GEOLOGICA CARPATHICA, OCTOBER 2007, 58, 5, 465–475

Miocene dextral transpression along the Csesznek Zone of the northern Bakony Mountains (Transdanubian Range, western Hungary)

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(Manuscript received June 5, 2006; accepted in revised form March 15, 2007)

Abstract: The authors performed geological mapping and microtectonic measurements around the Csesznek Zone in the northern Bakony Mts, Transdanubian Range, Hungary. As a result of structural observations a new structural-geological map was created for this area. Four tectonic phases were separated by the analysis of stress field. The oldest tectonic event detected in the research area was defined by a WNW–ESE compression and we attribute a Middle Eocene to the earliest Miocene (50–18 Ma) timing to this phase. On the basis of structural measurements and regional considerations we can tentatively separate two deformational events in the late Early to Middle Miocene (18–11 Ma) time span. The older "syn-rift phase" (18–14.5 Ma) is characterized by NE–SW tension and the younger phase is marked by NNW–SSE compression and perpendicular tension. This strike-slip-type stress field with transpressional character formed or reactivated the main dextral faults and associated overturned en echelon folds and thrusts in the Csesznek Zone. The latest, Late Miocene to Pliocene(?) extensional deformational phase (11–3? Ma) segmented the range with normal faults. The newly recognized transpressional character of the Csesznek Zone indicates that a short syn-rift event of the western Pannonian Basin was followed by widespread transpression, as it was also described in other parts of the Transdanubian Range. This transpression can be connected to basin inversion in the easternmost Alps, and important contractional deformation in the eastern Southern Alps, and northernmost Dinarides. The intensity of this transpression was declining to the NE, where the extensional deformation prevailed and was influenced by the subduction still going on along the Eastern Carpathian thrust front.

Key words: Miocene, Pannonian Basin, Transdanubian Range, strike-slip tectonics, transpression, stress field.

Introduction

The Bakony Mts occupies the central and southern part of the Transdanubian Range (TR), an elevated tectono-morphological ridge outstanding from the surrounding low hills and plains formed by Upper Miocene to Quaternary sediments (Fig. 1). The TR reveals unique information on the structural evolution of the western part of the Pannonian Basin and represents the connection between the Eastern Alps and Western Carpathians.

The TR is interpreted as the uppermost Cretaceous thrust sheet within the Alpine nappe pile (Fig. 1) based on seismic reflection profiles (Tari 1994, 1995), magnetotelluric soundings (Ádám et al. 1984; Horváth et al. 1987) and geochronological-tectonic studies of the outcropping footwall (Fodor et al. 2003). During the rifting of the Pannonian Basin System, the former thrust planes were reactivated as detachment faults, and the Transdanubian Range is situated in the hanging wall of a Miocene detachment fault system running down from the Kőszeg-Rechnitz Windows (Tari 1996). Related to this detachment faulting, the hanging wall was moderately dissected by normal faults. However, normal faulting was followed by 2 major structural events recognized by earlier studies (Mészáros 1983; Kiss et al. 2001); (1) late Middle Miocene dextral faults with strike-slip type stress field (with NNW–SSE compression); (2) and another relatively important Late Miocene tensional phase.

In our paper we present new paleostress data and structural observations from the northernmost edge of the Northern Bakony Mts from a deformation zone, which we will name as the Csesznek Zone (Fig. 1). Although the zone seems to be part of the systematic WNW striking dextral faults of the Transdanubian Range, it was not described up to the present. We demonstrate dextral faulting in a transpressional setting, which resulted in unusually strong folding of Paleogene rocks. Together with other faults, the Csesznek Zone marks a late Middle Miocene transpressional deformation, which was widespread in the western Pannonian Basin and also in the Eastern Alps and northernmost Dinarides.

Geological setting

The Castle Hill of Csesznek represents a WNW–ESE directed, elongated ridge bordered by significant faults (Figs. 2, 5A). This narrow structure is built up by the Upper Triassic Dachstein Limestone Formation and Eocene bioclastic-nummulitic limestone (Szőc Formation). The platform-type Dachstein Limestone Formation is the most frequent Mesozoic sedimentary rock in this part of the

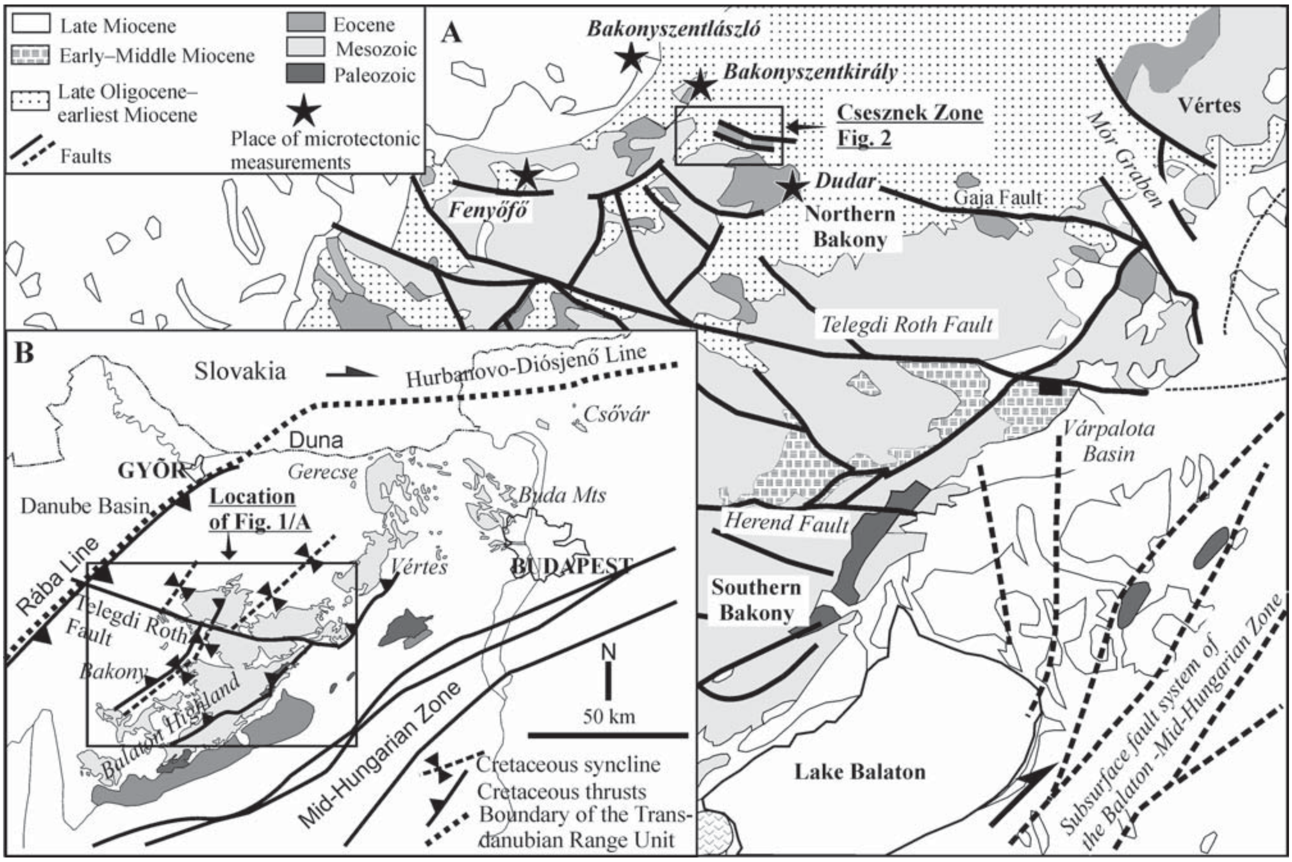

Fig. 1. Location of the studied area with the main structural element of the Transdanubian Range. Base map after Márton & Fodor (2003). Inset shows Permian-Mesozoic outcrops (light grey) and pre-Permian rocks (dark grey) and main Cretaceous structures.

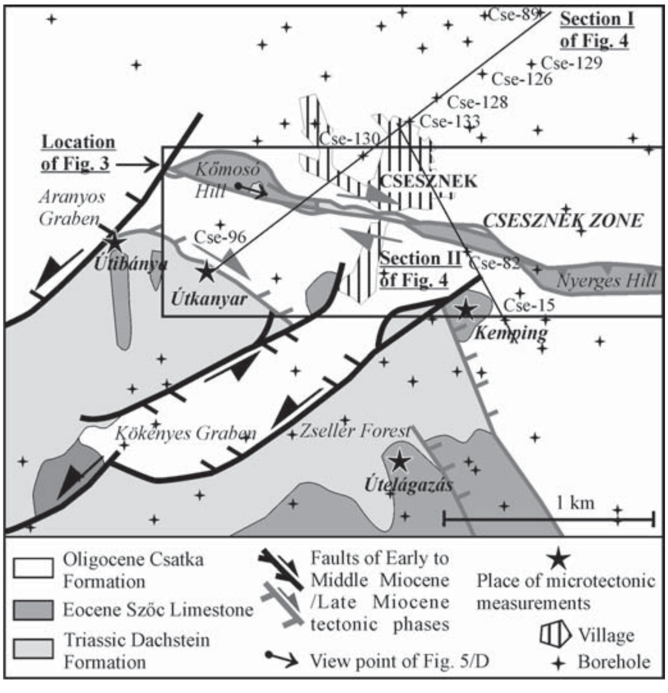

Fig. 2. Geological map of the Cseszenek Zone and surroundings (without Quaternary formations). Modified after Knauer et al. (1983) and Gyalog & Császár (1982).

Bakony Mts. We can also find the Dachstein Formation south of the Castle Hill in the Zsellér Forest (Fig. 2). Shallow water Middle Eocene nummulitic Szőc Limestone represents the overlying formation. The connection of the Dachstein and Szőc Formations is partly tectonic but locally sedimentary with angular unconformity. The surroundings of the Castle Hill (Fig. 2) are covered by the fluvial Upper Oligocene Csatka Formation, which contains siltstone, sandstone and conglomerate (Korpás 1981). The western continuation of the Cseszenek Zone is cut and obliterated by the NE–SW striking Aranyos Graben filled with the Csatka Formation (Fig. 2).

Methods

For the structural analysis, microtectonic data such as brittle faults, joints and stylolites were used (Ramsay & Huber 1987). Using striated fault planes, stress axes were defined with the software of Angelier (1984). In the case of multiphase faulting, faults were grouped in separate phases using the automatic separation software of Angelier & Manoussis (1980) and on simple kinematic assumptions following the model of Anderson (1951). After the paleostress tensor calculation, faulting events with similar paleostress axes were grouped into distinct tectonic phases.

We completed the microtectonic measurements with structural mapping of the area. In particular, we modified the fault pattern of earlier maps (Gyalog & Császár 1982). Outcrop-scale observations, the determined stress axes, apparent map displacements and cross-sections were used to determine the fault kinematics, which were not completed on earlier maps of the area of study (Gyalog & Császár 1982; Knauer et al. 1983).

Structural analysis

Phase 1

The first stress field is defined by a WNW–ESE compression, which can locally deviate up to E–W orientation (Fig. 3). Calculated σ_1 is horizontal, σ_3 is vertical or horizontal. NW-striking sinistral and W to WSW-striking dextral microfaults and reverse faults belong to this phase (see stereograms on Fig. 3).

We detected 7 microfaults belonging to this phase at the site Bakonyszentkirály (Fig. 3), where Triassic and Eocene limestones host reverse faults. Conjugate strike-slip faults are typical structures at the sites "Útibánya", "Dudar" (Márton & Fodor 2003), and "Fenyőfő" (Kiss & Fodor 2003) (Figs. 2 and 3). Near the Telegdi Roth Line, Sasvári et al. (2003, 2007) also observed sinistral slip along NW-trending faults.

The youngest deformed sediments belong to the Upper Oligocene Csatka Formation, thus the phase might have been active during most of the Early Miocene. A precise upper time constraint cannot be deduced from the research area, but projection from northern Hungary suggests pre-Ottnangian (pre-18 Ma) timing (Fodor et al. 1999; Márton & Fodor 2003). On the other hand, Eocene age of the stress field and related structures were proved in several parts of the Transdanubian Range. Syn-sedimentary structures were demonstrated in the Buda and Gerecse Hills (Fodor et al. 1992; Magyari 1994; Sztanó & Fodor 1997, respectively). In the Vértes Hills syn-sedimentary dykes and faults were perforated by Eocene molluscs and sponges (Kercsmár 1996, 2005) or were mineralized with syn-diagenetic iron coating (Mindszenty & Fodor 2002). The kinematics of these faults are similar to those observed near Csesznek, so we suggest Middle Eocene to earliest Miocene timing for phase 1.

Geological cross-sections (Fig. 4) can give a hint for an early deformation along the main fault zone. The thickness of the Eocene formations (between the top of the Triassic and the bottom of the Upper Oligocene) changes considerably on the two sides of the Csesznek Zone (e.g. between boreholes Cse-96, -15 and -130, -133 on Fig. 4). Further NE from the fault zone the Eocene thickness is constant, but a clear facies change occurs with a transition from a shallow marine to a shallow bathyal depositional environment from SSW to NNE (from the Szőc Limestone to Padrag Marl Formations). The explanation for this difference can be the following: 1) syn-sedimentary Eocene motion of an early Csesznek Zone inducing pronounced subsidence and facies change in the northern block, 2) latest Eocene to earliest Oligocene faulting of the formerly isopach Eocene rock body and subsequent Early Oligocene erosion of the southern block prior to Late Oligocene sedimentation, or 3) post-Oligocene large-scale dextral displacement, which juxtaposed two blocks with completely different Eocene sequences. Facies and thickness differences seem to prevail in a larger area (along the northern rim of the Bakony Mts) thus we suggest that the Eocene deformation and the two other solutions together can result in the present-day structural setting.

Phase 2

The next deformation is marked by NE–SW tension. Conjugate normal and oblique-normal faults represent the typical outcrop-scale structures (Fig. 3). These faults were observed at the "Útkanyar" and "Útelágazás" sites in Triassic and Eocene limestones, respectively (Fig. 3). It is possible that a dextral-normal fault of this phase bounds the southern block composed of Triassic and Eocene rocks (Fig. 2). Other similar structures in the surroundings can be attributed to this phase, like the important Mór Graben (Fig. 1, Budai et al. 2005).

The minimal stress axis of this phase is not very different from that of the next phase 3. The separation is based on the difference in style of deformation, and on regional considerations, coming from the entire Pannonian Basin. This latter suggests that NE–SW tension was characteristic of the rifting phase of the Pannonian Basin (Fodor et al. 1999), starting in the late Early Miocene (Ottnangian) and persisting up to early Middle Miocene (middle Badenian, from ~18 to ~14.5 Ma) (Fodor et al. 1999).

Phase 3

The third tensor group (Fig. 3) is defined by NW–SE to NNW–SSE compression and perpendicular tension. Calculated σ_1 is sub-horizontal, σ_3 is often sub-horizontal (strike-slip stress field) or vertical (compressional stress field).

Many slickensides show dextral and sinistral strike-slip kinematics, but gently dipping reverse or oblique-reverse faults also occur (Fig. 3). On a small-scale we can observe such reverse faults on the Castle Hill, e.g. gently dipping reverse microfaults at "Bozót" and "Kőmosó" outcrops (Fig. 3). These reverse faults were combined with strike-slip microfaults, so the fault pattern suggests transpressional deformation.

Map-scale structures of this phase are significant dextral faults (Fig. 3), which constitute the Csesznek Zone. The presented cross-sections seem to suggest that the origin of some of the faults may belong to phase 1, but the dominant kinematics, and the map-scale fault pattern of the Csesznek Zone were achieved during the transpressional deformation.

The contact of the dextral Csesznek Zone and the surrounding Oligocene Csatka Formation is tectonic. At

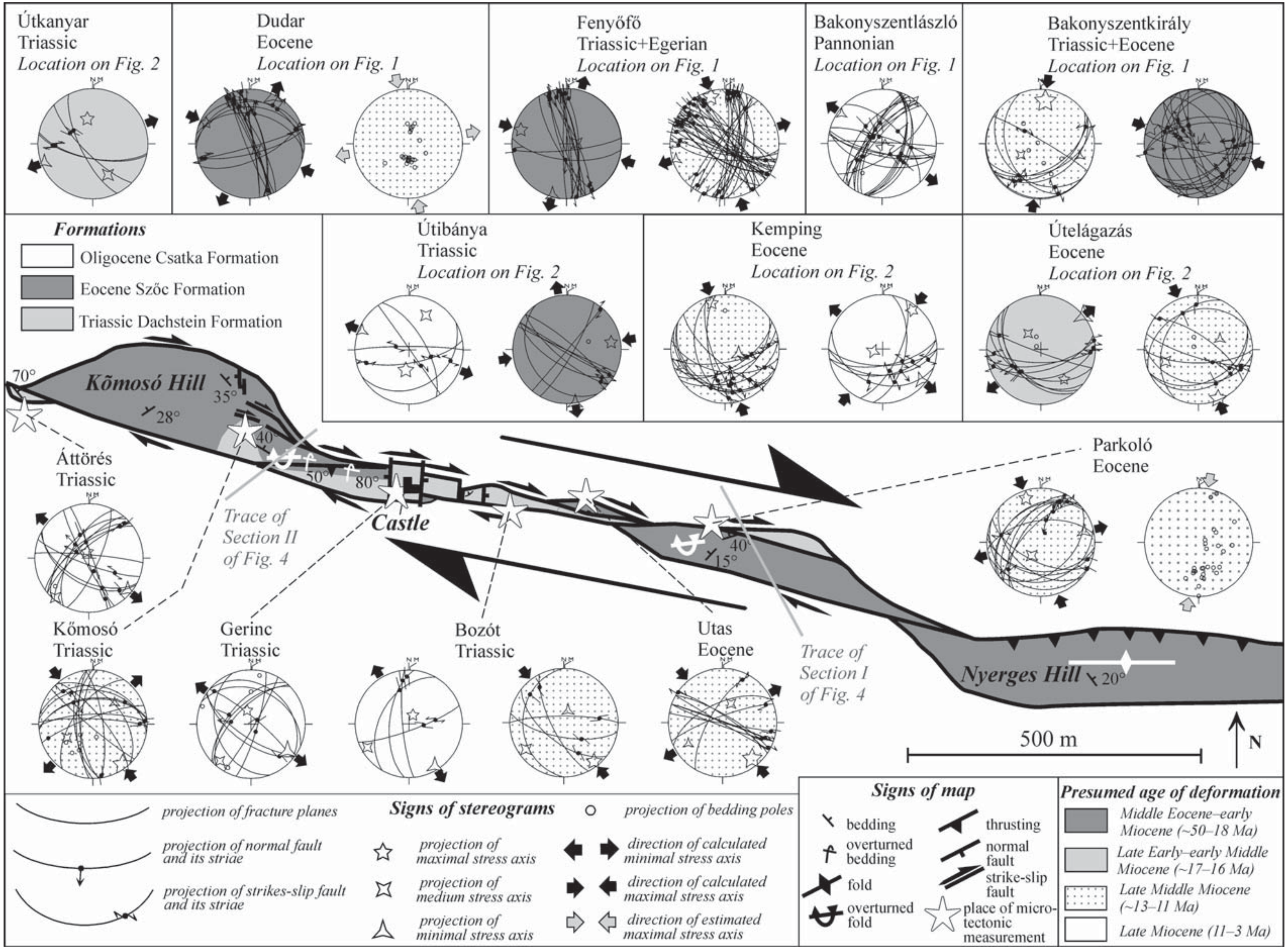

Fig. 3. Detailed geological map of the Csesznek Zone with locations of microtectonic measurements and the results of paleostress calculations (stereograms). Base map modified by Kiss & Fodor (2003) after Knauer et al. (1983) and Gyalog & Császár (1982).

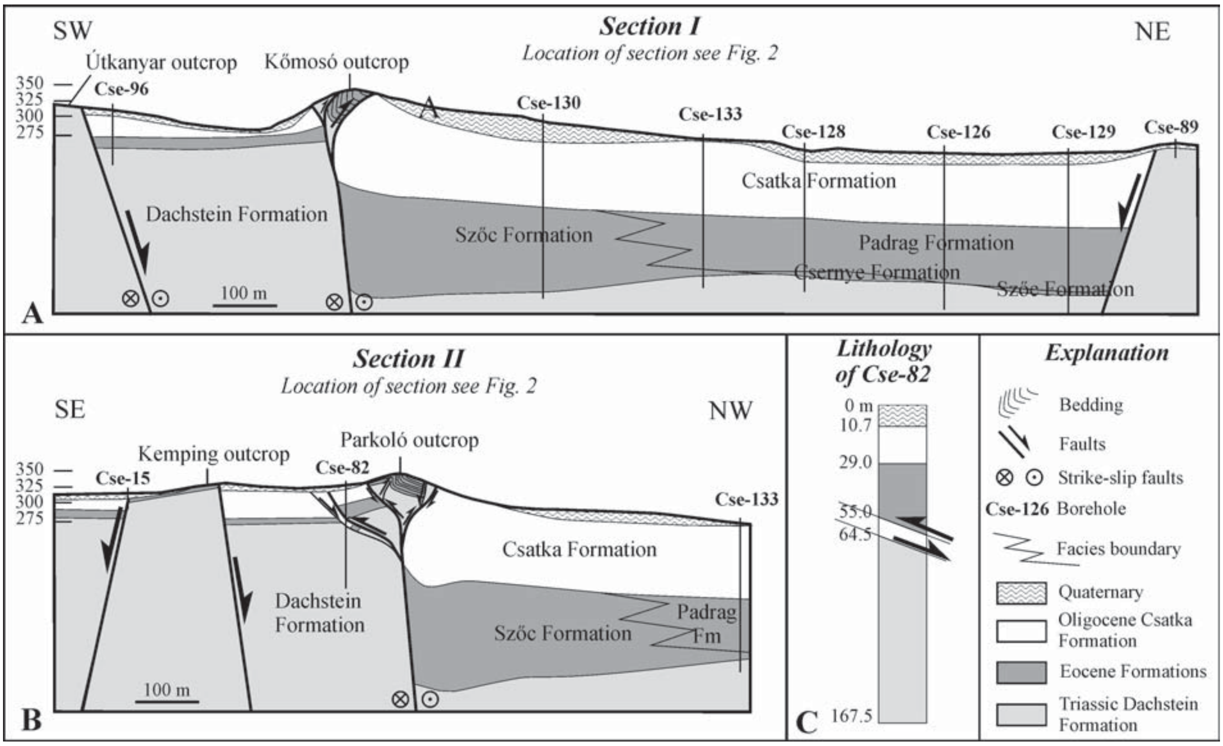

Fig. 4. Geological cross-sections throughout the Csesznek Zone. Note slightly changing geometry of the transpressional fault zone.

"Utas" outcrop we observed the strike-slip contact of the Oligocene, Triassic and Eocene blocks (Fig. 3). The main fault branch separates the Eocene and Oligocene formations with pinched Triassic rock slivers (Fig. 4).

We constructed two geological cross-sections based on well data around the Csesznek Zone (Figs. 2, 4). In the geological section (Fig. 4) the formation boundaries are clearly tectonic between the folded-overturned Eocene to Triassic units and the thick Oligocene formation. The most significant borehole (Cse-82) is found just SE of the folded Parkoló outcrop, near the southern boundary of the zone (Fig. 4). This well contains the repetition of Oligocene and Eocene layers (Knauer, pers. comm., 2003) indicating post-Oligocene compressional or transpressional strike-slip tectonics.

The uplifted Csesznek Zone might be expected to be dominated by folds and reverse faults, which initially developed at a high angle to the zone (Sanderson & Marchini 1984). These faults have a combination of reverse and strike-slip displacement. In fact, outcrop-scale faults often have oblique-reverse slip (Fig. 3, "Parkoló", "Bozót", "Kemping", "Útelágazás" sites). On the cross-sections, on either side of the blocks faults dip inward, producing wedge-shaped uplift (Fig. 4). In general these bounding faults will be steep, oblique-slip faults, but they may flatten upwards (Sanderson & Marchini 1984). They typically dip under uplifted blocks producing a positive flower structure.

The transpressional character is confirmed by overturned folds, which occur in the nummulitic Szőc Limestone west and east of the castle (Fig. 3); the eastern fold appeared on the earlier map (Gyalog & Császár 1982). To the east of the castle, near the road, the exposed fold has a sub-horizontal limb and a ~15 m high overturned limb with a sharp hinge zone (Fig. 5B). Slickenside lineations are typical on bedding planes of the steep to overturned limb. One *Nautilus* sp. from the Eocene limestone, situated at layer-parallel position, was also deformed by layer-parallel slip and bears striae on its sides (Fig. 5B). These observations point to flexural slip folding. The fold axis is trending E–W (Fig. 5B, stereogram), sub-parallel to the zone boundary. Eastward the fold may step to another fold, located on the Nyerges Hill (Fig. 3), which also trends E–W. The northern border of the continuation of the Castle Hill (the Nyerges Hill) can be an en echelon thrust belonging to the dextral-reverse fault system.

The other overturned fold is located at the western edge of the castle ridge, above the Kőmosó valley (Figs. 3, 5D). Bedding within the Eocene rocks near the creek dip 30–40° to the north and higher up bend to a sub-vertical to slightly overturned position (Figs. 4, 5C,D). The sub-vertical position of the strata can be verified by the presence of bedding-parallel nummulite tests and undulating bedding planes (Fig. 5C). The direction of the fold axis is WSW–ENE, being en echelon to the main dextral fault. Summarizing the observations we can say that the transpressional phase activated the long dextral faults bordering the castle ridge, and formed the WNW–ESE directed Csesznek Zone itself and the connecting en echelon structures.

This structural phase affected Eocene formation within the Csesznek Zone (outcrop "Utas", "Parkoló", "Kőmosó"). The imbricated Oligocene formation is affected by this

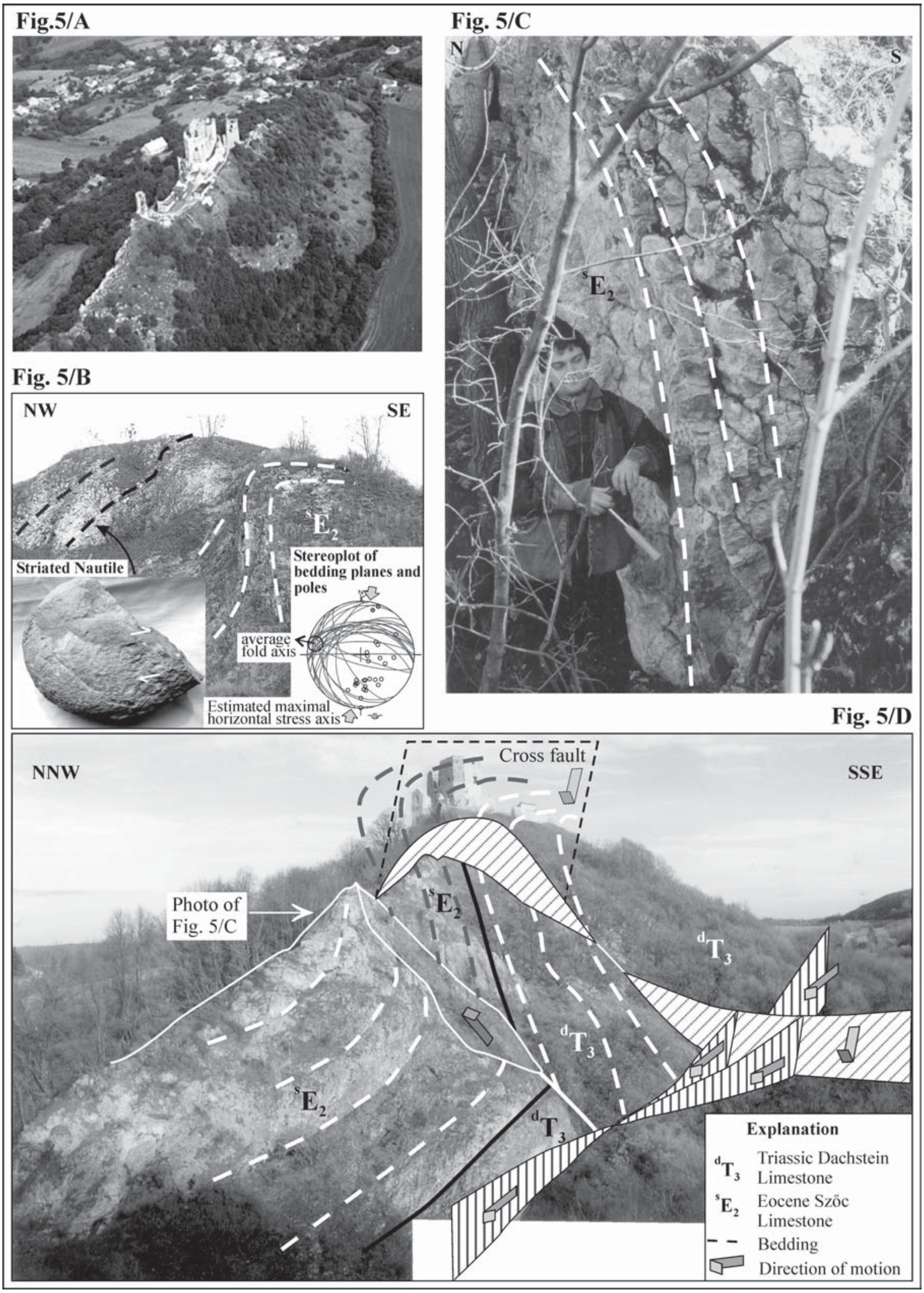

Fig. 5. Structural features of the Csesznek Zone. **A** — Panoramic view of the castle ridge, emphasizing the small width and relatively outstanding topography from surrounding areas. **B** — Asymmetric to slightly overturned anticline in the Eocene limestone strata in the eastern part of the Csesznek Ridge (Parkoló quarry). Note *Nautilus* sp. with striated sides, deformed by layer-parallel slip. **C** — Subvertical and slightly overturned Eocene limestone beds with wavy bedding planes. See Fig. 5D for location of picture. **D** — General view looking eastward to overturned beds between Kőmosó ravine and the castle.

deformation, which confirms the post-Oligocene timing of deformation (Cse-82 borehole, Figs. 2, 4).

Folding was also detected in the outcrop of Dudar by Taeger (1936), confirmed by our observation (location on Fig. 1, stereogram on Fig. 3). The youngest deformed rock in the surroundings of Csesznek was the Upper Oligocene Csatka Formation at Fenyőfő, ~10 km to the west from the Csesznek Zone (Kiss et al. 2001), where the geometry of conjugate strike-slip faults is very similar to that observed in the Csesznek Zone. More precise time constraint cannot be given from the northern Bakony Mts. On the other hand, similar structures of the central Bakony Mts (Telegdi Roth Line) indicate a mid-Miocene, more strictly Sarmatian age of deformation (Kókay 1976, 1996; Mészáros 1983).

Phase 4

The last stress field is well represented throughout the area. The phase is characterized by (W)NW–(E)SE tension. Meso-scale structures of this extension are conjugate normal faults and in some cases strike-slip faults.

Map-scale structures of this phase are N–S trending dextral-normal oblique faults, which cut through earlier dextral strike-slip faults of the Csesznek Zone itself (Fig. 3). Such a normal fault occurs west of the castle, and displaces sub-vertical to overturned Eocene and Triassic rocks (Fig. 5C,D). Within sub-vertical Eocene nummulitic limestone we observed a meter-wide tensional gap filled with clastic sediment (redeposited Oligocene?).

The extensional Aranyos and Kökényes Grabens are other map-scale structures, which are located west and south of the research area, respectively (Fig. 2, Kiss & Fodor 2003). The brittle structures of this phase can be identified at Bakonyszentlászló in lower Pannonian clay, so the age of this stress field can be late Pannonian or younger, Pliocene or even Quaternary. The age and the directions of the stress axes are similar to the latest Sarmatian–Pannonian tectonic phase described from the Porva Basin (Kiss 1999). The phase may correlate with a significant extensional event (post-rift event) in the latest Tertiary.

Discussion

Description of phases and connection with vertical-axis rotations

The oldest tectonic event (phase 1) represents a strike-slip type deformation, which might have changed temporally or spatially from transtension to transpression or even pure compression (Fig. 6). The deformation pattern and the stress field are similar to a number of observations derived from

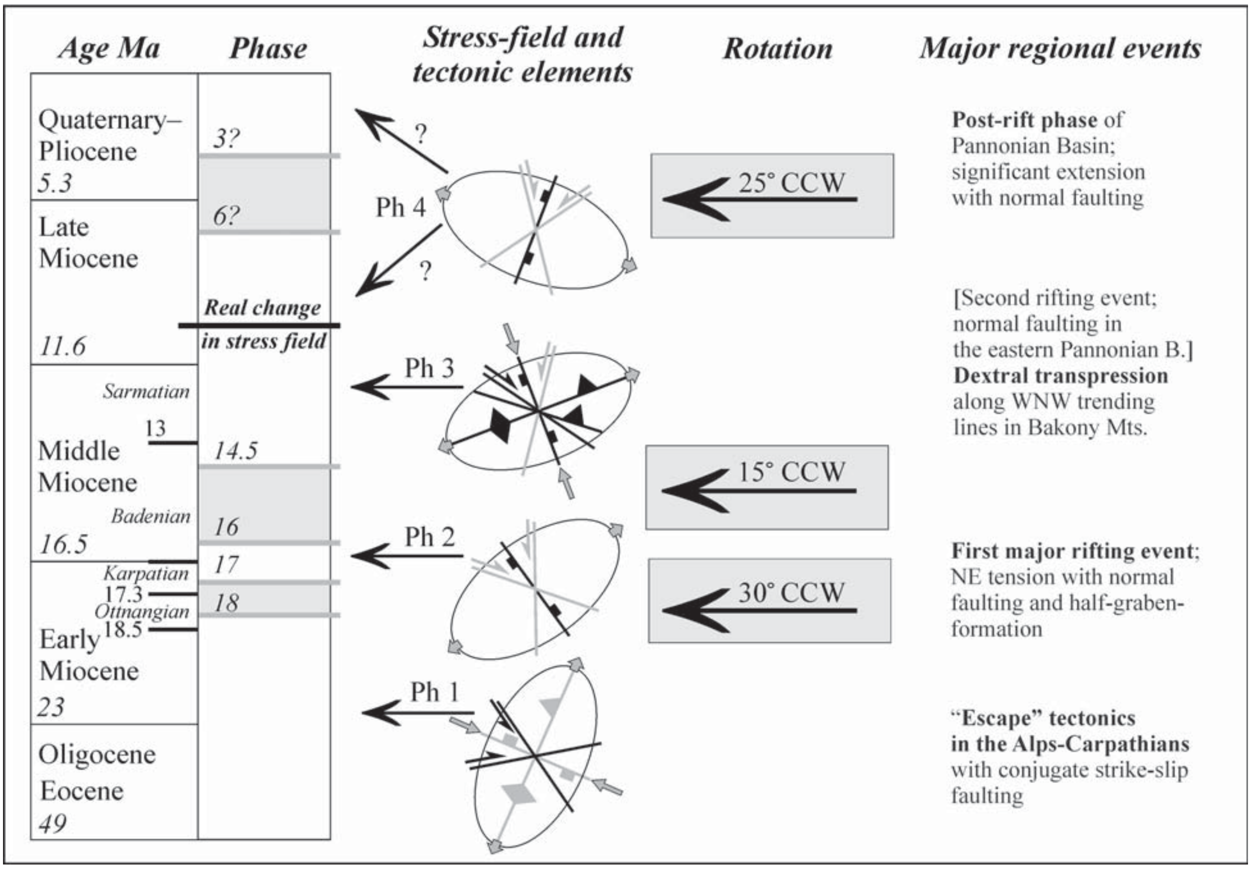

Fig. 6. Correlation of stress field, rotations and major tectonic events in the Bakony Mts the simplified pattern of significant tectonic elements are drawn in black colour; less significant elements are grey.

the central and northern Transdanubian Range (discussed in an earlier chapter). Along the Telegdi Roth Line Sasvári et al. (2003, 2007) measured pre-Ottnangian strike-slip faults. Their phases "2" and "3" could correspond to our "phase 1". In the Csesznek area, we have few data to separate two distinct phases.

The stress field might have induced an early phase of slip of Eocene age along the nascent Csesznek Zone. The modest faulting could induce differential subsidence between the southern and northern fault blocks and indirectly control the facies distribution in the Eocene basin. We may assume normal or oblique-normal kinematics along the incipient Csesznek Zone, which was sub-parallel to the WNW–ESE trending maximal horizontal stress axis (σ_1 or σ_2). On the other hand, the bulk of the strike-slip faults could be connected to the "escape/extrusion tectonics" of the Transdanubian Range and the whole Alcapa (Alpine-Carpathian-Pannonian) block (Csontos et al. 1991; Fodor et al. 1999; Sasvári et al. 2003).

The first brittle phase of faulting was followed by a counterclockwise rotation of approximately 30°. Although the time constraints are not very good in the Csesznek area, we suggest that the change from phase 1 to phase 2 could correspond to the first rotation event of Márton & Márton (1996) and Márton & Fodor (1995, 2003), having occurred between 18 and 17 Ma (Fig. 6).

The next deformation events (phases 2 and 3) took place in the late Early to Middle Miocene (Ottnangian to Sarmatian, 18–11 Ma), which traditionally corresponds to the rifting event of the Pannonian Basin. On the basis of the structural geometry and style of deformation we can tentatively separate two tectonic phases within this deformation. The older (phase 2) is characterized by NE–SW tension and represents the early syn-rift phase of the Pannonian Basin. The fault pattern was mainly marked by normal faults, but strike-slip faults with normal component of slip could also appear. This phase was not clearly recognized in the work of Kiss et al. (2001) but demonstrated in more recent publications (Kiss & Fodor 2003; Márton & Fodor 2003; Sasvári et al. 2003, "phase 4" of Sasvári et al. 2007).

The most significant deformation phase 3 is marked by NNW–SSE compression and perpendicular tension. This strike-slip type stress field with transpressional character formed the main dextral faults and associated overturned en echelon folds and thrusts. Detailed discussion of this deformation within and around the Transdanubian Range will be given in the next chapter. This deformation can be detected in other areas of the Transdanubian Range, as far north as the Vértes Hills (Kiss et al. 2001; Márton & Fodor 2003). It is interesting to note that Sasvári et al. (2003, 2007) did not really identify this stress field, their phases "4" and "5" are slightly different from our calculations. This difference can be attributed to varying outcrop conditions and/or different grouping of strike-slip faults.

Comparing the maximal horizontal stress axis of phases 2 and 3 a slight change of 15–20° in a clockwise direction can be detected (Fig. 6). This change in orientation can be correlated with the second rotation event of the Pannonian Basin, indicated by Márton & Márton (1996) and Márton & Fodor (1995). Following the compilation of Márton & Fodor (2003) the second rotation was about 15° in the Bakony Mts and occurred in the middle Badenian, around 16–14.5 Ma. A similar (apparent) clockwise change in stress direction can be deduced from the dextral faults of the TR; Mészáros (1983) and Tari (1991) indicated a relative chronology between older WNW and younger NW-striking dextral faults. All these data are in agreement with our data, namely the amount of rotation and its time span correspond well with the angular difference and the timing of phases 2 and 3.

The latest, Late Miocene extensional deformational stage (phase 4) segmented the Csesznek Ridge with normal faults. This phase corresponded to a noticeable "post-rift" deformation registered in the northern Bakony by Kiss et al. (2001) and along the Telegdi Roth Line by Sasvári et al. (2007, their phases "5 and/or 6"). Márton & Fodor (2003) indicated a young 25° CCW rotation in the Late Miocene or Pliocene. This rotation might have contributed to the change in stress field from phase 3 to 4 (Fig. 6). However, our data are not enough to decide about the structural role and timing of this rotation.

Analogue transpressional structures in the Transdanubian Range

Though a few structural elements were already drawn on maps (Knauer et al. 1983), the recognition of the transpressional deformation along the Csesznek Zone is a novelty. The characteristic feature of the zone is that the amount of contraction seems to be larger than along similar zones; the deformation resulted in overturned beds, development of folds and reverse faults.

The Csesznek Zone can be compared to similarly oriented dextral faults, which regularly cross-cut the central and southern Bakony Mts, some of them with a transpressional character. The Csesznek Zone itself may continue in the Gaja fault of the eastern Bakony Mts. However, the exact identity has not been established yet (Fig. 7). Closest to Csesznek, the NW–SE striking faults of the Porva Basin could have a normal-dextral displacement rather than a transpressional character (Kiss et al. 2001); this kinematic change can easily be explained by the difference in strike (Fig. 7).

Along the WNW-striking Telegdi Roth Fault (Figs. 1, 7), Mesozoic rocks were thrust over Middle Miocene strata (Balla & Dudko 1989; Csontos et al. 1991; Kókay 1996). Deformation generally affected Middle Miocene formations, but Upper Miocene rocks are not deformed. Kókay (1976) and Mészáros (1983) suggested that the main activity of the Telegdi Roth Fault was late Middle Miocene (Sarmatian) in the best-studied Várpalota Basin (Figs. 1, 7) although minor activity is probable through Ottnangian–Karpatian and Badenian sedimentation.

The Herend fault of the central Bakony Mts (Fig. 7) shows dextral kinematics, based on displaced markers and fault-slip data (Kókay 1966; Tari 1991; Fodor et al. 1999). It is related to early Badenian and Sarmatian basin subsid-

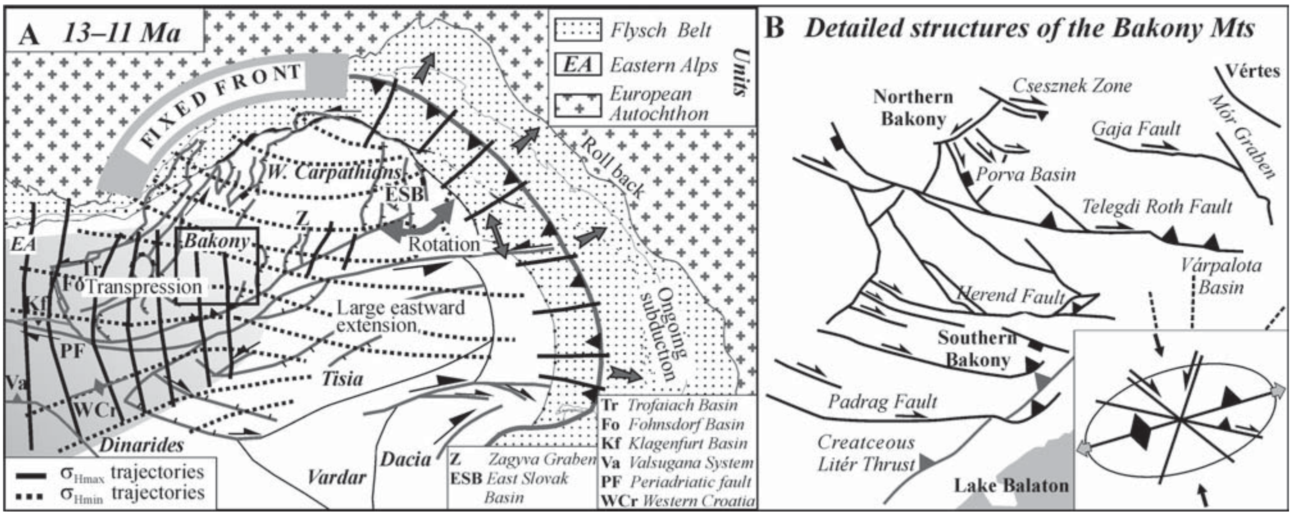

Fig. 7. Simplified structural framework of the Alpine-Carpathian region (modified after Fodor et al. 1999) showing the spatial extent of late Middle Miocene transpression. Frame indicates location of Fig. 7B with detailed sketch of transpressional structures of the Bakony Mts.

ence (in the west and in the east, respectively). The fault interacts with and partly reactivates Cretaceous thrusts in its eastern termination (Tari 1991).

In the southern Bakony Mts the Padrag fault (Fig. 7) has ~1.5–2 km separation, measured by the displaced Eocene sequence (Mészáros 1983). The fault also dismembers the Litér thrust by the same amount (Dudko in Budai et al. 1999). The displacement was accommodated by thrusting in the Balaton Highland (Mészáros 1983; Tari 1991; Budai et al. 1999; Fodor et al. 2005) showing the connection of contractional and strike-slip deformation. Reverse faulting or the combination of reverse and strike-slip faulting can be postulated south of Lake Balaton, where Balla et al. (1987) and Csontos et al. (2005) documented contractional structural elements on seismic reflection profiles (Fig. 7).

NE of the Bakony Mts, in the Vértes Hills this phase is represented only by outcrop-scale faults. Márton & Fodor (2003) described syn-rift normal faults, which are cut by reverse faults presumably belonging to this post-rift transpressional phase. This observation may imply that the intensity of the transpressional deformation decreases north–eastward, and no sign was documented northward, in the Gerecse and Buda Hills. In these areas only normal and oblique-normal faults of the syn-rift and/or post-rift phases appear, without interruption by strike-slip faulting (Fodor et al. 1999).

Alpine analogous structures

Traces of the Middle Miocene transpressional event occur west of the Bakony Mts, in the Eastern Alps. The south-western basin-margin of the pull-apart Fohnsdorf Basin (Fig. 7) is connected to the transpressional dextral Pols-Lavanttal fault system (Sachsenhofer et al. 2000). N-S compression resulted in the deformation of basin fill, uplift of the E–W trending basement ridge. The age of the deformation post-dates the middle Badenian, but cannot be determined more precisely (Sachsenhofer et al. 2000).

The formation of the pull-apart Trofaiach Basin (Fig. 7) in the Eastern Alps is related to the E–W trending Trofaiach strike-slip fault connected to the wrench corridor formation during the Miocene lateral extrusion of the Eastern Alps (Gruber et al. 2004). Later uplift of the basement rocks and tilting of the oldest basin fill are related to post-middle Badenian compression (Gruber et al. 2004).

Further to the south, important dextral slip can be documented along the Periadriatic fault system (PF). The NW–SE striking dextral tear faults and NW- to NNW-directed thrust planes of the Klagenfurt Basin (Fig. 7) affected the Middle Miocene (Sarmatian) sediments (Laubscher 1983). The basin subsidence was supposedly initiated by the distributed dextral strike-slip and thrust displacement along the northern Karawanken front (Nemes et al. 1997). The final NNW-directed thrust of the Karawanken Mts onto their forelands is characterized by a positive flower structure, which is kinematically linked to dextral transpressive shearing along the Periadriatic fault (Polinski & Eisbacher 1992). Pre-Pliocene dextral transpression is also present along the Slovenian segment of the PF, and can be separated from younger neotectonic deformation (Fodor et al. 1998). Further to the east, Tomljenović & Csontos (2001) demonstrated Sarmatian transpression in western Croatia (WCr, Fig. 7).

The eastern Southern Alps originated as a result of polyphase compressional deformation of late Tertiary age. The ENE–WSW striking Valsugana structural system (Va on Fig. 7) is Serravallian to Tortonian in age (Doglioni 1987; Castellarin & Cantelli 2000). The intense activity of this compressional event is documented both by stratigraphic and structural data which indicate some 4 km uplift in the hanging wall of the Valsugana thrust between 12 and 8 Ma. The deformation can be in part younger.

This short summary indicates that an important shortening phase occurred in the eastern Southern Alps–north-western Dinarides and in the easternmost Alps. Time constraints vary from place to place, but generally can be bracketed in the late Middle Miocene to earliest Late Miocene, between 14 and 10 or 8 Ma, although younger reactivation also occurred in some areas. Thrusting was often associated with dextral strike-slip faults. The transpressional deformation of the Bakony Mts and the Csesznek Zone can be connected to this widespread event. The intensity of this transpressional deformation seems to decrease north-eastward within the Transdanubian Range.

The recognition of this transpressional-strike-slip phase in the TR may have implications for the whole geodynamical framework of the Pannonian Basin. The late Early Miocene to Middle Miocene widespread rifting event of the Pannonian Basin is generally marked by normal faults, although locally strike-slip faults are also present, particularly in the TR. We demonstrated that this tensional (locally transtensional) event was followed by a transpressional deformation in the southern and central TR. This late Middle Miocene event seems to be coeval with renewed rifting in the eastern Pannonian Basin. Thick sedimentary, volcano-sedimentary layers were deposited, among others, in the Zagyva Graben and East Slovak Basin (Kováč et al. 1995). In this latter basin faulting was combined with differential rotation (Márton et al. 2000), which also enhanced faulting. The accelerated subsidence can be connected to the subduction below the Eastern Carpathians, which was still active in this time span (Maţenco 1997). While the East Carpathian subduction front was relatively short, the connected back-arc extension was restricted to the neighbouring eastern Pannonian Basin (Fig. 7). This also means that the short subduction front could not bring enough suction force to the western Pannonian and Eastern Alpine areas, which could not "escape" from the renewed push derived from the north-moving Adriatic plate (Fig. 7). Thus the syn-rift extension ended here by the late Middle Miocene and was replaced by compressional or transpressional deformation. This type of deformation prevailed up to recent times in the Southern Alps and in the Eastern Alps, but changed again to extension in the western Pannonian Basin (including the TR), where considerable normal faulting reoccurred again in the early Late Miocene.

Conclusions

Microtectonic data, field observations and well data demonstrate significant transpressional deformation along the Csesznek Zone, Bakony Mts, western Hungary. For the observed NNW–SSE compression we favour late Middle Miocene timing (~13–11 Ma). The Csesznek Zone is similar to other dextral transpressional faults of the Transdanubian Range (e.g. Telegdi Roth Line), although it might have accommodated larger contraction. Comparison to other Alpine transpressional elements suggests that this deformation was widespread in the easternmost Alps, Southern Alps, north-western Dinarides and also in the western Pannonian Basin, while the subduction and connecting tension were still active further to the east. The difference in deformation style can be explained by two boundary conditions: the renewed northward push of the Adriatic microplate, and the shorter subduction front in the Eastern Carpathians. The first effect induced important ~N–S shortening in the Southern and Eastern Alps and western Pannonian Basin, while the second could not provide enough driving force to eastward lateral shift and extension of the whole Pannonian Basin. In consequence, syn-rift extension ended earlier, in the late Middle Miocene in the western Pannonian Basin.

Acknowledgments: L. Fodor benefited from the Bolyai János scholarship of the Hungarian Academy of Sciences. The research was supported of the Hungarian Scientific Research Found OTKA No. 42799.

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