DEM based examination of pediment levels: a case study in Bükkalja, Hungary

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Abstract

Bükkalja is the southern pediment of Bükk Mountains. According to the geographic literature this area is divided into two pediment (geomorphic) levels. Using the methods of quantitative geomorphology, the Bükkalja pilot area was examined in this paper. The main objectives of the investigation were the validation of examinations based on the digital elevation model by the accepted scientific achievements (referring to the dual pediment), and the analysis of the role of Miocene welded ignimbrite cuestas in the evolution of the pediment. Applying different GIS based methods, the height and location of these levels were determined and their area calculated as well. Relationship was established between the location of the upper pediment level and the occurrence of welded ignimbrites on the surface. The leading role of welded ignimbrite cuestas was also confirmed by the morphometric analysis of tuff formations.

Keywords: planation surface, DEM, SRTM, Bükkalja, ignimbrite, morphometry

Introduction

In the present paper, GIS based geomorphological methods were applied for the study of planation surfaces. Bükkalja was chosen as the pilot area. Hopefully, on the basis of this case study, through the application of the methods suggested, general conclusions can be drawn also valid for the evolution of other pediments.

Planation surfaces, like pediments, glacis, pediplains, etchplains are among the most common landscapes on the Earth's surface. The term "planation surface" describes a geographically flat surface resulting from denudation. At the junction of slopes and plains the gently inclined, rock-cut surfaces, the pediments are the most prevalent landforms (Migoń, P. *et al*. 2005). In the Carpathian Basin, these denudational landforms, especially the pediments

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also can be found often on the margin of the mountains (Pécsi, M. 1963, 1964, 1969; Székely, A 1972, 1977). The evolution of pediments typically depends on the climatic conditions: they come into being only under semiarid climate. In Hungary there were periods, when the conditions were suitable for the evolution of planation surfaces. In our days these landforms are strongly dissected into interfluve hills (Gábris, Gy. 2007).

Authors of numerous international and Hungarian studies have examined the evolution of planation surfaces: paleo/fossil surfaces were investigated by e.g. Johansson, M. (1999), Feng, J. and Cui, Z. (2002), Coltorti, M. *et al.* (2007), Grohmann, C.H. *et al.* (2007). Some authors (Migoń, P. *et al.* 2005) tried to determine the age of the surfaces, and to reconstruct the landform evolution events that shaped them, others (Tokarev, V. *et al.* 1999; Csillag, G. 2004) applied digital elevation models (DEM) as well.

In the investigation of planation surfaces DEMs (digital elevation models) were used for denudation rate estimations, and for the calculation of eroded and transported sediments (Van Balen, R.T. *et al.* 2002; Roessner, S.–Strecker, M.R. 1997).

In the DEM based examination of planation surfaces the rock quality (resistancy to the erosion, i.e. "hardness") was also taken into consideration (Coltorti, M. and Pieruccini, P. 2000). In the Hungarian geographical literature, the studies of (periglacial) planation surfaces have played an important role (see the review by Gábris, Gy. 2007).

Quantitative geomorphology is the practice of terrain modeling and ground surface quantification, applying the knowledge of Earth science, mathematics, and computer science (Pike, R.J. 2002). Using of SRTM (NASA Shuttle Radar Topography Mission) based DEMs in GIS is an inexpensive method to regional geomorphologic examinations, which allows speed and precision for the calculation of morphometric parameters (Grohmann, C.H. *et al.* 2007).

In the present paper the study area of Bükkalja has been examined with methods of quantitative geomorphology. This research has three main goals. Firstly, to check the examinations based on SRTM DEM in pediment (in the study area of Bükkalja) by the accepted scientific achievements. The delineation and subdivision of Bükkalja (geomorphologic levels) was also carried out. Secondly, beside the validation, efforts were made to obtain results, which have led to further examinations.

The third main goal was to prove the role of Miocene welded ignimbrite cuestas in the evolution of pediment. Although the geomorphologic conditions of Bükkalja are well known, this knowledge comes mainly from traditional methods of morphologic examinations. The present research is an attempt to complement this knowledge from a different aspect, so that compared with the subjective methods a modern GIS based morphometric analysis could yield a more exact result.

The study area

The Bükkalja is the largest margin pediment in the North Hungarian Mountain Range, in fact in the whole Hungarian Mountains. Its area is 813 km^2 (Dövényi, Z. ed. 2010). The western and eastern boundaries of the area could be drawn easily: Tarna and the Sajó Valley, respectively.

The conventional southern border is situated along the row of settlements Kerecsend–Maklár–Mezőkövesd–Mezőnyárád–Bükkábrány–Vatta–Emőd (Dobos, A. 2006). However, it is difficult to mark the narrow boundaries to the south and north, because of the wide borderland between the Borsod Plain and Bükk Mountains. In this study, the boundary of the examined area is based on the official Hungarian landscape divisions (Dövényi, Z. ed. 2010) (*Figure 1*).

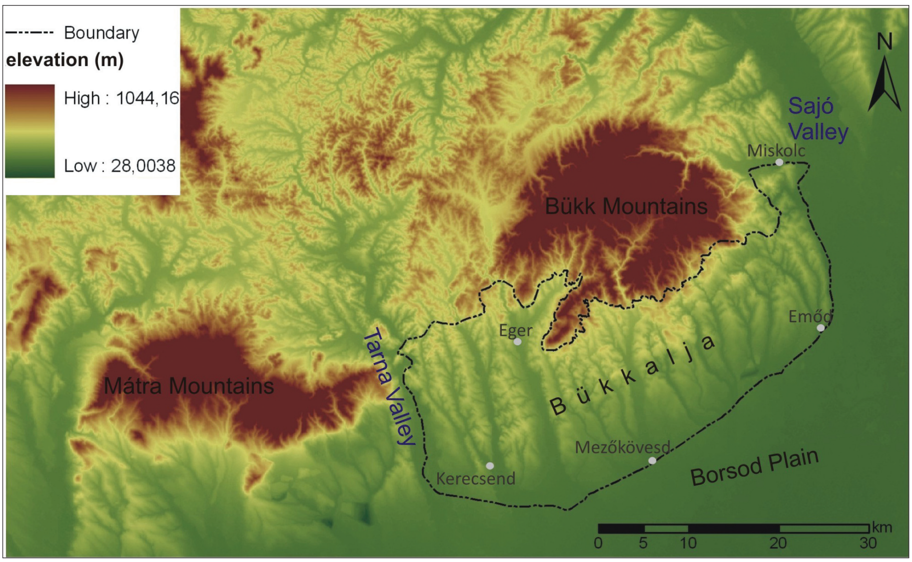

Fig. 1. The location of Bükkalja in the North Hungarian Mountains and the SRTM based DEM of the vicinity

Geological setting

The erosion, and therefore the evolution of planation surfaces as well – beside the climate, vegetation, and other geographic conditions – mainly depends on the geological setting. In the study area the rock quality ("hardness") has the most important role in the evolution of the surface.

The geological structure of Bükkalja is very diverse, determined mainly by Miocene pyroclastic rocks; and by younger, Pliocene-Pleistocene sediments. In the north the Bükkalja is joined to the Mesozoic rocks in the South Bükk with a narrow, interrupted, early Tertiary band of sediment: Eocene gravel, conglomerate and breccia, mottled clay; Upper Eocene limestone, marl, clayey marl; Oligocene clay, marl, clayey marl, flint, sand and sandstone.

The Eocene limestone near Bükkzsérc is classed as the Szépvölgy Limestone Formation. The Eocene–Oligocene marl, clayey marl belongs to the Buda Marl Formation. Between Noszvaj and Bükkzsérc, the stones of Oligocene Kiscell Clay Formation build up the bedrock (Pentelényi, L. 2002; Less, Gy. 2005).

The Bükkalja inclines to the Borsod Plain with Pannonian and early Pliocene marine sediments, and Pleistocene terrestrial deposits. The former are represented by Lower Pannonian sand, sandstone, mottled clay, clayey marl; Upper Pannonian sand, clay, gravel and seams of lignite, whereas the latter are Pleistocene gravelly-sandy deposits and loess (Hevesi, A. 1997). The wide central part of Bükkalja is built up of Miocene rhyolite, rhyodacite- and dacite tuffs, and welded ignimbrites (rheoignimbrites) *(Figure 2)*. The quality, compound of the pyroclasts is very diverse; they are classified into four formations by their properties *(Figure 2)*. The long cuestas of the lava rock hardness welded ignimbrites – oriented towards SWW–NEE − had played a decisive part in the evolution of Bükkalja valley system (Hevesi, A. 2002), and in the shaping of planation (pediment) surfaces as well.

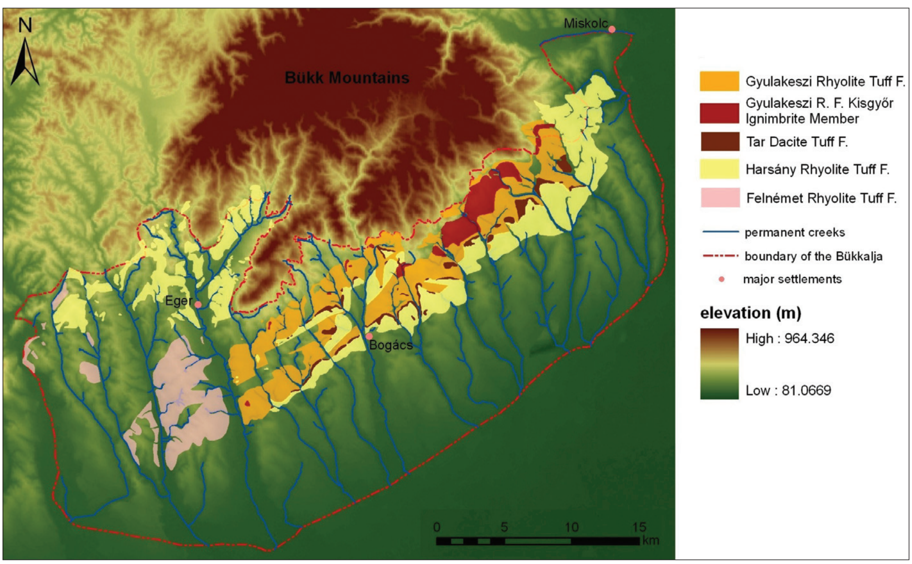

Fig. 2. The position of the Miocene pyroclastic rocks in Bükkalja. (*Source:* Gyalog, L. 2005)

The volcanism, which produced the 45 km long, 6–10 km wide band (Pentelényi, L. 2005) of pyroclasts, lasted from the Ottnangian period of the Miocene to the early Pannonian age (in terms of absolute age 21–13 million years ago). The volcanism, however, was not continuous, with interruptions between the eruptions, and the intensity of these eruptions, and the amount and quality of the materials were changing as well (Pentelényi, L. 2002, 2005; Lukács, R. *et al*. 2010).

The first part of the volcanism was the most intensive, which resulted in the widest formation, the Gyulakeszi Rhyolite Tuff Formation (Lower Rhyolite Tuff). The proportion of the welded-clinkered (rheo)ignimbrite variants is less than 50% (Pentelényi, L. 2002, 2005). These welded ignimbrite variants, which were previously delineated as lava cuestas (Balogh, L. 1963), are classified into the Kisgyőr Ignimbrite Member (Pentelényi, K. 2005). The center of the eruption must have been in the eastern foreland of Bükkalja (Pentelényi, K. 2002; Lukács, R. *et al*. 2010).

The volcanism recommenced at the end of the Carpathian. This eruption caused the appearance of the terrestrial dacite tuffs in the area. This is the Tar Dacite Tuff Formation (Middle Rhyolite Tuff). 90% of this formation consists of well-clinkered, welded ignimbrites (Pentelényi, L. 2002, 2005), therefore these are the "hardest" rocks among the pyroclast formations, the most resistant ones to denudation. This formation (and the Kisgyőr Ignimbrite Member as well) has had the most important role in the evolution of the pediment.

The volcanism resumed in the Badenian, which resulted in terrestrial, and marine rhyolite tuff. This is the Harsány Rhyolite Tuff Formation (Upper Rhyolite Tuff). Contrary to the Lower and Middle Rhyolite Tuff, this deposit does not contain welded ignimbrite, rheoignimbrite variants (Pentelényi, L. 2002, 2005).

On the western part of Bükkalja, between the valleys of Eger and Szóláti streams the pyroclasts belong to the Felnémet Rhyolite Tuff Formation. These rocks were formed during the Badenian and Sarmatian, and with results of further investigations, these could be drawn together with the Harsány Rhyolite Tuff Formation (Pentelényi, L. 2005). (The classification of these rocks is ambiguous: on the geologic map of the Bükk Mountains [Pelikán, P. 2002] the pyroclasts of the Tárkány-embayment, and north-western Bükkalja are illustrated as rocks of the Felnémet Formation, however, on the geologic map of Hungary [Gyalog, L. 2005] they are drawn as part of the Harsány Formation.)

According to Varga, Gy. (1981), the cause of the above mentioned intense welding is the low (3–5%) ash-content of these volcanic rocks. Because of the powerful eruptions, these pyroclasts were thrown some 10 kilometres far from the eruption center (Lukács, R. *et al*. 2010).

The evolution of pediment

The Bükkalja is a *dissected, dual pediment* surface. Along the margin of Bükk Mountains, the conditions of planation were given several times in the Miocene and at the Pliocene–Pleistocene boundary as well, but the exact date of the planation is still uncertain (Dobos, A. 2006).

As a consequence of the Bükk Mountains' rising, the Bükkalja mostly became a terrestrial area by the end of the Miocene. With the termination of the Miocene volcanism, the evolution of Bükkalja began at the end of Sarmatian age (Hevesi, A. 1978). In the Pannonian (Sümegium, Bérbaltavárium; 8–5.5 million years ago) under arid-semiarid climatic conditions the surface suffered sheet erosion mainly by torrents which continuously changed their riverbed and direction (Hevesi, A. 1978). At this time the ancestors of streams of the recent drainage network (Eger, Hór, Laskó and the Tárkány streams) began to form. The streams deposited their load into alluvial fans. These fans – built side by side – effected the shaping of a homogeneous planation surface (Dobos, A. 2006).

The mountain building processes caused the Miocene pyroclasts to topple from their originally horizontal position, so the beds incline with 8–25° steep slopes to south-west direction (Dobos, A. 2006; Pentelényi, L. 2002). The escarpments of the "hardest" welded ignimbrites (Tar Dacite Tuff Formation, Gyulakeszi Rhyolite Tuff Formation, Kisgyőr Ignimbrite Member) being distinctly higher than their surroundings, form long cuestas running south-west–north-east. Between the valleys of Kács- and Eger streams, tectonic movements caused these cuestas to occur in two parallel stripes. Geomorphologically these rocks can be found on the top of the interfluve hills. At present these escarpments at 300–350 m altitude (a.s.l.) represent much of the *older pediment* (Dobos, A. 2006).

In consequence of further rising of the Bükk Mountains (5.5–3 million years ago), and the growing relief, the older pediment was dissected by the permanent streams. At the end of Pliocene (Villányium, 2–1.8 million years ago) under dry, semiarid conditions, a *younger pediment* developed about 100 metres below the older surface, growing continuously to the detriment of its area (Pinczés, Z. *et al*. 1993; Dobos, A. 2006). Nowadays the portions of this younger and lower pediment are located at 200–280 m a.s.l. (Dobos, A. 2006).

The dissection of this dual pediment started already at the beginning of the Pliocene. Because of the rising quantity of precipitation and lowering temperature, landform evolution became controlled by the linear streams. By the end of Pliocene epoch, only those parts of the older pediment survived, which are the "hardest" i.e. the most resistant to denudation and primarily built up by welded ignimbrites (Pinczés, Z. *et al*. 1993). In the arid phases of the periglacial climate during the Pleistocene, sheet erosion, planation formed the surface, while in the humid periods the strengthening erosion of the stream channels formed V-shaped valleys. This process produced the long, parallel valleys, in which most of the permanent streams of the Bükkalja run up till now (Pinczés, Z. *et al*. 1993, Dobos, A. 2006). Apart from the valleys shaped by erosion, numerous dry valleys were formed by the process of derasion.

Materials and methods

As the older, upper level of the dual pediment is situated in the area of the welded ignimbrites, only the eastern part of the pediment (i.e. that lying east of Eger stream) was examined, where these rocks outcrop.

Apart from the uncertainty in the dating of planation, the location of the surfaces of dual pediments was also undefined. In order to exclude the subjective approach, to locate these pediment levels was attempted using GIS based methods.

Beside the SRTM digital elevation model, the welded ignimbrite hilltops as parts of the older, upper pediment also became involved in the study. They

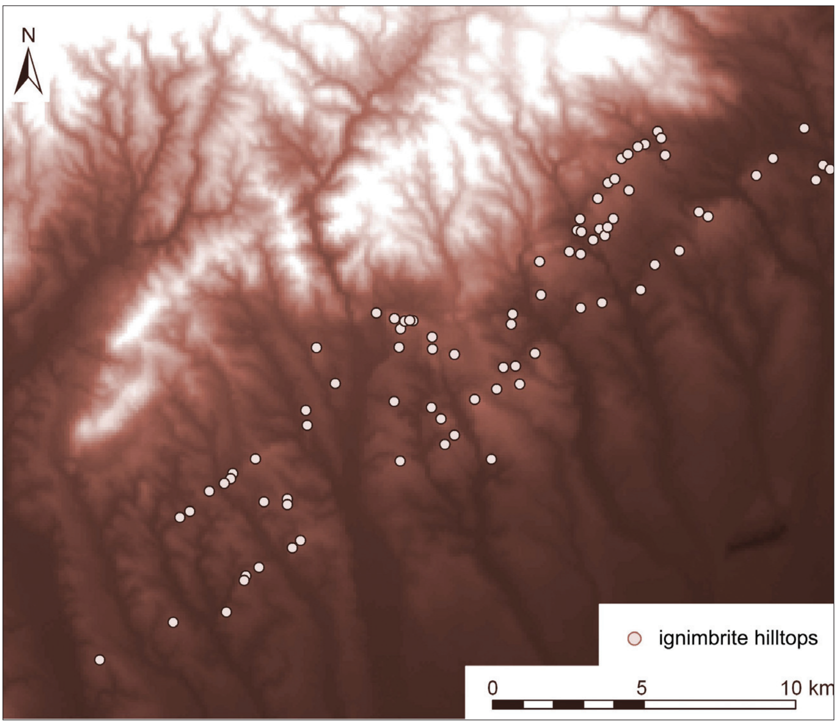

Fig. 3. The SRTM DEM of South Bükk, and Bükkalja showing the digitized ignimbrite summits

were digitized as the highest points of the interfluve hills. They were necessary for comparison with the location of pediment surfaces, defined by SRTM. These points were also used at the interpolation of a trend surface. The digitization of the height of hilltops was based on topographic contour maps at 1:10,000 scale, and on geologic maps at 1:100,000 scale (Pelikán, P. 2002; Gyalog, L. 2005). In this process, the height data of all welded ignimbrite hilltops of Bükkalja were determined. The SRTM database was used for the examination of the pediment, and the delineation of pediment levels *(Figure 3)*.

SRTM is a free digital elevation model, with a resolution of about 90 metres (Timár, G. *et al*. 2003). ArcGIS 9.3 software package was used for the analysis.

The investigation of relationship between the situation of welded ignimbrites and the upper, older level of dual pediment was also based on SRTM DEM. In the examination of the landforms only the ridges were used. They were identified by the "Topographic Position Index" (Weiss, A. 2001 cited Jenness, J. 2006).

For the morphometric analysis of ignimbrite cuestas, all of the patches were digitized, where the Miocene pyroclast formations occur on the surface. These polygons were digitized from geological maps of 1:100,000 scale (Pelikán, P. 2002; Gyalog, L. 2005).

Results and discussion

Examination of pediment levels

There was an attempt to determine the area of pediment based on the DEM histogram. In order to classify the pixels the local minimum, maximum, and inflection points of the histogram had to be determined. The histogram was approached with an eight-degree polynomial function. With the first derivation of the polynomial function, the minimum and maximum points could be calculated, and the second derivation of this function determined the inflection points. As the first step the pixels of the DEM were classified by the minimum and the maximum points of the histogram (which is about equal to the polynomial function points).

On the classified DEM, the class of the pixels between 175 and 370 m a.s.l. expressly shows the pediment *(Figure 4)*. The boundary of Bükkalja was vectorized previously on the base of the topographic map of 1:10,000 scale following the contour lines. Although this boundary is in well conformity with the border of the pediment classified from the DEM, there are some differences between them. Applying this method, the northern border of Bükkalja – which is difficult to delineate with the classic geomorpologic methods – could be

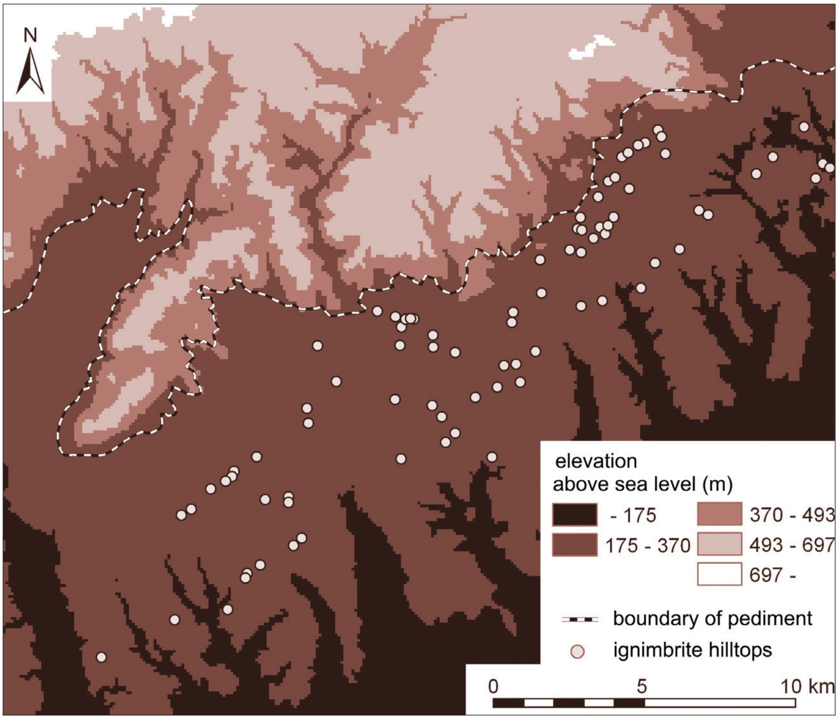

Fig. 4. Classified DEM on the base of the histogram's local minimum and maximum points

drawn exactly. According to this, the method described above can be used in the landscape classification, delimitation as well.

The other way to classify the DEM is the usage of the inflection points of the histogram *(Figure 5).* The DEM, according to the inflection points, shows the two different levels of pedimentation *(Figure 6).* The lower level is between 151–243 m, the upper is between 243–426 m. This figure shows that 87% of the ignimbrite summits are situated at the level of the upper pedimentation. This fact confirms the observation that the upper pedimentation was formed from the volcanic rocks. 13% of the ignimbrite summits are located along the north-eastern and south-western edges of the ignimbrite cuestas. The upper, older level is dissected along the streams springing from the South Bükk and running towards the Great Hungarian Plain (Alföld). On the north-eastern part of Bükkalja, the ignimbrite summits are arranged into two stripes. The southern stripe is more dissected than the northern one, and at the edges of this southern cuesta there are isolated ignimbrite blocks.

This examination leads to the result that the pediment is not uniform, it is fragmented both vertically and horizontally *(Figure 6)*. There are two different levels: the upper, older (243–426 m); and the lower, younger one (151–243 m).

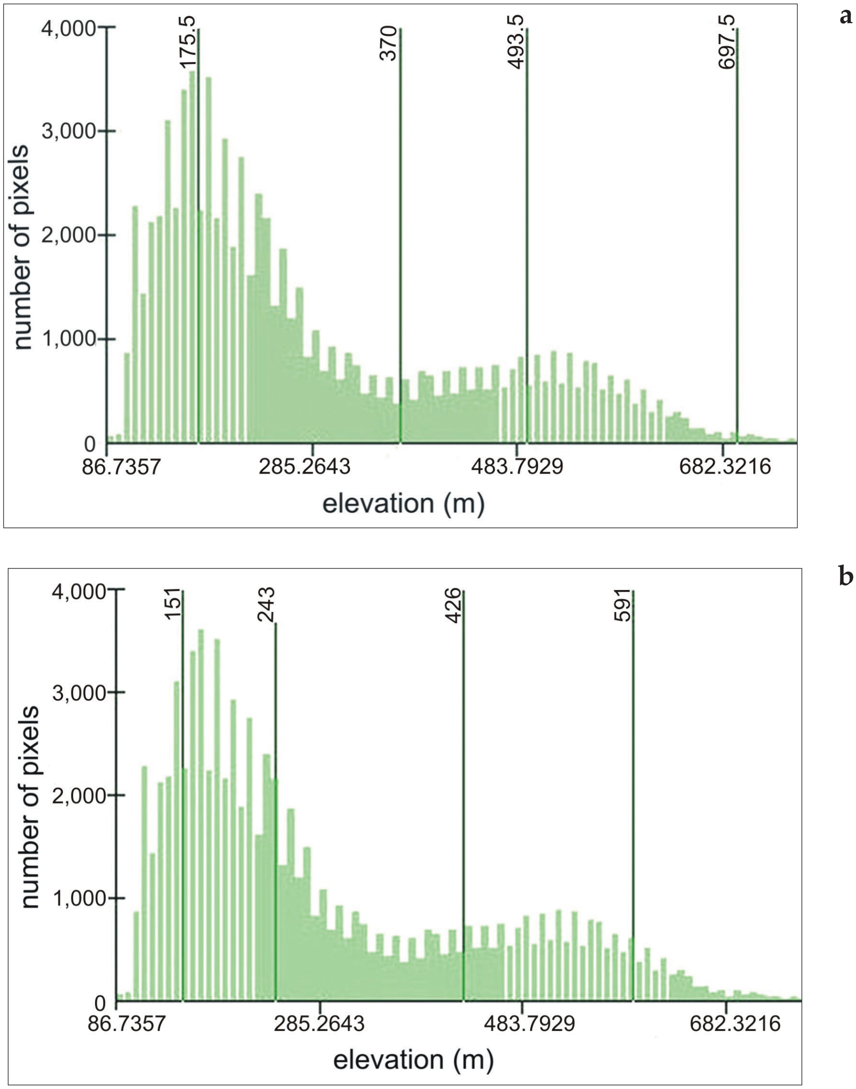

Fig. 5. Classification of pixels on the base of the histogram; a = local minimum and maximum points; b = inflection points

Based on the heights of the ignimbrite peaks a trend can be interpolated. This trend provides information from the spatial distribution of ignimbrite hilltops. The second-degree trend shows a saddle surface. The centre of the saddle coincides with the area of those ignimbrite summits, which form part of the less dissected pediment. The descending sides of the saddle show the more fragmented areas *(Figure 7)*.

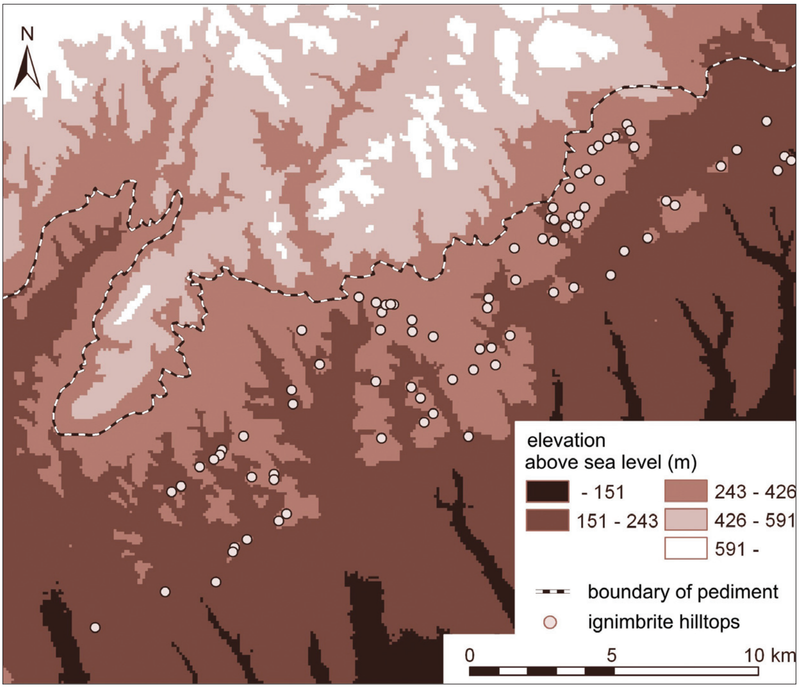

Fig. 6. Classified DEM on the base of the histogram's inflection points

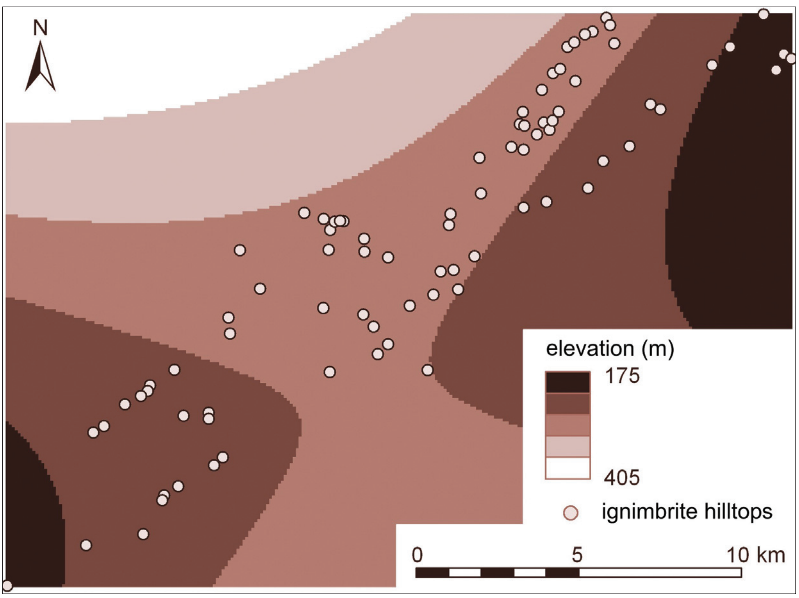

Fig. 7. Trend surface interpolated from elevation of ignimbrite hilltops

It shows that the pediment is divided into three parts from north-east to south-west. The central part of the surface is higher than the flanks, which indicate tectonic movements.

Delimitation of geomorphologic levels based on ridge height classification

In accordance with the dual pediment character (Dobos, A. 2006; Marton-Erdős, K. 2002) the pixels (ridges) of DEM by their height have been classified into two geomorphologic levels *(Figure 8)*. For the classification the ArcGIS 9.3 software Iso Cluster clustering algorithm (Spatial Analyst Tools/Multivariate) was used.

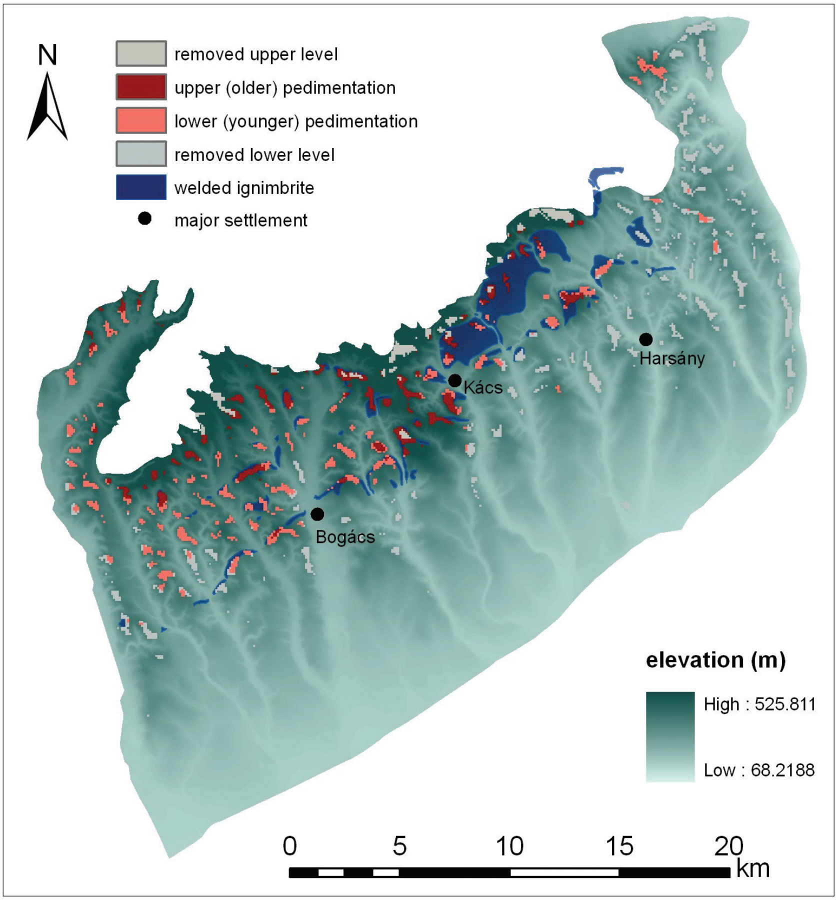

Fig. 8. Geomorphic levels of Bükkalja according to the classification of pixels (ridges) height

The selection of ridges with the Weiss method (Topographic Position Index) causes some problems. It classifies some landforms of the surface into the ridge category, which – according to the topographic maps and field observations – are not real ridges. Such landforms are the heights pushing from the South Bükk into the northern border of Bükkalja, the feet of landslides higher than the surroundings, or the southern, lowering part of interfluve hills.

To get around these problems, the pixels (ridges) were classified by their height into four classes applying statistical methods (*Table 1)*. Then the lowest class (which contains pixels classified by the method into ridges, being in fact not real ridges) and the highest one (the heights of northern border) were removed from the database. The easy separability of the pixels (by height and location equally) made this method possible *(Figure 8)*.

The pixels of first (lowest) class apparently may be part of ridges as well from geomorphologic point of view. Nevertheless, because of the low – often only some metres high – relative height, these pixels do not represent typical ridges. By removing the lowest and the highest classes, a rectified map was generated *(Figure 8)*, with the ridges of the pediment classified into two height classes which represent two geomorphic levels: the level 2 is the younger, lower; while the level 3 is the older, higher level of the pediment *(Figure 8, Table 1)*. The combined area of the two levels is 16.88 km^2, which is less than 2% of the whole territory of Bükkalja. The older, upper level is smaller: 673.24 ha, the younger, lower level comprises 1015.25 ha *(Table 1)*.

Table 1. Data of ridges classified into four height classes (calculated from pixel numbers)

Class/ geomorphic level	Area (ha)	Proportion of area (%)	Pixels on welded ignimbrites	
			Area (ha)	Proportion (%)
1 (lowest, removed)	1244.63	38.55	72.23	5.8
2 (lower level)	*1015.25*	*31.46*	*185.49*	*18.2*
3 (upper level)	*673.24*	*20.86*	*226.07*	*33.6*
4 (highest, removed)	294.80	9.13	19.87	6.7

During the analysis of the relationship between the welded ignimbrite cuestas and the ridges of the upper pediment level, the proportion of the pixels was also examined, identified as ridges by the above mentioned method of both geomorphic levels, occurring on ignimbrites (ArcGIS 9.3 Spatial Analyst/ Zonal Statistics as Table tool, *Table 1*).

According to the calculations, pixels of the upper pediment level occur in the greatest proportion on welded ignimbrite surfaces (33.6%, *Table 1*). Accordingly, this rock type has a leading role in the evolution of upper pediment level. The rest of the pixels belonging to this class are located mainly on the relatively high saddles between the welded ignimbrite ridges, and on the southern slopes of Nagy-Eged Hill (536 m).

On the examined eastern part of Bükkalja, following the direction of welded ignimbrite cuestas, the ridges of pediment levels are arranged into 2–3 parallel stripes.

Between the Tardi- and Kácsi streams, on the highest zone of the pediment, the stripes of the upper pediment level – breaking the lower level – are merged *(Figure 8)*. Portions of the younger, lower pediment level are located mainly to the south of the upper level.

In the Bogács–Cserépfalu depression, these lower ridges can be found between the stripes of the upper level. Even though the applied method has uncertainties, the results, i.e. the location of pediment levels are more complete and detailed than those in the former geographic literature (e.g. Dobos, A. 2006). The list of the major hills of the pediment (geomorphic) levels, based on the applied method, is shown in *tables 2* and *3*.

Table 2. Major ridges of older, upper geomorphic level

Name of hills	Elevation (m)	Formation
Kis Eged-hegy	302	Szépvölgy Limestone Formation
Sík-hegy	305	Kiscell Clay Formation
Mész-hegy	332	Gyulakeszi Rhyolite Tuff Formation Kisgyőr Ignimbrite Member (KIM)
Kavicsos-tető	332	Kiscell Clay Formation, Noszvaj Member
Ibolyás-tető	334	Kiscell Clay Formation, Noszvaj Member
Kőkötő-hegy	318	Tar Dacite Tuff Formation
Gyűr-tető	293	Tar Dacite Tuff Formation
Ravaszlyuk-tető	358	Kiscell Clay Formation
Nyomó-hegy	340	Gyulakeszi Rhyolite Tuff Formation KIM
Vén-hegy	291	Tar Dacite Tuff Formation
Mész-hegy (Cserépfalu)	353	Tar Dacite Tuff Formation
Kecsor-tető	295	Tar Dacite Tuff Formation
Sós-tető	342	Tar Dacite Tuff Formation
Szaduszka-tető	331	Gyulakeszi Rhyolite Tuff Formation KIM
Nagy Barátrét-tető	342	Kiscell Clay Formation/Gyulakeszi Rhyolite Tuff Formation
Mangó-tető	325	Tar Dacite Tuff Formation
Karud	371	Tar Dacite Tuff Formation
Szentkereszt-bérc	322	Tar Dacite Tuff Formation
Vár-hegy (Kács)	325	Tar Dacite Tuff Formation
Pallag	302	Gyulakeszi Rhyolite Tuff Formation KIM
Poklos	348	Gyulakeszi Rhyolite Tuff KIM
Kecet-tető	350	Gyulakeszi Rhyolite Tuff KIM
Dobrák-tető	350	Gyulakeszi Rhyolite Tuff KIM
Vár-hegy (Kisgyőr)	333	Gyulakeszi Rhyolite Tuff KIM
Kerek-hegy (Kisgyőr)	311	Gyulakeszi Rhyolite Tuff KIM
Halom-vár	317	Tar Dacite Tuff Formation

Table 3. Major ridges of younger, lower geomorphic level

Name of hills	Elevation (m)	Formation
Nyerges-tető	254	Gyulakeszi Rhyolite Tuff Formation
Aranybika-tető	286	Gyulakeszi Rhyolite Tuff Formation
Elő-hegy	269	Eger Formation/ Gyulakeszi Rhyolite Tuff
Ispán-hegy	260	Tar Dacite Tuff Formation
Deber-tető	255	Eger Formation
Méti-hegy	240	Eger Formation
Csobánka	275	Gyulakeszi Rhyolite Tuff Formation
Vásáros-hegy	268	Gyulakeszi Rhyolite Tuff Formation
Borda hegy	276	Tar Dacite Tuff Formation
Pipis-hegy	266	Tar Dacite Tuff Formation
Ortvány	270	Gyulakeszi Rhyolite Tuff Formation
Gyűr-hegy	264	Harsány Rhyolite Tuff Formation
Őr-hegy	272	Tar Dacite Tuff Formation
Berezd-tető	274	Gyulakeszi Rhyolite Tuff Formation
Égés-tető	282	Gyulakeszi Rhyolite Tuff Formation
Tardi-hegy	277	Gyulakeszi Rhyolite Tuff Formation
Vár-hegy (Cserépváralja)	291	Tar Dacite Tuff Formation
Kecskekő-tető	274	Tar Dacite Tuff Formation
Mátéka-tető	240	Harsány Rhyolite Tuff Formation
Meredek-hegy	277	Tar Dacite Tuff Formation
Bánya-tető	241	Tar Dacite Tuff Formation
Dongó-tető	240	Harsány Rhyolite Tuff Formation
Leányvár-tető	269	Harsány Rhyolite Tuff Formation

Morphometric analysis of ignimbrite cuestas

As the dual pediment of Bükkalja formed by ignimbrites, these rocks must have played a very important part in landform evolution. Applying the morphometric analysis an attempt was made to determine the degree of this importance. The territory of the older pediment is overlapping with the top of ignimbrite stripes, which points to the fact that they have a key role in geomorphic evolution. Among these formations, the most important rocks are the welded ignimbrites: Tar Dacite Tuff Formation, and Gyulakeszi Rhyolite Tuff Formation Kisgyőr Ignimbrite Member.

Compared to the neighborhood, these rocks are more resistant to erosion, their denudation is slower and less effective, therefore they form the higher, typical landforms of Bükkalja (this type of hill is the so-called "nyomó", after the famous Nyomó Hill, located in the Bogács–Cserépfalu depression). These ignimbrite cuestas had taken decisive part in the evolution of the drainage network as well (Vágó, J. 2006). Despite the leading role of the welded ignimbrites, we examined not only these rocks, but all of the Miocene tuff formations.

The GIS based detailed morphometric investigations were aimed to confirm the field observation, that the major properties of the terrain on the welded ignimbrites are significantly different from the properties in their neighborhood. The average elevation (a.s.l.), slope conditions and average relative relief values of tuff formations were compared with the same parameters on the whole territory of Bükkalja (*figures 9, 10* and *11*). The patches covered by tuffs on the surface were vectorized as polygons. The polygons of each tuff formation were considered as a single shapefile. During the calculations, the above mentioned properties of these polygons were determined on the basis of SRTM elevation model, and summarized by formations.

The average elevation of the whole area is 186.96 m. Average elevation of each tuff formation is above this value *(Figure 9)*, most of them are higher

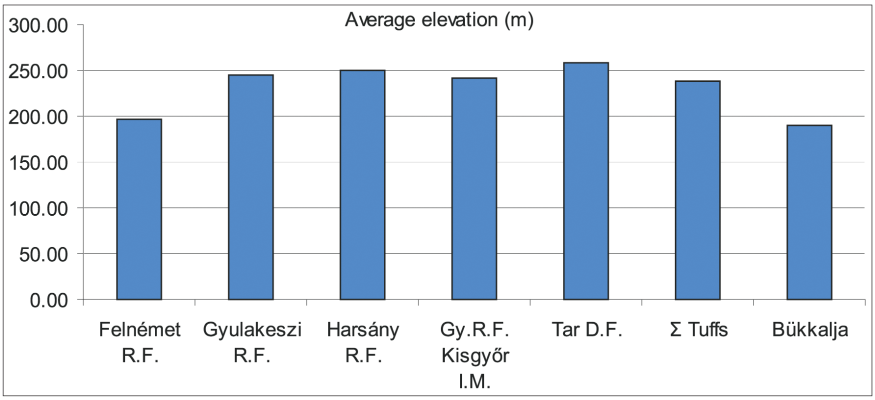

Fig. 9. Average elevation (a.s.l.) of tuff formations, compared to the average elevation of Bükkalja

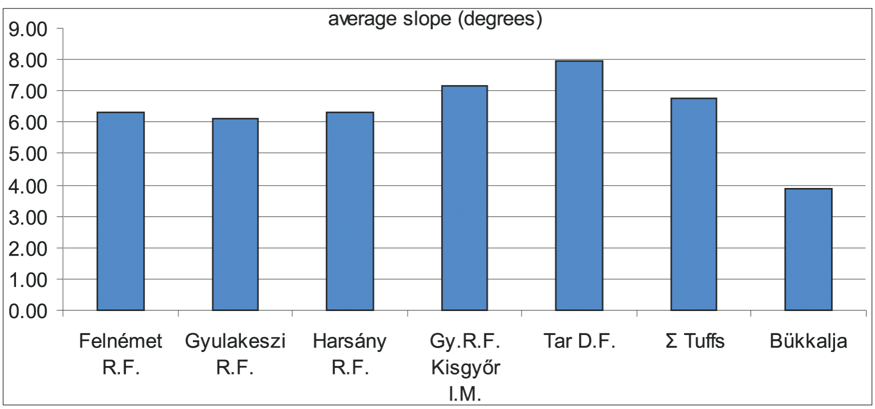

Fig. 10. Average slope angles of tuff formations, compared to the value of Bükkalja

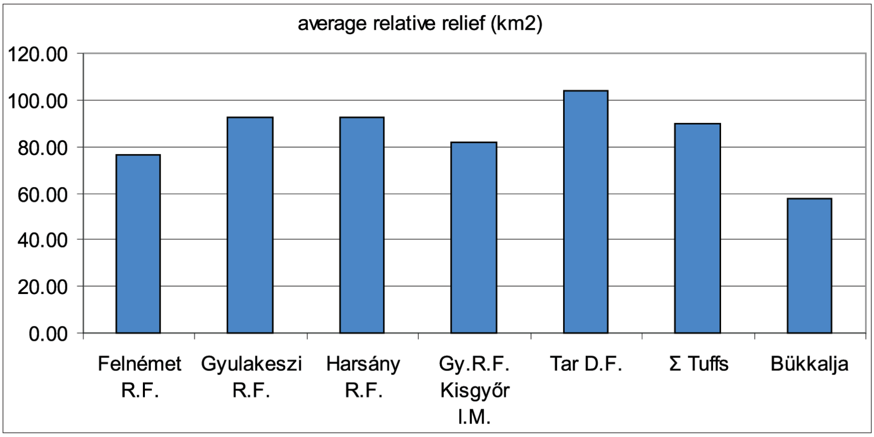

Fig. 11. Average relative relief of tuff formations, compared to the value of Bükkalja

than 240 m. Even the less resistant rocks with high erodibility, like unwelded blocks of Felnémet-, and Harsány Rhyolite Tuff Formations are higher than the average. The highest value belongs to the hills of Tar Dacite Tuff Formation (259 m) covered by rheoignimbrite, which confirms a great resistance to erosion of the welded ignimbrite variants.

The value of average slope *(Figure 10)* on the Bükkalja is less than 4°. Similarly to the elevation, the values of average slope in the case of all tuff formations are higher than the average. The highest slope data can be found at formations, which predominantly consist of welded ignimbrite variants. On the area of Tar Dacite Tuff Formation, Gyulakeszi Rhyolite Formation Kisgyőr Ignimbrite Member this value is double of the average.

The value of average relative relief on the pediment is less than 60 m/km^2 *(Figure 11)*. This parameter is also higher in the case of tuffs: the greatest values measured on the patches of Tar Dacite Tuff Formation are higher than 100 m/km^2. The relatively lower values of Kisgyőr Ignimbrite Member are explainable with the patches flatter, plateau-like appearance on the north-eastern part of Bükkalja. According to the results obtained, the welded ignimbrite stripes are well distinguishable from the other parts of Bükkalja, therefore their effect on the pediment is apparently evident.

Conclusions

According to the former results, the southern pediment of the Bükk is spatially demarcable using digital elevation model. The coincidence between this calculated pediment and the pediment border derived by classical (topographic based) methods is fairly good, but it is not perfect. The variation comes from the different objectivity of the methods. The DEM based calculation is more objective.

According to our results, classifying the SRTM by the inflection points of the histogram, pediment levels can be delineated. The Bükkalja is divided into two pediment levels: the upper, older level is situated between 243–426 m; and the lower, younger level evolved between 151–243 m.

Examining the spatial distribution of the hilltops a trend surface was interpolated. The second-degree trend shows a saddle surface. The highest, central part of this saddle surface is situated on the area of those ignimbrite hilltops, which are part of the less dissected pediment section.

Using an alternative method, analyzing the ridges in Bükkalja by their heights, the area of pediment levels was determined, and relationship was found between the location of welded ignimbrites and the upper level of pediment. The area of the upper level is 673.24 ha, while the area of the lower level is 1015.25 ha. According to the calculations, the welded ignimbrite surfaces have had a key role in the formation of upper pediment level.

With the morphometric analysis of ignimbrite cuestas the role of Miocene ignimbrite formations in the landscape evolution became verified.

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