To rotate or not to rotate: Palinspastic reconstruction of the Carpatho - Pannonian area during the Miocene

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Abstract. The correct palinspastic reconstruction of the Carpatho - Pannonian region requires that paleomagnetic observations are also taken into account. Since paleomagnetic data suggest that the major Neogene rotations started with the Ottnangian, we try to picture several geodynamic situations starting with the Eggenburgian pre rotational stage and ending with the Early Pannonian, when the last significant rotation was observed. During this time interval several compressive, extensive and rotational events took place that may be related to subduction pull and stretching of the overriding plate.

Key words: Carpatho-Pannonian region, Neogene, paleomagnetic investigation, block rotations

Introduction

The Carpatho - Pannonian region, due to voluminous prospecting works, can be considered as the natural laboratory of geodynamics. Despite of the very good knowledge of geology, tectonic pattern and evolution of the area, the solution of the Miocene palinspastic reconstructions causes many problems, which led various authors to develop different geodynamic models (Balla 1984, Kováč et al. 1989, Csontos et al. 1992, Kováč et. al. 1994, Csontos a Horváth 1995, Csontos 1995, Morley 1996).

The palinspastic reconstruction of the Carpathian accretionary prism (Outer Carpathians) poses the problems of simple restoration sections because they create the converging restoration paths with large amounts of strike parallel extension. Combination of thrust transport directions changing with time between and within thrust sheets and divergent transport directions helps to minimize the arc-parallel extension necessary (Morley 1996).

The Pannonian Basin System can be treated as the area where, besides large strike slip movements between the semirigid blocks, back arc extension must have played an important role during the Neogene (Royden 1993). Paleomagnetic data point out the existence of large scale rotation of blocks inside the Carpatho - Pannonian region. For the TISZA - DACIA microplate, more than 70^0 post-Cretaceous clockwise rotation is reported (Márton, 1986, Patrascu et al. 1990, 1994), for the northeastern part of the ALCAPA microplate Pelso and Austroalpine subunits 40 - 50° Ottnangian and 30° Early Badenian counter clockwise rotations were observed (Túnyi and Kováč 1991, Kováč and Túnyi 1995, Márton et al. 1995, Márton and Márton 1996) and the Transcarpathian subunit seems to have rotated in counter clocwise sense by about 30° during the Late Sarmatian - Early Pannonian.

The above mentioned rotations were realized along the semirigid microplates boundaries, but a part also inside their subunits (Márton and Fodor 1995) to compensate the stretching induced by subduction pull (book shelf or domino effect). How to treat the rotations in the Carpatho - Pannonian region by palinspastic reconstructions is a question analogous to the famous Shakespeare's Hamlet sentence "to be or not to be - to rotate or not to rotate"?

The microplates

The pre-Neogene basement units of the Carpatho - Pannonian region can be divided into two microplates (Fig.1): a northern one, called ALCAPA and a southern one, the TISZA-DACIA (Balla 1984, Csontos et al. 1992, Csontos 1995).

The ALCAPA microplate is built up by from the Austroalpine belt (Fuchs 1984) comprising the Eastern Alps and Western Carpathians, and the belt which is compared best to the Southern Alps and to the Internal Dinarides and it is exposed in the Transdanubian Central Range and the Igal - Bukk zone (Kázmér and Kovács 1985, Kázmér 1986, Csontos et al. 1992, Vöros 1993). These two subunits are separated by the Rába line in the west and the Hurbanovo Diósjenő line and rests of the Meliata suture in the central part (Plašienka et al. 1998). There is a third subunit which is the broader area of the Transcarpathian depression. The basement of this subunit consist of fragments from the

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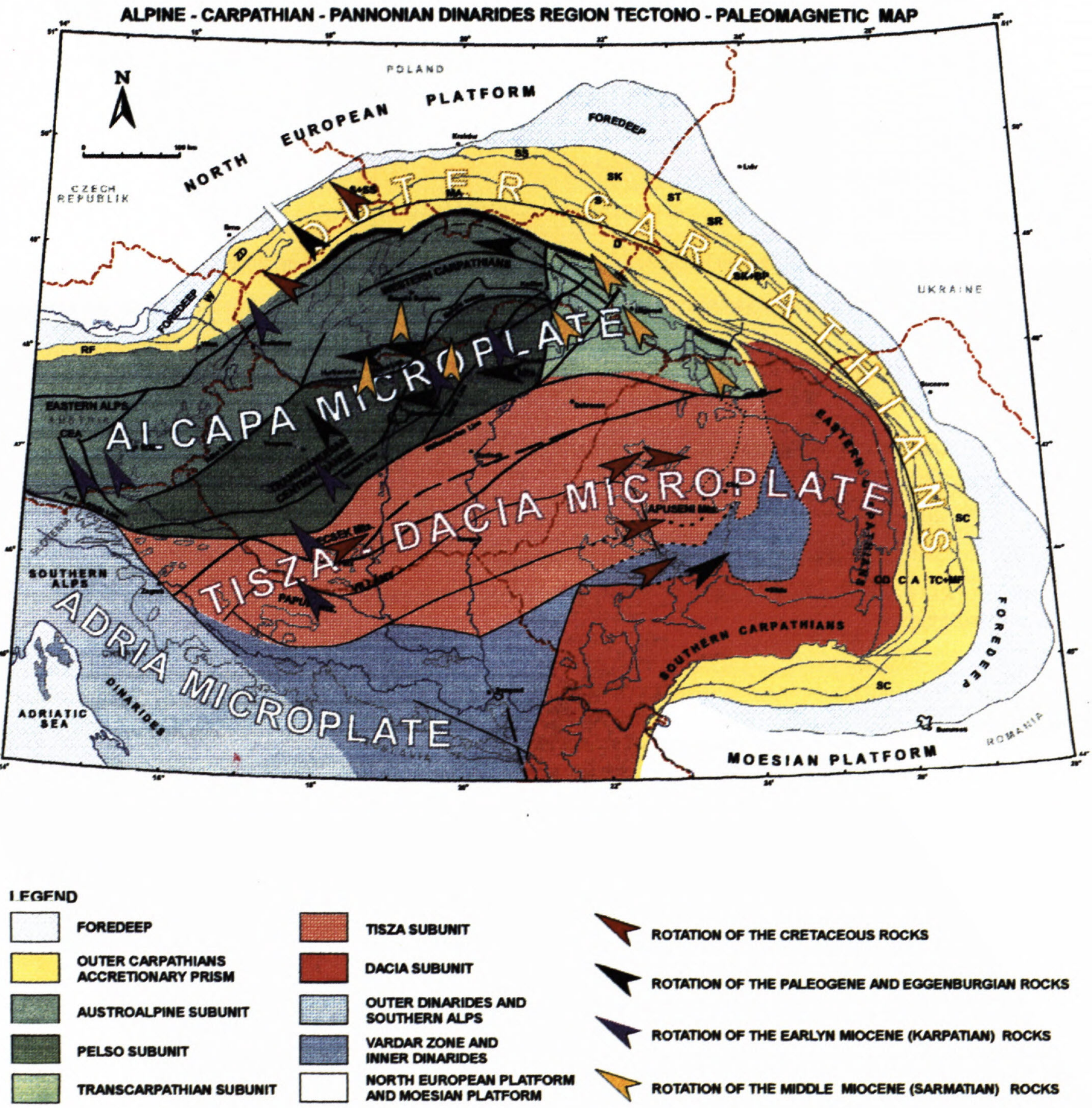


Fig. 1 The Carpatho-Pannonian region superunits, arrows indicate the paleomegnetic rotations

northern and southern microplate (e.g. Humenné or Zemplín units) plus the dominant Inatchevo - Kritchevo Penninic type rock complex (Soták et al. 1994, 1997).

The northern boundary of the ALCAPA microplate is the Pieniny Klippen Belt, an elongated laterally sheared zone composed mainly of Mesozoic rocks (Birkenmajer 1986, Mišík 1997). The southern boundary is represented by the Mid - Hungarian line, a very complicated zone from where the Szolnok unit flysch sequences were folded and thrusted over the TISZA - DACIA microplate (Nagymarosy and Báldi-Béke 1993).

The southern microplate TISZA - DACIA consists of at least three separate lithospheric fragments, having different tectonic histories (Csontos 1995). The Tisza subunit outcrops in the Mecsek, Villany, Papuk and Apuseni Mountains. The Dacia subunit is formed by the Inner and Outer Dacides of the Eastern Carpathians and by the Southern Carpathian units. The contact between the Tisza and Dacia subunits runs through the Metaliferi Mts. and the pre-Tertiary basement of the Transylvanian Basin. This border zone is represented by relicts of the Vardar unit (Sandulescu 1988).

The northern boundary of the Tisza lithospheric fragment is represented by the Mid Hungarian zone, the eastern boundary of the Dacia lithospheric fragment is the thrust front between the Outer Dacides and Internal Moldavide nappes. The southern boundary with the Adria is uncertain, after Csontos (1995) it may be the Sava line and the right lateral contact of the Serbo - Macedonian (Dacia) units with the Vardar zone (Inner Dinarides).

The third major microplate which had influenced the Carpatho - Pannonian realm evolution is the ADRIA microplate. The ADRIA microplate represents the southern boundaries of two superunits mentioned above. (Csontos 1995).

The Early Miocene counter clockwise rotation of the ALCAPA microplate.

The subduction of the Penninic crust below the Alpine thrust front during the Oligocene was followed by the same or similar subduction below the Central Western Carpathian thrust front during the Early Miocene. This process was associated with folding and thrusting of the Magura Nappe Group, Peri Klippen Belt Paleogene, Inatchevo - Kritchevo and Szolnok units during the Eggenburgian (Fig. 2).

The compression in front of the extruding ALCAPA microplate led to the disintegration of the Paleogene forearc basins and the opening of wrench fault furrow type basins (Kováč et al.1997, in press). The documented paleostress field with NW - SE oriented compression initiated a fault pattern with ENE - WSW right lateral strike slips and NE - SW thrusts. Similar fault pattern was described also from the Transdanubian Central Range and western part of the Tisza subunit in the Mecsek Mts. (Csontos et al. 1991. Fodor et al. 1992).

In the eastern part of the TISZA - DACIA microplate, in the Apuseni Mts. and the Transylvanian Basin, N - S compression was dominant during this time, similar to the compression observed in the southeastern margin of the ALCAPA microplate in the Buda and Transcarpathian Basins (Huismans et al. 1997, Kováč et al. 1994, 1995, Márton et al. 1995), mirroring the Penninic type crust subduction between microplates.

During the Ottnangian, beside the Alpine collision with the North European Platform and following eastward oriented extrusion of the ALCAPA microplate (Ratschbacher et al. 1989, 1991), the subduction retreat in front of the Carpathians was the driving force for the Carpatho - Pannonian region evolution.

In the Western Carpathians the Silesian unit was folded and thrusted in front of the Magura, Fore- Magura and Dukla units nappe pile over the Subsilesian and Skola internal zone. The subduction retreat in the Eastern Carpathians led to the Intra Burdigalian tectonic phase, when the front of the Internal Moldavide nappes (Convolute Flysch, Macla and Audia units) was formed (Sandulescu 1988, Micu 1990).

The initial extension compensating the subduction pull can be observed very well in structural and sedimentary record of the ALCAPA microplate, in the southern and central parts. In the NE - SW trending extension the Buda retroarc basin disintegrated and grabens opened along NW - SE normal faults in the southern (Novohrad - Nógrád Basin) and central part (Bánovce and Horná Nitra Basins) of the Western Carpathians (Sztano 1994, Vass et al. 1993, Hók et al. 1995) The subduction pull related stretching of the overriding plate was followed by acid volcanism in vicinity of the Mid Hungarian zone (Szabó et al. 1992).

In the Dacia subunit a NE trending compression induced the N - S to NNE - SSW oriented dextral displacements in the Southern Carpathians, followed by opening of the Getic depression (Ratschbacher et al. 1993, Matenco 1997).

On the basis of the outlined tectonic scenario, the post-Eggenburgian twisting of microplates in the Carpatho - Pannonian domain was influenced more by the subduction retreat in front of the Carpathians, than by the collision between the microplates

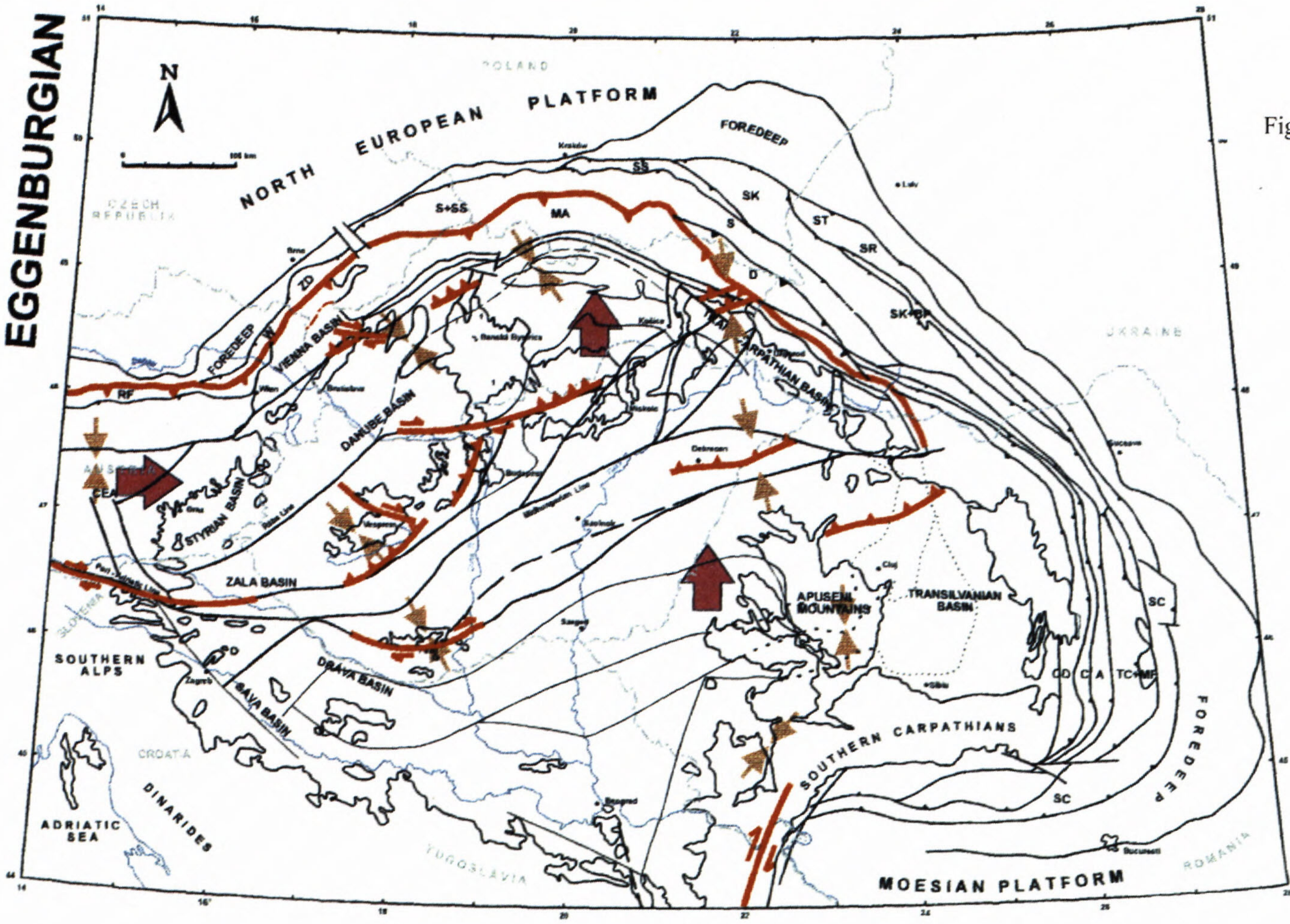
This process is documented by the north, northeastward movement of the TISZA - DACIA microplate associated with the Eggenburgian closing of the penninic type Inatchevo - Kritchevo and Szolnok zone in the north and the right lateral displacement of the Dacia subunit along the Internal Moldavide thrust front during the Ottnangian (Matenco 1997). The large clockwise rotation of the TISZA - DACIA microplate during the Early Miocene proposed by Balla (1984), Kováč et al. (1994) and Csontos (1995) seems not to be present.

The ALCAPA microplate counter clockwise rotation of 40^0 - $5O^0$ (Márton et al. 1995) was associated with the Ottnangian right lateral displacement of the semirigid microplate along the TISZA - DACIA northern margin (Mid Hungarian line). The block rotations were compensated by N - S to NNE -SSW oriented sinistral strike slips (Kováč and Hók 1993) and NW - SE trending normal faults acting in the NE - SW oriented initial extension induced by subduction retreat (Fig. 3).

The Early Badenian counter clockwise rotation of the ALCAPA microplate accompanied by possible slight clockwise rotation of the TISZA - DACIA microplate

The late Early Miocene period was influenced by subduction retreat along the front of the Western Carpathians (Fig. 4). The Pouzdřany and Ždanice units were thrusted over the Karpatian foredeep in front of the Magura Nappe Group (Rača unit) in the west, the Subsilesian and Silesian units in the north and Skola unit in the east (Oszczypko and Slaczka 1989, Kováč et al. 1989).

The subduction roll back initiated rifting and extension in the overriding ALCAPA and central part of the TISZA microplates during the Karpatian. The north, northeastward stretching was compensated in the East Alpine - Western Carpathian junction by the NE trending sinistral strike slips, which opened the pull apart Vienna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UKRAINE
AUSTRIA
STYRIAN BASIN
ZALA BASIN
APUSENI MOUNTAINS
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DRAVA BASIN
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Fig. 2

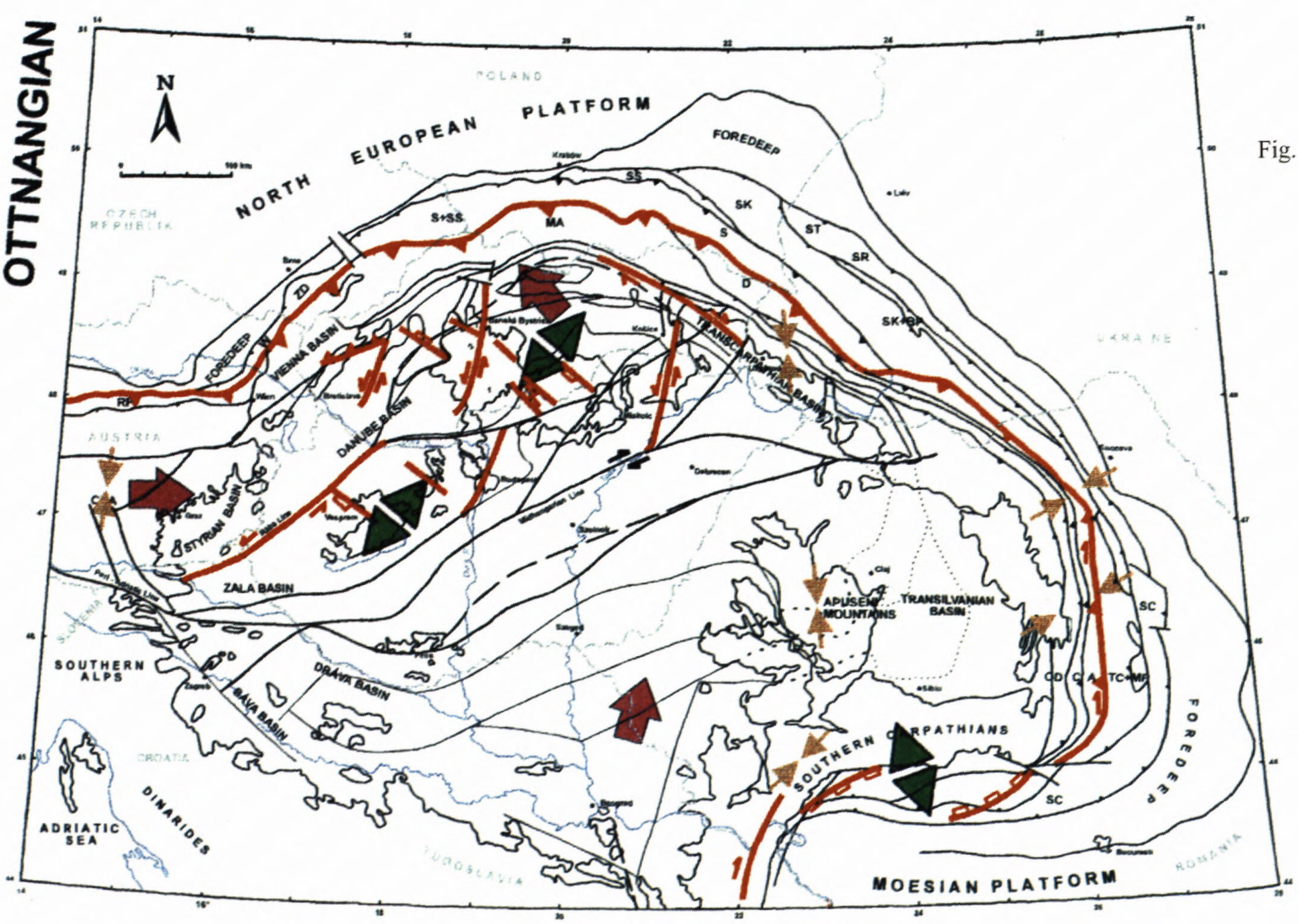
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Fig. 3

KARPATIAN

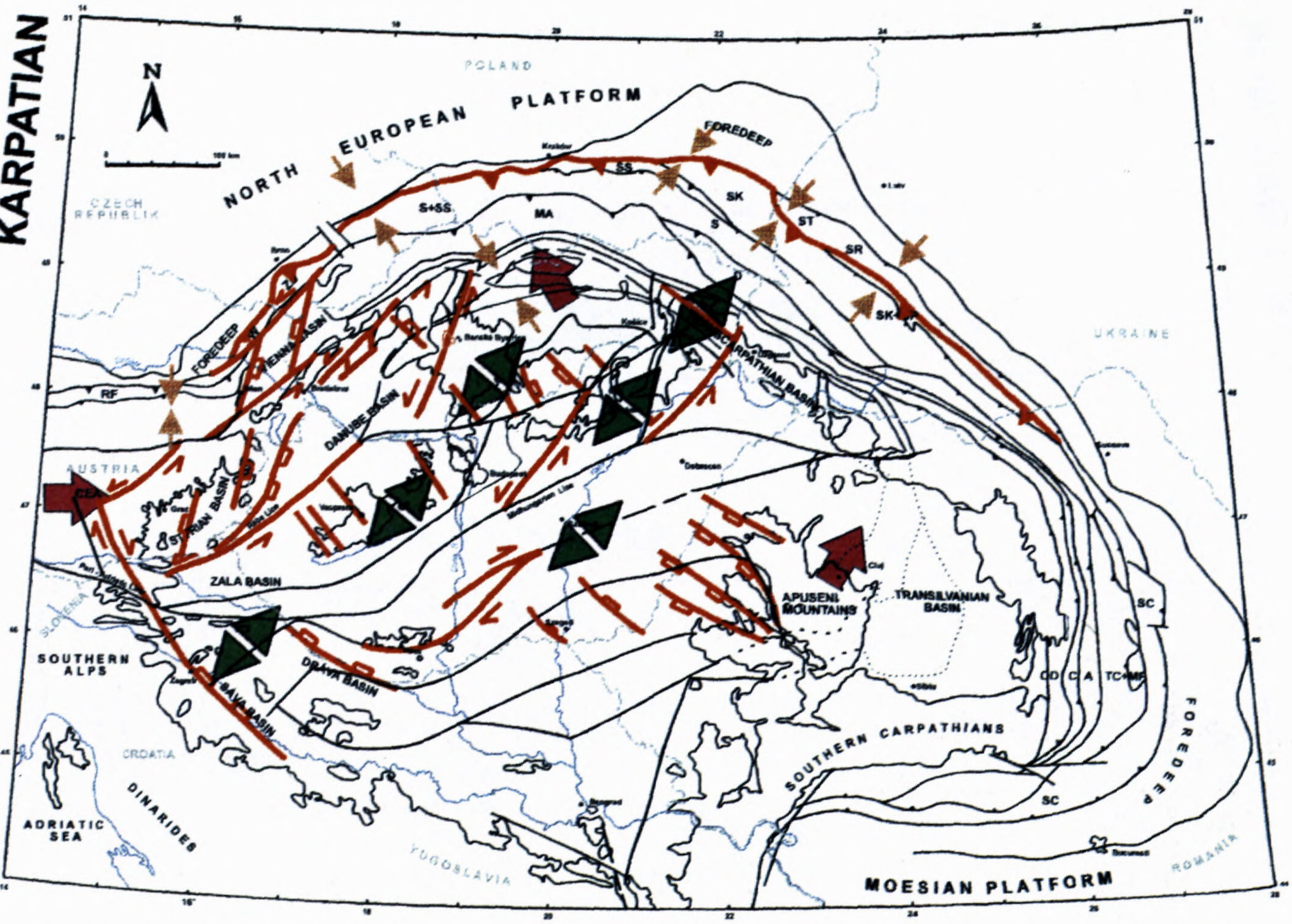

Fig. 4 Major tectonic elements which influenced the Karpatian evolution of the Carpatho-Pannonian region (explanation see Fig. 8)

Basin in the paleostress field with N - S oriented main compression (Fodor 1995).

The Karpatian paleostress field with dominant NE - SW oriented extension can be traced in both amalgamated microplates of the Carpatho - Pannonian region. The NW - SE trending normal faults opened the depocenters in the Western Carpathians, Novohrad - Nógrád Basin and Transcarpathian depression in the north, as well as in the Transdanubian Central Range and Great Hungarian Plain in the south (Hók et al. 1995, Kováč et al. 1995, Csontos and Horváth 1995).

The Early Badenian subduction retreat was followed by compression along the whole Carpathian front (Fig.5) and led to the Intra Badenian tectonic phase (Sandulescu 1988) associated with evaporite event (salinity crisis) known from the Carpathian foredeep during the Middle Miocene (Rögl and Steininger 1993, Steininger et al. 1985).

The Western Carpathian active thrust front remained in the north, where it was represented by the Subsilesian and Silesian units (in this time acting as a homogenous thrust sheet) and by the Skola and Borislav - Pokuty units thrusted over the Sambor - Rozniatov unit in the east (Oszczypko and Slaczka 1989).

In front of the Eastern Carpathians, the Tarcau and Marginal Folds units were thrusted over the Early Badenian deposits of the Subcarpathian Neogene unit (Micu 1990). The paleostress fields show a clockwise rotation of the main compression orientation along the Eastern Carpathian front from NE - SW to E - W in the south (Kováč et al. 1995, Matenco 1997).

The post-Karpatian 30° - 40° counter clockwise rotation (Roth 1980, Túnyi and Kováč 1991, Márton and Márton 1996) of the ALCAPA microplate (and also the western part of the Tisza subunit) was caused by the Western Carpathian subduction pull and extension of the overriding plate. The stretching activated the NE - SW to NNE - SSW trending left lateral strike slips (shear zones) and the NW - SE normal faults (Horváth 1993), which compensated the counter clockwise rotation of the semirigid ALCAPA microplate.

Fig. 2 Major tectonic elements which influenced the Eggenburgian evolution of the Carpatho-Pannonian region (explanation see Fig. 8)

Fig. 3 Major tectonic elements which influenced the Ottnangian evolution of the Carpatho-Pannonian region (explanation see Fig. 8)

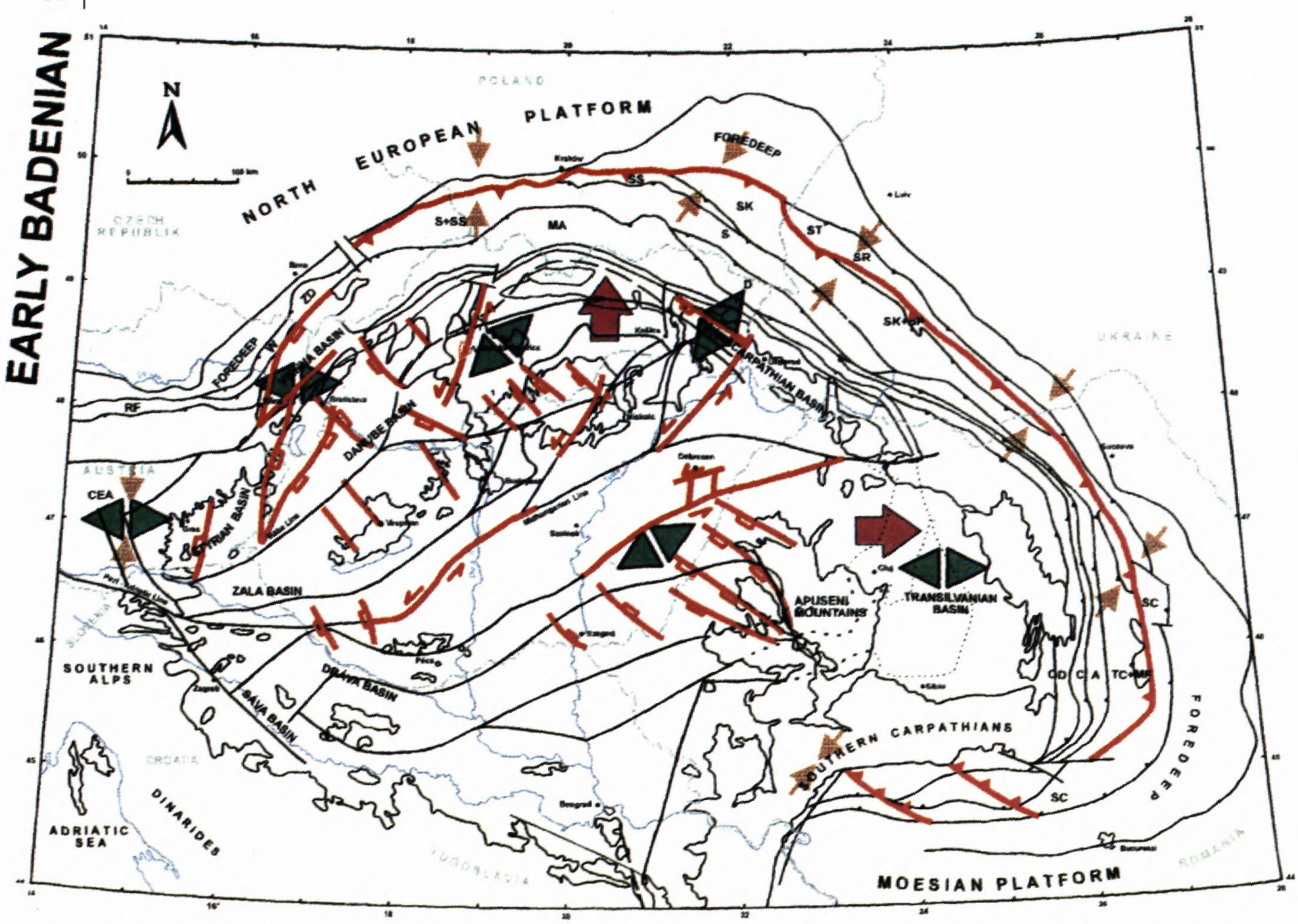

Fig. 5 Major tectonic elements which influenced the Early Badenian evolution of the Carpatho-Pannonian region (explanation see Fig. 8)

The stretching of the TISZA - DACIA unit in the Great Hungarian Plain and Transylvanian Basin, where the E - W oriented extension was documented (Csontos and Horváth 1995, Huismans et al. 1997), was induced by the accelerated subduction in the Eastern Carpathian front during the Intra Badenian phase (Micu 1990). We presuppose, that the extension in the Great Hungarian plain basement and the Transylvanian Basin was compensated by a slight clockwise rotation of eastern part of the microplate during this time. This idea is supported also by the Early Badenian tectonic pattern, with NE - SW to ENE -WSW oriented sinistral strike slips along the Mid Hungarian line and by the Early Badenian NW - SE stretching compressive structures and folds in the Getic depression (Matenco 1997).

The Late Sarmatian-Early Pannonian counter clockwise rotation of the Transcarpathian subunit accompanied by slight clockwise rotation of the Dacia subunit

The Late Badenian and Sarmatian evolution of the Carpathians was controlled by compression in front of the orogen (subduction), which led to the accretion of the Skola - Skiba - Tarcau and Borislav - Pokuty - Marginal Folds nappe pile at the active front of the Carpathians, thrusted over the Sambor - Rozniatov and Subcarpathian Neogene units (Oszczypko and Slaczka 1989, Micu 1990).

The subsurface load of the downgoing slab (Krzywiec and Jochim 1997) accelerated the foredeep subsidence before the front of the Carpathians (Kováč et al. in press.). At the end of the Badenian the Skola and Borislav - Pokuty units (in this time acting as a homogenous sheet) were thrusted over the Sambor - Rozniatov unit. It is important to note, that the last thrust of the Outer Western Carpathian front over the foredeep took place after the Early Sarmatian (Oszczypko and Slaczka 1989).

This process was followed by the subduction retreat in front of the Eastern Carpathians, where the accelerated thrust tectonics started during the Early Sarmatian. The Intra Sarmatian - Moldavian tectonic phase was accompanied by large overthrust of the Tarcau and Marginal Folds Nappes (in this time acting as a homogenous sheet) over the Subcarpathian Neogene unit, but the thrust of the Subcarpathian unit over the foredeep lasted till the end of the Pannonian (Sandulescu 1988, Micu 1990).

The Sarmatian thrust tectonic in the Outer Moldavides shows a radial pattern of the paleostress field, with NE - SW oriented compression in the northeast, with E - W

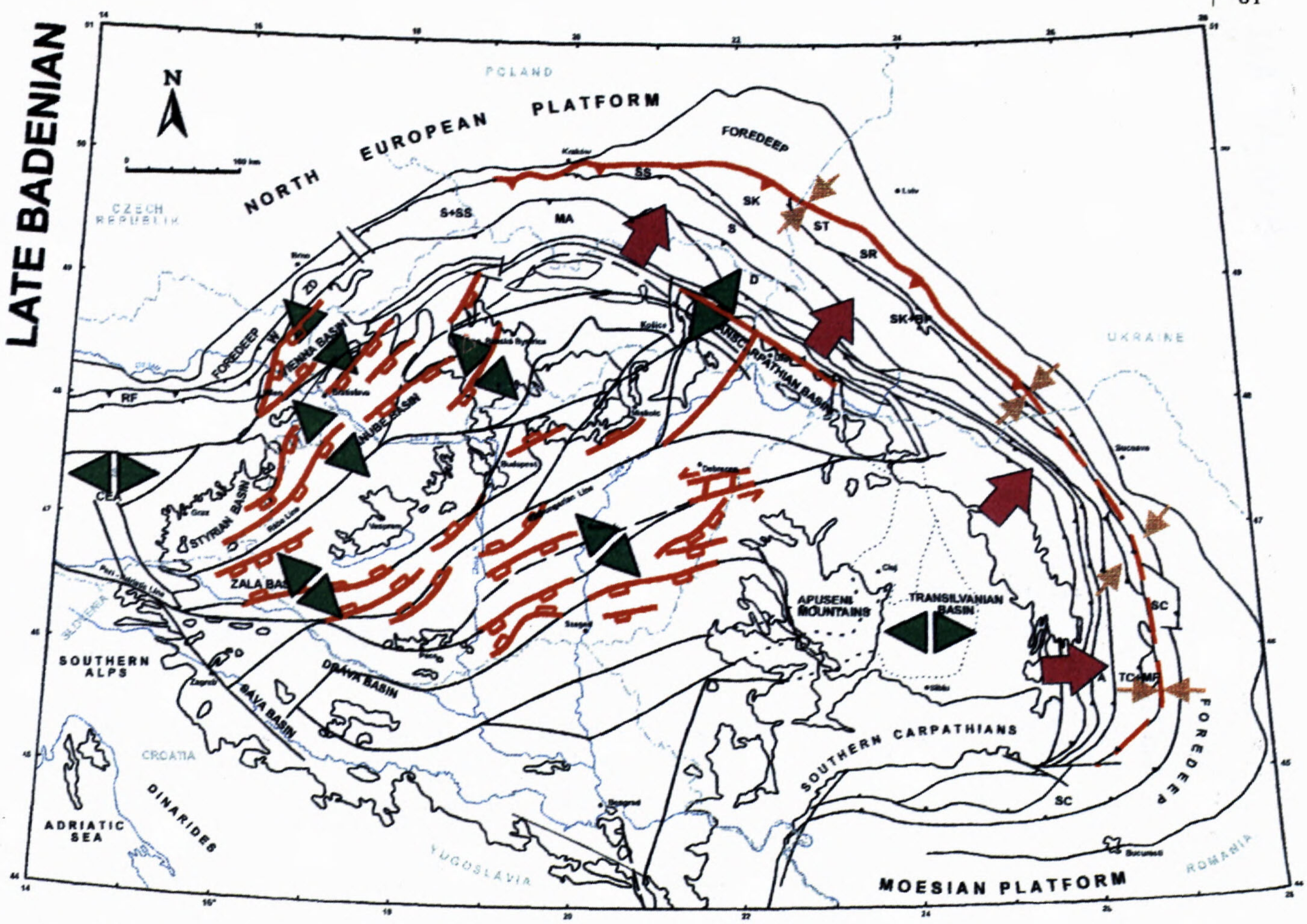

Fig. 6 Major tectonic elements which influenced the Late Badenian evolution of the Carpatho-Pannonian region (explanation see Fig. 8)

oriented compression in the east and with NW - SE oriented compression in the south (Matenco 1997).

The Late Badenian back arc extension was associated with updoming of the mantle masses accompanied by the areal type calc - alkaline volcanism (Pécskay et al. 1995). Meanwhile the volcanic chain in the hinterland of the Eastern Carpathians reached a character of island arc type volcanites during the Late Badenian and Sarmatian (Lexa et al. 1993).

It is important to note that the extension in the Pannonian Basin System during the Late Badenian shows different structural patterns in the east and in the west (Fig. 6).

In the western part of the Pannonian Basin System a NW - SE oriented extension controlled the function of NE - SW to NNE - SSW oriented normal and listric faults in the Danube Basin and intramontane basins of the Western Carpathians (Nemčok and Lexa 1990, Kováč et al. 1997). Very similar structural pattern can be observed along the western part of the Mid Hungarian line and in the Great Hungarian Plain (Csontos 1995).

In the east, a NE - SW to E - W oriented extension dominated in the Transcarpathian and Transylvanian Basins (Kováč et al. 1995, Huismans et al. 1997).

During the Early Sarmatian the structural pattern changes in the Carpatho - Pannonian region (Fig.7). In the northern and central part of the Western Carpathians a slight NE - SW oriented compression activated the ENE - WSW oriented sinistral strike slips during the active elongation of the Western Carpathians (Hók et al. 1995, Kováč et al. 1997). But the documented Early Sarmatian paleostress field with E - W oriented compression was followed by NW - SE oriented extension in the NW part of the Transcarpathian depression, i.e. in the East Slovakian Basin (Kováč et al. 1994, 1995).

In the TISZA - DACIA superunit the Sarmatian uplift led to ceasing of sedimentation in the Great Hungarian Plain (Meulenkamp et al. 1996). In the Transylvanian Basin the Sarmatian E - W extension (Huismans et al. 1997) was followed by NE - SW contraction (Matenco 1997).

Summarizing the above discussed facts, we infer that the rotation of the Transcarpathian depression basement took place due to Early Sarmatian subduction pull in the Western to Eastern Carpathians junction followed by the Late Sarmatian to Early Pannonian push of the slightly clockwise rotating eastern part of the Tisza-Dacia microplate, which was in this time influenced by the pull of the subduction in the southern part of the Eastern Carpathians.

The main tectonic structures accommodating the counter clockwise rotation of the Transcarpathian subunit were the NW - SE trending sinistral strike slips and the ENE - VSW to NE - SW oriented normal faults active

SARMATIAN

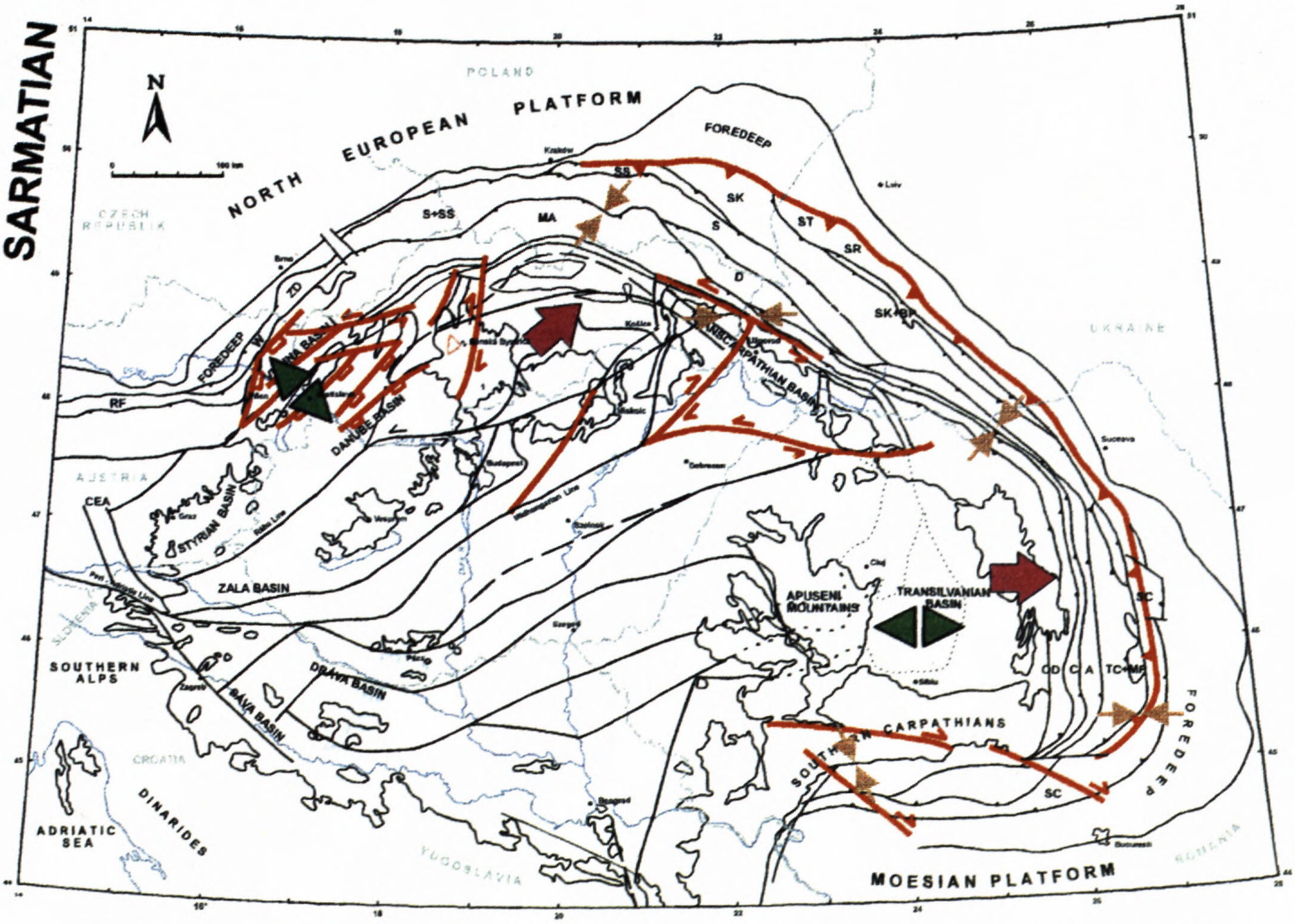

Fig. 7 Major tectonic elements which influenced the Sarmatian evolution of the Carpatho-Pannonian region (explanation see Fig. 8)

in NW - SE oriented extension in the Transcarpathian depression during the Late Sarmatian and Early Pannonian.

It seems that the counter clockwise rotation of the Transcarpathian subunit is contemporaneous with an Early Pannonian compressive event in the western part of the Intra Carpathian region (Fig.8): the change of paleostress field from NW - SE extension to NE - SW compression in the East Slovakian Basin occurs when the NW - SE oriented extension changes to N - S compression in the Central Western Carpathians (Hók et al. 1995, Kováč et al. 1994, 1995).

Following the above mentioned N - S oriented compression in the Central Western Carpathians we can observe the structural pattern formed by the same paleostress field in the Transdanubian Central range, Sava fold zone or Mecsek Mts., where E -W to NE - SW oriented folds and thrust are reported (Csontos et al. 1991, Csontos and Horváth 1995) and can be considered also as the compensation structures to the youngest rotation of the Intra Carpathian region.

The whole picture can be completed by E - W compression in the Eastern Alps (Pereson and Decker 1997) and E-W contraction in the Transylvanian Basin (Huismans et al. 1997).

The Upper Miocene period in the Carpatho - Pannonian region started with above mentioned slight rifting phase and was followed by large postrift thermal subsidence in the Pannonian back arc domain. Active subduction retreat is documented only in the southern part of the Eastern Carpathians. So far no paleomagnetic rotation was documented during this period.

Conclusions

The results of palinspastic reconstruction of the Carpatho - Pannonian region evolution during the Miocene, together with paleomagnetic investigations indicate:

- the large rotation of the TISZA - DACIA microplate must have taken place partly before and partly after the Early Miocene (Eggenburgian excluded)
- the large Early Miocene (Ottnangian) counter clockwise rotation of the ALCAPA microplate (40°-50°) was generated mainly by the Western Carpathians subduction pull
- the Early Badenian counter clockwise rotation (20° - 30°) of the Western Carpathians, the Pelso (and the northwestern part of the Tisza subunit) was due to the Western Carpathian subduction pull compensated by the initial rifting in back arc basin area

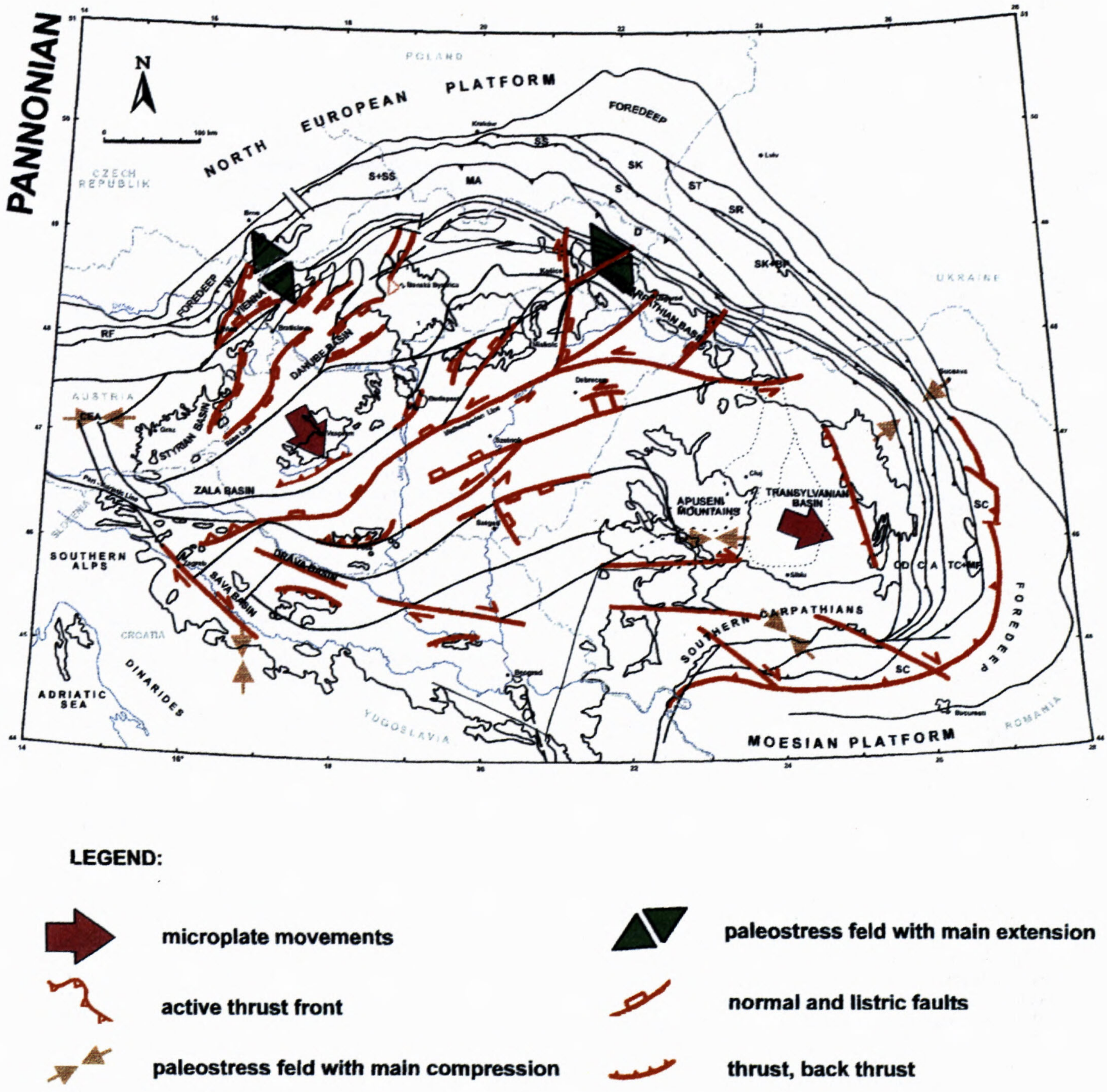

Fig. 8 Major tectonic elements which influenced the Pannonian evolution of the Carpatho-Pannonian region

- the palinspastic reconstruction requires a Badenian to Sarmatian slight clockwise rotation of the Apuseni Mts. and Dacides, due to the updoming of mantle masses in the back arc basin and the subduction retreat in Eastern Carpathians
- the Late Sarmatian-early Pannonian counter clockwise rotation (30° - 40°) of the Transcarpathian subunit reflects the last Western Carpathians overthrust in the north and twisting of the TISZA - DACIA superunit in the south
- In the Eggenburgian through Early Pannonian time period compressive, extensive and rotational events are recognized to have occured three times, always in the same order.

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