Tectonic and climatic forcing in Quaternary landscape evolution in the central Pannonian Basin: A quantitative geomorphological, geochronological and structural analysis
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CHAPTER 1: INTRODUCTION

1.1. Scope of the thesis

The main objective of this thesis is the investigation of Quaternary landscape evolution in the central part of the Pannonian Basin via differentiating between structural and surface processes. The style and rate of neotectonic deformation and its importance relative to denudation processes is of key importance for a better understanding of the Quaternary structural evolution of the Pannonian Basin. Similarly the distinction between diverse types of erosion – fluvial, eolian and mass wasting – provides new insights to Quaternary climate and tectonic controlled landscape evolution.

My objective is to present new information about the Quaternary inversion-related tectonic deformation of the Pannonian Basin focusing first on the quantification of vertical motions in the axial part of the Hungarian Mountain Range (HMR). In the study area, the Danube valley, the Quaternary uplift has been demonstrated by geological, geomorphological and geophysical methods (e.g. Pécsi 1959b, Kaiser 1997, Joó 1993, Horváth and Cloetingh 1996). However, the age and rate of this motion has remained uncertain so far. The incision-rate of the antecedent Danube valley is defined using earlier data and introducing a new dating method for the region, the exposure age dating using terrestrial in situ produced \(^{3}\)He. The obtained incision rates are considered to be valid for the quantification of the uplift of the central part of the HMR.

The morphotectonic study of a rolling hilly area, the Gödöllő Hills, is coupled with the structural analysis of the subsurface strata in order to describe the style and timing of the neotectonic inversion in the Central Pannonian Basin. Morphometry allows to separate landforms related to fluvial erosion, wind erosion and gravitational slope movements, and specifies areas where tectonic control on landforms is highly probable. A connection between landforms and structural elements may evidence the presence of Quaternary tectonic deformation and enables to define its role in landscape evolution.

The traditional geological, geophysical and geomorphological methodologies are insufficient to answer the question whether landscape evolution occurred due to climatic or tectonic control or both. Therefore, a new, multidisciplinary approach is introduced by the combination of the classical methods of geomorphology and field geology with geophysical techniques, structural analysis and quantitative geochronology. The study area is representative for the Pannonian Basin, nevertheless, the thesis aims at providing a novel methodology with application and new results useful for investigations in other areas of similar geologic-tectonic setting.

1.2. Multidisciplinary approach in modern Quaternary research

The youngest tectonic events and their structural expression is not yet well developed. They can be recognised and described properly only with a multidisciplinary approach. Geomorphology, seismology, geophysics, sedimentology, structural geology and geochronology are the main disciplines for a neotectonic study. Different geological settings and landscapes are involved in the analysis, which requires complex methodology and propose comprehensive interpretation of the Quaternary structural and surface processes.

There were significant climate oscillations during Quaternary times (e.g. Andersen and Borns 1997, Wilson et al 2000), which did not allow long-term stability of erosion styles. Climatic and tectonic processes take place simultaneously, thus the reconstructed sedimentary
record and geomorphological environment reflect their coupled effect. Climate controlled changes in the hydrological regime of a drainage basin may result in alterations of erosion and sedimentation similar to tectonic triggered processes (Tucker and Slingerland 1997, Bogaart and Van Balen 2000, Coulthard et al. 2000, Mol et al. 2000, Vandenberghe 2003). In this tectonic-geomorphologic-geochronologic analysis this joint effect is considered when interpreting the results of the sub-disciplines.

![Fig. 1-1. Shaded relief map of the Pannonian Basin system (based on SRTM data). Subsiding subbasins appear as extended lowlands, which are separated by uplifting basement units topographically expressed as mid-altitude mountain ranges. Bp: Budapest, VB: Vienna Basin, DrB: Drava Basin, SB: Sava Basin, MV: Mecsek-Villány Hills. Dashed rectangles indicate position of Figs. 1-3, 2-1 and 2-4.](image)

In areas of Quaternary uplift displacement of former planation surfaces, like river terraces, deflected river channels, peculiar drainage patterns and concavity of longitudinal river profiles are **geomorphic indicators** of young folding or faulting (e.g. Keller and Pinter 1996, Burbank 2001, Merrits et al. 1994, Demoulin 1998).

**Surface- and seismic-stratigraphy** allows the recognition of the deformation of the late Miocene - Plioceen strata (e.g. Tari et al. 1992, Horváth and Tari 1999, Sacchi et al. 1999). In a continental environment, such as the Pannonian Basin, Quaternary sediments are difficult to correlate. However, the presence of some marker horizons (e.g. Schweitzer and Szőör 1997, Horváth 2001), travertine horizons (e.g. Schweitzer and Scheuer 1995), gravel occurrences (e.g. Pécsi 1959b) and paleonthology (e.g. Jánossy 1979) enable sedimentological, paleo-morphological comparisons and age estimates. **Structural geology** provides means for the recognition of geodynamic processes leading to the observed deformation pattern (e.g. Horváth and Royden 1981, Csontos et al. 1992, 1998, Bada et al. 2001, Gerner et al. 1999, Fodor et al. 1999). **Geochronology** helps the timing and quantification of tectonic and erosion processes (e.g. Shackleton and Opdyke 1976, Bierman 1994, Heimsath et al. 2001, Wang Fei et al. 2004).
1.3. The study area

Pannonia was a Roman province in the area to the south and west of Danube River (currently called Transdanubia), which name has been extended in geodynamic context to the whole basin system. The name of the Carpathian Basin is used in geographical sense for the area in between the Eastern Alps, the Dinarides and the Carpathians (Figs. 1-1, 1-2).

![Fig. 1-2. Recent vertical and horizontal motions in the Pannonian Basin system. Areas of Quaternary uplift and subsidence were adopted from Horváth and Cloetingh (1996). Direction and velocity of horizontal displacements of the Western and Northeastern Units with respect to the stable Bohemian Massif are indicated with black arrows (Grenerczy et al., 2000, Grenerczy and Kenyeres 2005). Active deformation between these units is accommodated within a wide zone in the Central Pannonian Basin, the area in the scope of this study (indicated with black rectangle and inserted location map). A-A': position of the section in Fig. 3-1. along the Danube. VB: Vienna Basin, DB: Danube Basin, GHP: Great Hungarian Plain, JB: Jászság Basin, KB: Körös Basin, MT, Makó Trough, DrB: Drava Basin, SB: Sava Basin, TrH: Transdanubian Hills, TR: Transdanubian Range, NHR: North Hungarian Range, TR together with NHR form the Hungarian Mountain Range (HMR).]

The Central Pannonian Basin (Fig. 1-3) is an outstanding natural laboratory for the study of Quaternary landscape evolution. Seismic activity defined by earthquake epicenter distribution (Fig. 1-3B; Zsiros 2000, Tóth et al. 2002) is indicative of ongoing deformation and allows the identification of some major seismoactive fault zones (Fig. 1-3B; Bada et al. 2005a). Structural and surface processes revealed in the study area may be extended for the entire basin system,
which is attractive for a joint neotectonic and landscape evolution analysis. Two study areas were selected to represent the characteristic landscape-types of the region:

(1) The **Danube valley** is the only place where the uplifting Hungarian Mountain Range (HMR) is crossed by a river (Figs. 1-1, 1-2). This the antecedent terraced valley forms an excellent place for the quantitative study of Quaternary vertical motions (e.g. Pécsi 1959a,b). The central reach of the Danube valley is the **Danube Bend** (Fig. 1-3A), where the fastest uplift has been assumed on the basis of terrace studies (Cholnoky 1925, Kéz 1933, Noszky 1935, Bulla 1941, Láng 1955, Pécsi 1959b, Gábris 1994). Nevertheless, these studies are lacking absolute chronological data concerning the andesite strath terraces in the Danube Bend. A detailed re-evaluation of the former terrace chronologies and new $^3$He exposure ages of this study provide quantitative information on Quaternary valley evolution and tectonic uplift rates.

(2) The **Gödöllő Hills area** is part of the transitional zone between uplifting and subsiding regions of the Pannonian Basin (Figs. 1-2, 1-3) composed of thick late-Miocene – Pliocene sediments and Quaternary terrestrial cover. In this low hilly region neotectonic deformation may be reflected by certain landforms, peculiar river networks. The joint geomorphological and structural investigation of this study presents new data on the style of neotectonic deformation and its effect on landscape evolution. Quantitative morphometry provides better constraints on the relative influence of fluvial and wind erosion in shaping the Pannonian landscape.
1.4. Outline of the thesis and brief methodology

In chapter 2 a brief overview is provided about the geology and geomorphology of the Pannonian Basin. In this framework, the Neogene to Quaternary structural and landscape evolution of the area, and the most important climate related surface processes during the Quaternary glacials and interglacials are described. Special attention is paid to the timing, geodynamic evidences and structural manifestation of the neotectonic inversion phase, as this period governed the morphostructural evolution of the study area. The quantitative geochronological nature of this study demands the application of an unambiguous timescale. Therefore, a compiled chronology chart is presented that fits the local conditions of the intra-Carpathian area, and at the same time is comparable to the international Quaternary chronostratigraphy.

Chapter 3 is dedicated to the description of the Danube valley and the neighbouring parts of the HMR, which is of key importance for understanding the characteristics of the studied terrace system. A re-evaluation of former sedimentological, geomorphological, paleontological and chronological data concerning the Danube terraces and vertical deformation of the study area is presented. By the compilation of these data sets, the incision rate of the Danube is determined, which can be taken as relevant approximation for the uplift rate of the HMR (e.g. Pécsi 1959b). Using the compiled data set, possible climatic control upon terrace formation is also investigated.

In chapter 4 the principles of exposure age dating are introduced. This is the first application of this dating method in the Carpathian-Pannonian realm. Thus, an extensive methodological description of exposure dating using terrestrial in situ produced cosmogenic nuclides (TCN) is provided.

Chapter 5 lines the practical aspects TCN exposure age dating focussing on the application of $^3$He on volcanic lithology, in agreement with the selected nuclide and geological setting of the sampled area, the Danube Bend. Then the field and experimental data of $^3$He exposure age dating and the calculated incision rate of the Danube are presented. The obtained new terrace ages and incision rate are discussed in comparison with the “traditional” chronology.

Chapter 6 presents a DEM-based morphometric analysis of the Gödöllő Hills. Several morphometric maps are presented and morphometric indexes are calculated in order to quantitatively differentiate areas with diverse landscape evolution. The DEM study is combined with a detailed geomorphic survey based on topographic maps and geomorphic mapping. Dominance of fluvial or wind erosion is recognised successfully and locations where neotectonic warping may have influenced landscape evolution are highlighted.

In chapter 7 a structural analysis is carried out in Gödöllő Hills. Structural mapping based on seismic reflection profiles enables the recognition of the style and location of neotectonic deformation. Possibly active structures and connected areas of uplift and subsidence are constrained and compared to the results of the morphometric study. The influence of neotectonic motions on Quaternary landscape evolution and the relative role of structural deformation versus climate controlled surface sculpturing are determined.

In chapter 8 Quaternary tectonic deformation and landscape evolution of the study areas is summarized with special emphasize on the timing and rate of neotectonic warping and its surface expression. Relative importance of climate related landscape forming processes and neotectonic activity are also discussed. Regional conclusions are extended to the western part of the Pannonian Basin with similar geological and morphotectonic setting, providing better constraints on landscape evolution and active tectonic processes of the basin system.