Neotectonic and Landscape Evolution of the Gödöllő Hills, Central Pannonian Basin, Hungary

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Neotectonic inversion in the SW part of the Pannonian Basin started during the latest Miocene (~6 Ma) and gradually extended into the basin interior during Plio-Quaternary times (e.g. Fodor et al. 1998, 1999, Bada et al. 2001). During this phase overall extension and subsidence (syn- and post-rift phases) of the basin system stopped and compressional stresses triggered differential vertical motions – i.e. simultaneous uplift and subsidence – in the basin interior (e.g. Fodor et al. 1999, 2005, Bada et al. 2001). The Gödöllő Hills is a rolling hilly area of 105 to 344 m asl. height in the central Pannonian Basin, east of Budapest, capital of Hungary (Fig. 1). It is part of the transitional zone between uplifting and subsiding regions and is composed of late Miocene–Pliocene delta and fluvial sequences covered by up to 40 m Quaternary loess and/or eolian sand. Morphologically it consists of two relatively elevated and dissected ridges (Valkó and Úri Ridge) separated by a wide valley with smooth surface (Isaszeg Channel; Fig. 1). River deflections and drainage pattern anomalies suggest that neotectonic activity had considerable influence on landscape evolution. Joint geologic-geomorphologic study, seismic reflection profile analysis and structural mapping were carried out to constrain neotectonic warping of this region. Main goals of this study are (1) to define how neotectonic motions influenced Quaternary landscape evolution; and (2) to recognize the relative role of neotectonic deformation versus climate controlled surface sculpturing.

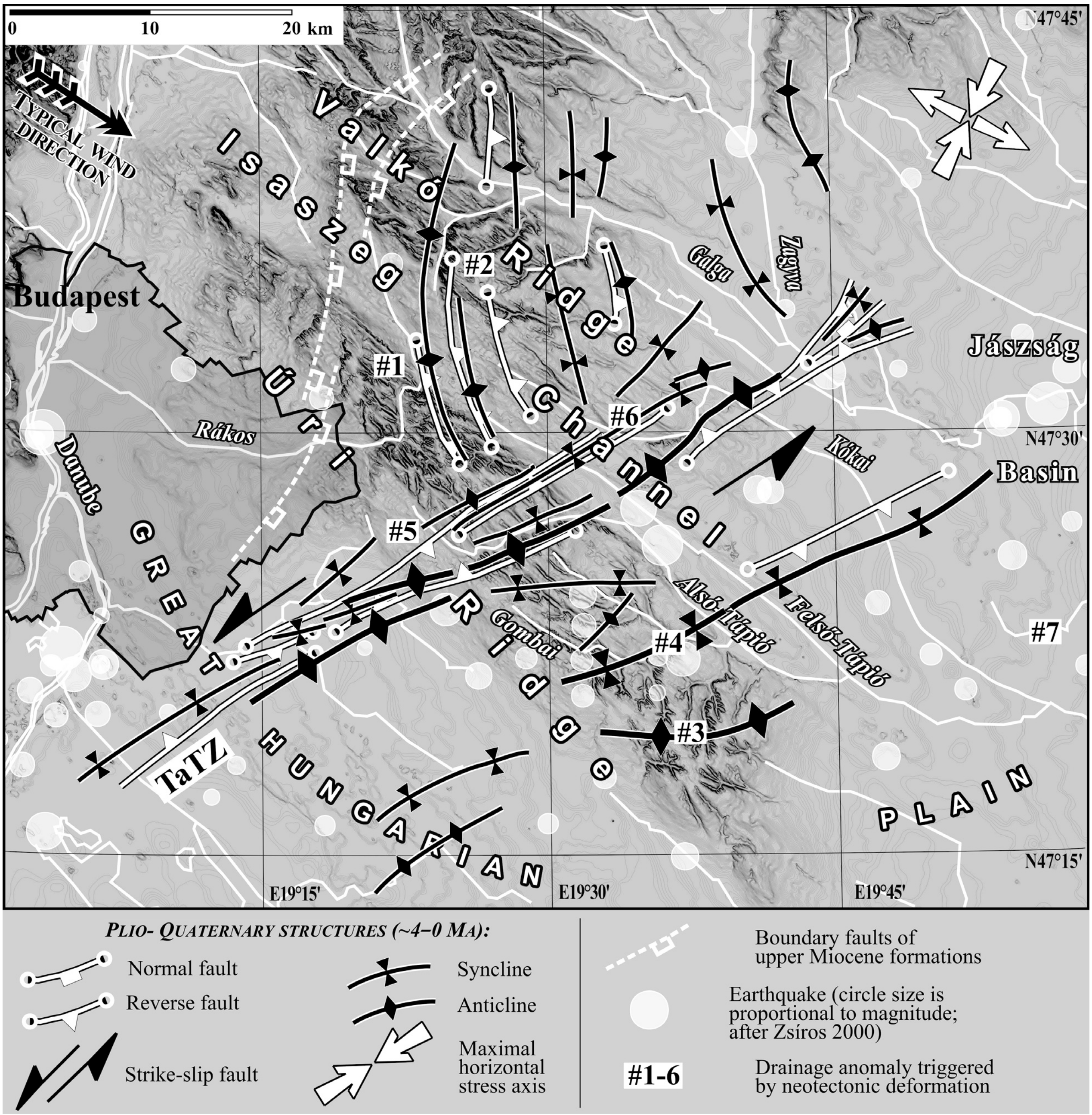
The uppermost imaged reflectors on seismic profiles belong to the late Miocene (post-rift, Pannonian) phase, occasionally up to the Pliocene fluvial sequences. The upper Miocene delta succession is a well reflecting formation below the Gödöllő Hills. Its characteristic layered-cake structure usually appears as continuous, gently dipping reflectors. The inversion in the study area is mainly expressed by the gentle folding of the uppermost imaged horizons with a maximum amplitude of a few hundred m, which verifies Pliocene–Quaternary deformation (~4–0 Ma). The structural map presented in Fig. 1. is depicting the deformation affecting the uppermost imaged reflectors, description of older structures is beyond the scope of this study.

In the northern part of the Gödöllő Hills reverse reactivation of N-S to NNW-SSE trending earlier – mainly syn-rift – normal faults, and connected folding of the uppermost imaged horizons is typical. The central area is crossed by a WSW-ENE trending fault zone, which was described by Tari et al. (1992) as a syn-rift transfer fault. Sudden changes in thickness and syn-tectonic wedges of lower upper Miocene layers refer to rejuvenation of transtensional flower structures during the beginning of the post-rift phase, recognised already by Csontos and Nagymarosy (1998). It was named by Fodor et al. (1999) Tóalmás Zone and dated as middle to late Miocene (~14–6 Ma). In this morphotectonic study this strike-slip zone is called Tápió–Tóalmás Zone (TaTZ, Fig. 1.) because the characteristic surface expression of its neotectonic transpressive reactivation in the Alsó-Tápó valley. Inversed negative flower structure and en echelon arrangement of the faults and related folds suggest sinistral motion and transpressional character of the TaTZ. This is indicative of a NE-SW compressional-transpressional stress field for the neotectonic phase (Fodor et al. 2005). Surface ruptures have not been documented in the northern area nor in the TaTZ. Reverse slip along reactivated syn-rift faults has been distributed into several small-scale fault branches within the upper Miocene layers and/or was accommodated by drag folds above the fault tips. South of the TaTZ the upper Miocene reflectors are folded into wide ~WSW-ENE trending anticlines and synclines with 100–300 m amplitude, and 10–20 km wavelength (below Gomba Depression and Pánd Antiform on Fig. 1). Earthquakes (Zsíros 2000, Fig. 1) in the southern area, in the Jászság Basin and in the W elongation of the TaTZ (S of Budapest) suggest that deformation may last until the Holocene.

Joint investigation of mapped structures and geomorphology revealed that peculiar drainage pattern indicates considerable influence of neotectonic deformation on landscape evolution however, some typical landforms lack structural control.

(1) The gentle SE slope of the smoothed envelope surface of the Gödöllő Hills resembles the common SE dip of the upper Miocene reflectors. The transitional position of the Gödöllő Hills between the uplifting Hungarian Mountain Range and the subsiding Great Hungarian Plain is allowed for this tilting. No structural lines are reconcilable with these valleys consequently, the characteristic NW-SE valley strike in the Gödöllő Hills is surface expression of the tilt of the entire area. Similarly, the sharp rectilinear margins of the Valkó and Úri Ridges and the Isaszeg Channel lack structural control.

(2) Some anomalies of the drainage pattern correspond to locations of structural deformation. Anticlines of the uppermost reflectors can frequently be connected to topographic highs and similarly synclines to topographic depressions. The uplift of anticlinal hinges led to enhanced surface erosion, river piracy and development of radial drainage networks. In the central part of the Úri Ridge dissected landscape suggests river incision triggered by young uplift of the underlying anticline. The same structure could have induced the



■ **Fig. 1.** Neotectonic deformation of the Gödöllő Hills superposed on the slope distribution map (steeper slopes are darker). See explanation in text. (modified after Fodor et al. 2005).

capture of the Rákos Creek (#1 on Fig. 1), which has been deflected from its consequent SE flow direction within the Isaszeg Channel and its lower reach is cutting through the Úri Ridge towards the Danube River. Further towards the N radial drainage pattern has developed most probably because of a growing anticline observed on seismic profiles (#2 on Fig. 1). In the SE part of the Úri Ridge the Pánd Antiform (#3 on Fig. 1) is also characterised by radial drainage pattern, which also has developed above an anticline of the upper Miocene layers. In subsiding depressions, like e.g. the Gomba Depression (#4 on Fig. 1) N of the Pánd Antiform, centripetal drainage pattern and alluvial sedimentation occurred.

(3) The upper and lower reaches of the Alsó-Tápió and Kókai Creeks follow the overall SE tilt of the area however, their intermediate section flows in a WSW-ENE direction. These

river reaches have been deflected by anticlines formed above en echelon segments of the TaTZ (#5 and #6 on Fig. 1). Eastwards the morphologic expression of the TaTZ decreases because of the smaller amplitude of the structures and the proximity of the subsiding Jászság Basin.

Typically minor amplitude of surface undulations respective to the amplitude of folding of the uppermost Miocene layers indicates that several episodes of Plio-Quaternary erosion smoothed the deforming topography. Characteristic NW winds and local variation of wind power led to the development of the typical NW-SE striking landforms. Accordingly the Valkó and Úri Ridges of the Gödöllő Hills form large scale yardangs separated by a wind channel (Isaszeg Channel). In the Isaszeg Channel the surface expression of the structures is further weakened by the strong areal denudation of the wind. The central and SE part of the ridges evolved in a wind-shielded position where climate oscillations led to various phases of loess deposition and fluvial erosion. Here surface dissection is significant yet overall lowering was smaller (see slope distribution on Fig. 1).

According to the seismic reflection profiles structural inversion is younger than ~4 Ma. Chronostratigraphy of the outcropping loess-paleosoil sequences suggest that surface expression of the neotectonic deformation – i.e. valley sections developed in consequence of river deflections in front of growing anticlines – is at least 400–600 ky old. The significant lag between the onset of the structural deformation and the appearance of its surface expression may be explained by two reasons. Firstly, the denudation processes were stronger during Pliocene – early Pleistocene times, thus they obliterated the surface deformations. Secondly, the deformation in the first period of the neotectonic phase was slower and the vertical motions have been accelerating towards present.

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Lower Crustal Channel Flow in Hot Orogens in Space and Time Exemplified by the Variscan Eastern Margin

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Recent considerations of detailed petrological, geochronological, geophysical and structural data allow us to make progress in understanding mechanisms of crustal-scale exhumation of orogenic lower crust associated with lithospheric indentation. Current numerical models (e.g. Beaumont group) suggest an emplacement of “hot-nappes” in subsurface channel-flow powered either by gravity potential or by an indentation of a weak hot root with a lower crustal rigid promontory attached to the subducting plate. Geological examples of channel-flow are based on localized occurrence of high-grade rocks along the S. Himalayan front resulting from ductile extrusion driven by gravitational collapse and focused erosion.

We present an example of several thousand square kilometres of flat-lying orogenic lower crust underlain by a basement promontory located at the retroside of the Variscan orogen along a 300 km long collisional front (Poland, Czechia and Austria).