Identifying surface remnants with methods of geoinformatics

Maradványfelszínek kimutatása geoinformatikai módszerekkel

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Összefoglalás: E tanulmány a maradványszintek azonosítására kísérel meg új geoinformatikai módszereket bemutatni, illetve a hagyományos és az új eljárások eredményeit veti össze. Bár korábban számos tanulmány született az egyes hegylábi részterületeket illetően, - alapvetően regionális jellegű, az egész észak-bükki előteret felölelő – kifejezetten térinformatikai módszereket alkalmazó – kutatás még nem hozott megnyugtató eredményeket e kérdéskörben. A tanulmány célja tehát a hagyományos és a geoinformatikai, adatbázison alapuló vizsgálatok eredményeit összevetni a maradványszintek elhelyezkedésére vonatkozóan; a lokális és regionális léptékű vizsgálatok eredményeinek összehasonlítása; új módszerek és alapvetően nem e célra kifejlesztett szoftverek és eljárások kipróbálása; a maradványfelszín eltérő definícióiból adódó problémák bemutatása, és a vizsgálati módszerek közül a legmegfelelőbb, a terület jellegétől függetlenül bárhol alkalmazható módszer kiválasztása. A Mátra- és Bükklábát bemutató digitális topográfiai adatbázisunk alapját az 1:50 000 léptékű térképek 10 m-es szintvonalai jelentették, a domborzatmodell krigeléssel készült, a szintvonalak digitalizálása a GeoMedia 4.0. 25x25 m/pixel felbontású DTM-ben a pixelek száma 2.373.000, ez képezte a statisztikus felszínelemzés adathalmazát. Geoinformatikai vizsgálatainkban a következő módszereket alkalmaztuk Idrisi és Global Mapper program segítségével (pufferelés, völgytalptól való izovonalas távolságok módszere, illetve a legkisebb lejtésű tetőszinti területek, keresztszelvények), kiegészítve más, nem feltétlenül e célra kidolgozott eljárással (cost push, gerincvonalas módszer – inverz lefolyási térkép alapján, a legkisebb hozzá/lefolyás elve). A mintaterület adottságaitól független, megbízható eredményt a legkisebb lejtésű tetőszinti területek, a keresztszelvények és a legkisebb hozzáfolyás elve alapján kijelölt felszínek adtak.

Abstract: This contribution aims to develop and apply new methods – mainly known but used for other purposes of surface analysis - to identify and evaluate surface remnants. It compares the methods of the traditional manual-visual evaluation and investigates the possibilities of their application in GIS. Neglecting the problems of the genesis of these surface remnants our methodological aim was to compare the results of local and regional-scale studies which was yet not possible due to the lack of data. The differences between the results, based on the different interpretation of surface remnants were also traced, such as methods independent from the tectonic and geomorphic settings of the sample area. Based on the 10 meter contour lines digitized by GeoMedia software a 1:50000 map of the northern foreland of Bükk and Mátra Mts. a DEM was generated with 25x25 m/pixels resolution providing a dataset of 2.37 million pixels on 1500 square kms for the surface analysis. We compared the following methods using Idrisi and Global Mapper: buffering – isometric lines measured from valleys –, minimum slope steepness, combined with other methods like cost push, ridge-lines based on the runoff of an inverted DEM, minimum runoff-values, automatic classification and cross-sections. The best methods – independent from the tectonic and geomorphic settings of the sample area – were the minimum runoff, cross-sections and the method of gentlest slopes.

Keywords: *northern foreland of the Bükk Mts., surface remnant, geoinformatics, statistical surface analysis, DEM*
Kulcsszavak: *Bükkalába, maradványfelszín, geoinformatika, statisztikus felszínelemzés, DTM*

1.1 Introduction, aims

This contribution focuses on developing and applying new methods to identify and evaluate surface remnants using geoinformatics; here we do not intend to deal with the genetics and age of surface remnants. Some of the methods applied are well known in traditional, manual evaluation, but were rarely tried on large datasets obtained from DEM.

Our main methodological goals were: (1) comparing the existing traditional (manual) and computerised methods, (2) introducing new methods, (3) testing the reliability of the developed new and traditional methods in order to identify methods independent from the different features and settings of the model area (general applicability), (4) comparing the results obtained from local scale and from regional scale surface remnant mapping.

The chosen investigation area is a well-known and researched area, which helps to explain the results of the analysis and extend the methods to different territories. However, earlier many investigations proved the existence of surface remnants on local scale – like Cserehát, Putnok Hilly Region, Tardona Hilly Region, Uppony Mts., Heves-Gömör Hilly Region (PEJA 1956, 1957, 1980, ÁDÁM 1984, MEZŐSI 1984, SZABÓ, J. 1998a, 1998b, SÜTŐ – SZALAI 2001, SZALAI et al. 2002a, 2002b, 2002c, DEMETER 2006), – regional scale evaluation (including the whole northern foreland of the Bükk Mts.) based especially on geoinformatics has not been carried out yet.

The authors seem to agree in the existence of a dissected surface remnant between 270-330 m altitude above sea level - however its classification, age, original height is still disputed -, that can be traced well on the Cserehát as an accumulational glacis, and on the Putnok Hilly Region. In the western regions it appears in the Pétervására Hilly Region and in the Cered-Almágy Basin as a pediment or eroded glacis or valley pediment.

The next level of surface remnants at 370-430 m is stongly ruined and its existence on regional scale – however it has already been identified on smaller catchment areas – is still disputed. The question is: can it be identified in regional scale using a dataset based on the DEM of the area.

The basis of the DEM was the 10 meter contour lines of a digitised map (scale 1:50000), the interpolation was carried out by kriging method. Contour lines were digitized in GeoMedia 4.0. The resolution was 25x25 m/pixels and resulted 2.373.000 cases composing the dataset of the investigation (**Fig. 1**). Cross-sections were created by Global Mapper 7.0.

The investigation area, the foreland of the Bükk Mts., is a tectonically exposed, uplifted, rotated, in the east sometimes imbricated (KOZÁK et al. 2001) horst-graben type surface consisting of dominantly semiconsoldated late oligocene molasse sediments in the western regions, exhumated, semi-exhumated consolidated Palaeozoic-Mesozoic limestones in the east, surrounded or overlain by coal-bearing miocene strata (PÜSPÖKI 2002). Denudation has been the main process in the last 2.5 million years on the area. Due to the role of the Darnó Fault System rocks of different age are often elevated, cut off and planed to the same altitude on the tectonically dissected area, which is in fact a definition for surface remnants. Therefore, neglecting the differences in rock quality (which cannot be done when measuring i.e. slope formation) we considered the top levels together in our investigations.

To demonstrate the versatility of tectonic and therefore geomorphic settings a cross-section of the catchment area of the Hódos Stream is shown on **Fig. 2**. The western region of the catchment is dominated by the Oligocene-Miocene glauconitic Pétervására Sandstone elevated at 400-500 meters, while the younger Salgótarján Lignite Fm. is elevetad in the east.

The vertical displacement was significant after the Carpathian as well (SZENTES 1960), which is confirmed by the disturbed bedding of coal seams in the Hódos valley, where 100 metres of differences in the altitude of coal seams can be traced within few kilometres.

Above the surface remnant at 270-330 m a strongly dissected region of 370-430 m can be found, which also appears in other catchments as watersheds (Pétervására Hilly Region), or as the top level of Palaeozoic limestones (Uppony Mts.) exhumating from under Miocene overlying strata.

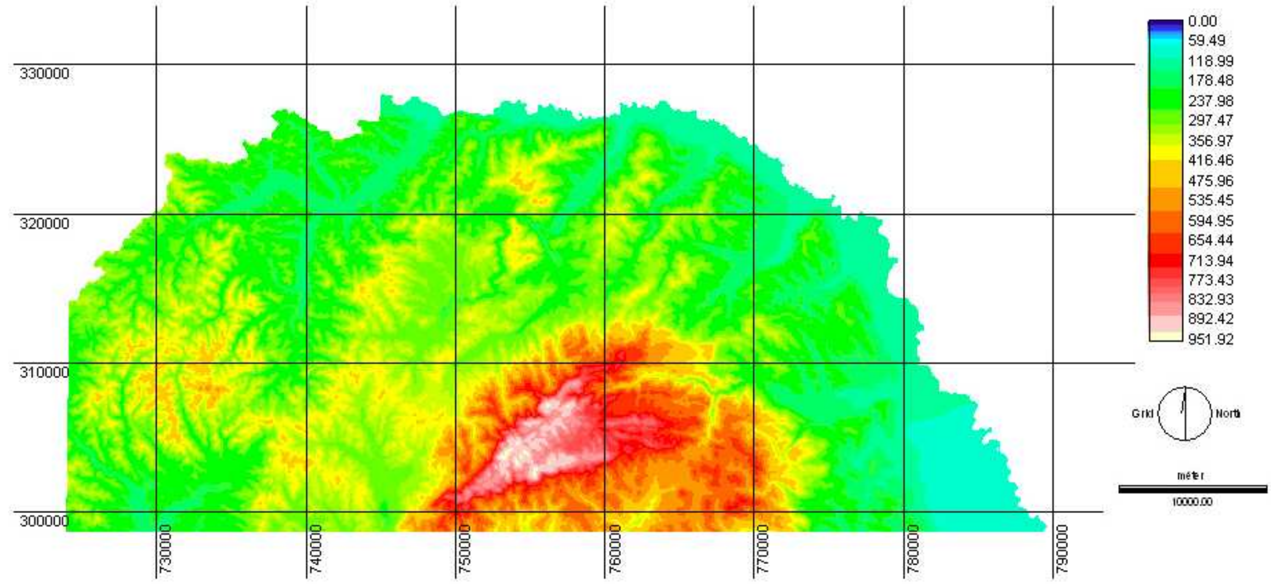


Fig 1. *The DEM of the investigated area;* ***1. ábra****. A vizsgálati terület digitális terepmodellje;*

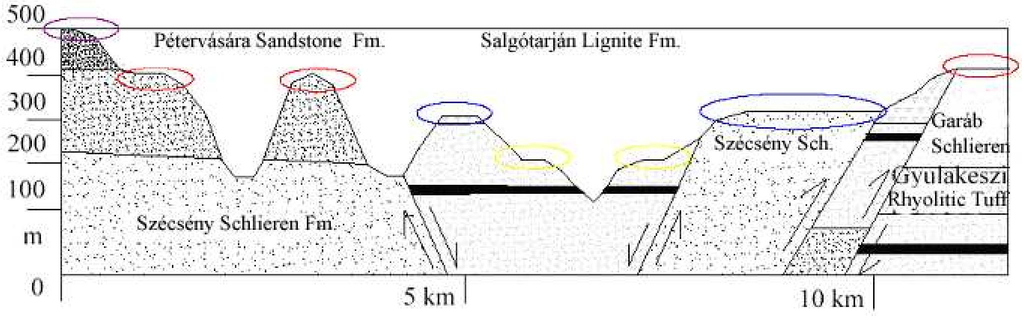


Fig. 2. *A simplified cross-section of the Hódos catchment with the surface remnants and terraces;*

2. ábra. *A Hódos-vízgyűjtő egyszerűsített keresztszelvénye a maradványfelszínekkel és a teraszszinttel*

1.2 Methods

Several methods existed before the worldwide spread of databases: these methods were to simplify the calculations since the instruments to evaluate large databases were not developed. Here we discuss some traditional, manual methods that can be reproduced by geoinformatics as well.

(1) Using the common set (points of intersections) of contour lines and waterflows (rivers, creeks) so-called „isobase-lines" can be drawn, which connect points with the same altitude. These lines intersect contour lines

representing geomorphic forms, like hills, creating a new surface which is called base-surface. The difference of the original surface and the base-surface (after subtracting them from each other) shows the altitude of the real surface above the base level, thus identifying points least exposed to erosion (FILOSZOFOV, 1959). A similar method is the map of dissection. Here the intersection points of contour lines and the lines of watershed are selected, and points with the same altitude are connected, thus the original altitude and the amount of removed material can be traced.

(2) Creating an isoline map based on the distance from the valleys (buffering), supposing that the least eroded area shows the greatest distance from the valleys symbolising the base level, a map of the least eroded areas can be drawn. This method cannot be used if the valleys or slopes are asymmetric, because in this case the isolines with the greatest distance from the valleys won't be equivelent with the ridge-lines. (The ridge is not located half-way between two valleys if the slopes are asymmetric, therefore the points with greatest distance from valleys will occur in steep slopes).

(3) Ridges with gentle sloping but of high altitude are also considered surface remnants where the erosion is thougth to be insignificant.

The latter two methods (buffering and the method of gentlest slopes) were applied in our examination using other methods (cost push, ridge lines – based on inverted runoff map, the points with the minimum runoff values – see detailed in the text).

It is important to point out that the 3 methods mentioned here are not equivalent, and they represent three different sights, therefore the areas of predicted surface remnants won't match. Thus the result is mainly dependent on the method chosen for analysing surface methods. Our goal was to decide which method is the best (indifferent) for sample areas with different features and settings.

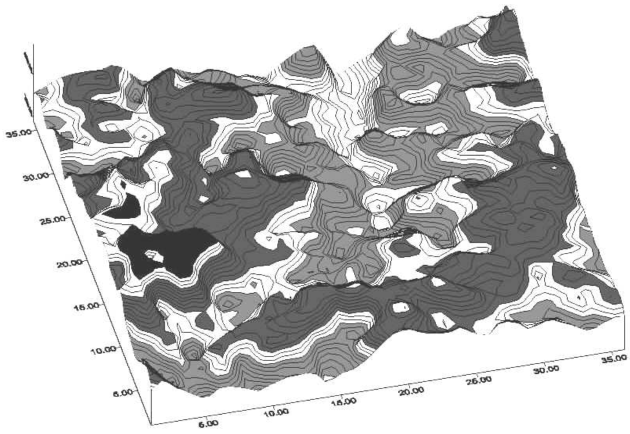
1.3 Discussion I. The results of applying different methods on local scale

Geoinformatics has brought minor successes in smaller catchment areas; with the aid of Surfer software surface remnants were identified on the Hódos catchment based on planes (representing palaeo-surfaces) fitted to the highest points of 100x100 m large squares (**Fig. 3**).

Unfortunately this method is unable to make difference between changes originating from tectonic movements, so it remains unclear whether the actual number of surface remnants equals with the original number of levels, or a former uniform surface remnant is dissected and elevated into different heights by faults. The method neither shows the original altitude of the surface, nor that to what extent the differences are results of selective denudation originating from the different resistance of rocks to erosion.

Therefore we examined other methods to identify surface remnants. Using Idrisi software we selected the pixels in the catchment above 270 m altitude and with 0-5% slope gradient, and presented their altitudinal distribution using a histogram with 10 meter interval width. After rescaling the data into intervals using equidistal scale representing the predicted surface remnants (270-330, 330-370, 370-430, 430-470, 470-530 m), 60% of the data was classified into the 270-330 m interval.

However, it was not a wide dataset, only dozens of pixels were evaluated, thus the result cannot be considered relevant. The only way to increase data number in a small, dissected catchment (60 km²) is to extend the investigated slope category to steeper slopes with 0-10% gradient.



Legend

remnant at 470-540 m; maradványfelszín 470-540 m-en

remnant at 370-440 m; maradványfelszín 370-440 m-en

remnant at 270-330 m; maradványfelszín 270-330 m-en

Fig. 3. *The reconstructed surface remnants on the Hódos-catchment*
3. ábra. *A Hódos-vízgyűjtő rekonstruált tetőszintjei*

Widening the dataset caused that the expressive mode between 270-330 meters disappeared. (**Fig 4**.). Instead of reducing the data by choosing the 270 m altitude as lower boundary, we used a buffer method: we excluded points within 50, then 150 metres distance from the waterflows from the investigation.

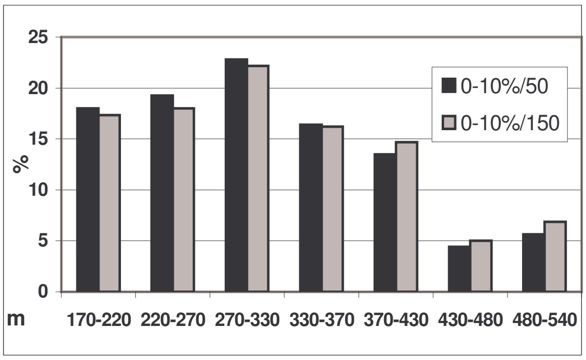


Fig. 4. *Identifying surface remnants on slopes with 0-10% steepness with a buffer of 50 and 150 m measured from the valley-lines*

4. ábra. *Maradványfelszínek kimutatása: 0-10% közötti meredekségű pontok megoszlása magassági kategóriák szerint a központi völgyektől számított 50, illetve 150 méteres távolságra*

1.4 Discussion II. The results of applying different methods on regional scale

In order to obtain better results, the investigated dataset was extended to the whole (1500 km^2) territory using the above mentioned database.

Fig. 5. shows the hipsometric curve of the area grouped into intervals with 10 m width. Half million pixels were grouped into the 270-330 m interval, which constitutes 20% of the pixels (**Fig. 6**.), while the interval width is only 7.5% of the total width. It can be concluded, that the 270-330 m interval is overrepresented. The distribution of the dataset is polimodal, poorly classified, furthermore another half million pixels can be found between 210-270 m, therefore we cannot trace surface remnants when the whole dataset is incorporated into the investigation. This proves that the area is dissected: a similar investigation in other areas (i.e. Cserehát) might bring success.

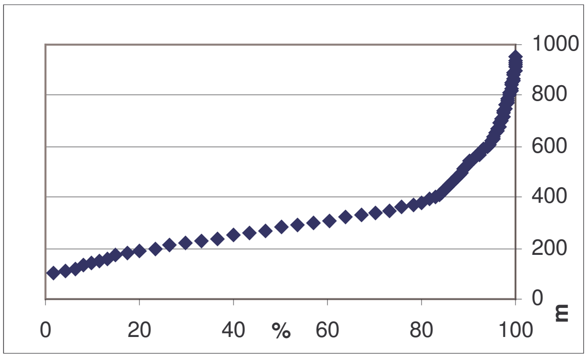


Fig. 5. *The hypsometric curve of the whole area*
5. ábra. *A terület hipszografikus görbéje*

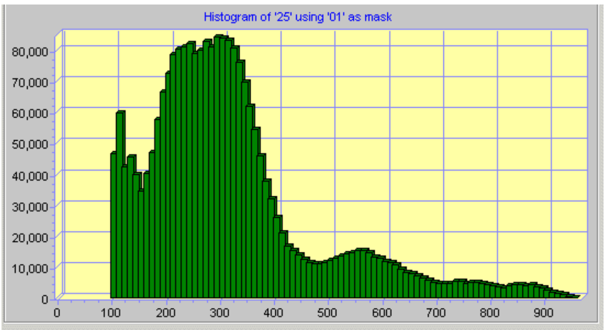


Fig. 6. *The histo image of the area at 25x25 m/pixels resolution*
6. ábra. *A mintaterület hisztogramja 25x25 m-es felbontás esetén*

The next experimental method was buffering: we excluded data within 1000 m distance from waterflows from the investigation. The waterflows were generated by Idrisi software, the distribution of the included points is shown on a histogram using 10 meter interval width (**Fig 7**.).

Thus the number of pixels was reduced to 777000, the average altitude increased to 382 meters confirming that the exclusion of points near the valleys was successful. The distribution of the dataset became more or less unimodal, showing the maximum data number at 330-350 m. Terraces were succesfully excluded. 230 000 pixels appear between 300-350 meter representing 30% of the whole dataset.

Since the asymmetricity of valleys and slopes is abundant in the foreland of the Bükk Mts. (**Fig. 8**.), and thus territories with greatest distance from valleys can be slopes not only ridges, the method is not applicable in such regions. Due to this phenomenon the selected areas cannot be considered the least eroded surface.

Since the above mentioned method did not bring success due to the specific tectonic settings resulting tilting, another method was applied. The so-called cost push method counts with the slope angle and with the distance from base level as well. The significance of this method is that the above mentioned buffering method did not count with the length and gradient of slopes, only horizontal distances were calculated with.

The result of the cost push method is shown on **Fig. 9**. 27% of the data was grouped into the intervals between 310-360 meters.

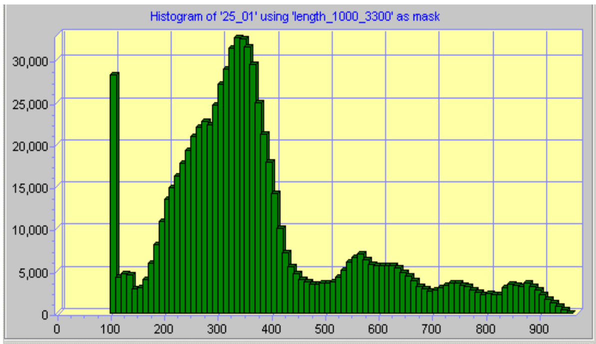


Fig. 7. *Identifying surface remnant with the help of buffering (isometric lines, 1000 m from valley-lines)*
7. ábra. *Maradványfelszínek kimutatása a völgytalptól mért távolság alapján (1000 méter)*

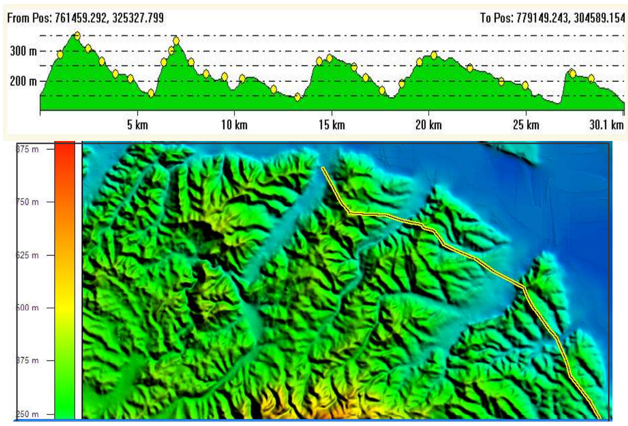


Fig. 8. *Asymmetric slopes and ridges on the Bükk foreland*
8. ábra*. Aszimmetrikus dombsor a Bükk előterében*

Nevertheless, the areas examined by the cost push method are not equal with the territorial distribution of ridges sometimes considered indicators of surface remnants (**Fig. 14**.). Since different distances (counted from the valleys) can be measured at any points of any ridges, a ridge can have different cost push values, thus the two sets, the ridges and the highest cost-push values are not equal. The same is true for simple buffering. This results from the two different definitions and interpretations of surface remnants. The one emphasizes the role of gentle sloping ridges, while the other focuses on the role of distance from base level (valleys).

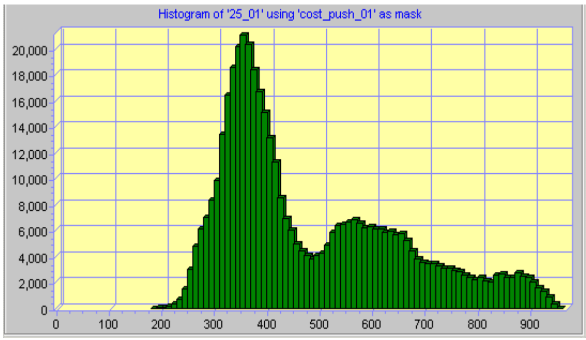


Fig. 9. *The histo image of the cost push method*
9. ábra. *A cost push módszer hisztogramja*

We compared the results of the two interpretations. Since the ridge-line cannot be defined directly in Idrisi we used gentle sloping and high altitude as criteria for surface remnants. Points 200 m above sea level and under 5% slope gradient were selected and grouped in intervals of 10 m width. Between 220-240 meters a terrace-level can be observed. To exclude points near the valleys which can reach 200-220 meters, we combined the method of gentlest slopes with buffering. Points within 200 meters distance from valleys were omitted. 60 000 pixels remained in the dataset (**Fig 10**.), which shows bimodality: beside the terraces we find a surface remnant between 310-340 m altitude above sea level (11500 and 16000 pixels, 20 and 27% respectively). This seems to be the best method: the histogram has the finest resolution here.

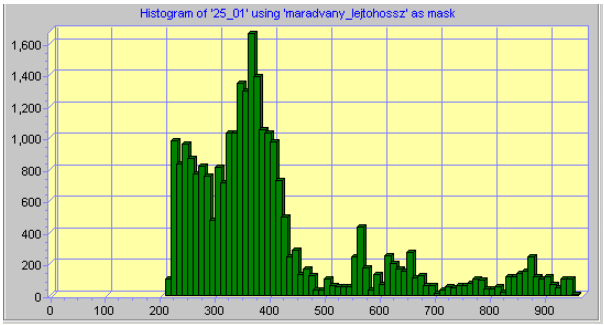


Fig. 10. *Histogram with the combination of least steep slopes (under 5%) and buffering*
10. ábra. *A pufferelés és a legkisebb lejtés egyidejű alkalmazásának hisztogramja*

Increasing the buffer distance to 1000 m did not bring better results. Since buffering is not successful, it means that the ridges are not far from the valleys in the examined area, which confirms that the Bükk foreland is a dissected region.

Since there is no way to select ridges directly but it is possible to pick the valleys, we inverted the runoff map. Thus the former ridges became valleys and the examination of the distribution of their altitude became possible. To avoid complications originating from multiplying the whole dataset by -1, we decided to subtract the original values of altitude from 1000. **Fig. 11** shows the results after regaining the original altitudes. Both the terraces at 220-240 meters and the surface remnant at 350-370 can be observed.

If the valleys of the inverted DEM are superponed to the ridges with gentlest slopes, the dataset will show significant differences (**Fig. 14**).

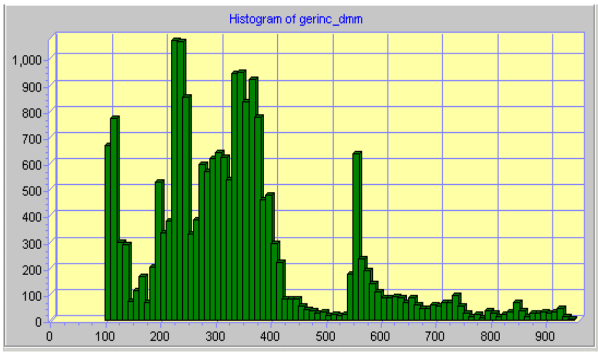


Fig. 11. *The histogram of the runoff (ridge) generated from the inverted DEM*
11. ábra*. A DTM inverzéből előállított lefolyási viszonyok - az eredeti DTM gerincvonalainak – hisztogramja*

The generated runoff map – which was later inverted – gave another idea to identify surface remnants. When the software generates the runoff map it identifies the azimuth of slope and counts the number of neighboring pixels from which water influx arrives. The runoff values are added downstreams involving all pixels, and the pixels with highest cumulative values are considered valleys. Thus pixels with runoff value less than 2 can be regarded as ridges.

This method of minimum runoff values, although it was developed for other purposes and not to identify fossil surface remnants is also applicable: the interval of terraces and the lower pediment can be traced on the bimodal histogram (170 000 pixels altogether) (**Fig. 12.**)

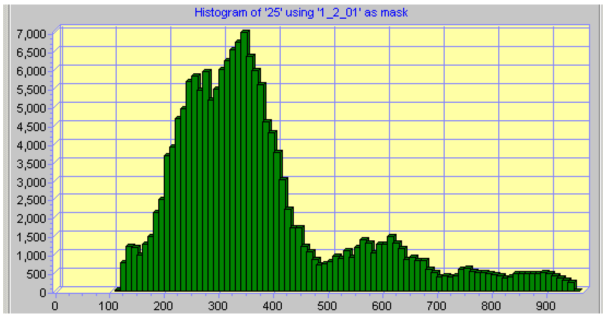


Fig. 12. *The histo of pixels with minimum runoff-value*

12. ábra*. A legkisebb lefolyási értékkel rendelkező pontok megoszlása*

The Idrisi software also has its own algorithm to classify surface landforms. The process is based on the relative position of the pixels. Each of the pixels are examined and compared with their neighbours regarding their relative altitude to each other, and they are classified into ridges, slopes, valleys etc. The ridges more than 100 meters distant from the valleys were excluded, thus the vertical distribution of the remainder can be examined. It seems that this programmed method is the worst of all to identify surface remnant, however it was originally planned to deal with this, unlike the other methods The 200000 pixels show even distribution between the 220-330 m altitude above sea level: neither of the surface remnants could be identified. (**Fig. 13**).

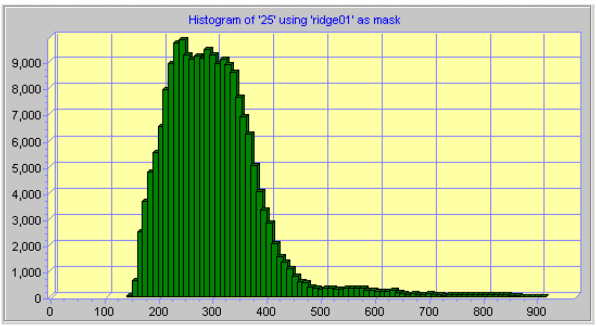


Fig. 13. *The histogram resulting from the automatic surface-form classification of the Idrisi (ridges)*

13. ábra. *Az Idrisi automatikus formaosztályzásából készült hisztogram (gerincek)*

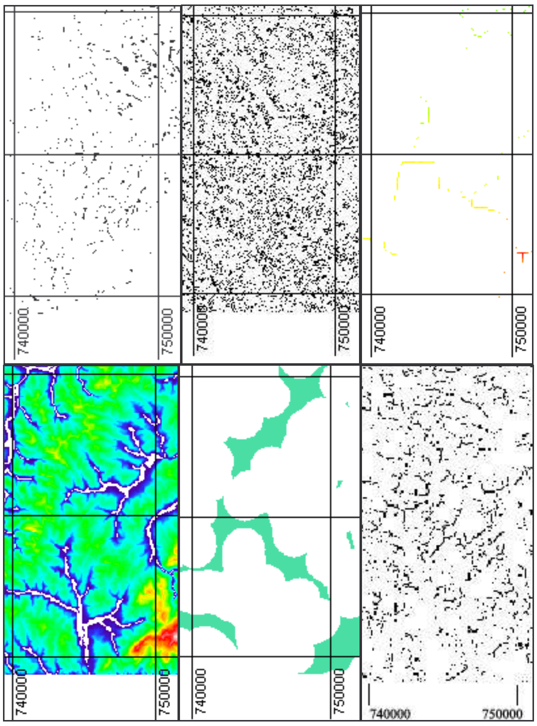


Fig. 14. *Comparing methods at the area of Szilvásvárad and Balaton: minimum steepness, ridges, runoff from the inverted DEM, cost push, buffering distances, minimum runff-values*

14. ábra*. A módszerek összevetése a Bükktől Ny-ra (Szilvásvárad, Balaton) Balról jobbra: kis meredekségű tetőszinti területek, gerincek, gerincvonalak az inverz DTM lefolyástérképe alapján, cost push, völgyektől mért távolság, legkisebb lefolyási értékszámmal bíró pontok*

The existence of surface remnants can be confirmed by the Sarmatian andesitic abrasional pebbles elevated at 300-350 meters above sea level in the eastern regions (due to the effect of tectonic elevation, denudation, isostasy, eustatic sea-level changes in the last 15 million years). Since the western part of the investigated area lack andesitic abrasional gravels, but ridges of the same height exist, this area can be regarded as a surface remnant (different rocks at the same altitude).

Cross-sections based on DEM can also be useful in identifying surface remnants (**Fig. 16.**). They can be even more helpful, than statistical surface analyses.

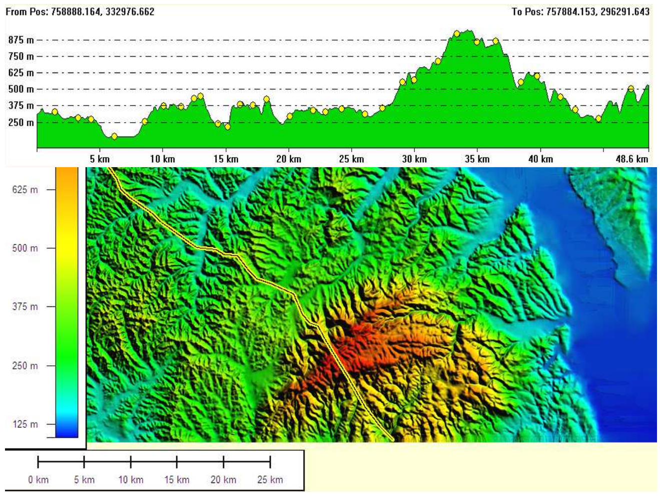


Fig. 15. *NW-SE cross section through the investigated area showing the main surface remnant at 350 m*

15. ábra. *ÉNy-DK irányú keresztszelvény: jól kirajzolódik a 350 m magasságban található tetőszint*

1.5 Conclusions

1. It has been proved, that surface remnants can be identified both on local and on regional scale by using geoinformatics and statistical surface analysis.
2. At local scale, in the catchment of Hódos Stream a terrace level and two surface remnants were identified using geoinformatics, which are in accordance with the results of traditional, manual methods.
3. At regional scale only one surface remnant and a terrace level was identified by computerised methods. The former is located at 300-350 metres while manual methods found it between 270-330 m above sea level. However, we should not forget that the original surface might have tilted, therefore it is not necessary to have the same altitude values in each catchment. The tilting of a surface may influence the appearance of modes, skewness and kurtosis.
4. Among the used buffer, cost push, minimum slopes, inverted runoff, minimum runoff, autoclassification methods the minimum slopes and minimum runoff methods proved to be the most reliable in the whole sample area.
5. We proved that the tectonic and geomorphic settings can influence the applicability of certain methods. When using these methods one should be aware of the fact that surface remnants have different definitions or interpretation and this is coupled by different methods and different datasets.

6. Comparing the results of the methods the dominant role of dissection can be stated overwhelming the lateral erosion.

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