LATE NEOGENE TRANSPRESSION IN THE NORTHERN THRUST ZONE, MECSEK MTS., HUNGARY

by

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Abstract

The compressional features in the Northern Thrust Zone of the Mecsek Mts. have been explained previously by successive dip-slip tectonic phases. I argue that these features can be best understood in terms of transpressional tectonics. The geological cross-sections of the study area are based on raw material exploration data and indicate an E-W striking positive flower structure. The complexity of the system can be due to zones of weakness in the basement, inherited from previous phases of tectonic evolution.

To the south of the Northern Thrust Zone an elongated and narrow trough formed during the Neogene. Here the thickness of the continental fluvial/alluvial, lacustrine and marine sedimentary succession exceeds 1000 m. I propose a model of strike-slip furrow basin for this markedly deformed and asymmetric trough. Gravity deposits, synsedimentary folds are related to episodic displacements on the main left-lateral strike-slip fault. As a consequence of wrenching, the footwall block uplifted and it was the main source of clastic influx for the adjacent basin, although longitudinal drainage also played an important role in sedimentary evolution.

Introduction

The Mecsek region is an elevated Upper Paleozoic-Mesozoic block in the southwestern part of the Pannonian Basin, which is outcropping from the Miocene to Quaternary basin fill. Its northern margin is made up by the Northern Thrust Zone (NTZ), which is a Mesozoic horst covering an area of about 15 km by 5 km with an elongation of E-W strike (insets of *Fig. 1*). It is considered the structurally most complex region of the Mecsek Mts. (WEIN, 1965). This complexity originated from superposition of different tectonic phases, and the younger deformations are influenced by the older lines of weakness.

The two-stage Austrian orogenic phase affected the Mecsek Mts. in the Cretaceous (VADÁSZ, 1935, WEIN, 1964, 1965, 1966, NÉMEDI VARGA, 1983). It deformed the Mesozoic strata into large amplitude, NW-vergent asymmetric folds and produced NW-directed thrusts. There was, however, a period of Cretaceous extension characterized by phonolite intrusions and normal faults perpendicular to the strike of the fold-belt (NÉMEDI VARGA, 1983).

Due to the large stratigraphic hiatus between the Upper Cretaceous and the Lower Miocene series there are only indirect evidences for a Paleogene(?) tectonic phase. Deformation due to a WNW-directed compressional stress field can be observed at different Mesozoic sites in the Mecsek Mts. and no trace of it could be found in Miocene rocks (BERGERAT and CSONTOS, 1989). The deformation is characterized by E-W striking right-lateral and NW-SW to N-S striking left-lateral faults.

The most important tectonic phase in the structural evolution of the NTZ took place in the Neogene (WEIN, 1964, 1965, 1966, MAUL, 1971, NÉMEDI VARGA, 1973, 1983, BERGERAT and CSONTOS, 1989). The development of the whole Pannonian region during this time interval was dominated by extensional normal faults and related transcurrent faults (HORVÁTH and ROYDEN, 1981, ROYDEN et al. 1983, HORVÁTH et al. 1987). Faulting culminated during the Middle and Late Miocene, but locally minor activity continued during the Pliocene. RUMPLER and HORVÁTH (1988) show that late Miocene through Pliocene compressional structures can also be found in the Pannonian Basin, and they are probably related to discontinuous and/or convergent strike-slip faults.

The purpose of this paper is to demonstrate transpressional structural development during the Neogene in the NTZ and to examine the tectonic control on sedimentation in this area.

Stratigraphy of the Northern Thrust Zone

The pre-Tertiary basement of the study area is composed of Mesozoic rocks. For a detailed description of the Triassic and Jurassic carbonates and Lower Cretaceous mafics, the reader is referred to WEIN (1965). To understand the Late Cenozoic evolution of the NTZ it is important to briefly summarize the stratigraphy of the Neogene series. The systematic investigation of these deposits in the eastern Mecsek was carried out by HÁMOR (1971). Based on his monograph a simplified synthetic stratigraphic column has been constructed for the NTZ. *(Fig. 2)*. HÁMOR (1971) suggested three major sedimentary cycles in the Miocene:

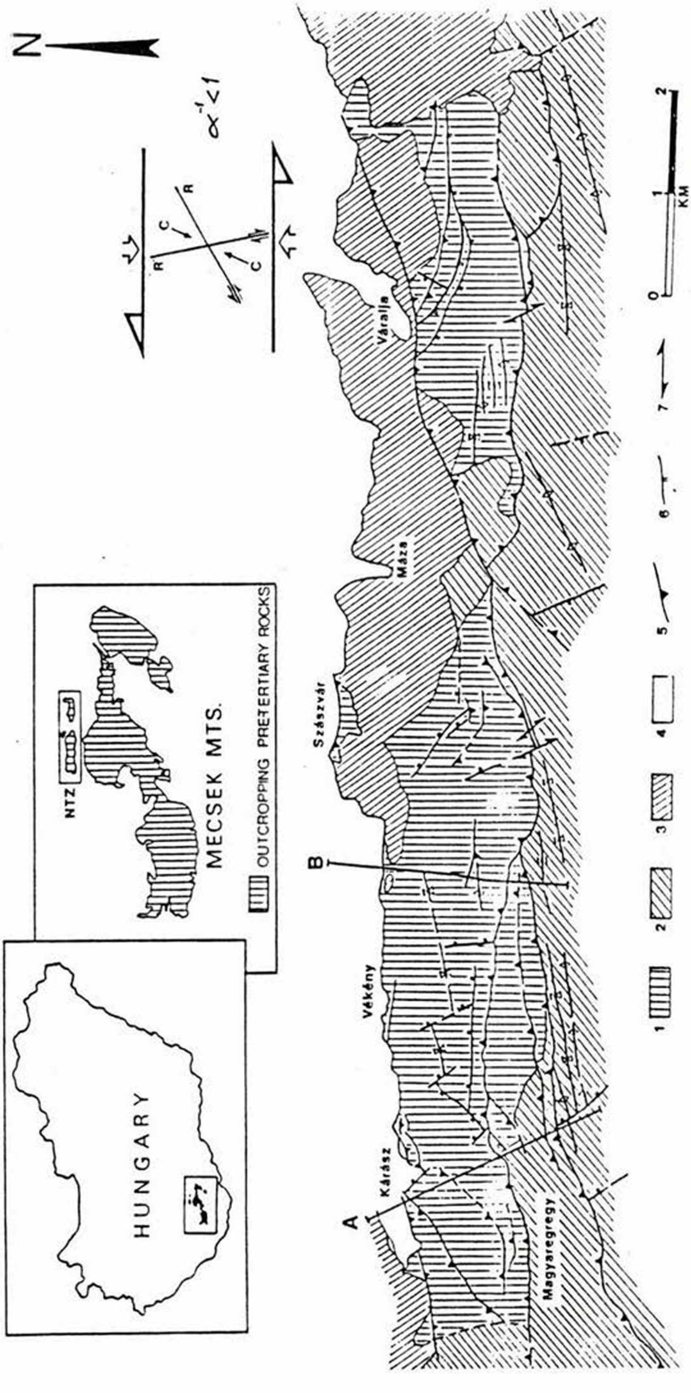

Fig. 1. Simplified geologic map of the Northern Thrust Zone. Insets show location of map. Diagram shows the orientation pattern of faults during sinistral simple shear under transpression (from SANDERSON and MARCHINI, 1984). C, compression axis, R,R', RIEDEL shears or strike-slip fault, 1, Mesozoic, 2, Miocene, 3, Pliocene, 4, Quaternary, 5, thrust, 6, normal fault, 7, wrench fault.

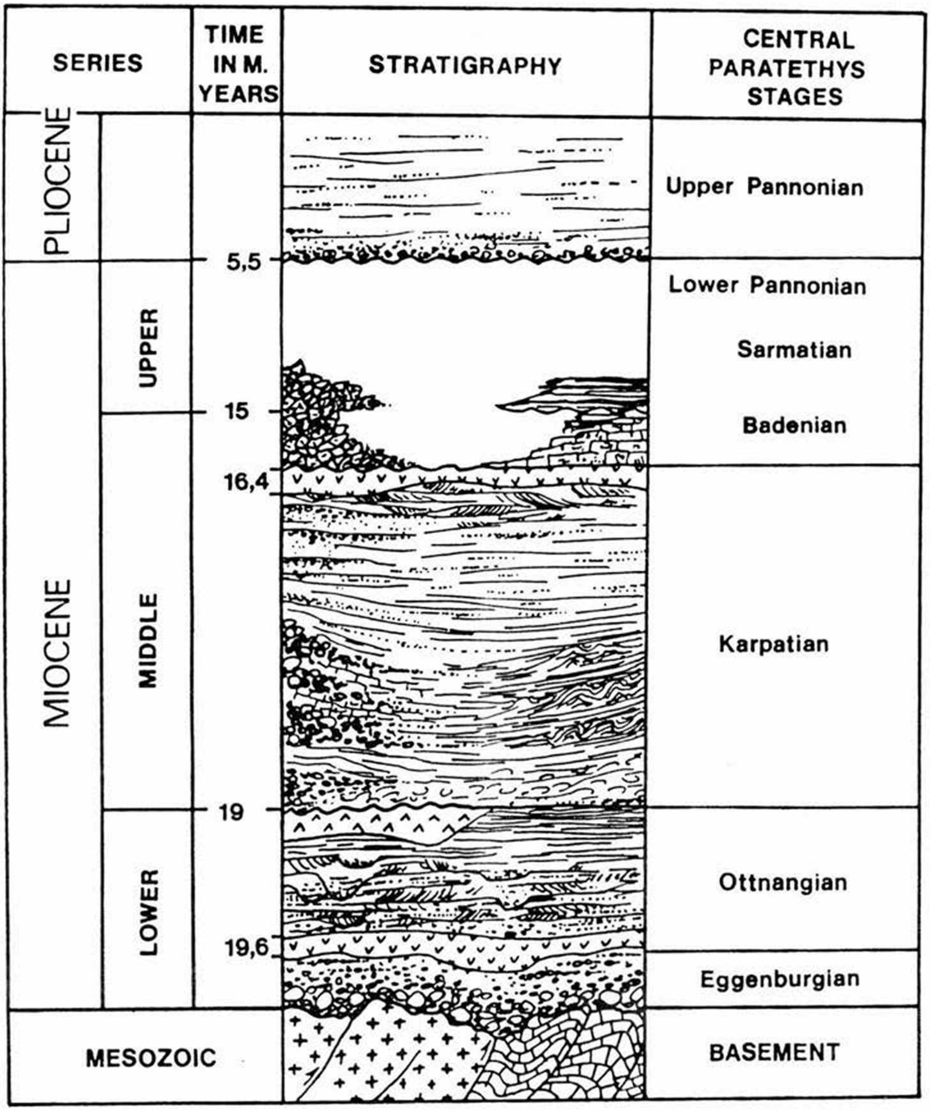

Fig. 2. Simplified synthetic stratigraphic column for the Neogene series of the Northern Thrust Zone (modified after HÁMBOR 1971, geochronology from HÁMOR et al. (1987)). For correlation between Central Paratethys and Mediterranean Neogene stages the reader is referred to STEININGER et al. (1988.)

First sedimentary cycle (Lower Miocene, from about 23 to 19 Ma). Sedimentation began by terrestrial debris. Grain-size distributions indicate fluvial transport from the S-SE. The thickness relations of this sandstone succession (Szászvár Formation) delineate an E-W striking basin characterized by lateral-transport directions. The pebble and cobble material in these deposits consists of Mesozoic carbonates and Paleozoic granite. The volcanic activity (Gyulakeszi Rhyolite Tuff) largely contributed to the filling of this basin. Intrabasinal redeposition of the volcanic material is quite common. The decreasing gradient of the paleomorphology is reflected on the overall fining-upward sedimentation. At the end of the sedimentary cycle continental lakes formed most probably with interior drainage. The typical sediments are laminated mudstones with sandy intercalations. Occasionally thin coal seams can be found.

Second sedimentary cycle (Middle Miocene, from about 19 to 15 Ma). At the beginning of this cycle marine transgression occurred and the elongate basin formed a narrow seaway in the southern foreland of the NTZ. The northern shoreline of this strait had a cliffed morphology, with alluvial fans derived from the exposed Lower Cretaceous basalt upland. The southern shore was characterized by low-gradient coastal plain made up of polymict sand, partly reworked from the older Miocene strata. Thickness data indicate an asymmetric graben with different depositional environments. In the area of maximum subsidence located to the North from the axis of the basin the estimated depth of the sea was in the order of hundred meters. In marginal position lagoonal deposition took place. In these local, restricted depressions laminated mudstones formed, probably recording seasonal variations. Slumps are very frequent in this strata. Marked faunal changes are thought to be resulted from transgressional episodes during this sedimentary cycle. The volcanic activity (Tar Dacite Tuff) was related to the tectonic processes and influenced the sedimentation. At the end of this sedimentary cycle regression occured. Marine silts (Tekeres Schlier) are overlain by shallow-marine sandstones. It is important to note that some coarsening-upward cycles can be found in the sandstone succession. The continuing regression caused by tectonic uplift has resulted in emergence of the central part of the basin above the sea level.

Third sedimentary cycle (Upper Miocene, from about 15 to 5,5 Ma). The transgression at the beginning of this cycle did not reach the uplifted central terrain. However, in the western end of the area (Magyaregregy) cliffed seashore formed, and abrasion produced clasts attaining several m in diameter indicating a very rough paleomorphology. Ore-bearing granite cobbles of unknown origin can be found also in the conglomerate. In the eastern end of the study area (Hidas) coal seams formed at the same time. This strata recorded vertical oscillatory movements of the sea level, probably caused by local tectonic activity.

The Pliocene series are represented by transgressive basal conglomerate, fine-grained sand, marl and sandy clay and they flank the northern margin of the NTZ (KLEB, 1973). A foredeep with E-W strike formed during this time. The depth of it exceeds 600 m (WEIN, 1965).

Structure of the Northern Thrust Zone and previous concepts about its formation.

Fig. 1 shows a simplified tectonic map of the NTZ after WEIN (1965). His surface mapping was carried out in 1:5000 scale and he took into consideration all the subsurface data which was available from the intensive coal mining and raw material exploration in the area. Two geological cross-sections presented in *Fig. 3/a* and *Fig. 4/a* are redrawn after WEIN (1965). These sections clearly demosntrate the structural complexity of the NTZ.

WEIN (1964, 1966) proposed a model of successive north and south directed dip-slip tectonic phases to explain the structural development of the region *(Fig. 5)*. In his model the formation of the narrow, deep Miocene graben was due to regional N–S extension *(Fig. 5/A)*. This asymmetric and elongate trough was superimposed on the Mesozoic basement. In the Upper Miocene the thick sedimentary infill of the graben was folded and overthrust by Mesozoic rocks during the Attican orogenic phase *(Fig. 5/B)*. According to WEIN (1964) this compressional episode generated all the S-vergent thrusts in the NTZ and thus formed an asymmetric "wedge structure". Thrust planes are usually very steep, even overturned locally (see *Fig. 4*).

After the Attican phase, during the uppermost Miocene and Pliocene, another extensional basin formed to the North of the NTZ *(Fig. 5/C)*. At the end of the Pliocene (Rhodanian compressional phase) the Mesozoic of the NTZ was thrust onto this throught *(Fig. 5/D)*. It is proven by drillhole data (WEIN, 1965). The magnitude of the overthrust exceeds 1 km along a low-angle, S-dipping fault plane. All of these led to the development of a symmetric "wedge structure". WEIN (1965) thought all the N-vergent Neogene thrusts as a result of the Rhodanian tectonic stage and considered them rejuvenated Cretaceous faults.

In contrast, HÁMOR (1971, p. 332) concluded that there was no evidence for structures originated during the Attican phase in the region. In his model terrestrial deposition began along NE-trending normal faults during the Savian orogenic cycle in the Early Miocene. Later, in the Middle Miocene two-stage Styrian phase created dominantly NW striking faults. HÁMOR (1971) similarly to WEIN (1964, 1965) considered the Pliocene Rhodanian phase as the most important period in the Neogene structural evolution of the NTZ. However, in contrast to WEIN (1964), he postulated that the S-vergent and N-vergent compressional structures formed contemporaneously during the Rhodanian phase. Finally, during the Quaternary the whole area suffered an uplift of some hundred meters.

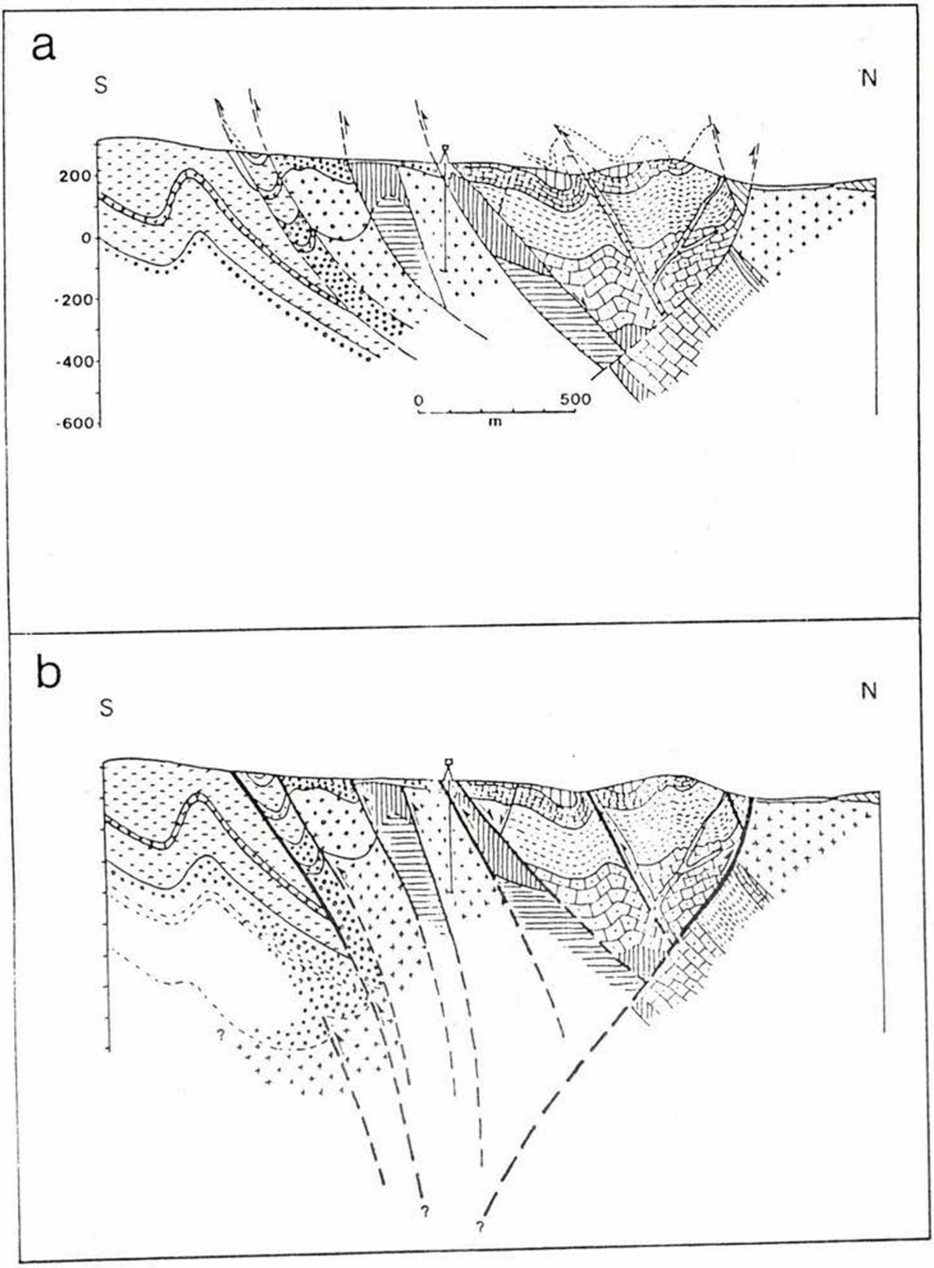

Fig. 3. (a) Geological cross-section A across Northern Thrust zone (from WEIN, 1965). See Fig. 1 for location of profile.

(b) Interpreted version of cross-section A indicating a positive flower structure (HARDING, 1985).

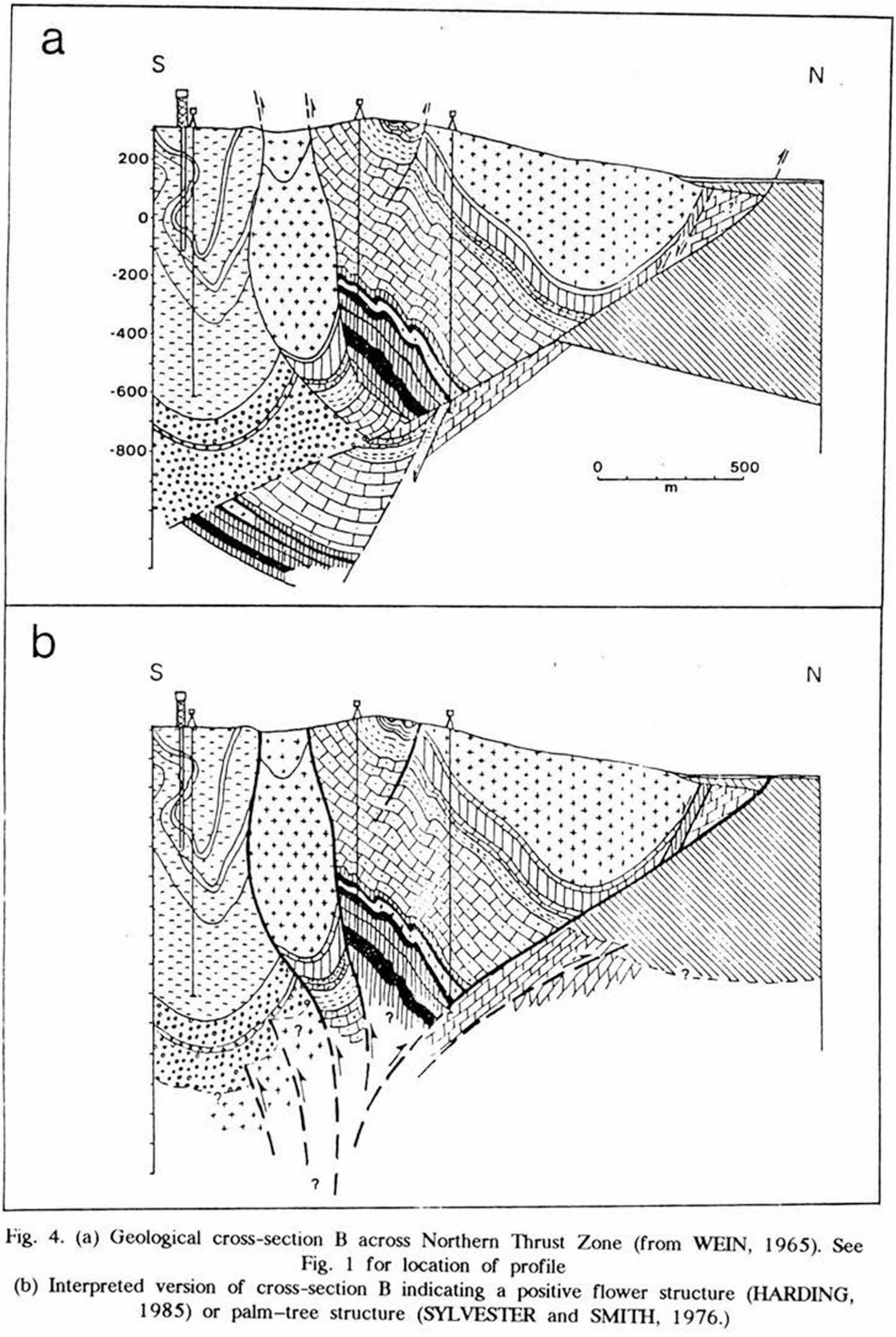

Fig. 4. (a) Geological cross-section B across Northern Thrust Zone (from WEIN, 1965). See Fig. 1 for location of profile
(b) Interpreted version of cross-section B indicating a positive flower structure (HARDING, 1985) or palm–tree structure (SYLVESTER and SMITH, 1976.)

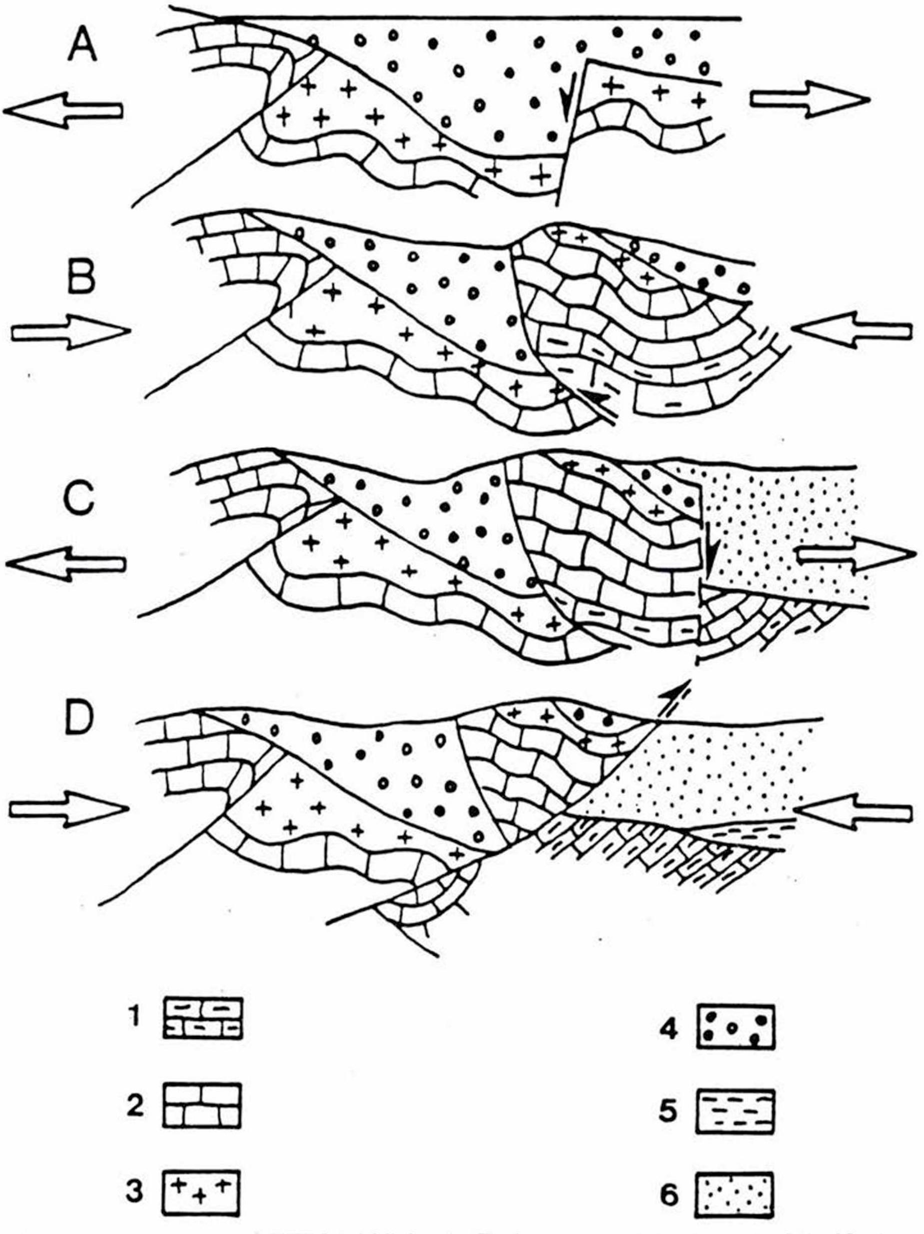

Fig. 5. Conceptual model of WEIN (1966) for the Tertiary sturctural development of the Northern Thrust Zone. (A) Extension during the Lower and Middle Miocene. (B) Compression in the Upper Miocene (Attican orogenic phase) and formation of an asymmetric "wedge structure". (C) Extension during the Pliocene. (D) Compression at the end of the Pliocene (Rhodanian orogenic phase) and formation of a symmetric "wedge structure" Legend: 1, Triassic, 2, Jurassic, 3, Lower Cretacous 4, Early to Middle Miocene, 5, Upper Miocene, 6, Pliocene.

BERGERAT and CSONTOS (1989) have carried out extensive microtectonic investigations in the Mecsek Mts. and distinguished five brittle deformational episodes during the Tertiary. Apart from an ESE-WNW compression of possibly Paleogene age, the first episode of deformation in the Neogene was characterized by a maximum stress of N-S direction. It generated mainly conjugate strike-slip shears: NW-SE to NNW-SSE striking right-lateral and NW-SW to ENE-WNW trending left-lateral faults. *Fig. 6/a* gives illustration for this phase. The site is located in the NTZ (Máza) and the measurements were carried out in the Gyulakeszi Rhyolite Tuff of Lower Miocene age.

The second episode of deformation in the Neogene was characterized by a dominant E-W extension. The extension occurred generally on N-S striking normal faults. The third episode of deformation is a N-S extensional phase which was deduced from the presence of a great number of ENE-WSW to ESE-WNW directed normal faults, bearing dip-slip striae or oblique-slip marks locally.

Finally, there was a NE-SW compressional stress field creating mainly inverse faults of roughly E-W direction. N-S to NNE-SSW directed right-lateral wrench faults also occur. KLEB (1973) measured the strike of joints in poorly consolidated Pliocene sediments in the northern foreland of the NTZ (Fig. 6/b). F. TÖRÖK constructed a diagram on the valley trends in the central part of the NTZ, supposing that the present-day morphology is tectonically preformed (Fig. 6/c). A fairly good correlation can be seen between the microtectonics, Pliocene joint strikes and morphology, indicating that all these data reflect the same structural phase affecting the area in the Pliocene.

VADÁSZ (1935), WEIN (1964, 1965, 1966), HÁMOR (1971), NÉMEDI VARGA (1963, 1983), although they recognize the existence of local strike-slip displacements, put an emphasis on the significance of pure dip-slip movements in the area. In contrast, it is proposed here that Neogene deformation in the NTZ was largely the result of strike-slip tectonics and the compressional structures should be attributed to the convergent component of this wrenching.

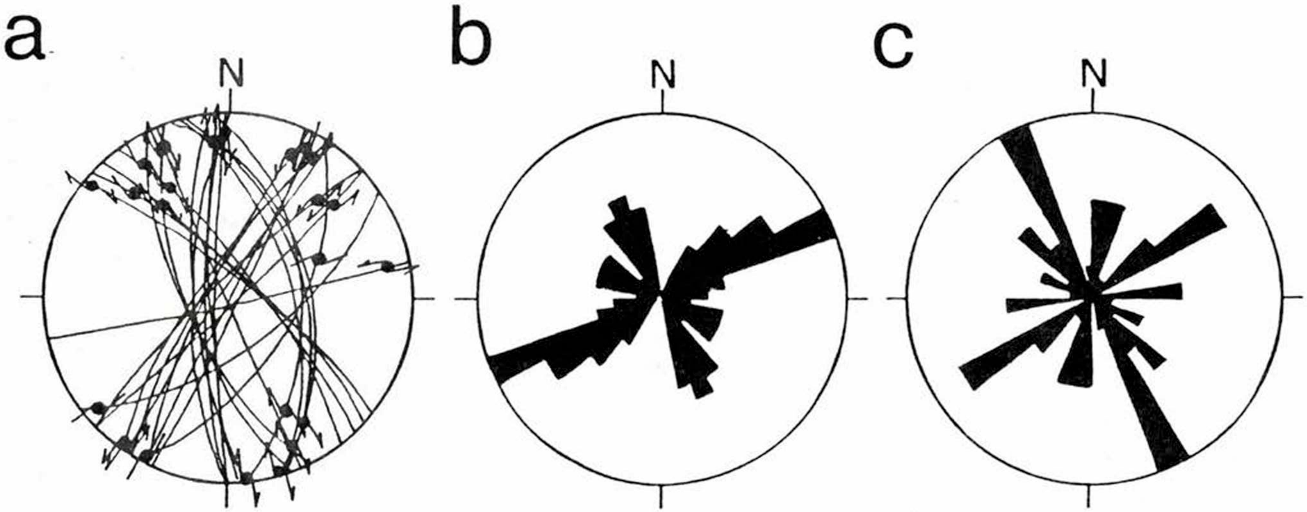

Fig. 6. (a) Microtectonic data from Máza after BERGERAT and CSONTOS (1989). Schmidt projection, lower hemisphere. The measurements were carried out on the Gyulakeszi Rhyolite Tuff of Lower Miocene age. (b) Strikes of fault planes measured by KLEB (1973) in Pliocene sands in the northern foreland of the Northern Thrust Zone. (c) Direction frequency diagram of valley trends in the central part of the Zone. It was computed by. F. TÖRÖK.

Tectono-sedimentary model for the Late Cenozoic evolution of the Northern Thrust Zone

The most striking structural features of the tectonic map of the NTZ *(Fig. 1)* are the throughgoing thrusts and reverse faults trending generally between N40° – N90°. Although at present these faults have a marked reverse separation, they were characterized by a more significant left-lateral strike-slip displacement (synthetic RIEDELS, WILCOX et al., 1973) during their earlier activity. The conjugate right-lateral shears (antithetic RIEDELS) strike to the NNW as it was indicated in several cases on the original map of WEIN (1965). I speculate, that the normal faults of the same strike probably also have a dextral component. In this way the structural pattern can be best understood in terms of a left-lateral simple-shear couple with a component of convergence. This class of strike-slip faults was termed transpressional by HARLAND (1971). The term has been generalized somewhat by SANDERSON and MARCHINI (1984). *Fig. 1* is a reproduction of their diagram showing the orientation patterns of faults during sinitral E-W trending simple shear under transpression. I consider this model plausible for explaining the observed structures in the NTZ of the Mecsek Mts. It is important to note that the transpression increased the angle between the RIEDELS and the overall trend of wrenching. This relationship was theoretically predicted by SANDERSON and MARCHINI (1984), and NAYLOR et al. (1986) have found evidence for it during their sandbox experiments. Hovewer, the deviations from the predicted pattern in the NTZ might have resulted from the structural heritage, i. e. the Late Cenozoic shearing deformed an inhomogenous material.

Structural criteria for differentiating contractional fault blocks (pure reverse-slip) and convergent wrench faults (oblique-slip by the dominance of wrenching) are given by HARDING and LOWELL (1979) and HARDING (1985) and they also support the transpressional interpretation. A contractional block fault has a consistent upthrown side and dip direction, and usually the boundary faults intersect and terminate abruptly. The deformed zone at convergent wrench faults, in contrast, is distinguished by lateral persistence of faults, including changes in vergence which is obviously the case in the NTZ.

The geological cross-sections of the NTZ (*Fig. 3/a* and *Fig. 4/a*) published by WEIN (1965) were constructed largely on the basis of data coming from the coal mines in the area. Therefore the upper 400-500 m parts of the profiles are based on detailed subsurface data. Taking into consideration that HÁMOR (1971) postulated the S-vergent and N-vergent thrusts and reverse faults synchronous, these sections indicate a single positive flower structure and this supports the transpressional model. A positive flower structure is defined as a linear antiform that is bounded longitudinally along its flanks by the upward and outward diverging strands of a wrench fault that have mostly reverse separations (HARDING, 1985). Since the lower portions of the profiles are poorly known and were constructed only tentatively by WEIN (1965), I reinterpreted them conceptually (*Fig. 3/b* and *4/b*). The flower "petals" bounding the pop-up block usually merge into a single steep fault plane at depth (SYLVESTER and SMITH, 1976, WOODCOCK and FISCHER, 1986, NAYLOR et al. 1986). Therefore I supposed a "root" fault-zone beneath the structure on which the whole horizontal displacement was taken up. Moreover, my interpreation takes into account the convex-upward geometry of fault branches which is characteristic for transpressional settings (e. g. LOWELL, 1972, SYLVESTER and SMITH, 1976).

Although only two geological corss-sections were repeated here, the many others, published by WEIN (1965), MAUL (1971), NÉMEDI VARGA (1971) should be interpreted the same way. These sections show high variability, the internal geometry of the flower structure varies laterally from place to place along the NTZ. This phenomenon is also characteristic for flower structures (e. g. DuPLESSIS and CLENDENIN, 1988) as well as the fault architecture asymmetry (HARDING, 1985).

The evolution of the elongated, narrow trough in the southern foreland of the NTZ can be best understood in terms of strike-slip furrow basin defined by MONTENAT et al. (1987). *Fig.* 7. shows the theoretical evolution of basins of this type. The first stage in the evolution of wrench furrows (Fig. 7/A) corresponds to the "phase of transtension" defined by MITCHELL and READING (1978) and READING (1980) in their general strike-slip cycle model. I ascribed the Early Miocene paleoenvironments *(Fig. 8)* of the studied basin to this stage. The subvertical oblique-slip faults had a dominant dip-slip component and an asymmetric half-graben formed during this time. Most of the basin fill was transported into this continental depression by rivers and the source areas were located to the South. The basin was characterized by longitudinal through-drainage, the sediments were transported to the West by an axial river. Grain-size distributions and the ratio of channel fill and fine-grained flood sediments indicate an earlier braided axial river from which a meandering one developed. The abrupt channel movements (avulsions) recorded by frequent intrabasinal redeposition of sediments might have originated during the episodes of oblique-slip movements on the dominant northern boundary fault of the half-graben.

The normal faults of the transtensional phase reactivated mostly as strike-slip faults at the beginning of the Middle Miocene. This intermediate stage ("phase of basin filling" of READING, 1980) of the wrench furrow evolution (see *Fig. 7/B*) was characterized by marine sedimentation *(Fig. 8)*. The northern edge of the basin was controlled by the most mobile wrench fault which defined a paleoshoreline during this time. Coarse clastics from the uplifted footwall reached the basin in the form of fan shaped debris cones and aprons. The conglomerate of this faulted margin interfingers with fine-grained mud sediments of the basin interior.

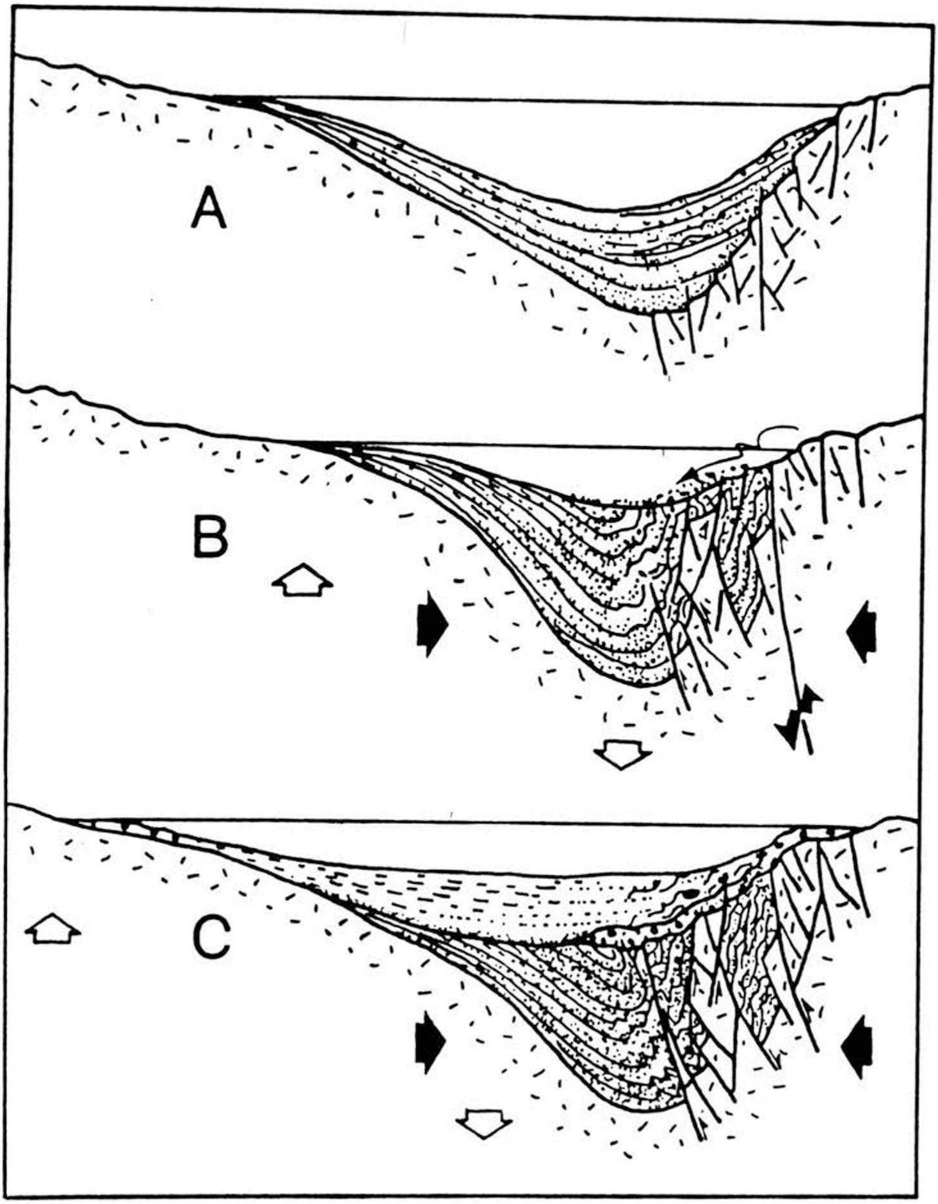

Fig. 7. Theoretical evolution of a wrench fault furrow basin after MONTENAT et al. (1987). (A) Formation of the furrow by transtensional tectonics. (B) Early synsedimentary tectonics controlled by reverse faults, drag faults, inducing a large mobility of basement detached blocks. (C) Raising of the first furrow inducing a centrifugal migration of the maximum subsidence axis. This model is considered plausible for the interpretation of tectono-sedimentary evolution of the NTZ.

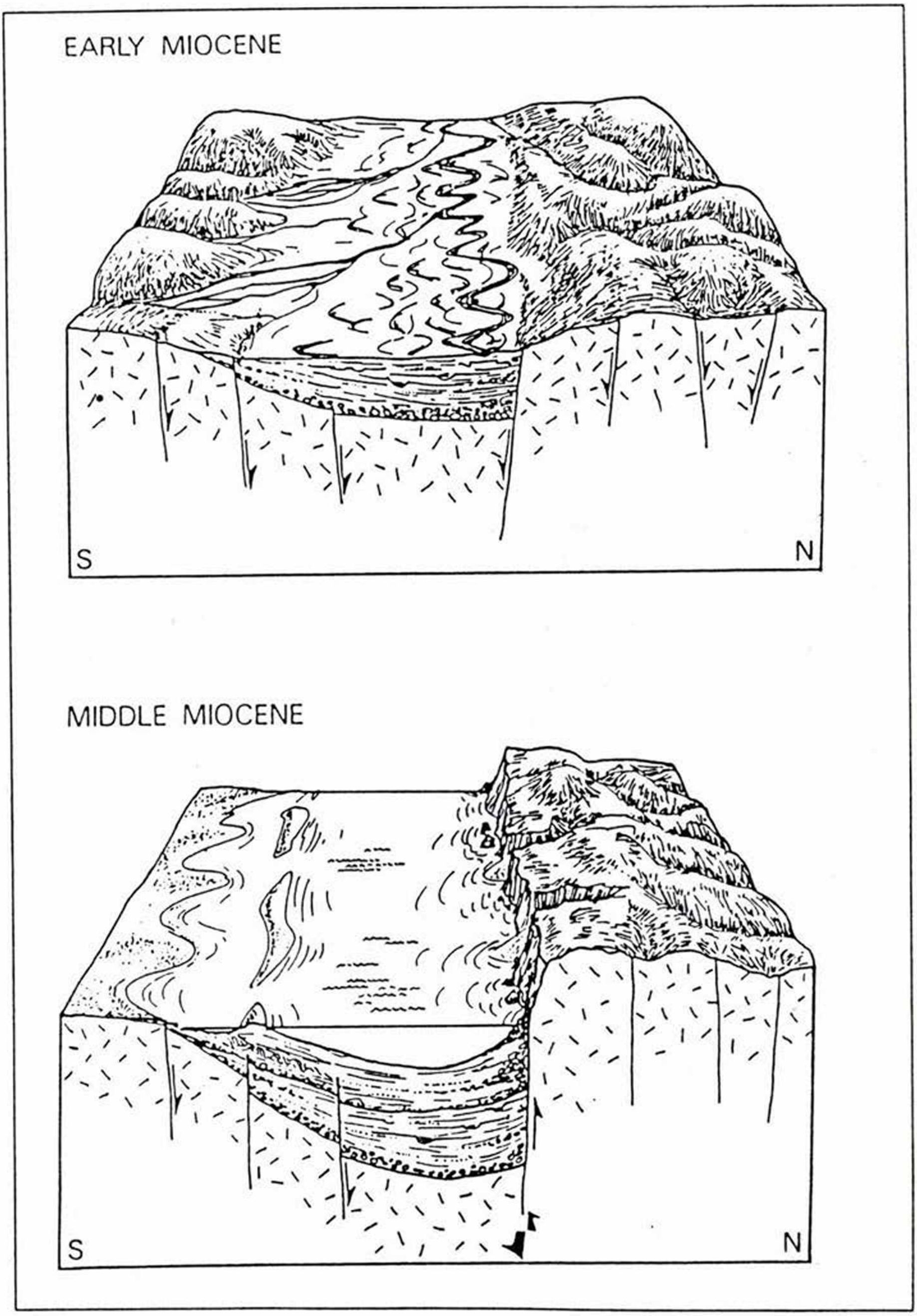

Fig. 8. Reconstructed Early Miocene and Middle Miocene paleoenvironments of the Northern Thrust Zone and its surroundings.

In the southern margin of the basin sedimentation was characterized by the deposition of predominantly silty, finely laminated mudstones. The frequent slump sheets in this unit can be considered tectonically triggered gravity deposits. Due to the thick sediment cover on the basement, the fault tip lines probably were buried beneath it, therefore the individual fault motions caused only minor, areally restricted synsedimentary deformation in the uppermost, poorly consolidated mudstone. This type of sedimentary response to tectonic activity is quite common in strike-slip settings (e. g. SMALLWOOD, 1986, MONTENAT et al. 1987).

The numerous transgressional episodes, reflected by simultaneous faunal changes in the whole basin (HÁMOR, 1971) are thought to be the consequence of local tectonic events rather than eustatic sea level rises. Similarly, the coarsening-upward sandstone sequences on a scale of some meters were also resulted from episodic displacements on the boundary faults, most probably associated with the vertical movements of the basin floor (cf. STEEL, 1976, STEEL and GLOPPEN, 1980).

Fig. 9 shows the Upper Miocene stage of the basin. In this "phase of transpression" (READING, 1980) the marine sedimentation ceased in the central part of the basin, due to tectonic uplift. This uplift was caused by the increasing compressional component of wrenching in the NTZ. The sedimentary fill of the basin was folded and intensive thrusting occurred at the margins *(cf. Fig 7/C)*. At the same time the appearance of megabreccia in the western end of the NTZ indicates a syndepositionally active fault zone. The presence of talus deposits composed of large angular clasts several meters long is characteristic for strike-slip basin margins (e. g. CROWELL, 1974, NILSEN and McLAUGHLIN, 1985, MONTENAT et al. 1987).

Transpressional activity culminated in the Pliocene and the present-day positive flower structure *(Fig. 9)* essentially formed during this times interval. N- and S-vergent thrusts developed simultaneously along the NTZ. There is no any direct data to estimate the cumulative Neogene left-slip offset in the NTZ, but it may be in the order of some tens of kms, while the amount of N-S shortening was about several kms. The whole structure uplifted and was subject of erosion in the Quaternary. The recent geomorphological features and the earthquakes reported from historical times suggest that the transpressional structural development still going on, with less intensity.

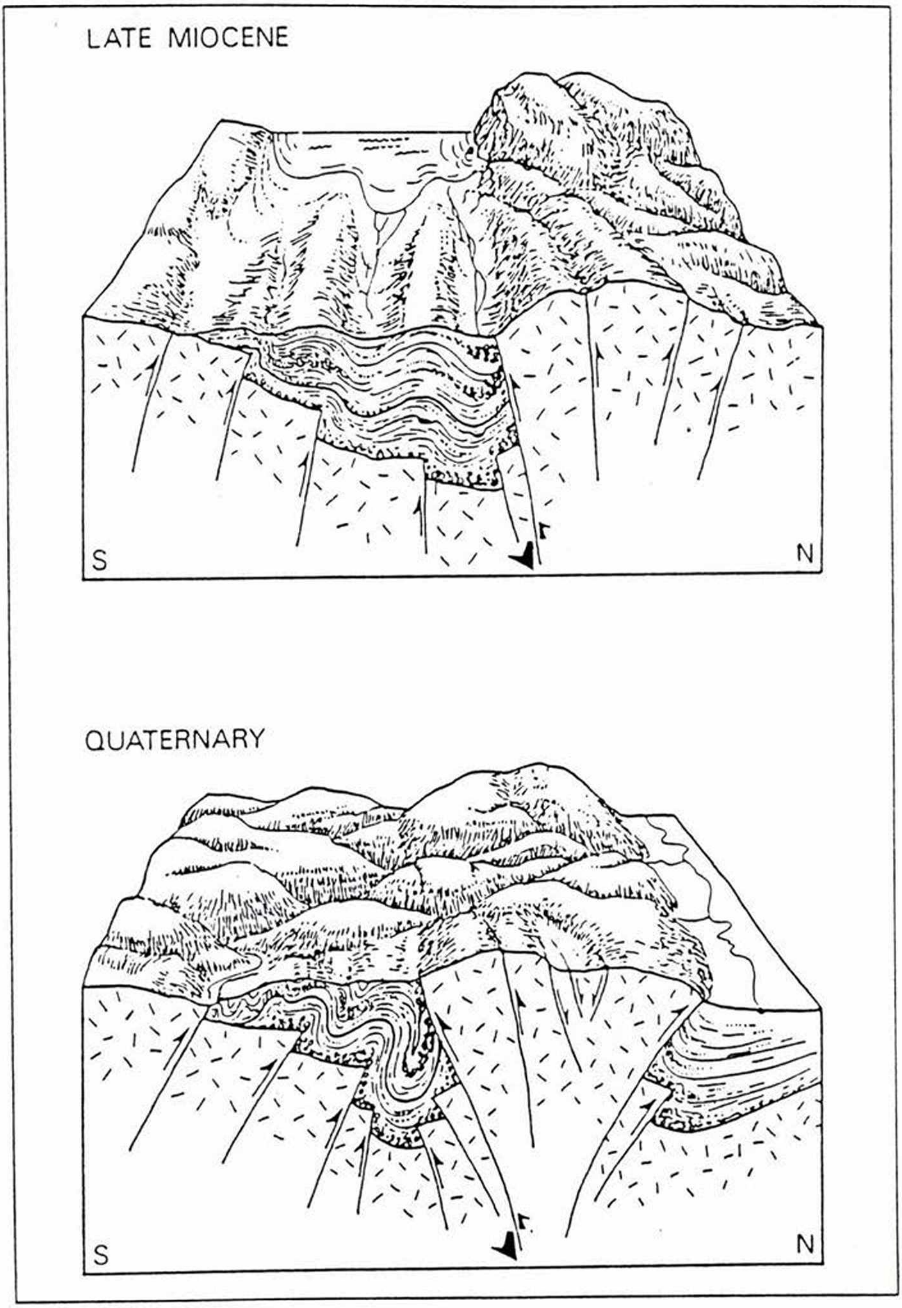

Fig. 9. Reconstructed Upper Miocene and Quaternary paleoenvironments of the Northern Thrust Zone and its surroundings.

Discussion

The concept of wedge structures (MIGLIORINI, 1951) was accepted by many authors in Hungary (e. g. KÓKAY, 1968, 1976, NÉMEDI VARGA, 1963, 1983, WEIN, 1965, 1966). This model was proposed by NÉMEDI VARGA (1963) and WEIN (1964) to explain the observed compressional features in the NTZ. The development of the symmetric wedge structure from an earlier asymmetric one (see *Fig. 5*) in successive dip-slip orogenic cycles does not appear to be tenable. It is proposed here that the structural features in the NTZ can be explained in terms of gradual strike-slip fault development during the Neogene, rather than due to different style of faulting in the course of several distinct orogenic phases.

The many other examples of asymmetric and symmetric wedge structures in Hungary should be viewed as "half-flowers" and positive flower structures, respectively (HARDING, 1985). It implies transpression not pure compression. The normal faults formed in the symmetric wedge structure of the NTZ could have been explained only in a very complicated way by NÉMEDI VARGA (1963). However, this phenomenon is quite common is positive flower structures.

There is an important consequence of these normal faults developed synchronously with the boundary thrusts. This extensional deformation of the pop-up block may confuse the interpretation of microtectonic data. Possible pitfalls in the microtectonic approach was illustrated by JACKSON et al. (1982) in the case of the El Asnam (Algeria) earthquake of 1980 (KING and VITA-FINZI, 1981). Although thrust faulting was responsible for the earthquake, the most obvious surface deformations were normal faults. Normal faulting occurred immediately above the thrust plane *(Fig. 10/a)*. In this area microtectonic measurements might have indicated an extensional stress field. I speculate that the same can be true for the NTZ *(Fig. 10/b)*. If it is really the case, the N-S extensional period determined by BERGERAT and CSONTOS (1989) does not represent a regional extensional event.

There can be another type of difficulty which also limits the validity of the microtectonically determined paleostress orientations. Block rotation (RON et al. 1984) in the NTZ due to the left-lateral shear might have created counterclockwise internal rotations. This type of deformation was demonstrated for the Transdanubian Central Range in the Pannonian Basin by TARI (1989). However, more work (systematic microtectonic and paleomagnetic measurements, etc.) is needed before any definitive statements can be made for the NTZ.

Similarly, further work has to be done to understand better the role of tectonic activity and eustatic sea level changes in sedimentation. For example, the marked drop of the sea level at 16,5 Ma (HAQ et al. 1987) might have contributed to the regressional event caused by tectonic uplift at the end of the Karpathian *(Fig. 2)*. The global transgression soon after this regression was completely overprinted by continuing uplift. Generally, local tectonic activity appears to have primarily controlled the sea level changes in the NTZ.

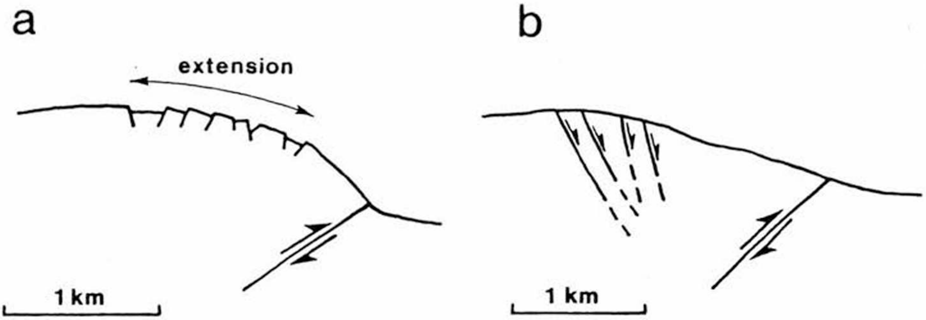

Fig. 10. (a) Section showing the surficial extension formed in the El Asnam (Algeria) earthquake of 1980 (adapted from KING and VITA-FINZI, 1981). This extension represents internal deformation of the hanging wall above the thrust which was responsible for the earthquake. (b) Simplified cross-section through the central part of the Northern Thrust Zone from MAUL (1971). It is proposed here that the presence of normal faults can be explained in the same way as in the case of El Asnam. See text for details.

Conclusions

The first Neogene period of tectonic activity occurred during the Lower Miocene in the southern foredeep of the Northern Thrust Zone, Mecsek Mts. Transtensional tectonics formed an asymmetric half-graben characterized by continental sedimentation. Rapid subsidence of the basin floor in the Middle Miocene has resulted in marine sedimentation typical of strike-slip basins. During the Upper Miocene and Pliocene folding and local uplift above the sea level of the basin fill occurred, due to transpression. The overall tectono-sedimentary evolution of the basin is characteristic for a strike-slip furrow basin.

The geological cross-secrtions and the map view of structural features of the NTZ indicate a throughgoing positive flower structure trending to the East. It has been formed during the Pliocene as a consequence of left-lateral transpression.

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REFERENCES

BERGERAT, F., L. CSONTOS (1989): Brittle tectonics and paleostress fields in the Mecsek and Villány Mts. (Hungary): correlation with the opening mechanism of the Pannonian Basin. Acta Geol. Hung. (in press)

CROWELL, J. C. (1974): Sedimentation along the San Andreas fault, California. In: DOTT, R. H. Jr. and SHAVER, R. H. (Eds): Modern and ancient geosynclinal sedimentation. Spec. Publ. Soc. Econ. Paleont. Miner, 19, 292-303.

DuPLESSIS, C. P., C. W. CLENDENIN (1988): The Bobbejaan water fault system south of Thabazimbi, western Transvaal. S. Afr. J. Geol. 91, 97-105.

HAQ, B. U., J. HARDENBOL, P. R. VAIL (1987): Chronology of fluctuating sea levels since the Triassic. Science, 235, 1156-1166.

HARDING, T. P., J. D. LOWELL (1979): Structural styles, their plate-tectonic habitats and hydrocarbon traps in petroleum provinces. Amer. Assoc. Petrol. Geol. Bull., 63, 1016-1058.

HARDING, T. P. (1985): Seismic characteristics and identification of negative flower structures, positive flower structures and positive structural inversion. Amer. Assoc. Petrol. Geol. Bull., 69, 582-600.

HARLAND, W. B. (1971): Tectonic transpression in Caledonian Spitsbergen. Geol. Mag. 108, 27-42.

HÁMOR G. (1971): The Miocene of the Eastern Mecsek Mts. (In Hungarian with German summary) Annals Hung. Geol. Inst., 51, 1, 1-484.

HÁMOR, G., T. BÁLDI, M. BOHN-HAVAS, L. HABLY, J. HALMAI, M. HAJÓS, J. KÓKAY, L. KORDOS, I. KORECZ-LAKY, E. NAGY, A. NAGYMAROSY, L. VÖLGYI (1987): The bio-, litho- and chronostratigraphy of the Hungarian Miocene. In: Proceedings of the VIIIth Congress of the Regional Committee on Mediterranean Neogene Stratigraphy, Budapest, 1985. Annals Hung. Geol. Inst., 70, 351-353.

HORVÁTH, F., L. ROYDEN (1981): Mechanism for the formation of the intra-Carpathian basins: a review. Earth Evol. Sci. 1, 307-316.

HORVÁTH F., J. RUMPLER, G. POGÁCSÁS, G. TARI (1987): Transtensional origin of the Pannonian Basin: new evidence and interpretation. Terra cognita, 7, 201.

JACKSON, J. A., G. KING, C. VITA-FINZI (1982): The neotectonics of the Aegean: an alternative view. Earth Planet. Sci. Lett., 61, 303-318.

KING, G. C. P., C. VITA-FINZI (1981): Active folding in the Algerian earthquake of 10. October 1980. Nature, 292, 22-26.

KLEB, B. (1973): The Pannonian geology of the Mecsek Mts. (In Hungarian with German summary) Annals, Hung. Geol. Inst., 53, 3, 747-943.

KÓKAY, J. (1968): Tectonic theories in the light of Bakony Mts. evidence. (In Hungarian) Földtani Közlöny, 98, 381-393.

KÓKAY, J. (1976): Geomechanical investigation of the southern margin of the Bakony Mts. and the age of the Litér fault line. Acta Geol. Hung., 20. 245-257.

LOWELL, J. D. (1972): Spitsbergen Tertiary orogenic belt and the Spitsbergen fracture zone. Geol. Soc. Amer. Bull. 83, 3091-3102.

MAUL, E. (1971): The Northern Thrust Zone (In Hungarian) In: The Lower Liassic coal sequence of the Mecsek Mts. Annals Hung. Geol. Inst., 51, 3, 71-100.

MIGLIORINI, C. I. (1951): Composite wedges and orogenic landslips in the Appennines. Int. Geol. Cong. Rep., 18th session, Great Britain, 1948, pt. 13, 186-194.

MITCHELL, A. H. G., H. G. READING (1978): Sedimentation and tectonics. In: READING, H. G. (Ed): Sedimentary Environments and Facies. Blackwell, Oxford, 439-476.

MONTENAT, C., P. OTT d'ESTEVOU, P. MASSE (1987): Tectonic-sedimentary characters of the Betic Neogene basins evolving in a crustal transcurrent shear zone (SE Spain). Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine, 11, 23-38.

NAYLOR, M. A., G. MANDL, C. H. K. SIJPESTEIJN (1986): Fault geometries in basement-induced wrench faulting under different initial stress states. J. Struct. Geol. 8, 737-752.

NÉMEDI VARGA Z. (1963): Structural investigations in the Kövestető phonolite area. (In Hungarian) Földtani Közlöny, 93, 37-53.

NÉMEDI VARGA Z. (1971): The Szászvár-Máza-Váralja-Nagymányok coal area (In Hungarian) In: The Lower Liassic coal sequence of the Mecsek Mts. Annals Hung. Geol. Int., 51, 3, 152-162.

NÉMEDI VARGA Z. (1983): Tectonics of the Mecsek Mts. in the Alpine orogenic cycle (In Hungarian) Annu. Rep. Hung. Geol. Inst., 1981, 467-484.

NILSEN, T. H., R. J. McLAUGHLIN (1985): Comparison of tectonic framework and depositional patterns of the Hornelen strike-slip basin of Norway and the Ridge and Little Sulphur Creek strike-slip basins of California. In: BIDDLE, K. T. and CHRISTIE-BLICK, N. (Eds.): Strike-slip deformation, basin formation and sedimentation. Spec. Publ. Soc. Econ. Paleont. Miner. 37, 79-103.

READING, H. G. (1980): Characteristics and recognition of strike-slip fault systems. In: BALLANCE, P. F. and READING, H. G. (Eds): Sedimentation in oblique-slip mobile zones. Spec. Publ. Int. Ass. Sedim. 4, 7-26.

RON, H., R. FREUND, Z. GARFUNKEL, A. NUR (1984): Block rotation by strike-slip faulting: structural and paleomagnetic evidence. J. Geophys. Res., 89, 6256-6270.

ROYDEN, L., F. HORVÁTH, J. RUMPLER (1983): Evolution of the Pannonian basin system, 1. Tectonics, Tectonics, 2, 63-90.

RUMPLER, J., F. HORVÁTH (1988): Some representative seismic reflection lines and structural interpretation from the Pannonian Basin. In: ROYDEN, L. H. and HORVÁTH F. (Eds.): The Pannonian Basin - a study in basin evolution. Amer. Assoc. Petrol. Geol. Memoir 45, 153-169.

SANDERSON, D. J., W. R. D. MARCHINI (1984): Transpression. J. Struct. Geol., 6, 449-458.

SMALLWOOD, S. D. (1986): Sedimentation across the Tywi Lineament, mid Wales. Phil. Trans. R. Soc. Lond., A317, 279-288.

STEEL, R. J. (1976): Devonian basins of western Norway - sedimentary response to tectonism and to varying tectonic context. Tectonophysics, 36, 207-224.

STEEL, R. J., T. G. GLOPPEN (1980): Late Caledonian (Devonian) basin formation, western Norway: signs of strike-slip tectonics during infilling. In: BALLANCE, P. F. and READING, H. G. (Eds.): Sedimentation in oblique-slip mobile zones. Spec. Publ. Int. Ass. Sedim. 4, 79-103.

STEININGER, F. F., C. MÜLLER, F. RÖGL (1988): Correlation of Central Paratethys, Eastern Paratethys, and Mediterranean Neogene stages. In: ROYDEN, L. H. and HORVÁTH F. (Eds.): The Pannonian Basin - a study in basin evolution. Amer. Assoc. Petrol. Geol. Memoir 45, 79-87.

SYLVESTER, A. G., R. R. SMITH (1976): Tectonic transpression and basement-controlled deformation in San Andreas fault zone, Salton Trough, California. Amer. Assoc. Petrol. Geol. Bull., 60, 2091-2102.

TARI G. (1989): Multiple Neogene block rotations in the Transdanubian Central Range. Terra Cognita (in press)

VADÁSZ E. (1935). The Mecsek Mts. (In Hungarian with German summary) Publ. Hung. R. Geol. Inst., Budapest, 1-180.

WEIN Gy. (1964): The vergency directing role of the fore-deeps in the mountains of Hungary. Acta Geol. Hung., 8, 347-355.

WEIN Gy. (1965): Geology of the "Northern Thrust Sheet" of the Mecsek Mts. (In Hungarian) Annu. Rep. Hung. Geol. Inst., 1963, 35-50.

WEIN Gy. (1966): Role of fore-deeps in the formation of scale structures in the Mecsek Mts. (In Hungarian) Magyar Geofizika,7, 55-60.

WILCOX, R. E., T. P. HARDING, D. R. SEELY (1973): Basic wrench tectonics. Amer. Assoc. Petrol. Geol. Bull., 57, 74-96.

WOODCOCK, N. H., M. FISCHER (1986): Strike-slip duplexes. J. Struct. Geol., 8, 725-735.