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THE RELATION OF THE SOUTH-EASTERN BÖRZSÖNY HILLS TO THE VISEGRAD GORGE, HUNGARY

Abstract. The Visegrád Gorge of the Danube evolved around the Plio-Pleistocene boundary. The Danube became the absolute base level of the streams in the south-eastern Börzsöny Hills. The tributaries of the Danube dissected the previous ancient surface creating geomorphological levels which correlate with the fluvial terraces of the Danube. Based on the determination of the dissected, ancient surfaces and other relict landforms of the south-eastern Börzsöny Hills, correlations were carried out between the evolutionary stages of the surfaces above and the fluvial terraces of Visegrád Gorge. To get relevant information, GIS methods, statistical, sediment and geomorphologic analysis were applied. The fluvial origin of the terraces situtated at higher altitudes of the Visegrád Gorge is doubtful. The results of this study comfirmed that the terrace are the remnants of an ancient relief which evolved before the Plio-Pleistocene boundary.

Key words: the south-eastern Börzsöny Hills, the Danube, the Visegrad Gorge, surface analysis, GIS

INTRODUCTION

As the Danube is the absolute base level and the hydrological axis of the Carpathian Basin, the investigation of the Danube valley has been a priority for years. The river section of the Visegrád Gorge is only 40-km-long, but it is one of the most investigated areas in Hungary. Several therories were proposed to explain the evolution of the valley. H. B ö c k h (1899), Gy. S ó b á n y i (1906) and Gy. H a l a v á t s (1898) considered that the Danube was flowing through an ancient valley. Other researchers referred to a valley of other origin such as epigenetic valley (V e n d l 1928; K á d á r 1955), antecedent gorge (C h o l n o k y 1925; K é z 1933; N o s z k y 1935; P é c s i 1959), rift valley (F o d o r et al. 1999) or an antecedent gorge modified by volcanic landforms (S z é k e l y 1997; K a r á t s o n 1997, 2007).

M. P é c s i (1959) proposed the theory of Quarternary evolution of the Visegrad Gorge (Fig. 1.) but at present the evolution of the gorge is considered

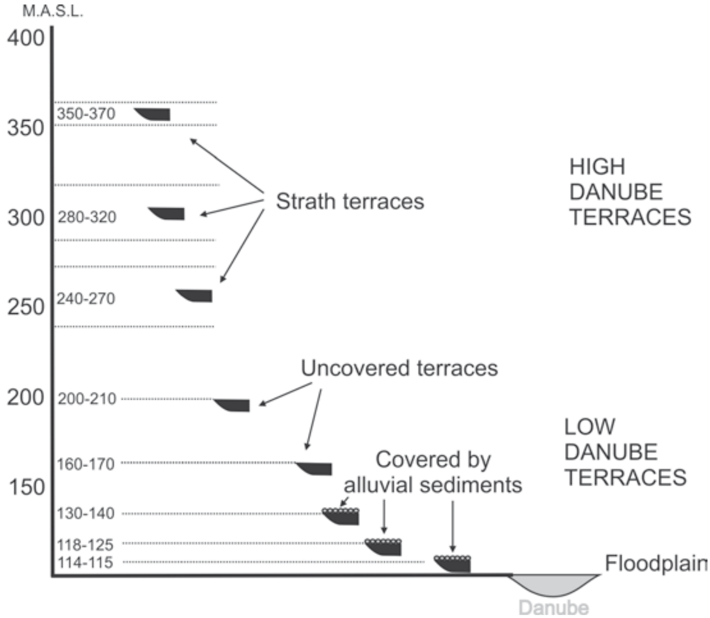

Fig. 1. Locations of fluvial terraces of the Danube in the Visegrád Gorge (by M. Pécsi 1959)

more complex (Scheuer, Schweitzer 1988; Ruszkiczay-Rüdiger 2005; Gábris, Nádor 2007).

The problem of the evolution of the Visegrád Gorge can be approached in several ways (geomorphological and tectonical investigations, the analysis of Quaternary sediments). The past 100 years of study shows that obtaining an overall and accurate image of the area requires using various approaches at the same time.

AIMS, BACKGROUND AND STUDY AREA

The reason for the incomplete results of earlier research of the Visegrád Gorge can be the fact that it focused only on the river valley (between the ridgelines). The authors of this paper point out that the sediments and the landforms along the narrow river section were eroded, so it is very important to investigate not only the valley but also its tributaries which are in a hydrological and geomorphological relationship with the river (Fig. 2).

The aim of our investigation was to define geomorphological levels of the tributary valleys of the Danube to reconstruct the geomorphological levels of the Visegrad Gorge. A similar landscape evolution provides a geomorphological relationship between these areas, which means that the geomorphological levels that evolved during the same geological periods are comparable.

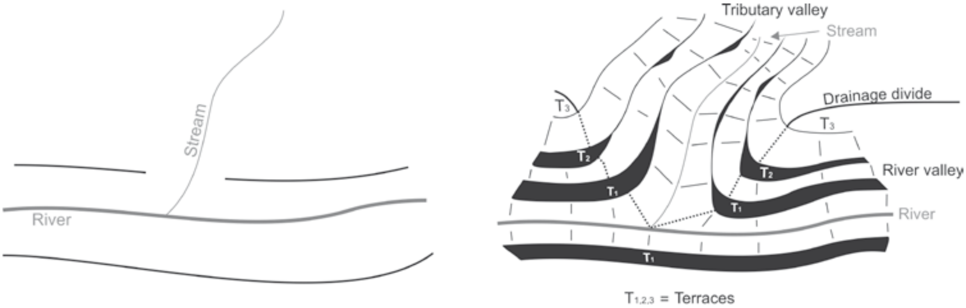

Fig. 2. Hydrological and geomorphological relationship between the Danube and its tributary valleys

In the case of the Danube, we used the terrace system defined by other authors. In the case of the south-eastern Börzsöny Hills, first we identified the flat-top surfaces applying GIS methods, then carried out statistical analysis using their altitudes, analysed their surface sediments, and determined the geomorphological levels. Finally, we compared the geomorphological levels of the Danube River valley with those of the tributary valleys.

We designated a study area that was hydrologically coherent and suitable for the investigation of landscape evolution. The study area consists of two subareas: the lower section of the Visegrád Gorge (the river valley) and the south-eastern Börzsöny Hills (tributaries) which belong to the watershed of the Danube.

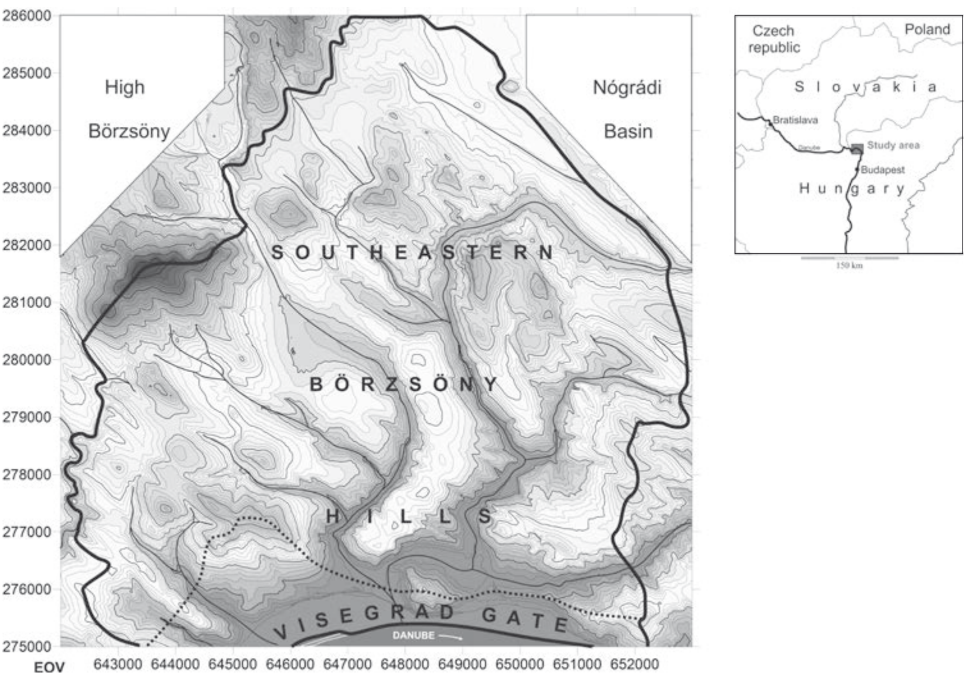

Fig. 3. Study area

The geomorphological levels of the Visegrád Gorge formerly identified as fluvial terraces are located between 100 m (the level of Danube) and 370 m a.s.l. The designated study area (111 km^2) is located between 100–530 m a.s.l., more than 97 km^2 of which is at the level of the fluvial terraces of the Danube. Hence, 88% of the area may be correlated with the Danube terraces.

METHODS

IDENTIFYING THE FLUVIAL TERRACES OF THE VISEGRÁD GORGE

The identification of the fluvial terraces of the Danube is based on earlier findings (Pécsi 1959) providing general data on the whole area of the gorge. To avoid scarce data coverage, an inventory was undertaken. The sources of the data were 1 : 10,000 topographic maps of Hungary and field measurements carried out with Magellan Professional Mobile Mapper CX GPS/GIS receiver.

IDENTIFYING THE FLAT-TOP SURFACES OF THE SOUTH-EASTERN BÖRZSÖNY HILLS WITH GIS METHODS

Using GIS methods, we selected the areas which could be potential lag surfaces and stream terraces (flat-top surfaces). After digitizing the contour lines of 1 : 10,000 topographic maps of Hungary (HD 72 EOV coordinate system), a 5-m resolution digital elevation model (DEM) was built using ARC GIS 10 software.

Since the relation and locations of the Holocene forms (floodplain of the Danube and valley floors of the streams in the south-eastern Börzsöny Hills) are evident, the application of GIS methods to compare them with the fluvial terraces of the Danube was not needed. Thus, the information about valley floors was not inserted into the database as it would have made data processing more difficult and complicated.

We assorted the flat-top surfaces appropriate for identifying the geomorphological levels with two different methods. The method of J. Wood (1996) is suitable for selecting landscape forms which are sloping in every direction. In the study area we used the method to select peaks which may be remnants of an ancient surface (Fig. 4A).

To identify gentle slope segments, we applied the method of R. Miller et al. (2012). Gentle slope segments consist of two parts: gently inclining slopes formed by erosion and accummulation and a flat-top preserving the original characteristics of the relict landform. The inclination of the gentle slopes is between 1.5–2.5 degrees, while that of the flat surfaces is between 0–1.5 degrees. We applied the method of R. Miller et al. (2012) to assort landscape forms characterised by pixel values between 0–15 degrees (Fig. 4B).

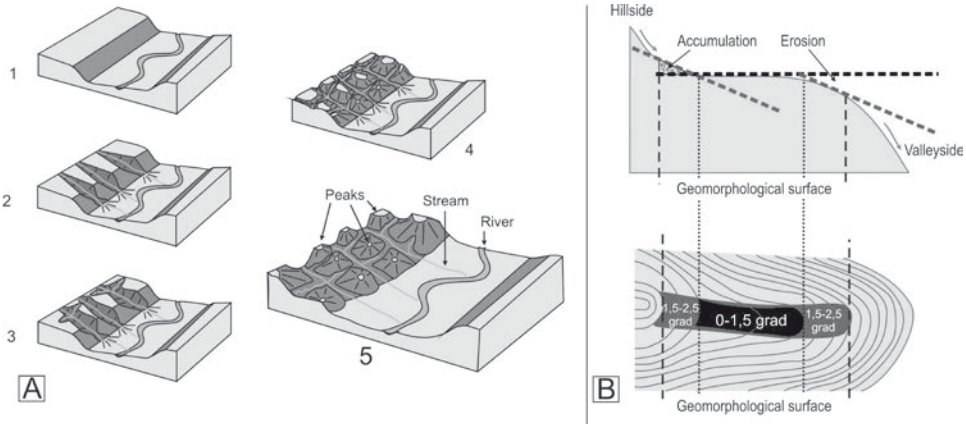

Fig. 4. Two types of flat-top surfaces. A — peaks (B u g y a 2009); B — gentle slope segments

Using GIS methods, we created a digital dataset including the peaks and the the gentle slope segments with inclination lower than 2.5 degrees.

INVESTIGATING THE RELATIONSHIP BETWEEN SELECTED SURFACES WITH SEDIMENT ANALYSIS

There are some flat-top surfaces which were covered by same type of sediments. The covered flat-top surfaces are remnants of a large, dissected ancient terrain. In the study area volcanic rocks are entirely or partly covered by Lajta limestones, deposited in the Badenian Sea and non-volcanic sandy pebbles. Analysing those sediments gives an opportunity to confirm the above-mentioned relationship.

The remnants of Lajta limestones deposited during the Badenian transgression were investigated exhaustively. It was established that in some places the limestone outcrops in the south-eastern Börzsöny Hills used to be part of an ancient, continuous surface. Considering it as evidence, we did not carry out sediment analysis. The limestone outcrops were defined as geomorphological levels.

The non-volcanic sandy gravel was analysed in two different ways. Field samples weighing several kilograms were collected, then sediment particles ranging between 1–3 mm in diameter were isolated by wet sieving and decanting method. After washing and drying the samples, a 4 cm × 4.5 cm sample of 5 mm in thickness was formed by adding water and cement. After the sample had become solid (about 2 weeks), it was divided into several 5 cm × 5 cm cover-slipped thin sections of 30 μm in thickness. The thin sections contained more than 200 mineral and rock particles. Besides, distinctive pebbles were collected during the field trips. Those were numbered and also incorpotated into 30 μm standard covered-slipped thin sections.

Flat-top surfaces, identified with GIS methods, evolved in uplifting areas. They are geomorphological elements with even surfaces shaped by linear erosion. Landscape forms can be classified into two categories according to their geologic history and evolution.

Lag surfaces: the remnants of an ancient terrain which evolved before the current drainage system.

Pleistocene stream terraces: their surfaces were also dissected and leveled by the current drainage system.

Since Pleistocene terraces were shaped by streams, flat surfaces located on the valley slopes are supposed to follow the longitudinal stream profiles. The streams played a role only in the dissection of the ancient surface, thus there is no relationship between the line joining the lag surfaces and the longitudinal stream profile (Fig. 5). In other words, ancient lag surfaces can be characterised by their absolute altitudes (a.s.l.), while Pleistocene terraces can be described by their relative altitudes above the valley floor. The remnants of the Pliocene surface are at a greater altitude, whereas the Pleistocene stream terraces are situated below them. The multiple levels of stream terraces are related to the Pleistocene climate changes, though the Pliocene surface may also have multiple levels, for example Pliocene piedmont steps. As they were originally situated above each other, their lag surfaces can also be at different altitudes.

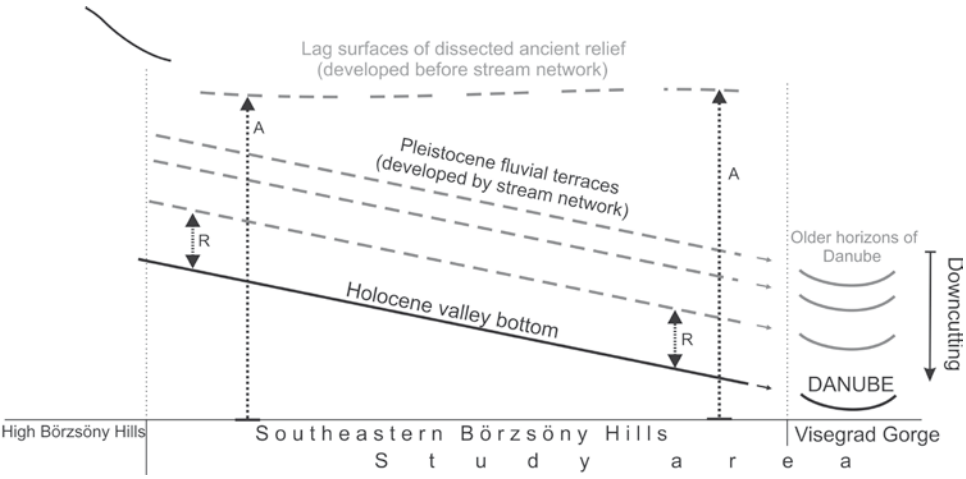

Fig. 5. Characteristic parameters of Pliocene and Pleistocene surfaces based on relative and absolute altitudes (by J. Szeberényi). Legend: A — absolute elevation, R — relative elevation

To perform a statistical analysis, a histogram representing the distribution of elevation data of flat-top surfaces identified using GIS methods was created. Elevation data were given in 5-m intervals. The peak values of the intervals represent the characteristic geomorphological levels. To separate lag surfaces from stream terraces, it was necessary to determine the longitudinal profiles of valley bottom as well. To do so, we determined contour lines of the valley floors, then we defined the distance between the contour lines and the Danube channel. Next, we projected the altitude and defined also the relative elevation of the flat-top surfaces above the valley floors. To quantify the geomorphological levels, we analysed the relationship between the trendlines adjusted to the data about the valley floors and about the flat-top surfaces.

RESULTS

IDENTIFYING THE FLUVIAL TERRACES AND GEOMORPHOLOGICAL LEVELS OF THE VISEGRÁD GORGE

M. Pécsi (1959) gave an overview of the area but did not provide any data. During the thorough field survey, we identified and documented the fluvial terraces. The data on younger terraces were consistent with the data fromearlier investigations. The alluvial levels are located at 103–104 m a.s.l. and 105–106 m a.s.l.; terraces covered by fluvial sediments are situated at 103–104 m a.s.l. and 105–106 m a.s.l.; uncovered terraces are located at 160–170 m a.s.l. and 200–210 m a.s.l.; rock terraces can be found at 250–270 m a.s.l., 290–300 m a.s.l. and 350–370 m a.s.l.

IDENTIFYING THE FLAT-TOP SURFACES OF SOUTH-EASTERN BÖRZSÖNY HILLS WITH GIS METHODS

For a further GIS analysis, we produced a digital elevation model (DEM) by digitalisation. For the projection of the DEM, we used the Uniform National Projection System (EOV). Applying the methods of J. Wood (2009) and R. Miller (2012) consecutively, we selected 224 segments of the flat-top surfaces (Fig. 6) using ArcGIS 10 software.

INVESTIGATING THE RELATIONSHIP OF SELECTED FLAT-TOP SURFACES WITH SEDIMENT ANALYSIS.

Lajta limestones occur in two main areas (Törökmező, Szokolya) at 260–270 m a.s.l. and at 350–360 m a.s.l. It can be concluded that as a likely result of vertical tectonic movements, the seafloor rocks of the Badenian sea are located at different levels above each other (Fig. 7). Both geomorphological levels are older than the Pleistocene fluvial sediments of the Danube.

Based on their mineral composition, fractures, roundness, surface marks and boulders embedded in the matrix of pebbles, it can be concluded that the

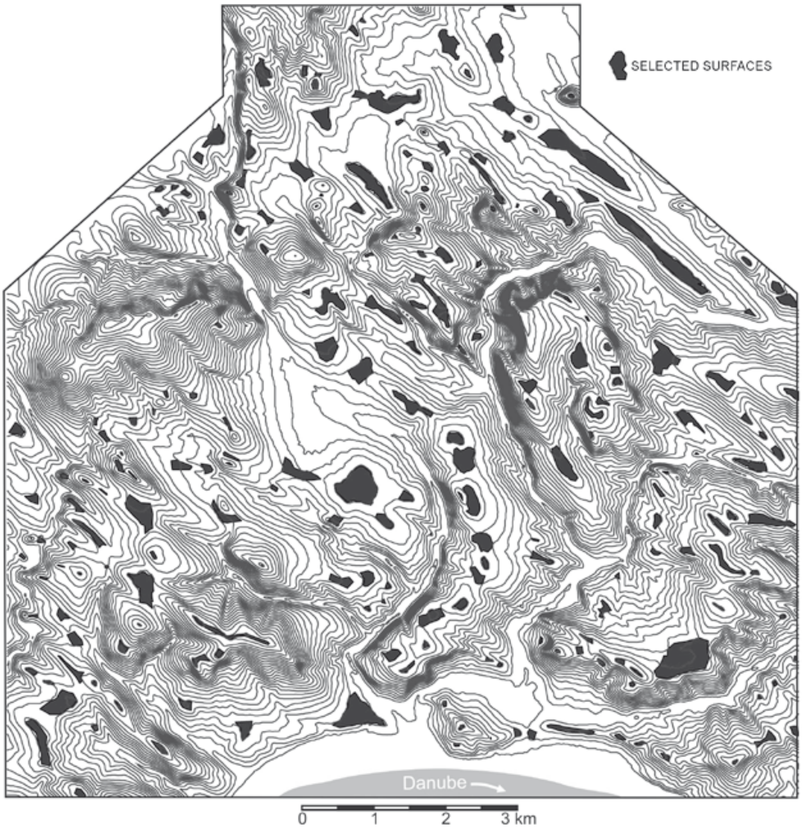

Fig. 6. Selected flat-top surfaces in the study area

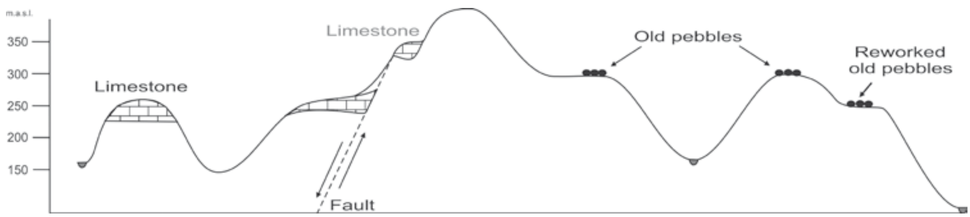

Fig. 7. Locations of old sediments (sketch)

patches of older pebbles occuring in the south-eastern Börzsöny Hills are of the same age. This confirms that the aforementioned patches are the remnants of ancient sedimentary layers preserved on the surface. The patches of pebbles are relatively far from each other but they are situated at the same geomorphological level (280–300 m a.s.l.).

There is a large elongated patch of pebbles, located lateraly in the central part of the study area at 250–260 m a.s.l. This is a redeposited sediment because the sediment mixture includes volcanic rocks and non-volcanic pebbles in a sandy-clay matrix. It confirms the existence of a former accumulation surface at that level (Fig. 8).

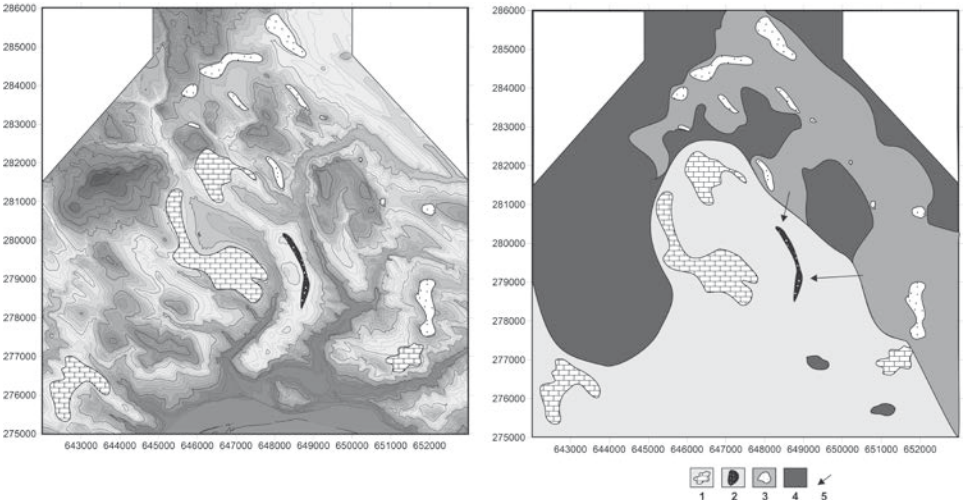

Fig. 8. Locations of old sediments in the study area. 1 — limestone, 2 — redeposited pebbles, 3 — pebbles in situ, 4 — volcanic rocks, 5 — direction of transport of old pebbles

IDENTIFING GEOMORPHOLOGICAL LEVELS WITH STATISTICAL ANALYSIS

224 selected sections of the flat-top surfaces were presented in a bar chart. On the right side of the diagram (230–370 m a.s.l.) the bars of higher values (230–260 m a.s.l., 275–300 m a.s.l., 320–335 m a.s.l., 350–370 m a.s.l.) are separeted from each other with bars of lower values (260–275 m a.s.l., 300–320 m a.s.l. and 335–350 m a.s.l.) (Fig. 9).

Flat-top surfaces in the south-eastern Börzsöny Hills are located at four geomorphological levels and can be classified into two main groups: high-level surfaces occuring above 230 m a.s.l. and low-level surfaces situated below 230 m a.s.l.

The fundamental differences between the two surface groups were confirmed by the correlation analysis of the variables of the two groups. The data of the two groups were also analysed depending on the values of the longitudinal stream profile. Correlation coefficient (R^2) was obtained from a regression analysis. As a result of the analysis, a trendline was adjusted to the longitudinal profile of valley bottom. Using the values of the trendline, the correlation coefficient was calculated to be $R^2 = 0.9787$ indicating a close correlation (Fig. 10A). We carried out the same analysis for the datasets of higher and lower surfaces as well. Adjusting a trendline to the data about selected flat-top surfaces situa-

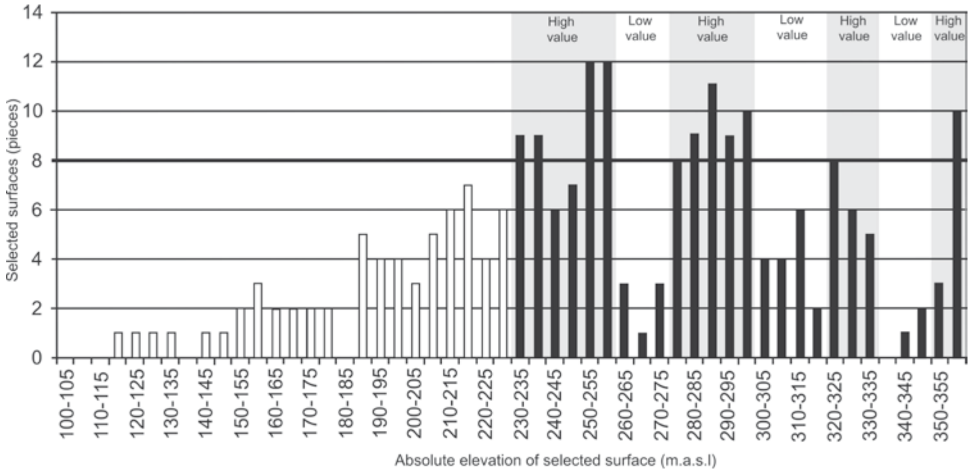

Fig. 9. Absolute elevation of selected flat-top surfaces

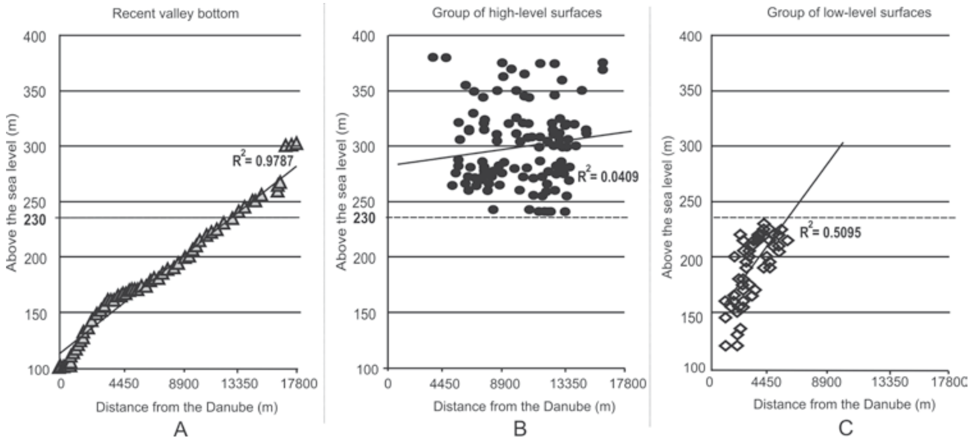

Fig. 10. Results of correlation analysis

ted at a higher altitude yielded a value of $R^2 = 0.0409$ (Fig. 10B), while in the case of selected lower-altitude flat-top surfaces the correlation coefficient was $R^2 = 0.5095$ (Fig. 10C). The lack of a strong correlation indicated by the latter values may have several reasons, however, it should be stated that the separation of the two surface groups is statistically well established.

The absolute altitudes of the lower-altitude surfaces show no distinctive pattern and thus cannot be treated as a sorting criterion. These surfaces were classified using their relative altitudes above valley floors, resulting in three classes of surfaces: at 15–25 m, 30–40 m and 60–70 m above the valley floor.

DISCUSION AND CONCLUSIONS

Surfaces situated at a higher altitude (230–350 m a.s.l.) can be classified into four groups. They can be characterised by their absolute altitudes and most are covered by older sediments. The geomorphological levels do not follow the longitudinal stream profiles. It means that they are the remnants of an acient surface (lag surface) which evolved prior to the current drainage system.

Surfaces located at a lower altitude (100–230 m a.s.l.) can be characterised by their realive altitudes above the valley floors and they are not covered with older sediments. The geomorphological levels follow the longitudinal profiles of the current streams. They are terraces shaped by the tributaries of the Danube during the Pleistocene.

The geomorphological levels of the south-eastern Börzsöny Hills and the fluvial terraces of the Danube are comparable (Fig. 11). The higher situated terraces described by M. Pécsi (1959) are comparable with the lag surfaces covered by older sediments in the south-eastern Börzsöny Hills; the lower fluvial terraces of the Danube are comparable with the Pleistocene stream terraces of the south-eastern Börzsöny Hills. Our investigations pointed out that the surfaces at higher altitudes, previously believed to be fluvial terraces of the Danube, are not in fact of fluvial origin, but they are remnants of an older, ancient terrain.

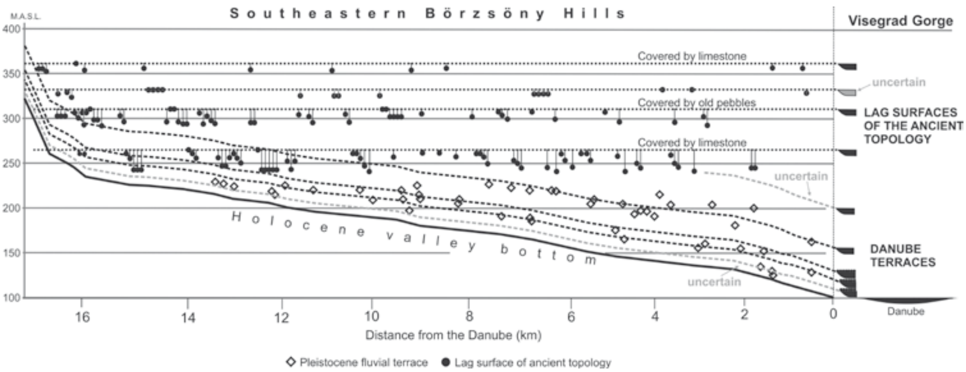

Fig. 11. Geomorphological levels of the Visegrád Gorge and the southeastern Börzsöny Hills

Each of the three Pleistocene-terrace series are comparable with any of the younger fluvial terraces of the Danube. It is a deficiency that two fluvial terraces located in the valley of the Danube are not comparable with any of the stream terraces. The age of these surfaces can be defined based on fluvial terraces of the Danube. These evolved in the Middle and Late Pleistocene.

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