

Extensometric observation of Earth tides and local tectonic processes at the Vyhne station, Slovakia

Ladislav BRIMICH¹, Martin BEDNÁRIK¹, Vladimír BEZÁK¹,
Igor KOHÚT¹, Dóra BÁN², Ildikó EPER-PÁPAI², Gyula MENTES²

¹ Earth Science Institute of the Slovak Academy of Sciences,
Dúbravská cesta 9, 840 05 Bratislava, Slovak Republic; e-mail: geofbrim@savba.sk

² Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences,
Hungarian Academy of Sciences, Csatkai E. u. 6-8., H-9400 Sopron, Hungary;
e-mail: mentes@ggki.hu

Abstract: The Vyhne Tidal Station of the Earth Science Institute of the Slovak Academy of Sciences is located in the former mining gallery of St. Anthony of Padua in the Vyhne valley, Štiavnické vrchy Mts., Central Slovakia. It is equipped with a 20.5 metre long quartz-tube extensometer measuring Earth's tides, and long-term tectonic deformations of the Earth's crust. Data between 2001 and 2015 with some diverse gaps were digitally collected, processed and analysed. The effects of the local conditions, such as structure of the observatory, cavity effect, topography and geological features of the surrounding rocks, were investigated in detail and these effects were taken into consideration during the interpretation of the results of the data analysis. Tidal analysis of the extensometric data between 2005 and 2015 revealed that the measured tidal amplitudes are close to the theoretical values. The tidal transfer of the observatory was also investigated by coherence analysis between the theoretical and the measured extensometric data. The coherence is better than 0.9 both in the diurnal and semidiurnal band. The effect of the free core nutation resonance was also investigated in the case of the K1 and P1 tidal components. Since the K1/O1 ratio was about the theoretical value 0.8, than the P1/O1 was between 1.0 and 1.15 instead of the theoretical value of 0.9. The rate of the long-term strain rate was also investigated and the obtained $-0.05 \mu\text{str}/\text{y}$ shows a good agreement with the strain rate inferred from GPS measurements in the Central European GPS Reference Network.

Key words: Earth tides, extensometric measurements, local effects, tectonic movements

1. Introduction

In 1984 the Geophysical Institute of the Slovak Academy of Sciences in cooperation with the Institute of the Physics of the Earth of the Academy of

Moscow installed an extensometer with photo-recorder in Vyhne, Slovakia (Brimich, 1988; Brimich and Latynina, 1989) for recording of Earth tide and recent tectonic movements. This instrument was mounted with the Hungarian capacitive transducer in 1996 (Mentes, 1991; 2008; 2010). In this study the results of the analysis of the digitally recorded extensometric data between 2005 and 2015 are described. The effect of the fluid core resonance is also investigated on the basis of the tidal analysis of the data. The tidal transfer of the Earth-observatory-instrument system was investigated by coherence analysis. The data recorded between 2001 and 2015 were used for the investigation of the local tectonic movements.

2. Tidal station in Vyhne

The Vyhne Tidal Station is located underground, in the gallery of St. Anthony of Padua in the Vyhne valley, Štiavnické vrchy Mts., Central Slovakia. The tidal station is close to the village Vyhne about 10 km from Banská Štiavnica (Fig. 1). The geographical coordinates of the station are given in Table 1.



Fig. 1. Location of the Vyhne Tidal Station in Slovakia.

2.1. Geological setting

The geological situation in the wider surroundings of Vyhne village is depicted in Fig. 2. The rock complexes are represented mainly by the basement rocks of the Štiavnica stratovolcano and Neogene volcanic rocks (*Konečný et al., 1998*). The basement is composed of Palaeozoic crystalline rocks and Mesozoic rocks (as cover and nappe units) and the Neogene intrusions. The crystalline rocks and their cover are part of the horst and tectonically belong to the Veporic unit – particularly the Ľubietová zone (*Fusán et al., 1969*). They are flanked by faults with a NE direction. They are represented mainly by the tectonically faulted granitoids, the so-called Vyhne crushed granite (*Šalát, 1954*), and by schists which, in analogy with the Veporicum crystalline rocks, probably represent the phyllonites. The Mesozoic rocks are represented by the Veľký Bok sequence of Triassic age. In the Vyhne area this sequence is stratigraphically incomplete – only some of the members are represented – especially the quartzites. The Mesozoic rocks are also, like the granitoids, intensively tectonically deformed and metamorphosed. These rock complexes are overthrust by the Hronicum nappe unit, especially the Šturec nappe, represented in the studied area mainly by Early Triassic layered quartzose sandstones and Middle Triassic limestones and dolomites. The nappe was pushed onto the eroded surface of the Veporic unit at a later stage of the Alpine tectonics. This is manifested in the structural discordance and differences in metamorphosis. The volcanic rocks developed on the morphologically segmented base and are the product of stratovolcano activity in the Badenian. The Hodruša intrusive complex is represented mostly by granodiorite and diorite intrusions of Badenian age with the symptoms of contact metamorphism on the older rocks.

The intense tectonic movements in the Tertiary but also in the earlier periods caused the deformation and fracturing of rocks. The granites of

Table 1. Location and parameters of the extensometer.

Coordinates of the Observatory			Parameters of the extensometer		
Longitude	Latitude	Height a.s.l. [m]	Azimuth of the instrument	Length of the instrument [m]	Scale factor [nstr/mV]
48° 29' 52"	18° 49' 48"	420	55°	20.5	-0.2503

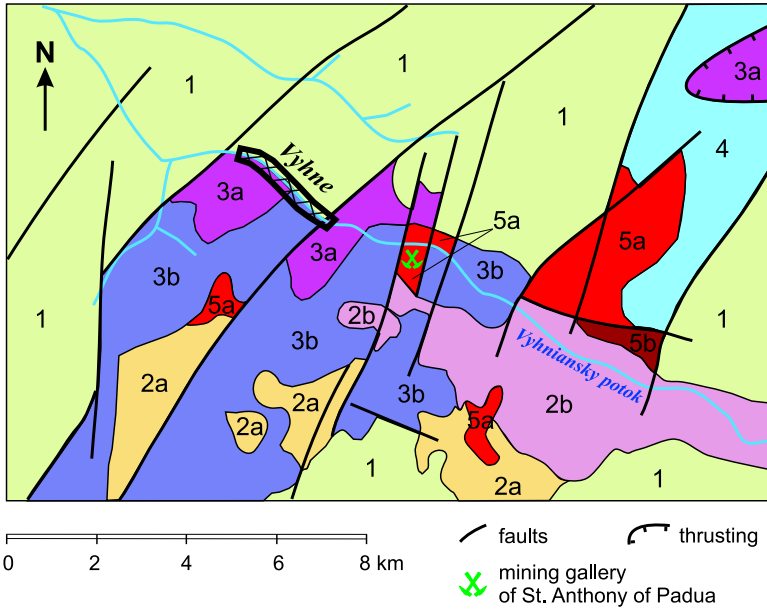


Fig. 2. Geological scheme of the surroundings of the Vyhne village, after *Konečný et al. (1998)*, simplified. 1 – volcanic complexes of the Štiavica stratovolcano (Badenian), 2 – Hodruša intrusive complex (Late Badenian-Early Sarmatian): a/ granodiorite, b/ diorite, 3 – Mesozoic complexes of the Hronicum nappe unit: a/ limestones, dolomites (Middle Triassic), b/ quartzose sandstones (Early Triassic), 4 – Veľký Bok Mesozoic sequence (limestones, dolomites, shales, quartzites, Triassic–Jurassic), 5 – Palaeozoic crystalline rocks of the Veporic unit: a/ porphyritic granodiorite (“Vyhne crushed granite”), b/ sericite-chlorite schists.

Palaeozoic age resulted in ductile deformation, in which the granite passes into orthogneisses. In the Cretaceous the Palaeoalpine tectonics resulted mainly in the creation of mylonite zones. This tectonics caused an intense deformation and metamorphism. It is a reflection of compression tectonics associated with the thrusting of nappes. The youngest Neopalpine tectonics in the Tertiary period was in the brittle mode and is manifested through the reactivation of older faults. Horsts are also typical of the area. They are related to the extension tectonics in the Neogene and closely related to the evolution of volcanism. Apart from the vertical movements, the Tertiary period also resulted in horizontal displacements mainly in the NE direction. This direction is typical mainly for the strike-slip system in the entire West-

ern Carpathians.

The St. Anthony of Padua gallery was driven into the Palaeozoic age granites, which were disturbed tectonically on two occasions. The first motion caused the mylonitization of the granites. The others tectonic movements were accompanied by young intrusions and mineralizations in the tectonically modified medium (*Brimich, 1988, 2006; Dudášová, 1998*).

At the distance of 43 m from the passage entrance (Fig. 3) there is a distinct penetration of young dacite, striking N-S in to ancient granites. The recording chamber is located beyond this penetration in comparatively well preserved granite. A vein zone with milonite and quartz lenses runs the length of the passage.

The relative depth of the location of the extensometer in the gallery is 50 m. Fig. 3 shows the sketch of the observatory and the geological settings of its near surroundings (*Brimich, 1988*). The temperature in the gallery is 6.8°C . The seasonal temperature changes are less than $\pm 0.04^{\circ}\text{C}$. The

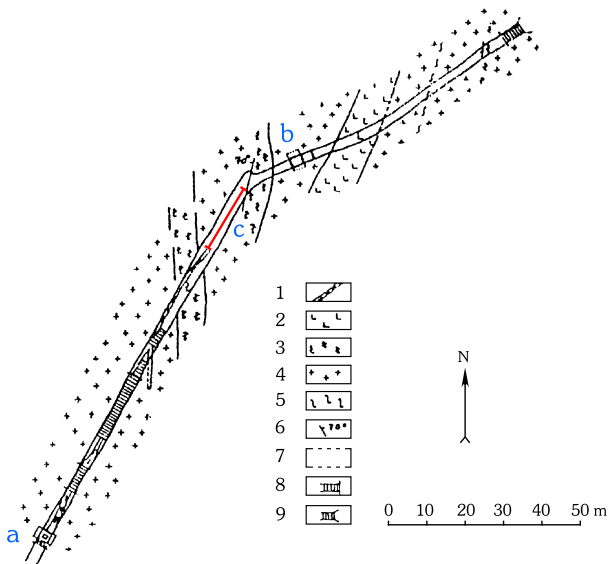


Fig. 3. Sketch of the tidal station in Vyhne. 1 – granite zone with mylonites and quartz; 2 – Neogene Dacite; 3 – ancient zone in granite; 4 – granite (Vyhne ancient granite – Palaeozoic); 5 – fault; 6 – fault with its slope; 7 – location of instruments (a – tiltmeter chamber, b – chamber for recording instruments, c – extensometer); 8 – walled-up areas; 9 – entrance to gallery (*Brimich, 1988*).

relative humidity in the gallery is about 80%. Fig. 4 shows the entrance to the observatory.



Fig. 4. Entrance of the Vyhne Tidal Station.

The station is currently equipped with a quartz-tube extensometer measuring the long-periodic (Earth's tides, annual temperature variations, etc.) and aperiodic (tectonic) deformations of the Earth's crust. Since the end of 2005 the station has been equipped with an α -particle counter to monitor the Radon emanation. At the beginning of 2006, a radio-frequency telemetric link connecting the seismological and tidal stations was established. With the satellite data connection of the seismic station Vyhne with the headquarters of the Geophysical Institute provided earlier, the data route from the tidal station's datalogger to our Bratislava workplace is now complete. Thus, the data acquisition process can be controlled better and the dropouts of data are prevented or minimized.

3. Construction of the quartz-tube extensometer

The length of the extensometer is 20.5 m. It is assembled from quartz tubes with a length of 2 m. The diameter of the tubes is 45 mm and their wall

thickness is 2.5 mm. The jointed tubes are suspended by invar wires (diameter: about $20\ \mu\text{m}$) on supports (Fig. 5) which are about 2.5 m apart. One end of the extensometer is fixed to the bed rock by means of a stainless steel dowel fixed by concrete in a hole drilled in the bedrock. A magnetostrictive actuator is joined to the other end of the dowel. The jointed quartz tubes are fastened to the other side of the magnetostrictive actuator which can move the quartz tube and serves for the regular daily calibration of the instrument. The displacement of the tube's free end relative to the bedrock is measured by a capacitive sensor.

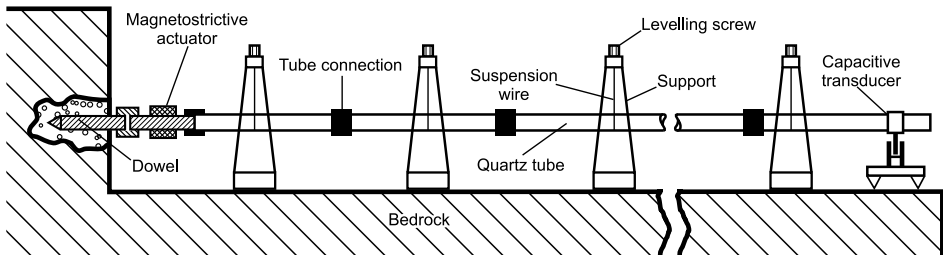


Fig. 5. Construction of the extensometer.

Since the scale factor of the built-in magnetostrictive calibrator and the capacitive sensor can be changed in time a regular calibration of the instrument is necessary. The idea of this calibration method developed in 2006 is very simple. It is a second capacitive sensor which can be regularly calibrated in a laboratory by a laser interferometer while the extensometer can continue working without a break. The difference between the portable and the fixed capacitive sensor is that the standing plates of the portable capacitive transducer are mounted on the free end of a magnetostrictive actuator, as shown in Fig. 6. One end of the magnetostrictive actuator is fixed to a rigid and very stable base plate. The other end of the actuator holds the two outer plates of the capacitive transducer, while its middle plate is fastened to the quartz tube of the extensometer. Thus, the magnetostrictive actuator can move the outer plates of the differential condenser relative to the middle plate and the displacement can be measured by the capacitive transducer. During in-situ calibration (Fig. 7), the displacement of the free end of the extensometer is simultaneously measured by the portable calibrator and the capacitive sensor of the extensometer. The portable calibrator

records both the impulses of the built-in magnetostrictive actuator of the extensometer and its own magnetostrictive actuator. Comparing the magnitudes of the two impulses, both the scale factor of the extensometer and the magnitude of the displacement of the built-in magnetostrictive actuator can be determined (Mentes, 2010).

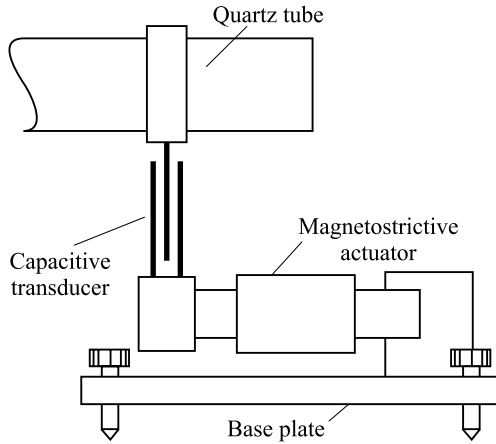


Fig. 6. Construction of the portable calibrator and principle of the in-situ calibration.



Fig. 7. In-situ calibration of the extensometer.

4. Tidal analysis

Since several short and long gaps accrue in the recorded extensometric data between 2001 and 2015, only the minimum yearly long continuous data were subjected to tidal analysis. The data were recorded with a sampling period of 10 minutes. These data were spike and step corrected and after this procedure the data were calibrated with the calibration factor obtained from the in-situ calibration in 2006. The calibrated data were decimated to 1 sample/hour for the tidal analysis with the ETERNA 3.40 program (Wenzel, 1996). Since the air pressure was not measured in the tidal station, the extensometric data were only corrected for the temperature and ocean load. The amplitude factors obtained for the years 2006, 2013, 2014 and 2015 are shown in Table 2. The effect of the correction of the extensometric data for temperature and ocean load (Earth model: Gutenberg-Bullen Model A average Earth (gbcont); ocean model: csr4.tr, local model: Mediterranean) is shown in Fig. 8 for the year 2015. The difference of the amplitude factors

Table 2. Results of tidal analysis.

Tidal wave	Frequency range [cpd]		Amplitude factors			
	from	to	2006	2013	2014	2015
Q1	0.50137	0.91139	1.23286	1.10392	1.00767	1.00485
O1	0.91139	0.94799	1.32056	1.10915	1.12015	1.02091
M1	0.94799	0.98185	1.38001	1.26646	0.91258	1.49134
P1	0.98185	0.99863	1.34620	1.28535	1.19283	1.32192
K1	0.99863	1.02362	1.10218	0.97072	0.95326	0.98203
J1	1.02362	1.05748	1.39127	1.32708	1.63448	2.07039
OO1	1.05748	1.47024	1.52772	0.93406	1.05329	0.92341
2N2	1.47024	1.88026	0.98679	1.10555	1.06491	1.08553
N2	1.88026	1.91412	1.14670	1.01055	0.98527	1.11123
M2	1.91412	1.95041	1.10958	1.04178	0.99554	0.96718
L2	1.95042	1.98428	0.77087	0.99380	0.86576	1.50954
S2	1.98428	2.00273	1.13277	0.93587	0.86729	0.77545
K2	2.00273	2.45194	1.07527	0.88044	0.97012	0.84314

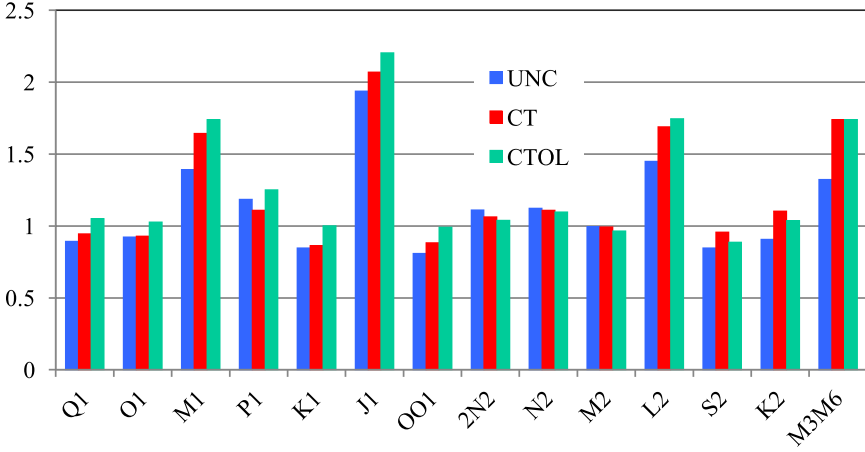


Fig. 8. The effect of the corrections on the data 2015. UNC = uncorrected, CT = corrected for temperature, CTOL = corrected for temperature and ocean load.

from one can be explained by local effects (e.g. topography, cavity effects, etc.) and the lack of the correction of the extensometric data for air pressure (Bednárík et al., 2001; Brimich, 2006).

5. Preliminary investigation of the Free Core Nutation

The Free Core Nutation (FCN) was investigated on the ratios of the amplitude factors $K1/O1$, $P1/O1$ (Boyarsky et al., 2003; Brimich, 2006). For the preliminary investigation we assume that the extensometer is situated in the east- west direction, so we calculate with the EW strain components. The theoretical values of the amplitude factors:

$$\eta_{K1} = \varphi_{EW}(K1)/\varphi_{EW}(O1) = 0.80,$$

$$\eta_{P1} = \varphi_{EW}(P1)/\varphi_{EW}(O1) = 0.94.$$

The results are summarized in Table 3. The deviation of the calculated values from the theoretical values originates probably from the fact that the extensometric data were not corrected for air pressure, the direction of the instrument deviates from EW and from the disturbing local effects.

Table 3. Results of the investigation of the FCN.

Ratio	Year			
	2006	2013	2014	2015
K1/O1	0.834	0.875	0.851	0.962
P1/O1	1.019	1.159	1.065	1.295

6. Investigation of the tidal transfer of the Earth – observatory – instrument system

According to Fig. 5, the bedrock between the two ends of the extensometer is also part of the instrument, so the quality of the extensometric measurements depends on the quality of the bedrock in the surroundings of the instrument. Discontinuities in the rock cause defective functioning of the instrument. The quality of the observation site was checked by coherence analysis and tidal evaluation of the measured data.

Tidal forces deform the solid Earth and this deformation is measured by extensometers in deep observatories built mainly in the bedrock, where the temperature is stable enough for a highly sensitive instrument. The measured tidal deformation is influenced among others by cavity and topographic effects and by the movements of the lithosphere plates. Due to the variation of temperature and air pressure, the rock deforms in the surroundings of the observatory, and the variation of these meteorological parameters has a direct effect on the instrument (Fig. 9). This latter can be neglected in the case of the extensometer in the Vyhne Tidal Station. Coherence analysis was used to test the observatory extensometer system. As input signal, the theoretical tide was always applied and was calculated by the PREDICT program of the ETERNA 3.40 tidal analysis program. The co-

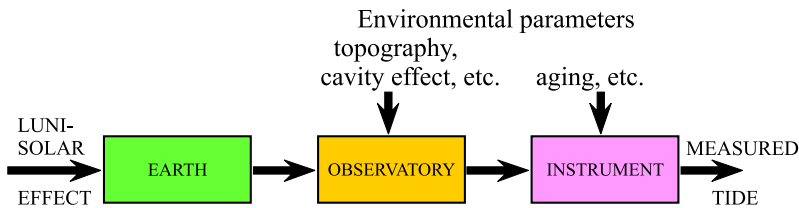


Fig. 9. Earth – observatory – instrument system.

herence analysis was repeated by taking the following measured data series as output signal: raw data, data corrected for barometric effect, and data corrected for both air pressure and temperature, where corrections were calculated by linear regression. The coherence function in Fig. 10 shows that the tidal transfer in the semidiurnal band is one and in the diurnal band is somewhat smaller than one. The reason for that is not yet known.

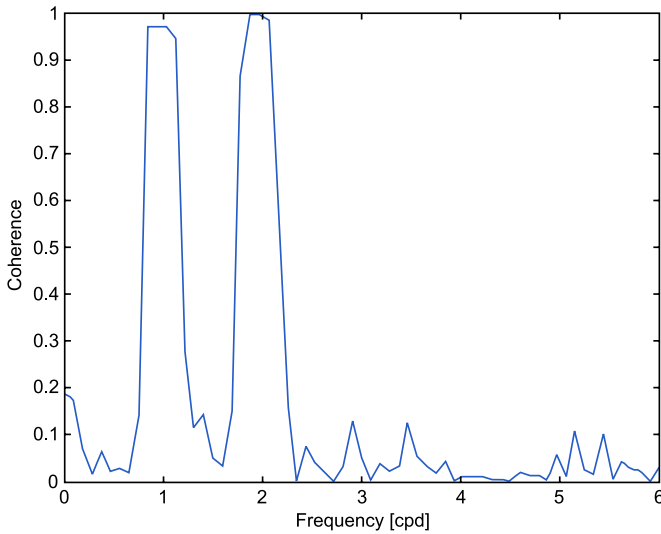


Fig. 10. Tidal transfer (coherence) function of the Earth – observatory – instrument system in the Vyhne Tidal Station. Input signal: theoretical tides, output signal: measured tides.

7. Long-term extensometric record – recent tectonic movements

The fifteen-year long extensometric record is shown in Fig. 11. The gaps in the record are partly of instrumental origin (e.g. data logger was out of range) and the large distance between the observatory and the institute. After the installation of the on-line data acquisition the data series have much smaller gaps. To determine the average yearly rate of the tectonic movements a linear regression line was fitted to the measured extensometric data. The obtained strain rate is $0.038 \mu\text{str}/\text{year}$ (relative deformation:

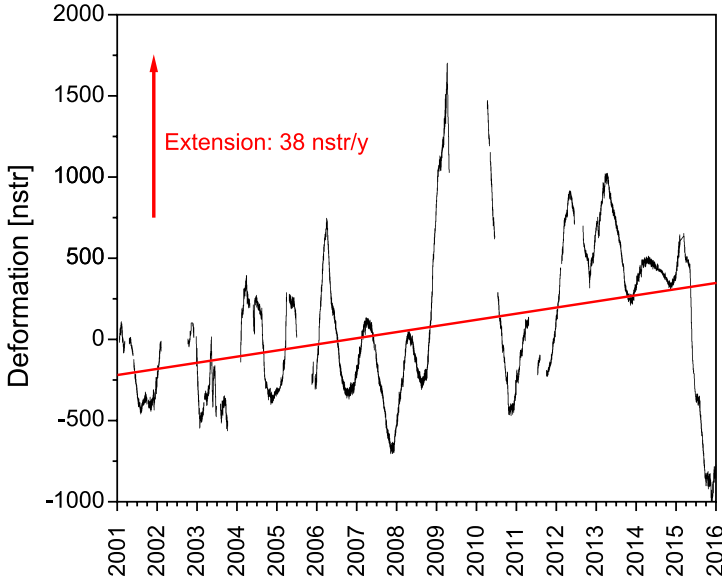


Fig. 11. Change of the strain between 2001 and 2015.

$0.038 \cdot 10^{-6}$) in the direction of the azimuth of the instrument. This local strain rate measured by the extensometer was compared by the strain rates determined by permanent and epoch-wise GPS measurements (CEPER, CEGERN, SGRN, TATRY, EMO) in Slovakia (*Hefty, 2010*). Fig. 12 shows the direction and the magnitudes of the horizontal displacement velocities at the GPS stations. It can be seen that the velocities are small in the vicinity of Vyhne. The surface extension inferred from the horizontal velocities range from 8 to 45 nstr/y and in the vicinity of Vyhne is between 20 and 30 nstr/y ($0.030 \mu\text{str/y}$). The extension rate measured by the Vyhne extensometer coincides very well with the values obtained also for the whole Pannonian-Basin (*Bada et al., 2007; Grenerczy et al., 2000*) and the strain rates obtained by *Dudášová (2005)* for the years 1991-93.

8. Conclusions

The results show that in spite of the long-term extensometer data being disturbed by local effects, the obtained tidal parameters are good, especially

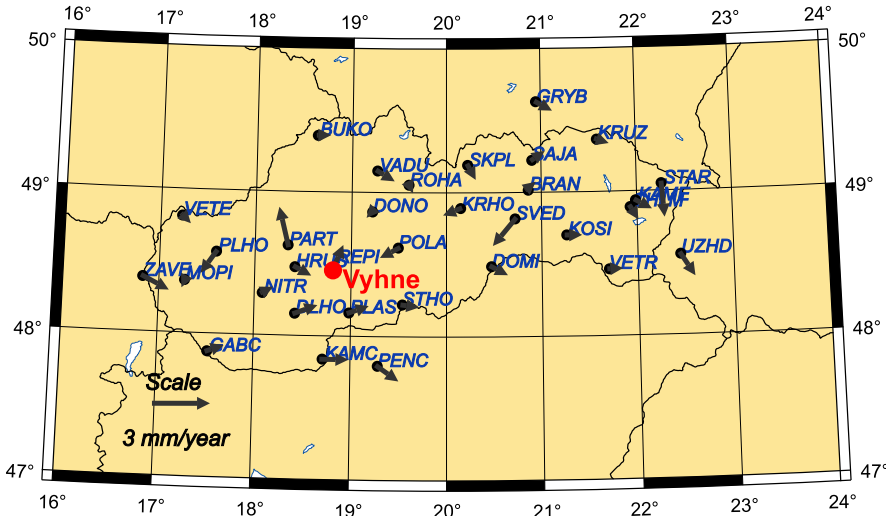


Fig. 12. Intraplate velocities from the Slovak geodynamic reference network (Hefty et al., 2010).

in the semi-diurnal band. The measured tectonic strain rate is in good accordance with the values inferred from GPS measurements.

The results of extensometric measurements in tidal domain have shown that the calibration accuracy of the extensometers increases by the in-situ method especially when the rising and falling edges of the displacement pulses are determined accurately. It can be achieved by applying a high record speed for the photorecorder. The other possibility is to use a function generator to energize the magnetostrictive coil by a sinusoidal calibration current. In this case the disturbing drift effect can be eliminated by applying a suitable frequency. The frequency characteristics of the extensometers appear to be determined by this method, too.

The tidal deformations are characterized by small positive anomalies. The positive anomalies dominate in the regions which are characterized by the high heat flows. The neighbourhood of the tidal station Vyhne is such a region (Hlavňová et al., 2015).

Acknowledgements. This research was carried out in the framework of the cooperation between the Earth Science Institute of the SAS and the Geodetic and Geo-

physical Institute, RCAES of HAS. The research was funded by the Slovak Research and Development Agency (APVV) under project No. APVV-0724-11, and by the VEGA grant agency under projects No. 2/0042/15 and 1/0141/15, as well as by the Hungarian National Research Fund (OTKA) under project K 109060.

References

- Bada G., Grenerczy Gy., Tóth L., Horváth F., Stein S., Cloetingh S., Windhoffer G., Fodor L., Pinter N., Fejes I., 2007: Motion of Adria and ongoing inversion of the Pannonian basin: Seismicity, GPS velocities and stress transfer. In: Stein S., Mazzotti S., (Eds.), *Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues*. Geological Society of America Special Paper, **425**, 16, 243–262, doi: 10.1130/2007.2425.
- Bednárík M., Brimich L., Dudášová V., 2001: Results of the extensometric measurements at the Vyhne tidal station. *Contributions to Geophysics and Geodesy*, **31**, 4, 635–642.
- Boyarsky E. A., Ducarme B., Latynina L. A., Vandercoilden L., 2003: An attempt to observe the Earth liquid core resonance with extensometers at Protvino Observatory. *Bull. d'Inf. Marées Terr.*, **138**, 10987–11009.
- Brimich L., 1988: Extensometric measurements at the Vyhne tidal station. *Contr. Geophys. Inst. Slov. Acad. Sci.*, **18**, 58–62.
- Brimich L., 2006: Strain measurements at the Vyhne tidal station. *Contributions to Geophysics and Geodesy*, **36**, 4, 361–371.
- Brimich L., Latynina L. A., 1989: The results of the extensometric observations in Vyhne, In: *Proceedings of the 6-th International Symposium, Geodesy and Physics of the Earth, ZIPE, Potsdam*, 239–254.
- Dudášová V., 1998: Description of the renovated extensometer at the Vyhne tidal station. *Contributions to Geophysics and Geodesy*, **28**, 197–203.
- Dudášová V., 2005: Study of the slow deformation observed at the Vyhne tidal station. *Contributions to Geophysics and Geodesy*, **35**, 4, 345–351.
- Fusán O., Kuthan M., Ďuratný S., Plančár J., Zbořil L., 1969: Geological composition of the neovolcanic basement in the central Slovakia (Geologická stavba podložia stredoslovenských neovulkanitov). *Zbor. geol. Vied. ZK, Bratislava*, **10**, 3–160.
- Grenerczy Gy., Kenyeres A., Fejes I., 2000: Present crustal movement and strain distribution in Central Europe inferred from GPS measurements. *J. Geophys. Res.*, **105**, B9, 21835–21846.
- Hefty J., Hipmanová L., Gerháťová E., Igondová M., Droščák B., 2010: Recent Geokinematics of Slovakia based on homogenized solutions of permanent and epoch GPS networks. *Acta Geodyn. Geomater.*, **7**, 3(159), 303–315.
- Hlavňová P., Bielik M., Dérerová J., Kohút I., Pašiaková M., 2015: A new lithospheric model in the eastern part of the Western Carpathians: 2D integrated modelling. *Contributions to Geophysics and Geodesy*, **45**, 1, 13–23.

-
- Konečný V., Lexa J., Halouzka R., Dublan L., Šimon L., Stolár M., Nagy A., Polák M., Vozár J., Havrila M., Pristaš J., 1998: Geological map of the region Štiavnické vrchy Mts. and Pohronský Inovec Mts. Geological Survey of the Slovak Republic, Bratislava.
- Mentes Gy., 1991: Installation of a quartz tube extensometer at the Sopron Observatory. *Bull. d'Inf. Marées Terr.*, **110**, 7936–7939.
- Mentes Gy., 2008: Observation of recent tectonic movements by extensometers in the Pannonian Basin. *Journal of Geodynamics*, **45**, 169–177.
- Mentes Gy., 2010: Quartz tube extensometer for observation of Earth tides and local tectonic deformations at the Sopronbánfalva Geodynamic Observatory, Hungary. *Rev. Sci. Instrum.*, **81**, 074501, doi: 10.1063/1.3470100.
- Šalát J., 1954: Petrography and petrochemistry of the eruptive rocks in the Hodruša-Vyhne area (Petrografia a petrochémia eruptívnych hornín v oblasti Hodruša-Vyhne). *Geol. Práce*, **39**, Bratislava, 55–92.
- Wenzel H. G., 1996: The nanogal software: Earth tide data processing package ETERNA 3.30. *Bull. d'Inf. Marées Terr.*, **124**, 9425–9439.