INVESTIGATION OF THE CONNECTION BETWEEN RECENT TECTONIC MOVEMENTS AND LANDSLIDES AT THE HIGH LOESS WALL ON THE BANK OF RIVER DANUBE[1]

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Abstract: In Hungary one of the most serious sources of geological risk is the sliding of the high loess banks of the river Danube. This paper deals with the investigation of the connection between the movements of the high loess wall and the geological formation under the high wall and in its surroundings. Two high sensitive borehole tiltmeters were installed on the area to monitor movements and deformations. One tiltmeter was placed on the loess wall and the other at the foot of the high wall, on the bank of the river. The results of the tilt measurements reflect well the geological structure of the test site.

1. Introduction

Tectonic movements influence mass movements strongly and vice versa large mass movements can contribute to tectonic movements. The analysis of tectonic discontinuities can be used to reconstruct the state of the stress in landslide endangered areas. To investigate the interaction between recent tectonic movements and mass movements the test site in Dunaföldvár was selected. This test site was established to monitor the deformations and movements of the high loess wall on the river bank of the Danube in the frame of a research project of the Hungarian Academy of Sciences in 2001. Later this area was used to investigate the connections between different physical, geophysical, geological, hydrological, meteorological, etc. phenomena and landslides in the frame of the EU 5 OASYS project from 2003 to 2005. The first reason of this research is that in Hungary one of the largest landslide endangered areas is the western bank of the river Danube. Along the river there are 20-40 m high steep river walls that are built up of loose sediment and are exposed to the erosion of the river since more than ten thousand years. Sometimes the human activity causes landslide motions here. A lot of buildings, industrial objects were built on the high walls without taking the geological conditions into consideration. Along the Danube there have already been settlements at the time of the Roman Empire. The rapid industrialization in the 20th century led to the development of more settlements and towns (e.g. Dunaújváros, Paks, Százhalombatta) in this area. Both old and new settlements are partly or fully built on the high walls or in their dangerous surroundings. For example, the “enigmatic” pipe line breakings in the oil refinery in Százhalombatta are in connection with the mass movements of the high walls. Similarly the landslides cause a lot of problems in small town Dunaföldvár (Figure 1)

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where the town is partly situated on the top of the high wall, many houses are built on the edge and at the foot of the loess wall. A number of landslides caused damages in this town (Figure 2) in the past. The latest one took place in 1994 and on the site of this landslide an artificial slope was formed. The town regularly spends a lot of money on the stabilisation of the loess wall to protect human life and properties. That is the second reason for choosing the high bank of the River Danube as test site in Dunaföldvár.

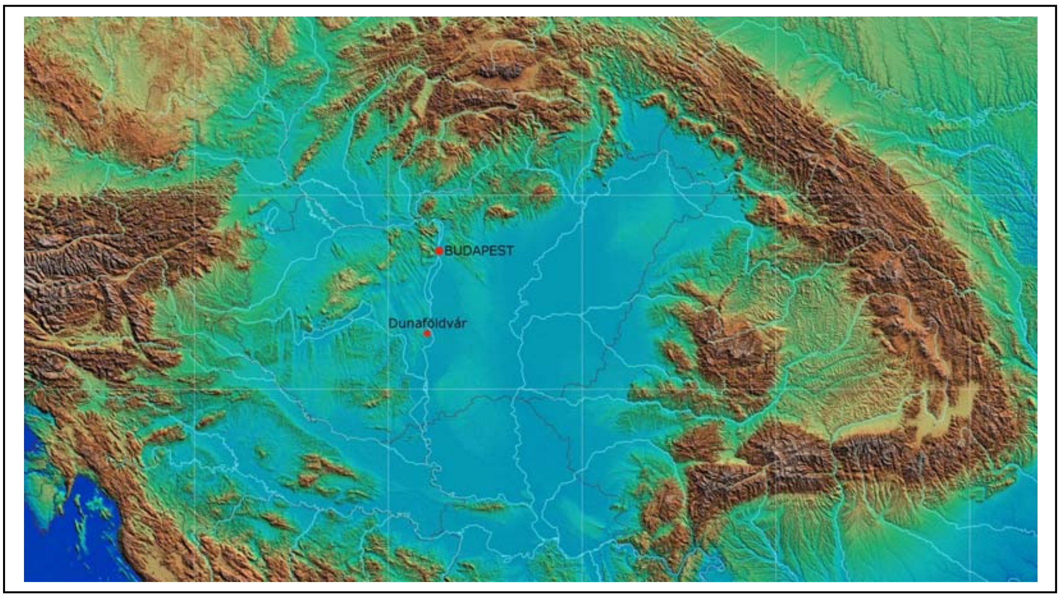


Figure 1: Location of Dunaföldvár in Hungary

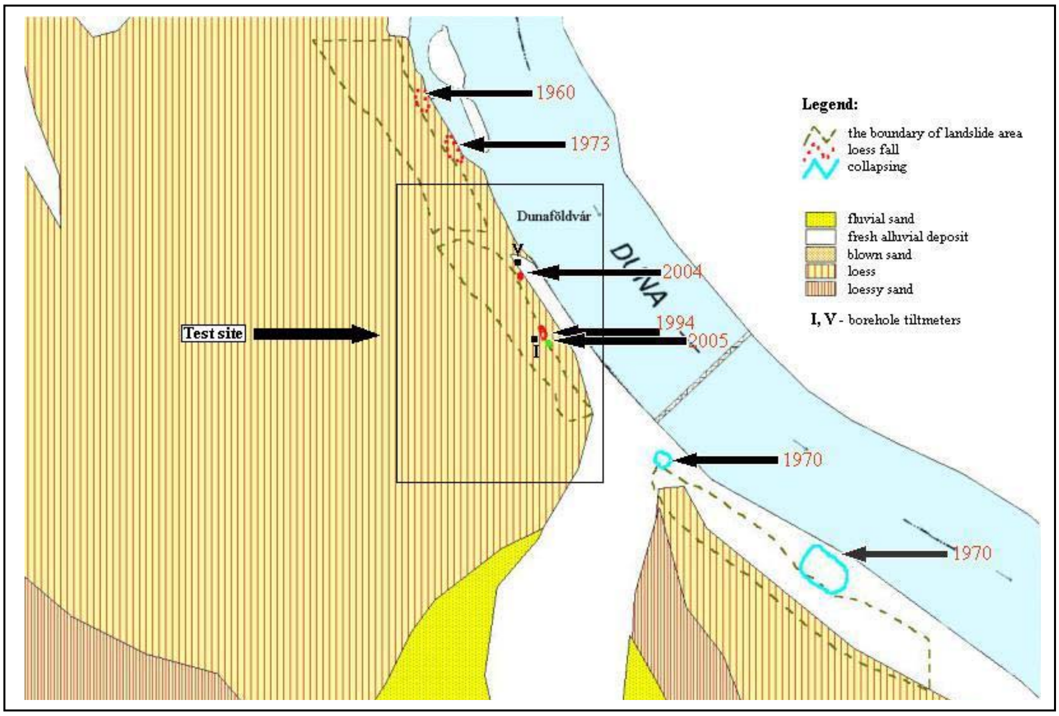


Figure 2: The test site and the historically big landslides at the high bank of River Danube in Dunaföldvár

Since 2002 high precision tilt monitoring has been carried out by means of continuously recording borehole tiltmeters and high precision geodetic measurements (GPS and precise levelling) have been done once in every year. Because of the limited accuracy of the geodetic measurements the tectonic movements can only be study from the data measured by tiltmeters.

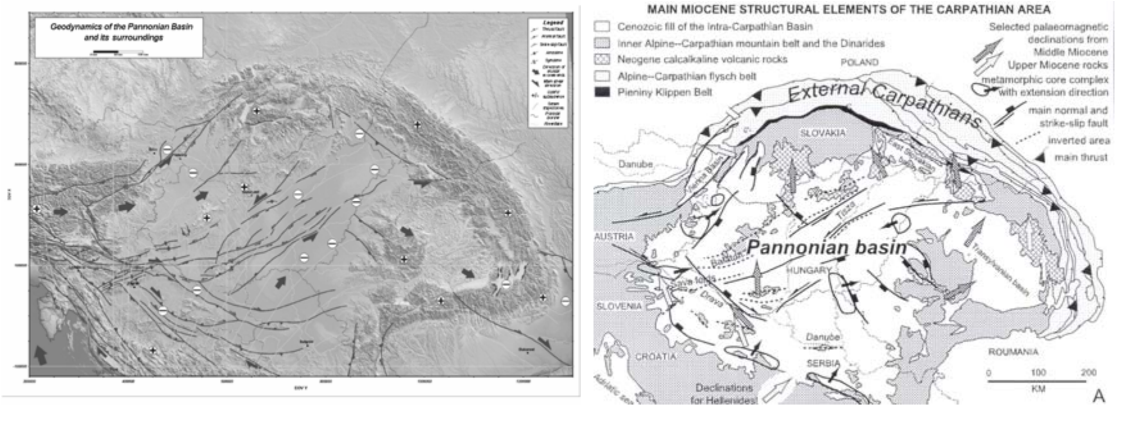
2. Neotectonics and geological structure of the test site and its surroundings

To interpret the results of the deformation and movements measurements on the high river bank of Danube and for the investigation of the connection between the movements of the high wall and recent tectonic movements the knowledge of the neotectonic phenomena and the geological structure of the test site and its surroundings is needed.

2.1. Neotectonics in the Pannonian basin

The recent tectonic movements in the Pannonian basin are primarily governed by the northward drift and counter-clockwise rotation of the Adriatic micro-plate as shown in Figure 3 [1]. Consequently, this rigid crustal block is actively indenting and pressing the Pannonian lithosphere against the European foreland. The structure is dominated by NE-SW and E-W oriented thrust faults and an ENE-WSW oriented transpressional deformation belt (near to the test site). These structures are completed by perpendicular normal faults. All these structures are generated in Early Miocene by a complicated opposite rotation of the two major Intra-Carpathian blocks: Alcapa and Tisza-Dacia. During Late-Miocene some of the thrust faults are reactivated and induce partly syn-, partly post-depositional folding. The NE-SW oriented transtensional left lateral fault system is also generated or reactivated during and after Late Miocene.

Calculated stress magnitudes seem to be efficient to cause large-scale folding and brittle failure of the lithosphere consistent with the ongoing inversion of the Pannonian basin system. GPS data show that crustal blocks in the Alpine-Carpathian orogenic belt move NW to NE with a velocity of about 4 mm/a with respect to the European foreland [2].



a. b.

Figure 3: Main tectonic units of the Carpathian-Pannonian are. (a) Direction of movements [1], (b) The main faults in the area [3]

The internal deformation of the tectonic units is manifested in the late-stage subsidence anomalies of the entire basin system and the presence of a set of seismoactive shear zones imaged by a combined analysis of high-resolution seismic profiling and earthquake epicentre distribution. The spatial distribution of subsiding and uplifting areas inside the Pannonian basin shows a very characteristic pattern. Several flat-lying, low-altitude areas (e.g., Great Hungarian Plain, Danube basin, Sava and Drava troughs) have been continuously subsiding since the onset of basin formation in the early Miocene and were completely filled with a 500-2500 m thick Pliocene-Quaternary alluvial-lacustrine sequences.

The temporal and spatial evolution of fault kinematics indicate a relatively early (latest Miocene) onset of basin inversion closest to the front of "Adria-push", the main engine driving inversion in the Pannonian basin. A strong spatial as well as temporal variation of horizontal and vertical motions during the latest stages of basin evolution has been documented. Uplift and fault reactivation has gradually become more and more delayed (Pliocene through Quaternary) towards the east-northeast, i.e. at greater distance from the collision zone between Adria and the Dinarides [2]. There is a tectonic line called Zagreb-Hernád line, which divides the country into two geological parts. It is a straight line from Zagreb to the Zemplén Mountains. A great part north of the Zagreb-Hernád line is a part of the African / Adria plate, which was pushed into present-day Hungary during the creation of the Eurasian Mountain System.

The Zagreb-Hernád line lies north of the test site in Dunaföldvár, which is in the zone of this line. The main fault system in surroundings of the test site is given in Figure 4.

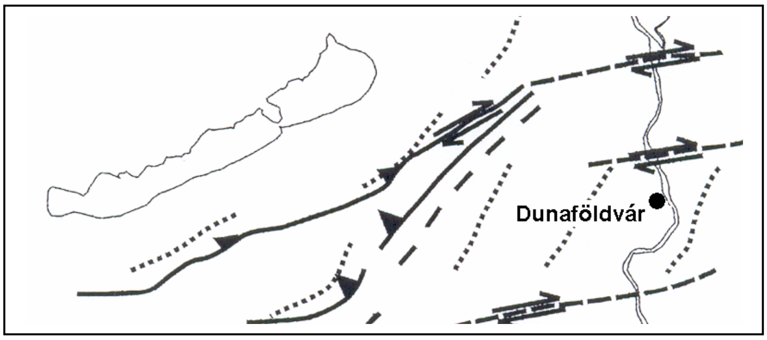


Figure 4: The main fault system in surroundings of Dunaföldvár

2.2. The geologic structure of the test site

The Upper Pannonian formations on this territory are composed of sand and in many cases of clayey, muddy strata which is intermittent by sand layers. The recent surface of the Upper Pannonian sediments differentiated only slightly compared to other regions of the Great Hungarian Plain in consequence of structural movements in the last 4-5 million years. The Pannonian surface rises staggered westwards from the river Danube.

On the Upper Pliocene deposits some ochre red, mediterranean type soil can be found originating from the Lower Pleistocene (Villanyian stage) with silt, meadow soil and fluvial sand-mud intercalations. This latter sequence is the Dunaföldvár formation. The Jaramillo palaeomagnetic event (0.9 million years) was revealed in the upper, pink coloured sandy strata of this formation. Following this, in the Pleistocene loess accumulated on the territory during lots of cycles, while loess highlands developed at some places which consist of loess and loess-like deposits with great thickness (40-80 m). The sequence of Felső-Öreghegy originating from the Pleistocene differs from those of Alsó-Öreghegy, namely in the case of the first one considerable hiatus appears, so the entire old loess series is missing and the lower part of the young loess series only partly evolved.

The Quaternary young movements played an important role in the evolution of high banks along the River Danube. The surface of the Upper Pannonian layers occurs in different heights within a small territory caused by step faults. The loess hills are sitting on the Pannonian anticlines for example at Dunaföldvár. The valley of river Danube gradually and locally subsided from the Upper Pleistocene to a different degree and these movements diverted the river westwards. The lateral erosion of river Danube also contributed greatly to the creation of the recent state besides structural movements.

The overlying recent soils of the loessland as well as the sandy gravel layers and the flood-plain sediments incidental to the river evolved in the Holocene, consequently in the course of the last 10 thousand years.

Figure 5 shows the test site in Dunaföldvár, which was established on the Felső-Öreghegy. The letters I and V denote the places of the borehole tiltmeters used for deformation measurements and Dfv1 – Dfv4 are the places of exploratory drillings. Figure 6 shows the geological cross-section between Felső-Öreghegy and the river Danube on the basis of the geotechnical survey performed by Pyrus Ltd. in 1994.

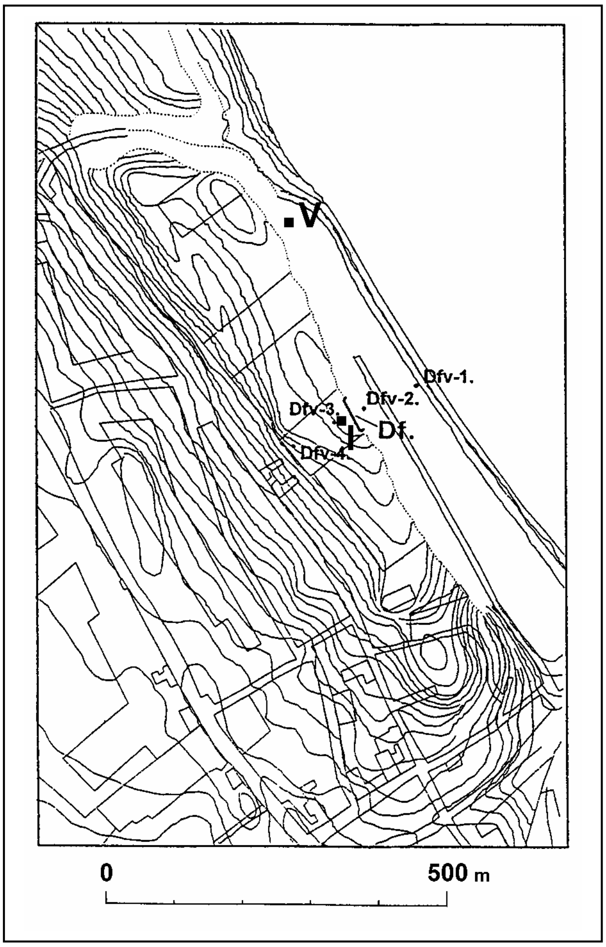


Figure 5: Location of the exploratory drillings in 1994 (Dfv-1., Dfv-2., Dfv-3., Dfv-4.) and borehole tiltmeters (I, V) at the test site (Felső-Öreghegy)

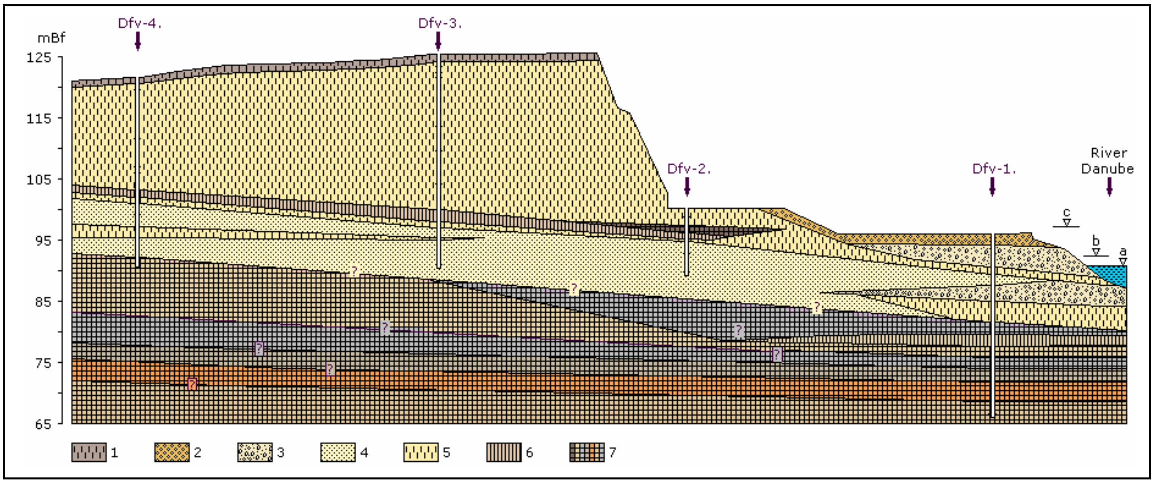
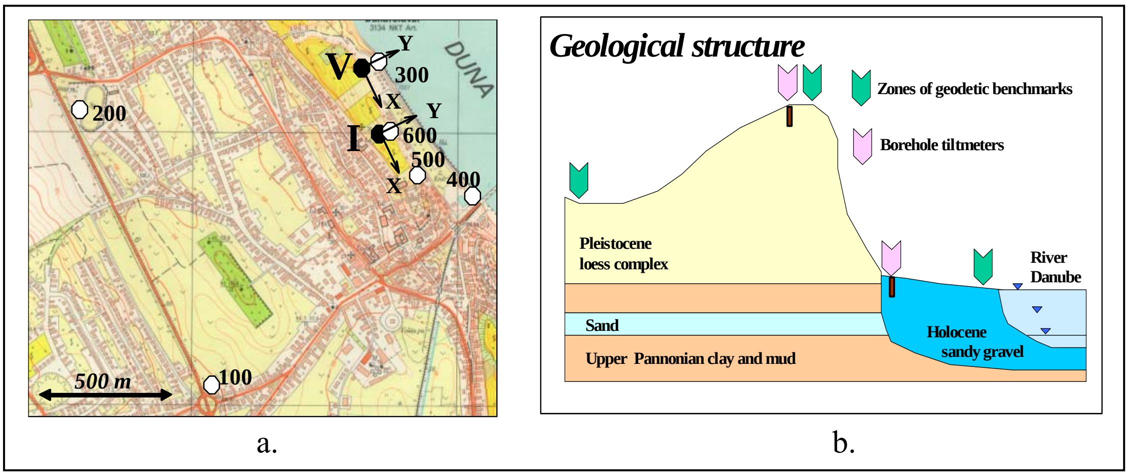


Figure 6: Geological cross-section between Felső-Öreghegy and the river Danube on the basis of the geotechnical survey performed by Pyrus Ltd. in 1994. Legend: 1 – recent filling mixed with silt affected by pedogenesis, 2 – sandy, pebbly filling, 3 – sandy gravel, 4 – sand, 5 – typical loess, 6 – palaeosol, 7 – clay, Dfv-1. –Dfv-4.: exploratory drillings, a – LW (lowest water), b – AW (average water), c – HW (highest water)

3. Monitoring the movements and deformations of the high loess wall

On the basis of the geological structure and topography a deformation measurement network was developed, which consists of six main geodetic benchmarks for GPS, high precision levelling and gravimetric measurements. Figure 7a shows the map of the geodetic network. Points 100-600 are the main benchmarks which are connected by the lines for levelling and field gravimetric measurements. These second order points are not shown in the Figure. The two-component borehole tiltmeters are installed near to points 300 and 600. The tiltmeter denoted by V is at the foot of the high wall on the bank of Danube and the second tiltmeter denoted by I is on the top of the loess wall. The positive tilt directions are also given in the Figure 7a. Figure 7b shows the simplified geological structure of the test site and the positions of the benchmarks.



a. b.

Figure 7: Map of the test site in Dunaföldvár (a), simplified geological structure of the high wall with the positions of the benchmarks (b)

The geodetic measurements were started in 2001 and repeated once in every year till 2005. Because the rate of tectonic movements is very low during this measuring period no significant horizontal and vertical displacements could be detected. The field gravimetric measurements were repeated twice in this period and were disturbed by ground water level variations.

The high accuracy tilt measurements have been carried out since June, 2002 and the obtained data series are suitable to detect small movements and deformations since the disturbing environmental effects, seasonal variations can be eliminated with sufficient accuracy. For tilt measurements two dual axis, borehole tiltmeters of type Applied Geomechanics Inc., model 722A with a resolution of 0.1 μrad were used. The instruments were installed in boreholes with a depth of 3 m, which ensured high temperature stability for instruments. The data were collected with a sampling rate of 1 data/hour.

4. Results of the tilt measurements

From the hourly recorded data daily averages were calculated using a moving averaging method. Figure 8 shows the calculated daily averages in the measuring period from 01.06.2002 to 31.10.2005. VX, VY, VT and IX, IY, IT denote the X, Y tilt components and the temperature at the foot and on the top of the high loess wall, respectively.

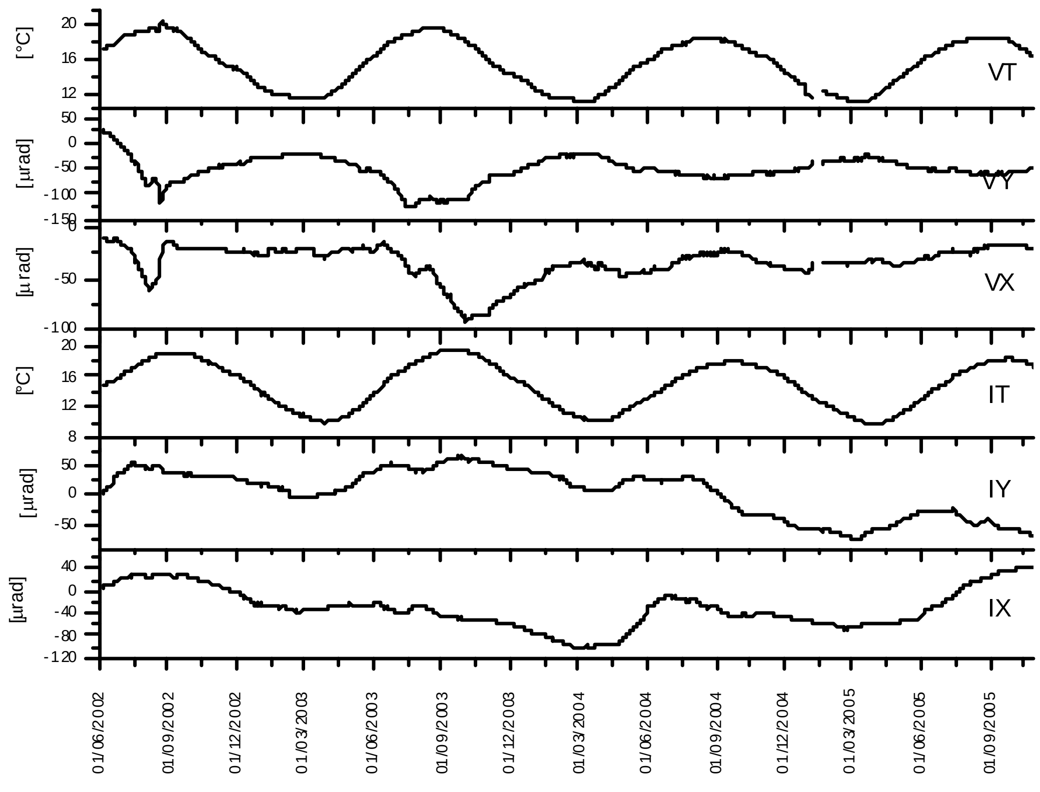


Figure 8: Daily mean values of the recorded data (VT = borehole temperature on the bank of the Danube, VX and VY = X and Y tilt components on the bank of the Danube, IT = borehole temperature on the top of the loess wall, IX and IY = tilt components on the top of the loess wall)

The measured tilt data correlates strongly with the temperature therefore it was temperature corrected by means of the regression method. The temperature corrected daily mean values are given in Figure 9.

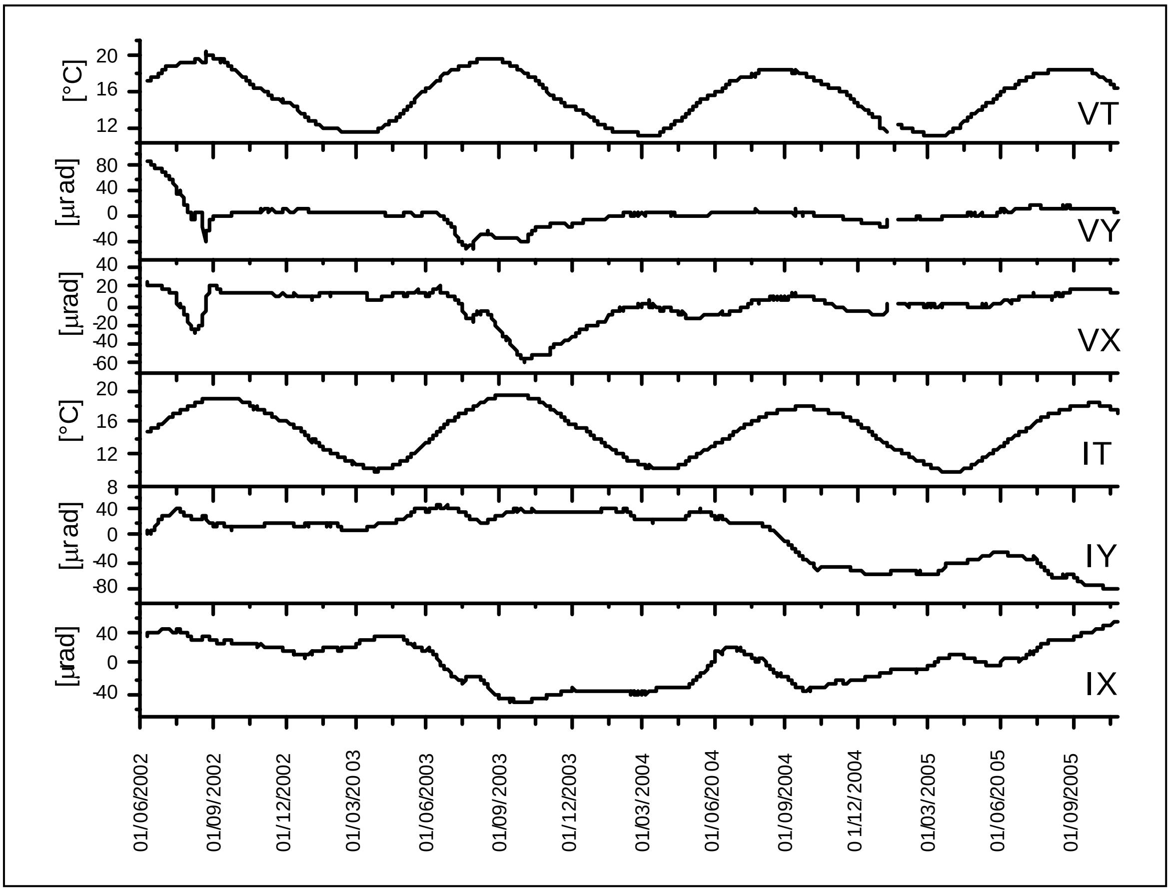


Figure 9: Daily mean values corrected with the temperature (VT = borehole temperature on the bank of the Danube, VX and VY = X and Y tilt components on the bank of the Danube, IT = borehole temperature on the top of the loess wall, IX and IY = tilt components on the top of the loess wall)

To get insight into the long term deformation and displacement processes the linear trend of the tilt data was calculated. Because the data series are long enough to eliminate the seasonal influences by a simple calculation of a regression line, the trends were calculated both from the raw and the temperature corrected data. The results are given in Table 1. The comparison of the corrected and uncorrected values shows small differences in the case of the tilt trend of the high wall and somewhat greater differences at the trend measured directly on the river bank. The directions of the trends are the same in all cases. The steepness of the tilt trends measured on the river bank is much smaller than the one measured on the high wall. The very little steepness of the temperature trend proves that the tilt trends are not of temperature origin.

The tiltmeters are installed with their Y axis perpendicular to the Danube, so the deviation of the Y axis from the East direction is about 30° to North. Thus the resulting continuous tilt has W-SW direction as it is shown in Figure 10. It means that the area west from the Danube is sinking to the normal fault runing about 500-1000 m far from the Danube and is parallel with the river. The measured tilt coincides with the tilt postulated on the basis of the geological structure.

Temperature correction	IX	IY	IT	VX	VY	VT
	µrad/day	µrad/day	°C/day	µrad/day	µrad/day	°C/day
Uncorrected	-0.0204	-0.0852	-0.0011	-0.0002	-0.0006	-0.0006
Corrected	-0.0125	-0.0806		-0.00001	-0.0049	

Table 1: Linear trends calculated from the raw and temperature corrected tilt data

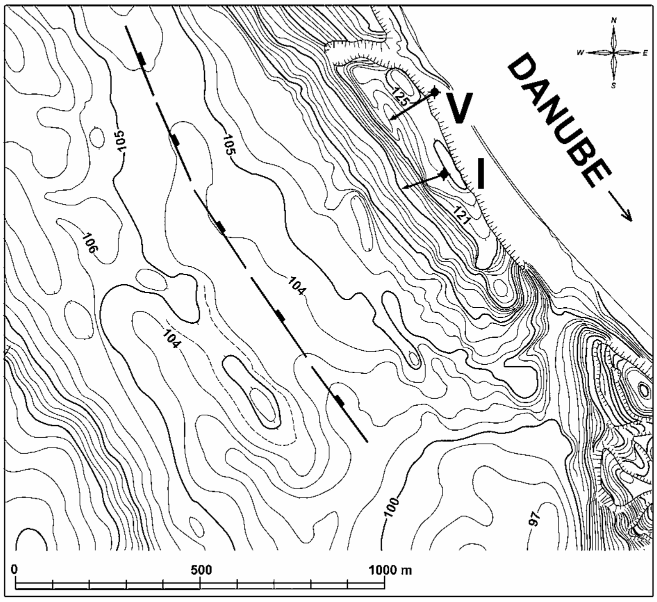


Figure 10: Direction of the measured tilts and the fault near to the test site

5. Conclusions

The results show that the tilts of the high loess wall can be measured by high sensitive borehole tiltmeters because the borehole ensures a temperature stable place for the instruments. The long periodic seasonal effects can be eliminated from long (some years) data series. The accuracy of the determination of the tectonic tilts is increasing with increasing length of the dataseries.

References:

[1] Csontos, L. Nagymarosy, A.: The Mid-Hungarian line: a zone of repeated tectonic inversions, Tectonophysics, 297, 51-71, 1998.

[2] Csontos, L. Magyari, B. Van Vliet-Lanoë, Musitz, B.: Neotectonics of the Somogy hills (Part II): Evidence from seismic sections, Tectonophysics, 410, 63-80, 2005.

[3] Csontos, L. Vörös, A.: Mesozoic plate tectonic reconstruction of the Carpathian region, Paleogeography, Paleoclimatology, Paleoecology, 210, 1-56, 2004.