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Gullies of two Hungarian regions – a case study

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Abstract

Gully erosion plays a decisive role in removing the fertile layer of the soil and it has an important long term effect in relief formation. The objective of this paper is to compare gully development and distribution in two pilot areas in Hungary and to reveal the factors controlling gully formation. The pilot areas are natural micro-regions, i.e. the Börzsöny Mountains and the Zselic hills. The results presented in this paper are based on the data of a nation-wide gully cadastre recently under compilation by the authors. The cadastre contains the gullies shown on digital maps (1: 10,000), gully lengths, mean gradients, land use and main properties of parent materials and soils. The results point to the development and formation of significantly different gullies in the pilot areas as a consequence of different environmental conditions. The most important result is the introduction of the concept of equivalent gully length characterizing the gullies of the given category. Topography is the main driving force in gully formation followed by land use type, parent rock and soil properties.

Keywords: gully erosion, gully cadastre, Zselic, Börzsöny

Introduction

Soil erosion is one of the most important agents in contemporary landscape formation. This statement applies also for the subhumid regions of Central Europe. Soil erosion attacks the uppermost, fertile soil layer and the eroded soil contains valuable nutrients (Farsang, A. *et al*. 2011; Borcsik, Z. *et al*. 2011). If the eroded soil will be transported into lakes eutrophication will be accelerated (Csathó, P. *et al.* 2007). Sheet erosion processes affect extended areas, the result is, however, a relatively slow change in topography. Gully erosion appears on relatively limited portions of the surface but it leads to the removal of a huge amount of soil and it makes rapid and remarkable change in surface topography (Pécsi, M. 1955; Kertész, Á. 2009). Both sheet and gully erosion contribute to relief formation (Jakab, G. *et al*. 2009). Gully erosion is a threshold

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phenomenon (Poesen, J. *et al.* 2003) but the identification of the threshold value is a very complex procedure (Poesen, J. *et al.* 2003; Kirkby, M. and Bull, L. 2000). The occurrence of gully, or sheet erosion may change also periodically. The glacial periods are presumed to have been ruled by gully erosion while the interglacials characterized by sheet erosion (Pécsi, M. 1997). Climate is not the only environmental condition that regulates soil erosion (Kertész, Á. 2006; Smolska, E. 2007) the role of soil properties, parent material (Buzek, L. 2007), topography and land use is also important (Kertész, Á. 2008). Many authors refer to the significance of land use changes (Grace, J.M. 2004; Gábris, Gy. *et al.* 2003; Galang, M.A. *et al*. 2007; Centeri, Cs. *et al.* 2009). The development of an already incised gully can only be stopped by radical changes and it is extremely expensive to remove it from the landscape (Kirkby, M. and Bracken, L.J. 2009)

Gullies develop mainly on loose, unconsolidated sediments such as loess and loess-like deposits (Poesen, J. *et al.* 2003; Zglobicki, W. and Baran-Zglobicka, B. 2011) as well as on marine sediments in the Mediterranean (Poesen, J. *et al.* 2006), and on sandstones (Hegedűs, K. *et al*. 2008) etc. Gullies developed on unconsolidated volcanic rocks represent a special type (Pintér, Z. *et al*. 2009). An example is the badland developed on rhyolite tuff in Kazár, Hungary (Horváth, G. *et al.* 2010).

Gully erosion has received less attention due to the complexity and difficulty of its investigation (Valentine, C. *et al.* 2005), nevertheless adequate gully susceptibility prediction would be necessary to control soil loss (Conforti, M. *et al.* 2010). There is no soil type, rock type, land use or topography which could alone launch gully initiation. The interaction of the factors controlling gully erosion is needed for gully formation (Muńoz-Robles, C. *et al*. 2010).

The aim of this study is to identify the spatial properties of gully erosion in two pilot areas in Hungary with the analysis of the recently compiled gully cadastre. The hypothesis to be tested is whether different environmental conditions (topography, land use, parent material and soil) generate distinct spatial patterns and distributions of gully systems. An additional goal is to identify the relationship between gully formation and land use change.

The study sites

In this study two pilot areas are compared, one from a mountain range and another from a hilly country, namely from the Börzsöny Mountains and from the Zselic hills, respectively. The Börzsöny Mountains are of volcanic origin, forested, with steep slopes and with high relative relief values. This area is selected because results of previous research are available from here (Madarász, B. 2009; Madarász, B. and Jakab, G. 2009).

Most of the Zselic hilly country pilot area is covered by loess and cultivated. Detailed investigations have been carried out in the Somogy hilly country for almost two decades (Jakab, G. 2008; Jakab, G. *et al*. 2005, 2009, 2010a) so the reason for choosing the nearby Zselic was to have a new sample area similar to the Somogy hills.

The pilot areas were identified according to the Inventory of Natural Micro-regions of Hungary (Dövényi, Z. ed. 2010). The Börzsöny pilot area covers 447 km^2 and is situated in the northern part of Hungary *(Figure 1).* It is a paleo-volcano formed in the Miocene between 16.5 and 13.5 Ma B.P. (Pécskay, Z. *et al.* 1995; Karátson, D. 2007). The older volcanic rocks of are mostly covered by younger volcanic deposits, however, at the margins of the mountain at some spots older deposits outcrop. During the Pliocene and Quaternary times erosion and tectonic movements were the main landscape forming agents in the Börzsöny (Láng, S. 1955). The recent surface and valley system was formed by the erosion of the nearly 800 m thick volcanic strata (Karátson, D. 2007). The elevation of the study area varies between 120 m and 939 m a.s.l. The characteristic surface forms are debris flows as well as elongated and steep hillsides dissected by relatively young V-shaped valleys. Relative relief values gradually decrease towards the periphery of the mountains, from 350–370 m km^{-2} to 100–150 m km^{-2} (Madarász, B. 2009). Most of the slopes are exposed to west–north-west and to east–south-east. The study area belongs to the cool and wet climate domain. Mean annual temperature does not exceed 8–8.5 °C with only 7–8 °C in the highest region. Annual precipitation varies between 600 and 800 mm with higher values in the peak region (Dövényi, Z. ed. 2010).

The Zselic hills (1170 km^2) are situated in the southern part of the Transdanubian Hills macro-region *(Figure 1).* It is a relatively plane area with gentle slopes similar to a pediment (Sebe, K. *et al.* 2008). Almost the whole area is covered by loess, mainly of Wurm origin, and can be classified mostly as slope loess (Kapronczay, J. 1965). At some deeper lying spots sandy Pannonian sediments occur on the surface (Lóczy, D. and Gyenizse, P. 2003). Forest management was the traditional main occupation and income source in the area (Gyenizse, P. *et al*. 2008) supported by a rather high amount of annual precipitation (700–750 mm, Kapronczay, J. 1966). With the expansion of arable fields soil erosion became an increasingly serious problem after Second World War (Lóczy, D. and Gyenizse, P. 2003). The area can be characterized as fragmented from geological and social aspects.

Methods

The gullies of the study areas were digitized using the 1:10,000 scale maps of the Unified National Map System (EOTR). A GIS was organized which con-

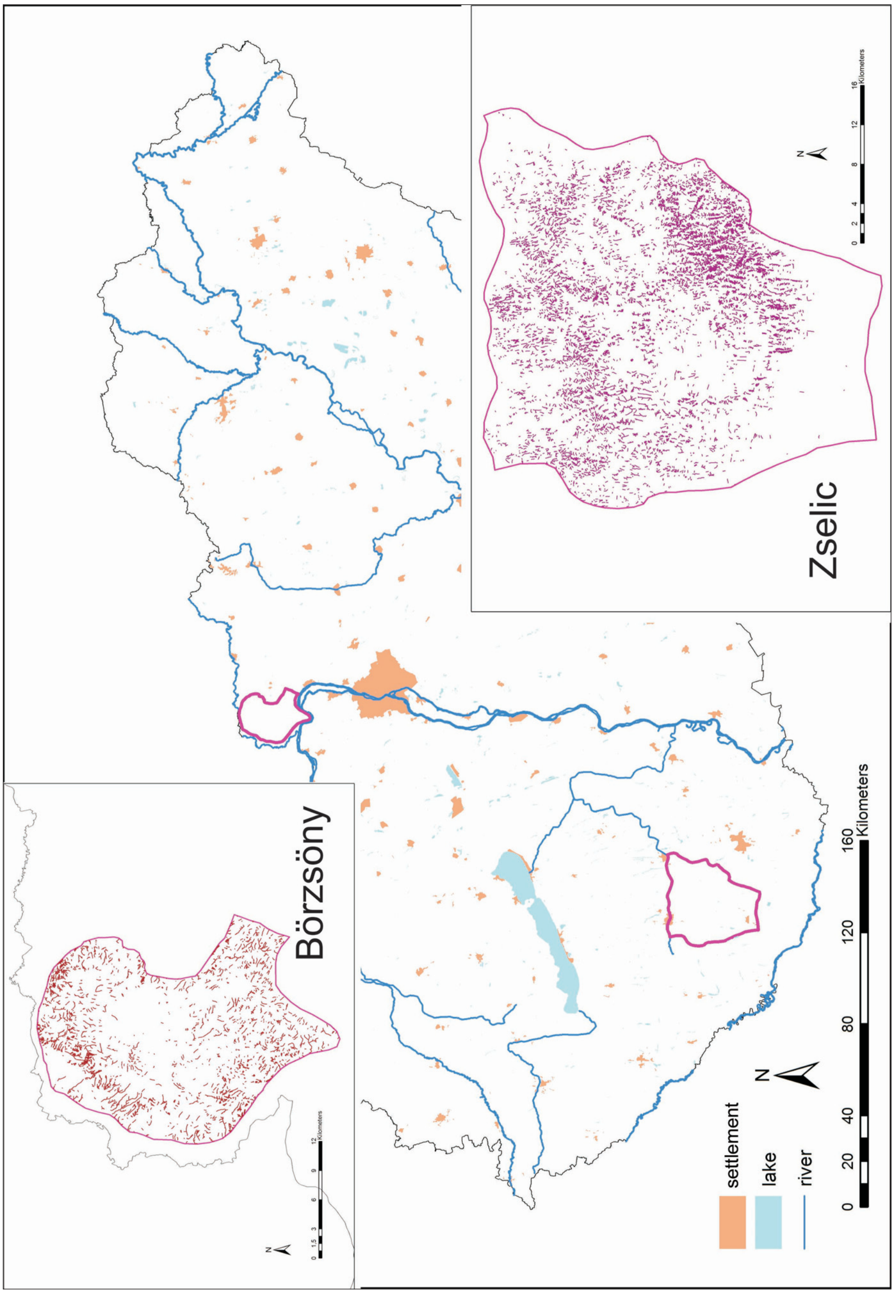

Fig. 1. Location of the study sites with the surveyed gullies

sisted of the digital map of the gullies, the map of soil properties, the land use map and the topographic map of the pilot areas. The map of soil properties is a map series derived from the AGROTOPO map at a scale of 1:100,000 (RISSAC 1991). This database contains information on soil type, parent material, texture, clay mineral composition, hydrology, pH, soil organic matter (SOM) and soil depth. The land use map was compiled on the basis of the CORINE Land Cover database (1:50,000) (Büttner, G. *et al*. 2002). Gully sections with intermittent or permanent water flows were excluded.

The original CORINE database has more than 60 land use types which had to be generalized for the purposes of the pilot study. As a result six land use types were created focusing on soil conservation, ranked according to their endangerment by soil erosion, i.e. cultivated area including arable land, vineyard and orchard followed by permanent vegetation, forest and wetland/scrubland. Elevation data are taken from SRTM (Shuttle Radar Topography Mission, Rabus, B. *et al.* 2003). The resolution is 90 m. The soil gradient map with five category classes (see e.g. Pécsi, M. 1991) was derived from the elevation model.

Soil, land use and topographic data are given for each gully. If a gully extends over two or more pixels then the gully is identified with the value/property occupying the largest area in the gully. Concerning numerical data the gully is identified with the arithmetical mean of the values of the pixels in question.

Results and discussion

The distribution of soil parent material and soil type is shown in *Table 1*. The Börzsöny is dominated by volcanic rocks mainly covered by Luvisol. On the remaining area Cambisol and Phaeozem are to be found. Phaeozem stands for a special type of soil developed on volcanic rocks named "erubáz soil" in

Table 1. Soil type and parent material distribution

Area	Soil type (%)					Parent material (%)			
	Phaeozem	Luvisol	Cambisol	Chernozem	Gleysol	Glacial and alluvial deposits	Loess	Tertiary and older deposits	Andesite, basalt, rhyolite
Börzsöny	4	81	15	0	0	0	1	33	66
Zselic	–	63	19	5	13	13	87	1	–

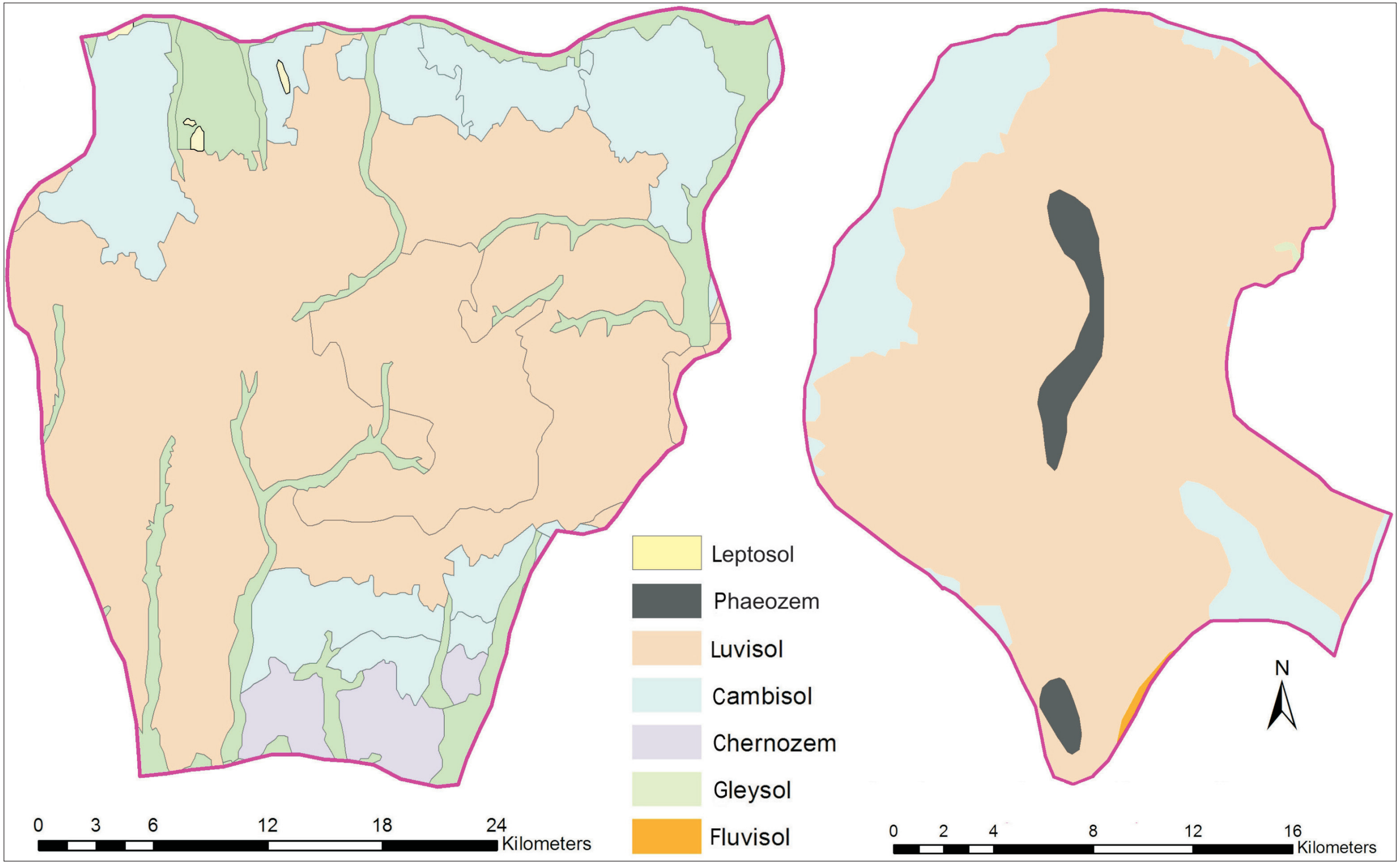

Fig. 2. Main soil types of the Zselic (left) and Börzsöny (right) study areas

the Hungarian nomenclature, see Madarász, B. 2009. In the valley bottoms and near the Danube Fluvisol occurs *(Figure 2).*

In the Zselic area loess is the dominant parent material. Texture and organic matter distribution data are shown in *Table 2*, soil depth in *Table 3*.

The Phaeozems of the Börzsöny site are shallow (soil depth < 40 cm), other soil types are thicker, up to 70 cm *(Table 3).* Presumably, deep gullies cannot be formed on volcanic rocks covered by shallow soils. There are gullies developed on this soil types, too. During the field campaigns there were detected deep gullies with steep slopes cut into the hard volcanic rock. These gullies can be older, developed presumably during the Pleistocene. There are also shallow gullies running parallel with each other and brought about by man induced activities (e.g. roads used for wood transport or for military training).

The central part of the Börzsöny was used by the army as a training area in the second half of the last century. These shallow gullies are not shown in the digital maps.

The Zselic pilot area has deep soils. Their high proportion (95%) can be explained by map generalization, the data are taken from the AGROTOPO map series (1:100,000). Small spots of Leptosol, however, could be observed all over in the area. The deep soils are mainly colluvia accumulated by erosion. Due to the porous parent rock it is hard to determine the boundary between the rock and the soil, especially in case of arable fields.

The two study sites have distinct land use structure (*Table 4* and *Figure 3*). The Börzsöny is almost completely covered by forest. The Zselic has large arable fields and the forest spots are fragmented. The average land area of the individual land use categories show similarity in the two pilot

Table 2. Texture and organic matter (OM) distribution

Area	Texture (%)		OM content distribution (%)				
	Loam	Clay loam	50–100 t ha^{-1}	100–200 t ha^{-1}	200–300 t ha^{-1}	300–400 t ha^{-1}	400 < t ha^{-1}
Börzsöny	23	77	0	96	4	–	–
Zselic	100	0	63	24	1	7	5

Table 3. Soil depth distribution

Area	Soil depth (%, cm)			
	20–40	40–70	70–100	100 <
Börzsöny	4	62	–	34
Zselic	0	–	5	95

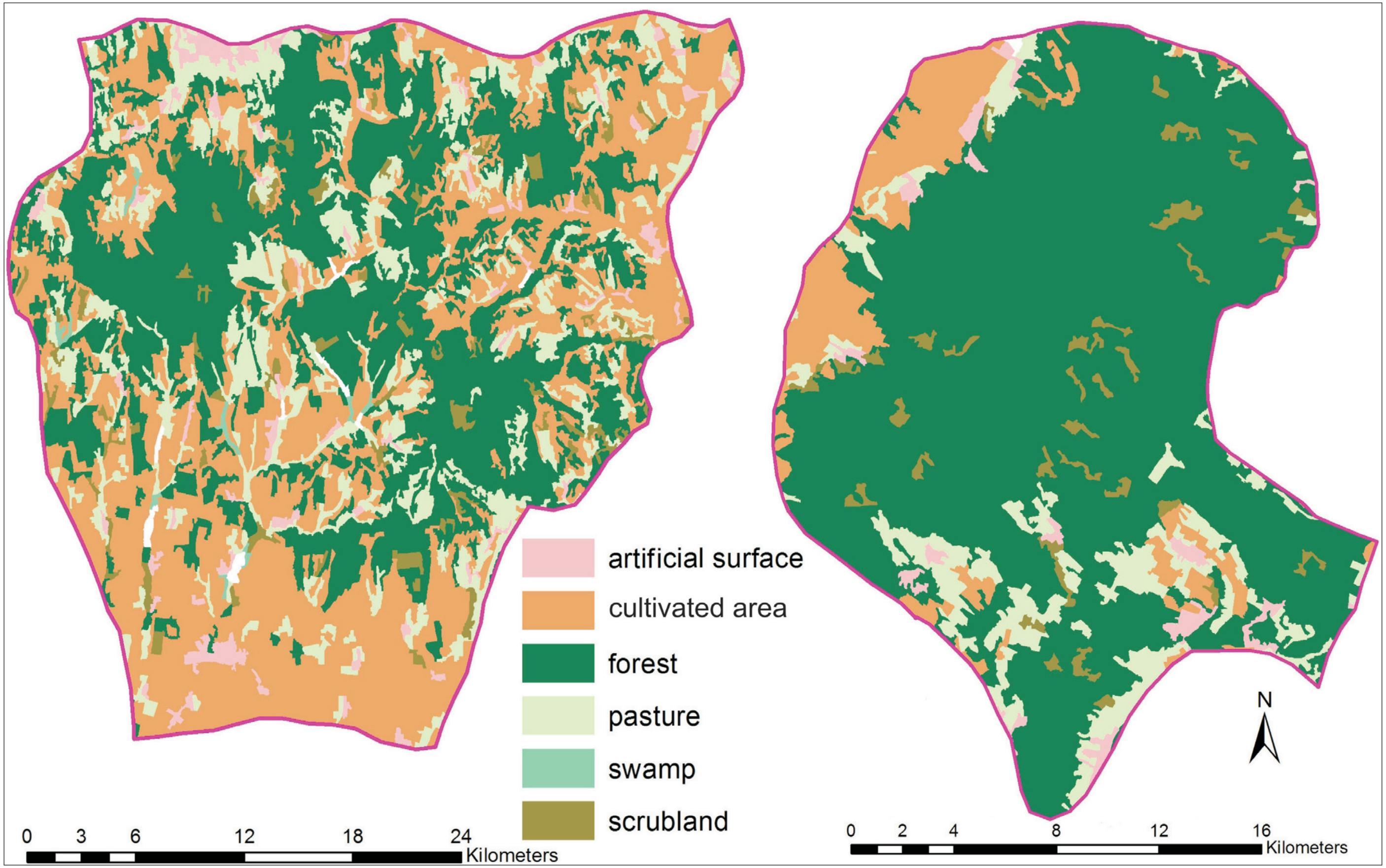

Fig. 3. Simplified land use map of the Zselic (left) and Börzsöny (right) study areas

Table 4. Land use distribution of the study sites derived form the CLC50 (2000) database

Land use	Zselic			Börzsöny		
	Total area (ha)	Rate (%)	Average area (ha)	Total area (ha)	Rate (%)	Average area (ha)
Artificial surface	3,585	3	50	985	2	47
Cultivated area	46,524	40	358	4,235	9	132
Forest	43,688	37	299	33,928	76	1,696
Pasture	19,076	16	64	4,134	9	63
Swamp	340	0	43	1	0	0
Scrubland	3,304	3	49	1,447	3	39

areas except for cultivated area and forest. Artificial areas include built-up areas, open-cast mines etc.

The distinct land use structure of the sites can be explained by different parent materials and relief conditions. In Börzsöny the largest homogeneous areas are covered by forest and they fall into the highest slope gradient class. In Zselic the steepest slopes have a very limited spatial extension, they are covered by forest, but the woodland is fragmented (*figures 4* and *5*).

Gully properties are summarized in *Table 5*. The gully dissection index value is almost the same in the two pilot areas. The average values are three times larger than the lower limit value (0.5) of the highest category of the Hungarian classification underlying the necessity of introducing an additional gully dissection category as already suggested (Jakab, G. *et al.* 2010b).

Average gully length is slightly higher in the Börzsöny. The difference between the average and median values point to the anomalous distribution of the data similar to the case of the Tetves catchment (Jakab, G. *et al.* 2005). The difference between the median values is also very small. The minimum gully length values (2 m, see *Table 5*) do not refer to real gully lengths as they represent only parts of gullies which are longer but they are cut by the border of the natural micro-regions.

Comparing maximum gully lengths of the pilot areas the value of Zselic is twice as large (16 km) as that of the Börzsöny. The explanation is the porous parent material and smaller gradient values in the Zselic area.

Table 5. Main gully properties

Indicator	Börzsöny	Zselic
Number of gullies	2,260	6,579
Dissection index (km km^{-2})	1.43	1.45
Total length (m)	638,309	1,693,374
Average length (m)	282	258
Minimum length (m)	2	2
Maximum length (m)	7,308	16,220
Median (m)	126	133

Comparing *tables 6* and *7* a conspicuous observation can be made, i.e. looking at the properties (e.g. soil type, land use etc.) there are only small differences between the percentage values calculated from the number of gullies, com-

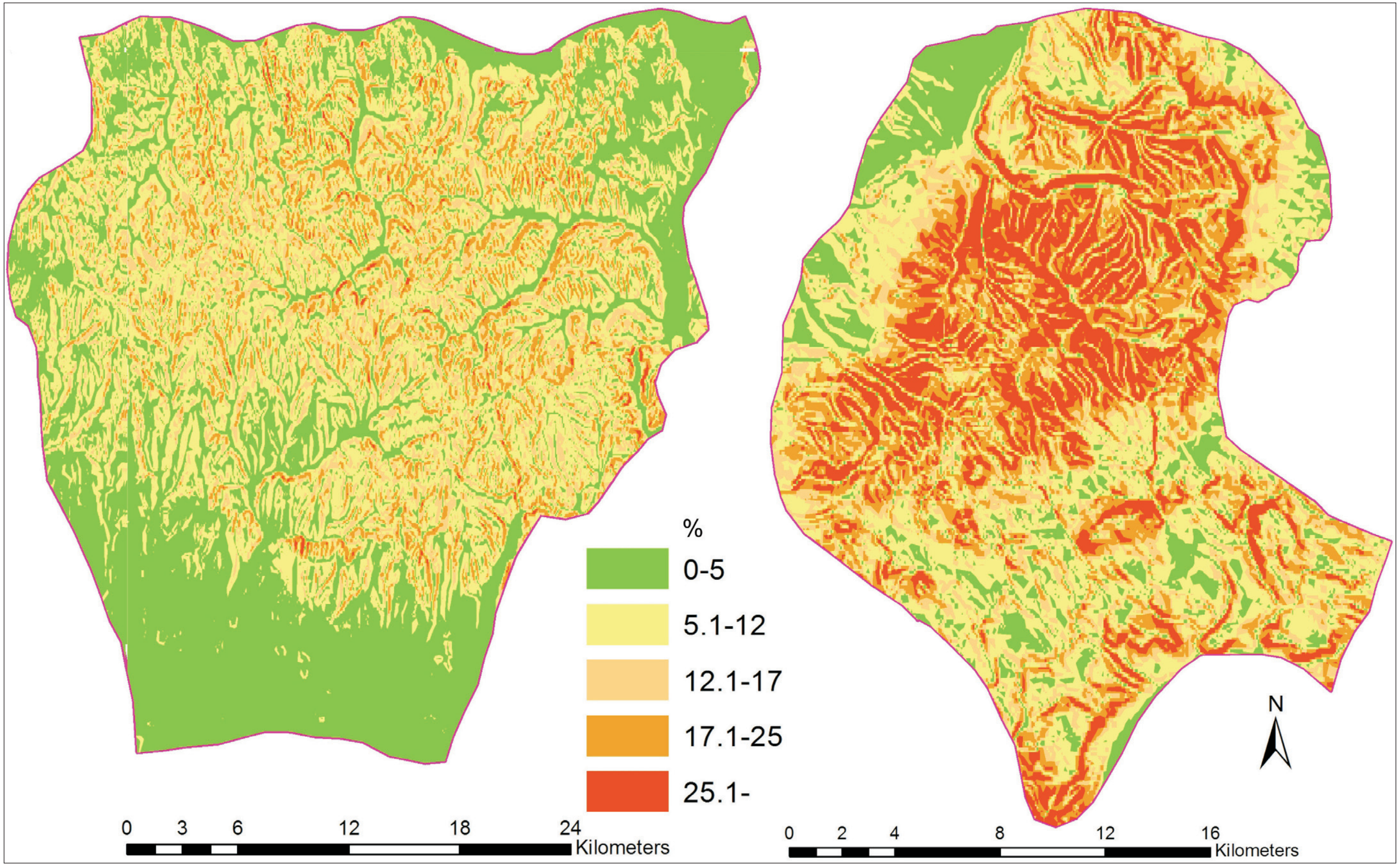

Fig. 4. Slope gradient distributions of the study areas derived from the SRTM database (Rabus, B. *et al.* 2003)

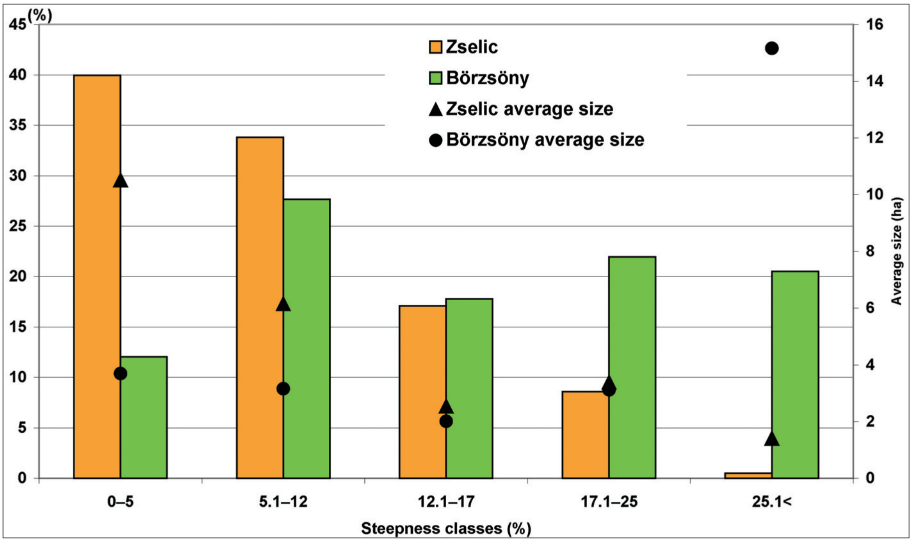

Fig. 5. Slope gradient classes of the Zselic and the Börzsöny study sites

Table 6. Average properties of the surveyed gullies in the Börzsöny

Property	Rate according to the number of gullies (%)	Rate according to gully length (%)	Average gully length (m)
Soil type			
Phaeozem	1.1	0	118
Luvisol	86.9	88	283
Cambisol	11.5	11	279
Chernozem	0.4	1	808
Parent rock			
Loess	1.9	3	441
Tertiary and older deposits	36.4	31.0	241
Volcanic rocks	61.7	66.0	302
Soil texture			
Sandy loam	0	1	110
Loam	30	26	242
Clay loam	70	73	297
OM content t ha^{-1}			
100–200	98.9	100	284
200–300	1.1	0	118
Soil depth (cm)			
20–40	1	0	118
40–70	61	66	305
> 100	38	34	251

Table 7. Average properties of the surveyed gullies in the Zselic

Property	Rate according to the number of gullies (%)	Rate according to gully length (%)	Average gully length (m)
Soil type			
Luvisol	79	81	265
Cambisol	18	17	236
Gleysol	3	1	195
Parent rock			
Glacial and alluvial deposits	2	2	224
Loess	96	97	260
Tercier and older deposits	2	1	144
Soil texture			
Loam	98.3	99	259
Clay loam	1.0	1	144
OM content t ha^{-1}			
50–100	79	81	264
100–200	20	18	232
> 400	1	0	191
Soil depth (cm)			
70–100	1	0	191
> 100	99	99	258

pared to those from gully length, e.g. the percentage of gullies on Luvisol is 86.9% versus 88.0%.

Analyzing the distribution of gullies according to soil types of the Börzsöny the first interesting phenomenon is that there are relatively few gullies on Phaeozem. The reason for this is the shallow soil on solid parent rock as mentioned above. Another reason may be the geomorphological position of these soils, i.e. they develop on the highest parts of the mountain, at the caldera fringe which is not a favourable location for gully formation because of the lack of sufficient catchment area. It is striking that the percentage of Luvisol is slightly higher than the percentage of its area. Compared with Cambisol the share of the latter is less than its territorial percentage. Luvisol is more resistant to gully erosion than Cambisol (Nachtergaele, J. and Poesen, J. 2002). The difference can be explained by the morphological position of the gullies.

Analyzing the role of soil texture the problem has to be dealt with that the AGROTOPO texture data give only one single value for the total soil profile and textural differences between the soil horizons are not taken into account. Loam is overrepresented, with a higher ratio of gullies on it than the territorial distribution of loam.

In Zselic the percentage of gullies on Luvisol is also high (*Table 8*) compared with the areal representation of this soil type. The reason for this

Table 8. Land use type distribution of the gully areas in 1985

Indicator	Börzsöny			Zselic		
	Arable land	Pasture	Forest	Arable land	Pasture	Forest
Total length (m)	11,343	76,619	550,347	45,032	135,941	1,512,401
Total length (%)	2	12	86	3	8	89
Number of gullies	37	266	1,959	201	867	5,512
Ratio of gullies (%)	2	12	86	3	13	84
Average length (m)	307	290	281	226	157	274
Median length (m)	161	131	124	184	110	135
Minimum length (m)	14	22	2	2	2	2
Maximum length (m)	2,558	6,990	7,308	1,235	2,430	22,124

is the same as in the Börzsöny, i.e. the morphological position of the gullies. The share of gullies developed on Cambisol is proportional with the territorial extension. On Gleysol and Chernozem there are hardly any gullies. This is normal concerning Gleysol but there should have been more gullies on Chernozem. This soil type is used as arable land where ephemeral gullies develop being not always shown on topographic maps (Jakab, G. *et al.* 2010a).

Gully distribution data on various parent rocks reflect the well known fact that gully development favours loess environment (Poesen, J. *et al.* 2003, 2005; Valentin, C. *et al.* 2005). Comparing the areal percentage of parent rocks with the percentage occurrence of gullies on them we can see that loess is overrepresented while glacial and alluvial deposits are underrepresented.

Analyzing the role of organic matter the well known positive effect of organic matter in preventing gully erosion can be recognized, i.e. with low OM content more gullies develop.

There is a close relationship between gully erosion and land use (*Table 8*). In both pilot areas most of the surveyed gullies were in the forest when the map was prepared. If gullies are deeply incised arable cultivation must be stopped and these gullies will not be classified into arable land any more (Jakab, G. 2006). These gullies will soon be covered by forest.

The overwhelming area of Börzsöny is covered by forest, but the proportion of gullies outside the forest area is higher than in the forest. In the Zselic most of the gullies are located in the forest (90%) in spite of the fact that the percentage of forests is less. Gullies on cultivated land generally are longer as shown by Vanwalleghem, T. *et al.* (2003).

Differences in average gully length among the land use categories in the Börzsöny are negligible, in the Zselic area they are bigger.

Land use types of the gullies in 2000 are presented in *Table 9*. Since 1985 the percentage of the number of gullies on arable land had increased in both areas, in Börzsöny from 2 to 6%, in Zselic from 3 to 8% and average gully length from 2 to 13% and 3 to 22%, respectively.

Table 9. *Land use type distribution of the gully areas derived from the 2000 CLC50 database*

Indicator	Börzsöny				Zselic			
	Cultivated area	Forest	Pasture	Scrubland	Cultivated area	Forest	Pasture	Scrubland
Total length (m)	82,968	455,933	81,718	6,247	370,862	1,088,531	197,872	30,491
Total length (%)	13	73	13	1	22	64	12	2
Number of gullies	126	1,812	242	33	1,128	4,398	847	165
Ratio of gullies (%)	6	82	11	1	18	67	13	3
Average length (m)	658	252	339	189	329	248	234	185
Median length (m)	265	119	150	115	180	108	143	103
Minimum length (m)	22	2	17	20	2	2	6	18
Maximum length (m)	6,990	5,561	7,308	1,078	16,220	8,237	3,081	2,531
Dissection index (km km^{-2})	2.0	1.3	2.0	–	0.8	2.5	1.0	–

Intensive land use increases the rate of both sheet and gully erosion (Centeri, Cs. 2002; Gábris, Gy. *et al.* 2000). A similar trend is connected with changing land use, i.e. with the transformation of the former forest and pasture into arable land.

The dissection index values vary between 0.8 and 2.3. Arable land and pasture have similar values in both areas. Much higher values should have been on arable land. The reason why this is not the case is that ephemeral gullies are not surveyed as mentioned above (Jakab, G. *et al*. 2010b) The forest can also be dissected due to the dirt roads running in them and because of the effect of rill and gully erosion taking place in the arable field upward the slope (Jakab, G. *et al.* 2010a).

Analyzing the trends of changes the following statements can be made. In Zselic 66% of the gullies which were classified as forest in 1985 had become arable land by 2000, in the Börzsöny this value is 50%.

It is difficult to evaluate the effect of gradient on gully formation as an elongated form of sometimes more than 10 km length is characterized by only one gradient value. Average gradient in the Börzsöny Mountains is 2.98, in the Zselic hills it is 2.69.

Conclusions

Two pilot areas were analyzed and compared in detail. As it was expected the gullies and gully systems of the pilot areas were different. It is difficult to assess the effects of the environmental factors because they are interrelated, not independent from each other, i.e. they constitute a complex system and this system as a whole controls gully development. Being aware of this statement it is assumed that soil properties exert the smallest impact on gully development. This conclusion is confirmed by the high share of gullies formed on Luvisol and it is known that Luvisol is resistant to gully erosion. The role of parent material in the process is very important. High gully erosion rate can be found on loess as the parent material. Relief and land use play the most important role in gully development. The effects of these two environmental factors cannot be treated separately, except in very small areas. In accordance with the results of Menéndez-Duarte, R., *et al.* (2007) the effect of topography is more decisive of the two because it controls also land use. The methodology of gully identification is not perfect as such formation is classified as a gully in the forest even if a considerable part of its catchment is on arable land. The method applied in the paper for the identification of gully gradient is suitable in small scale only.

In the Börzsöny Mountains very deep gullies can be found that have developed into valleys in some cases. They must be of Pleistocene, early Holocene origin as they are deeply cut into hard rock.

The analysis of the two pilot area revealed important characteristics of the gullies and pointed to some features of gully development. Future research will be devoted to the classified survey of gullies in the country (i.e. a detailed country-wide survey of ephemeral gullies).

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Predictive modelling of surface subsidence above an underground coal mine at Máza-Váralja-South (Northeast Mecsek, Hungary)

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Abstract

Today the number of the environmental hazards multiplied - mostly due of human impact. The anthropogenic landforms can be predicted by engineering methods in a mining area. These methods became the instruments of Environmental Impact Assessment (EIA). In this paper, such calculation method was applied, but it was combined with GIS. The vertical and horizontal spatial extent of a negative montanogenic landform was modelled. The results of this combined method estimate the locations of the expected major subsidences, thus it would be the basis of monitoring by surveying.

Keywords: subsidence sag and trough, Somosvári's modell, GIS, anthropogenic and environmental geomorphology

Introduction

The environmental problems of coal mining have been studied since it was industrialized. The number of scientific papers related to environmental impacts of the mining has increased since 1972 when the UN Conference on the Human Environment was held in Stockholm (Bian, Z. *et al.* 2010). However, the 1st International Symposium on Land Subsidence was organized by UNESCO in Tokyo as early as 1969 (Carreón-Freyre, D.C. 2010).

Surface subsidence is an inevitable corollary of underground mining. This phenomenon brings changes to surface landforms and to all natural factors (e.g. Blodgett, S. *et al.* 2002). The sag- to trough-shaped subsidence (Marino, G.G. 1993) was redefined and combined with definitions of Erdősi, F. (1987) after the geological and mining properties. The sag extends to only one level of the mining block, but the subsidence trough is the cummulative subsidence landform from different levels above a structural block. According

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to theory of Lehmann, K. (1919) the subsidence trough is found where the vertical and horizontal movements take place. Niemczyk, O. (1949) distinguished three further components of vertical and horizontal movement: inclination or tilt, curvature and strain (tension or compression), necessary to asses possible surface damage, because the buildings, the electrical poles, the trees are affected by them (Hoványi, L. 1968; Bahuguna, P.P. *et al.* 1991; Singh, M.M. 1991).

The maximum value of the mining subsidences could reach in some places -20 to -35 m e.g. in Ostrava-Karviná Region in Czech (Martinec, P. and Schejbalová, B. 2004; Brázdil, R. and Kirhcner, K. 2007), in Katowice Region or Rybnik Region in Poland (Liszkowski, J. 1991; Dulias, R. 2011) and in Ruhr Coal Basin in Germany (Drecker, P. *et al.* 1995).

Mining subsidence in Hungary was investigaed by Martos, F. (1956), Richter, R. (1965), Hoványi, L. (1968), Somosvári, Zs. (1989) at the Faculty of Mining Engineering University of Miskolc. The research program on the "determination of moving field of the cover layer above underground mining" took place between 1969 and 1984 in Mecsek Coal Basin (Somosvári, Zs. 2009). The mines closing inferred the subsidence calculation of time dependence after the change of political regime (Turza, I. 1990; Ládai, J.T. 2003). Because it is important when would stop the subsidence and its impacts.

The Calamites Ltd. plans to open an underground black coal mine at Máza-Váralja-South in the near future and therefore it is necessary to analyze the predictable environmental risks (Juhász, Á. 1976; Erdősi, F. and Lehmann, A. 1984; Fábián, Sz. Á. *et al.* 2006; Szabó, J. 2010). The longwall mining method, which will be applied, is a common technique for coal extraction in many countries, but the mining of large blocks induces severe ground movements - although their rate might be pre-calculated (Raman Rao, M. V. 2010).

Study area description

The study area of 10.5 km^2 is located eclosed by the villages Máza–Váralja–Óbánya (*Figure 1*) in the NE Mecsek Mountain (SE Transdanubia, Hungary). This area belongs to the region „Mecsek- and Tolna–Baranya Hills" (Pécsi, M. and Somogyi, S. 1967) and it is bounded by the Völgység Stream, and the Völgység Hills on the North. The NE and E part of the East Mecsek (Dobogó–Zengő-Group) consist of radially-orientated horst groups. The three main interfluve ridges diverge from the horst of Dobogó Peak (594 m) to N, NE and E direction. The ridges are lowering from the S (490 m) to north (290 m). Both of the two relevant valleys (the Váraljai Creek and the Mázai Creek) and catchment area has SW–NE direction and they are structurally guided erosional valleys. The minimum elevation of study area is 184.15 m in the Váraljai Creek. Erosional valleys, ravines, gullies, alluvial cones, interfluves and ridges are the typical

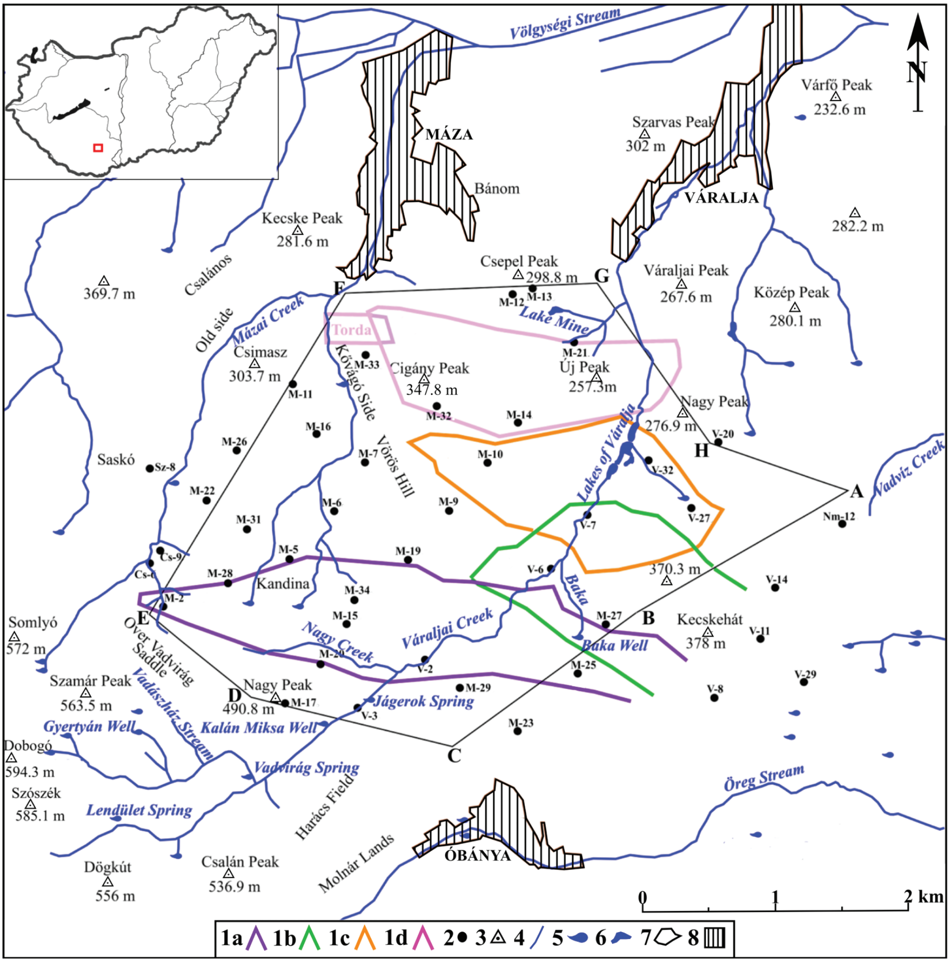

Fig. 1. Map of the study area. – 1a–1d = structural blocks; 2 = boreholes with numbers; 3 = major hill or peak; 4 = stream; 5 = spring; 6 = lake; 7 = study area bordered with cut-off points (A–H); 8 = settlements

landforms of the study area (Lovász, Gy. 1974). Former mine exploitation ended in 1965, therefore many anthropogenic forms, for instance spoil heaps and scarps could be found near settlements. Erdősi, F. (1987) reported four subsidence troughs of 3.75 km^2 area in North Mecsek mining districts.The old pits are located on the northern part of the study area. The large part of the study area is „untouched", and it belongs to the Duna-Drava National Park and the Natura 2000 network.

In ca. 24 km^2 area 62 boreholes were deepened between 1953 and 1985 (Szilágyi, T. and Villám, E. 1985). By a more recent analysis of borehole data seven structural blocks was assessed (Püspöki, Z. *et al.* 2009). These blocks include 24 black coal seams with an average thickness of 2.6 m and dip of 5–40° SSW.

The Lower Jurassic (Hettangian-Sinemurian) black coal seams are covered by Late Mesozoic sediments: marl, clay marl, aleurolite, calcareous marl, sandstone, stone flour and conglomerate. A significant tectonic and volcanic (basalt dykes, explosion breccia) events took place in this area in the early Cretaceous (but much younger movements are also known from the borehole). To the influence of movement the sedimentary deposits were folded and overlapped. According to Püspöki, Z. *et al*. 2010 the blocks have an imbricate structure: the violet block (+1) on the top, the green block (0) in the middle and the orange block (–1) on the bottom (*Figure 1*). The younger cover rocks from the Cenozoic era are lacustrine aleurolite, conglomerate, sandstone, andesite, rhyolite tuff, fluvial coarse-grained conglomerate, marl, lignite and Pleistocene loess, clay with stone flour and colluviums (Hámor, G. 1970; Szilágyi, T.–Villám, E. 1985).

Objectives and methods

The goal of this study was to determine the vertical and horizontal extent of subsidence landforms (sag and trough). Therefore the main goal was to apply a calculating method completed with GIS for mining engineering on the land subsidence. On the one hand, the surface subsidence was calculating as point grid in resolution of 50 m in one structural block (+1 East). On the other hand, surface model was interpolated and compared with real surface in detailed resolution of 5 m.

The method relies on the national and international literature (Somosvári, Zs. 1989). The input data were derived from the geological final report and excavation plans (Püspöki, Z. *et al.* 2009). According to the plans of 2009, the extraction of the total coal amount (to −300 m a.s.l.) would last about 30 years and the model display the predictable final ondition after movements.

The calculation of the data and the analysis was performed in *MacOsX (5.2.)* operation system and cost-effective free softwares were used. The values of subsidence were calculated on *NeoOffice Calc (2.2.4.*) in 50×50 m grid. The expected movements in the subsidence trough were determined from the Somosvári's model, because these differential equations considered the rock mechanical data, beside the mining data (Somosvári, Zs. 1989). Moreover, the geomorphologic data were encased to the equation, the mean relative elevation above the mining block. Natural surface processes were not considered because the anthropogenic subsidence is significantly greater as the natural denudation during 30 years. The surface data derived from 1:10,000 scaled topographic map (24–431, 24–433, 24–342, 24–344 in EOV Hungary's coordinate system). The staff of the University of Debrecen made the digitalization with *GeoMedia (6.0.)* software and I made a refinement with *QGIS (0.5.3.)* software. The mining plans and structural blocks were digitalized with *QGIS* also. The *Grass (6.4.0) GIS* software was applied to the modelling. The interpolation method is "*Regularized spline tension* (*v. surf. rst*)" with resolution of 5×5 m. The *Inkscape (0.48.1)* and *Gimp (2.6)* was applied to the figure editing.

Somosvári's model and the required data

The extraction of the coal seams reaches −300 m a.s.l. and it carries on three levels. Five structural blocks will be affected but in this paper only the +1 block was modelled. The main cross tunnel divides the +1 block into two parts and the width of the protect pillar increases with depth *(Figure 2).*

Both of the mining and rock mechanical data was considered in these differential equations.

In the first step, the basic of the equations the maximum subsidence ($w_0$max) was calculated:

$$w_{0\,\max} = M \cdot s \cdot (1 - \eta_t) \text{, where}$$

M is the extracted seam thickness *(Table 1),*

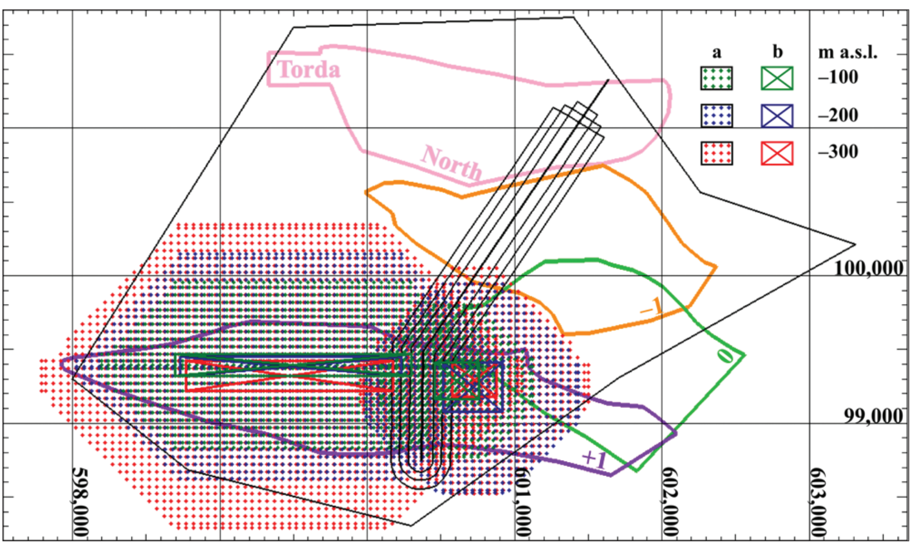

Fig. 2. Map of the mining block and grid points of the subsidence sags in +1 structural block

s is the subsidence factor, which has 0.82 value in the Mecsek Mountain after Hegedűs, Gy. (1971) and

ηt is the backfill coefficient that is an important factor of abandon method. This value is "0" by roof-fall method, "0.8" by machine backfilling, "0.55" by chamber-and-pillar working (Sütő, L. 2000). In the present case with "0" backfill coefficient was calculated, because the rock movements will be ignored naturally.

The system of the differential equation gives the following expression to the surface subsidence, in which the adequate connection and border conditions were considered (Somosvári, Zs. 1989).

If $x \geq 0$

$$\begin{aligned} w(x,y) = w_{0\max} \cdot \cos\frac{a \cdot \alpha \cdot \pi}{180} \cdot \{0.585 \cdot [\exp(-Ax) - \exp[-A(x+2l_x)]] - \\ -0.085 \cdot [\exp(-Cx) - \exp[-C(x+2l_x)]] - \\ -0.224 \cdot [1 - \exp(-\frac{k}{\sqrt{m-1}} \cdot \frac{y}{H})] \cdot [\exp(-Ax) - \exp(-Cx) - \\ -\exp[-A(x+2l_x)] + \exp[-C(x+2l_x)]]\} \end{aligned}$$

If $-2l_x \geq x \geq 0$

$$\begin{aligned} w(x,y) = w_{0\max} \cdot \cos\frac{a \cdot \alpha \cdot \pi}{180} \cdot \{1 + 0.585 \cdot [\exp(Cx) - \exp[-C(x+2l_x)]] - \\ -0.585 \cdot [\exp(-Ax) - \exp[-A(x+2l_x)]] + \\ +0.224 \cdot [1 - \exp(-\frac{k}{\sqrt{m-1}} \cdot \frac{y}{H})] \cdot [\exp(Ax) - \exp(-Cx) + \\ +\exp[-A(x+2l_x)] - \exp[-C(x+2l_x)]]\} \end{aligned}$$

where

$$A = 0.618 \cdot \frac{k}{H} \quad \text{and} \quad C = 1.618 \cdot \frac{k}{H}$$

where the coefficients depend on the direction in the grid (Staudinger, J. 1972).

The mining blocks have an horizontal extent in dip ($2l_x$) and in strike ($2l_y$) furthermore a vertical extent (*M*). The distance from the center of relative coordinate system is the "l". The rate of dip (α) of the coal seams of the mining block is 25°. The mean elevation above the mining blocks from the DEM was queried, thus the cover thickness from bottom edge (*Hb* = *ME*–100/–200/–300) and upper edge (*Hu* = *Hb*–*M*) of the extracted area was calculated in line of dip *(Table 1)*.[2]

[2] +1 = structural block; W = west side of the structural block; E = east side of the structural block; 1 = first level (–100); 2 = second level (–200); 3 = third level (–300); $2l_y$ = extent of

Table 1. Data of the +1 structural block and mining levels[1]

Block and levels	$2l_y$ [m]	$2l_x$ [m]	M [m]	ME [m]	Hu [m]	Hb [m]	k
+1W 1.	1,600	150	13.0	379.71	466.71	479.71	10
+1W 2.	1,500	130	20.9	380.75	559.85	580.75	9
+1W 3.	1,400	200	21.2	383.70	662.50	683.70	8
+1 E 1.	300	250	13.0	266.27	353.27	366.27	10
+1 E 2.	400	330	20.9	285.30	464.40	485.30	9
+1 E 3.	300	230	21.2	277.68	556.48	577.68	8

The Poisson Number (*m*) is a value of the deformation in cross and in length direction by one way tension state. The Poisson number is between 3.2 and 5.0, the rock parameter (*k*) is between 7.5 and 10.0 by medium hard marl and sandstone cover rock seams. The upper limits were applied for both geology determined parameters. Theoretically the rock parameter decreases with depth of mining level according to cracked rocks (*Table 1*). But it would be depend on the order of roof-fall in levels. Thus the limiting angle decreases and the sag becomes wider. The last rock mechanical data are the anisotropy (*a*) approx. 0.5. The delay time (T_0) of a rock movement is H_u/3.5 (Turza, I. 2006) that depends on cover thickness (H_u) above a point. Therefore the average time is 189.29 days (0.519 year) above the last mining level of +1 West block.

Results and discussion

The horizontal extent of the sag and trough

The limiting angle (*β*), the impact range (*r*) and the impact parameter (*IP*) is needed for calculating the horizontal extent of subsidence sag and trough. According to Somosvári, Zs. and Buócz, Z. (1993) calculating angle of draw is the first step:

$$\beta = arcctg\left[\frac{1}{0.618k}\ln\frac{0.585\cdot M\cdot s}{\Delta w}\pm\frac{1}{k}\right]$$

where the last point of the subsidence sag (*Δw*) is a new parameter, which has an insignificant value (0.01 m). Limiting angle (*β*) means the inclination of a section between last moving point and the edge of extracted block away from horizontal line. The impact range (*r*) is obtained from multiplying the seam

the extraction area in strike [m]; $2l_x$ = extent of the extraction area in dip; *M* =thickness of the coal seams or thickness of mining block; *ME* = relative mean of elevation above the mining block; H_u = the cover thickness from upper edge of the extracted area in line of dip; H_b = bottom edge of the extracted area in line of dip.

thickness by cotangent angle of draw. This range is the distance between the edge of the mining block in surface projection and last moving point.

$$r = H_u \cdot tg(90° \pm \beta)$$

The impact parameter is the distance from the centre in a relative grid (50×50 m). The value is totalled on the half horizontal size of extracted block and impact range (Turza, I. 2006). It should be noted, that the subsidence values were calculated from the edge to the centre of the extracted block in line of strike, but in line of dip the extent value could be calculated in both direction by Somosvári's formula in *NeoOffice Calc*. Because the contact conditions require that the calculated subsidence should be equal to each other by both side in the location $y = 0$ (Somosvári , Zs. 1989). The zero point is the connection point that ensures the connection between relative and EOV coordinate system. The zero point equals to centre of the extracted mining block, but the maximum subsidence would not occur here.

Resulting from the exponential function the subsidence of grid points decreasing to zero. The maximum extent of sag was developed belonging to the third level and it belongs to the subsidence trough too. Horizontal extent reaches 3,255.52 m in W–E direction (y) from 597,792.24 to 601,047.76 (EOV) and 2,055.52 m in S–N direction (x) from 98,292.24 to 100,347.76 (EOV) in western side of the structural block. But in eastern side of the block its extent reaches 1,546.96 m in W–E direction from 599,951.52 to 601,498.49 (EOV) and 1,476.96 m in S–N direction from 98,521.52 to 100,048.48 (EOV). The extent of other levels may be calculated in cognition of the connected point in EOV and impact parameter.

GIS modelling

The relative coordinates were calculated to EOV according to connection point. The 50×50 m grid points were imported to *Grass GIS* for generating the vector file (*Figure 2*). On the west side 4658 and on the east side 1721 grid points were totally calculated in three level of the +1 structural block (*Table 2*)[3]. The intermediate points were interpolated with *"v.surf.rst"* command in each level and the surface of the sags was determined.

The theoretical surfaces of sags on the west and the east side partly overlap therefore the sags were totalled to determine the subsidence trough (*Figure 3*). The map of trough was reclassified in eight categories. In the zero

[3] β = angle of draw in degree; r = impact range; *CP* = connection point in relative and in EOV coordinate system; *IP* = impacts parameter in West, East, North and South direction; *Points* = amount of grid points in 50×50 m.

Table 2. The horizontal extent of subsidence in mining levels of +1 structural block and the number of the calculated points

Block and levels	β [°]	r [m]	CP [y;x]	CP EOV [y;x]	IP Center [y;x]	IP W	IP E	IP S	IP N	Points
+1 W 1.	43.84	486.01	−800 −75	599,495 99,395	600,295 99,470	2,086.00	486.00	636.00	486.00	1,087
+1 W 2.	38.83	695.57	−750 −65	599,480 99,385	600,230 99,450	2,195.57	695.57	825.57	695.57	1493
+1 W 3.	35.53	927.76	−700 −100	599,470 99,320	600,120 99,420	2,327.76	927.76	1127.76	927.76	2078
Sum										4658
+1 E 1.	43.84	364.87	−150 −125	600,605 99,285	600,755 99,410	647.87	364.87	614.87	364.87	369
+1 E 2.	41.81	519.22	−200 −165	600,715 99,245	600,915 99,395	919.22	519.22	849.22	519.22	664
+1 E 3.	41.75	623.48	−150 −115	600,725 99,295	600,875 99,410	923.48	623.48	853.48	623.48	688

category, there is no vertical displacement or the value is negligible in terms of surface modification. But the negligible (0–-1) values play a role in the horizontal extent that it was represented by impacts parameter. The first category is the utmost and extends on area of 136.75 hectares (*Table 3*).

Table 3. The reclassified subsidence categories and their extension

Category	Area (ha)
1	136.75
2	37.86
3	23.48
4	17.04
5	15.02
6	11.63
7	1.69

The maximum value of the subsidence is known in sag from the calculated point of the relative grid. But the totalled maximum was queried only from interpolated trough. The minimum point of W–E profile curvature is −27.05 m on West and −32.15 m on East side of the trough (*Figure 3, Table 4*).

The maximum subsidence values are shifted to North. It is clearly visible on the N–S cross-section profile, because the general SSW dip effects closeness of the coal seams to the surface (*Figure 3*). Thereafter, trough DEM was extracted from the recent surface DEM to analyse a theoretical surface changing (*Figure 4*).

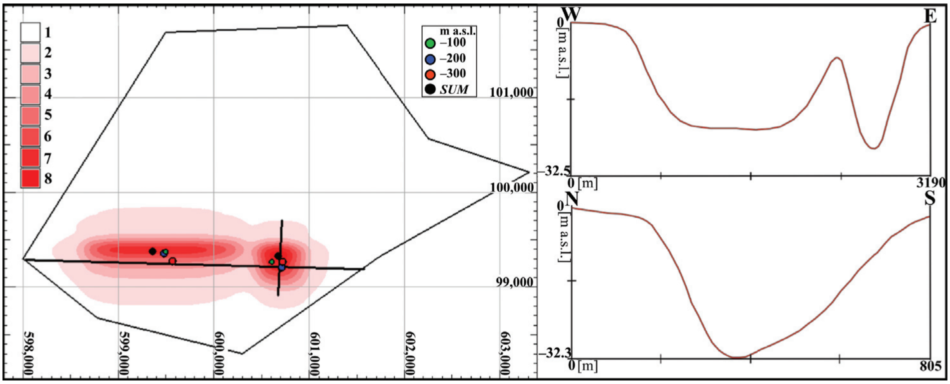

Fig. 3. Interpolated and totalled subsidence value of the trough and its WE and NS profile. 1 = 0 – (− 1); 2 = (− 1) – (−5); 3 = (− 5) – (−10); 4 = (−10) – (−15); 5 = (−15) – (−20); 6 = (−20) – (−25); 7 = (−25) – (−30); 8 = (−30) – (−35)

Table 4. Maximum subsidence of mining levels and trough

Level	S_{max} [m]	S_{max} EOV [y;x]
-100_W	−7.46	599,495; 99,370
-200_W	−10.80	599,480; 99,350
-300_W	−10.78	599,570; 99,270
Sum	*−27.05*	*599,360; 99,380*
-100_E	−8.71	600,605; 99,260
-200_E	−14.07	600,715; 99,210
-300_E	−10.46	600,725; 99,260
Sum	*−32.15*	*600,673; 99,326*

Discussion

Ground subsidence is simply defined as a lowering of the land surface elevation (Larson, K. J. *et al.* 1999). The vertical movements would be manifest not only in lowering of the elevation, but in changes of slope that seems on cross-sections of the *Fig. 4*. The utmost subsidence would occur in the East side of the trough in the upper section of theVáralja Creek. Accordingly, the erosion base would sink and the process explains its effect to every stream in the vicinity of the trough too.

In the calculation process, the 50×50 m grid was not worth to engross, because only 1–2 m difference are seemed between two neighbouring point in this resolution. It was essential to use the adequate interpolation method. The regularized spline tension method was suitable, because this algorithm

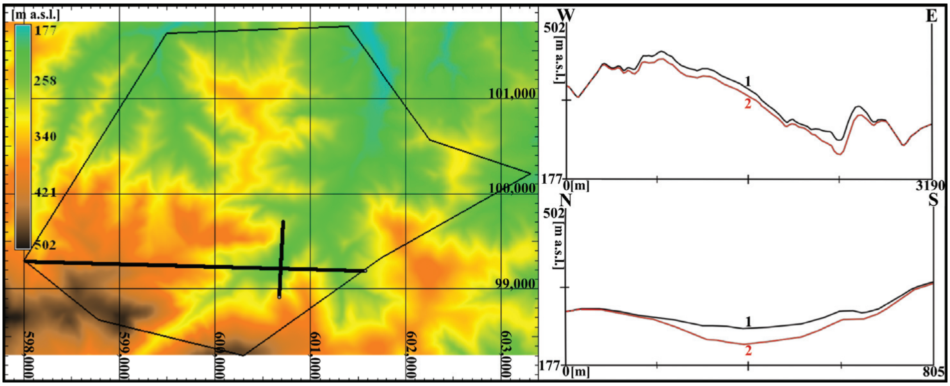

Fig. 4. Digital Elevation Model after subsidence and WE and NS profile of the elevation changes. – 1 = recent; 2 = subsidence surface (red)

produces smooth slope curves that fulfil the condition of orthogonality to contour lines better than standard grid (Mitášová, H. and Mitáš, L. 1993; Mitášová, H. and Hofierka, J. 1993).

The mean of the elevation was involved to the calculations because the separate query of the cover thickness would be difficult for each point. And it is also not justified because the bore log is unknown at each point for calculation of the rock parameters.

Conclusion

The horizontal extent of subsidence trough is 3,706.25 m from 597,792.24 to 601,498.49 in line of y, and 2,055.52 m from 98,292.24 to 100,347.76 in line of x. The extension of the trough is 2.44 km^2 without the zero category. The maximum subsidence is -27.05 on West and - 32.15 m on East side of the trough.

The applied model is suitable to calculation of the conceptual subsidence trough, which give a guideline to the geodesic surveying after starting mining. Thus the location of the maximum vertical movements and their horizontal extent would be recognized.

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Geomorphology and environmental history in the Drava valley, near Berzence

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Abstract

This geomorphological and environmental history case study aims at reconstructing the environmental conditions and the different ways of land use in the surroundings of Berzence in the Drava valley. The area's geomorphological evolution is examined with regards to the natural processes and the human impact that formed the landscape. The results indicate a tendency in the surface waters and underground waters for drying, mainly due to water regulation and canalization works. Findings from archaeological field walks, certified documents, and old maps are integrated in the reconstruction. Special attention is given to medieval fishing areas, iron processing sites and settlement structures.

Keywords: geomorphology, geoarchaeology, environmental history, Drava, Ždala, fishing, iron processing, water regulation

Introduction

The interaction between man and his environment in different historical eras can be better understood by getting acquainted with the landscape, which determines the lifestyle of its inhabitants in many respects, while bearing the traces of environmental impacts exerted by the society.

The human-environmental interaction has been studied in the Hungarian-Croatian border zone within three Hungarian settlements in Somogy County, Berzence, Somogyudvarhely, Gyékényes and two villages in Croatia, Gola and Ždala *(Figure 1).*

A current academic project aims at reconstructing the medieval settlement structure and the different ways of land use. The project involves explorations in four scientific disciplines: as historical study concerning a 14th century terrier describing the area in exceptional detail, data analysis of archaeological sites recorded during field survey, geoarchaeological studies based on pollen analysis of two samples, and a geomorphological survey. The

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Fig. 1. Location map of the study area. Viczián, I. – 1 = Drava plain; 2 = territories rising above the Drava plain with steep slopes; 3 = Hungarian-Croatian border; 4 = study area (*Figure 2*); 5 = area *of Figure 6*

aim of the present work is to describe the environmental (geomorphological, geological, hydrographical, hydrological) characteristics of the area, with special regards to environmental history, as well as to place these results into a historical-archaeological context.

A detailed geomorphological map of the area was prepared based on scientific publications and studies on geography, archaeology, history and local history, as well as using topographic maps, maps of the first to third military surveys, archive maps from the 18–19th centuries, georeferenced military aerial photographs from the last 60 years, and satellite images.

Geomorphological conditions

Although the publications dealing with the geomorphological conditions of the Drava river valley (Lovász, Gy. 1964, 1972; Bognár, A. and Schweitzer, F. 2005; Bognár, A. *et al*. 2009) typically concern large areas, mainly the entire territory of the Drava valley, they also provide fundamental conclusions regarding the geomorphological evolution of our study area. These studies have revealed that river channel variations and their effects on the geomorphic evolution are essentially determined by tectonic movements within the Drava valley. It was proven with geomorphological methods that a number of sub-basins exist in the Drava graben, characterised by multi-phase differential tectonic movements.

Two hydroelectric power plants were planned to be constructed on the Drava River in Croatia, in the immediate vicinity of our study area, one at Đurđevac (Gyurgyevác) (Jaskó, S. 1996) and another at Novo Virje (Sečen, V. *et al*. 2003). Both plans were eventually abandoned.

The current study area in the Drava valley is bordered on the north by the southern edge of the micro-region of Inner Somogy, defined by the settlements of Gyékényes, Berzence, Somogyudvarhely, while on the south by the Zsdála (Ždala) stream, also acting as the country border *(Figure 2)*.

The present landscape and the landforms were shaped predominantly by the Drava's fluvial processes in the late Pleistocene and during the Holocene phases. The area is geomorphologically divided into two different parts. The southern one belongs to the Central Drava valley microregion with distinctive fluvial landforms of the Drava from the late Holocene. The micro-region ends in a steep escarpment whose height is 8–10 m between Gyékényes and Berzence and 30 m between Berzence and Somogyudvarhely *(Photo 1)*. The sandy area of the Inner Somogy micro-region lies to the north of the escarpment. The changes of the Drava's channel configuration and the geomorphological evolution of the area were greatly determined by the different tectonic movements. The Drava valley narrows at the Zákány block then widens to the north into the study area, which tectonically corresponds to the Gyékényes–Gola sub-basin, and then it turns to the south approaching the escarpment at Bélavár.

The evolution of the alluvial fan in the Gyékényes–Gola sub-basin can be determined by three tectonically and geomorphologically successive periods (Lovász, Gy. *et al.* 2009) as follows. The earliest period was the end of the Pleistocene and the beginning of the Holocene, when the Drava flowed much further north, in the zone between the Zsdála stream and the scarp. The escarpment reflects the tectonic line at the boundary of the two micro-regions, the rising Inner Somogy and the subsiding Drava river valley. Besides, the lateral erosion of the Drava river has played a fundamental role in forming the scarp. The sandy sediments, which build up the escarpment, were also deposited by the meandering Drava and were partly reworked by the wind (Marosi, S. 1970). The second period was in the early Holocene, when the Drava basin was subsiding and the Zala Hills experienced uplift. The Drava has developed its alluvial fan and plain, providing the present geomorphological and geological character of the landscape. During the third period, in the second half of the

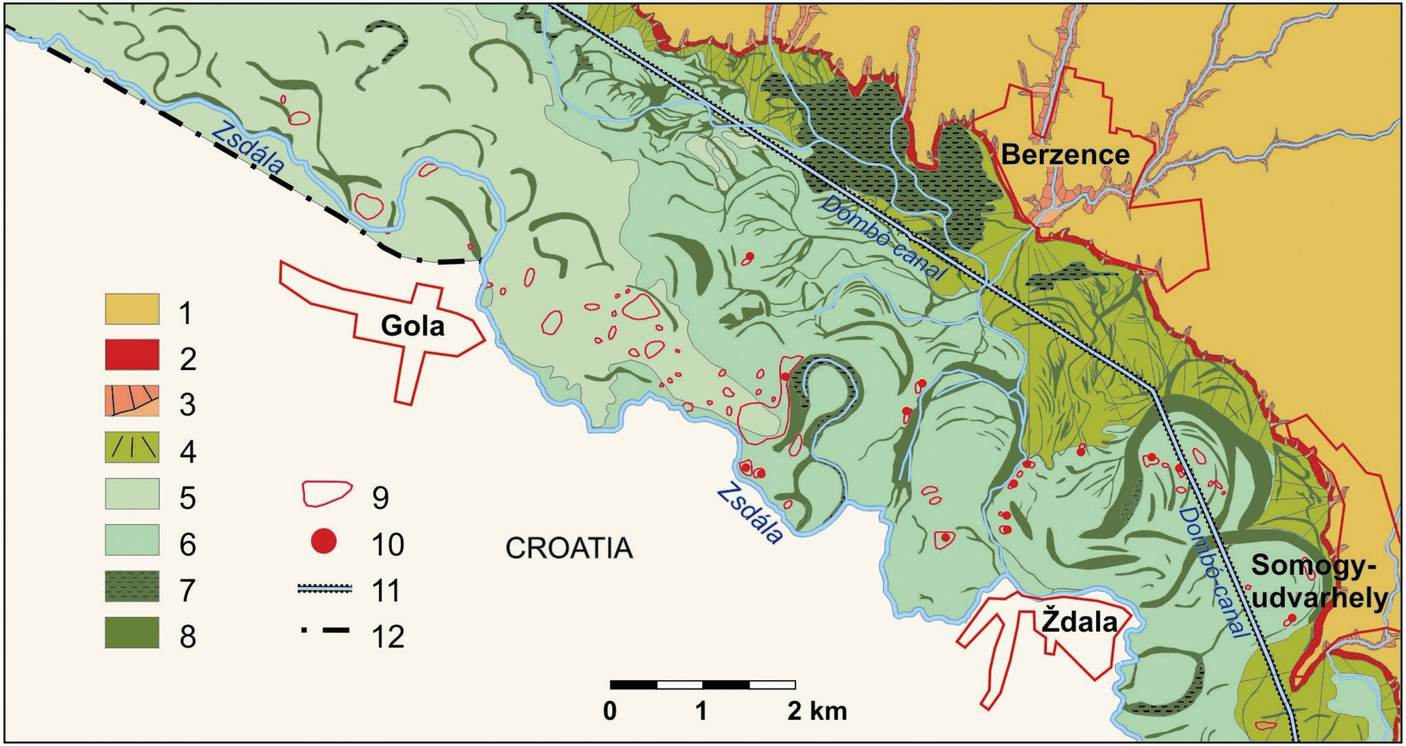

Fig. 2. Geomorphological map of the study area with archaeological sites from the Medieval Period. – 1 = alluvial plain with wind-blown sand forms; 2 = escarpment; 3 = stream valleys and gullies; 4 = alluvial fans; 5 = higher alluvial plain; 6 = lower alluvial plain; 7 = wetlands and marshy areas; 8 = low-lying paleochannels and channels of the perennial and ephemeral streams; 9 = archaeological sites from the Medieval Period; 10 = archaeological finds related to iron smelting activity; 11 = Dombó canal; 12 = Hungarian-Croatian border

Photo 1. Escarpment at Somogyudvarhely. Photo by Viczián, I. 2010

Holocene, the Drava abandoned its former channel by shifting further south, and obtained its current location (Lovász, Gy. *et al*. 2009).

Let us consider the geomorphological and environmental conditions of the study area from north to south. Since the environmental history studies did not touch in much detail the area of Inner Somogy, it will only be shortly dealt with here and its landforms are not shown in detail on the geomorphological map either. Samples from boreholes drilled on the margin of Inner Somogy near the escarpment were typically alluvial sand of the Drava with some intercalated layers of muddy, sandy and gravelly sediments. The area elevated in the Wurm and its surface were no longer formed by the main river, but primarily by the wind and the erosion of the streams shaping aeolian (wind-blown sand) and fluvial (gullies, erosional valleys) landforms (Lovász, Gy. 1964).

The escarpment, which forms the boundary between the two micro-regions, was developed in the late Pleistocene and early Holocene, when its profile was sapped and eroded by the Drava. The landforms of former river channels are quite recognisable at the foot and in the body of the scarp (*Figure 2*). Under the scarp, there are alluvial plains of low relief with streams that divide and flow in an intricately branching pattern. In some places they form wetlands and marshy areas. These areas had mostly been drained with the construction of the Dombó canal, but in other places the wetlands survived.

Flat alluvial fans are being deposited where the streams arriving from Inner Somogy enter the Drava valley at the foot of the scarp. It is their sediments that filled up partly or completely the late Holocene Drava channels. The neighbouring alluvial cones converge into a compound alluvial fan. In some places, marshy areas or fragments of former Drava channels are located between the fans.

The former 1 to 2 km wide swampy belt used to stretch along the escarpment. The wetland was supplied by the ground water from the alluvial fans and by the surface streams. The ground water level is still regulated by the Drava's regime. The wetland belt at the foot of the escarpment is dissected by the alluvial fans of the streams (Tekeres-berki, Lipéki and Vadaskerti streams at Berzence) flowing down from the north. The valleys and gullies of these streams provide a natural downward route from the settlements located at higher altitudes to the Drava valley. The surfaces of the major fans are higher than the surrounding territories, and they also mark the location of other possible routes across the wetlands.

The geomorphological and sedimentary features of the central Drava valley micro-region were basically affected by the fluvial evolution of the Drava and the subsidence of the basin in the early Holocene. The basin was predominantly filled up with gravelly fluvial sediments. Fragments of abandoned meanders and other relict landforms of the early Holocene floodplain can be seen in the area.

The alluvial plain can be divided into two geomorphological units *(Figure 2)*. The area at a lower elevation is the *lower alluvial plain*. North of it, at a slightly higher position is the *higher alluvial plain*. Each of the relict floodplain landforms has distinct sediments. The abandoned channels are filled up by fine sediments (silt, clay), the point bars are built up by sandy gravel, while the scroll bars are characterized by sandy and silty sediments. The sandy sediments in the alluvial fans of the streams originate from Inner Somogy.

The *lower alluvial plain* lies at 114 to 119 m elevation above sea level (a.s.l.). The flatland is characterized by mostly filled up abandoned meandering channels of the Drava from the early Holocene and a series of slightly raised point bars and low-lying scroll bars. The northern part of the area lying below the escarpment is covered by the sandy deposits of the streams of Inner Somogy. The surface of the interconnected alluvial fans is dissected by perennial, ephemeral and paleochannels of the streams and forms a gentle slope towards the lower alluvial plain.

Abandoned meanders of the Drava are well recognizable in the lower alluvial plain, especially on the territory situated between the Zsdála stream and the settlements Berzence and Somogyudvarhely *(Figure 2)*. The location of the channels proves that during the early Holocene the Drava flowed further north than currently.

The flow directions of the streams were naturally adjusted to the Drava's former meanders before the Dombó canal was excavated. The meanders collected all the water within the area and led it into the Zsdála stream and the Drava river.

Remnants of former meanders are predominantly filled up. Wetlands can be found only on their lower lying areas. The ground water level has lowered over the past centuries significantly, resulting in a considerable shrinkage of wetlands (including forested swamps, marshes, riparian and lacustrine wetlands). The agricultural activity has played a significant role in the vanishing of the meanders *(Photo 2)*. The shallow depressions of the meanders disappeared, especially in those places where they have been deforested and become cultivated as arable lands.

A number of gravel pits have been operating in the study area. Gravel is exploited in large quantities from below the ground water level, which is quite close to the surface. Gravel deposited by the Drava during the early Holocene

Photo 2. The Zsdála stream bed (on the left) and a former meander surrounded by forest (in the background). Photo by Viczián, I. 2010

can be found everywhere in a wide zone along the river. Underground waters seep easily through the gravel sheet, their table matches that of the Drava. The areas lying at a lower elevation, especially the early Holocene meanders and plains are temporarily or permanently waterlogged, depending on the level of the Drava, even if the given area lies relatively distant, as far as 5–6 km from the river.

Before the water regulation measures the areas of the *lower alluvial plain* have been speckled with marshy, swampy spots; periodically large areas were waterlogged and expansive flood-plain forests were dominating the landscape.

Remnants of former meanders can also be found in the areas of the *higher alluvial plain*, although they are much less in number and much more filled up. Parallel to the Zsdála stream, which runs in former early Holocene Drava meanders or branches, remnants of the earlier sections of the Zsdála can be discovered. The mean altitude of the area is 119–122 m a.s.l., rising merely a few meters above the lower alluvial plain. Due to its higher position, the Drava's surface-forming impact became less significant than on the lower areas. Currently, aside from erosion, mass movement, deflation, and anthropogenic impacts, especially agricultural activities, play a predominant role in landform evolution of the area. The former meanders have been filled up gradually, whilst their wet, marshy remnants retreated to smaller areas. Rain water, temporary and permanent ground water springs, and shallow underground waters are drained off by a system of channels and valleys towards the nearby lower surfaces.

The *higher alluvial plain* had probably been differentiated from the lower lands already during the early Holocene. As a result of the rising of the Zala Hills, the streams flowing into the Drava from the north deposited significant amounts of alluvial sediment. Northwest of the case study area, but also affecting it, in the region of Zákány, alluvial fans of two torrent watercourses were formed, pushing the Drava bed to the south and blocking or partly filling up the previous meanders (Lovász, Gy. 1964). The *higher alluvial plain* turned into a high flood area terrace. The development of the territory at a higher elevation can only partly be explained by the process of alluvial fan formation. Similar multi-phase differential tectonic movements characterize certain parts of the young Gyékényes–Gola basin. Based on the geomorphological situation of the former riverbeds in the Drava valley area and the extent to which they are filled up, it can be assumed that the area enclosed by Berzence–Gola–Somogyudvarhely subsided more definitely than the areas lying northwest and west of it. The area of the lower alluvial plain belonged to the Drava's zone of influence for a longer time and its fluvial landforms are also more intact, than the meander ruins and filled-up oxbow lakes of the higher alluvial plain. The watercourse (today's Dombó canal) collecting the streams from Inner Somogy incised the valley at the foot of the escarpment and the alluvial fans lining it got deeper at the same pace, while simultaneously the former Drava meanders got filled up. The straggly network of streams, wetlands and marshlands diversified the landscape. Flat ridges, somewhat higher than their surroundings, and marshes with groves were found 1.5–3 km west-southwest of Berzence, along the Dombó canal.

Environmental history research based on the geomorphological conditions

Three approaches were applied during the environment reconstruction. One of them explored the *present environmental conditions* and the natural processes and phenomena owing to environmental changes. Another method examined the *human impact on the landscape* in the past centuries, inferring tendencies in environmental changes. The third approach attempted to integrate the results of the *archaeological research* and the data from *historical sources*.

Present environmental conditions

Regarding the area's present environment, it is obvious that the current settlements are typically situated at the edge of the escarpment and on the higher alluvial plain. There are no significant settlements on any of the deeper territories of the *lower alluvial plain*, dissected by meanders. At the border of the two different micro-regions, the settlements at the edge of the escarpment are generally found along stream valleys. Apart from the availability of water, the valleys provide other advantages, such as a viable access down to the Drava valley areas. In addition, alluvial fans built by the streams, being elevated above their surroundings, ensure a safe surface for transportation.

The area of the Drava valley seems like a homogeneous flatland, nevertheless the slight elevation differences and the various flood plain landforms may be significant from the viewpoint of environmental history. The research shed light on the fact that on the alluvial plains of the Drava valley, along with the surface streams and the position of the flooded areas, the level of ground water is the key factor in the human-environment interaction. The geomorphological study of the flatland plays a fundamental role in the environmental reconstruction, since even the slightest differences in few meter elevation of the various forms may determine whether the given area had been a lake, a swamp, an area with risk of inland waters or a safe surface suitable for building upon. The area's landforms are typically those of riverside flood plain, i.e. they are the remnants of an early Holocene wash land, and currently do not strictly belong to the zone of influence of the Drava river. The river runs far from the area as it has left its earlier beds and the floods do not have an immediate effect presently. Naturally, it continues to have a significant impact indirectly on the hydrogeographic conditions with changes of its water level, ground waters, and larger inundations.

Human impact on the landscape

The hydrographic situation of the Drava valley and the resulting environmental conditions have greatly been affected by the various water regulation and canalization works, gravel pits, river bend cuts on certain sections of the Drava, as well as by the construction of hydroelectric power plants and dams. Most obvious are the ponds that remain of the gravelpits. These are found south of Somogyudvarhely, while gravel production is still going on south of Berzence.

The area's hydrographic conditions have been shaped fundamentally by the creation of the Dombó canal. The First Military Survey map from 1784 does not show the canal, neither does it mark any arable lands (except for Udvarhelypuszta), only forests, meadows, groves and swampy, marshy spots. The canal was created at the very beginning of the 19th century (Szállási, S. 1936). The Dombó, running roughly parallel to the line of the scarp, collects the streams of the territory and flows into the Drava at Bélavár, south of Somogyudvarhely. The canal and its related drainage ditches collect and drain the territory's waters. Its creation made the average ground water level drop and drained the formerly marshy lands on the lower alluvial plain and on the alluvial fans of the streams at the foot of the scarp. It made the ground water risk areas at the foot of the scarp dryer, such as the groves, marshlands, alluvial fans and certain parts of the Drava's early Holocene meanders. The cultivation of the areas with persistent high ground water tables formerly, became much safer, although swamps are still found on smaller surfaces.

The Turkish traveller Evliya Çelebi (Cselebi, E. 1985), in his description of the siege of Berzence in 1664 mentions the former swamp lying along today's Dombó canal. He writes the following: a two-hour long swamp extends at the southeastern and western parts of the castle.

The canal appears on the Second Military Survey map prepared in 1859 as well as on a map from 1868, found in the National Széchényi Library, marked TK 1975 and entitled *Plot division map of the fields of Berzence market-town*. These maps also depict the changes in landscape use, showing that in the Drava valley area more ploughlands, forests, and cleared woodlands turned into agricultural use are found, usually divided into small plots. The meadows and grazing lands are mostly found near the scarp and along the Dombó canal.

This is the condition rendered also on the cadastral map kept in the Archives of Somogy County. The canal and the drainage works were created according to the socio-economical needs of the time, allowing for more arable land and ensuring grounds for the Barcs–Murakeresztúr railway, completed in 1868.

Aside from the changes in ground water conditions and land use, the Dombó canal's construction caused major changes in the system of surface streams. Previously, the extensive network of stream beds arriving from the north converged south of Berzence and flowed into the Zsdála stream via the early Holocene Drava meander, between the settlements of Berzence and Zsdála. Near the mouth is a spot named Postamalom (comprising present-day Ždala) appearing on the second military survey and in several other maps. The name Postamalom (meaning "Post mill") suggests a stream copious in water, suitable for driving a mill. Through the creation of the Dombó canal and the diversion of water, the amount of water from the streams arriving into the former Drava meander has significantly diminished, causing substantial changes in the environmental conditions of the territory. Similarly, the area's smaller watercourses have dried up.

Other canalization and drainage works have been carried out later on in the area west of Berzence as well as south of Csurgó at the foot of the scarp, on the marshy lands of the stream's valley.

Clearly, the canalization and water management initiatives of the past centuries prompted the area to dry up and the former watercourses to disappear. Other than the local impacts, the engineering interventions concerning the Drava have had a fundamental effect on the hydrogeographical condition of the examined area. During the most active period of the flood control and water regulation measures on waterways between 1805 and 1848, 62 bends were cut within 75 km on the section between the mouth of Mura to the Drava and the mouth of Drava to the Danube, which resulted in a shortening of the river's original length by 40%. Smaller cuts were performed later on, including bends on the Drava section within the examined area, namely at Botovo in 1981 and at Bélavár in 1980 (Sečen, V. *et al.* 2003). The shorter watercourse greatly increased the water's power and its bed has incised by several meters, depending on the specific section of the Drava. The ground water level of the Drava valley region is determined by the river's watercourse. The deepened Drava bed and its lower water level brought about a general decrease in the ground water level.

Since the shorter watercourse carries off the floods in a shorter time, the inundation periods have also shortened and the impact of the seepage into the soil and that of water supply have also lessened. The wetland habitat of the flood plains, the areas under temporary water coverage, and the ponds in the flood plains formerly under permanent or seasonal waterlogging stopped receiving the same amount of water during inundations. This has also decreased the ground water levels. The impact of the floods has been further diminished by human action.

The series of hydroelectric power plants constructed on the Drava balances the river's water regime, since large amounts of water are kept behind the dams. This has also caused the level of high stages to diminish and the drainage periods to shorten. The areas affected by flooding have also shrunk due to the construction of dikes. Dikes have been built on the left bank of the Drava in a length of 123.4 km, on the right bank in a length of 136 km, and along the tributaries in a length of 86.5 km (Sečen, V. *et al.* 2003). Dikes are also found in the vicinity of the case study area, between Botovo and Répás (Repaš) on both banks of the river.

The mutually reinforcing anthropogenic impacts on the river's dynamics caused a general decline in the ground water level. According to the water gauge of Botovo, the average water level of the Drava lowered 2 meters between 1876 and 1998. This is further proved by the average April ground water level measured south of the examined area, on the other side of the border in Répás forest. In 1900 the ground water flooded approximately 40% of the Répás forest territory, whereas since 1990 the ground water has not even reached the surface (Sečen, V. *et al*. 2003). Evidently, a similar process has taken place in the case study area.

Water regulation measures resulted in a massive drop of the ground water level by several meters and in the disappearance or shrinkage of swampy, marshy lands and ponds both on the Drava and on the tributaries of the Zsdála. The areas formerly characterized by high ground water levels or temporary inundation became dryer. The environment has significantly transformed in the past few centuries due to human impact. Changes in the ecological conditions, such as the clearing of former woodlands and the intensified agricultural use also brought about essential changes in the Drava valley's flora and fauna and in the general outward appearance of the landscape.

Considering the present environmental conditions, geomorphological characteristics, anthropogenic impacts and the natural rate of sedimentation on flood plain forms, the picture of the Drava valley's medieval environmental condition becomes more articulated. It can be stated that the average depth of the ground water level in the area used to be less and the hydrographical situation has much been altered. In the Middle Ages the lower areas, typically the former Drava meanders and lowland, were covered by water, forming marshy lands and ponds. On the lower alluvial plain at the time of the Drava's flooding and during rainy seasons waterlogging appeared over large areas. Generally speaking, the lower areas offered adverse conditions for the establishment of permanent settlements. The elevated landforms of the higher alluvial plain were much more suitable to carry settlements, even though their lower parts also had marshy spots and were inundated. The belt encircling the escarpment on the south had extensive marshy, swampy areas and high ground water levels and uncontrolled ramifying watercourses weaved through it. The marshy belt was interrupted by the alluvial fans of larger streams. The streams and springs carried significantly more water than today, due to more abundant water supply, higher ground water levels and less filling up of waterbeds.

The question arises whether the Zsdála stream used to be a branch of the Drava during the Middle Ages and how much impact the Drava's floods had on the area. On several maps, found in the collection of the National Széchényi Library, the Zsdála stream appears as a branch of the Drava, for instance on the map TK 2149 from 1685, on TK 1119 from 1788 and on TK 1851 *(Figure 3)* from 1850. The area enclosed by the river and the stream is shown as Répás island on many maps. Hunfalvy, J. (1865) writes about the Drava: "… it often splits into several branches and embraces smaller or larger islands. … Among its largest islands are Répás island near Berzence, southeast of Novoszelló Légrád, …" The first military survey map from 1784 shows the

Fig. 3. Fragment of a map from 1850 showing the Zsdála stream as a branch of the Drava (OSZK – TK 1851)

Zsdála as a stream taking its source from the hills near Zákány. The same is illustrated on several other 18–19th century maps. It should be noted that the Zsdála stream used to run in an early Holocene Drava bed or branch and presumably it continued to be associated with the river during the second half of the Holocene as well. The heavily filled-up streambed today approaches the river by barely one kilometre near Gyékényes in the west. Several detailed archive maps present the Zsdála flowing into the Drava south of Zákány (from 1786: MOL S 12 Div 13 No 70:7 and 70:8, from 1793: MOL S 12 Div 13 No 237:1 and 237:2, from 1802: MOL S 12 Div 18 No 72:2 and 73:2, from 1822: MOL S 12 Div 12 No 24).

On the map from 1786 the "Einflus *(Einfluss)* der Sdalla Grabens" (the inflow of the Zsdála bed) appears with a small arrow, indicating the direction of flow towards the Drava *(Figure 4)*. Based on these, the water flowing into the formerly filled-up Drava bed probably reached the river partly south of Zákány and partly, continuing along today's Zsdála bed to the east, it flowed into the Drava at Bélavár.

After the exceptionally huge, destructive floods of the Drava, the water might have retreated to its earlier channels and a smaller portion of the flood might have been drained by the Zsdála. Whether there was a closer relationship between the two watercourses during the Middle Age remains an open

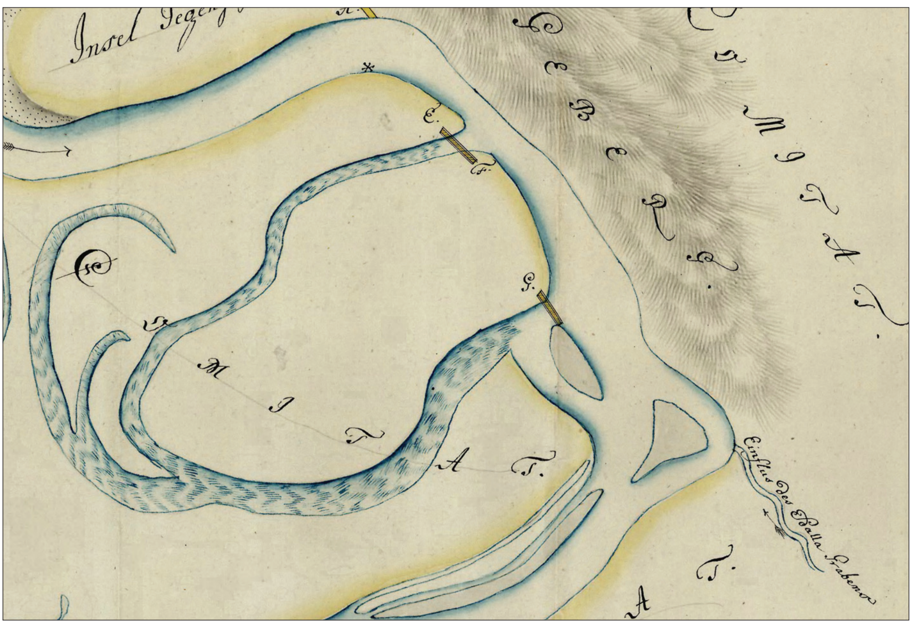

Fig. 4. Map from 1786 shows the connection of Zsdála and Drava at Zákány "Einflus *(Einfluss)* der Sdalla Grabens" = the inflow of the Zsdála bed (MOL S 12 Div 13 No 70:7)

question due to the lack of sufficient data. Nevertheless, one circumstance should be noted, namely that during the Drava's floods the river dammed up the Zsdála, strengthening the area's wetland nature and increasing the length of inundation periods.

During our geomorphological field studies, moving along the Zsdála stream, the streambed's canal-like character was conspicuous. The watercourse runs between artificial ditches through lengthy sections, its deepened bed has played a certain role in draining the surrounding marshland. Based on the maps from the last centuries however, it can be maintained that its configuration and course have not changed significantly.

Archaeological research and historical sources

Finally, let us introduce briefly some of the preliminary results of the data analysis of written sources, early maps and of archaeological field walkings intending to illustrate the ways of wetland use and the relations between fishing activities and settlement strategies.

A document from 1377 divides certain territories of former settlements between three landowners (MOL DL 6419). The description mentions approximately twenty fishponds and fish traps, and gives a picture of the features characteristic of the settlement structure and landscape usage of a floodplain area.

In the following, those features of ponds and fishing places will be discussed that emerge from the source itself. The document refers to ponds usually as *piscina*, but the terms *geregye* and *strugh* are also frequently mentioned in the terrier. The term *strugh* is derived from the slavic word *struga*, meaning watercourse, or bend (Kiss, K. 1978). Referring to *geregye,* the document referres to it as *captura piscium*, meaning fish trap. The form of the often mentioned *geregye* is known from modern, ethnographic analogues *(Photo 3)*. It is the simplest type of barrier device built of pales, sods and soil and used in fisheries of shallow and sluggish waters of inundation areas. With the help of this weir, the water is closed in its full width, and the fishes that swim up into the oxbow lakes and meanders during the time of inundation can be closed and preserved for a long time (Belényesy, M. 1953; Szilágyi, M. 2001). According to the description of Mathias Bél from the 18th century, the fishermen drove the backwater backwards when it started to flow towards the river, and at the same time they built a barrier behind them, so the water filled with fish was funnelled to another place closed by the barrier (Bél, M. 1941).

Based on our source from 1377, the above-described or a very similar device is presumed to have existed on the inundation area of the Drava. During high stages the oxbow lakes and abandoned channels were flooded and as the water level fell, the *geregye* concentrated and funnelled fish to a

Photo 3. Barrier device built of wattle, used on sluggish water of the inundation area. Bés (Ung County). Photo by Bellon, T. 1986. (Szilágyi, M. 2001)

place, where they were caught at a later time. According to a reference from the document, during floods, entire fields or meadows got under water, where fishing appeared as an organised activity of the village community, aiming not to offend each other's interests: *"when the water overflows the meadow … serfs are not allowed to set up fish traps or other devices"* or elsewhere:*"in the forests all the serfs are obliged to set up fish traps at the same time"*.

Turning to archaeological data, nearly 90 sites have been recorded within the study area, dating from prehistory to the late Medieval Period. It can be seen at first look that it was a densely settled territory during the Middle Ages, even if settlements did not exist simultaneously. At the present stage of the field walkings, traces of two larger villages and several – presumably temporary – small settlements were found dating from the Medieval Period. Both of the large villages are situated along the Zsdála stream and most of the small sites lie near or next to the Zsdála or to one of the oxbow lakes or abandoned river channels. Regarding archaeological sites on the research area, two different patterns of settlements can be distinguished. On higher terrain (119–122 m), in the western–northwestern part of the area, sites have turned up more densely and evenly distributed, while sites of lower elevation (114–119 m) to the east–southeast are principally aligned along the meanders of abandoned rivers. Additionally, several sites from the Arpadian age on the lower terrain contained finds related to iron smelting activity, such as slags, iron blooms and pieces of tuyères *(Figure 5)*. The formation of bog iron is typical in reductive environments, in areas with high ground water level, swampy and marshy lands, just as this area used to be during most of the Holocene. The presence of iron-based industrial activity during the Arpadian age, where attention was focused on the exploitation of alluvial iron ores, demonstrates the further use of wetlands as a resource for activities other than fishing.

Where might have these ponds and fishing areas been? It should be noted that the whereabouts of sites described in the title deed documents cannot always be precisely identified and possibly several of them are found beyond the area of archaeological study and geomorphological mapping. In the territory of Inner Somogy, damming up the streams of the valleys, cutting into the surface ensure the creation of ponds. Such ponds still exist today near Berzence and north of it, on the Tekeres-berki stream as well as southeast of Csurgó.

On the territory of the Drava valley, the former meanders might have served as fish-ponds or barrage areas suitable for fishing. Among them those should be considered which lay at a lower elevation, had significant surface and underground water supply, but were not yet filled up. These conditions are true mostly in case of the meanders located between Gola, Berzence and Zsdála settlements: the double meander to the west and the meander to the east that once drained the water of the streams. A stream abounding in water used to run in the eastward meander until the construction of the Dombó canal. It used to collect the waters arriving from the north, and drained them into the Zsdála stream. The average ground water level being much higher than today, this important stream collecting the waters of the area supplied sufficient water for the meander. The position of the meander allows for damming up the mentioned stream.

The other area that can be considered suitable for fishing is the double meander that lies 500 m west of the previous one. Currently, there is a gravel pit on the site of these meanders. The joint meanders did not have any watercourses arriving from far away. Nevertheless, the higher ground water level, the alluvial plain lying at a higher elevation, the ground water springs in the meander and certain circumstances allowed for enough water to be supplied from the Zsdála stream to have a permanent water surface here in the form of two ponds. When the nearby stream was dammed up (for instance, near the former Postamalom area) further water supply was possible. The southern meander is shown as a pond called "N(agy) Gerend" (today's Kis- and Nagy-Gerendai-dűlő) on a map from 1851, found in the collection of the National Széchényi Library (no. TK 1851, *Figure 3*). The area is still a marshland with alder groves. One of the two large villages, discovered during the archaeological fieldworks is located in the territory named Lankóc-puszta

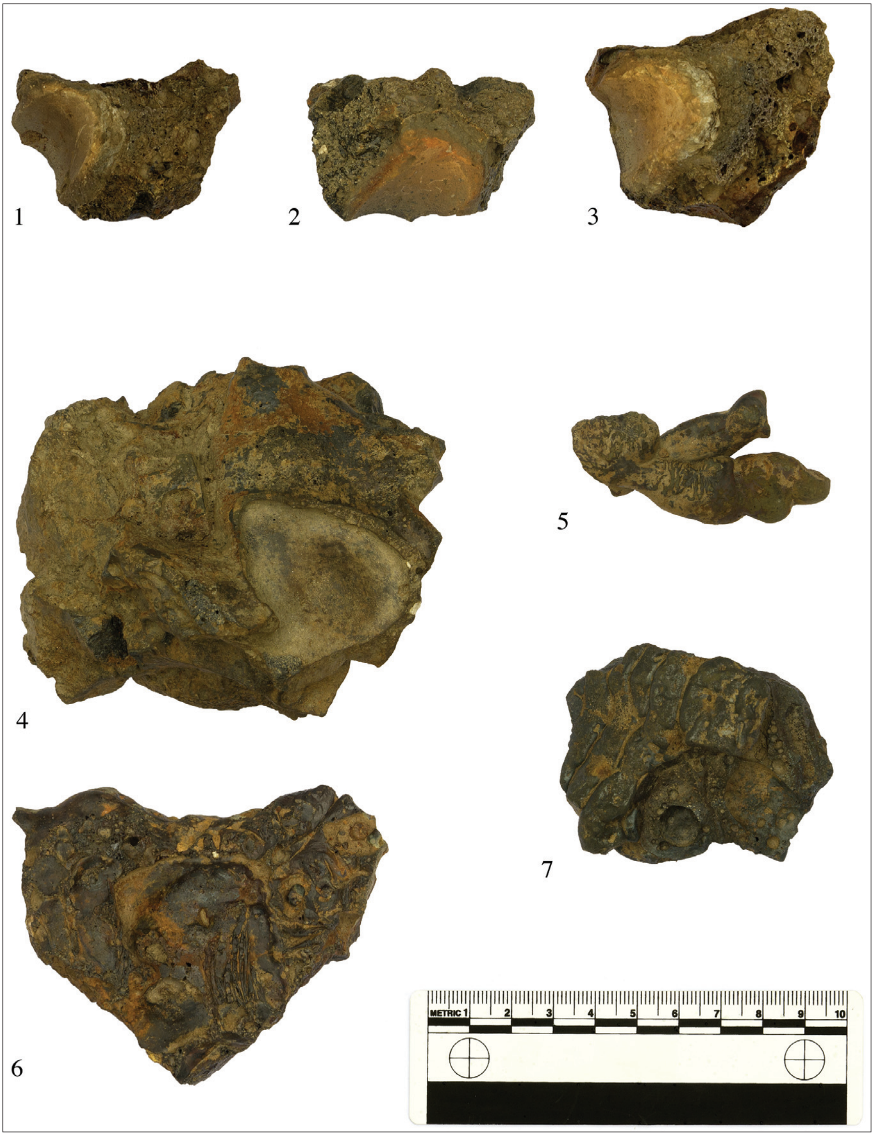

Fig. 5. Pieces of tuyères embedded in slag (1–3); pieces of slag (4–7). Photo by Zatykó, Cs.

on the northwestern part of the study area. The site can be identified with the medieval settlement of Lankóc, which is mentioned in written sources, and was inhabited from the Arpadian Era to the late Middle Ages. The other large village expands from the Zsdála stream to the double meander nearby.

Fig. 6. Traces of a medieval settlement within the township of Berzence on a satellite photograph. *Source:* Google Earth 2008

It contains finds mainly from the 15^{th}–16^{th} centuries in its southern part and potteries from the 12^{th}–14^{th} centuries in its northern area. A satellite image of the site *(Figure 6)* indicates a large brick building traced during the field walking, with lines of streets and a road leading towards an oxbow lake on the east (today's pebble quarry*)*. Smaller ponds might have formed at the foot of the escarpment on plains without an outlet and in the other meanders, although these are less probable.

Summary

This geomorphological and environmental history case study was aimed at reconstructing the medieval environmental conditions. A detailed geomorphological map of the area was prepared to provide basic information about the environment and possible land use of the specific archaeological sites. The analysis and assessment of human impact on the environment in the past centuries helped to get a picture about the changes in environmental conditions. The most significant transformations with a tendency for drying occurred primarily in the surface waters and underground waters. Gaining knowledge about the geomorphological features as well as on the natural and human-induced processes made it possible to reconstruct the hydrographic conditions of the period and the possible methods of land use.

On the one hand, geomorphological research has provided support to the preparation of archaeological field work, interpretation of the results from historical investigations, and the reconstruction of environmental conditions and land use during the different historical periods. On the other hand, the results of archaeological and historical research can contribute to the geomorphological studies considerably and provide essential data regarding the environmental conditions and changes.

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Hungary in Maps

Edited by
Károly Kocsis and Ferenc Schweitzer

Geographical Research Institute Hungarian Academy of Sciences
Budapest, 2009. 212 p.

'Hungary in Maps' is the latest volume in a series of atlases published by the Geographical Research Institute of the Hungarian Academy of Sciences. A unique publication, it combines the best features of the books and atlases that have been published in Hungary during the last decades. This work provides a clear, masterly and comprehensive overview of present-day Hungary by a distinguished team of contributors, presenting the results of research in the fields of geography, demography, economics, history, geophysics, geology, hydrology, meteorology, pedology and other earth sciences. The 172 lavish, full-colour maps and diagrams, along with 52 tables are complemented by clear, authoritative explanatory notes, revealing a fresh perspective on the anatomy of modern day Hungary. Although the emphasis is largely placed on contemporary Hungary, important sections are devoted to the historical development of the natural and human environment as well.

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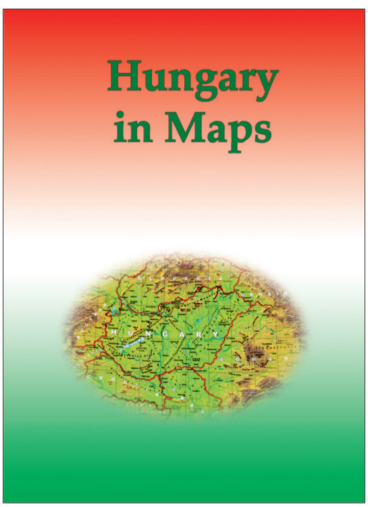

This project serves as a preliminary study for the new, 3rd edition of the National Atlas of Hungary, that is to be co-ordinated by the Geographical Research Institute of the Hungarian Academy of Sciences.

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Large-scale relief of the Slovak Karst and Aggtelek Karst (Gömör–Torna/Gemer–Turňa Karst) – a DEM-based study

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Abstract

The surface of the Gömör–Torna/Gemer–Turňa Karst (GTK) was largely formed by Pannonian or Pliocene pediplanation. Although this surface has been dissected by subsequent tectonic and fluvial processes, the present karst plateaus still preserve large pieces of this once homogeneous surface. GIS-based statistical methods have been used to calculate exact aspects and slopes of the relict surfaces using the Shuttle Radar Topography Mission digital terrain model (SRTM DTM). Topographic swath profiles proved to be especially useful in the analysis, because top levels of the relief are marked in these profiles thus facilitating the identification and quantitative characterisation of these relict surfaces.

Analysis results show that a general 1° slope is valid for most of the GTK. This very low slope angle is typical for particular karst plateaus as well as for long north to south cross-sections covering the whole karst area. Based on the smooth-filtered DTM the largest, most homogeneous surfaces (Plešivská plateau, Silická plateau) have a dominant south–south-western aspect, many other plateaus have southern aspect, whereas peripheral plateaus slope towards the margins. Uplift resulted in a uniform tilt in the western part of the area including the Slovenské rudohorie (Slovak Ore Mts.) found north of the GTK, while in the central and eastern zones the blocks uplifted to different elevations and their tilts are more varied. In these zones, the Slovenské rudohorie are above the elevation trend of GTK, therefore a fault step also separates these morphological units.

The origin of Slaná (Sajó) and Štítnik (Csetnek) valleys (east and west of Plešivská plateau) is debatable in the literature. Taking into consideration the good fit of topographic trends on opposite sides of valleys, vertical faulting can be excluded, therefore superimposition/antecedence could be the dominant process although tectonic preformation certainly had some influence in case of Štítnik valley. Before the tectonic uplift of GTK or in its early phase, water courses flowing in north to south direction existed in the central parts. Traces of these flows are observable in the present relief around Jablonovské sedlo (saddle) and Derenk.

Keywords: Gömör–Torna/Gemer–Turňa Karst, Aggtelek Karst, Slovak Karst, digital terrain analysis, tectonic geomorphology, swath analysis, Quaternary landform evolution.

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Introduction

Gömör–Torna/Gemer–Turňa Karst (GTK) is situated in a transitional position between the uplifting Carpathian mountain ranges (here: Slovenské rudohorie/Gömör–Szepesi-érchegység) and the subsiding Pannonian Basin that determine its landform evolution. The present relief largely consists of karst plateaus sharply outlined by steep slopes. Plateaus (further „p.") are separated from each other by deeply cut valleys and basins *(Figure 1).* This is particularly true for the northern, large plateaus (Plešivská p., Silická p., etc.), while the southern parts (e.g. Aggtelek p.) are more dissected and the proportion of flat areas is limited. The karst terrain is predominantly built up of middle and upper Triassic karstifiable rocks, the most extensive being the Wetterstein Limestone and Dolomite, but Gutenstein Limestone and Dolomite as well as Steinalm Limestone are also widespread. Structurally, the GTK consists of overlying nappes studied in details by previous geologic research (e.g. Less, Gy. 1998; Mello, J. 1996, 1997).

Due to the varied surface and underground landforms of the karst terrain the area has been the object of extensive geomorphological studies (Gaál L. 1997; Hevesi A. 1991; Jakál, J. 1975; Jakucs L. 1956; Láng S. 1955; Mazur, E. 1973; Mezősi G. 1984; Móga J. 1998; Sásdi L. 1990; Telbisz, T. 2001; Telbisz, T. and Móga, J. 2005; Telbisz, T. *et al.* 2006; Veress, M. 2008; Zámbó, L. 1998). The present relief of the karst plateaus is so homogeneous that researchers unanimously state the one-time existence of a large, uniform pediplanation surface. However, there are different views about the age of pediplanation. Slovak authors (Gaál, L. and Bella, P. 2005 and references therein) suggest Pannonian age, whereas certain Hungarian geographers (Láng, S. 1955; Mezősi, G. 1984; Zámbó, L. 1998) mention Pliocene age for the pediplanation. In the wake of pediplanation most part of the area became covered in a varied thickness by the coarse-grained Poltar Gravel (Borsod Gravel in Hungarian terminology), which was deposited here by rivers arriving from the northern mountainous territory. Meanwhile the GTK uplifted in several phases. During the Attic phase of Pliocene only the northern parts uplifted and fluvial incision took place there. Later on uplift stopped and subsidence followed. As a result gravelly sediments accumulated exceeding 100 m thickness in the Slaná (Sajó) and Štítnik (Csetnek) valleys as well as in the Rožňava (Rozsnyó) basin (Gaál, L. and Bella, P. 2005; Petrvalská, A. 2010). Uplift recommenced during the Pleistocene that led to the erosion of non-karstifying covering rocks giving place to karstification in a growing extent.

The relict surface conserved by the karst plateaus is characterized by southern aspect and 2–5° slope angles according to Jakucs, L. and Móga, J. (2002), Sásdi, L. (1990) and Zámbó, L. (1998). Some data about the relative displacements of particular blocks is given by Sásdi, L. (1990).

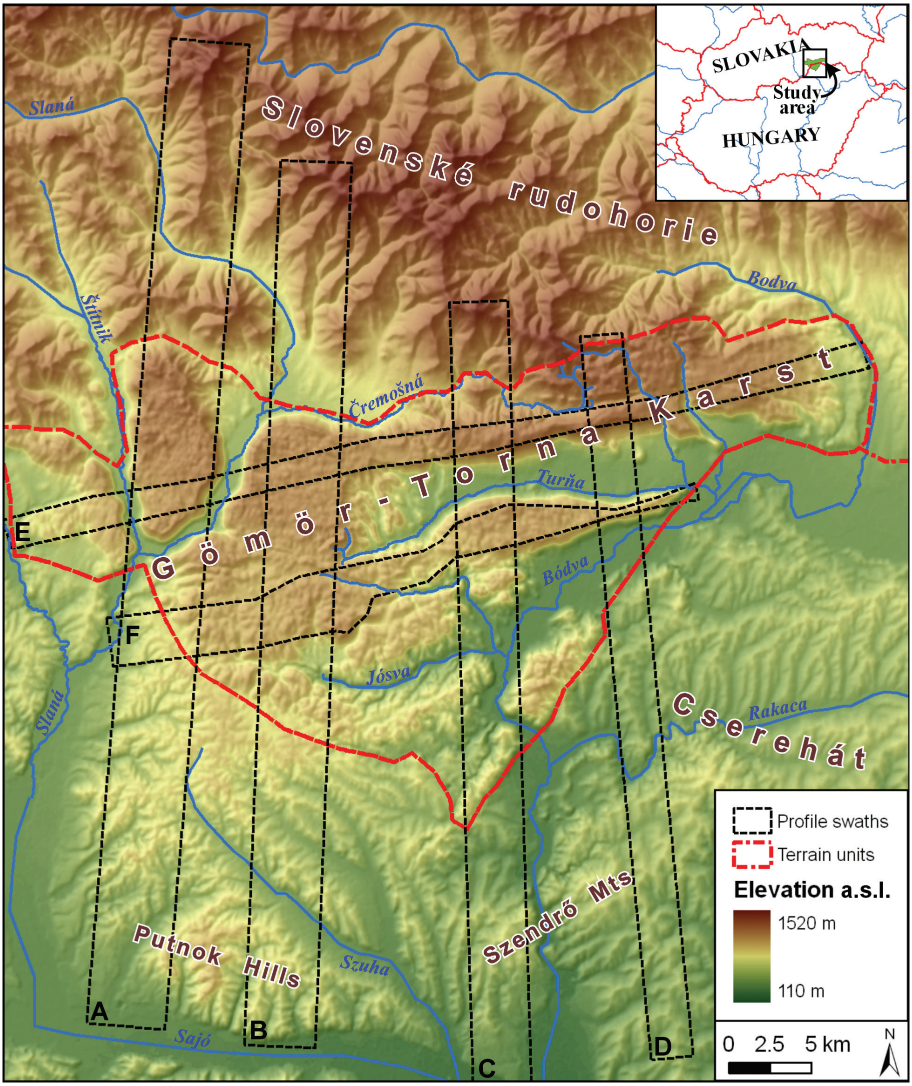


Fig. 1. Shaded and stretch-colored DEM of the study area with the terrain units of *Fig. 3* and swath locations of *figs 5* and *6*. Inset map shows the location of the study area

In spite of the wealth of geomorphological studies, digital terrain analysis of the GTK has not yet been carried out. In fact, part of the study area, the Plešivská p. was investigated by means of digital elevation models by Telbisz, T. *et al.* 2009. Another pediment surface, not far from the venue of the present study, Bükkalja was also investigated by digital terrain analysis (Vágó, J. and Hegedűs, A. 2011).

Quantitative analysis of the relief can be more precise and diverse using digital terrain models (DTMs). Characteristic levels in elevation, generalized cross-sections, slope and aspect values of single pixels and larger units can be determined that may provide important supplementary data for a better understanding of Quaternary landform evolution of the area. It is the aim of this paper.

Methodology and data

For the analysis, Shuttle Radar Topography Mission digital terrain model (SRTM DTM) was used (see e.g. Rabus, B. *et al.* 2003). It has approximately 90 m horizontal resolution, which is absolutely suitable for the morphometric study of the plateaus. This resolution implies that slope angles calculated from the SRTM data underestimate the real ones, however, in this study mostly long slopes are considered, which are not biased. Beside standard slope and aspect maps derived from the DTM, mainly topographic profiles were used in the analysis. Instead of using simple line-based profiles, swath profiles were constructed. Swath profiles reflect elevation data of a wider zone by calculating minimum, mean and maximum elevation values at a certain distance from the startline. This method has a widespread application in tectonic geomorphology (e.g. Fielding, E.J. 1996; Korup, O. *et al.* 2005; Kühni, A. and Pfiffner, O.A. 2001), since it is more reliable than arbitrary line-based cross-sections. The maximum curve of the swath profile shows the elevation of mountain tops and ridges, therefore it provides a good approximation of the relict surface. The mean curve eliminates the noise effects of particular, „irregular" minor landforms, whereas the minimum curve detects the elevation of valley bottoms.

The characteristic slopes of the studied surfaces were calculated from trendlines fitted to swath profiles. This method really gives the general trend of the surface as opposed to calculating the mean of pixel slope angles that is rather a measure of surface dissection. The basic units of the analysis were karst plateaus, which were outlined on the DTM-derived slope map *(Figure 2).* Surface slope values abruptly changed at 8° slope, therefore this limit was used as a boundary. Furthermore, plateau boundaries were finely corrected taking lithology into consideration (after Less, Gy. *et al.* 1988; Mello, J. 1996, 1997), and elevation position as well. Basin-like karstified plains such as Jósvafő p. and Silická Brezová polje were excluded from the plateau analysis. The extensive Silická p. was divided into several pieces based on internal topographic boundaries. The delimitation of units was problematic in the southern areas due to the highly dissected surface. Here, the too small subunits were merged into larger pieces (e.g. Aggtelek p.). Another problem arose in finding the eastern boundary of Jasovská p., because this plateau descends eastwards gradually. Finally,

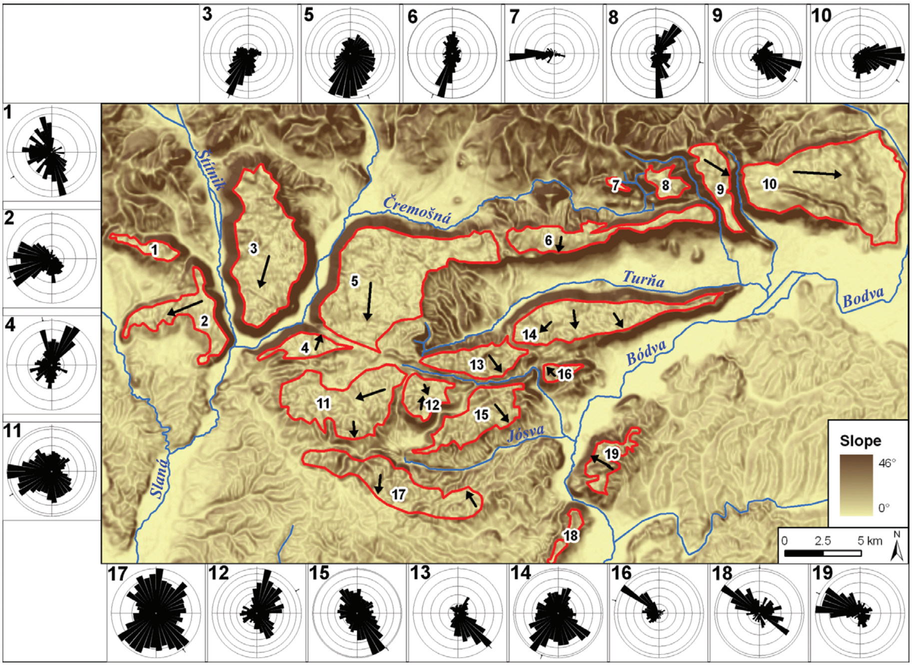


Fig. 2. Slope map of the Gömör–Torna Karst with plateau boundaries and generalized aspect roses. Arrows indicate the locally dominant aspect. Numbers indicate plateaus with reference to *Table 1.*

the plateau limit was extended to the Bodva (Bódva) river based on lithology since Wetterstein Limestone blocks outcrop even next to the river.

Altogether, 19 plateaus were identified, whose data are summarized in *Table 1.* The largest plateaus according to the above criteria are Silická p. and Jasovská p. with an area of more than 47 km^2, and the third one is Plešivská p. with 33 km^2. The smallest though topographically clearly identifiable plateau is Žl'ab Mt. with 0.6 km^2 surrounded by the tributaries of Čremošná (Csermosnya) stream.

An important goal of the present study was to determine the dominant aspects of plateaus as objectively as possible. To avoid the biasing effects of minor landforms, even the SRTM DTM was smoothed by a 450 m radius median filter in this analysis. From the smoothed DTM rose diagrams were constructed using pixel aspect values and these diagrams are suitable for the analysis of large scale aspects of plateau surfaces *(Figure 2).* Characteristic aspect directions were also marked in *Figure 2* as arrows. The exact location of arrows, though simplified for the sake of visibility, were set based on the aspect map (which is not published here).

Table 1. Dominant aspect and trendline slope data of the plateaus

Plateau name	Area (km^2)	Dominant aspect	Swath azimuth	Trendline slope
1. Jelšavská/Jolsvai p.	3.0	NNW, SSE, W	260	1.26
2. Koniarska/Konyárt p.	11.7	WSW	245	4.77; 1.22
3. Plešivská/Pelsőci p.	33.0	SSW	205	1.45 (1.6; 2.88; 0)
4. Bučina/Bikk p.	5.2	NNE	215	0
5. Silická/Szilicei p.	47.6	S	190	-0.09; 2.91
6. Horný/Felső Mt.	13.3	SSW	195	1.32; 2.19
7. Žľab/Mészkő Mt.	0.6	W	-	-
8. Bôrčianska/Barkai p.	3.4	NE, S	175	0; 4.22
9. Zádielska/Szádelői p.	8.0	SE	130	2.15; 7.28; 0
10. Jasovská/Jászói p.	47.1	E	95	0.6; 3.64
11. Kečovská/Kecső-Haragistya p.	23.9	E, SE, S	250	1.36; 0.24
12. Nagyoldal	6.2	NNE, SE	200	0.8; -3.88
13. W-Alsó Mt.	9.8	SE	135	4.06; 0; 4.72
14. E-Alsó Mt.	21.3	SW,S,SE	175	0.51
15. Szinpetri p.	13.2	SSE	150	0.86
16. Páska-bükk	1.9	NE	120	-5.29
17. Aggtelek p.	20.7	NW-NE, SW-SE	180	1.23
18. Rudabánya Mts.	2.1	NW, SE	-	-
19. Szalonna Mts.	5.5	WNW	-	-

Trendline slopes were calculated from swath profiles with azimuths given in this table. In case of compound surfaces, several trend slopes are given in an approximately N–S order. Exception is Plešivská p., where the first value refers to the entire plateau. Slope values were not calculated for 7 (too small) and 18, 19 (too narrow)

Results

Elevation and slope distributions

At first, the whole study area (as in *Figure 1*) was distributed into three large units: Slovenské rudohorie, GTK and southern hills (this latter unit comprises the hilly landscapes found south of the GTK, namely Putnok Hills, Szendrő Mts. and parts of Cserehát). These units were compared using the statistical distributions of the two most important terrain parameters, elevation and slope *(Figure 3).* The transitional position of GTK is reflected in the elevation histograms. At first, it is surprising that the most frequent elevation categories in the GTK histogram are related to relatively low levels (150–160 m; 190–200 m and 260–270 m a.s.l.) that is due to the largely extensive low-elevation valley bottoms belonging to the GTK (Bódva, Turňa and Slaná, respectively). These levels are very similar to the dominant 180–240 m of the southern hills. Higher up, there are peaks at 340–350 m elevation, which is the characteristic level of Aggtelek p. and at 530–590 m elevation, which is the most frequent level of the southern part of Plešivská p., Silická p., Alsó Mt., Nagyoldal, Jelšavská p., southern part of Zádielska p., central part of Jasovská p. The proportion of

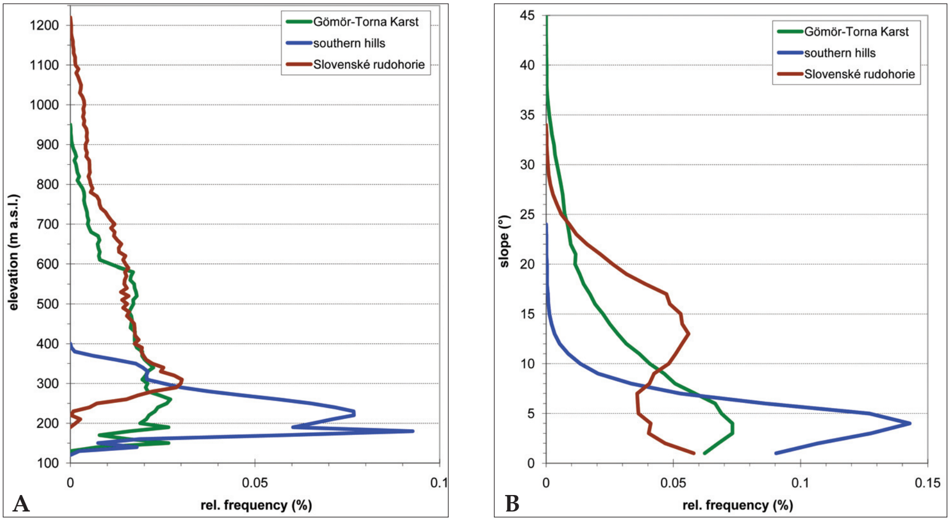


Fig. 3. General terrain characteristics of the study area. The boundaries of the three units (Slovenské rudohorie, Gömör–Torna Karst and the southern hills, including Putnok Hills, Szendrő Mts. and parts of Cserehát) are shown in *Fig. 1.* – A = Elevation distribution; B = Slope distribution

areas even higher abruptly decreases and is markedly less than in the Slovenské rudohorie. A less significant peak is however present at 690–700 m elevation due to the northern part of Plešivská p., Horný Mt. and the western part of Jasovská p.

The elevation distributions of each plateau are presented in *Figure 4.* This clearly supports the flatness of most plateaus, since in most cases, half of the terrain (the part represented by the box in *Figure 4*) is generally found within a 40 m high elevation range. Nevertheless, some exceptions exist from this rule: Jasovská p. (10), which gradually lowers towards the east, Zádielska p. (9) having a 200 m drop towards south and the very extensive Plešivská p. sloping towards south–south-west (3). In turn, the largest Silická p. has a strikingly narrow elevation range. Furthermore, based on this figure, it is clear, that the highest level is represented not by Plešivská p. as it is mentioned by some authors erroneously (Zámbó L. 1998) but by the north–eastern plateaus, namely the tiny Žl'ab Mt. (7) and Bôrčianska p. (8) being the highest and Horný Mt. (6) as well as Zádielska p. (9).

Slope histograms *(Figure 3b)* also discriminate the three main units. The characteristic 4° slope of the southern hills means that in spite of the intense fluvial dissection, the slopes of this morphological unit are gentle. The comparison of Slovenské rudohorie and GTK slope histograms clearly demonstrate the main characteristics of karst terrains, i.e. the GTK is the „leader" both

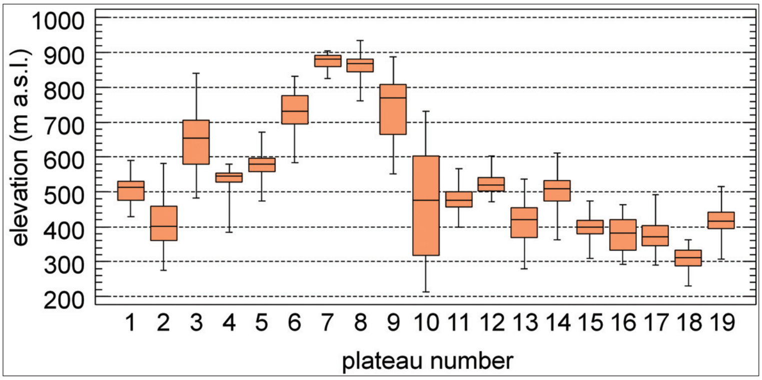


Fig. 4. Comparison of plateau elevation distributions (boxes represent the interquartile range; whiskers the full range; the box-dividing line is the median). For plateau numeration see *Table 1.*

in the gentle slope (<9°) category (due to the wide valley bottoms and plain plateaus) as well as in the steepest slope (>24°) category, which is in turn due to the steep plateau edges and gorge valley sides. On the contrary, in the medium slope categories, the Slovenské rudohorie, which are of predominantly fluvially formed have higher proportions.

Dominant aspect and slope trends of the plateaus

In most cases, aspect rose diagrams *(Figure 2)* provide a well-interpretable dominant direction. Nevertheless, the picture is more complicated where the plateau is dissected by larger valleys not removed by the DTM-smoothing (e.g. Aggtelek p.), because valley side aspects are also represented in the rose diagrams, therefore angle categories rectangular to the original flow directions are emphasized. Similarly, in case of too narrow plateaus (e.g. Rudabánya Mts.), aspect directions at right angle to the strike are more pronounced due to the regression of edge slopes.

The surface of the two largest plateaus (Plešivská p. and Silická p.) and Horný Mt. basically slope towards south–south-west. Marginal plateaus generally slope outwards. In the north-west, Jelšavská p. and Koniarska p. slope towards west–south-west, however it is not the main direction in the Jelšavská rose diagram, because north–north-west and south–south-east directions overcome this, probably due to the narrowness of the plateau. In the north–east, Zádielska p. and Jasovská p. face to east–south–east and east, respectively. In the south–west, Kečovská-Haragistya p. slopes towards west–south–west, whereas in south-east the easternmost part of Alsó Mt. faces south-east. Thus, based on the aspect analysis, the aforementioned plateaus seem to have preserved the large-scale morphology of the pediplanated surface.

„Irregular" dominant aspects are found in Rudabánya Mts. and Szalonna Mts. (both slope towards north–west) as well as in Bučina p., the southern part of Nagyoldal (oriented towards north–north-east) and in the eastern part of Aggtelek p. (towards north–north-west). Smaller exceptions are Páska-bükk (towards north–west), Žl'ab Mt. (towards west) and Bôrčianska p. (towards north–east).

Minor irregularities can be explained by former valleys, but major anomalies are more likely of tectonic origin, especially the relatively flat Bučina p. and Nagyoldal could have a north–north-eastern tilt relative to other units. Tectonic tilt could also produce the north-western aspect of Szalonna Mts. and Rudabánya Mts.

Swath profiles parallel with the main directions inferred from the rose diagrams were created for each plateau (except the smallest Žl'ab Mt. as well as Rudabánya and Szalonna Mts., which are not interpretable in this context). Trendlines were fitted to these profiles and the general slopes of plateaus were calculated from the trend. Swath azimuths and trendline slopes are given in *Table 1.* Some plateaus can be divided into several parts based on slope trends, in these cases, several slope values are provided in an approximate north to south order.

Negative values mark that the slope is opposite to the swath azimuth. These data make up an essential part of the present surface analysis. Based on these data, it is stated that the general slopes are typically very gentle (lower than is usually mentioned in the above cited papers), between 0.5° and 1.5°. Significant deviations from these values are considered anomalies, which require explanation.

Negative values refer to plateaus already mentioned in the previous paragraph (Nagyoldal, Páska-bükk) and suggest either tectonic tilt (Nagyoldal) or the existence of a former valley (Páska-bükk), perhaps both. Beside negative values, there are zero slopes as well, marking large, almost flat terrains, particularly the northern part of Silická p., but other examples are the southern part of Plešivská p., Bučina p., northern part of Bôrčianska p., southern part of Zádielska p. and western part of Alsó Mt. Supposedly, these zero-slope surfaces were influenced by differential tilting during Quaternary tectonic uplift.

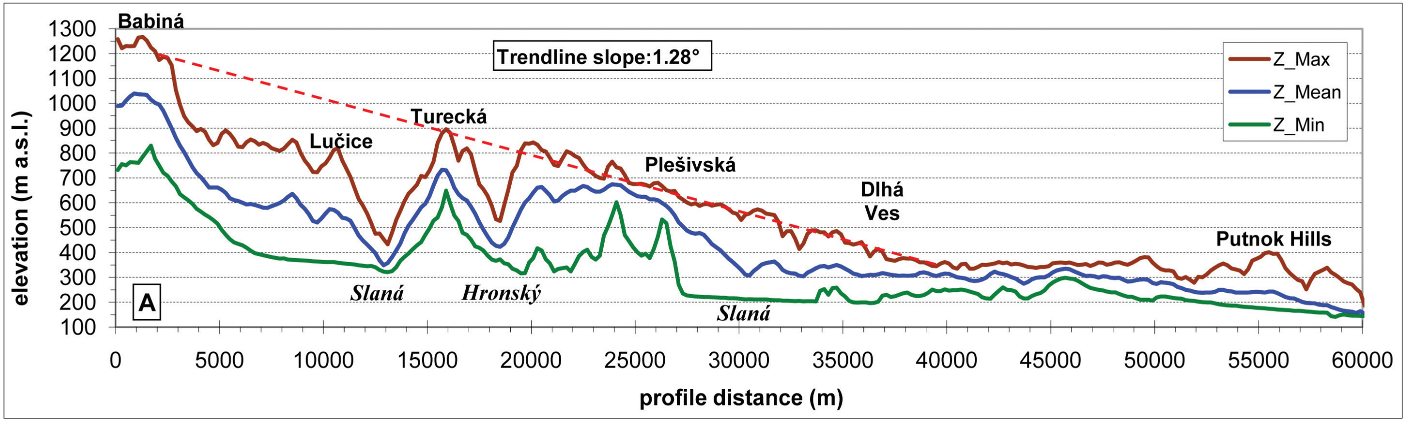
On the contrary, one may find relatively steep (ca 3–7°) intraplateau steps in the Koniarska p., Jasovská p., southern part of Plešivská p., southern part of Silická p., Bôrčianska p., Zádielska p. and the western part of Alsó Mt. The first two examples are due to the relatively steep outside lowering of GTK. The other examples are linked to tectonic lines (Pasková/Páskaháza–Silica/Szilice line, Miglinc-Čremošná line and Derenk depression).

Topographic swath profile analysis

Long swath profiles (with 40–60 km length) were created to study the large-scale uniformity of slopes in GTK *(Figure 5).* Four swath profiles *(Figure 5A–D)* have nearly north to south directions and trend from the Slovenské rudohorie to the southern valley segment of Sajó.

In the westernmost profile *(Figure 5A)* it is observed that the level of Turecká (Török-hegy) and even the elevation of Babiná (Bábaszék) fits well to the northern extension of the Plešivská p. trend. Taking it into account, the relatively low elevation of Lučice ridge can be explained by differential erosion only and tectonic segmentation is not evident in this swath. The southern continuation of the Plešivská p. trend fits even better to the surface down to the line of Dlhá Ves (Gömörhosszúszó). Amazingly, the Slaná valley is hardly detectable in the maximum curve that proves the similarity of top levels at both sides of the valley. The longscale validity of slope trendline suggests that this zone moved as a large unit during tectonic uplift. The general 1.28° slope of the trend is well within the slope range of individual plateaus. Again, this fact supports the tectonic unity of the western swath down to Dlhá Ves. Nevertheless, south of it the karstifiable rocks are covered, and the maximum curve becomes almost horizontal. This implies that since the last sedimentation, this area has escaped tectonic tilting and only slight uplift took place here causing the remarkable fluvial dissection observable in the DTM as well *(Figure 1).* The relief is increased only in the southernmost part of the profile, where the Putnok Hills stand out with erosional residues of the Poltár (Borsod) Gravel sediments that once covered the whole area. In turn, the mean and minimum curves show slightly decreasing southward trends.

The second swath profile *(Figure 5B)* shows some similarities to the first one, but there are several different details. Considering the karst area of this section it is also possible to recognise a trend though the fit is not as good as in the westernmost swath. The northern continuation of the trend slightly shoot over Rákoš (Rákos) Mt. but given the uncertainties it is supposed that this could be part of the same palaeosurface. In contrast, the elevation of Skalisko (Nagy-kő) is much higher than the estimation from the trend that suggests a separated, higher-rate tectonic uplift of Slovenské rudohorie in this section. The karst terrain ends with a sharp north-facing cliff at Čremošná valley. The aforementioned striking flatness of Silická p. is also discernible in the swath profile and its northern parts are found below the trendline. Opposedly, the also flat and faintly north-facing Nagyoldal is above the trend. In fact, it seems that Silická p. and Nagyoldal share a common and flatter trend. At the southern end of open karst, just south of Aggtelek p., there is a drop in the maximum curve, but the decreasing trend is observed down to about 40 km along the profile, from where the surface becomes constant. Therefore, in this swath, the



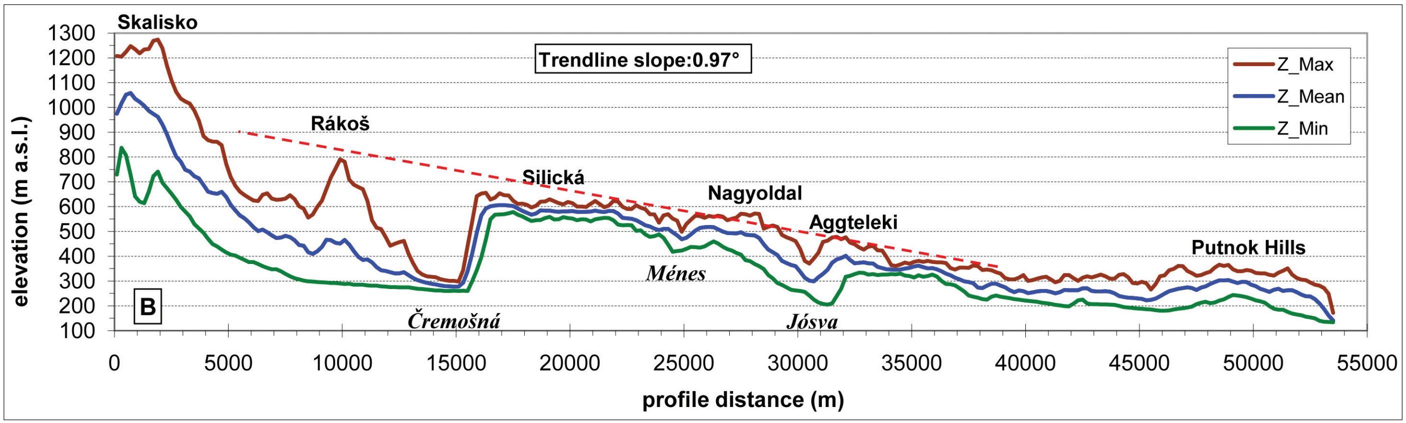
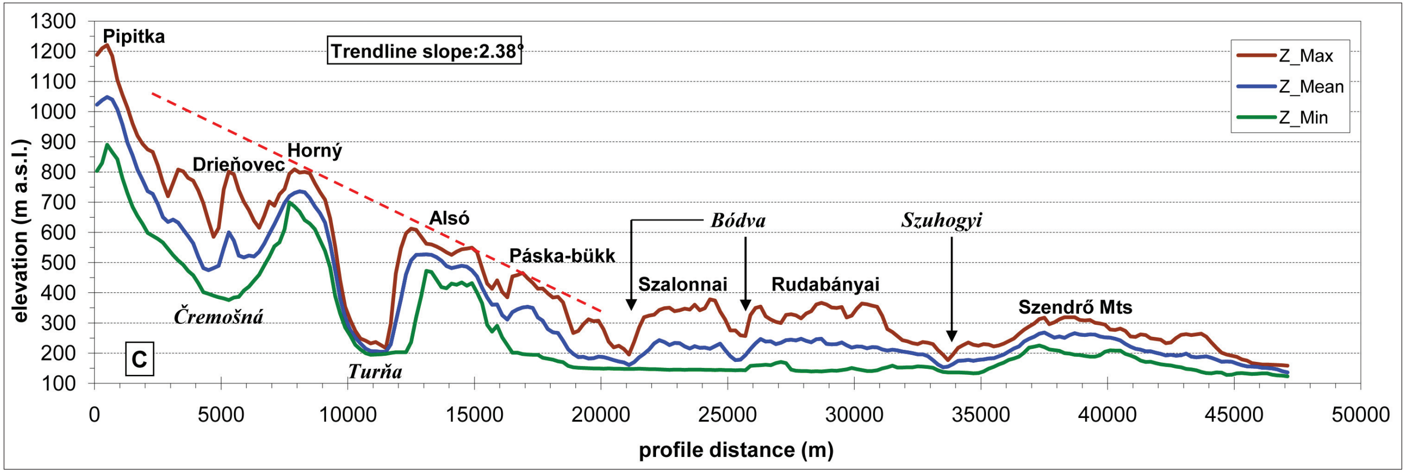


Fig. 5. Swath profiles across the study area (~N–S profiles: A, B, C, D; ~WSW–ENE profiles: E, F). Red, dashed lines are elevation trendlines fitted to the maximum curve. For profile locations see *Fig. 1.*



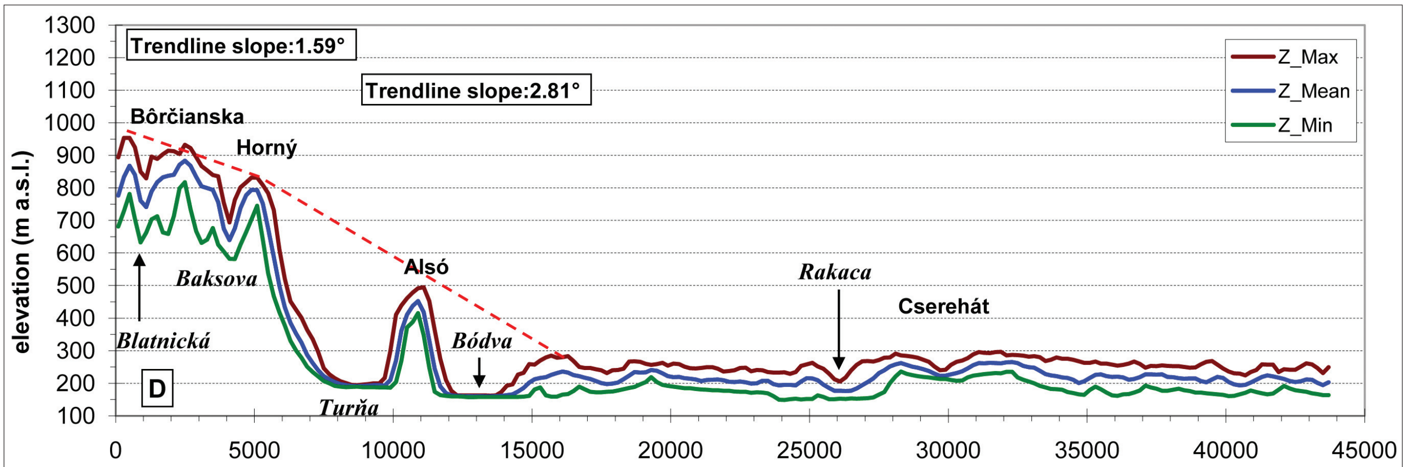
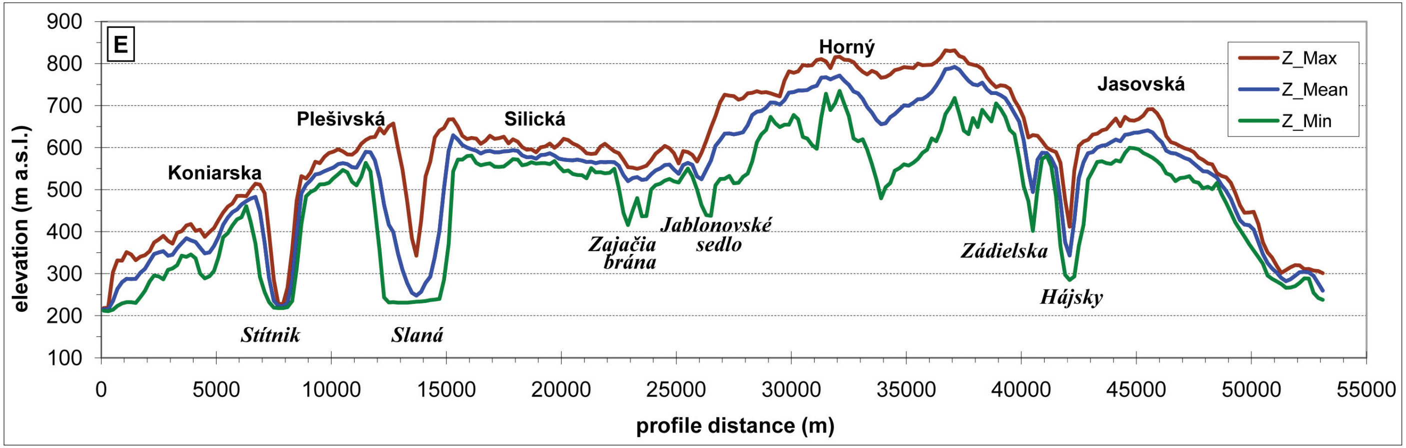


Fig. 5. Continuation



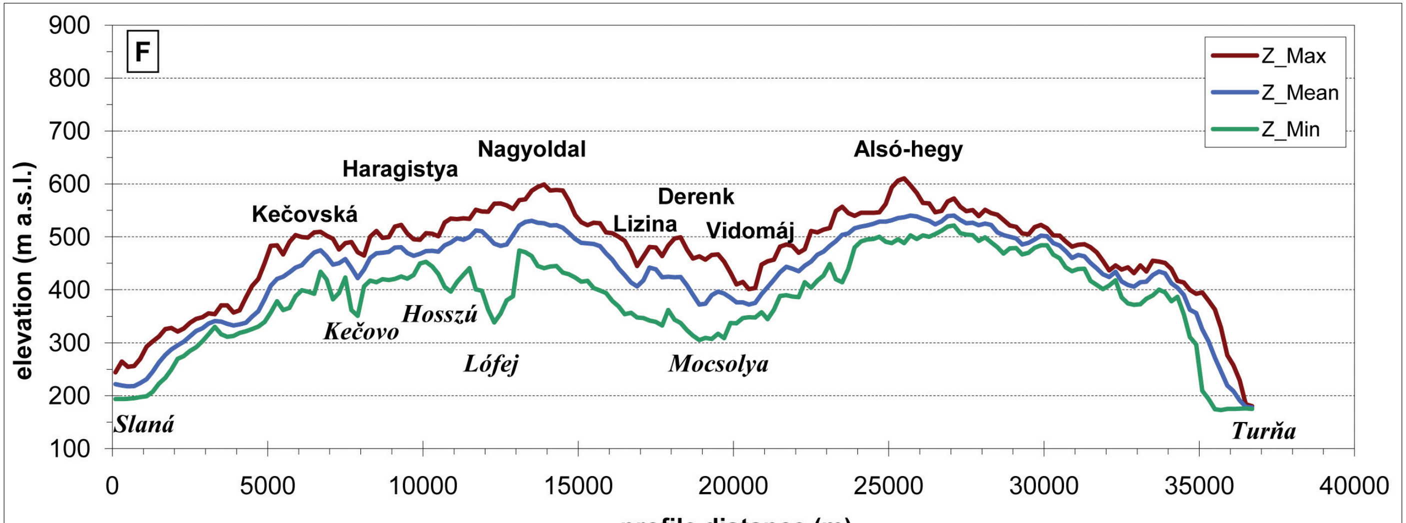


Fig. 5. Continuation

change in surface trend does not coincide with the boundary of open karst. The general 0.97° slope of the karst terrain is also within the plateau slope range, but it is somewhat lower than the value of the westernmost swath. The smaller Ménes and larger Jósva valleys are largely rectangular to the swath and are clearly detectable in all the three curves.

The third swath profile *(Figure 5C)* is more different. The trend fitted to Horný Mt., Alsó Mt. and the southern slope of Páska-bükk results in 2.36° general slope. This value is steeper than the individual values of Horný Mt. and Alsó Mt. (see *Table 1*). However, the northern extension of the trend does not reach the Pipitka (Pipityke) level that suggests again a separate and higher-rate uplift of Slovenské rudohorie.

On the contrary, the Drienovec (Som-hegy) top level (built up of Dachstein Limestone and separated from Horný Mt. by the tributaries of Čremošná) is well below the trend. All of these facts indicate that the blocks found north and south of Turňa valley as well as the Slovenské rudohorie block had differential uplift and the northern blocks were elevated to higher level than in the western segment of GTK. Three steps (Pipitka, Drienovec–Horný, Alsó Mt.–Páska-bükk) and a trough (Turňa) can be recognised within this swath. The trend is abruptly finished south of Páska-bükk and the mean curve shows three slightly southward sloping units (Szalonna Mts., Rudabánya Mts., Szendrő Mts). It should be noted that the given swath profile is somewhat misleading for the Szalonna Mts., because only the western margin of the mountains fall within the swath and Szalonna Mts. are in fact higher then Rudabánya Mts.

The easternmost swath profile *(Figure 5D)* is similar to the previous one. Two separate trends are valid for the top level of Bôrčianska p.–Horný Mt. and for the Horný Mt.–Alsó Mt.–Bódva left bank Triassic limestone hills. The steep slope (2.81°) of the latter trend also supports the separate tectonic uplift of Horný Mt. and Alsó Mt. In the north, the Blatnicka (Szár-patak) valley formed at lithological-structural boundary and the Baksova (Baksa) valley formed along a fault line are clearly observable in all the three curves. The extreme flat accumulation plains of Turňa and Bódva valleys, formed in tectonic depressions, are also detected. Cserehát Hills are somewhat more dissected but can be largely characterized as a uniform surface, slightly sloping southward and divided into two segments by the Rakaca valley.

The two last swath profiles *(Figure 5E* and *F)* are oriented ca west–south–west to east–north-east. They were constructed in order to visualize west–east differences between the karst plateaus and to outline the cross-section of active and inactive valleys flowing in a north to south direction.

In the northern swath profile *(Figure 5E)* it is observed that relief trends are continued at the opposite sides of Štítnik, Slaná and Hájský (Áji) rivers. This observation excludes uplift differences (but not horizontal faulting) between valley sides along these river sections, thus diminishing the importance of tectonic preformation. So superimposition/antecedence could be the dominant process in the formation of these valley sections. Nevertheless, tectonic preformation certainly had some influence in case of Štítnik valley (where covered faults are marked in the geologic map by Mello, J. 1996) and cave phases during the development of Hájský valley are not excluded either. On the other hand, abrupt topographic changes are unambiguously present east of Jablonovské sedlo and west of Zádielska valley.These topographic steps are in agreement of the previously mentioned higher-rate uplift of Horný Mt. and indicate that tectonic preformation was important in the formation of these valleys. It is noted that Jablonovské sedlo (Szoros-kő-nyereg) and Zajačia brána (Nyúlkapu) are probably the elevated and dried out remnants of palaeovalleys, therefore they are to be considered wind gaps. The two ends of the swath profile reflect the western and eastern lowering of GTK margins. A slight east–south-east sloping of Silická p. is also discernible. A local minimum artefact is present in the minimum (and partly in the mean) curve at Horný Mt. because the plateau narrows here extremely that is not perfectly followed by the swath boundary, therefore pixels of lower elevation at the edge of the plateau are also represented in the swath profile.

The southern swath profile *(Figure 5F)* portrays a more or less symmetric, truncated convex profile, sloping towards the margins. The open karst terrain has a gentle slope only (from Nagyoldal to Kečovská p. and the Alsó Mt. towards the east), while the edges of the karst plateau are characterised by steeper slopes. In the western end of the profile down to the Slaná river there is a gentler slope section, which is a covered karst terrain.

In the middle of the profile, the Derenk depression is probably of tectonic origin. Incisions that are observed mainly in the maximum curve (Kečovo/Kecső, Lizina, Vidomáj) indicate north to south oriented palaeovalleys. Other valleys (Hosszú, Lófej), which are absent in the maximum curve are rather of regression origin.

Conclusions

At present, the large-scale general slope of GTK in a north to south cross-section is ca 1°. This value is typical of most individual plateaus and of the general profile of the study area. Consequently, if pre-uplift surface is considered, an even gentler slope must be inferred, i.e the area had to be almost flat during pediplanation.

Due to the flatness of the terrain, the river pathways flowing through the area were hardly constant and flow directions could be very different from those of the present-day water courses except where inherited by superimposition. According to the swath profile analysis, the Jablonovské sedlo and Zajačia brána as well as incisions above Lizina-source and Vidomájpuszta could be potential water pathways. Further research should focus on the analyis of the former drainage network.

The uplift of the GTK had a somewhat changing style from the west towards the east. In the western segment the surface was tectonically uplifted and tilted as a single unit including the Slovenské rudohorie peaks, although differential erosion removed more material from the rudohorie section. Rivers (Štítnik, Slaná) formed superimposed/antecedent valleys in this segment.

On the contrary, in the central and eastern segments of the GTK, the Slovenské rudohorie had a separate and higher-rate uplift that created a tectonic step between the mountains and the karst terrain. In addition, in this part of the area, differential uplift took place even within the GTK, the northeastern blocks (Horný Mt., Zádielska p., Bôrčianska p., Žl'ab Mt.) experienced the most intense elevation whereas local subsidence (Rožňava basin, Turňa valley, Derenk depression, Jósvafő p., Bódva valley) also contributed to the increase of large-scale relative relief. There are several subareas with almost zero slope (the most extensive being the northern part of Silická p.); in these cases a slight northward tilt is supposed.

The hilly region south of GTK has a largely uniform, almost plain maximum surface suggesting that tectonic tilting was insignificant within this region since the last sedimentation. However, as a response to the slight uplift, the landscape was strongly dissected by fluvial processes.

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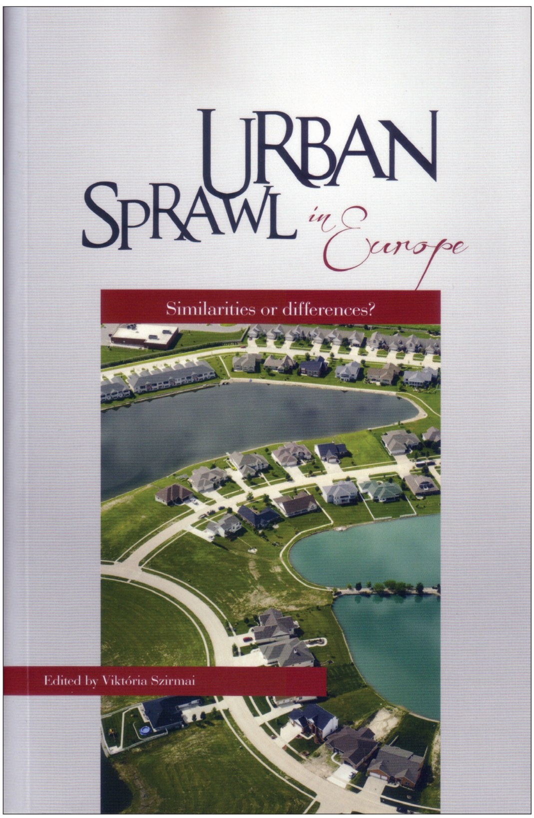
Hungarian Geographical Bulletin 60 (4) (2011) pp. 397–402.

Szirmai, V. (ed.): Urban Sprawl in Europe. Similarities or Differences? Budapest, Aula Kiadó, 2011. 280 p.

Perhaps the two most pervasive phenomena of urban development in western societies have been suburbanisation and gentrification for the last fifty years. In order to find out the relevance of these terms in urban studies I made a web search in *google scholar*. For the terms suburbanisation and sprawl the combined result was over 68 thousand items, whereas for the term gentrification 33,200. Thus, altogether over 100 thousand items in the global academic records can be directly linked to these two concepts. Therefore, we can truly say that *Urban Sprawl in Europe* can draw great attention in the academic sphere and it can extend our knowledge about urban development processes in Europe.

The book consists of three major parts and contains eight chapters. The first part of the book sets the theoretical framework of the topic. In her problem raising introductory chapter Viktória Szirmai, editor of the volume, provides an overview about the conceptual background of *urban sprawl* and *gentrification*. The process of urban sprawl in Europe followed the North American model with some delay, and it became the dominant urban phenomenon in the western half of the continent only by the 1960s and 70s. The reasons were more or less the same as in the US, growing motorisation, declining housing and environmental quality in the historic inner-cities, endeavour of the middle-class for single family homes etc., nevertheless, the spatial results were different. European suburbs always had settlement history; they were never monofunctional in an American sense, they were organically integrated in the settlement system, and their size and morphological appearance were not comparable to those American dormitory estates. Yet, according to Szirmai there are clear signs of convergence as European and especially East Central European cities now face similar tensions that previously characterised mainly American urban societies.



Our cities have undergone increasing fragmentation, the rise of individualism, the disintegration of community sense and weakening social cohesion, as well as growing segregation of different social strata. These societal trends are coupled with the uncontrolled expansion of the built environment and the shrinkage of natural environment, the shift of investment and consumption from the core city towards the periphery. The reason can be explained with a single word: suburbanisation. In her chapter Szirmai not only conceptualise the core topic of the volume, but provides an overview how planning regimes tried to answer the challenges of suburbanisation and urban sprawl from the garden city movement of Ebenezer Howard to the current planning instruments applied in different European cities including the Hungarian Act on Spatial Planning in the Agglomeration of Budapest from 2005 and its recent amendments in 2011.

In the final section of the introductory chapter we can read a comparative analysis about the state of the art in the four cities that are subjects of the subsequent chapters of the book: Copenhagen, Paris, Vienna and Budapest. The author concludes that the key terms of urban sprawl and gentrification need to be considered more as complementary concepts, which together can help us to understand and explain the socio-spatial rearrangements of contemporary European cities.

The second chapter of the book provides the wider theoretical background of the book. In his conceptual paper György Enyedi briefly summarizes and comments the characteristic features of the stage model of modern urbanisation. The phenomenon of urban sprawl can fit into the second stage of the model, whereas gentrification can be linked to the fourth i.e. re-urbanisation. Enyedi not only describes the main features of the different stages but explains their underpinning mechanisms in a comparative manner. Arriving at the most recent stage of global urban development he clearly expresses his criticism: "I have never accepted this fourth stage".

According to Enyedi moving back to the city centres meant rather a rearrangement within the population of urban agglomeration than a new growth stage. Indeed, unlike the previous three stages of urbanisation which spread from their origin to other parts of the world over several decades, the so-called re-urbanisation stage did not mean an abrupt change in the concentration or de-concentration processes of labour force and jobs within urban regions. Enyedi explains the renewed growth of city centres by the *urbanisation of globalisation*. According to his concept globalisation and the emergence of global economy gives rise to new growth centres that are normally located in the heart of global cities attracting knowledge-based branches of the economy and their highly skilled workforce, the *creative class*. At the same time Enyedi also makes self-critique and modifies his earlier assumption linking the return of people and jobs to the city centres with the spread of IT sector. I found his writing a marvellous example how academics should critically revise their concepts and opinions from time to time.

The second part of the book focuses on the versatile process of urban sprawl in four European metropolises: *Copenhagen, Paris, Vienna and Budapest*. These cities followed distinct historical pathways which left their imprints on their current socio-spatial structure. They also represent different urban cultures and planning traditions which enable the reader to get a comprehensive picture about the core topic of the book.

The third chapter of the book is a masterpiece shedding light to the genesis of urban sprawl, its influencing factors and outcomes in Denmark. In their lyric paper Henrik Reeh and Martin Zerlang approach the main topic of the book in a highly sophisticated and artistic manner. First the so-called *Fingerplan strategy* is introduced that intended to earmark the axes of urban development around Copenhagen as early as 1947–1948. There were hardly any signs of suburbanisation around post-war Copenhagen at that time but

Steen Eiler Rasmussen, chairman of the Fingerplan Commission and hence father of the strategy set the main directions of future urban development. In the subsequent decades the city and its agglomeration developed according to these guidelines in full harmony. The author Martin Zerlang could personally follow the aftermath of the Fingerplan as young resident of *Farum*, a quickly growing suburban settlement at the tip of the second finger. His fascinating tale is full of personal impressions, emotions, and anecdotes from that period making the story very enjoyable.

The second part of the paper discusses two ongoing large-scale urban planning projects that are aimed to harmonize urban sprawl and sustainability around Copenhagen: the *Køge Kyst* and the *Ørestad* projects. Both of them intend to reduce the psychological boundary between the capital city and the rest of the country, to improve living conditions and to harmonise spatial development within the agglomeration of Copenhagen that would, according to the expectations, lead to increasing competitiveness of the city within the European and global urban system. Coming from a country where planning in general has a stigma, and often considered as a communist type of intervention in our daily life, I was amazed to read the highly sophisticated examples of Danish planning practice.

The case study on Paris from Nadine Cattan gives statistical evidence that even though the first phase of suburbanisation around the French capital could already be detected in the 1960s, its peak coincided with the late 1970s and early 1980s, and the process is not yet over. In the last half a century suburbanisation took different directions around Paris and it has different speed, but it has not stopped yet. I think this is a clear message for 'model makers' that urban development is a more complicated issue than one would believe and a couple of indicators is not enough to give convincing explanations for the growth or shrinkage of our cities. The author provides accurate analysis about the population dynamics of different urban zones in the Paris metropolitan area; she studies the changes of land use and their environmental consequences. As a reader I found most interesting her gender related analysis about commuting behaviour of residents around Paris pointing out the process of *'spatial entrapment'*.

Similarly to Paris, the case study on Vienna also confirms that urban sprawl and gentrification go hand in hand today. Peter Görgl, Marco Helbich, Walter Matznetter and Heinz Fassmann analyse the population dynamics in the metropolitan area of Vienna putting emphasis not only on the level of growth but also on the demographic aspects of population change. As they conclude patterns of suburbanisation and re-urbanisation can be observed side by side in the city and its surroundings. According to their expectations suburbanisation will remain and important factor of urban development in Vienna in the coming years. They also point out one specific character of Vienna. Unlike most European urban regions Vienna does not face any risk of shrinkage. It is projected for the next decades that both the city proper and the agglomeration will experience a continual population growth in the future, partly as a consequence of international migration.

Finally, the fourth case study explores the process of urban sprawl and its socio-spatial consequences in the Budapest metropolitan region. Viktória Szirmai and her co-authors put the emphasis on the social consequences of urban sprawl around the Hungarian capital city in their case study. Basis of the investigation is a representative questionnaire survey and in depth interviews carried out in Budapest and its agglomeration. Qualitative data confirm that socio-spatial disparities among different types of settlements of the urban region have been increasing in the last two decades. Although disparities do not show the *dichotomy* typical in the west, nevertheless the processes leading to dichotomy are already visible.

The third part of the book focuses less on urban sprawl, but its complementary process: *gentrification*. Yvonne Franz reports on the social consequences of urban renewal in

Vienna. She concludes that compared to other cities in the world the risk of gentrification is generally lower in the Austrian capital mainly because of the strong control and influence of local state through a well developed social housing system. Franz points out initial pockets of gentrification in the urban fabric and she carefully analyses them as case studies. Her investigations confirm that gentrification became really a complex phenomenon by now, with many different forms and faces. An interesting result of her study is the introduction of the concept of *state-led gentrification*. This is very similar to the state of the art in many post-socialist cities, including Budapest. In this respect we can grasp certain similarities in the gentrification process of the two former *K und K* capital cities.

The final chapter of the book deals with different practices of urban renewal and their social consequences in the inner-city of Budapest. In the empirical part of the paper Gábor Csanádi and his co-authors first investigates core areas of urban renewal in the inner part of the city as possible places of gentrification, then they sharpen the focus of analysis using Inner-Erzsébetváros as a case-study. The lessons from Budapest clearly show that gentrification under post-socialist circumstances differ from the western model in many respect. The reasons are manifold: the low level of demand on the housing market, the lack of private rental sector, and the relative lack of gentrifiers. This result should remind us at least two things. First, gentrification has become a container concept in the western literature by now meaning a lot of different changes in inner-city neighbourhoods. Secondly, concepts applied in the west are not always applicable for other cities, like post-socialist cities. The one size fits all concept is, therefore, misleading.

To sum up, I found the eight chapters of this book highly informative and stimulating and I strongly recommend this book for all those academics and stakeholders beyond the academia who are interested in urban studies and would like to know more about the complex nature of urban development of our age.

Zoltán Kovács

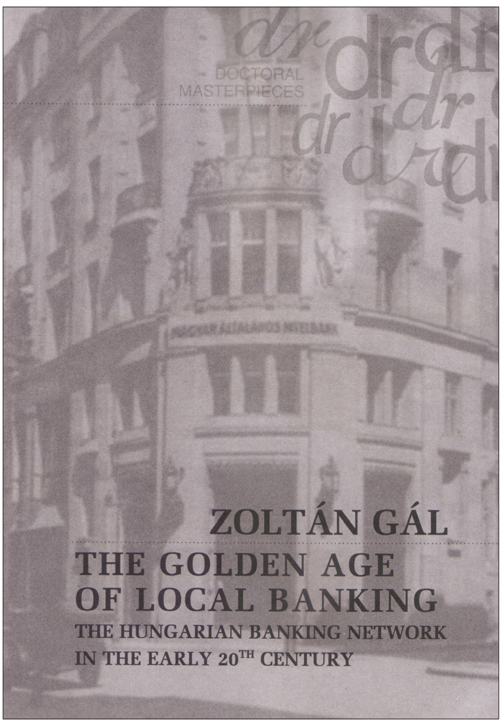
Gál, Z.: The Golden Age of Local Banking. The Hungarian Banking Network in the Early 20th Century. Gondolat Kiadó, 2010. Budapest, 199 p

Though this book was issued in 2010, the review is being published only in the end of 2011. This delay, however, does not lessen the actuality of the book. On the contrary, this way Viktor Orbán, the prime minister of Hungary and Jean-Claude Trichet, the president of the European Central Bank can also contribute to the review. If you would like to know, please read the review.

In our age economic strength responsible for social, urban and regional development is expressed in the condition of all services, referred to as the third (tertiary) sector of economy. The stronger the tertiary is the more powerful the economy stands. And the cream of the tertiary services is the banking that yields the greatest profit with the least investment. The American Historical Geography School found that the features of the urban network are in strong correlation with the spatial structure of the banking system.

Zoltán Gál examines in this book the impact of the Hungarian banking system on regional and urban development in the early 20th century, when local banks were already important territorial elements of the financial space developing close links to regional economic structures. Why can a Hungarian topic be interesting to others than Hungarians?

First, this book opens a window on the past of Central European provincial banks. We are reminded to the fascinating world of the provincial elites we have forgotten. By combining quantitative analysis of financial stocks and flows with original insights into the relationships between financial development and urban development, we witness a creative marriage of financial geography and financial history.



The book's theme resonates with particular significance in the context of the ongoing financial crisis, which has demonstrated what happens when banks indulge indiscriminately in globalization and innovation, neglecting local knowledge, local responsibilities and local innovations.

Second, the author has found new and original methods to exploit the data, which remained after the provincial banks disappeared. He offers a set of highly innovative approaches to important issues regarding the economic history of a Central European country, in fact including the present Slovakia, parts of Romania, Serbia and Ukraine, including the role of financial intermediaries in urban development, the hierarchy of financial centers and economic disparities within this Euro Region.

Jean-Claude Trichet, the president of the European Central Bank stated on 4th October 2011 that our ongoing financial crisis resembles to the global financial breakdown of 1929 in many aspects, though governments intervene more successfully than at that time. What can be the reason for it? They must be using the support of local expertise of a long history. This is what this book concentrates on: finding the roots of local banking expertise.

Viktor Orbán, the prime minister of Hungary said during his visit in Saudi Arabia on 4th October that one of the ways leading out of the worldwide banking crisis is hidden in the sleeping economic potentials of the Central European countries. These economic potentials must include the top ranking branch of the tertiary sector i.e. finance on the local and not global level.

The nature, the root and the history of local banking of the Central European region are important to know once financial, economic and regional reshaping is demanded and called for. Now, a large part of the Central European land used to belong to the historical Hungarian state, the territory of which is examined in the book of Zoltán Gál.

These are the reasons which make his book an interesting, timely and topical issue in our days for not only Hungarian geographers and economists, but for everyone being interested in the financial and economic reconstruction of the Central European region, what is more in overcoming the global financial crisis. Thus the laziness of the reviewer is rewarded by the increasing actuality and timeliness of this volume that has been published in the doctorial masterpieces series.

István Tózsa

Hungarian Geographical Bulletin 60 (4) (2011) pp. 403–405.

Report on the 2011 annual meeting of the IGU Globility Commission

The Global Change and Human Mobility ("Globility") Commission[1] of the International Geographical Union (IGU) was established in 2000 by Professor Armando Montanari, Department of European and Comparative Studies, University of Rome "La Sapienza". The general objectives of the commission are to examine those forms of human mobility that may be related to the processes of global change, to the new forms of investment, local development and to social and cultural behaviour. Since its establishment the Globility Commission has organized numerous meetings all around the world. The 2011 annual meeting of the commission was held in Rome on September 23–24. The venue of the conference was the Faculty of Humanistic Sciences, University of Rome "La Sapienza".

Opening speech by Prof. Bernardini at the Conference

[1] For further information please visit the website of the Globility Commission at http://130.54.245.7/geo/globility/

Three major topics were discussed at the meeting: human mobility and business sector; human mobility and higher education students; and human mobility and cultural changes. The first day of the conference was devoted to sessions and discussion, while on the second day a full-day field trip was offered by the organizers. It was the organizers' priority to make the meeting accessible to a greater number of colleagues therefore all the sessions were streamed live on the "digilab" website (http://digilab.uniroma1.it/) of the University of Rome "La Sapienza". This meant a real innovation, which provided an excellent opportunity for everybody to follow the program of the conference live all over the world.

The conference started with greetings from Prof. Francesca Bernardini, director of Department of European, American and Intercultural Studies, University of Rome "La Sapienza"; Prof. Carlo Brusa, chairman of the PRIN 2008 on migrations and cultural interactions. Integration and territorial setting in Italy, and from Prof. Montanari, chairman of Globility Commission. In his presentation, Prof. Montanari gave a brief summary of the history and major achievements of the commission since its foundation. He emphasized that this commission had always been a small and family-like group, where members were not just colleagues but also friends. He pointed out that the topics discussed were particularly current and important, since the recent global changes had resulted in a shift from traditional (production and/or consumption led) mobility patterns towards information based mobility.

The first session of the conference chaired also by Prof. Montanari, addressed the topics of international mobility of university students (by Clarisse Didelon, Le Havre University & Yann Richard, Paris 1 Panthéon-Sorbonne University and Filippo Belloc & Barbara Staniscia, University of Rome "La Sapienza"), the second-hand car trade between Belgium and West Africa (by Martin Rosenfeld, Université Libre de Bruxelles) and the application of neural network models to human mobility (by Luca Deravignone, Alessandro di Ludovico & Marco Ramazzotti, University of Rome "La Sapienza").

The second session was chaired by Prof. Klaus Friedrich (Martin-Luther-University, Halle), where the first lecture was given by two Italian colleagues (Prof. Carlo Brusa and Davide Papotti) on the international mobility of university students through the example of two North Italian cities (Parma and Vercelli). After that two intriguing presentations were made by Professor Yoshitaka Ishikawa, secretary of Globility Commission, Kyoto University and Yuzuru Isoda, Tohoku University (Japan) on the issues of evacuation and human mobility in the wake of the devastating earthquake, tsunami, and nuclear plant accident that hit Japan in March, 2011. The first presentation concentrated primarily on theoretical issues and on the difficulties of maintaining and harmonizing statistics concerning evacuees in different prefectures. The second presentation gave an insight into the demographic features and everyday lives of evacuees.

Following lunch, the program of the conference continued with the third session chaired by Prof. Yoshitaka. The session started with a lecture delivered by Prof. Friedrich, who presented the problems of the German reunification and the economic recovery in East Germany generating significant migration between the territories of the former West and East Germany. The next presentation was made by colleagues from Latvia– Prof. Zaiga Krisjane, Maris Berzins and Andris Bauls – on employment mobility patterns and its determinants. The last speaker was Guoqing Du from Rikkyo University, Saitama, Japan, who introduced the changes and regional differences of naturalized population in Japan.

The fourth and last session of the meeting was chaired by Prof. Krisjane, University of Latvia, Riga. Firstly, the author of the present report introduced the results of an empirical study aimed to explore the major features of cross-border shopping flows in two cities (Debrecen and Oradea) on opposite sides of the Hungarian–Romanian border. The co-author of the paper was Prof. István Süli-Zakar, Department of Social Geography and Regional Development Planning, University of Debrecen, Hungary. A lecture was held by Italian colleagues (Salvatore Cannizzaro, Catania University and Gian Luigi Corinto, Macerata University) on the impacts of migrant workers on the South-East Sicily horticultural district. Finally, the last presentation also reported on Italy (Bernardo Cardinale & Rosy Scarlata, Teramo University), discussing the impact of international migration on the population dynamics in the Ascoli Piceno–Teramo urban system.

The second day of the meeting comprised a full-day field trip, which enabled participants to directly experience the past and present aspects of human mobility in Rome and its surroundings. The field trip was guided by Prof. Montanari, Barbara Staniscia, member of the PRIN 2008 Project, and by Marco Ramazzotti, researcher of the Department of Near East Archeology and Art History at the La Sapienza University.

In the morning the excursion led to the south-western part of Rome called the EUR district. The EUR is a strange residential and business district of Rome representing the urban development ambitions of Mussolini and his Fascist party. The area was originally planned as the site for the 1942 world exhibition, which had been eventually cancelled owing to World War II. Today the EUR district is full of office buildings, business headquarters, convention centres, museums, as well as shops and bars visited by and people working and living there.

Following the short visit to the EUR district, the group arrived in Lido di Ostia, which is a town located on the Tyrrhenian Sea. The town and its neighbourhood were founded in 1884, after the reclaiming of the nearby marshland. Soon the new village became the favourite seaside resort of the Romans. Many recreation facilities were built after World War II, and Ostia experienced a tourist boom. However, the environmental burden imposed by overcrowding (e.g. sea pollution, erosion of the coastline, sea level rise) is also apparent in the context of limited natural and cultural resources.

In the afternoon Ostia Antica, a huge archaeological park in the place of ancient Rome's port was visited. The ancient city was situated at the mouth of the River Tiber, but because of silting and a drop in sea level, the site now lies 3 km from the Tyrrhenian Sea. Ancient buildings, magnificent frescoes and impressive mosaics were excellently preserved in the area. Ostia Antica is an outstanding testimony of human mobility during the ancient times.

The 2011 annual meeting of the International Geographical Union (IGU) Globility Commission was fruitful and well-organized, where participants managed to experience new aspects of human mobility in theory and practice. The Globility Commission is planning to hold its next sessions in the frame of IGU Regional Conference in Santiago, Chile between November 14–18, 2011. In 2012, the commission will hold its meeting in Cologne, Germany.

Mihály Tömöri

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