S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
Vol. XLIV, 2010: 61–76 PL ISSSN 0081-6434
L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

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RECENT LANDSLIDE ACTIVITY IN THE TIHANY PENINSULA (BALATON HIGHLAND, HUNGARY)

Abstract. Landslides have affected the shore of Tihany Peninsula since the Balaton was formed. Numerous movements have been recognized on the peninsula in historical time, but information is unavailable about landslides around the Ciprián Spring. However, we identified two landslides next to the spring in the last decade. A footpath is continuously demolished and relocated in the vicinity of the spring. The Former Hungarian studies indicate a strong connection between the length of rainy period and mass movements, however in the studied area a continuous database of precipitation and exact date of mass movements is unavailable. Based on statistical analysis of precipitation of synoptic meteorological measurement stations (Siófok and Keszthely) and incomplete datasets of Tihany we think that two rainy periods may have impacted landslides.

Key words: mass movement, climate change, geomorphic hazards, springs, Hungary

INTRODUCTION

Among the hazardous natural processes, the mass movements represent an outstanding phenomenon in Hungary (Pécsi and Juhász 1974; Szabó 1996; Fábián 2003; Lóczy et al. 2007; Szabó et al. 2007). These can be interpreted as local hazards, since their appearance is rather punctiform; similarly, the mass movements on a larger scale can be interpreted only on detailed maps and map series (*cf.* Fig. 13 and Fig. 14/b in Szabó 1996). More than 80% of the registered mass movements belong to the landslide category (Fodor and Kleb 1986; Szabó 1996).

There are Hungarian geomorphologic regions and microregions, where — due to the coincidence of the motion-triggering natural and anthropogenic factors — the mass movements occur more frequently. Such areas are for instance the zones of riverbank and lake-side high bluffs being investigated by Karácsonyi and Scheuer 1972; Scheuer 1979; Fodor et al. (1981), Szabó (1996) and Juhász (1999, 2004), which have a minor territorial extension, though 14% of the registered movements takes place within their region.

This category involves the Tihany Peninsula as well (Fig. 1), where the water level of Lake Balaton meets a relatively high (80–100 m), steep (typically $\alpha > 20°$), loose shore, based on Tertiary sedimentary rocks. Landslides have occurred in this contact zone for hundreds of years. The development of these were influenced by 1, the water-level of the Balaton, the pre-regulation water-level oscillation of which reached ±6–8 m (Lóczy 1913; Cholnoky 1918; Bulla 1943; Marosi and Szilárd 1981); 2, the quantity of precipitation (Juhász 1999, 2004); as well as 3, the anthropogenic impacts, since the peninsula has been inhabited for millennia.

Next to the spring, there were no mass movements recorded during the last 150 years, though the engineering geological mapping of the investigated area described it as not evaluable, old, mixed, landslide material (Láng et al. 1969).

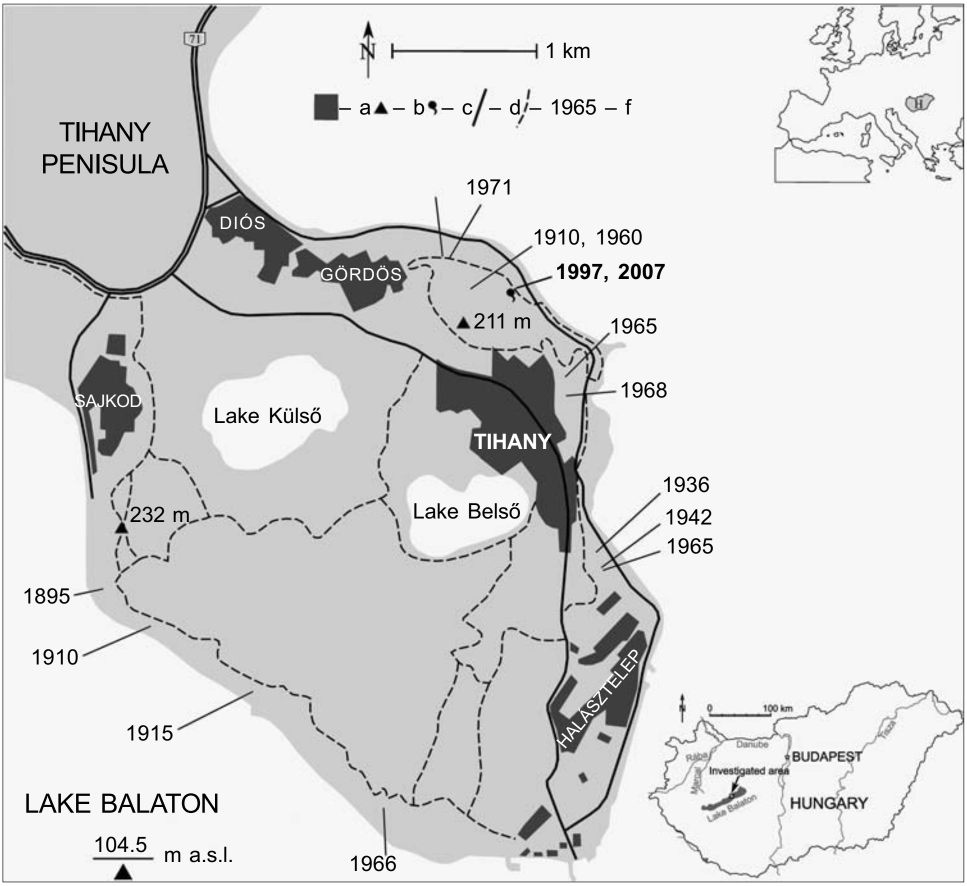

Fig. 1. The map of Tihany Peninsula. Date and location of movements according to Juhász Á. 1999, 2004 (redrawn by I. and P. Kovács). a — settlement, b — peak, c — Ciprián Spring, d — road, e — footpath, f — date of landslides

The relation between the landslides and the precipitation oscillation was examined in many ways (W a s o w s k i 1998; C o r o m i n a s and M o y a 1999; M r o z e k et al. 2000), but the significance of the connection is not unambiguous in each case (F l a g e o l l e t et al. 1999). The investigation of the Tihany Peninsula was started on the following base: next to the Ciprián Spring new movements were realized in 1996 and 2007.

AIMS

The research aimed at the land survey of the area, as well as the geomorphologic and DEM-sketch representation of the formations as the result of the mass movements. Another aim was to classify these mass movements of the research area into the Hungarian classifying system (P é c s i et al. 1976; S z a b ó 1996), to explain the dependence of an effect upon a cause of the motion-triggering factors and also to evaluate the connection between the spring activity, the climate and the realized movements.

MATERIALS AND METHODS

The research based on the examination and evaluation of the relevant national and international geomorphic, geologic and hydrographical scientific literature. Regular survey (observations of possible movements several times annually) and detailed field trips, examinations (field measurements) were completed in the research area.

To define the exact location and relief of the landslide, angular and distance measurements were carried out with a *THEO 020A/010A 10-G 236b* analogue theodolite. At the beginning of the measurement sequence, the starting point was set out above the spring, from which the head scarp could be observed to a suitable degree, after that the data of the height of the theodolite was recorded and the difference between the height of the known reference point (spring) and the theodolite was documented as well. Following this, the landslide mass was measured by levelling. The measured data were related to the height and absolute geographical location (EOV coordinates) of the Ciprián Spring, and were converted into real data. The measurement was corrected with the points created by the *Garmin eTrex Legend* GPS. The x, y and z coordinates of the points were defined with trigonometric functions. As a consequence of the accurateness of the theodolite, the resulting points was processed with a precision of a millimetre. With the consideration of the probable faults, the resolution was finally converted into an accurateness of some centimetres.

The sketch map and DEM representing the morphologic relations of the landslide were completed according to the information resulting from the field survey, by means of the *Inkscape 0.46* and *GRASS 6.4* programmes. The vector maps edited from the relative altitude data of the measured points were rasterized, interpolated and smoothed, in order to get values, which represent reality to the utmost extent.

In order to complete the digital surface model of the landslide mass, the above mentioned, measured altitude points were applied, which were imported to the *Grass GIS 6.3.0* with the *v.in.db* command.

A mask was created with the *v.delaunay* module from the vector points and was modified by *v.digit*. The mask (vector format) was transformed to raster map with *v.to.rast* and applied for the whole mapset using *r.mask*. The applied raster mask limited the raster operations to the measured points of landslide (to the surface of the landslide).

The *v.surf.rst* module of Grass GIS created DEM from the vector point map using tension parameter, which was calibrated to 40 (Mitashova and Mitas 1993; Mitasova and Hofierka 1993; Mitashova et al. 2005).

The discharge of the spring was measured with calibrated measuring-dish. A simple statistical analysis was accomplished with the former climate and discharge data. The discharge data of the spring has been collected since 1950, unfortunately quite randomly. The daily discharge was registered only between 1977 and 1979. This period involving continuous data line was applied in the analysis.

The detailed climate data regarding the Tihany Peninsula are available only from the periods 1934–39, 1951–66, 1974–84 and 2000–2006, since the measuring station of the Hungarian Meteorological Service (HMS) to be found in the research area is only of second or third rate, therefore the continuous measurement activity was suspended many times. Recently, precipitation measurements were accomplished by the Balaton Limnological Research Institute – Hungarian Academy of Sciences (BLRI HAS) on the territory of the Balaton Uplands National Park Directorate (BUNPD) as well.

In order to complete the insufficient data lines, the full data stock of the synoptic meteorological measurement station in Siófok (being ca. 15 km away) was meant to be applied, thus an f-test was carried out for the above mentioned four periods, comparing the annual measured precipitation in Siófok and Tihany. Unfortunately, there is a significant difference between the dispersion of the two samples; therefore it cannot be directly used as data substitution. This is the result of the local configuration of the terrain.

As a consequence, only the precipitation data of Tihany being measured in different periods were applied, taking the risk of data-hiatus. The annual precipitation data of the four time intervals have also undergone the f-test, in order to find out, whether there are any significant differences between them, and whether they are comparable with each other.

RESULTS

GEOMORPHOLOGY OF THE STUDIED AREA

The fully examined area (the direct environment of the Ciprián Spring) is part of a multi-generation, complex landslide system. West-southwest from the spring, there is a scarp of a former large landslide, as well as its mass and toe in the front, which extends up to the road leading to the ferry. According to former examinations, this was interpreted as a typical obsequent landslide (Láng et al. 1969). The previously mapped, large movement can be traced back from the Ciprián Spring up to the boundary of Gödrös (Láng et al. 1969) in a width of 100–150 m, parallel to the shores of Lake Balaton. Along the footpath leading from the Ciprián Spring to the landing place in Tihany, in the section between the spring and the crossing road, smaller landslides and breakdowns are typical. In the above mentioned section, there is a more significant, deep gully, which is retrogressive till the edge of Óvár's scarp; and several smaller gullies can be observed as well (Fig. 2).

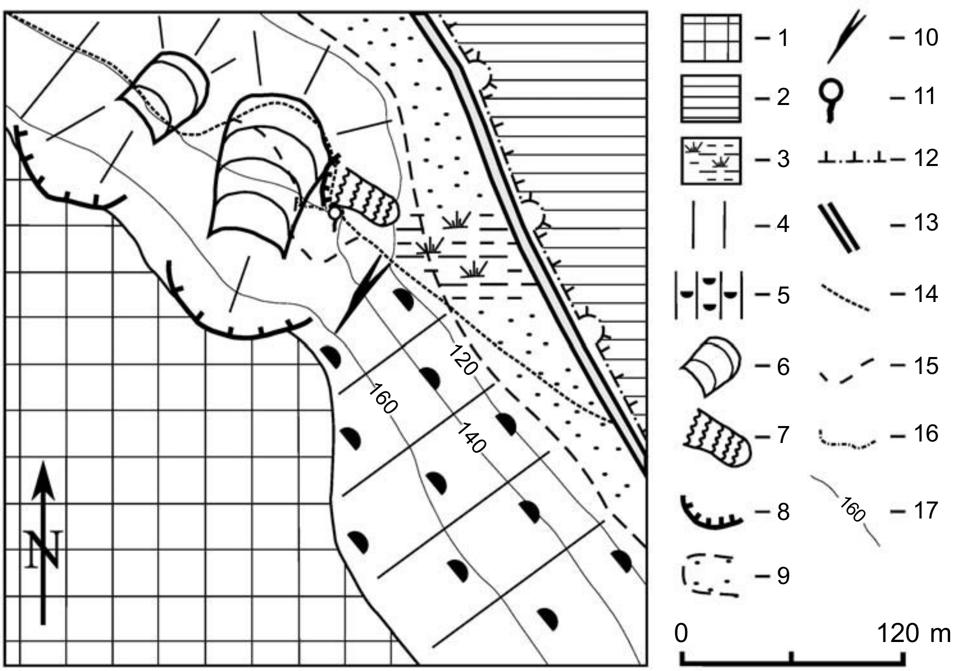

Fig. 2. Geomorphic map of the investigated area (edited by Sz. Á. Fábián). 1 — basalt plateau, 2 — Balaton Lake, 3 — wetland, 4 — slopes, 5 — unstable slopes, 6 — fossil landslide, 7 — recent landslide, 8 — head scarp, 9 — former shoreline, 10 — erosion gully, 11 — spring, 12 — stone dike, 13 — road, 14 — footpath (before 1996), 15 — footpath (nowadays), 16 — footpath stairs (between 1996–2007), 17 — contour line (m a.s.l.)

The examined fresh landslides can hardly be integrated into the landslide-categorization system worked out by Pécsi (1971) and Szabó (1983). This is the result of the fact that the already discussed former, larger landslide of the studied area was temporarily stabilized, and only the eastern, steep head part of the relatively intact toe started to move. The new movement phase is indicated by two landslides respectively (1996, 2007). The movement in 1996 occurred as a mass movement with a small scarp, moving only a minor quantity of rocks, and having a minimal influence on its surroundings. A 15 m long section of the red-cross-indicated footpath – which also represents the geological educational path named after Lajos Lóczy – was demolished by the movement. The rejuvenating movement – after ten years' time – had a larger territorial extension, a larger mass of moved material, and a more significant environmental impact. The mass of this movement was entirely destroyed by the newer, deeper seated landslide, which broke up along a 30 m wide scarp (Photo 1 and 2) and stretched 27 m

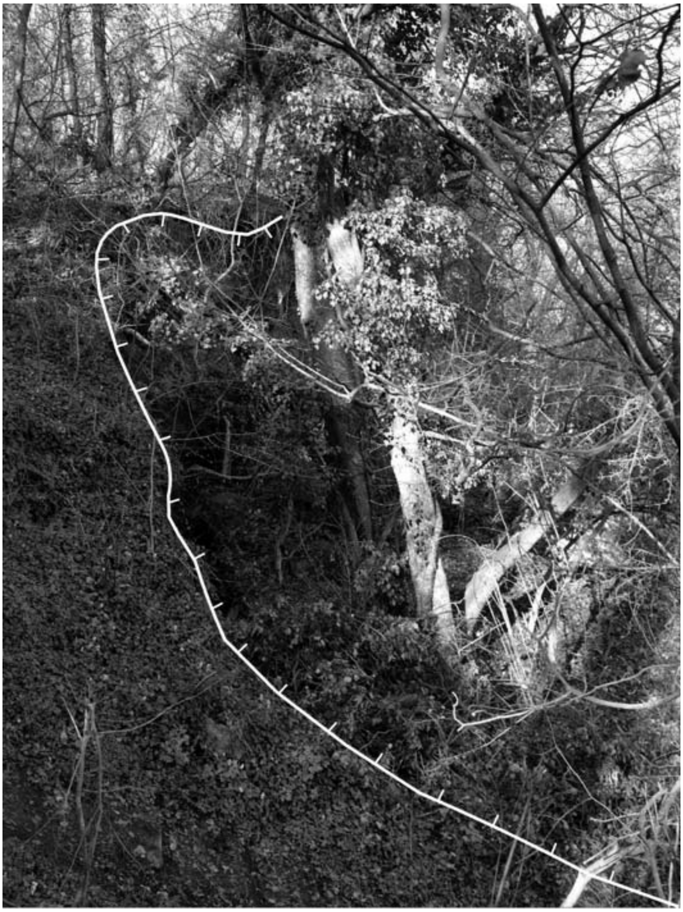

Photo 1. The head scrap of the landslide at Ciprián Spring in 2007 (Photo by G. Varga)

Photo 2. Main features of the investigated landslide (Photo by G. Varga). 1/A – former footpath, 1/B – destroyed stairs, 2 – head scarp, 3 – blocks of landslide, 4 – counterfort

long to the bottom of the slope. During the whole movement process, the stairs of the footpath built after 1996, as well as the counterfort in the front of the spring got damaged. At the same time, new seepage water sprang on the mass of the landslide (Fig. 3 and 4). This seepage water – finding its way to the surface – played an important role in the development of the mass movement, since it drenched the Pannonian clay layers. Nevertheless, the movement process was not purely a landslide along a shear plane: it was a transitional, collapse and slide movement, during which the steep wall downfaulted 4 metres. Meanwhile, the surface of the downfaulted, sliding mass split up, and remained close (10–30 cm) to each other in larger blocks (though not in slices), in the direction of the slope, on a descending level. The seepage water occurs at the lower part of the blocks – where the steep slope suffers a fracture – and the lobate of the landslide also starts from here. Its material consists partly of pressed clay deposit, which represents the basis of the shear plane and is also continuously drenched by the seepage water – even after the larger movements. As a result of this, the mass of the slide became plas-

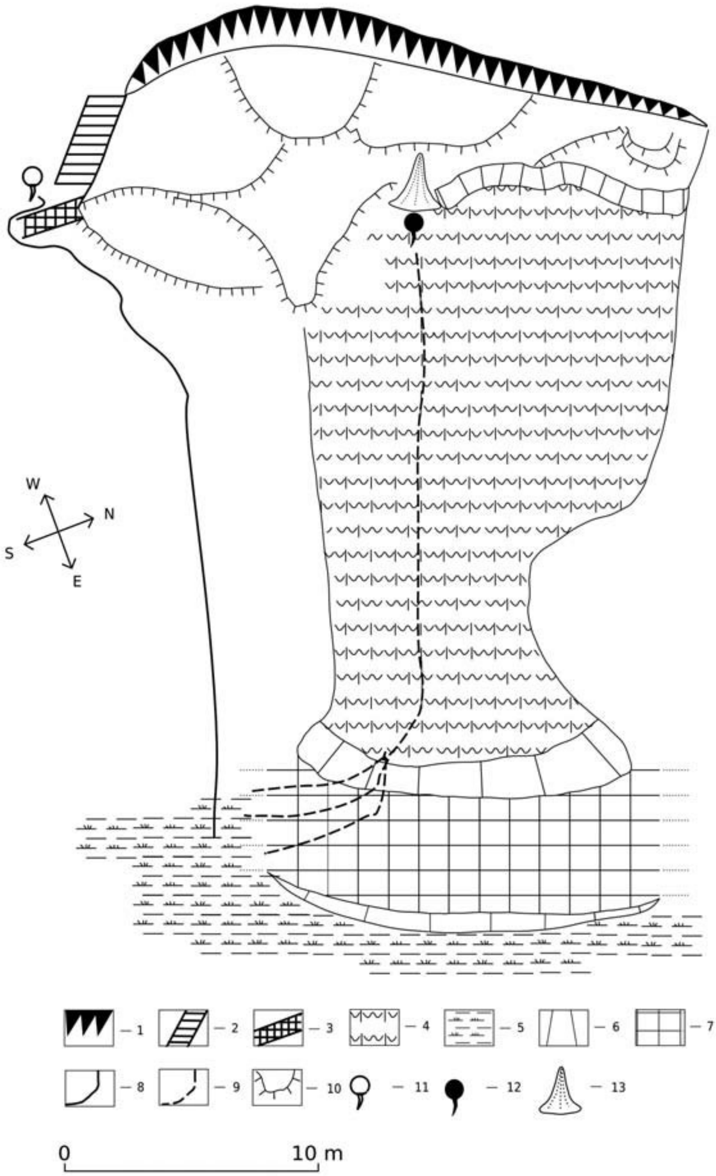

Fig. 3. Detailed geomorphologic sketch of the landslide in 2007 (edited by B. Radvánszky). 1 — head scrap, 2 — footpath, 3 — retaining wall of the spring, 4 — clump of the landslide, 5 — wetland, 6 — slope, 7 — former abrasion platform, 8 — stream, 9 — new stream after the mass movement, 10 — small scarp, 11 — Ciprián Spring, 12 — new spring after the mass movement, 13 — detrital cone

tic; therefore its movement has also a transitional solifluction character. The other consequence of the drench is that the surface of the landslide mass evenly descends, and there is no craquelure on it.

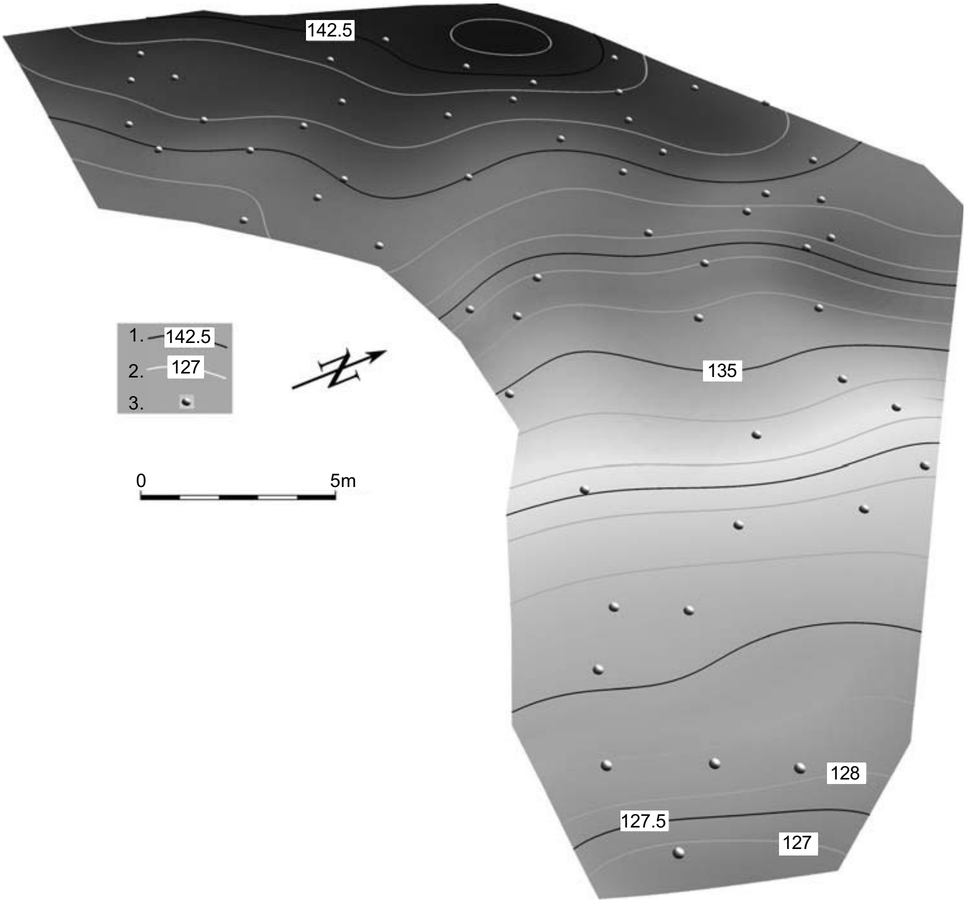

Fig. 4 DEM of the landslide in 2007 (edited by I. P. Kovács).
1 – contour line in 2.5 m steps, 2 – contour line in 1 m steps, 3 – measured points

CIPRIÁN SPRING

The Ciprián Spring (also known as the Russian Well) is the only spring in the Tihany Peninsula, being situated in the north-eastern part of it. It got its name from the orthodox monks settled by King András I. (1046–1060).

In the scientific literature the exact height of the spring is unambiguous. According to the Register of Springs in Hungary (OVF-VITUKI 1997) and the National Register of Springs (VITUKI 2007) it is located 165 m above sea level, though according to the tourist map of the peninsula, the 1 : 10 000 scale map (43–234) of the Unified National Mapping System (Hungarian abbr. EOTR) and the engineering geological map series of Lake Balaton's surroundings it can be found exactly below 140 m above sea level. The own measuring (*Garmin eTrex Legend C type* GPS) defined the location of the spring at 138 m above sea level.

The starting point of the spring activity is hard to register. It is widely known, that the spring was the water source of the monks living in the nearby cave-dwellings (its name can refer to this). Nevertheless, the first (1763–87) and second (1819–69) military survey maps do not mark the spring! Similarly, not even the chapter entitled "The springs around Balaton" in the great work "The results of the scientific research of the Balaton" (Lóczy 1913) mentions the spring. The publications about the Tihany Peninsula by Lóczy (1913) and Cholnoky (1932, 1944) do not refer to the contact spring either, which later turned out to have permanent discharge (OVF-VITUKI 1997). It is especially interesting, that the first edition of the National Register of Springs started by Kessler (1959) and later digitalized by the Environmental Protecting and Water Management Research Institute (EPWMRI, abbrev in Hungarian: VITUKI) also ignores the presence of the spring.

According to the subsequent descriptions (VITUKI 2007) the spring has got two stems; one of them is occupied, thus there are discharge data since the occupation (1950). The occupation takes the form of a brickwork rubble stone well house, which got a concrete facade. At the other stem (its location being not identified in the database!) the water of the contact spring flows directly through its natural "channel" to reach the lower lying territories (VITUKI 2007).

According to the National Register of Springs (VITUKI 2007) the water providing rock of the permanently active spring is Pliocene (?) basalt tuff. On the one hand, the recent volcanologic researches (Németh et al. 2001) claim that the volcanic activity of the area took place at the end of the Miocene, which fact is verified by the absolute chronologic (K/Ar) data (7,96 ± 0,03 Ma) as well (Wijbrans et al. 2007). On the other hand, the engineering geological map series of the Balaton's surroundings (1969) suggest that the environment of the spring consists of Pannonian clay rocks, which could be observed by the authors as well, since the examined landslide reveals them.

Based on the measured complete daily data line ranging from 1 January 1977 to 31 December 1979, the mean discharge of the spring took 2.28 l/min, while its dispersion was 3.54 (OVF-VITUKI 1997). The highest daily discharge was 4 l/min, while the lowest took 1 l/min. The highest registered discharge was 30 l/min (?), which was recorded on 7 February 1982. According to the whole available data line, we can question the reliability of the maximum discharge – maybe it was a clerical error.

The mean monthly discharge of the above mentioned three-year data line increases from January to March, following the raise of the monthly total precipitation. The discharge declines in April, and rises again from May till June. The mean discharge of July significantly – by 0.42 l/min – decreases compared to June. There is an observable increase in August, followed by a decrease lasting till October. As a result of the annual secondary precipitation maximum, the discharge reaches the 2.62 and 2.4 l/min values in November and December respectively. On 19 July 2007, at the actualization of the National Register of Springs, 2 l/min discharge was recorded. During one of the field trips, the authors also checked the discharge of the occupied spring; it was 1.26 l/min.

In the mass of the landslide, we also found an effluent point (probably the already mentioned unoccupied spring), which arises approximately in the altitude of the occupied spring (±0.5 m). In its present state, the category of seepage water would be more appropriate, since it is nearly impossible to define its spring point.

To the east of the Ciprián Spring, on a level with the Tihany road, the earlier maps (Láng et al. 1969) mark springing water; which drenched the area, and turned it into a damp, impassable territory. This fact is also verified by the authors' own field observations (Legend 3 in Fig. 2).

STATISTICAL ANALYSIS OF PRECIPITATION

The control period was represented by the timeline of 1951–1966; this being the longest constant data line. Based on the result of the f-test, it is 95% sure that the dispersion of the two samples of 1951–66 and 1974–84 is equivalent, therefore the two-sample t-test can be carried out. The same f-test reveals a significant difference in the case of the period 1999–2007, which can be either the result of the removal of the measuring station, or of the slow but steady decrease in the quantity of precipitation (Bihari et al. 2008).

The main aim of the t-test is – according to our zero hypotheses – to prove that there is no noteworthy difference between the mean values of the two samples. The t-value of the examined periods takes 4.5. According to the sample size the degrees of freedom is 24. Based on the limits chart of the t-distribution, the t-value even exceeds that of belonging to 99%, therefore the annual precipitation values between 1974 and 1984 were different from those of the control period. In our case, this means a decrease in the annual precipitation compared to the control period.

The surveys up to the present registered returning periods every third-fourth year with more precipitation, and these were related to the landslides in the peninsula (Juhász 1999, 2004). The concerned two youngest (1996 and 2007) movements at Ciprián Spring can be more or less integrated into the series of the known active mass movement periods (1908–10; 1936–37; 1965–68) being present in the whole peninsula (Juhász 1999).

As a result of the geographical location of the Tihany Peninsula, it has Submediterranean climate characteristics. The annual mean precipitation of the years 1951–66 took 611 mm (NOAA); in the period 1999–2007 it made 575 mm (Vers 2008a), but in 2007 its value reached 820 mm (Vers 2008b)! 17% of the annual precipitation (105 mm) is realized in winter. Spring is wetter than winter, by an average of 70–75 mm. The precipitation in summer takes 31% of the annual value (191 mm). In autumn, an average of 135 mm rainfall was recorded in the peninsula.

According to earlier researches, among the measuring stations around Lake Balaton the least precipitation was registered in Tihany (B o g d á n f f y 1898), where in the period 1901–1940 the daily precipitation exceeded the 50 mm value on average 11 times annually (H a j ó s y 1952). These are connected to intensive rainfalls. As an impact of the Mediterranean cyclones, a secondary precipitation maximum evolves in November.

In 2007, only spring witnessed less precipitation than the average (–6%; –10 mm). The other seasons' registered precipitation values exceeded the average: in winter by 86,6% (91 mm), in summer by 47,2% (102 mm) and in autumn by 127,4% (37 mm). In 2007, the monthly precipitation values also differ from the mean value, even the tendencies within the year are diverse (Fig. 5). The first precipitation maximum can be observed in May (119 mm), which is followed by a peak – instead of the secondary maximum of autumn – already in August (146 mm!).

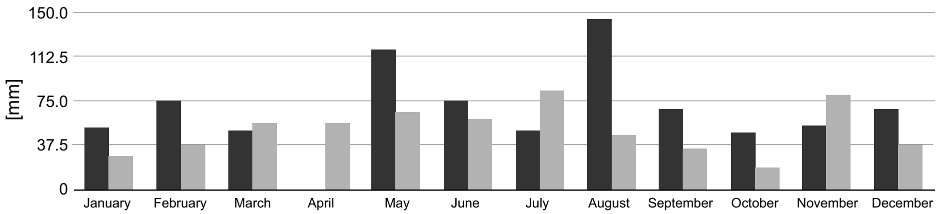

Fig. 5. Monthly precipitation in 2007 (dark) and mean monthly precipitation between 1951–66 (light) (Source: OMSZ and ex verbis J. V e r s 2008b, edited by B. Radvánszky).

A daily precipitation of 70 mm was registered on 11 August 2007, which was preceded by two rainy days, with a total rainfall of 27 mm. Further to this, within these months – being significantly different from the average, rainless weather – two rainy periods can be differentiated (20–23. and 27–30.) (Fig. 6). The active

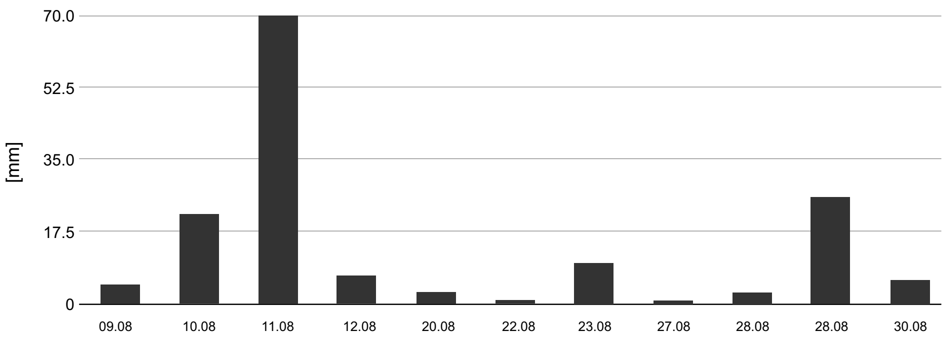

Fig. 6. Daily precipitation in August of 2007 (according to ex verbis J. V e r s 2008b, edited by B. Radvánszky)

movement was detected during the field trip on 19 September 2007, therefore it is presumably the result of the intensive rainfall in August.

CONCLUSIONS

According to our previous researches and own field observations, it becomes unambiguous, that during the past 150 years – except for the period 1996–2007 – there have been no mass movements next to the Ciprián Spring.

It is also indisputable, that there surely have been movements before, which started from the edge of Óvár, in the section between Gödrös and the spring. These were larger movements, the scarp and masses of which can be observed very well even nowadays. Their development is likely in connection with the Holocene natural water-level oscillation of the Balaton, and with the climate change as well.

There are no records in the Hungarian scientific literature regarding the exact time of the movement in 1996 – according to the authors own observation, it could happen in the first quarter of the year. Further to this, there were no precipitation data available from Tihany either, though based on the data provided by the synoptic measuring stations near Lake Balaton (Siófok, Keszthely), December 1995 and January 1996 was definitely rainy (Tab. 1). Based on these, we can presume that in the given period there was more rainfall in Tihany as well.

Table 1

Compared precipitation [mm] of the Balaton Region in winter 1996–97

	December 1995	Mean precipitation in December (1961–90)	January 1996	Mean precipitation in January (1961–90)
Siófok	120	45.1	78	36.4
Keszthely	80	43.4	41	34.3

The exact date of the movement in 2007 is also missing; according to own observations the most likely period could be August 2007. There were no recordable movements at the end of June 2007, though at the beginning of September, there was already a movement, which appeared to be quite fresh. The formation of the mass movement is therefore likely to coincide with the above analyzed rainy period of August.

The exploration of the more precise connection between the extremely wet periods and the mass movements needs further data-collection (at least daily precipitation data) and researches in the examined area. Regarding the current climate changes, it is even more important to understand the relation between the recent geomorphic evolution and the climate (Gil and Długosz 2006; Gorczyca 2008; Fábián et al. 2009, Radvánszky and Jacob 2009).

ACKNOWLEDGEMENTS

In our research, we received help from — and therefore give thanks to — the following colleagues: Titusz Bugya, Levente Ronczyk and István Viczián. Further to this, we thank the Balaton Uplands National Park Directorate and the colleagues of the South Transdanubian Environmental Protecting and Water Management Directorate for the climate and hydrologic data. We are also grateful to Richárd Korzenszky, the Prior of the Abbey of Tihany, for his help with finding the historic sources. The completion of the study was subsidized by the application of the *Science, Please!* Research Team on Innovation (TÁMOP-4.2.2/08/1/2008-0011).

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