYNAMICAL STUDIES IN THE SUDETES: EXAMPLE OF BĚLÁ FAULT ZONE (THE NÍZKÝ JESENÍK MTS.)

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ABSTRACT

Geophysical data are used not only, in geological mapping, exploration of mineral resources, hydrogeology, but are also important for other branches such as environmental protection, civil engineering and archeology. That is why, within the project CzechGeo/EPOS (www.czechgeo.cz), geophysical data access is solved as a separate topic under the guidance of the Czech Geological Survey (hereinafter CGS). In accordance with the current needs of national and international activities (INSPIRE, EPOS, IAGA), an inventory of available data, its consolidation and harmonization according to national and international standards is conducted. The aim is to store securely and permanently valuable data, which in many cases cannot be reinstated.

On the example from the Nížký Jeseník Mts. possible advantages and utilization of Archive data for mapping and verification of the movement tendencies gained from GNSS networks – EPN, EAST SUDETEN and MORAVA are demonstrated.

Very valuable information for the interpretation of structural and tectonic conditions is provided by geophysical data (seismic reflection profiles, gravity and magnetic data, etc.) in the area of interest, especially in terms of monitoring the main fault systems and the character of the basement structures.

INTRODUCTION

Using an example from the Nížký Jeseník Mts. we demonstrate a successful usage of geophysical Archive data in mapping and verification of recent crustal movement tendencies that follow from data gained within the EPN, EAST SUDETEN and MORAVA GNSS networks. The area under discussion is covered by these three geodetic networks that monitor long-term recent Earth's surface movement tendencies in northern Moravia. The monitoring results of approx. 20 years lead to a conclusion of significant horizontal dextral displacement tendencies that are concentrated along the Bělá fault system (Buday et al., 1995 – Fig. 1). The continuation of the latter towards the NW is associated with the Marginal Sudetic Fault.

In the paper, we aim at showing of this structure verification of the results of the GNSS monitoring. Another aim is to calculate the possible depth level of the source generating the observed tectonic motions.

Highly valuable information is additionally provided by geophysical data (seismic reflection profiles, recent vertical movements (RVM), earthquake foci IEP MU, GRAV/MAG data, etc.).

The main goal of the paper remains interpretation of structural and tectonic features and their recent dynamics in the area of study, based mostly on data from the monitoring of the main fault

systems and on characteristics of the basement structures.

GEOLOGICAL SETTINGS

The area with the most intensive recent movements tendencies (Fig. 1) is located in the Moravian-Silesian part of the European Variscan orogen; more precisely of its youngest Culm facies (D-LC), easternmost part. Geographically it belongs to the Nížký Jeseník Highlands and geologically and stratigraphically to the Lower Carboniferous (Viséan) sequence of so the called Culm facies. Generally the western parts of area are composed of prevailing pelitic turbidites, while greywackes prevail in the east (Fig. 1). The Culm facies sediments tectonically overlie those of the Devonian carbonate facies as proved by the borehole Potštát 1 (Čížek and Tomek, 1991).

Let us summarize the present state of knowledge, especially that one concerning structural geology and thermal history. Since the evaluation of seismic reflection profiles and the borehole Potštát-1 (Čížek and Tomek, 1991) the model of thin-skinned southeasterly tectonic transport within the fold-and-thrust belt has been accepted. Most recent work regarding thermal history of the Culm basin (Jirman et al., 2018) brings about a model based on study of the Culm facies (D-LC) vitrinity reflectance in surface

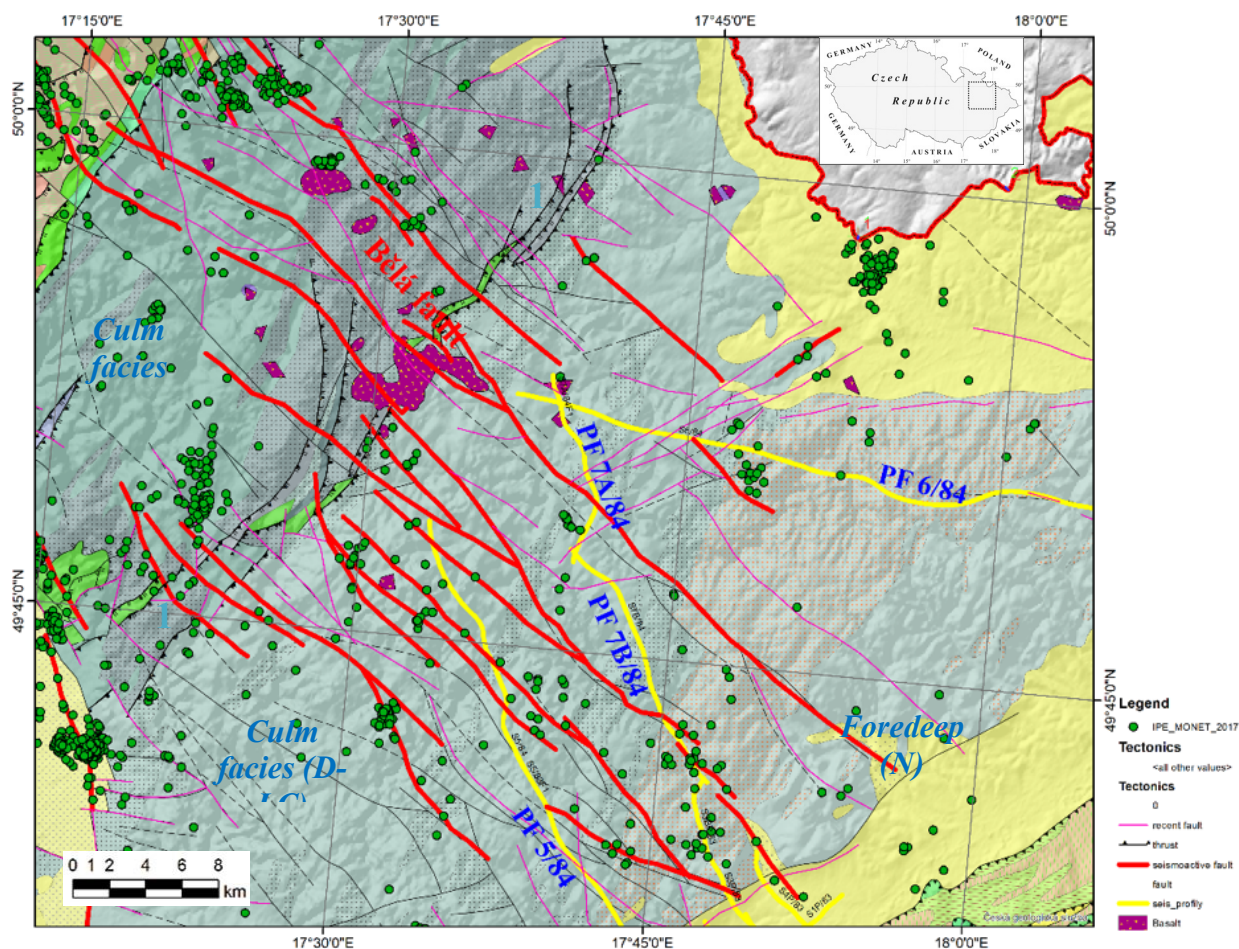


Fig. 1 Map of the Culm area with location of the Bělá fault system, complemented by recent earthquake data (1996 to 2017 – Sýkorová et al., 2018). Explanations: N- Neogene, D-LC- Devonian – Lower Carboniferous, violet color – neovolcanics, 1- Šternberk-Horní Benešov tectonic zone

and borehole (Potštát-1) samples. The supposed maximum paleotemperatures calculated were 260–285 °C for parautochthonous limestone sequences and 310–400 °C for tectonically overthrust sediments of the Culm facies. The estimated primary thickness of a sedimentary pile of the Culm facies rocks corresponding with the measured vitrinity reflectance, and thus the calculated paleotemperatures, exceeds 7 km. According to Jirman et al. (2018) the maximum thermal maturity of the flysch deposits was acquired prior to the Variscan overthrusting, i.e. before 325 Ma. The Devonian carbonate complex reached its maximum thermal maturity already after the overthrusting of the partly eroded flysch sequence before 320 Ma.

METHODOLOGY AND PROCESSING

We used the following data processing, verification and analysis techniques to evaluate movement tendencies and their interpretation:

- Processing of an archive data from CGS-GEOFOND Prague database (geological maps, wells and geochemical data, seismic reflection profiles in SGY versions, radiometric map of the Czech Republic (Manová and Matolín, 1995))
- Geophysical data of Geofyzika a.s., Brno (gravity

and magnetic data, seismic reflection profiles)

- Catalog of Earthquakes (Institute of Physics of the Earth, Masaryk University (IPE MU), USGS))
- GNSS data from available networks (Švábenský et al., 2012; Pospíšil et al., 2017; Kaplon et al., 2014)
- Recent vertical movements data (Vyskočil, 1996)

Archive Data - The geophysical database of the CGS, department GEOFOND includes the results of geophysical measurements (surveys) in the territory of the Czech Republic, which was mostly taken by the former Geofyzika Brno company from state budget funds from the end of World War II to the end of 2003. Now, they are mostly updating new data from air-borne measurement and gravimetric mapping projects financed mainly the Ministry of the Environment of the Czech Republic (hereinafter MŽP ČR).

Since 2018, as part of the CzechGeo/EPOS project, this data will be gradually made available through map applications.

DATA USED FOR VERIFICATION AND REINTERPRETATION

One of important tasks was to verify the movement trends. Suitable data and criteria were

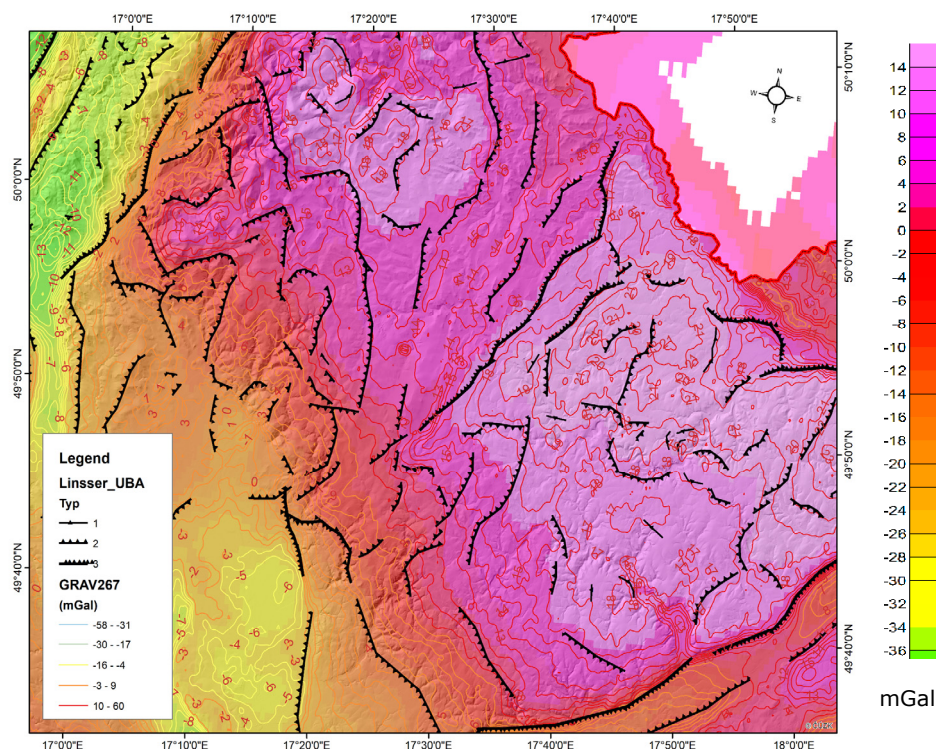


Fig. 2 Demonstration of combination of the Map of Complete Bouguer anomalies, compiled for the reduction density 2.67 kgdm^{-3} archived in GEOFOND Database with the derived map of Vertical density boundaries (Linsser indications of density contacts). The contour interval is 21 mGal. The Linsser indications represent spatial and material characteristics of density contact, approximating it by a vertical fault model (Linsser, 1967). The intensity of the Linsser indication is given by the product $E \times C$, where E is the amplitude of the gravity effect and C is the coincidence between the observed gravity anomaly and the gravity effect of the fault model. Black line segments show the positions of density contacts at the depth of 1 km.

collected and interpreted to prove faults within the studied area and to explain their character and kinematics. Geomorphological studies and data (Roštinský et al., 2013; Grygar and Jelinek, 2000) completed with geophysical data of sufficient aerial extent were involved to submit the geological model.

GEOPHYSICAL DATA

Gravity Data - A detailed gravity map of Complete Bouguer anomalies, compiled for a reduction density of 2.67 kgdm^{-3} , on a scale of 1:25 000 for the entire Czech Republic, does not provide more detailed information about the NW-SE tectonics. The main structural units of the Silesia and the Culm area with their effects can be observed from the presented map (Fig. 2) and give the size of individual anomalies, they can be judged by their powers. Horizontal gravity gradients or vertical density interfaces (Linsser, 1967) dominate mainly N-S and NE-SW directions. That's why we used gravity maps for verification at least.

Magnetic Data - Magnetic map of ΔT anomalies of the Czech Republic has been compiled on the basis of measurements made with airborne proton magnetometer with digital registration at 80 m above the terrain surface (approx. 55 % of the CR area), distance of flight lines - 250 m, period measurements from 1974 to 2004 (Gnojek et al., 2000). Final version of map of anomalous field delta T of the Czech Republic were processed for epoch 1981 (Fig. 3). All above discussed geological and

tectonic problems can be followed in the Magnetic map processed by Oasis Montaj SW.

Seismic Data - The map layer "the Seismic reflection profiles" shows only those reflective seismic profiles that have been registered with digital seismic apparatus, and seismic data has been stored either in the SEG-Y international format or in the corporate CGG format. This condition is fulfilled by reflective seismic profiles from 1971 to 1994, which were measured and processed by the former company Geofyzika Brno from the state budget.

Access to own seismic data, either in digital format (SEG-Y or CCG format) and raster format (tiff), is only possible with the consent of the Department of Geology of the Ministry of the Environment of the Czech Republic, as the owner of the data. For commercial customers, "lending" is tied to the existence of a reconnaissance territory and is charged. The results of other seismic measurements, such as refractive seismic profiles (regardless of type of registration) and reflective seismic profiles with analogue registration, are not included in the map layer "Seismic reflection profiles" and are only available in the form of archival reports. There is possibility to attach a layer of seismic well logs measured on the boreholes near the reflection profiles, but these do not exist for our area.

Figure 4 shows the reflective seismic profile used 7A/84. This profile intersects almost perpendicularly the southern part of Bělá fault zone.

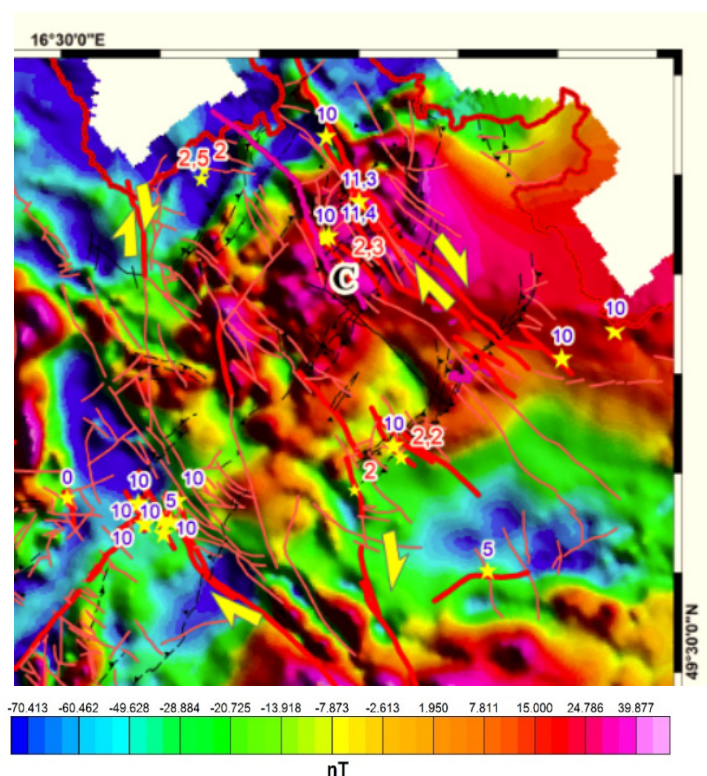


Fig. 3 Map of magnetic anomalies ΔT (the difference between the measured magnetic field inductance value and the IGRF field reference value for the epoch 1981.0). Map is complemented with recent earthquakes epicentres (yellow stars (Sýkorová et al., 2018)) with magnitude values (M - red) and estimated depths of the hypocentres (blue).

Earthquakes Foci - The available earthquake foci come from the worldwide USGS Earthquake Catalog and regional earthquake catalogs by the Institute of Physics of the Earth at the Masaryk University in Brno (IPE MU, incl. events recorded by Sýkorová et al. (2018) and the Institute of Geophysics of the Czech Academy of Sciences (IG CAS). In the Nízký Jeseník Mts., the earthquakes commonly reach a local magnitude (M) of 1–3 with estimated depths of ~1–12 km at W from the Šternberk – Horní Benešov fault system and depth 14 – 24 km on the E of the Culm area.

Earlier, the illustration and interpretation of the earthquake epicenters and hypocenter depths were collected for the regional maps (Kárník et al., 1984a, 1984b; Schenková and Kárník, Eds., 1985), in case of known historic macroseismic fields supplemented with an estimation of asymmetric seismic energy attenuation related to local tectonic structures (Procházková and Kárník, 1978; processed after the methodology by Schenk et al., 1989), and in some places also with calculated focal mechanisms (Haviř, 2004; Špaček et al., 2015, 2006).

GNSS Data on Moravia Territory (EPN, MORAVA, EAST SUDETEN, CZEPOS) - Results of the mapped horizontal movement tendencies of the Northern Moravia area offer in the recent period the following GNSS networks:

Epoch geodynamic networks:

- SNĚŽNÍK
- MORAVA
- EAST SUDETEN,

- HIGHLANDS

Permanent networks:

- EPN, CZEPOS, VESOG, GEONAS (public and research networks),
- TOPNET, VRS Now Czech, GEOORBIT (commercial private networks)

For the analyses of the area of interest the MORAVA, EAST SUDETEN and CZEPOS networks were used, only. Data were processed from time period/interval mentioned below.

The existing epoch geodynamic networks are characterized by many common features, notably by a careful selection of point locations in terms of the optimal observation conditions and assumed tectonic phenomena. The effort to stabilize sites embedded in the rock substrate or stable objects with a fixed base, allowing for forced centring of the receiving antennas, is also important. It has been desirable to use unmodified instrumentation at individual points. Overview of position of all GNSS networks points is in Figure 5 and the brief characteristics of the individual networks are as follows:

- SNĚŽNÍK – built in 1992 in cooperation between two academic institutions: Wrocław University of Environmental and Life Sciences (PL) and Brno University of Technology (CR). Its basic research results were presented by Švábenský et al. (2012);
- MORAVA – larger network established in 1994 under joint research activities of the VŠB – Technical University of Ostrava and Czech Technical University in Praha to study tectonics of crustal structures in the Bohemian Massif –



Fig. 4 Seismic reflection profile 7A/ 84, type Slalom Line SL. fold 24, datum plane 300m, scale 1:20,000, ©GEOFOND-CGS Praha.

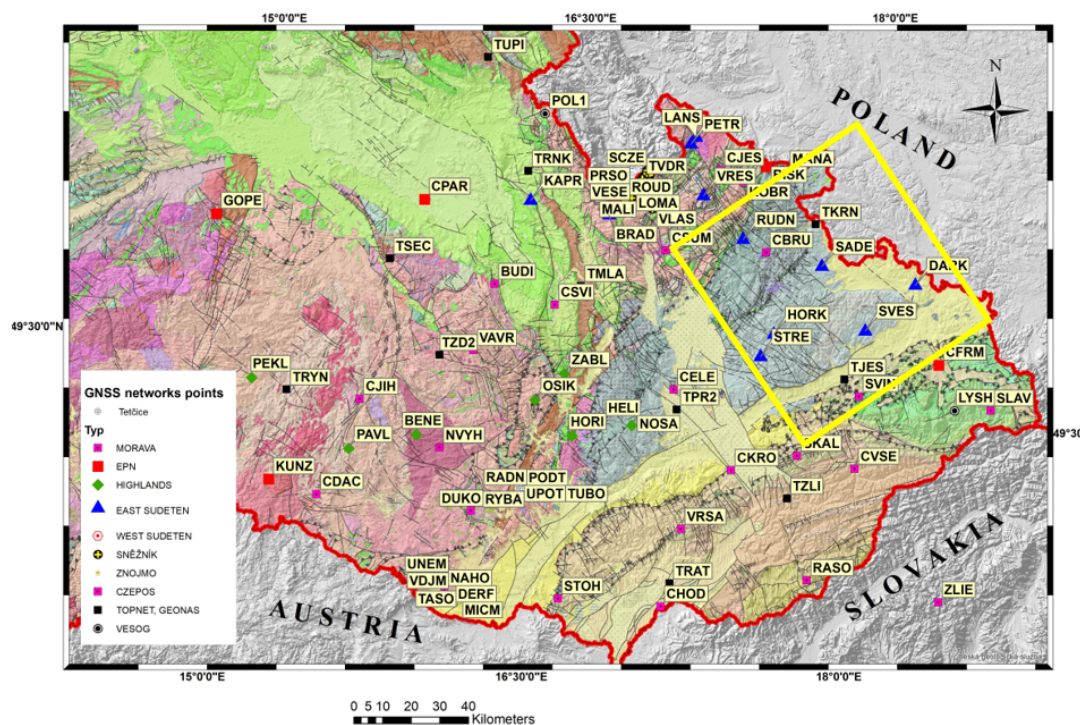


Fig. 5 GNSS points in the Moravian area. Part of Culm complex is limited by yellow rectangle. In background of image is Geological map of Czech Republic (Cháb et al., 2007).

Western Carpathians contact area (Foldyna et al., 1997), later used and remeasured by the Institute of Geodesy at the Brno University of Technology (IG BUT);

- EAST SUDETEN – built in 1997 by the Institute of Rock Structure and Mechanics, Czech Academy of Sciences (IRSM CAS to investigate fracture structures in the NE part of the Bohemian Massif (Schenk et al., 2002);
- HIGHLANDS – established in 2005 by the Institute of Rock Structure and Mechanics, Czech Academy of Sciences to study the mountainous areas in the E part of the Bohemian Massif (Schenk et al., 2009).

A few results from the WEST SUDETEN network (N part of the Bohemian Massif; established by the IRSM in 2001; Schenk et al., 2006; Kaplon et al., 2014) were also applied. Generally, results from 10–20 years lasting periods of repeated measurements could be taken into account in case of particular networks.

Since 1994, epoch GNSS measurements in the Czech part of the SNĚŽNÍK network in regular annual campaigns have been carrying out by the IG BUT (Švábenský et al., 2012). The same institute also participated in the first three campaigns in the MORAVA network (1994–1996), and in 2009–2015 it performed almost complete (except for two points) re-measurement of this network (primary information in (Roštínský et al., 2013; Švábenský et al., 2014, 2011). Moreover, observations at selected points of the EAST SUDETEN and HIGHLANDS networks were also performed (Pospíšil et al., 2017) indicating recent movements along important active fault zones in the central part of the Eastern Bohemian Massif (EBM). The main focus of the research was on the

structures reaching ~1 mm annual velocities or even more (max. 2 mm/year) including the Diendorf–Čebín tectonic zone (DCTZ (Roštínský et al., 2013), Železné hory – Tišnov tectonic zone ZHT (Švábenský et al., 2014) and wider area of the northern Boskovice Graben (Pospíšil et al., 2017). The studies significantly supplemented geological and geophysical data on these tectonic zones. For our purposes, the presented GNSS results from the Moravia network (MN - Pospíšil et al., 2017), which were supplemented with data from the East Sudeten Networks (ESN - Schenk et al., 2002), Sněžník (SN - Švábenský et al. 2012) and marginally Highlands (HN - Schenk et al., 2009) and also with latest unified and uniformly reprocessed data of Kaplon et al., (2014).

Recent Vertical Movements (RVM) - The study of the Recent movements of Earth crustal blocks through geodetic measurements has been carried out and ensured on the territory of the Czech Republic through the Research Institute of Geodesy, Topography and Cartography (VÚGTK) since the end of the 1950s.

For the purpose of verifying the horizontal movement tendencies, we also used the results of vertical velocities w_{0i} , obtained from repeated leveling from 1974–1984, which were equalized for the whole territory of the former Czech Republic (Vanko and Vyskočil, 1987). Annual rates have been established with respect to the Basic reference point ŽELEŠICE (SW from Brno). The leveling network was densified throughout the Czech Republic and results compiled to the map at the original scale of 1: 200,000, with an isolation interval of 0.1 mm / year. The reduced version of this map to a scale of 1: 1 000 000 (Vyskočil, 1996) was digitized and modified to a simplified and clearer version but with

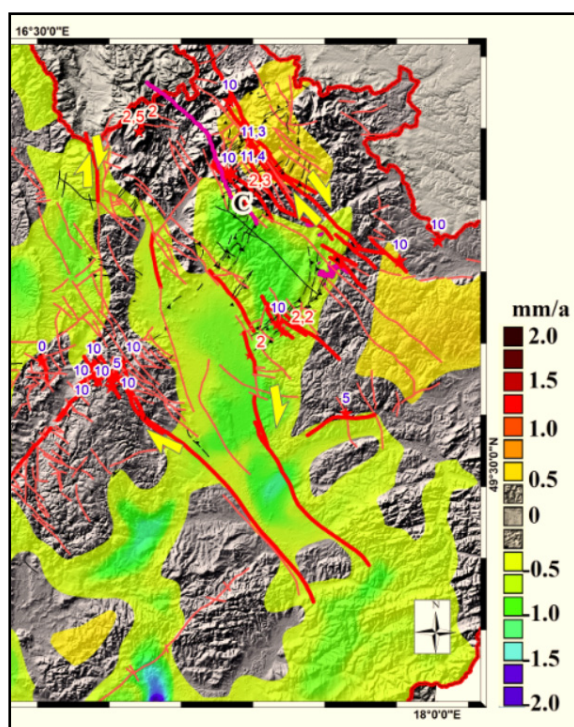


Fig. 6 Map of Recent vertical velocities (mm/a) (Vyskočil, 1996), modified by authors). In the area of interest, vertical motion tendencies of tectonic blocks dominate. North of the Bělá fault there are positive tendencies, whereas negative tendencies prevail south of it. Tectonic block with Culm facies on the East area shows relative uplift. C – position of Bělá fault zone

the same resolution, supplied by geological faults (Czech Geological Survey Prague). The underlying layer was used the illuminated radar relief (SRTM DEM data - ©NASA/USGS – illumination 315W/elevation 45 ° (Fig. 6) and DMR 4D (web of the State Administration of Land Surveying and Cadastre (CUZK)). This was the way to observe (to show) the relation between morphological structures and active zones with vertical move trends (Fig. 6).

RESULTS – GEODYNAMIC DATA ANALYSES

The Culm area has one of the highest movement tendencies in Moravia. The observed movements between the points CBRU, BISK, SADE in the north and STRE and HORK points in the south range between -2.1 mmy^{-1} to -0.4 mmy^{-1} . When comparing with known active fault systems in a given area, it has been shown that the Bělá tectonic system plays a dominant role here (Buday et al., 1995). The character of the movements, not only according to the results of GNSS measurements (Kaplon et al., 2014), but also according to seismological data (Sýkorová et al., 2018; Špaček et al., 2015), is interpreted as dextral and is distributed among several segments of the fault system.

The basic knowledge, that can be observed from velocity vectors (Kaplon et al., 2014), is that while in the Silesian area all the elements of motion are bound to the Sudetic Marginal fault and the Bělá fault zone, behind the Šternberk-Horní Benešov fault system (Fig. 1) is the main movement of blocks shifted to

southern blocks of the continuing the Bělá fault system (Figs. 3, 4, 7). It is confirmed also by earthquake foci which are concentrate along and near to Haná fault (northern margin of the the Upper Moravian Basin (Fig. 7).

We have used the reflection seismic profiles from the CGS - GEOFOND database to verify and especially to identify potential active faults on which these recent movements could take place. Because of the orientation NW-SSE, we have chosen profile 7A/84 (Kolejka et al., 1985 (Fig. 8)), since its direction towards the fault system of Bělá is the most complex. The analysis of the other profiles (5/84, 6/84 and 7B/84 (Čížek and Tomek, 1991) shows that the basic structural-tectonic conditions could be fairly well interpreted, but the detailed tectonic definition of the individual breaks is very complicated due to the strong shrinkage. Nevertheless, it has been possible to find fundamental changes in the orientation and inclination of individual reflexes and, in particular, to define the main and fundamental structural horizons in this area. First of all, it has been shown, in accordance with the previous interpretations (Čížek and Tomek, 1991), that in the section there are clearly different orientations of the structures at the top and bottom of the cut.

DISCUSSION AND CONCLUSIONS

The presented study evaluating results of the GNSS measurements, additionally confronted with regional recent vertical movements and a number of geomorphological and geophysical indicators, provides a lot of new information about older geodynamic and recent kinematic conditions of this area in its most complicated part, just represented by the Culm area. Application of the complex approach correlating comparable outputs of more disciplines led to more reliable description of significant basic or derived structural features. The previous structural, morphotectonic and geophysical analyses (Badura and Rauch, 2014; Grygar and Jelínek, 2000; Havíř, 2002, 1999; Jelínek, 2003; Kárník et al., 1984; Labák and Bouček, 1996; Lenhardt et al., 2007; Pazdírková et al., 2015; Procházková and Kárník, 1978; Schenk et al., 1989; Skácelová and Havíř, 1999; Špaček, et al. 2015, 2008, 2006; Vyskočil, 1996; Zedník et al., 2001) were especially considered at revealing the spatial patterns of linear landforms and their interrelationships with regional geophysical fields. Many of these works also included data on historic and primarily recent seismic activity, its focal mechanisms or earthquake patterns, eventually even information about neovolcanite occurrences or CO_2 emissions, i.e. phenomena evidencing true recent geodynamic activity.

Whereas the GNSS results are related to surface block boundaries, the driving factors are to be searched in deeper parts of the fault structures. Thus, even at the clearly linked cases it is difficult to exactly estimate the approximate depth level at which the respective movement is currently generated and determine in more detail its form (commonly steep thrust zone or deep-seated fault).

Therefore, the controlling process of suggested interpretations should include, besides evaluation of regional seismic data, also an assessment of available reflection seismic profiles running across the most active subareas that facilitate to define a geodynamical character of deep geological structures.

The correlation to the gravity, magnetic or radiometric boundaries appeared to be sufficient enough to reliably determine the main fault. Moreover, the collaborative application of all three disciplines predicts more important disruptions and linear fracture systems in the EBM than displayed in the available geological maps. When the location of geomorphological phenomena is additionally compared with the seismically active tectonic boundaries (Fig. 3), it is also indicated a high possibility of their generation in deeper parts of the crust.

The deduced model of the main active fault systems (Fig. 8) reflects not only surface structural plan of the Culm area. A reliability of the proposed geodynamical conception at the deeper structural levels is in case of the two problematic areas supported by a geological assessment of several reflection seismic profiles (CGS – Geofond): 7A/84, 6/84-83, 5/83-84 (Culmian Complex of the RHH).

The former explanation (Buday et al., 1995; Čížek and Tomek, 1991; Hladil et al., 1990) were focused on internal structure of the local Culmian Complex, especially its variable thickness and degree of deformation. The new model (Fig. 8) aimed at character of the deep basement of the Culmian Complex and more detail inner in the Culmian complex itself:

- The seismic profile reflects partly the fold and thrust structures in the near surface parts.
- It starts as a „flower structure“ in the W and continues most probably as SE-vergent
- Bělá fault system is the youngest one, displaces the variscan systems of first and second order and seems to show an asymmetrical flower structure system
- There is an apparent difference in the structural image between the upper segment (above master decollement) and lower segment (central and western part below the master decollement, the „carbonate complex“)
- There are common dome structures within the tectonic slices of the carbonate complex.
- Due to the changing orientation (trajectory) of the 7A profile (from NNW-SSE to NNE-SSW) the section does not reflect properly the sense of tectonic transport
- Pure limestones of the Macocha Formation display specific pattern in any part of seismic profiles. It is well recognizable and distinct from other lithologies.

Nevertheless, a few fundamental questions remain unanswered. Above all, answer the question of what is in the basement of the Culmian facies? Is it always metamorphic crystalline basement, or are there

some remnants of the Cambrian siliciclastics known from Southern Moravia and Southern Poland boreholes?

It can be said that archival data continue to provide invaluable data for new interpretations, with minimal cost.

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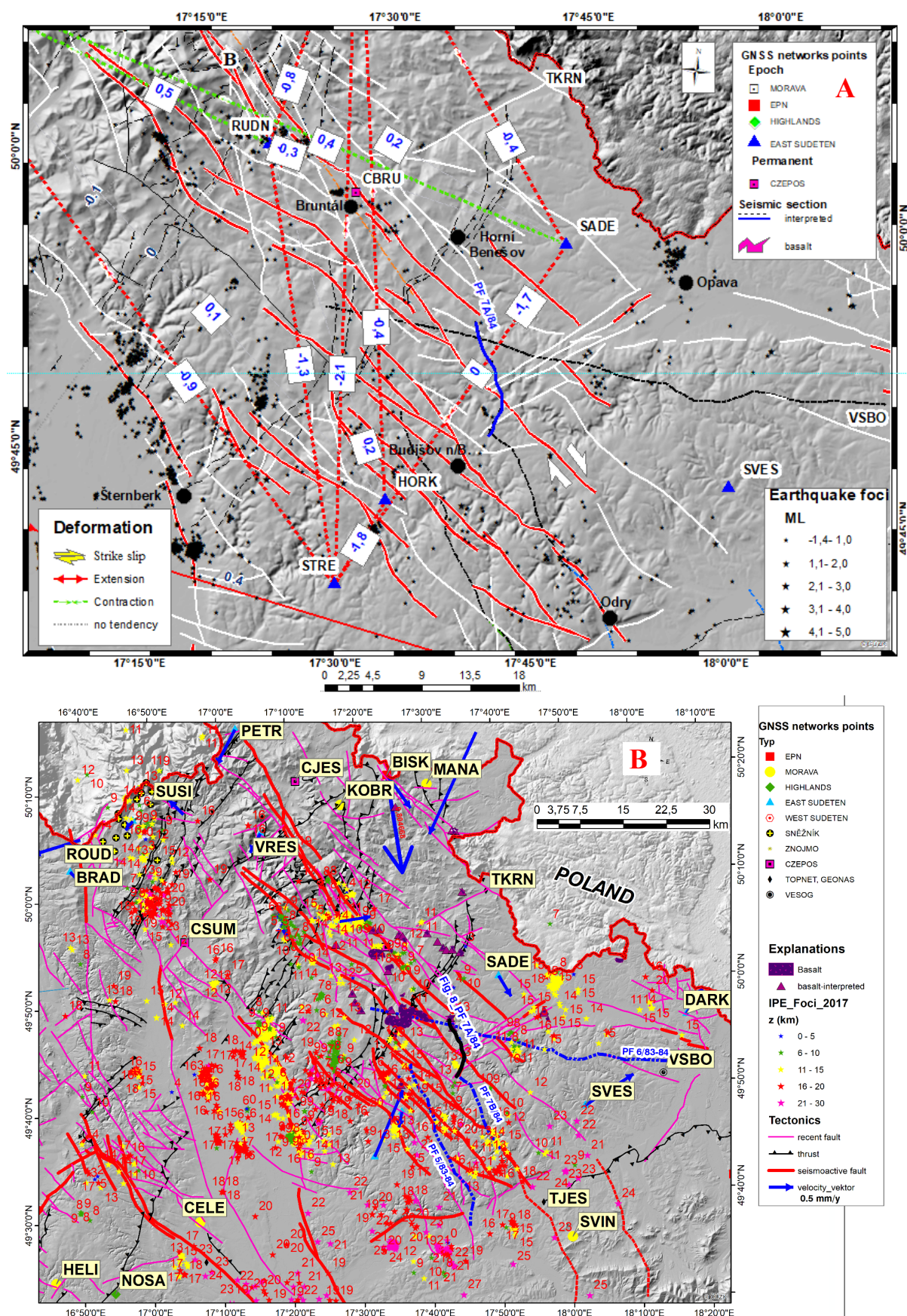


Fig. 7 The results of GNSS measurement of movement tendencies in the area of Nizký Jeseník, built by the Culmian facies (Devonian, Lower Carboniferous), supplemented by interpreted recent faults and earthquake foci. The figure A on the top is supplied by available seismic reflection profiles. The values between individual points are relative differences.

In the figure B - on the bottom are the earthquakes with depths of hypocenters – in the western part of the Culm area are depths between 10 to 14 km, on the eastern edge - 16 to 24 km. Blue arrows are velocity vectors from GNSS measurements (Kaplun et al., 2014), blue letter A - Šternberk-Horní Benešov tectonic zone.

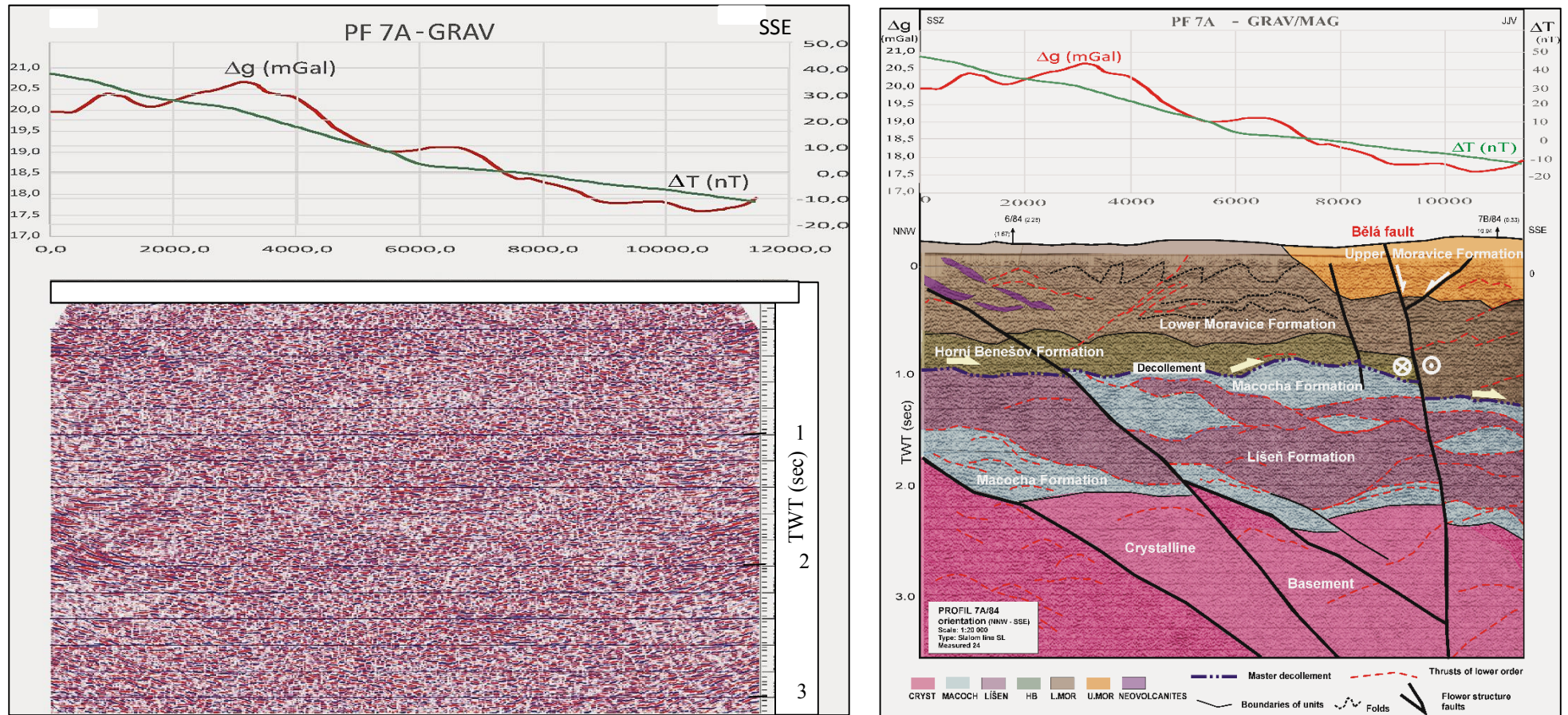


Fig. 8 Interpretation of the seismic reflection profile No. 7A/84. Left – migration section, Right – geological interpretation of profile. Section is supplied of the curves of Δg and ΔT anomalies. Interpreted neovolcanic basalts suggest presence of the basaltoid complex Velký and Malý Roudný, west of the profile.

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