1. Introduction

The post-conference excursion connected to the 11th Meeting of the Central European Tectonic Studies Group in Vágesztes will give an insight into the complex post-Mesozoic structural evolution of the Transdanubian Range. The main points will include deformation features from Eocene to late Miocene with a notion to neotectonic deformation. Near the conference location, from the Vágesztes castle we can have a look to the Early Miocene strike-slip fault, one of the largest within the TR. Exposures of the southern boundary fault of the Vértes Hills offer the possibility to discuss rifting of the Pannonian Basin and neotectonic aspects as well. Excellent outcrops of the Gánt mining area expose diverse structures from the Early Miocene strike-slip faults to the Miocene syn-rift and post-rift faults. The main structural attraction of this site is a 3D view of fault relay ramps between oblique-slip faults. We will discuss the geometry and formation of late Miocene so-called post-rift grabens and the related sediment pattern. We tackle the origin of this post-rift deformation, which is not part of the classical concepts about the Pannonian basin. Visited stops and a brief description of topics which are planned to discuss are listed below (Fig. 1).

Vágesztes castle: **Early Miocene dextral fault** — displacement markers, small pull-apart depressions, Miocene strike-slip and normal faults, Eocene depression

Csókakő quarry and castle: Cenozoic basin-margin fault — geometry of and deformation within a fault zone, inheritance from early phase, comparison of fault and seismic data, question of neotectonic reactivation

Csákberény: graben-margin fault — geomophological expression of the fault, direct comparison with seismic data nearby. Landscape evolution and neotectonic activity

Gánt open pit mines: Miocene strike-slip faults, oblique-slip normal faults, relay ramps — 3D view of faults with divers kinematics, techniques of fault-slip analysis and field measurements, interaction of overlapping faults, superposition of different fault slip events, fluid flow and mineralisation along faults

Csákvár: basin margin fault of a late Miocene depression — appearance and message of eroded fault scarps, constraints on fault geometry and timing of fault activity from boreholes and seismic data set

2. Geological setting of the Pannonian Basin

The location of the field trip, the central part of the Pannonian Basin is situated within the Alpine, Carpathian, and Dinaric orogenic belt (Fig. 1). The main Miocene basin forming phase was preceded by several episodes of compressional to transpressional basin formation of Middle Eocene to early Miocene age (Fig. 1b, c). These are the regional D6 to D8 deformation phases of Fodor (2008). The related basins of Hungary were located in a retroarc position with respect to the Alpine-Carpathian thrust front (Tari et al. 1993). At that time the area of the future Pannonian basin was integral part of the compressional Alpine orogen.

During the second part of this transpressional basin evolution, an important fault zone cut through the entire Alpine-Carpathian orogen. The combined Periadriatic Fault (PAF) and Mid-Hungarian shear zone resulted in dextral displacement of 60–150km and brought eastward the easternmost Alps, Western Carpathians NW Pannonia, the so-called AlCaPa block. This is the regional D8 phase. The dextral slip was associated with thrusting (Csontos and Nagymarosy 1998) (Fig. 1c). The major fault disrupted the former Paleogene basins and also the Mesozoic facies belts.

The Miocene basin system was formed due to lithospheric extension during the late early to late Miocene times, from 19 Ma (Royden and Horváth, 1988). Based on subsidence analysis and geophysical data, Royden et al. (1983) separated the syn- and post-rift phases, although recent structural analyses revealed a more complex evolution (Tari et al., 1992; Fodor et al., 1999; Horváth et al., 2006). The syn-rift phase of ~19–11 Ma resulted in the formation of numerous grabens filled with relatively thin syn-rift sediments of marine to brackish origin (Royden and Horváth, 1988; Tari, 1994; Csontos, 1995; Fodor et al., 1999) (Fig. 1d).

Crustal extension was followed by a post-rift phase characterised by thinning and updoming of the lithospheric mantle, thermal contraction, and related subsidence of the entire basin (Horváth and Royden, 1981) (Fig. 1e). Moderate faulting occurred in some parts of the basin, including the field trip area. Post-rift subsidence was compensated by intense sedimentation in the brackish to freshwater Lake Pannon during the late Miocene (Jámbor, 1989; Juhász, 1991). Deltaic to littoral sediments progressively filled up the lake, while all sub-basins became fluvial dominated by the end of the Miocene (Vakarcs et al., 1994, Magyar et al., 2012).

The end of rift evolution was related to the end of thrusting along the Carpathian arc (Horváth et al., 2006), which occurred in the early late Miocene in the Eastern Carpathian segment (~9–10 Ma, Maţenco and Bertotti, 2000). At the same time, however, the northern push exerted by the Adriatic microplate continued from the south. As the Pannonian Basin lithosphere had no free space to further extend eastward, a new phase of deformation started. This phase resulted in inversion of the basin and can be considered as neotectonic phase (Horváth, 1995; Bada et al., 1999).

Corresponding to this evolution, the central Pannonian Basin underwent several phases of Cenozoic faulting, resulted in a dense network of faults of variable orientation. One way to present this evolution is the usage of stress field data, which are briefly exemplified by simplified diagram on Fig. 1. During the Cenozoic, stress axes were gradually rotating in clockwise sense and governed the activity and kinematics of the fault pattern (Bergerat, 1989; Csontos et al., 1991; Fodor et al., 1999).

The Pannonian Basin holds considerable amount of hydrocarbon accumulations. Several of the above mentioned tectonic factors influenced the formation of source rocks, migration pathways and trapping (Royden and Horváth 1988; Horváth 1995). Just to mention some of them, Paleogene and Miocene subsidence resulted in source rock formation. Maturation of organic matter was enhanced by the important late Miocene (post-rift) subsidence. Penetrative Miocene faulting permitted the formation of extensive migration pathways. Traps are connected to faults, fault-related folds and neotectonic folds of varying age and kinematics. All of these features emphasize the importance

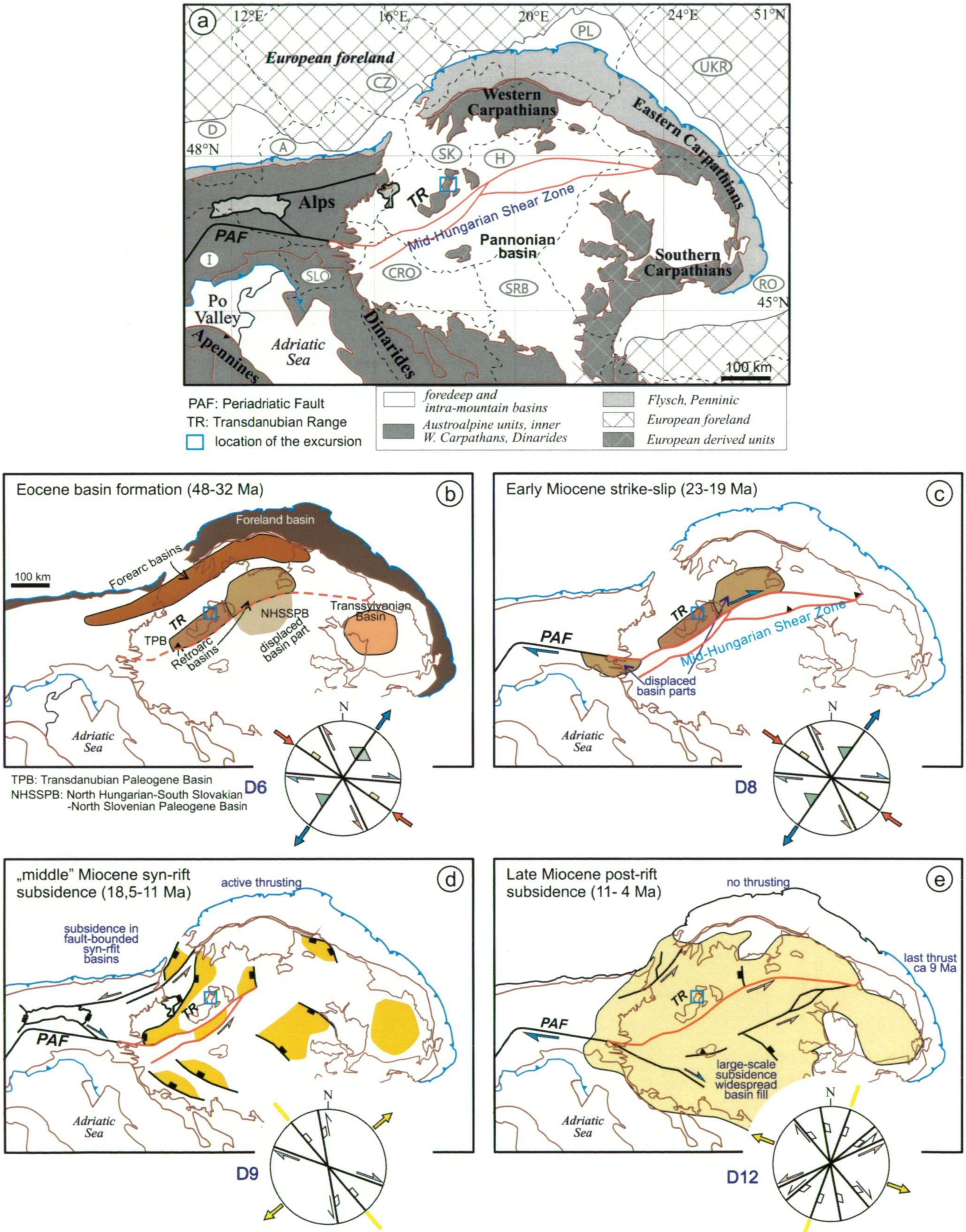

Fig. 1. Geodynamic setting and schematic structural evolution of the Pannonian Basin within the Alpine-Carpathian-Dinaridic orogen.

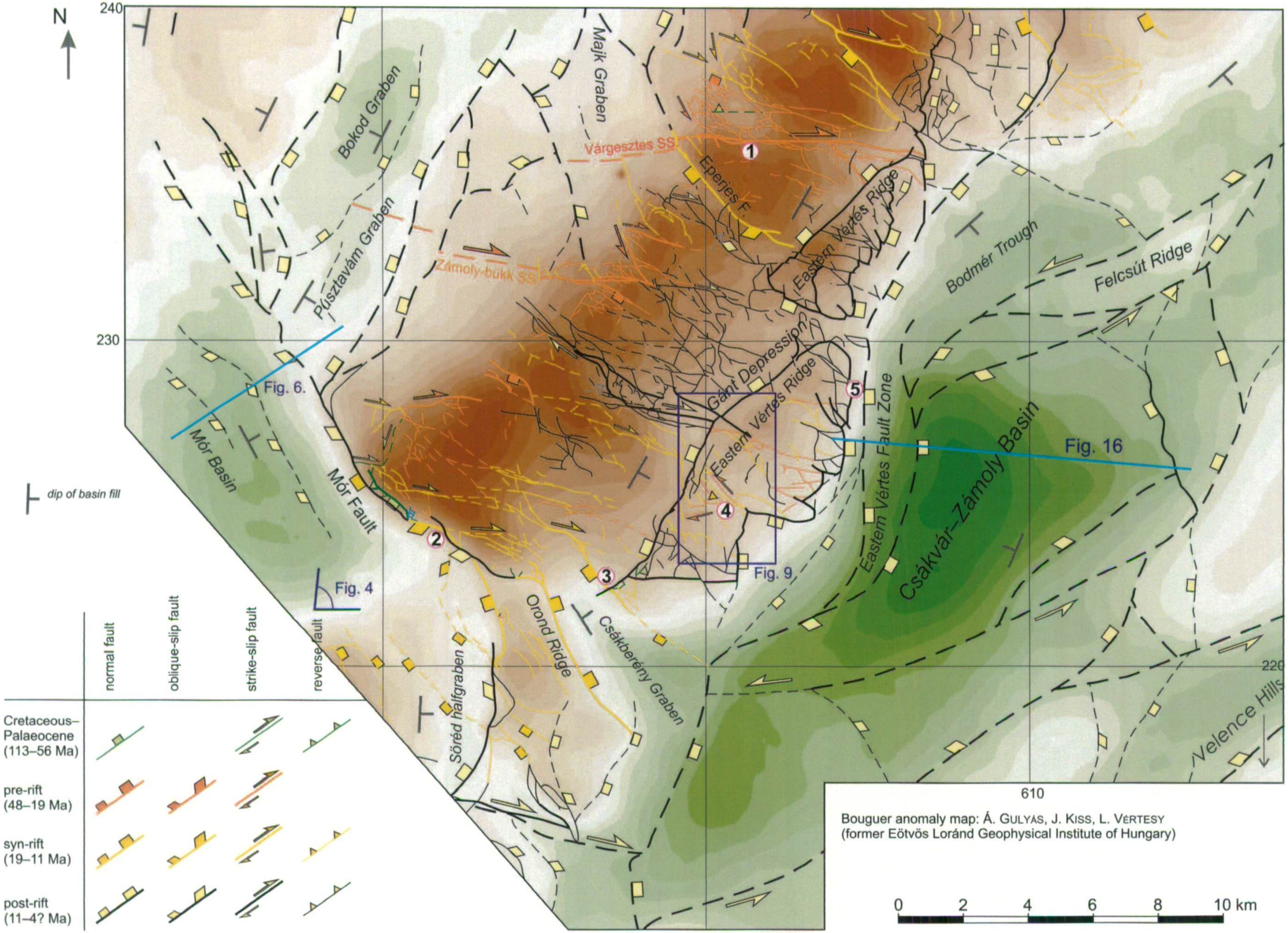

Fig. 2. Bouguer anomaly map and structures of the Vértes Hills and surrounding basins (after Budai and Fodor 2008).

of understanding structural evolution of the Pannonian Basin, and of other sedimentary basin worldwide.

3. Cenozoic faulting in the Vértes Hills

The Vértes Hills are part of the Transdanubian Range (TR) which occupied a central position within the Pannonian Basin. The hills underwent the complex faulting evolution which is briefly outlined in the previous chapter and on Fig. 1. One way to study the Cenozoic deformation is the comparison of mapped faults and the gravity data. This is shown on Fig. 2, where the Bouguer anomaly map was placed below the fault pattern of the Vértes Hills and surrounding Cenozoic basins. As one can see the change in the anomaly map correspond to steep faults, and the negative values characterise the basins with Cenozoic sedimentary fill.

The oldest Cenozoic deformation phase, which was related to sedimentation, was the mid-Eocene basin formation. This D6 phase resulted in very gentle folds, namely two basins on the NW and SE limbs of the central Vértes ridge, which can be considered as an antiform. In the basins, the successions are thicker and more complete, while the central ridge was only inundated during the later part of the Eocene sedimentation. Few cross faults were associated with the folding, for example the Zámoly-bükk Fault (Fig. 2) and the marginal fault of the Csákberény graben (Stop 3).

The mid-to late Oligocene D7 phase resulted in amplification of NE–SW trending folds and the formation of the Mór fault (Stop 2, Fig. 2). The two major E– trending strike-slip faults are dextral in character and Early Miocene in age with occasional Eocene initiation. It is possible that these D8 dextral faults are the far-field echo of the major shear along the combined PAF–Mid-Hungarian Zone. The conjugate sinistral faults can be found near the dextral faults and in the Gánt area (Stop 4).

The syn-rift phase is marked by NW–SE striking normal or normal-oblique faults, like those in Stop 4. The Mór fault was reactivated (Stop 2) and the Eperjes faults accumulated ~200 m slip. The syn-rift phase was disrupted by a short-lived strike-slip phase (D11) between 12 and 10 Ma. There is no map-scale faults to this phase, but outcrop-scale reverse and dextral faults can locally be detected (Stop 4).

The post-rift deformation was surprisingly strong in the Vértes Hills and needs explanation. Important grabens and basins were formed at both sides of the Vértes Hills. In the eastern side the Zámoly Basin was filled up by several hundred meters of post-rift sediments of Late Miocene to earliest Pliocene(?) age. The suddenly subsiding basin was first accumulated lagunal or lacustrine marls than was filled by deltas from the NW. Final stage was marked by fluvial to terrestrial sedimentation (Csillag et al., 2008).

Deformation was coeval with basin-margin faulting, particularly along the western margin of the Zámoly Basin and along the Eastern Vértes Ridge. Syn-sedimentary character of faulting is based on borehole data, syn-sedimentary dykes and few seismic profiles. Stress data indicate E–W to SE-NW extension during this D12 phase (Fodor, 2008).

Neotectonic faulting in the Vértes Hills can be demonstrated by combined methodology including surface geological and geomorphological mapping, structural analysis, earthquake monitoring. All these data suggest the neotectonic activity of some faults. The Mór Fault has a well-known historical seismic activity (Stop 2). Geomorphic and structural data also point to faulting along the Mór and nearby faults (Fodor, 2008; Fodor et al., 2007). The western margin fault of the Eastern Vértes Ridge could have Quaternary slip as revealed by geomorphic and borehole data (Stop3). Finally, the southern fault of the Felcsút ridge could be reactivated as reverse fault during the Quaternary. This slip changed the drainage pattern (Fodor et al. 2005).

4. Excursion stops

Stop 1. Várgesztes, castle. Panoramic view to Early Miocene dextral and sinistral fault, pull-apart depressions

47°28'4.34"N, 18°23'45.78"E

The top of the castle permits a panoramic view in several directions, and shows the general tectonic-morphological expression of the Cenozoic deformations in the central Vértes Hills. The main structure is the Várgesztes strike-slip fault which cut across the Vértes Hills in E–W direction. The fault has dextral separation as pointed out by the fault pattern, regional stress field evolution and displacement markers (Gyalog, 1992; Fodor, 2008). These latters are the displaced formation boundaries within the Triassic rocks and the basal Eocene unconformity (Fig. 3). The dextral slip was associated with the formation of small pull-apart depressions. These contained subsided packages of late Oligocene clastics which were encountered by shallow boreholes (Gyalog, 1992; Fodor et al., 2008). Because most of this soft sediment was eroded, the pull-apart depressions are present as a series of narrow valleys: one is just south from the castle hill.

Looking to the north, the morphological depression below Várgesztes village is bounded by faults or folds on each sides. The small depression was born in the Eocene, when the NW margin was gently folded and isolated a marginal marine lagoon from the open sea. After the Eocene and late Oligocene sedimentation, the north-eastern margin was cut by a NW–SE trending sinistral strike-slip fault which runs at the foot of rocky Eocene limestone cliffs. Finally, the SW margin is bounded by a Miocene normal fault.

Stop 2. Csókakő, quarry and castle

Quarry: 47° 21' 31.91" N,18° 16' 44.98" E
Castle: 47° 21' 37.12" N,18° 16' 37.97" E

The Vértes Hills are limited by a major fault on their south-western side, called here as Mór Fault (Fig. 4). The curved, slightly segmented fault zone is expressed in the morphology as a steep slope of 100–250m height. The total displacement of the fault can reach 1000–1200m, taking into account borehole and seismic reflection data. The fault forms the NE boundary of the Mór graben (Fig. 2., 4). The fault has two closely spaced segments, which have different evolutions. The timing of slip events can be determined using combined data sets