CHAPTER 6: DEM-BASED MORPHOMETRY, MORPHOTECTONICS AND QUATERNARY SURFACE PROCESSES OF THE GÖDÖLLŐ HILLS

The Gödöllő Hills are situated to the east of Budapest (Figs. 1-3; 2-4; 6-1), forming a NW-SE trending range of rolling hills (maximum elevation in the northwest: Margita, 344 m asl), gradually smoothing into the sandy lowland of the GHP around 110 m asl. To the north and west the Gödöllő Hills are bounded by the terraced valleys of the Galga Creek and the Danube River, respectively. The Gödöllő Hills represent the northeasternmost part of the transitional zone linking the uplifting Hungarian Mountain Range (HMR) with the subsiding Great Hungarian Plain (GHP; Figs. 1-2, 1-3A). This is a zone of intensive deformation between the HMR and the NE-SW trending Mid-Hungarian Shear Zone (MHSZ) situated south of the area (Balla 1985; Fig. 1-2). Previous chapters (chapters 3 and 5) provided information about river incision and vertical motions in the uplifting HMR via terrace chronology of the Danube valley. The evolution of the Gödöllő Hills has also been affected by the incision of the Danube River, which controlled the erosion base of the western part of the area.

The Gödöllő Hills are a promising study area for the better understanding of the style of neotectonic deformation and its influence on Quaternary landscape evolution in the Central Pannonian Basin. This study explores areal differences in erosional processes and attempts to identify sites where structural deformation could play a significant role in Quaternary landscape evolution.

Geology, landscape and drainage network of the Gödöllő Hills largely resembles the Transdanubian Hills. Therefore, methodology and results of this study may be applied for the Quaternary structural and surface development of the Transdanubian part of the NW-SE trending transitional zone, too. Results presented in this chapter are to be published by Ruszkiczay-Rüdiger et al. (submitted).

6.1. Methodology

The morphotectonic study of the Gödöllő Hills, a low hilly terrain of quasi-homogeneous lithology, required different methodology from that applied for the terrace-research in the Danube valley. A multidisciplinary approach combined traditional structural geology with geomorphology and fieldwork, which were completed by computer-aided digital elevation model (DEM) analysis and a structural analysis using subsurface geophysical data (chapter 7).

Morphometry is defined as the quantitative measurement of landscape shape (Keller and Pinter 2002), which allows the objective comparison of landforms. The DEM-based morphometric analysis of the Gödöllő Hills made possible the quantification of main features of the drainage network and surface morphology. Geomorphic indexes, hypsometric analysis and quantitative differentiation of surface roughness are tools for the delineation of distinct topographic units and help in the recognition of terrains affected by neotectonic deformation. Orientations and patterns of the river network also were examined. River deflections, for example, can be triggered by tectonic warping, and radial or centrifetal drainage networks may show areas above uplifting antiforms or subsiding synforms (e.g. Burbank and Anderson 2001, Keller and Pinter 2002). Changes in relief pattern also may indicate different lithologic domains or spatial alternation of the predominant type of erosion (fluvial erosion, deflation and mass wasting). Hence, morphometry was controlled by field observations and geomorphic mapping. Geomorphic mapping means the registration and genetic classification of the
landforms observed in the field and on topographic maps. Two multielectrode resistivity profiles provided information about the topmost ~80 m below the surface, which assisted the interpretation of Quaternary sedimentation and valley evolution.

Fig. 6-1. Slope-map of the Gödöllő Hills with major settlements and most important geographic names, ventifact occurrences (after Jámbor 2002), and typical loess-paleosol profiles. On the base-map darker colours indicate steeper slopes (max. slope angle 25-30°). Small inset is the shaded relief map of the area. Note the gradual smoothing into the lowlands towards the E and the sharp edge towards the SW. B: Bag, Ai: Albertirsa, F: Fót, G: Gödöllő, Gh: Galgahévíz, H: Hatvan, Is: Isaszeg, Jb: Jászberény, M: Mende, P: Pánd, T: Tőalmás, U: Úri, Va: Valkó.

6.2. Geology of the Gödöllő Hills

Pre-Tertiary basement is found at a depth of 1500-2000 m below the surface of the Gödöllő Hills. This basement is covered by Paleogene to middle Miocene sediments of variable thickness. These are exposed only in the northwest part of the Gödöllő Hills (e.g. Láng 1967), forming narrow, NW-SE trending ridges of 240-290 m asl. height (e.g. Somlyó; Fig. 6-1).
Similarly to the Transdanubian area, syn-rift sedimentary successions are erosionally truncated (Figs. 2-2, 2-3) and covered unconformably by the post-rift, late Miocene (Pannonian) – Pliocene sedimentary suite reaching 1000-1500 m in thickness (Szentes 1943, Rónai 1985). The fine-grained lacustrine lower Pannonian is covered by a thick upper Pannonian delta sequence – mostly sand, silt and clay layers – prograding to the SE into the former Lake Pannon. The uppermost Pannonian and lower Pliocene sandstones indicate a shift from deltaic to fluvial environment showing characteristic features of a braided channel system (Uhrin 2005) in the SE foreland of the slightly emerged HMR. Müller and Magyar (1992) suggested that this facies change occurred between 6 and 8 Ma. According to the mammal fauna (Mottl 1939) the sedimentation of the cross-bedded sandstones lasted at least until the middle Pliocene, reaching a thickness up to ~200 m. Heavy-mineral composition of this sandstone does not match that of the Danube, preferably, it had its origin in the eroding late Miocene (Pannonian) sediments and the adjacent mountains to the N and NE (Szabóné Drubina 1981). Surface occurrences of this formation are restricted mostly to north- and northwest-facing, steep valley sides in the northern and central parts of the Gödöllő Hills.

During late Pliocene times the climate was still warm, but arid and semiarid phases altered (Schweitzer 1997a). In such climate conditions the entire transitional zone, including the Gödöllő Hills were affected by pedimentation, which resulted in the truncation of the middle Pliocene sandstones (Figs. 2-2, 2-3). This unconformity surface is usually covered by terrestrial sediments of Quaternary age, up to a thickness of 40 m.

6.3. Quaternary sedimentation, field observations and geomorphic mapping

The Pliocene-Pleistocene boundary is seldom exposed in the study area. In the northern and western part of the Gödöllő Hills some outcrops of the Pliocene sandstone could be studied (Szentes 1943, Uhrin 2005). These outcrops show evidences of a significant period of erosion and truncation before the Pleistocene sedimentation. In the surroundings of the Rákos Creek a marly-limy loess body of ~1m thickness was frequently observed between the cross-bedded sandstone and the loess. On the other hand, during repeated field studies no evidence was found about the existence of remnants of a thin freshwater limestone layer overlying the Pliocene sandstone, which was described by several authors (Noszky 1925, Szentes 1943, Leél-Össy 1953, Balla 1959, Pávai Vajna 1941, Láng 1967).

Lower Pleistocene is represented only in the northern part of the area on the form of scattered pebbles of poorly constrained age above hilltops around the Galga River. According to Szentes (1943) these may represent remnants of an early Pleistocene gravel sheet. 6-8 m below the modern valley floor of the Galga Creek *Elephas meridionalis* bearing gravel was described (Szentes 1943), which also can be placed into this phase (Jánossy 1979). These formations still indicate warm and arid climate similar to late Pliocene times.

To the W and NW of the area several ventifact occurrences have been described (Fig 6-1; Jámbor 1992, 2002). These ventifacts usually are wind-polished pebbles of the lower-Miocene gravel, that has been exposed during Plio-Quaternary arid climate spells. Pebbles with desert varnish sometimes buried under red clay were also described from this area (Mogyorőd, Schweitzer 1997a).

Loess, fine sandy loess and wind-blow sand are the most common Quaternary sediments in the Gödöllő Hills. There are two relatively elevated and dissected ridges, the Valkó and Úri Ridges, which are covered by a thick loess-paleosol sequence. This sequence is missing from the low and smooth topography Isaszeg Channel between the Ridges (Fig. 6-1), and also from the highest central-northern part of the Valkó Ridge, north of the town of Gödöllő. These terrains are characterized by a smooth wind-blow sand sheet, or hummocky surface with sand
dunes and deflation hollows (see section about geomorphic mapping). Eolian sand also occurs in the Galga valley and is predominant in the Isaszeg Channel. Wind-blown sand covers river terraces of the neighbouring Pest Plain, and the GHP south of the study area.

**Fig. 6-2.** Most important loess-paleosol profiles in the Gödöllő Hills (see locations in Fig. 6-1). The loess-paleosol sequence at Mende contains the most complete “young loess” sequence in the Gödöllő Hills (compare with the Basaharc profile in Fig. 3-11), although the marker horizon of the Bag Tephra has not been described from this outcrop. Paleosol horizons: h1 and h2: humic horizons, MF: Mende Upper, BD: Basaharc Double, BA: Basaharc Lower, MB: Mende Base. Luminescence ages: a-d: average luminescence ages compiled from Wintle and Packman (1988); Zöller and Wagner (1990); Frechen et al. (1997), Horváth (2001) and Novothny et al. (2002). Note the significant hiatus between the MF soil and the underlying loess body. e: geochemical similarity after Pouclet et al. (1999).

The loess is intercalated by several paleosol horizons suggesting climatic oscillations and providing the basis of the Quaternary stratigraphy in the area. Loess sedimentation occurred under cold and dry phases of the Pleistocene in extended grasslands of periglacial steppes. Paleosol horizons developed under mild and humid – interglacial and interstadial – conditions and separate the subsequent periods of loess formation.

**Loess stratigraphy**

Thickness and physical appearance (e.g. colour, grain size distribution, humus and CaCO₃ content) of the paleosol horizons are extremely variable plus recognition and dating of hiatuses are problematic. The presence of some marker horizons within the loess deposits (Photo 6-1; e.g. Horváth 2001), magnetic susceptibility (Horváth and Bradák 2003, Bradák pers. comm.) and absolute age data (Wintle and Packman 1988; Zöller and Wagner 1990; Frechen et al. 1997; Novothny et al. 2002) help settling surface-stratigraphic correlations.

**Photo 6-1** Typical occurrences of the Bag Tephra. A: at Bag and B: at Isaszeg (for loess chronology refer to Fig. 6-2, for location Fig. 6-1). The Tephra is a 1-3 cm wide, discontinuous horizon within the loess. Its colour is yellow or grey; colour does not indicate change in geochemical and mineralogical composition.
A characteristic profile south of the Alsó-Tápió Creek, in the village of Mende (Fig. 6-2) represents the most complete sequence of the “young loesses” (Pécsi 1982) in the region. This consists of four well-developed paleosols, which are – from the lowest soil upwards – the Mende Base (MB), Basaharc Lower (BA), Basaharc Double (BD), Mende Upper (MF) and two weak humic horizons (h2 and h1). The entire “young” loess sequence shows normal magnetic polarity, thus it is younger than 780 ka (Pécsi and Pevzner 1974, Márton 1979). In the Galga valley, the MF and the h1-2 horizons are typically missing (Fig 6-2; e.g. Pécsi 1977, 1993). According to luminescence data (e.g. Frechen et al. 1997, Novothny et al. 2002), the deposition of the lower part of the MF double soil took place during the OIS 5, possibly during the last interglacial (OIS 5e). A large time gap was recorded above this horizon (Fig. 6-2; e.g. Frechen et al. 1997, Novothny et al. 2002) indicating of an erosional event after the soil formation.

The Bag Tephra is a 1-3 cm thick but discontinuous volcanic tuff horizon in the loess between the MB and BA paleosols (Photo 6-1). According to its estimated age of ~350 ky (Pouclet et al. 1999; see in Chapter 3 at the Basaharc profile; Fig. 3-11) its stratigraphic position constrains the age of the lowest loess layers in the Gödöllő Hills. The Bag Tephra was first described in the Galga valley at Bag (Kriván and Rózsavölgyi 1964, Horváth 2001). In the Galga valley the tephra bearing loess-paleosol sequence covers a low terrace (tIIb?, Pécsi 1959b) suggesting that the age of the valley is at least ~400 ky. (Photo 6-2A) The Bag Tephra has not been found in the section at Mende. South of Isaszeg, Horváth and Bradák (2003)
described a new occurrence of the Bag Tephra indicating an old age also for the loess in the surroundings of the Rákos Creek (Fig. 6-2).

In the southeastern part of the Gödöllő Hills fine-sandy-loess covers the flat hilltops and the gently dipping SE facing slopes with increasing the proportion of fine sand in the loess towards the SE. In the outcrops of this region only the uppermost paleosol (MF) and the humic horizons (h1 and h2) can be observed (e.g. Úri, Albertirsa; Fig. 6-2), the older horizons are apparently missing.

**Resedimentation features**

Sloping horizons and signs of creeping, sliding and solifluction of the paleosols are frequent in the area (Photos 6-2B-D, 6-3A-D). Resedimentation and slope movements are commonly observed at the Plio-Quaternary boundary, too. These features may be connected to the truncation and subsequent dissection of the landscape. South of the first bend of the Rákos valley at the village of Isaszeg (Fig. 6-1), the upper horizons of the Pliocene sandstone were mixed with red clayey-sand and with white soft-limy-marly material typical of the Plio-Pleistocene boundary. Apparently the material moved downslope towards the Rákos valley (Photo 6-3A) and the mixed red-clayey sand gradually thins out and disappears towards the hilltop.

Disturbed and dipping loess-paleosol sequences are exposed typically in the valley-sides. Fig. 6-1 shows the locations of the most important outcrops where signs of slope motions, landslides, soil creep or dipping paleosol layers were observed. In the Galga-valley signs of creeping in the BA soil point towards the current valley-floor (Photo 6-2B). In the upper part of the Hajta valley sliding and solifluction of a loess-paleosol sequence towards the present-day valley floor can be observed (Photo 6-3B). Further uphill, in the same valley-side an inclined reddish-brown paleosol is exposed (Photo 6-2C). At Súlysáp, block sliding again towards the present valley-floor has been observed (Photo 6-3C). Close to this location a paleovalley-infill was found in the valley-floor of a modern derasional valley (Photo 6-2D). In the Sósi valley a mixed, resedimented horizon of limy-marly-loessy material was observed above the loess (Photo 6-3D). The boundary between the loess and the mixed unit is sharp suggesting a relatively fast event of the slope motion (e.g. landslide).

**Multielectrode resistivity profiles**

To study the timing of loess deposition and valley formation a multielectrode resistivity profile was measured south of the Alsó-Tápió valley SW of the village of Úri (Fodor et al. 2003b; Fig. 6-3A, Photo 6-4B). This method enables the distinction among the sediments of different textures down to depths of 60-80 m. The profile crosses two of the SE trending valleys and ridges. Several shallow boreholes (U1-U4 on Fig. 6-3A) were drilled along the section to calibrate the geophysical measurement. The ridges are covered by fine sandy loess, which appears on the profile with high resistivity values (40-90 Ωm). In the valleys this sediment is missing or thinned. The loessy layer is underlain by a sedimentary body characterized by low resistivity (10-30 Ωm) corresponding to silty clay. The borehole in the smaller valley (U3) reached this material at the depth of 2 m and its base was not reached until the bottom of the hole at 4.5 m. The resistivity profile shows that on the ridges the upper, fine-sandy loess layer is 15-20 m thick, so that boreholes U1 and U4, both ~4 m deep, did not fully penetrate the unit. Topography of the base of the loess is flat with a gentle slope towards a larger valley on the SW.

Fig. 6-3B shows a NW-SE trending resistivity profile measured along a ridge-top north of the village of Mende. It verifies the presence of a 15-20 m loessy layer having a base slightly
inclined to the SE, towards the Alsó-Tápió valley. The deformation at the base of the loess is possibly caused by the Tápió-Tóalmás strike-slip Zone (TaTZ, see tectonic interpretation in chapter 7; Fodor et al. 2005b; Ruszkiczay-Rüdiger et al. 2006).

[Image: Fig. 6-3. Multielectrode resistivity profiles and their location on the slope map at the villages of Úri (A) and Mende (B) (after Fodor et al. 2003b) U1-U4 and M1 are locations of shallow boreholes. Supposed boundary of the strike slip fault zone (Tápió-Tóalmás Zone, TaTZ) is indicated with dashed lines on the location map (see also the structural map on Fig. 7-7). Numbers of the drainage basins appear in boxes.]

**Geomorphometric mapping**

Geomorphometric mapping was carried out in the central part of the Gödöllő Hills, including the most dissected parts of the Valkó and Úri Ridges and the most elevated central part of the Isaszeg Channel. The detailed geomorphometric mapping attempted to clarify the main surface processes that shaped the landforms analysed in section 6.4.

Geomorphometric mapping was based on 1:10,000 scale topographic maps with a contour interval of 2.5 m (13 sheets of 6x4 km size; Fig. 6-4) . Topographic maps are in the “Uniform National Projection System” of Hungary (in the following EOV). Landforms recognised on the topo-maps and surface lithology were controlled by field observations.

On the geomorphic map (Fig. 6-4) negative (gullies, valleys) and positive (hilltops, ridges) landforms were identified. These were connected by slopes shaped by erosion and mass wasting processes. Mass wasting or derasion (after Pécsi 1964) means mainly areal denudation of slopes. It is used for gravitational and frost-related slope movements like creeping and sliding. During Quaternary glaciations periglacial conditions triggered intensive mass movements on the slopes, which could considerably re-shape the original landforms.

**Description of the mapped landforms (Fig. 6-4A and B)**

In the following key features for the genetic classification of the landforms, both on the topo-maps and in the field, are presented.

1) **Negative landforms**
   - **Erosional valley**: at least four contour lines break with an acute angle, smaller than 120°. With some exceptions they form a continuous network. Erosional valleys in the study are usually wide compared to the discharges of their streams.
Photo 6-3. Some typical outcrops with resedimentation features in the Gödöllő Hills. One segment of the scalebars is 10 cm. For location see Fig. 6-1. A: Isaszeg – southern side of the Rákos valley. A clast of loessy-fine sand and red clay is mingled into the underlying Pliocene sand. The red clay possibly covered the Pliocene sandstone however, it is not known from other outcrops in the Gödöllő Hills. B: Valkó – Hajta valley. Sliding and solifluction disturbed the dark brown paleosol layer dipping towards the present valley floor. C: Súlysáp – confluence of the Alsó- and Felső-Tápió valleys. The loess-paleosol sequence slid towards the valley floor, rotated blocks have no tectonic origin. D: South of Galgahévíz – Sósi valley. The loess is truncated and covered by a disturbed strata of mixed loess, sand, clay and marl. A shape of a former valley is outlined by the U shaped dark brown layer.

- Gully: narrow and relatively deep, V shaped ravine with steep sides. On the map the sharp break in acute angle of the contour lines is indicative for a gully, or they are marked with a separate symbol. Sometimes anthropogenic factors – e.g. road-cut, deforestation, agriculture – play important role in gully erosion. Most commonly ravines occur on the steepest middle part of the slopes on loessy lithology. Some gullies apparently do not join the main stream because their debris has been spread over the concave lower part of the slope and no incised channel could develop towards the main channel (e.g. slopes above the Sápi Creek on Fig. 6-4B).

- Derasional valley: wide, bowl shaped valleys formed mainly by mass wasting processes without water-flow in the valley floor (Photo 6-4B). The length-width ratio of these valleys is smaller than 4:1, and they do not outline continuous networks. Instead they appear individually on slopes or ridges and commonly form wide, circular valley-heads above the erosional valleys. They are identified on the map by well-rounded bending in an obtuse angle of at least two contour lines, which never break. Scars of landslides also appear on the geomorphic map as short derasional valleys.

Next double page:

Fig. 6-4. Geomorphic map of the central part of the Gödöllő Hills. Small inset shows the position of the mapped area. Blue and green colouring show the northern (A) and southern parts (B) of the figure, respectively. On the loess-covered Ridges fluvial erosion was the main driving force of valley formation. In the Isaszeg Channel eolian landforms suggest major role of deflation. Slopes and valley-heads are typically reshaped by mass movements.
Chapter 6: Morphotectonics of the Gödöllő Hills
- Derasional-erosional valley: shallow, bowl shaped valleys (or valley-sections) similar to the derasional valleys, but are larger (length-width ratio is at least 4:1). On the topographic map they appear as bending of at least 4 contour lines in an acute angle. Under periglacial conditions small creeks were not able to transport the slope-debris reaching their valley-floors. Hence their valleys became wider and shallower, so-called derasional-erosional valleys. This process was typical in the headwaters and upper stream-reaches in the Gödöllő Hills (Photo 6-4C). Derasional-erosional valleys may occur individually, but most frequently they form part of the erosional valley system, typically on the smooth sandy terrains (e.g. east of Isaszeg in the Isaszeg Channel on Fig. 6-4A).

Photo 6-4. Characteristic landscapes of the Gödöllő Hills. Note the smooth landforms and the absence of a waterflow in the derasional valleys. The arrows indicate the slope direction. For location see Fig. 6-1. A: Upper reach of the Alsó-Tápió valley. At this segment there is no permanent waterflow in the valley, it is evolving as a derasional-erosional valley. B: Derasional valley SE of Úri. The yellow line shows the approximate position of the multielectrode resistivity profile of Fig. 6-3A.

2) Positive landforms
Positive landforms are the ridges and summit levels between the valleys, thus their formation was closely linked to the valley forming erosional and derasional processes. As erosional valleys are usually re-shaped to a certain degree by mass-wasting, on the geomorphic map all positive landforms are considered as both erosional and derasional landforms. Where eolian reshaping of the landforms is significant, it is marked by separate symbology (see later).
- Hill-top: highest topographic levels, usually a large flat topped terrains. Their position with respect to the NE trending valleys is typical: they emerge steeply above the valley to the north and long, gentle ridges connect them with the next valley in the SE (e.g. SE of the Alsó-Tápió valley on Fig. 6-4B).
- Local-top: large flat topped terrains, elevated from their surroundings but, not the highest summits of a given ridge. They are frequently leant against the slope of a higher terrain or they are connected to the slope by a shallow saddle (e.g. NE of Isaszeg, S of the Sósi Creek on Fig. 6-4A).
- Isolated hill: slightly similar landforms to the “local-top”. However, the isolated hills are of smaller size and they are always cut from the adjacent slope or ridge by regressing valleys (e.g. NE of Mende on Fig. 6-4B).
- Ridge: longitudinal ranges between two valleys. Ridges have gradual slope along strike from the top or local top level towards the trunk channel. The boundary of the ridges has been drawn where the gently dipping ridge-tops break and the steeper valley-slopes initiate. Slope angle of the ridges is not expressed on the map.