Observation of local tectonic movements by a quartz-tube extensometer in the Sopronbánfalva Geodynamic Observatory, in Hungary–Validation of extensometric data by tidal analysis and simultaneous radon concentration measurements

Gyula Mentes

Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences; Csatkai E. u. 6-8, H-9400 Sopron, Hungary

Fax: +36-99-508-355

Email: mentes@ggki.hu

Abstract

In 1990 a quartz tube extensometer was installed in the Sopronbánfalva Geodynamic Observatory (SGO) of the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences. On the basis of the 20 year data series, an average strain rate of -5.36 µstr/y was determined. Because the instrumental drift can also cause a slow change in the output signal of the sensor similar to the tectonic movements, a lot of efforts were made to determine the drift of the extensometer. The instrument has no detectable drift according to the instrumental calibrations (regular calibration, parallel recording by more displacement sensors, etc.). Since autumn of 2008, the radon concentration has been continuously monitored by an AlfaGuard instrument in the SGO. The investigation of the relationship between strain and radon concentration also showed the absence of instrumental drift, so the instrument measures real tectonic movements. The results of the extensometric measurements show that the rate of tectonic movement is not constant. During the period 1993-2001, the strain rate accelerated to a maximum of -8.6 µstr/y in 2001, and then decelerated again between 2002-2010 to approx. -2.5 µstr/y in 2010.

Keywords: Extensometer; Instrument stability; Radon concentration; Strain; Tectonic movements

1. Introduction

Different types of extensometers (quartz tube, invar wire, crack gauge TM 71, laser) are widely used for observation of tectonic movements and for measurement of the solid Earth's tide (e.g. Agnew, 1986; Košťák et al. 2011; Crescentini et al. 1997; Jahr et al. 2006; Onoue et al. 2001). In the Sopronbánfalva Geodynamic Observatory, a quartz tube extensometer was installed in cooperation between the Geodetic and Geophysical Research Institute (GGRI) of the Hungarian Academy of Sciences and the Institute of Physics of the Earth of the (former) USSR Academy of Sciences, in Moscow. The electronic distance voltage transducer of the instrument was developed at the GGRI. The instrument is used for observation of the solid Earth's tide and measurement of local tectonic movements and deformations. The extensometer has been working continuously since May, 1990. There were only some interruptions in recording, not longer than a few days, due to technical problems or maintenance. Now a 20 year continuous record from 1 January, 2009 to 31 December, 2010 is available for analysis of the tectonic movements at the observatory. Since the radon gas concentration is high in the observatory, a radon monitor was also installed near the extensometer in autumn of 2008 to investigate the relationship between strain and radon concentration.

The measured local strain rate at the different extensometric stations is in the order of some µstr/y (Onoue et al. 2001; Takemoto et al. 2006a, 2006b; Venedikov et al. 2006). Similarly the strain rate in the SGO (average strain rate: 5.36 µstr/y) is higher by some order of magnitude (Mentes, 2008) than the rates measured in the European GPS network (Bada et al. 2007b; Grenerczy et al. 2000; Grenerczy et al. 2005). This is why this difference is the subject of regular debate. GPS specialists state that the higher tectonic rate measured by the extensometer is due to the drift of the instrument. Much effort was devoted to ensure the high reliability of extensometric measurements at the SGO (Mentes, 2010). This paper describes the results of the tectonic movement monitoring in the last 20 years. The relationships between strain and radon concentration measurements are investigated and extensometric data are validated by radon concentration measurements. The strain rate measured by the extensometer is compared with the strain rates inferred from permanent and epoch-wise GPS measurements in the Central European GPS Geodynamic Reference Network (CEGRN) and in the Hungarian GPS Geodynamic Reference Network (HGRN) in Central Europe and the possible reasons for the high rate difference are discussed.

2. Observation site and method

The Sopronbánfalva (a suburb of Sopron) Geodynamic Observatory (SGO) is located on the Hungarian-Austrian border in the Sopron Mountains (Fig. 1). The area belongs to the extensions of the Eastern Alps. The coordinates of the observatory are: 47º40’55’’ N, 16º33’32” E; it is 220 m a.s.l. The observatory is an artificial gallery driven into gneiss. Its ground plane is shown in Fig. 2. The overlay of the gallery is about 60 m thick. The yearly mean value of the temperature is 10.4 ºC in the gallery and the yearly and daily temperature variations are less than 0.5 ºC and 0.05 ºC, respectively. The relative humidity is 90% and it is nearly constant. The gallery where the instruments are placed is thermally insulated, but there can be slow air transport via the conduit for the electric cables of the instruments. This slow ventilation ensures that the indoor and outdoor barometric pressures are the same and do not considerably influence the temperature in the gallery as proved by the measurements.

The extensometer is 22 m long and it was assembled from quartz tubes 2 m long, 45 mm in diameter, with walls 2.5 mm thick. The tubes are joined together by means of a special adhesive technology. The jointed tubes are suspended from supports by invar wires. One end of the extensometer is fixed to the bedrock by means of a stainless steel dowel. The other end of the dowel holds a magnetostictive actuator which can move the quartz tube joined to the actuator. The displacement of the other end of the quartz tube is measured by a capacitive transducer relative to the bedrock. In this way the extensometer measures the deformation of the rock between its two ends. Switching a constant current (150 mA) on the coil of the magnetostrictive actuator, it moves the quartz tube and provides daily calibration of the instrument. The location of the extensometer in the gallery can be seen in Fig.2. Its azimuth is 116°. The scale factor of the extensometer is 2.093±0.032 nm/mV. Mentes (2010) describes the construction and calibration of the instrument in detail.

The radon concentration was measured by a radon monitor of type AlphaGuard PQ2000PRO near the extensometer (Fig. 2). The AlphaGuard can be used for continuous determination of the radon and radon progeny concentration as well as air pressure and temperature (http://www.genitron.de). This radon monitor is suitable for continuous monitoring of radon concentrations between 2 – 2 000 000 Bq/m^3. Its sensitivity is 5 cpm at 100 Bq/m^3. It has a long-term stable calibration factor (guaranteed for 5 years). The extensometric, radon, outdoor temperature and air pressure data were measured hourly.

3. Results of extensometric measurements

Fig. 3 shows the extensometric raw data in the period from 1 January, 1991 to 31 December, 2010. The extensometric data are given in nstr (1 nstr=10^{-9} relative extension= measured displacement/length of the extensometer). This 20 year continuous data series show a compressive deformation in the bedrock at the measuring site. The seasonal variation of the raw data is due to the annual outdoor temperature variation (Mentes and Eper-Pápai, 2006). The rate of the movement is not constant. The steepness of the line fitted to the raw data in Fig. 3 gives the average strain rate detected on the full length of the extensometer, which is -5.36 µstr/y. To investigate the variation of the strain rate, the yearly average rates were determined by fitting a line to the yearly extensometric data. The results are plotted in Fig. 4.

4. Validation of extensometric data

4. 1. Tidal analysis

To check the firm connection of the instrument to the bedrock, the extensometric data were subjected to tidal analysis by the ETERNA 3.40 Earth tide data processing program (Wenzel, 1996) using the Wahr-Dehant Earth model (Dehant, 1987) and the HW95 tidal potential catalogue (Hartmann and Wenzel, 1995). Table 1 shows the amplitude factors (measured/theoretical amplitudes) for the main lunar diurnal O1 and the semidiurnal M2 waves obtained by the tidal analysis. The main lunar waves are only used for the comparison because the meteorological effects are in close connection with the Sun and not with the Moon. The reason for the difference of the amplitude factors from one is due to the fact that the ETERNA 3.40 program is not calibrated for extensometric measurements since the measured strain caused by tidal forces depends on the quality of the rock in the vicinity of the observatory. The variation of the amplitude factors is not connected with the variation of the strain rates in the investigated period (2000-2010). The results of the tidal analysis show that the instrument is firmly attached to the bedrock. The regular calibration and stability investigation of the extensometer prove that the instrument has no detectable electrical drift; the tube is rigid (Mentes, 2010) and the tectonic movement rates are reliable.

4. 2. Validation of extensometric data by radon concentration measurements

The left side of Fig. 5 shows the outdoor temperature, the barometric pressure, strain and radon concentration data between 1 February, 2009 and 31 October, 2010. It shows that temperature has a significant long-term effect on the strain and radon concentration data while the effect of the barometric pressure is minor. To study the long-term relationship between the different data, a polynomial of the 9th order was fitted on the data series. These polynomials are plotted on the right side of Fig. 5. It is clear that the polynomial fitted to the radon data does not represent the radon concentration data during the winter. The result is the same when the data is filtered by a low-pass filter with a cut-off frequency of 0.003 cpd to remove the short-periodic variations. For that reason only the summer periods (from 1 June, 2009 to 31

August, 2009 and from 1 June, 2010 to 31August, 2010) were investigated. First the radon concentration and temperature were correlated, and then the radon data was corrected by the temperature by means of a simple linear regression. Then the temperature corrected radon data was corrected by the air pressure data by the same method. The extensometer is not sensitive to the direct effect of the temperature and air pressure (Mentes and Eper-Pápai, 2006; Mentes, 2008). These parameters have only an indirect effect on the extensometric data due to deformation of the rock. This later effect influences also the strain of the rock (also measured by the extensometer) and therefore the emanation of the radon. That is why the strain data was not corrected with the temperature and air pressure. Finally, the temperature and air pressure corrected radon data were correlated with the strain data, in order to determine the regression coefficient between radon and the strain data. The regression coefficient gives the change of the radon concentration caused by 1 nstr. The value obtained for the summer of 2009 is 0.0424 kBq/m^3/nstr (empirical correlation index: R^2=0.9834) and for the summer of 2010 is 0.0151 kBq/m^3/nstr (R^2=0.9673). The R-square values show a very good correlation between radon concentration and strain values. In the summer of 2010, the regression coefficient is less than the value in the summer of 2009. Figure 5 shows that the amplitude of the radon concentration curve is smaller in 2010 than in summer 2009. The reason is that the stress in the rock is higher due to the compression of the rock. If we divide the difference between the maxima of the radon concentration (points A and B in Fig. 5) by the difference of the measured strains between these points (112 kBq/m^3/2700 nstr) we get 0.0414 kBq/m^3/nstr, which is the value of the regression coefficient obtained for the summer of 2009. Otherwise, if the stress in the rock in the summer of 2010 were the same as in 2009, the radon concentration would be the same value as in 2009. It means that the higher the compression of the rock is, the less the radon is emanated from the rock. This fact proves unambiguously that the strain measured by the extensometer is real strain and does not contain instrumental drift.

5. Discussion

Crustal movements and deformations in Central Europe are investigated on the basis of continuous and repeated measurements of the coordinates of permanent and epoch GPS stations of the Central European GPS Reference Network. Measurements began in 1994. Measurements and data processing are carried out by different groups in close international co-operation, e.g. within the Central Europe Regional Geodynamics Projects CERGOP and CERGOP-2 (Grenerczy et al. 2000; Caporali et al. 2008). Grenerczy et al. (2000) determined the strain rate from GPS data (from 1994 to 1998) of the CEGRN and the Hungarian GPS Geodynamic Reference Network in two regions (A and B in Fig. 6). In region A they obtained a principal contraction strain rate -8.6 ± 2.5 nstr/y in the NE-SW direction (G1 in Fig.6). About the same principal contraction rate -8.0 ± 5.3 nstr/y (G2 in Fig. 6) was determined in the B region but its direction is NW-SE. Bus et al. (2009) calculated a principal contraction rate -4.1 nstr/y with a NEE - WWS direction for the whole Central Pannonian (CP) area from the HGRN data from 1991 to 2007. In the sub-network A they obtained practically the same value (-7.6 nstr/y) as was earlier calculated by Grenerczy et al. (2000). In the Mur-Mürz (MM) zone, parallel with the fault -12 nstr/y contraction, while perpendicular to it 9.6 nstr/y an extensional rate (transtension, see Fodor et al. 2005) was obtained. The extensometer in Sopron has about the same azimuth as the direction of the principal extensional rate in the MM zone and in the A section (in Fig. 6) and the direction of the principal contraction strain rate in the B section. These directions correspond to forces which move the East Alpine-North Pannonian unit to the east and rotate it clockwise (Bada et al. 2007a; Caporali et al. 2008). Results derived from a borehole breakout, earthquake focal mechanism (FMS) and overcoring measurements in the vicinity of the MM zone which show diverse local maximum strain directions (Bada et al. 2007b). Some of them are parallel with the extensometer at the Sopron station. Thus we can assume that the direction of the extensometer is near the direction of the principal contraction strain rate in this region; (see also the maximum shortening direction map made by Olaiz et al. (2009)). The deformation in the Pannonian basin is not uniform. It is concentrated mostly in the western and central parts of the basin (e.g. Bada et al. 2007a). The vertical movements, such as uplift and subsidence, induce horizontal strain (Caporali 2009). One of the reasons for the high strain rate measured by the extensometer in the SGO is probably the difference of the vertical velocities in the East Alpine region and in the Pannonian basin (Cloetingh et al. 2005; Dombrádi et al. 2010). However, the main reason for the much higher strain rate (in the order of μstr/y) measured by the extensometer than strain rates determined from GPS measurements is inherent in the difference of the measuring methods. The extensometer measures local strain rates, since only global strain rates for large areas can be determined from GPS measurements. The weak lithosphere (folding and compression) absorbs the strain in the Pannonian basin (Dombrádi et al. 2010) while faults between GPS stations and earthquakes in the region release the strain (Bada et al. 2007b; Bus et al. 2009).

Fig. 6 shows GPS velocities (simple arrows) in Sopron and in its surroundings. We see that at the GPS stations in Sopron and DISZ, the eastward component of the velocity is larger than at the stations in the Alps (HFLK, SBGZ, GRAZ). This fact can cause the decreasing contraction rate measured by the extensometer in Sopron. The variation of the strain rate is probably due to the spatial and temporal distribution of the earthquakes in the region of the SGO (BUS et al. 2009; Kiszely 2010). Baseline length variations – probably due to strain variations – were also determined from long-term GPS observations (Caporali and Martin, 2000).

6. Conclusions

Data obtained from a quartz-tube extensometer located in the Sopronbánfalva Geodynamic Observatory at the foot of the Eastern Alps have shown a long-term compressive strain rate of -5.36 µstr/y. However, considerable strain variation was observed during the whole period of 20 years of observation. During the period 1993-2001 the strain rate accelerated to a maximum of -8.6 µstr/y in 2001, and then decelerated again between 2002-2010 to approximately -2.5 µstr/y in 2010. The strain results were validated by a simultaneous two year radon monitoring in 2009/10. Correlations proved absence of instrumental drift in our extensometric data.

Since strain variations measured by the extensometer are below of the threshold of the measurability by GPS methods on short base lines, the continuous extensometric measurements play a very important role in the study of local geodynamic processes.

Acknowledgements

This work was funded by the Hungarian National Research Fund (OTKA) under project No. 71952. Special thanks to Ildikó Eperné-Pápai for her help in data preprocessing and Tibor Molnár for his careful maintenance of the instruments.

References

Agnew, D.C., 1986. Strainmeters and tiltmeters. Rev. Geophys. 24 (3), 579–624.

Bada, G., Grenerczy, Gy., Tóth, L., Horváth, F., Stein, S., Cloetingh, S., Windhoffer, G., Fodor, L., Pinter, N., Fejes, I., 2007a. 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.

Bada, G., Horváth, F., Dövényi, P., Szafián, P., Windhoffer, G., Clothing, S., 2007b. Present day stress field and tectonic inversion in the Pannonian basin. Global Planet Change 58, 165–180.

Bus, Z., Grenerczy, Gy., Tóth, L., Mónus, P., 2009. Active crustal deformation in two seismogenic zones of the Pannonian region – GPS versus seismological observations. Techtonophysics, 474, 343–352.

Caporali, A., 2009. Lithospheric flexure, uplift and expected horizontal strain rate in the Pannonian Carpathian region. Tectonophysics 474, 337–342.

Caporali, A., Martin, S., 2000. First results from GPS measurements on present day alpine kinematics. J. Geodyn., 30, 275–283.

Caporali, A, Aichhorn, C., Becker, M., Fejes, I., Gerhatova, L., Ghitau, D., Grenerczy, G., Hefty, J., Krauss, S., Medak, D., Milev, G., Mojzes, M., Mulic, M., Nardo ,A., Pesec, P., Rus, T., Simek, J., Sledzinski, J., Solaric, M., Stangl, G., Vespe, F., Virag, G., Vodopivec, F., Zablotskyi, F., 2008. Geokinematics of Central Europe: New insights from the CERGOP-2/Environment Project. J. Geodyn., 45, 246–256.

Cloetingh, S., Maţenco, L., Bada, G., Dinu, C., Mocanu, B., 2005. The evolution of the Carpathians–Pannonian system: Interaction between neotectonics, deep structure, polyphase orogeny and sedimentary basins in a source to sink natural laboratory. Tectonophysics 410, 1–14.

Crescentini, L., Amoruso, A., Fiocco, G., Visconti, G., 1997. Installation of a high-sensitivity laser strainmeter in a tunnel in central Italy. Rev. Sci. Insrum. 68 (8), 3206–3210.

Dehant, V., 1987. Tidal parameters for an unelastic Earth. Phys. Earth Planet. Interiors 49, 97–116.

Dombrádi, E., Sokoutis, D., Bada, G., Cloetingh, S., Horváth, F., 2010. Modelling recent deformation of the Pannonian lithosphere: Lithospheric folding and tectonic topography. Tectonophysics 484, 103–118.

Fodor, L., Bada, G., Csillag, G., Horváth, E., Ruszkiczay-Rüdiger, Zs., Palotás, K., Síkhegyi, F., Timár, G., Cloetingh, S., Horváth., F. 2005. An outline of neotectonic structures and morphotectonics of the western and central Pannonian Basin. Tectonophysics 410, 15– 41.

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.

Grenerczy, Gy., Sella, G., Stein, S., Kenyeres, A., 2005. Tectonic implications of the GPS velocity field in the northern Adriatic region. Geophys. Res. Lett. 32, L16311, doi: 10.1029/2005GL022947.

Haas, J., (Ed), 2001. Geology of Hungary. Eötvös University Press, Budapest, pp. 315.

Hartmann, T., Wenzel, H.G., 1995. The HW95 tidal potential catalogue. Geophys. Res. Lett. 22 (24), 3553–3556.

Jahr, T., Kroner, C., Lippmann, A., 2006. Strainmeters at Moxa Observatory. J. Geodyn. 41 (1-3), 205–212.

Kiszely, M. M.,2010. Statistical analysis of earthquakes and Quarry blasts in the Carpathian Basin – New problems and facilities. Carpath J Earth Env. 5 (2), 101–110.

Košťák, B., Mrlina, J., Stemberk, J., Chán, B., 2011. Tectonic movements monitored in the Bohemian Massif. J. Geodyn. 52, 34–44.

Mentes, Gy., 2008. Observation of recent tectonic movements by extensometers in the Pannonian Basin. J. Geodyn. 45, 169–177, doi:10.1016/j.jog.2007.10.001.

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.

Mentes Gy., Eper-Pápai, I., 2006. Investigation of meteorological effects on strain measurements at two stations in Hungary. J. Geodyn., 41 (1-3), 259–267.

Olaiz, A.J., Muñoz-Martín, A., De Vicente, G., Vegas, R., Cloetingh, S., 2009. European continuous active tectonic strain–stress map. Tectonophysics 474, 33–40.

Onoue, K., Mukai, A., Takemoto, S., 2001. Tidal strain observed with extensometers in Donzurubo Observatory, Nara, Japan. J. Geod. Soc. Jpn. 47 (1), 141–147.

Takemoto, S., Momose, H., Araya, A., Morii, W., Akamatsu, J., Ohashi, M., Takamori, A., Miyoki, S., Uchiyama, T., Tatsumi, D., Higashi, T., Telada, S., Fukuda, Y., 2006a. A 100 m long laser strainmeter system in the Kamioke Mine, Japan, for precise observations of tidal strains. J. Geodyn., 41(1-3), 23–29.

Takemoto, S., Lee, M., Chen, C-Y., Kao, M-C., Mukai, A., Ikawa, T., Kuroda, T., Abe, T., 2006b. Tidal strain observations in Chu-Chie, Taiwan. J. Geodyn., 41(1-3), 198–204.

Venedikov, A.P., Arnoso, J., Cai, W., Vieira, R., Tan, S., Velez, E.J., 2006. Separation of the longterm termal effects from strain measurements in the Geodinamics Laboratory of Lanzarote. J. Geodyn., 41(1-3), 213–220.

Wenzel, H.G., 1996. The nanogal software: Earth tide data processing package ETERNA 3.30. Bull. d'Inf. Marées Terr. 124, 9425–9439.

Table 1. Amplitude factors calculated from data series measured from 2000 to 2010

Wave	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average ± stdv
O1	0.686	0.652	0.687	0.724	0.716	0.695	0.691	0.735	0.692	0.626	0.549	0.648 ±0.05
M2	1.087	1.144	1.212	1.186	0.959	1.129	1.292	1.236	1.268	1.163	0.951	1.148±0.11

Figure captions

Fig. 1. The location of the Sopronbánfalva Geodynamic Observatory (SGO) in the Sopron Mountains, Hungary and the geological setting of the measurement site (Haas, 2001).

Fig. 2. Ground-plan of the Sopronbánfalva Geodynamic Observatory.

Fig. 3. Raw extensometric data from 1 Jan.1991 to 31 Dec. 2010.

Fig. 4. Yearly variation of the strain rates.

Fig. 5. Temperature, barometric pressure, strain and radon concentration data measured in the SGO between 1 Feb. 2009 and 31 Oct. 2010. Measured raw data are on the left, polynomials fitted to the raw data are on the right.

Fig. 6. GPS velocities and strain rates in the region of the SGO (SOPRON).Arrows denote the intraplate velocities inferred from GPS measurements. Velocities at the sites WTZR, HFLK, HUTB, GRAZ, PENZ, DISZ were determined by Caporali et al. (2008); the velocity at the site SOPRON was determined by Grenerczy et al. (2000). Double arrows denote the strain rates inferred from GPS observations. The strain rate given in Sopron was determined by the extensometer.

Figures

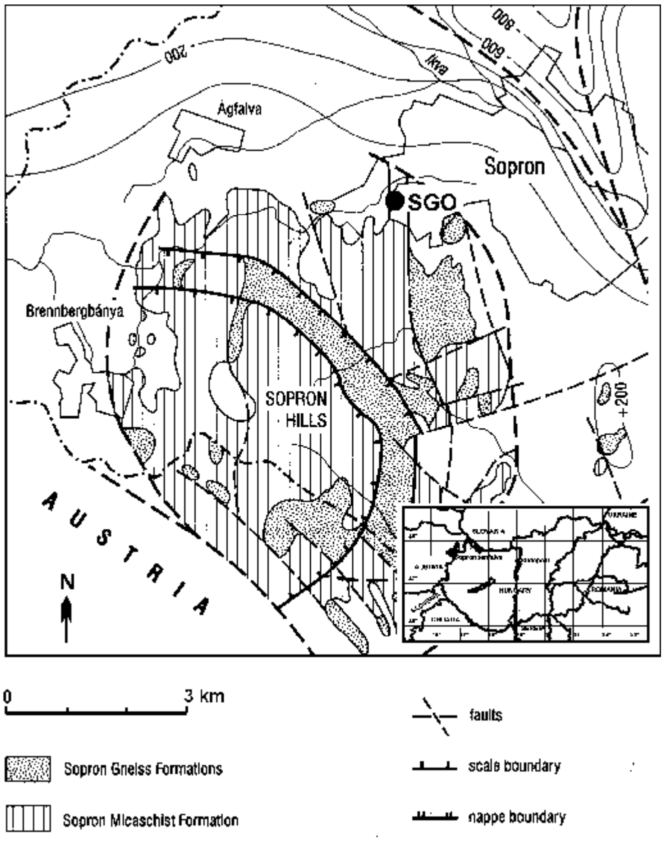

Fig. 1.

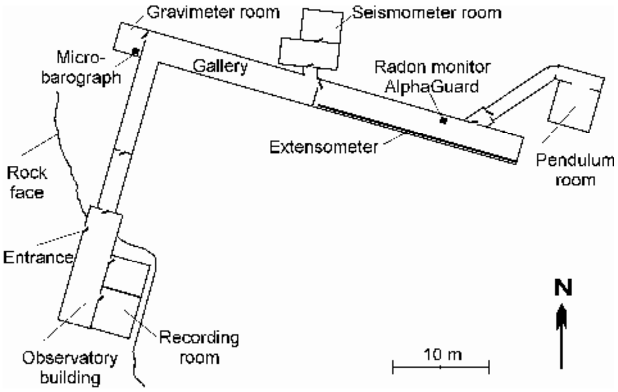

Fig. 2.

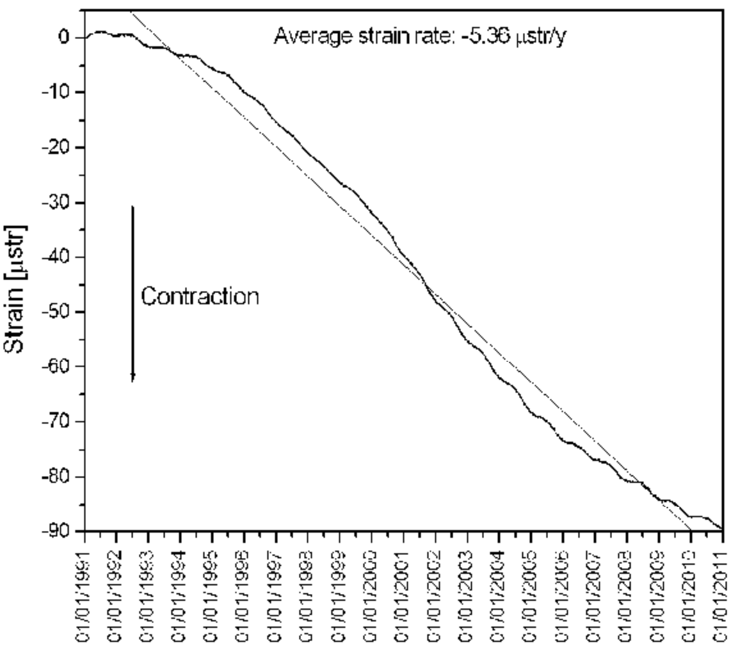
Average strain rate: -5.36 µstr/y
Strain [µstr]
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Contraction
01/01/1991
01/01/1992
01/01/1993
01/01/1994
01/01/1995
01/01/1996
01/01/1997
01/01/1998
01/01/1999
01/01/2000
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
01/01/2006
01/01/2007
01/01/2008
01/01/2009
01/01/2010
01/01/2011

Fig. 3.

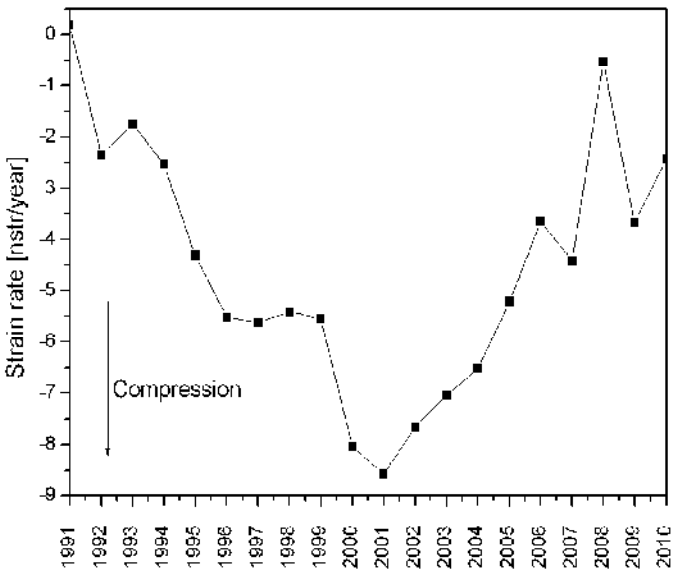
Strain rate [nstr/year]
0
-1
-2
3
-4
-5
-6
-7
-8
-9
Compression
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

Fig. 4.

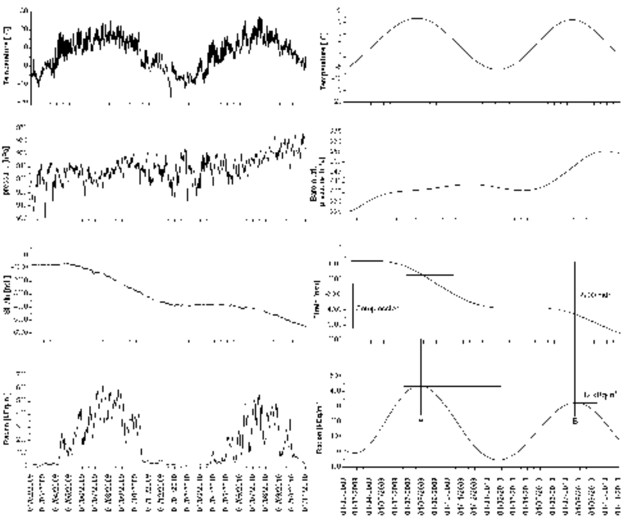

Fig. 5.

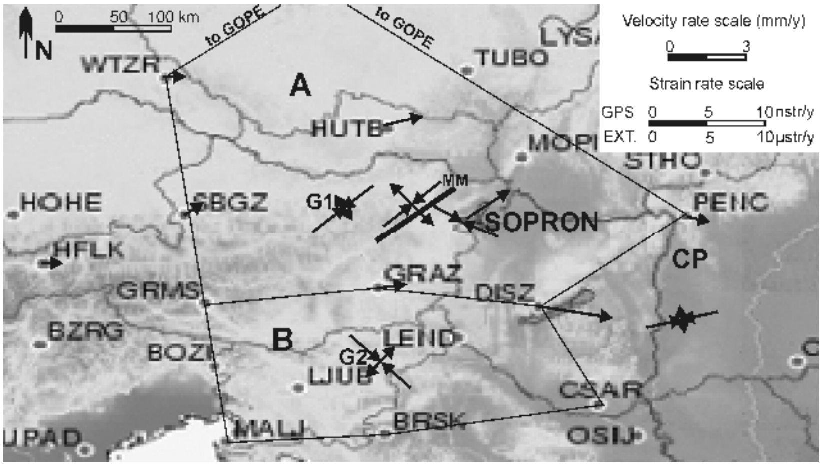
0
50
100 km
N
to GOPE
to GOPE
WTZR
TUBO
LYS
A
HUTB
MOPI
STHO
HOHE
SBGZ
G1
MM
SOPRON
PENC
HFLK
CP
GRMS
GRAZ
DISZ
BZRG
B
LEND
BOZI
G2
LJUB
CSAR
MALJ
BRSK
OSIJ
UPAD
Velocity rate scale (mm/y)
0
3
Strain rate scale
GPS 0 5 10nstr/y
EXT. 0 5 10μstr/y

Fig. 6.