Theses of doctoral (PhD) dissertation

UP, Faculty of Natural Sciences

Doctoral School of Earth Sciences

About the origin of the landforms of the Balf block

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Pécs, 2010

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Research task, objectives

The study area is located at the transition zone between the Alps and Carpathian basin. Structurally it is a foothill of the Eastern Alps where the chrystallin rocks of Sopron Mountains are covered by Badenian and Sarmathian sediments. Its central part is composed of Lajta limestone. This plateau-like carbonate terrain is called Balf block. The Balf block (*Figure 1*) forms a hardly dissected small height (200–300 meter) derasion-erosion hill between Lake Fertő and the Sopron basin.

The territory actually belongs to the World Heritage for its specially protected natural values as the flora of Szárhalmi forest and for such historical memories as Fertőrákos quarry or Mithras cave. Historically the area is characterized by an intense land use.

Detailed geomorphological mapping explored unusual, active depression systems. The origin of these landforms could not be clarified purely on the basis of the morphological features. Karstic, anthropogenic and mixed origin could be assumed.

The main aim of the dissertation is to clarify the origin of the landforms and their associated cavities, caves, taking into account the natural origin (karstic processes) conditions and the likely anthropogenic factors. Related tasks/objectives:

- to learn more about the geological environment - the geological structure and tectonic relationships
- detailed mapping and characterization of the landforms
- the geomorphological analysis, interpretation of the landforms
- examination the karstification tendency of the rock
- research and exploration of such subsurface forms which can be associated with the forms observed on the surface
- examination the effectiveness and applicability of geophysical methods in the respective geological and geomorphological environment
- processing of archive data referring to the historical influences and anthropogenic origin

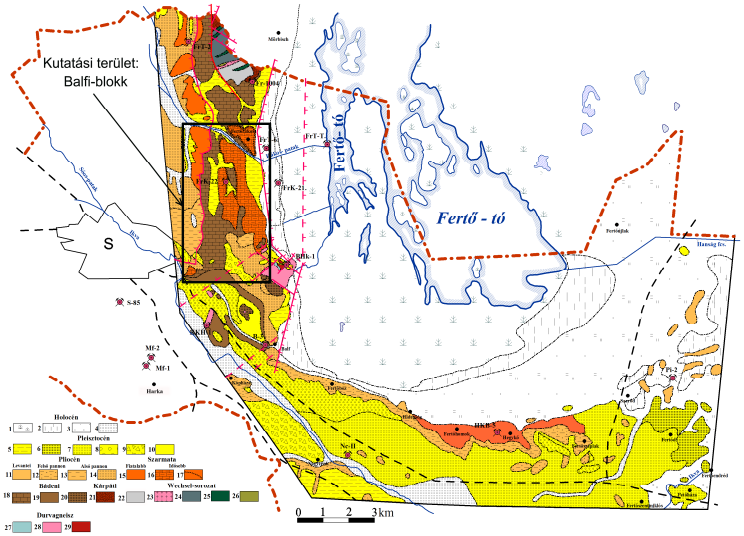

Figure 1. Geological map of the study site and its environs
(PRODÁN, T. H. 2010 based on manuscript of IVANCSICS J.)
1. Reed 2. Muskeg, mull soil 3. Gravel, sand, silt 4. Holocene generally 5. Sandy loess 6. Fluvial gravel 7. Fluvial debris 8. Fluvial gravel (Fertőboz) 9. Terrace gravel 10. Pleistocene generally 11. Fluvial sand 12. Clay, marl, sand 13. Clay, sandy clay, ferrous clay 14. Sand and gravel with small amount conglomerate 15. Sand, sandstone, gravel, conglomerate 16. Limestone, sandy limestone 17. Conglomerate bedrock 18. Coarse limestone, lime-sand 19. Clay, silty clay 20. Conglomerate bedrock 21. Rust gravel 22. Mica-schist with phyllite 23. Muscovite gneiss 24. Feldspathic mica-schist 25. Amphibolite, amphibolite slate 26. Leuco-phyllite 27. Disthen-quarzit 28. Muscovite-biotite gneiss 29. Mica-schist

The characteristic curved edge depressions like forms (*Figure 2*) reminding of collapse dolinas are grouped in depression systems. The origin of these landforms could not be clarified purely on the basis of the surface, field observation and morphological analysis. The geological structure of the area, the relations between geological structure and the location of depression systems were in detail examined. Subsurface conditions were also investigated by different geophysical methods. Considering the physical properties of the limestone and possibilities offered by the terrain geoelectric, electromagnetic and geomagnetic methods were applied. In lack of final geological and geophysical evidences industrial archeology

records were searched for. Great number of historical documents describes intense medieval quarrying and lime burning activity on the territory, which also makes the artificial origin more likely.

Beyond the clarification of the origin and expected future development of morphological forms the further aim of this study is to provide methodological aspects for characterisation of landforms, detection of underground cavities and buried objects in similar environment.

Figure 2. Typical landforms on the reserch area (PRODÁN T.)

The geological structure - Neogene sedimentation

The investigated area is structurally a foothill of the Eastern Alps, where the crystalline schists of the Sopron Mountains are overlaid with several hundred meters thick sediment. The older Paleozoic crystalline rocks appear on the surface only in a few places on this area. The Neogene sediment sequence is unconformable on the Paleozoic basement, so the Mesozoic and Paleogene formations are absent. The sedimentation started in the Miocene. At the beginning of the Badenian Lajta limestone was formed on the shallow coastal parts of the sea. As a result of the regression between Badenian and Sarmathian the Badenian limestone is overlaid by sand and conglomerates. During the next transgression in Sarmathian practically the earlier facies returned which resulted in deposition of Sarmathian clay and limestone.

The carbonate terrain is strongly fragmented by faults and fractures. Presumably a part of faults has many times renewed. Renewing of the faults formed around the early Miocene has affected

also the later sediments. The major fault lines have N-S direction (their age is at least Badenian), the transcurrent faults are secondary, but there may be plenty irregular inferior faults apart from these.

The karst water gently slopes up toward the Lake Neusiedl. The former springs of the Fertő shore have dried up due to intense pumping by Sopron Regional Waterworks. The waterfront drilling line was installed 2 km long on the fault (so called Eastern fault) which made the eastern boundary of the Balf block.

Since detailed geological map was not available the proper geological map (*Figure 1*) of the area was compiled on the basis of a former manuscript, additional geological mapping and personal communications.

The history of evolution of the present relief

The evolution of the present relief began with the retraction of Pannon Lake. By the elevation of the edge of Alps pedimentation started on the Neogene (Badenian, Sarmathian, Pannonian) surface. The piedmont residues slightly incline and intersect the Badenian, Sarmathian and Pannonian sediments of different resistance. On the Balf block the Lajtai Limestone is planed together with the oldest and youngest Sarmathian layers (limestone, sandstone, sand, gravel, conglomerate) and clayey, sandy surface of Upper Pannonian. The pedimentation continued in the lower part of the Pliocene, which was followed by the afforestation of the area and formation of gallery forests. Results of that are the formation of fluviolacustric water system and cross-stratified sand. In the warm, humid Middle- and Upper Pliocene the surface was formed by strong weathering, areal and lateral erosion. On the fragmented piedmonts red clays developed. Beside renewable crustal movements mainly the erosion, deflation, the loess and the loess-like formations dominated after the Pliocene. During the Pleistocene ice ages the solifluction, derasion and deluvial processes were dominating beside the debris cone formation and valley formation. The Kőhidai basin was formed at the same time with the sinking of the Fertő basin during the new-Pleistocene crustal movements. The waters of the Kőhidai basin are carry away in Lake Fertő by the Rákos brook (with antecedent valley in Lajta Limestone). The present hydrographic and topographic

image was formed by the end of the Wurm glacial and early Holocene after the Alpine ice sheet melting. Then, mainly from Roman times onwards the anthropogenic effects were dominated in the landscape developement.

Geomorphological studies

Characterization of surface forms

Basically three versions of surface forms could be distinguished.

- The small-sized simple depressions are generally shallow with uneven bottom. Semi-detached twin depressions also occur. Inside these forms the limestone outcrops very seldom.
- The small-sized complex depressions with horizontal dimension of 50-100 m and uneven bottom are composed from more than two fragment-depressions. Deposition related elevations, heaps can be observed in their interior.
- The large-sized complex depressions or depression systems. All the four systems are several hundred meters wide and slightly elongate in E-W direction. Since numerous fragment depressions interlock into each other a significant number of their marginal slopes are archedly joined. The edge of the depression system is formed typically by the succession of semicircular asymmetrical depressions (asymmetrical collapse dolines). These forms either do not have side slope towards the interior of depression system, or if so, that has small inclination. Their steep side slopes form the edge slope of depression system. The limestone typically appears at these places. In their interior small mounds (up to 1-2 m in diameter) may rarely occur. The 1-2 m wide debris- and weathering product heaps at the rocky and steep lateral slopes are more frequent.

At the side walls of dolines small caves, caverns take place. The entrances of some caves are partly blocked up by the collapsing material. The threaded lined up dolinas are separated from each other by thresholds, semithresholds. The thresholds are narrow forms between two dolines, which are the remains of the original terrain.

Caves, voids

On the basis of relative position of caves depression system related and independent caves can be distinguished.

Two small caverns and the cave of Szárhalmi-quarry are *independent of the depression systems*. These cavities were discovered and opened during mining activity. The cave of Szárhalmi quarry is about 20 m long (4.0-4.5 m high, 7 m wide) in the fault direction. There is no indication of karst processes in the lower part of the cave, solution forms occur only at the upper part.

An example for *depression system related cave* is the so called Zsivány cave. The cave is located in dip direction. Its height is 1-2 m, the horizontal size is approximately 20 m x 50 m. The room is partly separated by eleven pillars. The present entrances were formed by the breakdown of the ceiling. The number of entrances was changing quite quickly during the last 60 years. See e.g. Kotsis (1940). New connections are opened by the breakdown of the ceiling while others become blocked in the side wall of collapse depressions. The lack of any karst signatures and the pillars suggest that the cave was formed in the course of mining, however any proper entrance through which the quarried stone could be easily transported out is not known.

Smaller caves, holes opening *from the slope walls of the depression* systems are present in each of the major depression systems, moreover they can be found in some of the smaller-sized complex depressions, too. Two versions of this cave type can be distinguished: *sack-like* and *bridge-like caves*. The sack-like caves appear at the edges of depression systems in the continuation of the collapse dolinas. The bridge-like caves are in connection with thresholds, semi thresholds and form passes between the neighbouring collapse dolines. Their typical height is 1-2 m.

Geomorphological analysis of the depressions, depression systems

On the basis of geomorphological analysis natural, karstic origin could be supposed for the curved edge depressions, depression systems.

The forms opening from the walls (collapse dolinas) of the depressions interlocked when they were formed or later, during the evolution. So the large-sized depressions are collapse uvalas, the semicircular depressions on their edge are recent, small asymmetric collapse dolinas. The elevations in their interior could be remains of the original terrain. The heaps at the side of the walls were formed by the breakdown of the lateral walls.

In their interior the rarely occurred small mounds have clastic structure, which suggest formation by breakdown or artificial material reworking (*Figure 3*).

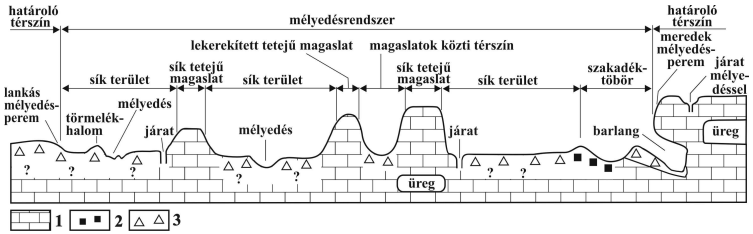

Figure 3. Theoretical geomorphological profile of the depression systems of the Balf block
1. limestone 2. scree 3. soil debris and detritus (PRODÁN T. – V ERESS M. 2007)

By comparison of the geological map with the morphological map it was found that the morphological formations always coincide with the appearance of limestone at the surface. In terms of our examinations it is indifferent whether the age of limestone is Badenian or Sarmathian because both share the same physical-chemical properties. This spatial correlation may, but need not, reinforce karstic origin assumption.

However, taken into account the other conditions of karstification a number of doubt arises in connection with karstic origin. The depression systems can not be connected to the

tectonic lines known from geological mapping and former geophysical measurements. The less stratification, the poor compactation and hardly fragmentation of limestone is indicated by excavations and drilling data. On the rock samples collected from depression systems the primary porosity of rock was examined.

Porosity of the rock samples collected from the test area is around 20%, the porosity of the rocks samples from deeper depth (10-20 m) is around 10%. These high values of porosity and the permeability (*Figure 4*) indicate that this rock is less susceptible to karstification. Beside the high porosity and permeability the relief is just like that the water can not be accumulate on the territory of the depression systems – at least in the similar climate conditions as in the present – which may result significant karst processes.

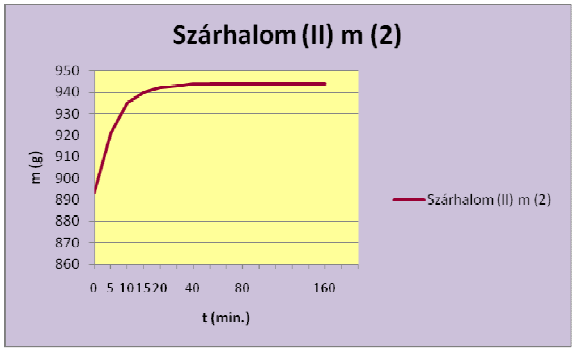

Figure 4: Typical curve of water absorption (Szárhalom 2) (PRODÁN T.)

Results of geophysical measurements

Due to the topography, the geological structure (the high horizontal and vertical segmentation of the rock physics parameters), the diverse positions and geometry of the karstic formations (sinkholes, cavities) the research of the karstic areas represents a real challenge for geophysics. The more suitable geophysical methods had been selected on the basis of geomorphological mapping, geological data and rock physics parameters. Noise level was also taken into account.

To examine the possible spatial correlation between depression systems and tectonic lines VLF profiling was made. Detailed GPR, geomagnetic mapping, respectively 2D and 3D geoelectric tomography were performed over subsurface formation on a suitably selected test area.

Overview VLF measurements

VLF electromagnetic method is based on large distance, low frequency (10-30 kHz) radiowave propagation. The ratio of the electric and magnetic field depends on the near-surface (upper 30 m) resistivity. Very Low Frequency (VLF) electromagnetic method is generally used in primary exploration e.g. in detecting lateral changes of the resistivity along fracture zones. The linear relation between horizontal and vertical magnetic components is computed. The vertical component originates purely from secondary sources while horizontal component is composed from primary and secondary sources. Significant anomalies appear when crossing a conductive fracture zone, strike. A VLF-Hz profile in approximately N-S direction crossing the whole carbonate terrain was made. Four additional profiles were measured with much higher resolution. These VLF measurements identified several new fractures beside of the previously known tectonic lines but no spatial relationship was found between them and the examined morphological formations.

Detailed geophysical mapping

Of course application of laborious, high resolution methods is impossible on the whole area. A test area (*Figures 1 and 6*) was chosen where each typical surface forms and presumable caves and voids also occur. Further requirements were the low electromagnetic noise level, flat surface, sparse vegetation. The test area is located on the edge of depression system marked B-11. There is a double dolina separated by a bridge-like cave in the vicinity. An almost fully blocked narrow entrance of a presumably sack-like cave can be observed on the neighbouring side wall.

GPR measurement

The GPR is a widely used efficient method to detect vertical changes of resistivity and dielectric constant near the surface. The high-frequency (50-500 MHz) electromagnetic wave generated on the surface penetrates into the soil and it is reflected from the surfaces where the dielectric constant changes. The depth of the penetration depends on the electric properties of the sediment and on the frequency. High conductivity cause high absorption but it may attain even 20 m in dry soil without clay on 100 MHz. On the GPR profile horizontal and quasy-horizontal layering is generally easy to follow but the indication of 2D and 3D structures is much more complicated. Diffractions, multiple reflections occur depending on the electromagnetic properties and geometry of the object and on the wavelength applied.

Four GPR profiles were measured parallel to the road at the edge of collapse depression (S1-S4) and perpendicularly six additional ones (S5-S10). The length of the radar profiles were 21 m each. The applied 250 MHz provides high vertical resolution but the penetration depth proved to be shallow mainly due to the clay and water content of the soil. Slight indication of the cave also appear at 100 MHz, but the wavelength seems to be large in comparison with the vertical size of the cave.

Geomagnetic measurement

On the test area in a 0.25 m x 0.25 m regular network high-resolution magnetic measurement was performed. Scalar value of the geomagnetic field was measured by an Overhauser-effect proton magnetometer. Reference field values were taken from the nearby (NCK) geomagnetic observatory. Geomagnetic methods detect the spatial variation of the Earth’s magnetic field, better to say its scalar value. The local field is a superimposition of the main field and the local induced and remanent magnetisation. The anomalous magnetic field is caused by remanent magnetisation or lateral changes of magnetic susceptibility (induced magnetisation). There is no indication of remanent magnetisation on the anomaly map but the cave clearly appears in form of an elongated anomaly. The weak

(cca. 5nT) positive anomaly (*Figure 5*) indicates that this subsurface cave is partly filled by higher susceptibility material.

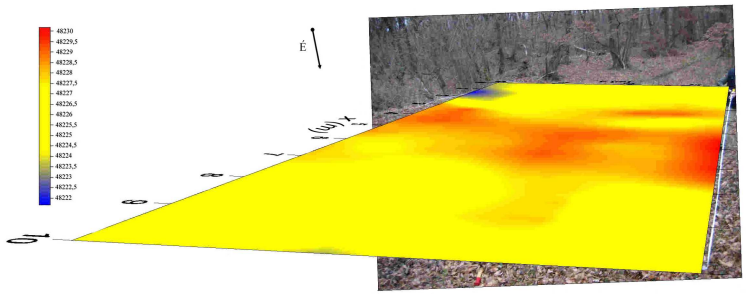

Figure 5. Magnetic anomaly above the study site (PRODÁN T.)

Geoelectric measurements

The theory and methodology of geoelectrical methods are relatively simple. Each of them are based on the vertical and horizontal changes of subsurface resistivity. The response of the earth (surface potential difference) to quasi DC electric current is measured. In the simple conventional cases two current electrodes and two potential electrodes are applied in different colinear spatial arrangements. The investigation depth i.e. the thickness the current passes depends on the distance of current electrodes for Schlumberger and Wenner configurations. In case of dipole-dipole configuration the investigation depth depends on the offset of trasmitter-receiver electrode pairs. Successively greater distance results in a series of apparent resistivities from which the vertical distribution of subsurface resistivity is obtained by different numerical inversions.

On test area geoelectric tomography was conducted with 168 electrodes in a regular 26 m x 27.5 m network from which 8000 apparent resistivity values were obtained. The big resistivity contrast between the air-filled the cave and embedding rock is very good indicating by the three-dimensional image of the inversion. Figure 6 depicts the image obtained by supposing that the resistivity of the embedding rock is 100 ohmm while that of the cave is 3000 ohmm.

The resistivity contrast is remarkable at the boundary of the cave. There are no indications of underground drainage and passages. High conductivity infilling material (clay, water) does not appear.

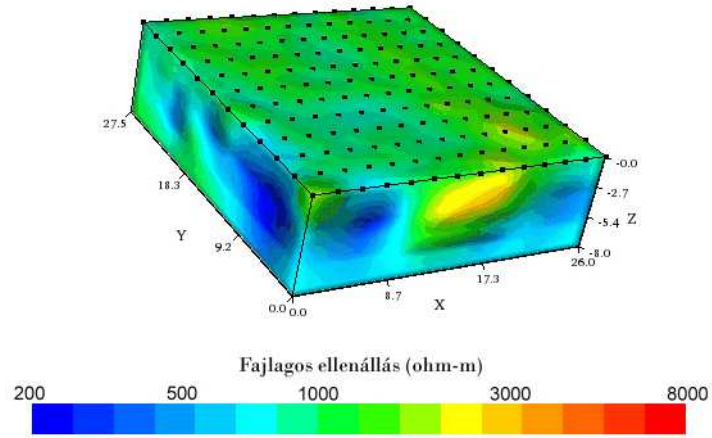

Figure 6. 3D geoelectric image of the investigated cave (PRODÁN T.)

The resistivity of the embedding rock was also determined from a couple of 1D Schlumberger soundings. Its value (100-300 ohmm) can be regarded typical for the whole carbonate terrain. Sudden resistivity increases of several thousands ohmm can be interpreted as voids and caves filled (at least partly) by air.

To confirm the 3D image additional 2D profiles were measured applying two different configurations. The proper imaging of cavity size, depth is influenced by the variable resistivity of the rock. Due to the desiccation of the rock and soil the resistivity appearing on the 2D inverted profiles are higher than during the 1D and 3D measurement was. The soil is well separated, but the dried up weathered layer is not well-defined.

In all directions well-defined cave opening from the side wall of the depression is indicated by detailed geophysical measurements. In dimensions either place of material excavation and/or could have

served as lodgings. In dimensions and shapes the researched landforms shows a great similarity on the whole carbonate terrain.

Industrial archeology

An attempt has been made to support our assumption concerning the anthropogenic origin of the examined formations with historical data and archival documents. The architectural significance of Lajta limestone used since the Roman times is known from a number of sources. It is known to be transported on the 80 km continuous waterway to the construction of the abbey church built in 1208 of Lébény and later it was also a popular building stone in Vienna and Sopron. The abundant archival material was published by several authors, for example Nováki (1962), Mollay (1992), Gömöri (1981). This relatively small area supplied a very big district with building stone and caustic lime according to their works. According to the evidence of a map presenting the market district of the caustic lime of Sopron the entire former county of Sopron was supplied with slack lime. Nováki (1962) presents data and map about the 17-19 century's lime-burning on the area on the basis of the documents found in the State Archives of Sopron. The lime-kilns of the city during the 15-16th century worked on the investigated area (Okl. II/5. 94. 1499, Okl. II/5. 89. 1498 of Sopron Archives). The caustic lime was transported to the city on the Kalkweg (Chalcway). The medieval small-scale lime-burning was replaced by large-scale technologies in the 18th century.

In the course of our several years' work the erosion and degradation processes were also monitored. From recent quickness of these processes the age of the landforms can also be estimated. In all probability the erosion and degradation of the former quarrying sites**,** the lime-kilns and associated stores began not earlier than 500-1000 years ago.

Exploitation of the results, further research

The main aim of the research was to prove the origin of the geomorphological landforms. The karstic origin became questionable already during the geomorphological analysis, so the problem was studied in wide geographic and geological context. Detailed geological map of the area was compiled on the basis of unpublished or only partially published data. For the reconstruction of the palaeogeographic image and surface evolution literary data and reports found in the archives of the former Geological Service were worked up. These results *could be of use for* other local *environmental, geotechnical, geological, hydrogeological investigation*. Subsurface formations were researched by geophysical methods, for the *anthropogenic origin* circumstantial evidence were obtained. Through the knowledge relative to the origin of the landforms and through observation of them *the time course and spatial extent of the* expected *erosional, collapse processes can be estimated*. This may be important in terms of land use. Due to the topography, the geological structure (the high horizontal and vertical segmentation of the rock physics parameters), the diverse positions and geometry of the karstic formations (sinkholes, cavities) the research of the karstic areas represents a real challenge for geophysics. The more suitable geophysical methods had been selected on the basis of geomorphological mapping, geological data and rock physics parameters. Noise level was also taken into account**.** *The good imaging properties of the applied methods were demonstrated, these investigations provide methodological aspects for characterisation of landforms, detection of underground cavities and buried objects in similar environment*. On the base of our historical research the artificial origin of the landforms can be considered proven. So the further analysis of the surface forms from *cultural-historical and industrial archaeological point of view is also important*.

In the future field work extension of the geomagnetic mapping to the wider environment of the depression systems may play important role. Temperature of lime burning exceeds the so called Curie temperature which means that traces remanent magnetisation can not be excluded at certain places. Further – either buried – place of lime-

kilns could be identified. On the basis of the practical experience obtained on the test area a research project started (OTKA project). The aim of that is on the one hand to improve the mapping properties of the geoelectrical methods, analysis of the parameter sensitivity, on the other hand examination of the measurement conditions's effect – in this case the variable water content of the high porosity rock – by repeated soundings on the same place (on the area studied in the dissertation).

Summary of the main results

THESES

I. The study area is structurally a foothill of the Eastern Alps where the chrystallin rocks are covered by Badenian and Sarmathian limestone. The plateau-like carbonate terrain called Balf block is composed of Lajta limestone. Great number of landforms were found and analyzed during the detailed geomorphological mapping. The characteristic curved edge depressions are grouped in three depression systems. On the basis of the morphological features the small sized depressions with uneven bottom and deposition related heaps inside are of artificial origin. KaRstic origin can be assumed in case of large depressions and depression systems which can be characterized as follows. The large-sized complex depressions or depression systems are several hundred meters wide and slightly elongate in E-W direction. Numerous fragment depressions interlock into each other, a significant number of their marginal slopes are archedly joined. The edge of the depression system is formed typically by the succession of semicircular asymmetrical depressions (asymmetrical collapse dolinas). These forms either do not have side slope towards the interior of depression system, or if so, that has small inclination. Their steep side slopes form the edge slope of depression system. In their interior small mounds (up to 1-2 m in diameter) may rarely occur. The 1-2 m wide debris- and weathering product heaps at the rocky and steep lateral slopes are more frequent. At the side walls of dolinas small caves, caverns take place. The entrances of some caves are partly blocked up by the collapsing material.

II. In the course of our several years' work the erosion and degradation processes were also monitored. Trees of 30-50 years age are tilted at the edges, sidewalls, slopes are hardly covered by vegetation. Intensive erosion can be observed on the ever increasing curve of the pathways. From recent quickness of these processes the age of the landforms can also be estimated. It seems that the erosion and degradation

processes happen more on historic than geologic timescale. Although these processes are not linear, in high probability the decay of the former quarrying sites**,** the lime-kilns and associated stores began not earlier than 500-1000 years ago.

III. On the basis of geologic map, the depression systems coincide with the occurences limestone of high (90-95%) $CaCO_3$ content at the central part of the Balf block. Spatial correlation between fractures, fracture zones and the location of depression systems is very poor. Porosity and permeability of the limestone was determined on different samples. Porosity of the near surface samples exceeds 20%. Porosity decreases with depth, its value is about 10% at the depth of 20 m. The samples (average mass of 1000 g) fully saturated within 10 seconds. Secondary porosity can be hardly observed. Low compaction, high porosity and permeability makes the assumption of karstic origin very questionable.

IV. The former geophysical measurements from the whole territory were reevaluated. On the basis of few but well distributed 1D geoelctric sounding the typical layering i.e. spatial distribution of the resistivity was determined. These data were completed by electromagnetic (VLF) measurement. VLF method is extremely sensitive for the lateral inhomogeneities of the subsurface (upper 20 m). These VLF measurements identified several new fractures beside of the previously known tectonic lines but no spatial relationship was found between them and the examined morphological formations. Detection of smaller 3D inhomogeneities requires more sophisticated and labour-consuming methods. On the basis of the primary geophysical investigations a smaller area, so called test area was chosen.

V. The test area is located on the edge of depression system marked B-11, where each typical surface forms and presumable caves and voids also occur. Further requirements were the low electromagnetic noise level, flat surface, sparse vegetation. On the GPR profile the diffraction hyperbola and multiple reflections slightly indicates the cave. The applied 250 MHz provides high vertical resolution but the penetration depth proved to be shallow mainly due to the clay and water

content of the soil. Slight indication of the cave also appear at 100 MHz, but the wavelength (approximately 2 m) seems to be large in comparison with the vertical size of the cave. The geomagnetic anomaly map provides information about the position of the cavity. It can be also concluded, that the cavity is partially filled with weathered/organic material which has higher susceptibility compared to its environment. The vertical electric soundings proved to be very efficient. The weathered material near the surface, the big resistivity differences between the limestone and the air filling the subsurface cavity made the reliable imaging possible. The geophysical measurements appear to support the hypothesis of artificial origin rather than karst processes.

VI. The architectural significance of Lajta limestone used since the Roman times is known from a number of sources. It was also a popular building stone in Vienna and Sopron. The abundant archival material was published by several authors and documents found in the State Archives of Sopron. The lime-kilns of the city during the 15-16. century worked on the investigated area. According to historic maps the caustic lime was transported to the city on the Kalkweg (Chalcway). In all probability the depression like forms originated by exploitation of small scale mines. Raw material was excavated also from the sidewall of the mine space. These caves may have been served as shelters. The medieval small-scale lime-burning was replaced by large-scale technologies in the 18th century. These archaeological documents also confirm the hypothesis of artificial origin rather than karst processes.

PUBLICATION LIST
IN THE TOPIC OF THE DISSERTATION

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PRODÁN, T. H. 2010: Investigation of depression systems on a carbonate terrain near Sopron, Hungary. Carpathian Journal of Earth and Environmental Sciences, October 2010, Vol. 5, No. 2, Baia-Mare, pp. 193-202. (IF: 0.606)

Publications in other journals

PRODÁN T. H. 2010: A Balfi-blokk felszínformáinak eredetéről. Földrajzi Közlemények, 134/4, pp. 393-404.

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PRODÁN, T. H. 2009: Application of geoelectric and electromagnetic surveys in a depression system investigation near Sopron. In: Szarka L. (szerk.) IAGA 11th Scientific Assembly: Abstract Book. Sopron, Hungary, 2009.08.23-2009.08.30. Sopron: Geodetic and Geophysical Research Institute of the HAS, Paper 118-THU-P1530-0836. (Poster session)

PRODÁN T. H. 2009: A Balfi-tönk morfológiai képződményeinek eredetéről, XII. Karsztfejlődés Konferencia, Szombathely, 2009. március 20-21., p. 41.

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