Summary

The aim of the dissertation is to describe the explored structural features of a southeastern, lesser-known part of the Bükk Mountains (NE Hungary) and to revise the existing deformation history models using the data collected from a 80 km^2 area in outcrop scale. These models concern the rocks of other parts of the Bükk Mts. or of the whole Bükk Mts, but cannot contradict the features observed here.

The description and classification of the deformation features can be achieved by observation of the deformation style (that is, the geometry of the structural elements of a certain phase) and overprinting relations between the elements of different style. One third of the cca. 900 documented outcrops lies outside the particularly explored area, so these give a possibility to get a knowledge about the spatial relations of the phenomena, the rock bodies and structural elements with the structure of continuously attached parts of the Bükk Mts. and its foreland.

Based on the style, there are three style groups to distinguish, which represent at once three stages of the deformation history.

The first style group comprises almost exclusively ductile features. The deformation affected the whole mass of the rock bodies (although in different degrees), and caused the formation of cleavage in most of them, in several cases it also caused folding. Most important factors of the fold style formation were thickness ratios and competence contrasts of the beds. In the identical rock types there is a spatial style difference to observe, so tectofacies and, based on that, two structural units can be defined, bordered by later shear zones. According to the results of our investigations (NÉMETH AND MÁDAI 2005), the activation of the deformation mechanisms identified in limestone (the most prevalent rock type in the area) need the same pressure-temperature conditions as the p-T maxima of the metamorphism proved by ÁRKAI (1973) from metavolcanite and clastic sedimentary rocks. The deformation markers are the products of one single deformation phase (early phase) inside both structural units, but comparing the two units, they are not necessarily coeval.

The features of the second style group represent the brittle-ductile transition. In carbonates the brittle elements dominate. From the ductile elements occur mostly those, which can be formed by pressure solution. Characteristic feature of these brittle-ductile transition in the area is that deformation is not equally intensive in all parts of the rock bodies but concentrates in certain zones. In these zones (where it can be demonstrated) there occured strike-slip movements of (minimally) km-order of magnitude or even 10km-order of magnitude in the zones bordering the two structural units. These deformation events produced the present attached position of the tectofacies units, which have a slightly different stratigraphy and were deformed in a different way in the early phase.

The third style group comprises solely brittle elements; these are the imprints of the youngest deformation events. As the previous phases produced oriented texture and several joint sets, movements occured mostly along preexisting fractures, that is, these imprints can be found with dense spacing on the outcrops, but there is a concentration of them in narrow zones of large-scale movements, e.g. on the edges of the mountains with large level differences. Based on the slickenline systems observed on the outcrops, five major movement system were distinguished, which were active on the whole area and probably beyond it too.

The most probable deformation history based on the observations begins with the early phase when the structural units were parts of an orogen in different depths. In that time the units were far away not only from the present geographical position of the Bükk Mts. but also from eachother. The deformation processes connected with the strike-slip motion along the Mid-Hungarian Zone (or rather in an earlier zone not distinguishable from the later Mid-

Hungarian Zone) produced the juxtaposed or overthrusted situation of the horses of the structural units with elements of the second style group. In that time the Bükk Unit was formed with its present borders: the Darnó Zone on NW, the Mid-Hungarian Zone on S and the Hernád Zone on E. The third style group comprises imprints of near-surface deformations connected with the uplift of the present Bükk Mts. which produced the inselberg-topography elevated some km-s from the basement of the Pannonian Basin. This uplift proceeded in a space exposed to shortening with strike-slip motions of higher order of magnitude than the vertical component, and it cannot be regarded as a finished process.

Theses

1. The deformation structures of the explored area can be arranged into three groups by their style. This grouping means a chronological order as well. In the *early phase* the deformations were chiefly ductile: a cleavage was formed and the bedding was folded. In the *shifting phase* brittle and ductile deformations occured at the same time as accompaniments of km-magnitude or larger strike-slip faulting (or in some cases thrusting) along discrete zones. The deformations of the *uplift phase* were essentially brittle not only in fault zones, but in the whole rock mass by means of a penetrative, systematic fracture system formed during previous deformation events.
2. The style of the oldest (early phase) deformation structures in the eastern part of the Bükk Mountains can be characterized as follows: on outcrop scale the formation of class 2 (RAMSAY 1967) or nearly class 2 multilayer folds is typical with thickening of the layers in the hinge zones. The folding is always accompanied by a cleavage, which is less intensive in the hinge zones than on the fold limbs. The intersection lineation between bedding and cleavage is horizontal in almost every cases. The style of the folding depends on the thickness ratios of the competent and the incompetent beds as well as on the competence contrast. The mechanism of the folding was flexural shear (not often flexural slip) in rock bodies with beds of different competence, while in rock bodies without bedding or with beds with low competence contrast (first of all in massive limestone) it was passive shear.
3. Based on the local style differences of the early phase structures (that is, on the tectofacies of the rocks) the explored area can be divided in two structural units („tectofacies units"). The *Bükkszentkereszt Tectofacies Unit* is characterized by intensive ductile deformation in almost every rock body, while in the *Bükkszentlászló Tectofacies Unit* the structures of the brittle-ductile transition are present (resembling on the style of later structures) and the intensity of the deformation was lower.
4. The early phase deformation was produced in a single, continuous sequence of deformation events, because overprints with the same style occur only exceptionally, produced likely by progressive folding. Based on textural investigations of limestone samples and the P-T conditions (>100 MPa differential stress and 2-300°C temperature) necessary to the formation of the deformation structures observed on these (NÉMETH AND MÁDAI 2005), the deformation occured simultaneously with the anchi-epizonal metamorphism affecting the explored area, proved by ÁRKAI (1973), but not likely simultaneously in both tectofacies units.
5. The traceable map-scale structures of the shifting phase are steeply dipping (or nearly vertical) strike-slip fault zones. Ductile and brittle deformation structures were formed (in some cases overprinting each other) during progressive deformation. Deformation style was affected by early phase structures, mainly by the cleavage causing mechanical anisotropy. The folding of the bedding and/or the cleavage is connected with the fault

zones, and reflects the shear along these. Folding was formed by slip on fracture planes along the bedding or the cleavage or by formation of a crenulation cleavage.

6. On the NW-SE striking fault zones bordering the two tectofacies units the displacement in the shifting phase was sinistral strike-slip or sinistral-oblique thrusting. The magnitude of the displacement is at least some 10 km based on the observable km-magnitude displacement along some branches of these zones and on the present adjacent position of the different tectofacies units (with slightly different lithology as well). The direction of the largest principal stress (σ_1) during this deformation was cca. E-W horizontal (according to the present position with respect to the geographical coordinate system).
7. In the uplift phase there were 9 movement systems to separate based on the slip systems observed on the outcrops and to arrange into chronological order based on overprinting relations. From these movement systems 5 different sequence of deformation events were reconstructed, which affected the whole explored area and possibly have regional significance. The age of these sequences was estimated by correlation with data concerning the sedimentation, the paleogeography, the tectonics and the slip systems in the Tertiary strata known from the surroundings of the Bükk (e. g. PELIKÁN 2002, FODOR *& al.* 1999). The sequences are as follows:
   - 7.1. Thrust system with N-W shortening in the Paleocene-Eocene (most probably in the Middle Eocene), still with shifting phase-style deformation markers at the start of the sequence of the deformation events.
   - 7.2. Strike-slip system with SW-NE horizontal highest principal stress in the Oligocene, with relative uplift of the E-SE sides of the faults.
   - 7.3. Extensive strike-slip or normal fault system with N-S extension and cca. E-W horizontal highest principal stress at the end of the Oligocene and in the Early Miocene up to the formation of the lower rhyolite tuff horizon.
   - 7.4. Strike-slip system with NW-SE horizontal highest principal stress in the Middle Miocene, with nearly E-W striking dextral strike-slip faults.
   - 7.5. At the beginning strike-slip, later thrust system with WSW-ENE horizontal highest principal stress at the end of the Miocene and continuously up to the Quaternary, with NW-SE striking sinistral strike-slip faulting on the NE edge of the mountains, and with N-W striking dextral-oblique thrusting in the whole area.

References

ÁRKAI P. 1973: Pumpellyte-prehnite-quartz facies Alpine metamorphism in the Middle Triassic volcanogenic-sedimentary sequences of the Bükk Mountains, NE Hungary. *Acta Geologica Hungarica* **17/1-3**, pp. 67-83.

FODOR L. – CSONTOS L. – BADA G. – GYÖRFI I. – BENKOVICS L. 1999: Tertiary tectonic evolution of the Pannonian basin system and neighbouring orogens: a new synthesis of paleostress data. *In:* DURAND, B. – JOLIVET, L. – HORVÁTH F. – SÉRANNE, M. *(eds)*: The Mediterranean Basins: Tertiary extension within the Alpine Orogen. *Geological Society, London, Special Publications* **156**, pp. 295-334.

NÉMETH N. – MÁDAI F. 2005: Early phase ductile deformation elements in the limestone of the eastern part of the Bükk Mts, Hungary. *Acta Geologica Hungarica* **48/3**, pp. 283-297.

PELIKÁN P. 2002: Földtani felépítés, rétegtani áttekintés. Fejlődéstörténet I: szerkezetfejlődés. [Geology, overwiev of the stratigraphy. Evolution I: structural evolution] *In:* BARÁZ CS. *ed:* A Bükki Nemzeti Park. *BNP igazgatóság*

RAMSAY, J. G. 1967: Folding and fracturing of rocks. *McGraw-Hill, New York*, 568 p.