1 **Comparison of two extensometric stations in Hungary**

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11 **Abstract**

12 Quartz-tube extensometers are used to measure rock deformations in two geodynamic

13 observatories in Hungary in order to contribute to the investigation of recent tectonic

14 movements on the area of the Pannonian Basin. One of the observatories is situated on the

15 border of the Alps at Sopronbánfalva and is set in the metamorphic (gneiss) material of the

16 mountains. The other station is in the basically karstic environment of the Mátyáshegy

17 (Mátyás Hill) near Budapest. The aim of this paper is to investigate how the local conditions,

18 such as structure of the observatory, topography or geologic features of the surrounding rocks,

19 lead to additional or modified deformations of the extensometric stations. Data collected over

20 eight years were processed and analysed to compare the observatories taking into account

21 geologic, lithologic and topograpic properties of the measurement sites. Tidal and coherence

22 analysis of the continuous strain measurements revealed that the instrument at Sopronbánfalva

23 is more sensitive to atmospheric pressure loading than the extensometer at Mátyáshegy.

24 Signal to noise values from the data processing of the short period variations support the

25 higher stability of tidal strain measurements at Mátyáshegy. The strain rates measured by

extensometers in both observatories are in good agreement with the strain rates inferred from

GPS measurements of the Hungarian GPS Geodynamic Reference Network and the Central

European GPS Reference Network.

1. Introduction

Extensometric measurements provide horizontal deformation data which incorporates the

short period tidal variations as well as local tectonic deformations in the long run, but the

recorded data are influenced by different effects depending on the local conditions of the

measurement site. Many publications deal with the influence of the construction and the

surroundings of the instrument's site appearing as cavity, topographic and lithologic effects

(e.g., Harrison, 1976; Brimich et al., 1998; Gebauer et al., 2009). Other works have been

published on the effect of atmospheric pressure loading on horizontal deformation

measurements (e.g., Müller and Zürn, 1983; Dal Moro and Zadro, 1998; Kroner et al., 2005;

Steffen et al., 2006; Zürn et al., 2007) under the conditions at a given measurement site and a

given type of measurement device.

In Hungary two observatories were established for seismic and gravity measurements and for

observation of tectonic movements and tides of the solid Earth: the Mátyáshegy Gravity and

Geodynamic Observatory (MGGO) in Budapest in a cave in Mátyáshegy and the

Sopronbánfalva Geodynamical Observatory (SGO) in Sopronbánfalva in an artificial gallery

(Fig. 1). In the MGGO two extensometers were installed in 1981 and 1985 (Latinina et al.,

1984) and in the SGO one extensometer in 1990. All instruments are quartz-tube

extensometers with capacitive transducers. Their construction and calibration are described in

detail by Mentes (2010). Since the measuring instruments are of the same type and capability

to monitor deformations, it is a good opportunity to compare two geodynamic observatories

51 which lie in different geologic, topographic and tectonic environments. Features of the

52 geodynamic deformation measurements at both sites in the high and low frequency ranges of

53 the signals are presented in this paper.

54 **2. Observation sites**

55 **2.1. Sopronbánfalva Geodynamic Observatory**

56 The Sopronbánfalva Geodynamic Observatory is located on the Hungarian-Austrian border in

57 the Sopron Mountains. The area belongs to the extensions of the Eastern Alps (Alpokalja

58 region), which extend eastward to the Rába fault (Fig. 1) regarded as the easternmost

59 termination of the Alps in Hungary. The crystalline rocks of the Alpokalja region crop out in

60 an area of 40 km^2 and are composed of folded, medium grade crystalline shists and

61 subordinate low-grade tectonites (muscovite gneiss and leucophyllite). The crystalline

62 basement of the mountains is covered by Neogene sediments. The Sopron Mountains consist

63 of metamorphic rocks of Palaeozoic age such as gneiss and different mica schists (Haas,

64 2001). The geological map of the surroundings of the observatory can be seen in Fig. 2. The

65 observatory is an artificial gallery driven into an outcrop of the muscovite gneiss which

66 belongs to the most schistose variety of the medium-grained gneisses called 'Sopron type

67 gneisses' (Kisházi and Ivancsics, 1985). The rock cover above of the observatory is about 60

68 m. There are no fractures and faults in the vicinity of the observatory. The yearly mean value

69 of the temperature is 10.4 ◦C in the gallery and the yearly and daily temperature variations are

70 less than 0.5 ◦C and 0.05 ◦C, respectively. The relative humidity is 90% and it is nearly

71 constant. The gallery where the extensometer is placed is thermally insulated but not perfectly

72 hermetically sealed. It means that there is a slow air circulation via the duct for the electric

73 cables of the instruments. This ventilation does not change the temperature in the gallery and

74 the instrument is not directly sensitive to air pressure variations (Mentes, 2000). The

75 coordinates of the SGO and the length and azimuth of the extensometer are given in Table 1.

76 The ground plane of the observatory and the location of the extensometer, which is nearly

77 perpendicular to the rock wall are shown in Fig. 3.

78 **2.2. Mátyáshegy Gravity and Geodynamic Observatory**

79 The Mátyáshegy Gravity and Geodynamic Observatory is situated in the karstic environment

80 of Mátyáshegy in the north-western suburban part of Budapest. The Mátyáshegy is a part of

81 the Buda Mountains, in north central Hungary, belonging to the regional unit 'Transdanubian

82 Mountains' (Fig. 1). The karstic cave system of the hill is the longest (13.465 km) exposed

83 cave system of West Hungary. The galleries were created by thermal water from the upper

84 Triassic flinty limestone and the discordantly bedding marine upper Eocene nummulitic

85 limestone. These formations are parts of the karstic water reservoir of the hydrology of this

86 area. The highest parts of the cavity reach up into the concordant bryozoan Marl. The tunnels

87 and galleries of the observatory were based on the natural cave system and were artificially

88 formed, mainly in the upper Eocene nummulitic limestone formation. Fig. 4 shows the

89 topographic map of the surroundings of the observatory and its entrance in the area of the

90 quarry located on the south-western side of the hill. The ground plane of the observatory with

91 the long (E1) and short (E2) extensometers is shown in Fig. 5. The galleries run under about

92 30 m of rock cover; the temperature variation in the inner galleries is less than 0.2 °C over a

93 year. The level of the karstic water is about a hundred meters deeper than the level of the

94 station. The River Danube flows about 2 km away from the observatory.

95 **3. Method**

96 Extensometric data recorded between 2005 and 2012 were used for calculations and for

97 comparison of the measurement sites. In both cases the sampling rate is one minute. High

98 frequency noises (well above the tidal range) are removed by built-in electric filters. Step and

99 spike disturbances were corrected and gaps in the data series were filled with adjusted

100 theoretical values in the course of preprocessing. The volume of the gaps is below 3 % per a

101 year at SGO and about 10 % for E2 at MGGO. However, the rate of the missing data was also

102 3 % for E2 in 2012. Continuous operation of E1 extensometer was interrupted for periods of

103 many months due to technical problems in 2011 and 2012. The signals were finally sampled

104 to one data/hour rate.

105 Features and transfer characteristics of the deformation measurements in the short-term band

106 of variations were examined by means of tidal analysis. Calculations were completed by the

107 ETERNA 3.40 Earth tide data processing package (Wenzel, 1996), using the Wahr-Dehant

108 Earth model (Wahr, 1981; Dehant, 1987) and the HW95 tidal potential catalogue (Hartmann

109 and Wenzel, 1995). A built-in high-pass filter of the program package (with a cut-off

110 frequency of 0.8 cpd) was used during the tidal evaluation. The residual strain data of the tidal

111 analysis were subjected to a Fourier transformation. The signal transfer properties of the two

112 stations were compared by tidal and coherence analyses. The admittances between strain and

113 the outer temperature were determined by a simple linear regression method. Coherence

114 analysis between theoretical and measured tide was used to investigate the transfer function of

115 the observatories (Formenti, 1999).

116 **4. Results**

117 **4.1. Tidal analysis**

118 A data series collected over eight years of the extensometer (SE) in the SGO (Fig. 3) and of

119 the extensometers E1 and E2 in the MGGO (Fig. 5) were subjected to tidal analysis

120 decomposing the data into one year segments. Evaluation of the data measured by

121 extensometer E1 – which resulted in highly distorted tidal parameters – was left out of the

122 investigation. Since the systematic checking and yearly calibration of the E1 extensometer

123 show proper functioning of the instrument in all other respects, the disturbed transfer

124 characteristics of the tidal signals is probably due to the relative position of the extensometer

125 to the gallery system of the observatory (see Fig. 5). The value of the tidal parameters from

126   analysis varies between 2–5 % at both measurement sites in the consecutive years, so data

127   processing of 2012 represents the multi-year measurement period. Adjusted tidal amplitudes

128   and the amplitude factors (measured/theoretical amplitudes) along with the standard

129   deviations of the adjustment for each component are listed in Table 2. The most striking

130   difference is the reduced diurnal amplitudes in the SGO. The main measured amplitudes are

131   44-60 % of the theoretical tidal deformation values. At the same time the S2 component in the

132   semidiurnal band is higher by a factor of 1.5 than it should be. Reduced amplitudes of E2 are

133   also adjusted in the diurnal band, which is similar to the SE results, but the differences

134   between the measured and theoretical values are much smaller. The most conspicuous

135   difference appears here in the K1 diurnal amplitude which decreased 25 %.

136   Since atmospheric pressure variations are among the main loading factors which affect the

137   deformation measurements at almost all kind of measurement sites (e. g. Rabbel and Zschau,

138   1985; Sun et al., 1995; Onoue and Takemoto , 1998; Kroner et al., 2005), pressure data series

139   measured in the observatories were taken into account and included in the tidal analysis. Data

140   processing results are presented in Table 2. In Fig. 6 the adjusted tidal amplitudes from the

141   analysis procedures can easily be compared. At Sopronbánfalva the linear regression

142   correction of the strain data by air pressure yielded an increase of about 5–10 % in the diurnal

143   band, while there is a more prominent decrease of 40 % at the S2 component, due to which

144   the S2 amplitude significantly improved compared to the theoretical value. From the

145   Mátyáshegy E2 data the analysis of the pressure-effect corrected extensometric series resulted

146   in insignificant, maximum 2 %, amplitude variations. This difference in the pressure

147   correction results are reflected also by the pressure sensitivity of the observatories, i.e. 4.5 nstr

148   hPa^{-1} in the SGO is against the value of the coefficient of 0.5 nstr/hPa in the MGGO. If the

149   deformation records are corrected for barometric pressure applying the above correction

150   factors in the time domain, the standard deviation of the residual signals (which are the

151   theoretical tides subtracted from the measured data) decrease from 6.1 to 5.1 nstr at the SGO

152   and from 2.6 to 2.5 nstr at the MGGO due to the correction.

153   The noticeable difference in the effect of atmospheric pressure variations at the two

154   measurement sites is demonstrated in Fig. 7. Here the residual of the high-pass filtered strain

155   data, which is provided by ETERNA among the analysis results, were subjected to a Fourier

156   transformation. Fast Fourier Transformation amplitudes of the residuals – after uncorrected

157   strain and pressure corrected strain analyses – are compared for both observatories in the tidal

158   frequency band (0-2.5 cpd). In the Sopronbánfalva data, an apparent decrease of the residual

159   amplitudes can be seen, especially in the 1 cpd band, while in Mátyáshegy amplitude changes

160   can hardly be noticed. The effect of the barometric pressure correction is characterised also by

161   numerical values: the average standard deviations of the tidal amplitudes (Table 2) and the

162   average spectral noise of the residual amplitudes (Fig. 7) decreased in the 1 cpd band (0.8–1.2

163   cpd) by 41 % at Sopronbánfalva and 4 % at Mátyáshegy, while in the 2 cpd band (1.8–2.2

164   cpd) by 22 % at Sopronbánfalva and below 1 % at Mátyáshegy. The values from the different

165   calculation methods agree with each other within 1 % in 1 cpd and 2 % in 2 cpd bands.

166   Overall characteristic of the tidal parameter determination at the investigated observatories is

167   concluded from Table 2. The determination is twice as accurate at the MGGO than it is at the

168   SGO for the comparison of the standard deviations of amplitude values for the main waves,

169   and of the standard deviations of weight unit of the adjustments. It matches the outcome of the

170   pressure correction of the data.

171   **4.2. Coherence analysis**

172   The two observatories were tested also by coherence analysis to determine how they transfer

173   the tidal signal. The coherence was calculated between theoretical and measured strain tide as

174   input and output signals of the Earth–observatory–system. The transfer function of the system

175   can be seen in Fig. 8. At the SGO the coherence is better than 0.95 in the semidiurnal band,

176 while in the diurnal band it is about 0.8. At the MGGO the coherence values are better than in

177 the SGO which means that the transfer of the tidal signal is less damped than at the SGO.

178 **4.3. Long term variations**

179 Deformation measurement data collected over eight years from the two observatories were

180 investigated. The recorded strain data of the Sopronbánfalva extensometer are drawn in Fig. 9

181 and curves of the E1 and E2 extensometers in the Mátyáshegy Observatory can be seen in

182 Figs. 10 and 11. The long-term variations are approximated in the Figures by linear trend lines

183 fitted to each data series along the recording period 2005–2012. The steepness of the trend

184 lines is the average strain rate in the investigated period. The measured strain rates are

185 summarised in Table 3 which also contains the strain rates measured in the MGGO by Varga

186 and Varga (1994) between 1990 and 1992. The peak to peak magnitudes of the yearly rock

187 strain variations caused mainly by the outer temperature variations (Mentes, 2000) –

188 determined after removing the trend from the curves – and the admittances between strain and

189 the outer temperature are listed in Table 3. This yearly period at SE and E1 clearly appears in

190 Figs. 9 and 10, while it is inconspicuous in the record of E2 (Fig. 11). The jumps and steep

191 changes in the strain records of the MGGO (Figs. 10 and 11) can be in connection with the

192 karstic water level changes under the observatory (Varga and Varga, 1994).

193 **5. Discussion**

194 Tidal analysis results reveal that the Mátyáshegy E2 instrument has a better capability to

195 transfer data of the horizontal high frequency deformations than the extensometer in the SGO.

196 Different behaviour of the extensometers due to atmospheric pressure loading can be

197 disclosed if the pressure parameter is included in the tidal analysis and the strain data is

198 corrected by a simple linear regression. Almost one order of magnitude higher regression

199 value resulted for SGO (4.5 nstr hPa^{-1}) than for MGGO (0.5 nstr hPa^{-1}). At the SGO a

200 significant improvement of the tidal adjustment resulted, while in Mátyáshegy the effect is not

201 detectable.

202 Beyond the similar instrument construction and the similar length of the galleries where the

203 instruments are placed, the overlaying topography of the measurement sites is also similar. At

204 the same time the rock coverage over the extensometers is two times higher at Soprobánfalva

205 than at Mátyáshegy, the gallery system of the MGGO is much more complex – due to the

206 original dissolved cave forms – than that of the SGO and a major difference exists in the

207 azimuths of the instruments. From point of the modifying cavity effect – being one of the

208 main site factors to be taken into consideration – a finite element model calculation resulted in

209 an 8 % increase of tidal rock deformation at the MGGO site. Such model calculations are not

210 at our disposal for the SGO, though from the literature the order of the disturbing cavity effect

211 for tidal strain, depending on the measurement arrangement and geometry, is about 1–10 %

212 (Harrison,1976; Sato and Harrison 1990). Thus, since the highest distortion of tidal

213 amplitudes in the SGO varies between 40–60 %, this correction item cannot be resolved here.

214 Lithologic parameters of the surrounding rocks at the measurement sites which describe the

215 different rock materials are listed in Table 4. On the basis of the model calculations of

216 Gebauer et al. (2009, 2010), where the cavity, topographic and lithologic effect on horizontal

217 deformations under atmospheric pressure load were investigated, the results of their

218 conclusions can be applied to these observatories in the increasing order of the magnitude of

219 the effect:

220 – The extent of the cavity effect for the lithologies of these observatories is about 0.1 nstr

221 hPa^{-1}, it is too small to be comparable with the difference in atmospheric pressure load effect

222 between SGO and MGGO. At the same time the galleries of SE and E2 are of almost the same

223 size and length.

224 – Since the rock cover above the instruments is different, a 20–30 % increase in the effect of

225 topography can be supposed at Sopronbánfalva (60 m) compared to Mátyáshegy (30 m), but

226 similarly to the previous effect its magnitude is small (below 0.5 nstr hPa^{-1}) and it may

227 explain only a minor part of the difference.

228 – From model calculations, a difference in the deformation effects in the order of about 2–2.5

229 nstr hPa^{-1} derives from the observatories having different rock material parameters and this

230 value much better approaches the difference of the pressure effects which were provided by

231 tidal analysis.

232 The above mentioned pressure load effects are related to a uniform pressure load condition.

233 Dynamic loading cases are also incorporated in the finite element modelling of Gebauer et al.

234 (2009, 2010). Since at Sopronbánfalva the gallery of the extensometer is parallel and at

235 Mátyáshegy the gallery of E2 is almost perpendicular to the prevailing wind direction, which

236 is the same above the regions of the observatories, the significantly higher pressure effect is in

237 good agreement with the modelling results.

238 On the basis of eight years of measurements it seems that two extensometers (SE and E1)

239 with almost the same azimuth, though far away from each other geographically, behave

240 similarly in the sense of yearly deformation changes. Nevertheless the different yearly

241 amplitudes should be noticed. The similarity between the conditions of the instruments is the

242 position of the galleries (where they are placed) relative to the topography of the surface

243 forms, the steep scarps, of the observatories. However, the Mátyáshegy Observatory has a

244 cave system while at Sopronbánfalva the galleries were made only for the instruments. This

245 complex gallery system of the MGGO leads to the different transfer mechanism induced by

246 temperature variations in the case of E1 and E2 (Figs. 10 and 11). Due to their free

247 unhindered deformation, the rock walls between the galleries in the MGGO absorb a part of

248 the deformation energy caused by barometric pressure and temperature variations. This can

249 explain the lower pressure admittance and temperature induced peak to peak yearly strain

250 variations in the MGGO compared to SGO (Table 3).

251 The highest rate of the long-term deformation changes at Sopronbánfalva can be attributed to

252 the geographical location of the instrument. The area belongs to the marginal mountainous

253 region of the Pannonian Basin with mostly crystalline bedrock types, and this East Alpine

254 region is characterised by different vertical deformation velocities compared to the central

255 parts of the Pannonian Basin (Cloetingh et al., 2005; Caporali, 2009; Dombrádi et al., 2010).

256 The folding and compression of the weak lithosphere absorbs the strain in the Pannonian

257 Basin (Dombrádi et al., 2010) which explains the small strain rates measured in the

258 Mátyáshegy Observatory. Extensometer E2 is nearly parallel to the maximum horizontal

259 stress direction assumed by Bada et al. (2007a, b) and it measures a higher rate than E1 (Table

260 3) which lies almost perpendicular to the direction of E2. These local strain rates are in good

261 accordance with the strain rates measured by geodetic methods (see Table 3). The strain rates

262 determined from GPS measurements in the Hungarian GPS Geodynamic Reference Network

263 and the Central European GPS Reference Network (Grenerczy et al., 2000, 2005) are three

264 orders of magnitude smaller than the values measured by the extensometers. It can be

265 explained by the difference of the measurement techniques. While the extensometer measures

266 local strain rates, only global strain rates for large areas can be determined from GPS

267 measurements. The faults between GPS stations and earthquakes in the region release the

268 strain (Bada et al., 2007b; Bus et al., 2009). In the region of the SGO the strain rate measured

269 by GPS is twice the value obtained in Central Hungary. Varga et al. (2002) determined a

270 strain rate of $-0.08\ \mu\text{str year}^{-1}$ from the Hungarian Triangulation Network in the Budapest

271 region, which is the same value measured by the E1 extensometer in the MMGO. Although

272 extensometric measurements are influenced by local tectonic processes (e.g., orogenic forces),

273 they describe the recent tectonic movements in the Pannonian Basin very well.

7. Conclusions

The uniform construction of the extensometers in the Mátyáshegy Gravity and Geodynamic Observatory and in the Sopronbánfalva Geodynamic Observatory ensures that in the course of comparison any differences in the measurement characteristics can be attributed to geologic, topographic properties and meteorological conditions of the measurement sites.

Tidal analysis of the extensometric data between 2005 and 2012 revealed that the measured tidal amplitudes are close to the theoretical values in the MGGO while they are 44-60 % smaller in the diurnal band in the SGO. The difference in the tidal signals (also proved by coherence analysis) can be attributed to the different barometric pressure sensitivity of the observatories (4.5 nstr hPa^{-1} in the SGO and 0.5 nstr hPa^{-1} in MGGO).

The results of the barometric pressure correction show that while in the MGGO a simple regression correction yields good improvement of the signal-to-noise ratio in the strain data, in the SGO a more sophisticated reduction method is needed which takes into account regional and possibly global air pressure data to correct for the effect of passing weather fronts.

The long-term thermal effect in the MGGO is about the half of the one in the SGO. The difference between the pressure and thermal sensitivity of the observatories is due to the different geologic, lithology parameters, gallery system and the position of the instrument relative to the topography of the measurement sites.

In contrast with the different transfer characteristics of the observatories in the tidal domain and the high long-term disturbances in the MGGO, probably caused by karstic water variations, the measured strain rates are in good agreement with the GPS measurements in the Hungarian GPS Geodynamic Reference Network and the Central European GPS Reference Network.

298 The investigated geodynamic observatories and extensometers are parts of an extensometric

299 observatory network on the territory of the Pannonian Basin. Therefore the analysis results

300 may be utilized when the deformation measurements of the network are processed and the

301 specific sensitivity of the measurement locations can lead to satisfactory corrections both in

302 the high and low frequency ranges of the signals. It may contribute to a unified evaluation and

303 interpretation.

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400

401 **Figure captions**

402 **Fig. 1.** Extensometric stations in Hungary.

403 **Fig. 2.** Geological map (Haas, 2001) of the surroundings of the SGO.

404 **Fig. 3.** Ground plane of the SGO with the instruments.

405 **Fig. 4.** Topographic map of the surroundings of the Mátyáshegy Observatory (Budai and

406 Gyalog, 2009).

407 **Fig. 5.** Ground plane of the MGGO with the instruments.

408 **Fig. 6.** Amplitudes of tidal components from ETERNA analysis of extensometric data from

409 Sopronbánfalva (SE) and Mátyáshegy (E2) observatories. U, C and T denote amplitudes from

410 analysing raw data, data corrected for barometric pressure by ETERNA and theoretical tide,

411 respectively.

412 **Fig. 7.** Fast Fourier Transformation amplitudes of tidal analysis residuals at the SGO and

413 MGGO. a) and c) residual amplitudes after strain analysis, b) and d) residual amplitudes after

414 local barometric pressure corrected strain analysis.

415 **Fig. 8.** Transfer characteristic (coherence function between the theoretical and measured

416 tides) of the Earth – observatory – instrument system at the SGO and at the MGGO.

417 **Fig. 9.** Extensometric raw data at the SGO from 1 Jan. 2005 to 31 Dec. 2012.

418 **Fig. 10.** Extensometric raw data measured by extensometer E1 at the MGGO from 1 Jan.

419 2005 to 31 Dec. 2012.

420 **Fig. 11.** Extensometric raw data measured by extensometer E2 at the MGGO from 1 Jan.
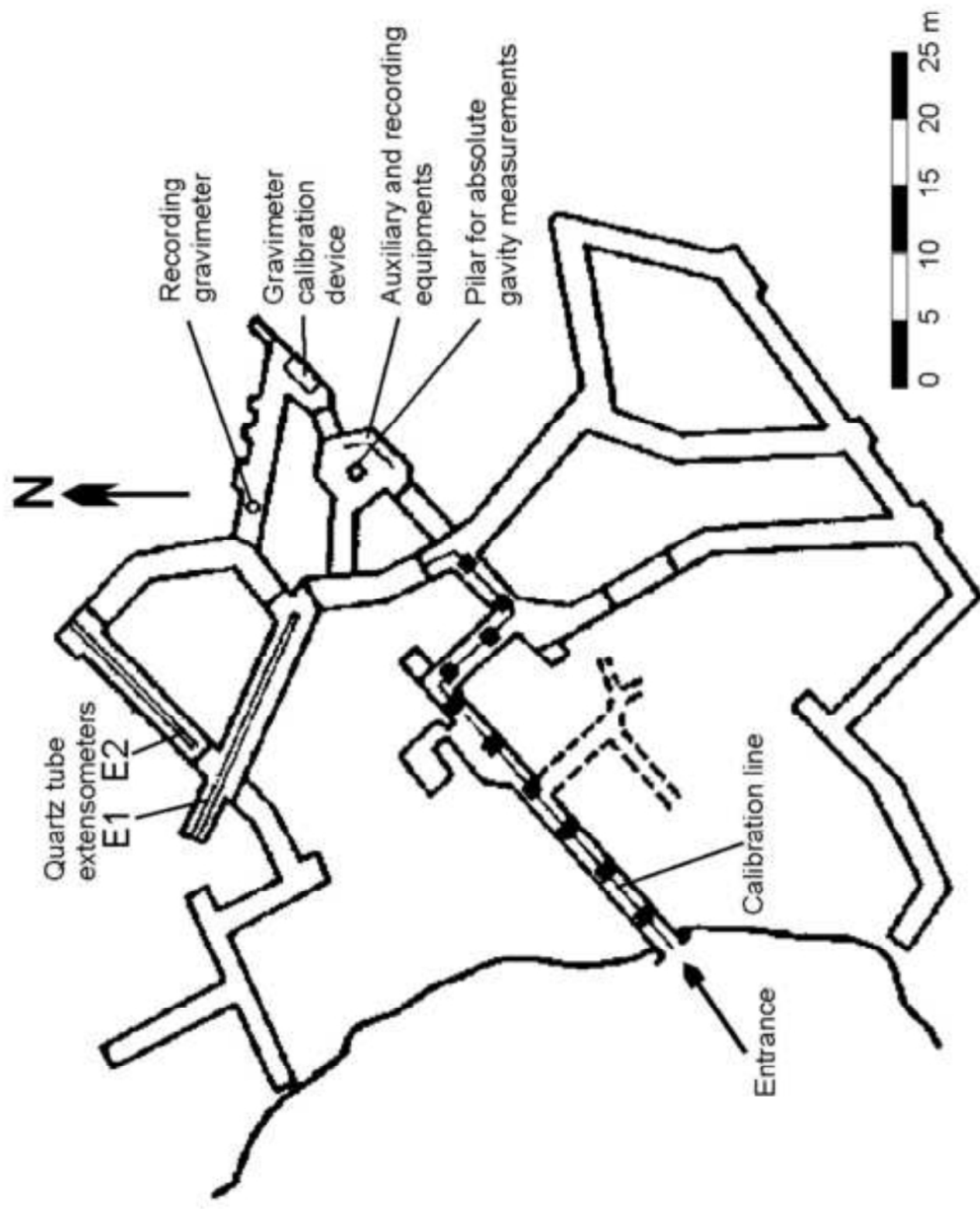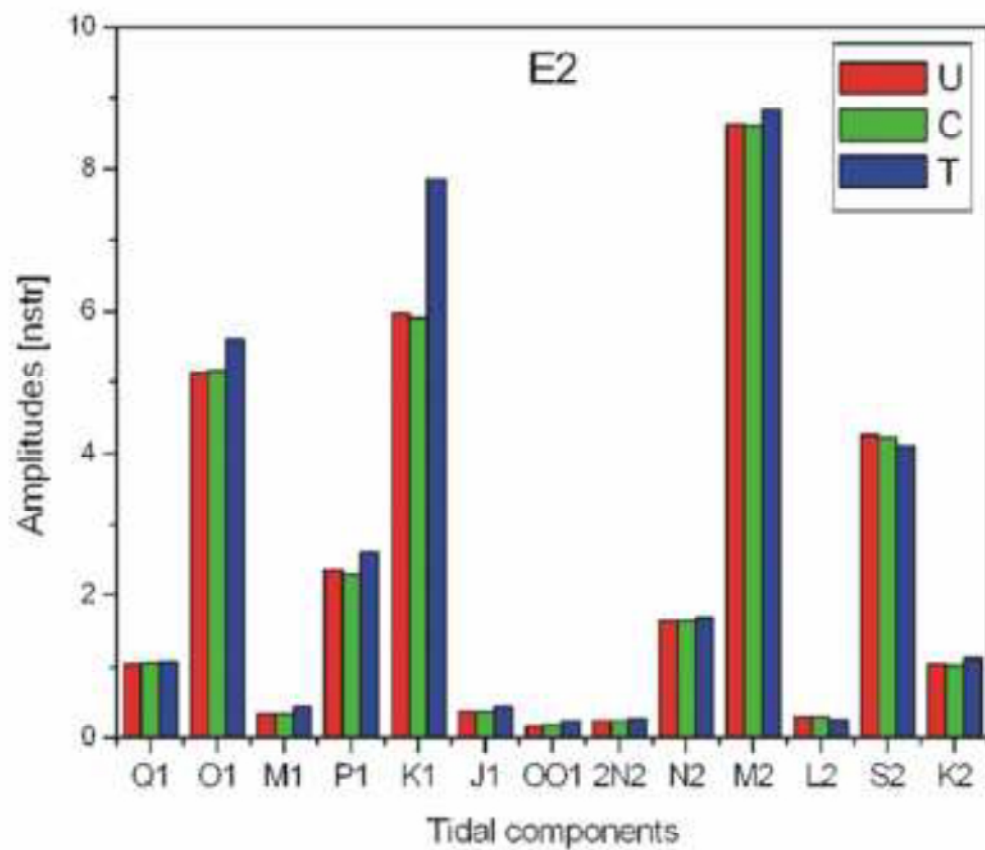
421 2005 to 31 Dec. 2012.

422

Figure2
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Figure2

Figure5

Table1

Table 1. Coordinates and parameters of the extensometers.

Extensometer	Coordinates of the station			Azimuth of the instrument	Length of the instrument [m]
	Latitude	Longitude	Height a.s.l. [m]		
Mátyáshegy E1	47° 33' 11"	19° 20' 24"	240	114°	21.3
Mátyáshegy E2	47° 33' 11"	19° 20' 24"	240	38°	13.8
Sopronbánfalva	47° 40' 55"	16° 33' 32"	220	116°	22

Table2

Table 2. Tidal analysis results of the deformation data recorded at the Sopronbánfalva Observatory and at the Mátyáshegy Observatory (extensometer E2) between 01 January 2012 and 31 December 2012.

Waves	Sopronbánfalva				Budapest E2			
	Analysis of uncorrected data		Analysis with pressure data		Analysis of uncorrected data		Analysis with pressure data	
	Amplitude±S.D. [nstr]	Amplitude factor±S.D.	Amplitude±S.D. [nstr]	Amplitude factor±S.D.	Amplitude±S.D. [nstr]	Amplitude factor±S.D.	Amplitude±S.D. [nstr]	Amplitude factor±S.D.
Q1	0.752±0.247	0.596±0.196	0.891±0.145	0.706±0.115	1.048±0.085	0.977±0.080	1.051±0.082	0.980±0.077
O1	3.786±0.267	0.574±0.040	3.981±0.157	0.604±0.024	5.151±0.092	0.919±0.016	5.173±0.089	0.923±0.016
M1	0.306±0.282	0.591±0.543	0.238±0.165	0.460±0.319	0.341±0.097	0.774±0.219	0.341±0.093	0.774±0.211
P1	1.083±0.259	0.353±0.085	0.933±0.152	0.304±0.050	2.350±0.090	0.901±0.034	2.291±0.087	0.879±0.033
K1	4.041±0.271	0.436±0.029	4.048±0.159	0.437±0.017	5.986±0.094	0.760±0.012	5.918±0.091	0.751±0.012
J1	0.351±0.270	0.678±0.520	0.408±0.159	0.787±0.306	0.361±0.093	0.819±0.212	0.368±0.090	0.834±0.204
OO1	0.220±0.304	0.774±1.072	0.432±0.179	1.522±0.630	0.165±0.105	0.686±0.435	0.182±0.101	0.755±0.420
2N2	0.150±0.080	0.969±0.518	0.132±0.061	0.852±0.397	0.239±0.035	0.884±0.128	0.242±0.034	0.898±0.128
N2	0.889±0.105	0.918±0.109	0.927±0.081	0.958±0.083	1.631±0.046	0.964±0.027	1.634±0.046	0.966±0.027
M2	4.864±0.104	0.962±0.020	4.767±0.079	0.943±0.016	8.635±0.046	0.978±0.005	8.620±0.046	0.976±0.005
L2	0.085±0.081	0.594±0.564	0.119±0.062	0.833±0.432	0.286±0.035	1.146±0.140	0.292±0.035	1.169±0.139
S2	3.709±0.103	1.576±0.044	2.128±0.084	0.904±0.036	4.257±0.046	1.036±0.011	4.212±0.046	1.025±0.011
K2	0.813±0.115	1.272±0.181	0.487±0.089	0.762±0.139	1.050±0.051	0.941±0.046	1.030±0.051	0.923±0.046
S.D. of weight unit [nstr]	3.915		2.239		1.434		1.384	
Pressure regression coefficient [nstr/hPa]			4.5				0.5	

Table3

Table 3. Results of the long-term extensometric and geodetic measurements. (GPS SGO and GPS MGGO denote GPS measurements in the region of SGO and MGGO, respectively; HTN MGGO denote the strain rate determined from the Hungarian Triangulation Network in the region of the MGGO.)

Measuring method	Strain rate [μstr year^{-1}]	Type of deformation	Admittance μstr °C^{-1}	Annual peak to peak strain variation [μstr]	Mesurement period
SGO E1	–3.5	compression	0.023	1	2005–2012
MGGO E1	0.0076	extension	0.009	0.4	2005–2012
MGGO E2	–0.444	compression	0.006	0.3	2005–2012
MGGO E1	–0.08	compression	–	–	1990–1992
MGGO E2	–2.24	compression	–	–	1990–1992
GPS SGO	–0.008	compression	–	–	1991–2007
GPS MGGO	–0.004	compression	–	–	1991–2007
HTN MGGO	–0.08	compression	–	–	1878–1965

Table4

Table 4. Lithologic parameters of the rock around the observatories

Observatory	Rock material	Density [kg m^{-3}]	Young's modulus [GPa]	Poisson ratio
Sopronbánfalva	Gneiss	2700	45.5	0.12
Mátyáshegy	Limestone	2500	65.0	0.25

Table 4. Lithologic parameters of the rock around the observatories

Observatory	Rock material	Density [kg m^{-3}]	Young's modulus [GPa]	Poisson ratio
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Mátyáshegy	Limestone	2500	65.0	0.25