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The reason of the faults orthogonal relationship in the Western Carpathians basins and depressions

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Abstract. The structural trend of the Neogene depressions in the Western Carpathians is usually controlled by the youngest fault systems, which participated on their opening or were sin-sedimentary with the basin filling. For the Vienna basin and for the partial depressions of the Danube basin (Blatné, Rišňovce and Komjatice) such structural trend controlling faults are faults with NE-SW strike. Roughly, from N-S oriented Central Slovakian Fault Belt toward the east the orientation of the controlling fault systems is changed and in the South Slovakian depressions, especially in the Ipeľská kotlina Depression, the structural trend is controlled by faults with NW-SE and NNW-SSE strikes. The reason of the orthogonal relationship of the mentioned fault systems is in various age of origin, and/or activity of the faults and in the relationship to the rotation of viscoelastic lithosphere blocks. The faults with NE-SW strike, controlling the structure of the Vienna Basin and the northern promontories of the Danube Basin, originated or they were reactivated since the Middle Badenian, when the rotation of the block was already finished. The faults with NW-SE and NNW-SSE strike in the South Slovakian depressions originated or they were reactivated in the Early Miocene and/or in the Early Badenian, respectivelly. Their origin or activity was preceded by the block rotation, or the faults with NNW strike had been formed before the second phase of the rotation. The fact, that after the Early Badenian the South Slovakian depressions did not subsided caused, that the faults originating in the Middle Miocene paleostress field with the maximum compression in the NE-SW direction did not have controlling role on the structure of depressions.

Key words: Western Carpathians, Neogene sedimentary basins, fault structure, paleostress, block rotations.

Introduction

Faults breaking down the basins and depressions of Western Carpathians usually create fault systems of certain strikes. However, in majority of basins and depressions there is one dominating fault system, it breaks down or overlaps others. It is usually the youngest fault system synsedimentary with basin filling, which creates characteristic structural trends of basins/depressions. In the western part of the Western Carpathians the dominating fault system has NE-SW strike (Vienna Basin, Danube Basin – its northern promontories: Blatné, Rišňovce, Komjatice and partly also Želiezovce depressions). Roughly, eastward from the Central Slovakian Fault Belt running in N-E direction the strike of controlling fault system changes. The South Slovakian depressions, especially Ipeľská kotlina Depression, have the structural trends controlled by faults with NW-SE or NNW-SSE strikes (fig. 1). New information about faults opening and structural modelling of the young Western Carpathians basins, especially information obtained by structural measuring of the brittle deformations, as well as results of paleomagnetic researches, help to understand reasons of orthogonal relationship of the fault systems controlling the recent basins/depressions structure.

Time and reasons of origin of NE-SW fault system – the most significant fault system of the Vienna and Danube basins

Faults, which have opened Vienna Basin in transtensional regime and longitudinally split up the basin to series of horsts and grabens (Buday in Buday et al., 1967; Gaža et al., 1983), are synsedimentary with Badenian and Sarmatian basin filling. Stress field recorded by the brittle deformations of deposits from both sides of the Malé Karpaty Mts. gave birth of faults and stimulated their activity in this period. In the Middle Miocene paleostress field the direction of the main compression was NE-SW or NNE-SSW and the direction of the extension was NW-SE (Marko et al., 1991; Marko et al., 1995). This stress field, invoked activity or birth of faults with NE and NNE strike (fig. 2).

The Vienna Basin had its first stage of tectonic development in Lower Miocene. In Late Karpatian and Early Badenian it had suffered structural remodelling. However, the depressions at the northern margin of the Danube Basin - depressions Blatné, Rišňovce and Komjatice started to open in Middle and Late Badenian, in the same stress field in which the Vienna Basin was opened after the structural remodelling. It means that the depressions were opened under the control of faults with NE-SW to NNE-SSW strikes (fig. 3), (Adam & Dlabač 1961; Gaža et al., 1985). The orientation of these faults as well as orientation of the depressions, which were confined by the faults, was final. Rotation of lithospheric blocks during Miocene (proved by paleomagnetic measurements, the total value of the rotation was about 60-70° CCW) ceased in Early Miocene (Kováč & Túnyi, 1995). The paleomeridians of younger rocks are identical with the recent ones, what means that they did not rotate.

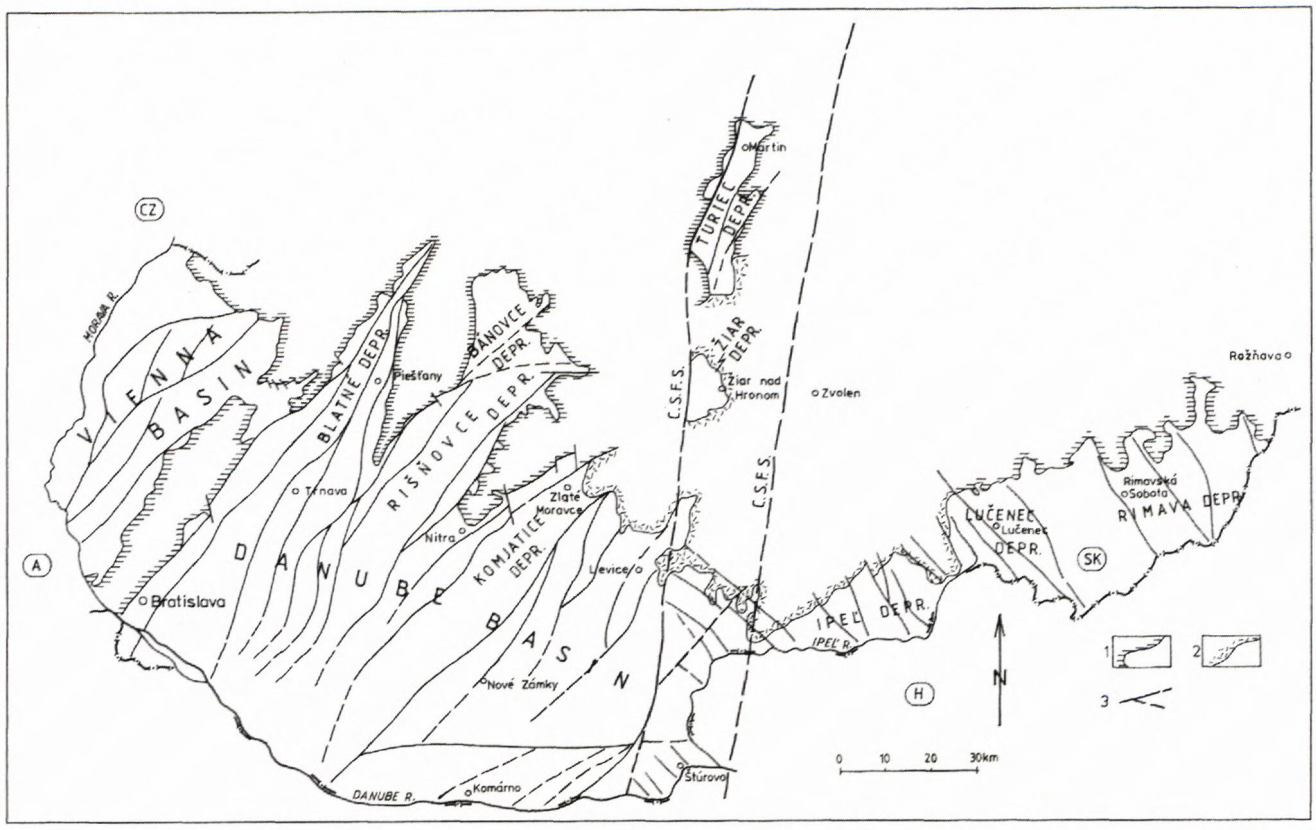

Fig. 1. Dominant faults of the Vienna and Danube basins and South Slovakian depressions.
The relationship of both Vienna and Danube basins faults with faults in South Slovakian depressions is orthogonal. Westward of the Central Slovakian Fault Belt (CSFB) the faults have NE-SW, NNE-SSW strike, and eastward of the belt the prevailing fault strike is NNW -SSE, NW- SE.
Explanations: 1 – present day margin of the Neogene basin and depressions, 2 – neovolcanics at the margin of basins and depressions 3 – faults

It must be remarked that mechanism of NE-SW fault system activity was not equal in the Vienna Basin and in partial depressions of the Danube Basin. In Vienna basin, which lay near subduction zone of Outer Carpathians, the NE-SW fault system opened the basin by pull-apart mechanism (Royden, 1985; Vass et al., 1988), whereas faults with the same strike in partial depressions of the Danube Basin originated or revived under heterogeneous stretching of the lithosphere. The thermal stretching of the lithosphere in the central zone of the Danube Basin passed through to basin outer zone, where this effect caused break down of the upper crust and opening of the depressions (Vass & Pereszlényi, 1998). The faults were mainly normal and only some of them were strike-slips.

In the South Slovakian depressions and south-eastern part of the Danube Lowland, where Štúrovo Paleogene crops out, the dominating fault system has strike NW-SE to NNW-SSE (Seneš, 1960; Vass et al., 1979; Vass & Elečko et al., 1989, 1992). Although the faults with NW strike were active in Quaternary, they are older. Faults, which split up the Štúrovo Paleogene and Gerecse Hills, were brought to existence or reactivated in Middle to Late Paleogene in the stress field with maximum compression in NW-SE, or WNW-ESE direction and extension in the NE-SW direction. In the Gerecse Hills there were normal or normal – strike-slip faults, which controlled Eocene and Oligocene sedimentation (Fodor, 1992). According to Seneš (1960) faults with NW-SE strike splitting up Štúrovo Paleogene deposits were created or reactivated before Lutetian (after biostratigraphical revision in Early Lutetian, Samuel & Váňová, 1967) and they were active as synsedimentary faults until the end of Eocene, some of them also during Oligocene. In this period, probably in stress field, which was estimated from the measurements in the Gerecse Hills, were born also faults confaining the buried graben of Cerovo-Dačov Lom, which are not recorded in present day structure of Ipeľská kotlina Depression and Krupinská planina Plateau (Vass et al., 1993). Faults of NW-SE system, expressive in the recent structure of the Ipeľská kotlina Depression and also in the structure of two other depressions (Lučenská kotlina and Rimavská kotlina), were born in the Early Miocene paloestress field characteristic by the extensions in NE-SW direction and by compression in vertical position (Vass et al., 1993). In this stress field Dačov Lom Graben was generated. The faults confining the graben controlled the distribution of depositional centres of Číž, Krupiná and Lučenec formations (Kiscelian and Egerian), influenced deposition of Bukovinka Formation, especially rhyodacite tuffs within the formation (late Eggenburgian) and coal seams within the Pôtor Member of Šalgótarján Formation (Ottnangian). The coal seams in the most

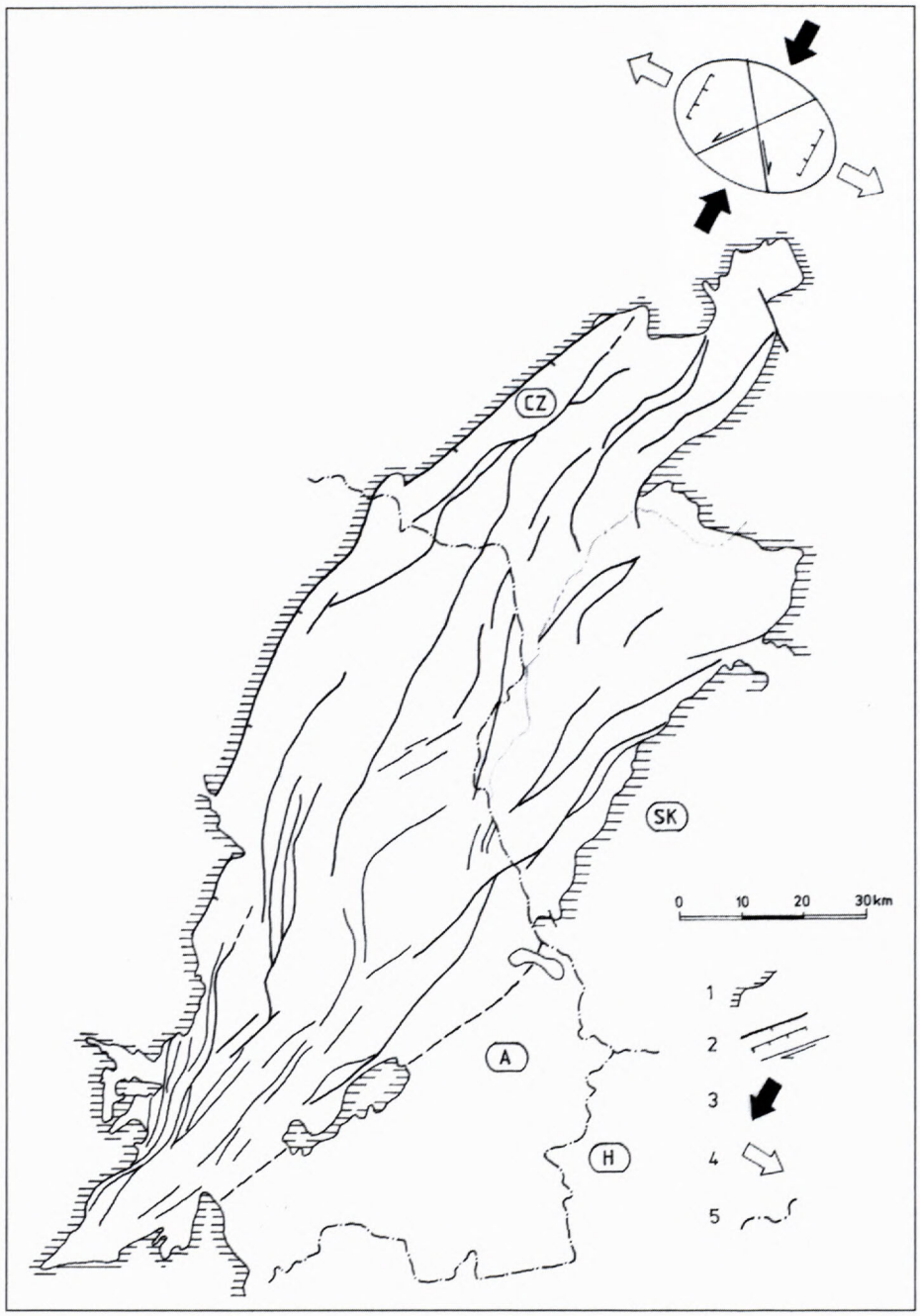

Fig. 2. The fault system of NE-SW direction controlling the most expressive grabens and horsts of the Vienna Basin (normal faults and strike-slips; after Buday, Hronec, Jiříček, Kocák, Friedl, Grill, Janoschek, Unterwelz compiled by Jiříček & Wessely 1989, in Hamilton et al., 1990). The faults were born or reactivated in Middle Badenian paleostress field, the diagram (after Marko et al., 1995) see in upper right corner of the figure.
Explanations: 1 – margin of the basin, 2 – normal and strike-slip faults, 3 – direction of the maximum compression, 4 – direction of the maximum extension, 5 – state borders between Slovakia (SK), Hungary (H), Austria (A) and Czech Republic (CZ).

complete development (i.e. three seams) are spread in the central and eastern part of the Dočov Lom Graben. In the graben there was also the main deposition centre of the Modrý Kameň Formation (Karpatian) in the outhern Slovakia (fig. 4). The faults of the eastern wing of the graben must been active after Karpatian and before Badenian, because they controlled erosional truncation of the Lower Miocene deposits at the eastern edge of the Ipeľská kotlina Depression. So, the Badenian deposits lay discordantly upon various members of Modrý Kameň or Šalgótarján formations.

During the Early Badenian in the paleostress field with maximum compression in the NNW-SSE direction the Želiezovce depression with axis of NW-SE direction in the eastern part of the Danube Basin was formed. Its edges were probably controlled by faults of the same direction (Vass et al., 1993). The depression was confined by the faults especially at its northeastern edge, where they confined the partial Semerovce depression, the Santovka-Turovce Horst and the Plášťovce Depression. The synsedimentary activity of the folts confining the Santovka - Turovce Horst is confirmed by the fact, that the horst as barrier hampered the dense currents of the volcanidetritic material running down the slopes of rising Štiavnica Stratovolcano, and the horst prevented its spreading over the Želiezovce Depression as turbidity currents. The material from dense currents was deposited in the Plášťovce Depression as Plášťovce Member (Vass, 1971; Vass & Krystek, 1975; Vass et al., 1995).

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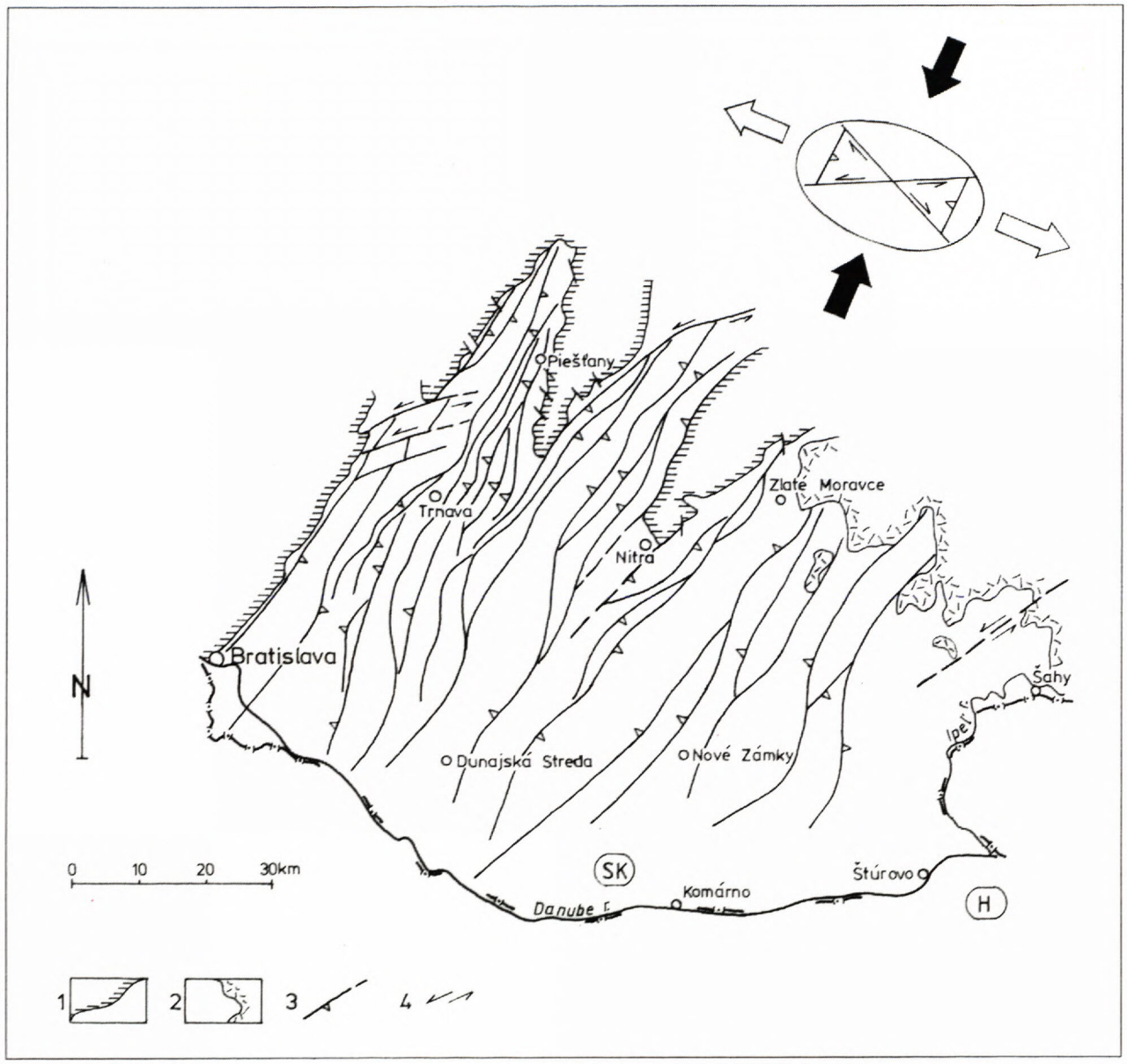

Fig. 3. The dominating fault system of Danube Basin (Pěničková & Dvořáková in Gaža, 1985) born or reactivated in Middle - Late Badenian paleostress field (Marko et al., 1991; Vass et al., 1993).
Explanations: 1 – today basin margin, 2 – neovolcanics at northeast basin margin, 3 – normal fault, 4 – strike-slip

The normal faults with NNW-SSE or NW-SE strike were generated in South Slovakian depressions during Early Badenian in the stress field with the main compression in the NNW-SSE or NW-SE direction (in today coordinates). Most of them epigenetically broke up the pre-Badenian rocks and modelled young expressive structure of the South Slovakian depressions. These faults split up the Rimava, Lučenec and Ipeľ depressions into series of horsts and grabens (fig. 5; Vass, et al., 1979, 1981; Vass & Elečko, et al., 1989, 1992). Among them the Strháre - Trenč Graben is the most significant (Vass in Vass, et al., 1979; Vass & Elečko, et al., 1989, 1992). In this graben we could date the fault activity. The faults were controlling the sedimentation of the volcaniclastic material of Early Badenian Vinica Formation (Vass, 1963). On the crossings of the Šahy-Lysec volcani-tectonic zone with the faults of NNW-SSE strike there were opened ascending ways for andesite magma, products of which built up already mentioned Vinica Formation and also younger Opava and Lysec formations (Konečný in Vass et al., 1979).

Remanent magnetism measurements of Cenozoic rocks in the area of the Eastern Alps, Carpathians and Pannonian basin (ALCAPA) proved, that during the Cenozoic there was rotation of blocks of viscoelastic lithosphere. In the western part of the Western Carpathian arch the left (CCW) rotation achieved the value 42°-80° (Túnyi & Kováč, 1991; Kováč & Túnyi, 1995). The referred authors originally thought about two pulses of rotations, after Eggenburgian and after Karpatian. Leter on they thing about one rotation pulse, at the boundary between Early and Middle Miocene. Thus, in the given area

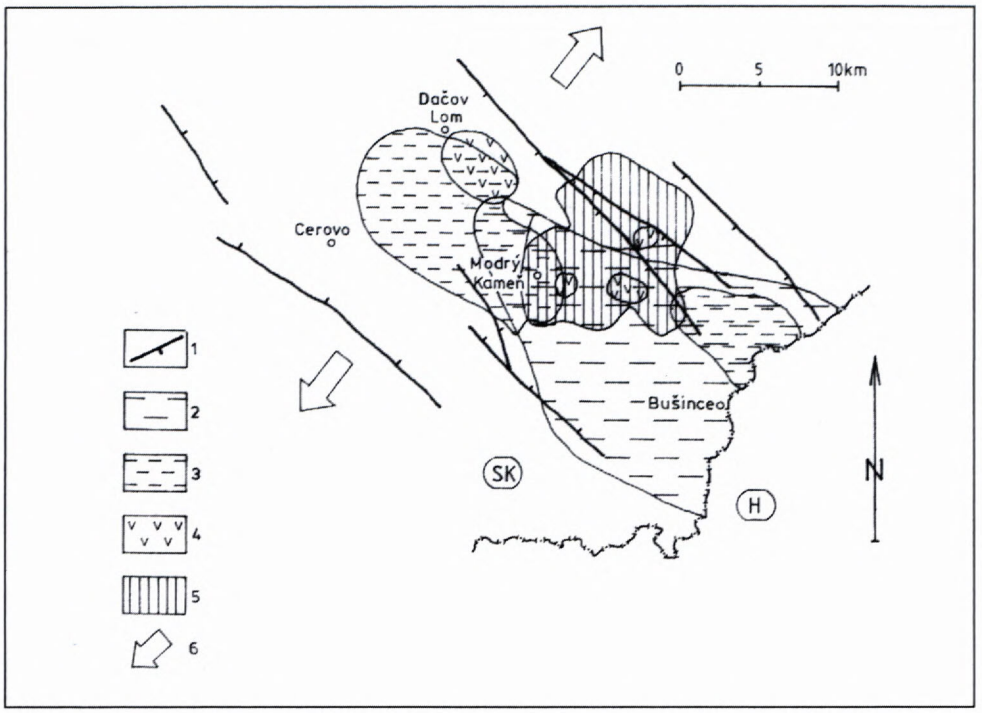

Fig. 4. The Dačov Lom Graben (Vass in Vass et al., 1979), originated by the Early Miocene extension (present day coordinates). The graben's faults controlled depositional centres of Číž, Krupiná and Lučenec formations (Kiscellian and Egerian). They influenced the sedimentation of the Bukovinka Formation (Eggenburgian), the coal seams of Šalgótarján Formation (Ottnangian) and the deposition centres of Modrý Kameň Formations (Karpatian).
Explanations: 1 – fault, 2 – zone of maximum thickness of Číž, Krupiná and Lučenec formations (Kiscellian and Egerian, Oligocene to oldest Miocene), 3 – maximum accumulation of Modrý Kameň Formation, 4 – rhyodacite tuffs of Bukovinka Formation, 5 – area of the Pôtor Member full sequence extension (3 seams) in Šalgótarján Formation, 6 – direction of extension

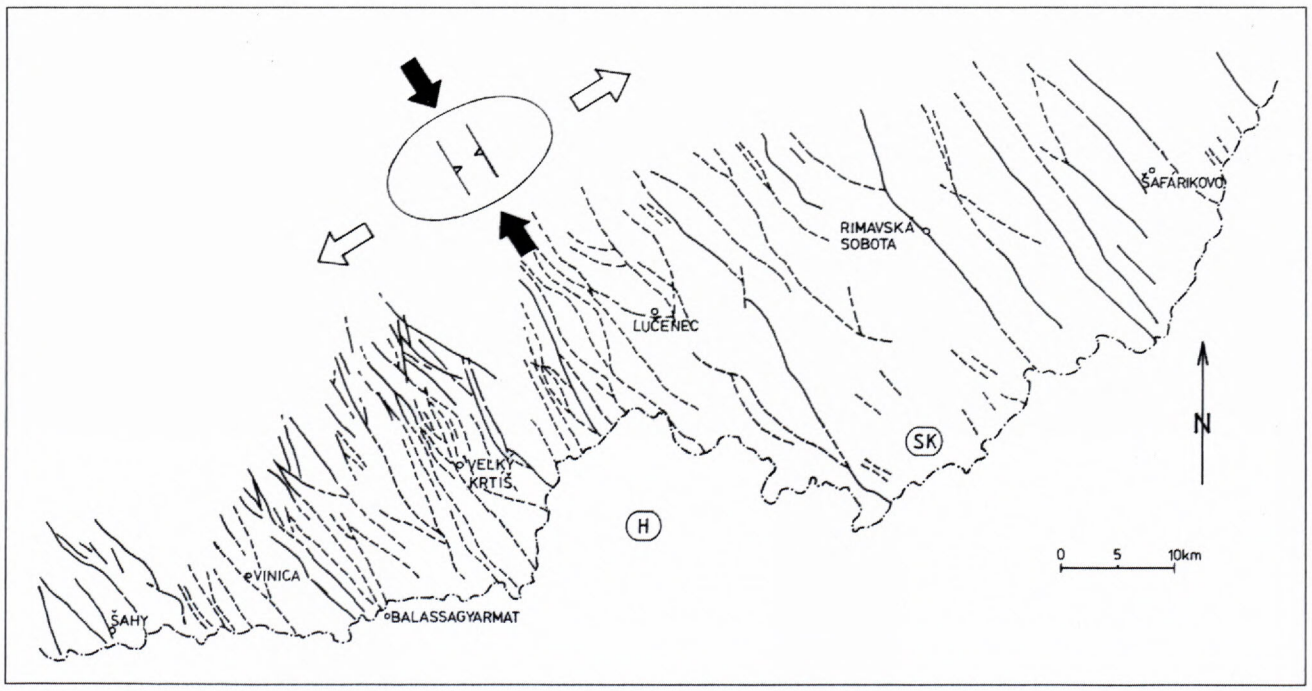

Fig. 5. Faults of South Slovakian depressions dominating in present day structure (after maps in scales 1:50 000 by Konečný et al., 1979; Elečko et al., 1985; Vass et al., 1992) and Early Badenian paleostress field (Vass et al., 1993) which caused the faults birth or reactivation (in recent coordinates).

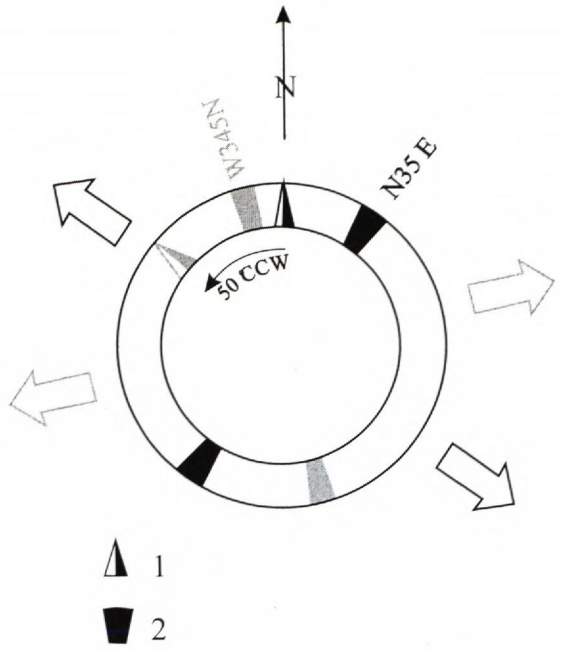

Fig. 6. The early Miocene extension (empty arrows) in the NW-SE direction. The brittle deformations and normal faults, which were generated or activated by the extension, had the general strike N35E (i.e. NE-SW). The 50° contrclockwise rotation (CCW: Márton et al., 1995, 1996) reoriented the brittle deformations and faults to the direction W345N (i.e. NNW-SSE) before Middle Miocene. The direction and size of rotation,the ratated paleomeridian, structural trend and apparent extension after the rotation are on the figure in light-grey colour.
Explanations: 1 – direction of paleomeridian, 2 – structural trend.

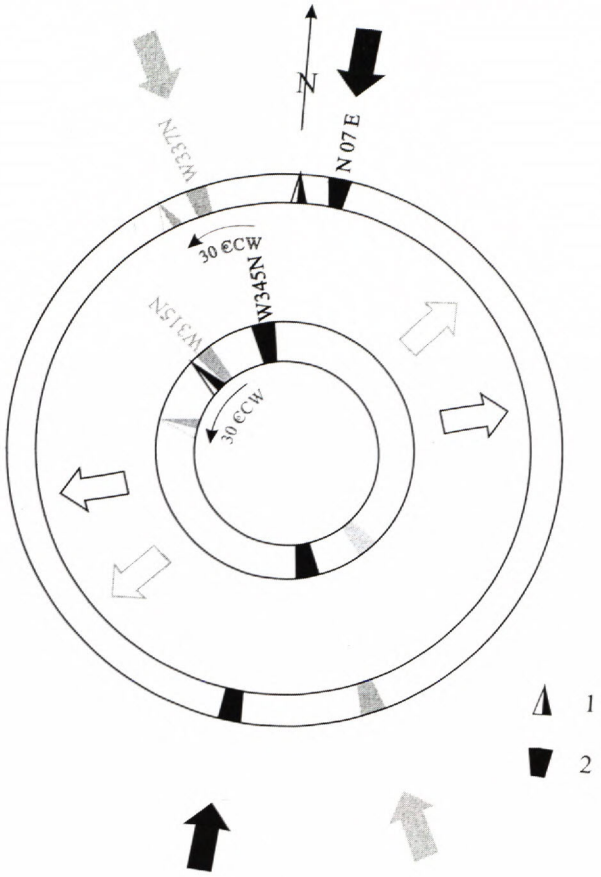

Fig. 7. The Early Badenian compression (full arrows) in the direction N07E.The brittle deformations and normal faults, formed due to the compression, had the general direction identical with the direction of the maximum compression. The 30° contrclockwise rotation (CCW, Márton 1995, 1996) during or at the end or Early Badenian turned the Early Badenian brittle deformations and faults to the direction W337N (NNW-SSE, outer circle) and Early Miocene brittle deformations and faults (inner circle) to the direction W315N (NW-SE). Direction and the size of the rotation, the rotated paleomeridians, both structural trends, apparent Early Badenian compression and Early Miocene compression are in light-grey colour.
Explanations:1 – direction of paleomeridians, 2 – structural trend

there were conditions for at least one rotation. It happened before the Middle Miocene opening of partial depressions at the north of the Danube Basin, i. e. before birth, or reactivation of faults, which the opening enabled.

In the area of the Southern Slovakia and Northern Hungary (westward of the Hornád Fault Zone) there were also Miocene rotations of viscoelastic lithosphere block. Two phases of rotations were identified, with the total rotation angle value 80° (Márton et al., 1995, 1996; Márton & Márton, 1996). The first rotation phase (50° CCW) took place in Late Ottnangian, or after Ottnangian in extension conditions with vertical compression (see above), i.e. during a stress relax, what is kinetic situation favourable for large block rotation.

The second rotation phase 30° CCW took place after Karpatian and before Middle Badenian. The rotation was preceded by the period of the region uplifting, what is proved by the erosional truncation of Early Miocene deposits and discordant position of Early Badenian rocks on various members of Modrý Kameň and Šalgótarján formations (Vass in Vass et al., 1979), as well as by degree of the smectite illitisation in the Plachtince Clay, a member of the Šalgótarján Formation. This indicates 600 m truncation of Karpatian and Ottnangian deposits before Early Badenian (Vass & Šucha, 1994). During Early Badenian the forces controlling the uplift retreated. The area of Ipeľská kotlina Depression starts to subside again and thank to this the sea penetrate into depression up to Sahy - Lysec Zone, where the andesite volcanism was activated. Probably during Early Badenian a new stress turnover appeared, the sea retreated and simultaneously the building up of Vinica andesite formation was over and its erosion began.

This period was favourable for left rotation about 30° CCW. The faults controlling sedimentation during Early Miocene from the direction cca E35 N, in which they originated, or were reactivated under the influence of the NE-SW extension, turned by 50° CCW rotation into new direction cca N345 W (fig. 6). After the first and before the second rotation phase, during Early Badenian the pa-

Fig. 8. a) Mutual spatial relationship of the Early Miocene (light-grey) and Early Badenian faults (black) in the Ipeľská kotlina Depression .b) the general trend of Early Miocene (light-grey) and Early Badenian faults is oblique under the angle 22°

leostress situation was changed. The maximum extension was oriented in the direction cca N-S (N 07 E). In such stress field new normal faults originated parallel with the direction of the maximum compression. After the second rotation 30° CCW the older Early Miocene faults were turned into direction N315 W and younger Early Badenian into the direction cca N337 W (fig. 7). This spatial relationship of faults at the Southern Slovakia is obvious in the Ipeľská kotlina Depression, where older faults forming the Dočov Lom Graben have NW-SE direction and the younger faults synsedimentary with Early Badenian forming the Strháre-Trenč Graben and also other blocks have NNW-SSE strike (fig. 8). This fact was noted by Vass (1963), when he described the mutual relationship of older and younger faults in the area of Strháre – Trenč Graben as a structure of normal faults crossing. One of the possible explanations of such structure origin is the above mentioned time schedule of fault generation in the relation to left rotation of viscoelastic lithosphere block.

It is obvious from the above, that the faults in South Slovakian depressions with NW strike originated in Early Miocene before the first left block rotation of viscoelastic lithosphere. In the period of Early Badenian between the first and the second phase of the rotation faults with NNW strike originated.

After the rotations, the whole South Slovakian - North Hungarian domain was uplifted, what is proved by the fact, that in this domain the younger

Middle Miocene deposits (Middle Badenian - Sarmatian) as well as the Late Miocene and Pliocene lacustrine deposits, massively developed in South Hungary and in Danube Basin are missing, or they do not form considerable accumulations, with exception of the southern margins of uplifted domain.

The paleostress field for the period younger than Early Badenian in the Central West Carpathians was characteristic by a compression in the NE-SW direction. Doubtlessly this direction found responds also in uplifted South Slovakian - North Hungarian domain, where the normal faults of NW-SE direction were created or reactivated. However, these faults broke up the domain epigenetically and they did not have any opportunity to act as synsedimentary faults. Thus as a dominating structural elements in the South Slovakian Depressions the faults of NW-SE and NNW-SSE strike remained. Transversal faults (NE-SW strike) are less significant, although there are proves about their activity during Quaternary (river valleys orientation, asymmetry of river terraces). Nevertheless, also the faults with NW-SE strike were active during Quaternary (Vass & Elečko eds. 1989, 1992).

Conclusion

The reason of faults orthogonal relationship in the Western Carpathians determining dominating structure in young basins and depressions westward and eastward of Central Slovakian Fault Belt (fig. 1) is various age of the faults. Faults of the NE-SW fault system of the Vienna Basin as well as the faults of Blatné, Rišňovce and Komjatice depressions in the Danube Basin or faults of the horsts Malé Karpaty, Považský Inovec and Tríbeč Mts. and of the Levice Horst were born or reactivated in Middle Badenian and were active as synsedimentary faults until the end of Sarmatian, partly also in Late Pannonian. The matter is about faults origin or activity after the rotation of viscoelastic block of the western domain of the Western Carpathians. Those faults controlled synrift stage in the outer zone of Danube (thermal) basin.

The faults with NW-SE and NNW-SSE strike, being the most important structural element of the South Slovakian depressions were born or reactivated in Early Miocene and in Early Badenian. Their original orientation was about NE-SW. Due to rotation of viscoelastic block of lithosphere by 80° CCW the faults were turned to recent NW - SE direction. In the Early Badenian, after the first rotation phase the normal faults originated having approximate N-S strike. Due to the second rotation phase by 30° CCW they were turned to the recent position, thus their recent orientation is NNW-SSE.

After finishing the left rotation the whole South Slovakian - North Hungarian domain began to rise. In the paleostress field with main compression of NE – SW direction (in which the Western Carpathians were since the Middle Badenian) not only the crust of newly formed Danube Basin but also the crust of South Slovakian - North Hungarian domain were broken up by parallel faults with main compression. Because the domain was uplifted, any important accumulation of Middle Miocene marine and Late Miocene - Pliocene lacustrine deposits occurred here, with exception of the southern marginal areas. Thus the faults with NE-SW strike only epigenetically broke up the domain and they did not controlled syngenetic accumulation of deposits. Thus as the dominant structural element in the South Slovakian depressions are the faults of NW-SE and WNW-SSE strike, i.e. faults which are in orthogonal relation to the main faults controlling the post - Early Badenian sedimentary filling of depressions on the Danube Basin northern margin.

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