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1 **Observation of recent tectonic movements by extensometers in the Pannonian Basin**

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7

8 **Abstract**

9 In Hungary four extensometric observatories were established in the last two decades. The  
10 extensometers were installed primarily for observations of Earth tides. A 15-year continuous  
11 data series (1991-2005) was recorded at the Sopronbánfalva station and a 7-year record  
12 (1993-1999) was obtained at the Pécs station. The length of the measured continuous data  
13 series at the two other stations (Bakonya and Budapest) is only a few years. The long-term  
14 data records were also applied to the investigation of long-periodic deformations caused by  
15 recent tectonic movements. To get an insight into the present day tectonic processes on the  
16 margin of the Pannonian Basin, the measurement results of two additional stations (Vyhne in  
17 Slovakia and Beregovo in Ukraine) were also included into the investigations. The seasonal  
18 variations in the long data series due to temperature and air pressure effects were eliminated.  
19 The residual curve – after the correction of the seasonal effects and filtering the “high  
20 frequency” components (e.g. earthquakes, Earth tides, etc.) – contains the instrumental drift. It  
21 is impossible to determine this curve mathematically. It can be diminished by special  
22 instrumental solutions and by regular calibration of the instruments. This paper shows  
23 methods and possible solutions how the instrumental drift was investigated and eliminated in  
24 order to get the most reliable data for studying recent tectonic movements. The reliability of  
25 the extensometric measurements was tested by the tidal evaluation of the data series. The

26 results of the observations show that the Pannonian Basin is under compressive stress. The  
27 strain rates measured by extensometers on the margin of the basin are about three orders of  
28 magnitude higher than the intra-plate strains obtained by GPS measurements. The reason for  
29 this large difference arises from the interaction between the plate boundary and intra-plate  
30 forces and from the different measurement techniques. Investigations showed that the rate of  
31 the tectonic movements varies, and depends on the local geographical and topographical  
32 conditions.

33 Keywords: Earth tides; Extensometer; Seasonal effect; Tectonic movements; Varying  
34 deformation rate

35

## 36 **1. Introduction**

37 The gravitational attractive force of celestial bodies, such as the Sun and the Moon affects the  
38 gravity field and produces Earth's deformations as the Earth responds elastically to the tidal  
39 forces. The tidal phenomena are described in details by Melchior (1978). The solid Earth tides  
40 are recorded by very highly sensitive and stable gravimeters, tilt meters (e.g. Braitenberg et  
41 al., 2006; d' Oreye de Lantremange and Zürn, 2006), and extensometers (e.g. Jahr et al.,  
42 2006; Mentés, 1991; 2005; Takemoto et al., 2006) in observatories built in bedrock, which  
43 ensures a stable measuring place and constant temperature for the instruments. In Hungary  
44 four extensometric observatories were established for recording Earth tides and tectonic  
45 movements during the 1980s and 1990s. In addition, two other stations situated on the margin  
46 of the Pannonian Basin were involved in the investigation of recent tectonic movements:  
47 Vyhne in Slovakia and Beregovo in Ukraine.

48 Since extensometers measure the distance change between two points on the Earth's surface  
49 and due to their high accuracy and stability, they are also able to measure the deformation of  
50 the rock caused by tectonic movements as well as Earth tides. While the continuous GPS and

51 the intermittent VLBI measurements give us information on the global movements and  
52 deformations (displacements between points with a distance of about 100-1000 km) of  
53 tectonic plates, the extensometers measure the local deformation in the surroundings of the  
54 observatory. The recorded deformations are partly caused by the global deformation field in  
55 the vicinity of the measurement place and partly they originate from different local  
56 geodynamic and other (meteorological, hydrological, etc.) disturbances. This is why a lot of  
57 effort is made to eliminate the local and meteorological effects (Mentes and Eper-Pápai, 2006;  
58 Venedikov et al., 2006). In most cases the perfect separation of the geodynamic and the  
59 disturbing seasonal and local factors is very difficult or impossible. The same can be said  
60 about the elimination of instrumental drift. This is the reason why special emphasis is placed  
61 on the reliability investigation of the measured extensometric data in this paper.

62 As a first step, the extensometric network established in the Carpathian-Balkan Region is  
63 introduced and the instruments are described. Thereafter the data analysing technique and the  
64 newest results of the extensometric deformation measurements in the Pannonian Basin are  
65 given. Finally, the results of the measurements are discussed, focusing on the interpretation of  
66 the extensometric measurements on the basis of present day knowledge of the recent tectonics  
67 of the Pannonian Basin.

68

## 69 **2. Extensometric network and extensometers in the Pannonian Basin**

70 In Hungary the first observatory for Earth tides observation was established by the Geodetic  
71 and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI) in  
72 Sopronbánfalva, near Sopron, in 1968 (Mentes, 2005). First measurements were carried out  
73 by two pairs of horizontal pendulums, one of Melchior type and the other of Tomaschek-  
74 Ellenberger type. In 1975 these instruments were replaced by a pair of horizontal pendulums  
75 with capacitive transducers (Mentes, 1981). The very sensitive pendulums needed frequent

76 handling and adjustment, which – owing to the high radon concentration in the thermally  
77 insulated recording room – was injurious to health. In May 1990 the horizontal pendulums  
78 were replaced by an extensometer which was installed in cooperation with the Geophysical  
79 Institute of Moscow (Mentes 1991). This type of instrument requires less frequent (about bi-  
80 monthly) adjustments than the pendulums (about weekly).

81 The first extensometer in Hungary was installed by the Eötvös Loránd Geophysical Institute  
82 (ELGI) in Budapest, in the Mátyáshegy Observatory. It was done in the spring of 1980 in  
83 cooperation with the Geophysical Institute of Moscow (Latinina et al., 1984). In the beginning  
84 the displacement sensor of this instrument was a photo-recorder. A capacitive displacement  
85 transducer was developed in the GGRI by Mentes (1981, 1991) and it was mounted onto this  
86 instrument in 1981. The second extensometer was built also by the ELGI at the end of the  
87 1980s and it was originally equipped with the capacitive sensor. Both instruments had been  
88 working until 1996. In 2004, after a recording break of about 7 years, the extensometers were  
89 renewed and equipped with new capacitive sensors which are products of the GGRI.

90 Furthermore, a new digital data acquisition system was installed by the ELGI. The  
91 instruments have been recording continuously since 2004 (Mentes et al., 2006b).

92 In 1990 an extensometer was established by the Mecsekérc Corporation in the frame of a co-  
93 operation with the GGRI (Mentes and Berta, 1997). The instrument was placed in the vicinity  
94 of a planned repository for highly radioactive waste, to investigate the tectonic movements  
95 and deformations. This station was built in a uranium mine at a depth of 1040 m relative to  
96 the surface, far away from the working area of the mine. Since the uranium mine was closed  
97 in 1999, a new 3D extensometric observatory was established in Bakonya (near the closed  
98 station) in 2000. In this observatory four instruments were installed: a 20 m long  
99 extensometer (E1) operating parallel with a short instrument (E2) with a length of 1.7 m, a

100 short extensometer (E3) perpendicular to the long one and a vertical instrument (E4). These  
101 latter extensometers are also 1.7 m long (Mentes et al., 2006a).

102 In 1984 the Geophysical Institute of the Slovakian Academy of Sciences in cooperation with  
103 the Geophysical Institute of Moscow installed an extensometer with photo-recorder in Vyhne,  
104 Slovakia (Brimich, 1988). This instrument was mounted with the Hungarian capacitive  
105 transducer in 1996.

106 Besides the common instrument developments there is also a close cooperation between the  
107 Geophysical Institute of Moscow and the GGRI investigating tectonic movements of the  
108 Carpathian-Balkan Region. For this purpose the extensometric data measured by two  
109 extensometers in the Geodynamic Observatory in Beregovo (Ukraine) were also processed  
110 and analysed. This observatory is no longer functioning.

111 Figure 1 shows the extensometric network established in the Carpathian-Balkan Region and  
112 the parameters of the instruments are given in Table 1. A detailed description of the  
113 extensometric stations and the quartz-tube extensometers used in the observatories is given by  
114 Mentes (1991), Mentes and Eper-Pápai (2006), Mentes et al. (2006a) and Brimich (2006).

115

### 116 **3. Instrumental solutions for increasing the reliability of extensometric measurements**

117 Instruments of very high resolution and stability are required to measure tidal and tectonic  
118 deformations since the amplitude of the tidal waves ( $10^{-7}$  m) and the rate of the tectonic  
119 movements ( $10^{-8}$  -  $10^{-6}$  m/year) is very small. A magnetostrictive calibration unit is built into  
120 the extensometer for controlling the sensitivity of the instrument every day. This unit can test  
121 both the capacitive displacement transducer and the rigidity of the quartz-tube. The quartz-  
122 tube transfers the displacement of one end point of the instrument to the other where the  
123 transducer is placed, so the stability and the rigidity of the tube are very important from the  
124 point of view of measurement reliability. For the sake of a unified calibration of the

125 extensometers at the different stations a new laboratorial calibration device was developed by  
126 Mentés (1993, 1995a, 1995b) in the GGRI. The characteristics of the calibration device can  
127 be determined by means of a laser interferometer in large (5-10  $\mu\text{m}$ ) steps and knowing the  
128 characteristic, displacements with a resolution better than 1 nm can be measured. This device  
129 is applicable both for the laboratory test of magnetostrictive coils and for a regular, in-situ  
130 calibration of the extensometers in observatories. All extensometers in Hungary and the  
131 instrument in Vyhne were calibrated by means of this device (Mentés, 1997; Mentés and  
132 Brimich, 1996).

133 Temperature and air pressure variations influence the accuracy of the measurements; therefore  
134 both parameters are measured inside and outside of the observatories. The daily and the  
135 annual inside temperature variations in all observatories are less than 0.05  $^{\circ}\text{C}$  and 0.5  $^{\circ}\text{C}$ ,  
136 respectively. The temperature and barometric effects cannot be corrected perfectly since they  
137 are time-dependent (Kroner and Jentzsch 1998; Arnosó et al. 2002). This is why there are no  
138 exact mathematical methods to separate the meteorological effects from the tectonic  
139 movements. First of all, long-term (a number of years) measurements are necessary for  
140 eliminating the seasonal (temperature, air pressure, etc.) effects during the data processing.

141 The extensometric data also contains instrumental drift resulting from the aging of the  
142 mechanical and electronic components of the instrument. The drift has about the same low  
143 rate as the tectonic movements, so they cannot be separated by mathematical methods,  
144 therefore instrumental solutions should be applied. The sensitivity of the capacitive sensor  
145 and the rigidity of the quartz-tube can be regularly controlled by the built-in calibration  
146 device, but the connections between the rock and the instrument are uncontrollable in this  
147 way. The problem can be solved – if it is possible – by parallel measurements with more  
148 instruments. At the Bakonya station this method was applied. Parallel with the long  
149 extensometer (E1) a short instrument was installed (E2). Figure 2 shows the step corrected

150 raw data measured by the two instruments of the same type. In Fig. 2 the relative  
151 displacement, the strain – measured displacement( $\Delta L$ )/length of the extensometer (L) – is  
152 given for the sake of a direct comparison of the data measured by the two extensometers of  
153 unequal lengths. It can be seen that the two curves are very similar, the correlation coefficient  
154 between the curves is 0.97 which means that the instruments are working properly. The short  
155 extensometer (E2) measured higher relative displacements than the long instrument (E1). The  
156 reason is that the short extensometer has not got a built-in calibration unit and the calibration  
157 factor of the capacitive sensor measured in laboratory has changed after building the sensor  
158 into the extensometer. Because the long extensometer is regularly calibrated by the built-in  
159 magnetostrictive coil, and the curves of the two extensometers are very well correlated, we  
160 can state that the displacements measured by the long extensometer (E1) are real tectonic  
161 movements. Another solution for controlling of the instrumental drift would be the parallel  
162 recording by more instruments of different types. In this case we can expect that the  
163 behaviour of the instruments and so the character of the instrumental drift will also be  
164 different, which can be used for the estimation of the instrumental drift. If there is no  
165 possibility to install two or more parallel instruments, then an extensometer can be set up with  
166 two or more parallel working capacitive sensors because the electrical units are mainly  
167 responsible for the instrumental drift. In the last two years this latter solution was applied in  
168 the Sopronbánfalva observatory where three capacitive sensors were mounted onto the  
169 extensometer to test the stability of the electronic sensor. It has to be mentioned that no  
170 notable drift was detected during our investigations. The variation of the sensitivity measured  
171 by the built-in calibration device and during the regular, yearly in-situ calibrations is less than  
172 0.1 per cent at all instruments.

173

#### 174 **4. Data analysis technique**

175 The recorded extensometric data contains components in a wide frequency band: seismic  
176 signals, free oscillations of the Earth, Earth tides and tectonic movements, etc. Since the  
177 disturbing meteorological effects, such as the temperature and air pressure variations, have  
178 about the same frequency range as the Earth tides, it is very important to eliminate the  
179 influence of these factors to obtain the tidal parameters with the highest possible accuracy. In  
180 the GGRI a lot of efforts were made both to determine the stability of the different  
181 observatories against thermal and air pressure variations and to develop methods for  
182 eliminating the meteorological effects (Mentes, 2000; Mentes and Eper-Pápai, 2006).

183 The tidal evaluation of the measured strain data is a basic analysis technique, not only in tidal  
184 research for a better knowledge of the inner structure of the Earth, but also when  
185 extensometers are used for tectonic measurements. Namely, if there is a bad connection  
186 between the bedrock and the instrument, the extensometer cannot exactly follow the real  
187 displacements of the bedrock. Thus it is not able to provide reliable information for tectonic  
188 investigations, neither is the detection of tidal waves possible. This is why the tidal evaluation  
189 must always be carried out. The procedure can be accomplished in two ways: the simplest  
190 method is the Fourier-analysis of the extensometric data. First, the data series are corrected  
191 for the temperature and the air pressure, generally by means of a regression method (Mentes  
192 and Eper-Pápai, 2006). After subtraction of the trend, the corrected tidal data series are  
193 Fourier-transformed and the amplitude spectra are plotted. Such a spectrum shows the  
194 presence or absence of the main tidal waves, from which conclusions can be drawn whether  
195 the instrument in the recording place works well or not. The second method is the  
196 determination of the tidal parameters by means of a tidal evaluation program. The most  
197 popular and widely-used program package is the ETERNA 3.30 software. A detailed  
198 description of this program is given by Wenzel (1996). Using the Hartman and Wenzel (1995)  
199 tidal potential catalogue, 12935 tidal waves can be taken into account for the calculations.

200 Earth tides can be predicted and the measured data can be analysed by this program package.  
201 The program is able to carry out temperature and barometric corrections automatically using  
202 the measured meteorological data. The output of the program is the amplitudes of the  
203 theoretical tidal waves, the amplitude factors (measured/theoretical amplitude), and phase  
204 leads of the measured waves relative to the theoretical ones and the errors of the  
205 determination of amplitude factors and phase leads. The program furnishes the waves in  
206 special wave groups. Using the second method, the tidal results can be applied both for tidal  
207 research and for control of the instrument during tectonic observations. Then we can assume  
208 that the extensometer works well if the tidal parameters we obtain are in reasonable  
209 agreement with the theoretical ones.

210 To determine the very long-period components of the extensometric data a polynomial of the  
211 9<sup>th</sup> order is fitted to the data series. The fitted curve represents the tectonic movements and the  
212 instrumental drift. If this latter is diminished by instrumental solutions, we can say that the  
213 polynomial describes the tectonic deformation. To get the average rate of the tectonic  
214 movements in the investigated period, a regression line is fitted to the extensometric data  
215 series and the steepness of this line gives the rate of the movement. Both fitting procedures  
216 are equivalent with the filtering of the high frequency and seasonal components of the data.  
217 For the tidal evaluation we applied the ETERNA 3.30 software using the Wahr-Dehant Earth  
218 model (Dehant, 1987) and the regression method for the determination of the average rates of  
219 the tectonic movements.

220

## 221 **5. Results of the measurements**

222 Figure 3 shows the strain data (raw data/length of the extensometer) measured at the  
223 Geodynamic Observatory in Sopronbánfalva between 1991 and 2005. This unique, 15 year,  
224 continuous data series shows a compressive deformation in the bedrock at the measuring site.

225 It can be seen that the rate of the movement is not constant. Between 1991 and 1996 the  
226 compression was much slower than later, and after 2004 the rate of displacement became  
227 slower gently again. The calibration factor of the instrument was unchanged in the whole  
228 observation period. The amplitude factors obtained by the tidal analysis do not show  
229 significant changes. Two periods of 2002-2003 and 2004-2005 were chosen for the  
230 comparison because a new digital recording system with high resolution (20 bits) has  
231 operated since the beginning of the second period. Table 2 shows the main lunar diurnal O1  
232 and the semidiurnal M2 waves obtained by the tidal analysis. We use only the main lunar  
233 waves for the comparison because the meteorological effects are in close connections with the  
234 Sun and not with the Moon. Both waves have a little bit higher amplitude factor in the second  
235 (2004-2005) than in the first (2002-2003) recording period. However, this small difference is  
236 within the uncertainty range of the amplitude factors; the decreasing steepness of the  
237 displacement curve is not caused by decreasing sensitivity of the instrument. The same is  
238 confirmed by the regular test and calibration of the instrument. This means that the decreasing  
239 steepness of the measured deformation curve indicates the decreasing rate of the tectonic  
240 movements.

241 Figure 4 shows the strain data measured in the uranium mine in Pécs between 1993 and 1999.  
242 Tidal analysis of data in years 1993, 1997 and 1998 was chosen for controlling the  
243 instrument's performance, because in these years the direction of the deformation was  
244 different. First, from the beginning of 1993 to the end of 1995, a dilatation was observed.  
245 From that time till the second half of 1998, a contraction was measured, and thereafter  
246 another dilatation was recorded. In 1997 the contraction had a high rate which started to  
247 decrease and the deformation changed from contraction to dilatation in 1998. Table 3 shows  
248 The O1 and M2 waves obtained by the tidal analysis. It is interesting that the amplitude  
249 factors are smaller in the uranium mine than in Sopronbánfalva and there are no large

250 differences between the amplitude factors of the diurnal and semidiurnal tidal constituents.  
251 This is probably due to the better stability of the deep (1040 m) observatory in the mine,  
252 compared with the surface observatory in Bánfalva (Mentes and Eper-Pápai 2006). It must be  
253 mentioned that the program ETERNA 3.30 is not calibrated for the extensometric  
254 measurements. The tidal parameters can strongly depend on the geology, surface topology,  
255 etc. of the surroundings of the observatory and these features of the observation site cannot be  
256 taken into account by the program. In Table 3 we see that no significant changes appear in the  
257 amplitude factors between years 1993 and 1998. On the basis of our tidal and instrumental  
258 investigations we can assume that the changes in the direction and rate of the measured  
259 deformation at the Pécs station are tectonic rather than of instrumental origin.

260 The long-term displacement records at Sopronbánfalva and Pécs stations (Figs. 2. and 3.)  
261 show that the rate of tectonic movements (steepness of the displacement curve) varies. An  
262 average deformation rate can be given as the steepness of the regression line fitted on the  
263 whole curve. It is obvious that the value of this rate depends on the length of the recording  
264 period. Therefore such an average rate is valid only in the investigated time intervals.

265 The direction of the deformations and the average displacement and strain rates of tectonic  
266 movements measured in the Carpathian-Balkan Region together with the interval of the  
267 observations are given in Table 4. All the values are related to the direction of the  
268 extensometers (see Table 1).

269 The extensometric data recorded at the Bakonya station was investigated in detail by Mentes  
270 et al. (2006a). The rate of the tectonic movements at this station is about the same as it was  
271 measured earlier in the uranium mine (see Fig. 2).

272 After the reconstruction of the instruments at the Budapest station, the data were analysed by  
273 Mentes et al. (2006b) but the new records after the reconstruction are not long enough to  
274 calculate the rate of the movements with an appropriate accuracy due to seasonal effects. The

275 results of the first measurements show that the rates of the tectonic movements seem to have a  
276 good agreement with the rates (E1:  $-0.08 \cdot 10^{-6}/\text{year}$ , E2:  $-2.24 \cdot 10^{-6}/\text{year}$ ) measured before and  
277 published by Varga and Varga (1994).

278 The data series measured at the Vyhne station is not continuous due to technical reasons. The  
279 rate of the tectonic movements can only be calculated for more independent periods of  
280 different data length because the long data gaps cannot be filled in reliably. A deformation  
281 rate of  $0.040 \cdot 10^{-6}/\text{year}$  dilatation was given by Varga and Varga (1994) for the years 1985-  
282 1991. The same value can be estimated from the separate data series for the years 1992-1993  
283 published by Dudášová (2005) and in 2004 a compression with a rate of  $-0.127 \cdot 10^{-6}/\text{year}$  was  
284 calculated. This last value is strongly influenced by seasonal variations and other local effects  
285 which cannot be eliminated because of the short recording period.

286

#### 287 **4. Discussion**

288 In Table 4 we see that the rates of tectonic movements are much higher in Sopronbánfalva,  
289 Pécs and Bakonya than at the other stations. The Sopronbánfalva observatory lies at the  
290 eastern foothills of the Alps. The reason for the measured high strain is that gravity forces  
291 associated with elevated topography and the crustal thickness variations of the Alpine  
292 mountain belt induce horizontal compression, locally exceeding the magnitude of the far-field  
293 tectonic stresses. The change of the strain rate is probably in connection with the local  
294 tectonic processes due to frontal collision of the Adriatic indenter (Bada et al., 2006) into the  
295 Alps and with the lateral extrusion of the Eastern Alps (Bada et al., 2001). The Pécs and  
296 Bakonya stations have similar geographical situations as the station Sopronbánfalva since  
297 they lie at the foothills of the Mecsek Mountain. The changing magnitude and direction of the  
298 measured tectonic movement rate at the Pécs station can be explained – as for the  
299 Sopronbánfalva station – by the interaction between the NNE-SSW compressive stress due to

300 the movement of the Adriatic plate and the orogenic stress in the surroundings of the Mecsek  
301 Mountain.

302 According to Bada et al. (2001), a high level compressive stress is concentrated at the  
303 northern and eastern edges of the laterally constrained Carpathian embayment. The measured  
304 deformation rate at the Beregovo station is in accordance with this assumption. In Beregovo  
305 extensometer E2 measured higher compression ( $-2.41 \cdot 10^{-6}/\text{year}$ ) than instrument E1 ( $-0.15 \cdot 10^{-6}/\text{year}$ )  
306 because the direction of E2 is closer to the assumed main stress direction.

307 In contrast with the results obtained at the Beregovo station, the deformation rate ( $0.04 \cdot 10^{-6}/\text{year}$ )  
308 measured in Vyhne is much smaller. Probably, the hilly, varied topography of the  
309 mountainous area in the vicinity of the observatory is responsible for the small values here.

310 The Budapest observatory is almost in the middle of the Pannonian Basin. It lies between the  
311 uplifting Transdanubia and the partly subsiding Great Hungarian Plain. Therefore stress  
312 measurements are very important at this site. Unfortunately, the recording periods are short  
313 and interrupted by long gaps. In addition the extensometric measurements are disturbed by the  
314 level variation of karstic water which is in connection with the water level of the River  
315 Danube (Varga and Varga, 1994). Notwithstanding, the rates of displacement measured here  
316 support the assertions of geologists. Extensometer E2 is nearly parallel to the maximum  
317 horizontal stress direction assumed, for example, by Bada et al. (2006). It measured a much  
318 higher rate ( $-2.24 \cdot 10^{-6}/\text{year}$ ) than E1 ( $-0.08 \cdot 10^{-6}/\text{year}$ ) which is perpendicular to E2.

319 Varga et al. (2002) investigated the results of the Hungarian triangulation measurements  
320 carried out in four campaigns, years: 1878-1899, 1901-1907, 1925-1955, 1950-1965. For the  
321 strain rate investigations they used only that points at which the same directions were always  
322 used for the measurements. They found only 8 points in the 400 triangles which were in  
323 undamaged condition during the four measurement campaigns. At these points the error of the  
324 displacement determination is in the same order as the displacement. They obtained an

325 averaged compression strain rate  $-3 \cdot 10^{-8}$ /year with a SW-NE direction in the middle of the  
326 Pannonian Basin (see Fig. 5). Extensometer E2 in Budapest measured about 70 times higher  
327 rate in this direction (its azimuth is  $38^\circ$ ) and E1 (its direction is about NWW-SEE) measured  
328 about the same rate which was obtained from the triangulations. The reason for the high  
329 differences can be attributed to the short recording period.

330 Grenerczy et al. (2005) investigated data from the Central European GPS Geodynamic  
331 Reference Network (CEGRN) and the European Permanent GPS Network (EPN). From seven  
332 GPS campaigns organized between 1994 and 2003 in the northern Adriatic region,  $-4 \cdot 10^{-9}$   
333 /year contraction in SW-NE direction was obtained in the Pannonian Basin. In the Alpine-  
334 North Pannonian unit the obtained strain rate does not exceed  $-30 \cdot 10^{-9}$ /year. The direction of  
335 the compression here is NW-SE (see Fig. 5). This coincides with the direction of the  
336 extensometer in Sopronbánfalva. The strain rate measured at this station is about 150 times  
337 higher than obtained from GPS measurements. The small strain rates measured by GPS are  
338 due to the long distance between the GPS stations and so the large scale features can only be  
339 investigated. In this case the observed uniform strain rates are very small because the strain is  
340 concentrated in the vicinity of active faults (Grenerczy et al., 2000). The strain rates measured  
341 by GPS in the Pannonian Basin and in its surrounding are given by Grenerczy et al. (2000,  
342 2005) in detail.

343 At the Sopron and Pécs/Bakonya stations the regional tectonic stresses are increased by local  
344 topographical and geodynamic effects. These facts explain why the strain rates measured by  
345 extensometers are about two-three orders of magnitude higher than the “large scale” values  
346 obtained by GPS measurements. Therefore, GPS stations should be situated very densely on  
347 boundary areas to get reliable “small scale” strain rates which are comparable with the values  
348 obtained by extensometers. The accuracy of GPS measurements should be increased by long-  
349 term observations. At present, the interval of the GPS measurements is not long enough to

350 determine the average rates of the tectonic deformations reliably due to the changing  
351 characteristic (see Figs. 3. and 4.) and seasonal and environmental effects. Maybe these latter  
352 effects are responsible for the high error of the rate determination. Namely, the error of the  
353 strain rates obtained by GPS measurements has the same order of magnitude as the calculated  
354 rates.

355 Figure 5 shows the strain rate values (Table 4) and directions measured by extensometers,  
356 GPS and obtained from the triangulation network. The direction of the strains measured by  
357 extensometers corresponds to the azimuth of the instruments. The higher values are measured  
358 where the direction of the extensometer coincides with the main stress direction inferred from  
359 the analysis of stress indicators, seismic-tectonic studies and structural investigations (Bada et  
360 al., 2006).

361

## 362 **5. Conclusions**

363 The results of the extensometric observations in accordance with the VLBI (Ward, 1994) and  
364 GPS measurements (Grenerczy et al., 2000, 2005) confirm the fact that the Pannonian Basin  
365 is subject to compressive stress caused by the N-NE displacement and counter-clockwise  
366 rotation of the Adriatic micro-plate relative to Europe (Bada et al., 1999, 2001, 2006). On the  
367 basis of our long-term extensometric observations and according to our investigations, we  
368 infer that the rate of the tectonic motion and deformation is not constant. To prove this  
369 hypothesis unambiguously, longer observations, more stable and accurate instruments, and  
370 much more subtle methods are necessary for the elimination of local and meteorological  
371 effects, than we have at present. Our results prove that besides GPS and VLBI measurements,  
372 very highly sensitive extensometers are suitable for observation of recent tectonic movements,  
373 especially for the investigation of local geodynamic phenomena. The parallel application of  
374 the global (GPS) and local (extensometric) measuring techniques can contribute to a better

375 interpretation of the measured data and to understand geodynamic phenomena. The accuracy  
376 of the permanent GPS and VLBI measurements is also influenced by seasonal effects,  
377 similarly to the extensometers (Mendes et al., 2006) and hereby these measurements can also  
378 contribute to understanding and eliminating the local disturbing effects.

379

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### 385 **References:**

386 Arnoso, J., Ducarme, B., Venedikov, A. P., Vieira, R., 2002. Time variations and anomalies  
387 in the air pressure admittance of superconducting tidal gravity data, *Bull. d'Inf. Marées Terr.*  
388 136, 10793-10808.

389 Bada, G., Horváth, F., Gerner, P., Fejes, I., 1999. Review of the present-day geodynamics of  
390 the Pannonian-basin: progress and problems, *Geodynamics* 27, 501-527.

391 Bada, G., Horváth, F., Cloething S., Coblenz, D. D., Tóth, T., 2001. Role of topography-  
392 induced gravitational stresses in the basin inversion: The case study of the Pannonian basin.  
393 *Tectonics*, 20 (3), 343-363.

394 Bada, G., Grenerczy, Gy., Tóth, L., Horváth, F., Stein, S., Cloetingh, S., Windhoffer, G.,  
395 Fodor, L., Pinter, N., Fejes, I., 2006. Motion of Adria and ongoing inversion of the Pannonian  
396 basin: Seismicity, GPS velocities and stress transfer. In: Stein, S., Mazzotti, S., (Eds.),  
397 *Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues*. GSA Special Paper  
398 425, in press.

- 399 Braitenberg, C., Romeo, G., Taccetti, Q., Nagy, I., 2006. The very-broad-band long-base  
400 tiltmeters of Grotta Gigante (Trieste, Italy): Secular term tilting and the great Sumatra-  
401 Andaman islands earthquake of December 26, 2004. *J. Geodyn.* 41 (1-3), 164-174.
- 402 Brimich, L., 1988. Extensometric measurements at the Vyhne tidal station. *Contributions of*  
403 *the Geophysical Institute of the Slovak Academy of Sciences*, 18, 58-62.
- 404 Brimich, L., 2006. Strain measurements at the Vyhne tidal station. *Contributions to*  
405 *Geophysics and Geodesy, Geophysical Institute of the Slovak Academy of Sciences*, 36 (4),  
406 361-371.
- 407 Dehant, V., 1987. Tidal parameters for an unelastic Earth. *Physics of the Earth and Planetary*  
408 *Interiors*, 49, 97-116.
- 409 Dudášová, V., 2005. Study of the slow deformation observed at the Vyhne tidal station.  
410 *Contributions to Geophysics and Geodesy, Geophysical Institute of the Slovak Academy of*  
411 *Sciences*, 35 (4), 345-351.
- 412 Grenerczy, Gy., Kenyeres, A., Fejes, I., 2000. Present crustal movement and strain  
413 distribution in Central Europe inferred from GPS measurements. *J. Geophys. Res.* 105 (B9),  
414 21835-21846.
- 415 Grenerczy, Gy., Sella, G., Stein, S., Kenyeres, A., 2005. Tectonic implications of the GPS  
416 velocity field in the northern Adriatic region. *Geophys. Res. Lett.* 32, L16311, doi:  
417 10.1029/2005GL022947.
- 418 Hartmann, T., Wenzel, H. G., 1995. The HW95 tidal potential catalogue. *Geophys. Res. Lett.*  
419 22 (24), 3553-3556.
- 420 Imanishi, Y., Kokubo, K., Tatehata, H., 2006. Effect of underground water on gravity  
421 observations at Matsushiro, Japan. *J. Geodyn.* 41 (1-3), 221-226.
- 422 Jahr, T., Kroner, C., Lippmann, A., 2006. Strainmeters at Moxa Observatory. *J. Geodyn.* 41  
423 (1-3), 205-212.

- 424 Kroner, C., Jentzsch, G., 1998. Comparison of air pressure reducing methods and discussion  
425 of other influences on gravity, In: Ducarme, B., Plâquet, P. (Eds.), Proceedings of the 13th  
426 International Symposium on Earth Tides, Brussels, 423-430.
- 427 Latinina, L. A., Szabó, G., Varga, P., 1984. Observations of the deformation of the Earth's  
428 crust in the „Mátyáshegy”-cave near Budapest, Acta Geod. Geoph. Mont. Hung. 19 (3-4),  
429 197-205.
- 430 Melchior, P., 1978. The Tides of the Planet Earth. Pergamon Press, Oxford, 609 pp.
- 431 Mendes, C.P.J., Heinkelmann, J., Boehm, J., Weber, R., Schuh, H. 2006. Contributions of  
432 GPS and VLBI for understanding station motions. J. Geodyn. 41 (1-3), 87-93.
- 433 Mentés, G., 1981. Horizontal pendulum with capacitive transducer, Acta Geod. Geoph.  
434 Mont. Hung. 16 (2-4), 269-280.
- 435 Mentés, G., 1991. Installation of a quartz tube extensometer at the Sopron Observatory.  
436 Bull. d'Inf. Marées Terr. 110, 7936-7939.
- 437 Mentés, G., 1993. Sort remarks concerning the calibration of quartz tube extensometers, Bull.  
438 d'Inf. Marées Terr. 115, 8467-8471.
- 439 Mentés, G., 1995a. In-situ calibration of quartz tube extensometers. Bull. d'Inf. Marées Terr.  
440 121, 9070-9075.
- 441 Mentés, G., 1995b. High Precision Calibration of Quartz Tube Extensometers In: Hsu H. T.  
442 (Ed), Proceedings of the Twelfth International Symposium on Earth Tides, Science Press,  
443 Beijing, New York, 209-214.
- 444 Mentés, G., 1997. Continuous Methods for Geodynamic, Environmental and Industrial  
445 Deformation Measurements. (in Hungarian), Academic Doctor Dissertation, Sopron,  
446 (Hungarian Academy of Sciences), p. 173.

- 447 Mentés, G., 2000. Influence of Temperature and Barometric Pressure Variations on  
448 Extensometric Deformation Measurements at the Sopron Station. *Acta Geod. Geoph. Hung.*  
449 35(3), 277-282.
- 450 Mentés, G., 2005. Results of Tidal Research. *Acta Geod. Geoph. Hung.* 40(3-4), 293-305.
- 451 Mentés, G., Berta, Z., 1997. First results of the extensometric measurements in South  
452 Hungary, *Bull. d'Inf. Marées Terr.* 127, 9744-9749.
- 453 Mentés, G., Berta, Z., Eper-P, I., 2006a. Stability investigation of the new three-dimensional  
454 extensometric observatory in Bakonya, Hungary. *Bull. d'Inf. Marées Terr.* 141, 11253-11262.
- 455 Mentés, G., Brimich, L., 1996. Calibration of quartz-tube extensometer at the Vyhne tidal  
456 station. *Contributions of the Geophysical Institute of the Slovak Academy of Sciences*, 26,  
457 85-92.
- 458 Mentés, G., Eper-Pápai, I., 2006a. Investigation of meteorological effects on strain  
459 measurements at two stations in Hungary. *J. Geodyn.* 41 (1-3), 259-267.
- 460 Mentés, G., Eper-Pápai, I., Kis, M., Újvári, G., 2006b. New results of the extensometric  
461 measurements at Budapest observatory. *Bull. d'Inf. Marées Terr.* 141, 11263-11269.
- 462 D' Oreye de Lantremange, N., Zürn, W., 2006. Quarter-diurnal tides observed with a long-  
463 base water-tube tiltmeter in the Grand Duchy of Luxembourg. *J. Geodyn.* 41 (1-3), 175-182.
- 464 Takemoto, S., Lee, M., Chen, C.-Y., Kao, M.-C., Mukai, A., Ikawa, T., Kuroda, T., Abe, T.,  
465 2006. Tidal strain observations in Chu-Chie, Taiwan. *J. Geodyn.* 41 (1-3), 198-204.
- 466 Varga, P., Varga, T., 1994. Recent horizontal deformation in the Pannonian basin measured  
467 with extensometers. *Acta Geod. Geoph. Mont. Hung.* 29 (1-2), 57-80.
- 468 Varga, P., Verbitzkie, T.Z., Latinina, L.A., Brimich, L., Mentés, G., Szádetzki-Kardos, G.,  
469 Eperne, P.I., Guseva, T.V., Ignatishin, V.V., 2002. Horizontal deformation of the Earth's  
470 crust in the Carpathian region. (In Russian), *Science and Technology in Russia*. No.7 (58) –  
471 No.1 (59), 5-8.

- 472 Venedikov, A.P., Arnosó, J., Cai, W., Vieira, R., Tan, S., Velez, E.J., 2006. Separation of the  
473 long-term thermal effects from the strain measurements in the Geodynamics Laboratory of  
474 Lanzarote. *J. Geodyn.* 41 (1-3), 213-220.
- 475 Ward, S.N. 1994. Constraints on the seismotectonics of the central Mediterranean from very  
476 long baseline interferometry. *Geophys. J. Int.* 117, 441-452.
- 477 Wenzel, H.G., 1996. The nanogal software: Earth tide data processing package ETERNA  
478 3.30. *Bull. d'Inf. Marées Terr.* 124, 9425-9439.

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479 **Captures of the Figures**

480 Fig. 1. Extensometric network in the Carpathian-Balkan Region

481 Fig. 2. Records of the extensometric measurements carried out by two parallel extensometers  
482 at the 3D Extensometric Station in Bakonya

483 Fig. 3. Strain measured in the Sopronbánfalva Geodynamic Observatory from 01.01.1991 till  
484 31.12.2005.

485 Fig. 4. Strain measured in the uranium mine in Pécs from 01.01.1993. till 01.07.1999.

486 Fig. 5. Average strain rates (values in  $10^{-6}/\text{year}$ ) obtained from extensometric and GPS  
487 measurements (denoted by GPS) and from the deformation analysis of the Hungarian

488 triangulation network (denoted by T). Extensometric data measured at the observatories:

489 Bakonya (Ba), Beregovo (Be), Budapest (Bu), Pécs (P), Sopron (S). The lines show the strain

490 direction (azimuth of the extensometers) and their length is not proportional to the measured

491 strain.

492 Table 1. Parameters of the extensometers in the Carpathian-Balkan Region

Extensometer	Coordinates of the station			Azimuth of the instrument	Length of the instrument [m]
	Latitude	Longitude	Height a.s.l. [m]		
Bakonya E1.	46° 5' 43"	18° 4' 25"	346	0°	20
Bakonya E2.	46° 5' 43"	18° 4' 25"	346	0°	1.7
Bakonya E3.	46° 5' 43"	18° 4' 25"	346	90°	1.7
Bakonya E4.	46° 5' 43"	18° 4' 25"	346	Vertical	1.7
Beregovo E1.	48° 13' 12"	22° 42'	-	73°	27.5
Beregovo E2.	48° 13' 12"	22° 42'	-	37°	11.4
Budapest E1.	47° 33' 11"	19° 20' 24"	240	114°	21.3
Budapest E2.	47° 33' 11"	19° 20' 24"	240	38°	13.8
Pécs	46° 6' 52"	18° 7' 49"	-694	19°	20.5
Sopronbánfalva	47° 40' 55"	16° 33' 32"	220	116°	22
Vyhne	48° 29' 52"	18° 49' 48"	420	55°	20.5

493

494

495 Table 2. Tidal parameters calculated from the extensometric data series 2002-2003 and 2004-  
 496 2005 measured at the Sopronbánfalva Geodynamic Observatory

Data series	Waves	Theoretical amplitude [10 <sup>-9</sup> ]	Measured amplitude [10 <sup>-9</sup> ]	Amplitude factor±stdv	Phase lead±stdv [degree]
2002 -2003	O1	6.594	3.684	0.56±0.03	-3±3
	M2	5.057	4.913	0.97±0.01	-9±1
2004 -2005	O1	6.594	3.976	0.60±0.02	-7±2
	M2	5.057	5.225	1.03±0.01	-13±1

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499 Table 3. Tidal parameters calculated from the extensometric data series measured at Péc  
 500 station in years: 1993, 1997 and 1998

Data series	Waves	Theoretical amplitude [10 <sup>-9</sup> ]	Measured amplitude [10 <sup>-9</sup> ]	Amplitude factor±stdv	Phase lead±stdv [degree]
1993	O1	4.749	2.552	0.54±0.05	-2±5
	M2	10.902	5.447	0.50±0.02	-21±2
1997	O1	4.749	2.503	0.53±0.06	-20±6
	M2	10.902	5.277	0.48±0.01	-32±1
1998	O1	4.749	2.235	0.47±0.04	-21±4
	M2	10.902	5.041	0.46±0.01	-46±1

501

502

503 Table 4. Average strain rates measured by extensometers in the Carpathian-Balkan Region

Extensometer	Average strain rate [ $10^{-6}$ /year]	Direction of the strain	Type of the deformation	Time interval of the measurements
Bakonya E1.	-4.20	S-N	compression	2004-2005
Beregovo E1.	-0.15	WSW-NEE	compression	1986-1991
Beregovo E2.	-2.41	SW-NE	compression	1986-1991
Budapest E1.	-0.08	NWW-SEE	compression	1990-1992
Budapest E2.	-2.24	SW-NE	compression	1990-1992
Pécs	-4.15	SWS-NNE	compression	1993-1999
Sopronbátfalva	-4.74	WNW-SEE	compression	1991-2006
Vyhne	0.04	WSW-NEE	extension	1985-1993

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