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Danube Region Environmental Geology Programme DANREG — Explanatory Notes | Editor: G. Császár

Tectonic Map

Antonyina DUDKO[1]
Julian PISTOTNIK[2]
Mihal ELEČKO[3]
Dionyz VASS[3]
Jozef HÓK[3]
Jozef VOZÁR[3]
Alexander NAGY[3]
Ján ŠEFARA[3]

[1]Geological Institute of Hungary
H–1143 Budapest, Stefánia út 14.

[2]Geological Survey of Austria
Rasumofskygasse 23, A–1031 Vienna

[3]Geological Survey of Slovak Republik
Mlynská Dolina 1, 817 04 Bratislava

Introduction

The Tectonic Map shows the structure of the area including structural elements, tectonic units as well as its tectonic activity in geological time and the nature of tectonic movements. The legend of the map was approved by all partners.

In the DANREG area the following regional geological units are partly or fully included: Danube Basin (geographically subdivided into Kisalföld (Little Hungarian Plain) and Danube Lowland, respectively), Vienna Basin, Ipel' Basin, Malé Karpaty (Little Carapthian Mts), Dorog and Zsámbék basins, as well as volcanic muntains such ad the Krupinská planina, Visegrád and Börzsöny Mts.

Several tectonic phases and main structural units bearing different structural elements have been distinguished in the area. The geological formations were merged according to the main phases. A reference number has been assigned to each major tectonic line.

General regional setting of the DANREG area

The basement of the Little Hungarian Plain and the northern Danube Basin can be subdivided into two major units: the Alpine–Carpathian belt (East Alpine–West Carpathian Nappe) in the western and northern parts and the Pelso Megaunit [in the *sense* of Fülöp *et al.* 1987, Fülöp & Dank (ed.) 1986, Dank & Fülöp 1990] of the Transdanubian Range (TR) in the southeastern part. The two units are separated from each other by the Rába–Hurbanovo Fault Zone (Vozár 1996) which is an important transform fault zone well known from seismic and magnetotelluric measurements.

The Rába Line traversing the basement of the Little Hungarian Plain and its north-eastern prolongation, the Hurbanovo–Diósjenõ Line constitute the main structural boundary between these units.

Recently, the model gained wide-ranging approval stressing that the Pelso Unit had acquired its present position after having been pushed away from the Alpine and Dinaride region during Palaeogene–Early Miocene time (Kázmér & Kovács 1985, Balla 1987, 1989a, Nagymarosy 1990, Csontos *et al.* 1992, Haas *et al.* 1995). The TR is considered to be a part of the Pelso Megaunit. In this unit are amalgamated lithospheric blocks escaped from the Central Alps and the NW Dinarides along large strike-slip faults: the sinistral Rába–Hurbanovo–Diósjenõ (25) bordering the Pelso Unit towards the N and the dextral Balaton Line (behind the DANREG area) towards the South.

The sinistral movement of the Pelso Megaunit along the Rába–Hurbanovo–Diósjenõ Line was connected with counter-clockwise block rotation (CCW, Balla 1985). Palaeomagnetic investigations indicated that the rotation took place in two pulses: the first by 50° at the end of Ottnangian, the second by 30° at the end of the Karpathian age and/or in Early Badenian (Márton *et al.* 1995, 1996; Márton & Márton 1996). The first stage of rotation may have been connected with the escape of the Megaunit from the Alpine area.

The main features of the present setting of the area were brought about in the Miocene. This period was characterised by transtensional basin evolution and calc-alkali volcanic activity. The most of the interpretable lineaments are also associated with this period.

The process of basin opening in the northern part of the basin had a character of an asymmetric lithospheric extension (Vass & Pereszlényi 1998). The extension style fits well with a model of heterogeneous lithospheric stretching (Coward 1986).

The southern Danube Basin, Little Hungarian Plain is considered to be a transtensional basin (Horváth & Royden 1981) with a pull-apart mechanism of basin opening (Royden 1988, Balla 1989a). Such a mechanism corresponds to the synrift phase of basin filling.

The Vienna Basin after the end of Alpine thrusting, from the Karpathian time opened by means of pull-apart mechanism in a palaeostress field with S–N compression. However, the faults responsible for its opening, neither penetrated deeper into the crust, nor did they intersect the crust, respectively (thin-skinned pull-apart; Royden 1985). In the Late Miocene to Pliocene transtensional and extensional tectonic regime characterised the area.

The subsidence of the Danube Basin during the Late Miocene and Pliocene was comparatively passive and is attributed to terminal postrift phase (Royden *et al.* 1983, Royden 1988, Horváth 1990, 1993).

Basic tectonic units and structural elements of the DANREG area

Sopron area

The pre-Cainozoic rocks of the Sopron area belong to the East–Alpine Units. They crop out in the Sopron Hills. The Grobgneiss Formation and Wechsel series at Fertõrákos have been submitted to amphibolite facies Variscan regional metamorphism (280–359 Ma, Fülöp 1990). The retrograde greenschist facies metamorphism is assumed to have taken place during the Austrian phase (92–124 Ma).

The pre-Tertiary rocks outcropping in the Sopron region reveal a basically SW dipping schistosity. The structural elements indicate a NNW oriented, last-phase nappe movement (Pahr 1991). A lineation of similar orientation (Vendel 1947, 1981) presents scarce folds (or rather flexures) with variable axis orientation.

One of the elements in the Neogene structure of Sopron Hills is the Jávor Basin confined by roughly N–S striking faults. The faults developed presumably in the Sarmatian (Pannonian) period, since a right-handed Pannonian synsedimentary fault of similar strike was identified east of the basin (Rosta 1993, Kõhida Line (34). In the vicinity of Sopron Hills Fodor *et al.* (1990) reconstructed for the Middle Miocene (Sarmatian) – Pliocene interval basically the same tensional stress field characterised by ESE–WNW direction.

Faults measured in the exposures of the Ligeterdõ Gravel Formation (Ottnangian) are also of roughly N–S strike. The Sopron Line (32) traverses the Sopron Hills separating its south-western part from the north-eastern one and bordering the Jávor Basin from the south. The Sopron Hills themselves are bordered in turn by the Kópháza Line (35) from the south-east constituting simultaneously the north-western boundary of the Nagycenk Basin. We assume that they are conjugated faults associated with the formation of Miocene basins.

Danube Basin

Basement of the basin

The pre-Neogene basement of the Little Hungarian Plain is composed mostly by metamorphic rocks.

The slightly metamorphic schist assemblage in the basement of the Mihályi Horst may be subdivided according to Balla [(ed.) 1993, 1994] into the Vaszar type as an unambiguous equivalent of the Transdanubian Range type Palaeozoic. The Mihályi schists are tentatively correlated with the Graz Palaeozoic. The Sausal Palaeozoic, or the Kõszeg Mesozoic are analogues of the mentioned formations and/or they are regarded to be of West Carpathian provenience. The Nemeskolta schists may have filled the dislocation zone associated with the Rába Line and might as well be made up by rocks of varied origin.

In the basement of the western part of the Little Hungarian Plain seismic profiles Pogácsás *et al.* (1991) delineated four, roughly N–S striking nappe boundaries on the basis of seismic profiles. One of them dips towards SE, E while the other three towards W, WNW. The E, SE dipping plane represents the northern prolongation of the nappe boundary traversing the eastern side of the Kõszeg Penninicum. The second one passes close to the axis line of Csapod Basin, whereas the third and fourth ones can be traced in the western and eastern limbs of the Mihályi Horst, respectively. Balla (1994) suggests that the nappes dipping opposite one against the other constitute a synform structure between the northern prolongation of the Kõszeg Hills and the Mihályi Horst. the same author also pointed out the discrepancies between the position of "nappe boundaries" on the map interpreted upon borehole data and seismic profiles, respectively, as well as between the extent of crystalline and slightly metamorphic rocks and the position of seismic "nappes". Nappe boundaries are indicated without age record. Alpine geologists (Pahr 1991, Koller & Pahr 1980) distinguish two phases in the adjacent region as Cretaceous (75 Ma B.P.) and Neogene (22 Ma B.P.) respectively.

The tectonic units of the Alpine–Carpathian Belt in the pre-Tertiary basement of the northern part of the Danube Basin are from the top to the bottom the Silicicum (*sensu* Mello 1979) from the Inner Western Carpathians; from the Central Western Carpathians the nappes of the Hronicum (prevailingly Late Palaeozoic of the ˇturec nappe), the nappes of the Fatricum (KríΩna Nappe *sensu* Andrusov *et al.* 1973), the Southern and Northern Veporicum (*sensu* Vozárová & Vozár, 1988) and the Tatricum (*sensu* Andrusov *et al.* 1973), which in the DANREG area are subdivided into three groups, the Tribeè, PovaΩsk˝ Inovec and Malé Karpaty Groups. The lowermost tectonic units in the Danube Basin are the very problematic Upper Austroalpine Mihályi Phyllite (correlatable with the Graz Palaeozoic) and the southern Penninicum in the Gabèíkovo Depression (correlated by Vozár, 1996 with the Kõszeg and Rechnitz areas).

The basement of Little Hungarian Plain east of the Rába Line is build up by rocks belonging to the Transdanubian Range and/or to the Pelso Megaunit (see bellow).

Neogene of the Danube Basin

The Danube Basin is a thermal extensional basin, which began to open at the end of the Early Miocene. The basin is filled mainly by siliciclastics accompanied by caustobioliths and seldom by organic limestones. The main part of the synrifting phase took place during the Middle Miocene (Badenian to Sarmatian). The process of basin filling was terminated by a postrift phase during the Late Miocene (Pannonian–Pontian) and Pliocene.

The rifting stage, i.e. initial stage of basinal extension was not uniform throughout the whole basin. Fault-controlled initial synrift subsidence was more intensive in the outer zone of extension at the northern margin of the basin (in the Blatné, Riπnovce, Komjatice and ≥eliezovce depressions) than in the internal zone of extension (Gabèíkovo depression) north of the Danube River.

The postrift sediments (Pannonian to Pliocene) in the northern part of the Danube Basin are distributed in an opposite way compared to the synrift ones. The maximum thickness of postrift sediments occurs in the internal zone close to the Danube River (surroundings of the town Dunajská Streda). The postrift sediments in the outer zone of the basin are considerably thinner. The postrift sediments are only in some cases disrupted by faults.

During the Badenian the tectonic development in the area of the Danube Basin was under the control of the palaeostress with in NNE–SSW directed compression (Vass *et al.* 1993). NNE striking normal as well as strike-slip faults developed under such stress conditions. They have formed a block structure well observed especially in the northern part of the basin. Southwards, it is masked by younger postrift sediments mostly undisturbed by faults. The faults constrain a series of horsts and grabens (after Adam & Dlabac 1961, Penicková & Dvoráková in GaΩa *et al.*, 1985) as follows (from east to west):

— Komárno high blocks limited towards NW by the Komárno/Komárom faults (13).

— ≥eliezovce Graben limited towards SE, E by the Hron faults (24) the Hont fault (15) and towards NW by the Levice faults (12).

— Levice Horst limited to NW by the ˇurany faults (11) having to the S continuation in the Pannonhalma fault

— Komjatice Graben limited to NW by the Mojmírovce faults (9) having the continuation in the Ásványráró fault.

— Nitra Horst limited to NW by the Vel’ké ZáluΩie faults (8).

— Riπòovce Graben limited to NW by the Sladkovièovo faults (6).

— Inovec horst limited to NW by the Cífer–Mihályi-W faults (5). Southwards the horst fades away and cannot be unequivocally identified on the transversal seismic line.

— Farther to the south the Mihályi Horst may be an equivalent of the Inovec Horst.

— Blatné Graben limited towards NW by the Boleráz-Balf fault (3).

— Bratislava, or Malé Karpaty Mts Horst.

The northern part of the Danube Basin (Danube Lowland) is also disrupted by faults of other fault systems. One of them, striking NW–SE, includes the Borinka fault (16), the Soloπnica fault (18), the Saliby fault (19) and a parallel, unnamed fault running south of the latter. These faults may be contemporaneous with the Ölved–Dobrá Voda fault (20; they run parallel to it), but there is no information on their origin and activity.

Another fault system strikes north–south. Although it may be older, eventually as old as Palaeogene, its last manifestations are relatively young (it disturbs faults striking NE and NNE).

The faults of synrift phase confine three Miocene subbasins and/or grabens: Nagycenk Basin, Csapod Basin and Gyõr Basin.

The Nagycenk Basin is delimited to the NW by the Kópháza fault (35) and to the SE by the eastern Nagycenk fault (36). Between the Nagycenk and Csapod basins there is a less expressed unnamed horst. The Csapod Basin is delimited to the east by the western Mihályi fault (5) continuing towards the north as the Cífer faults. Between the Csapod and the Gyõr basins there is the Mihályi Horst, which is limited to the E by the eastern Mihályi fault (39). The Gyõr Basin is a asymmetric graben divided into several partial blocks by faults of NNE–NE strike as follows: Mojmírovce–Ásványráró (9), Pásztori–Palkovièovo (10), Rába–Hurbanovo–Diósjenõ (25), Pannonhalma–ˇurány (11), Komárom/Komárno, 13), Nagyigmánd (40). The marginal south-eastern fault of the Gyõr Basin bordering the basin towards the Transdanubian Range is the Hont fault (15). The dip of all mentioned faults is NW.

The southern part of the Danube Basin was subsiding during the Late Miocene and Pliocene while the Transdanubian Range in its western neighbourhood preserved its uplifted position (Jámbor 1980)

Transdanubian Range Unit (TR)

Two major events can be identified in the Mesozoic–Cainozoic evolution of the Transdanubian Range: (1) folding (accompanied by reverse faults and perhaps overthrusts) and structural buckling in the Middle Cretaceous and (2) structural rearrangements in Palaeogene–Neogene times.

A break in sedimentation occurred between the Late Cretaceous and the Middle Eocene in the area and their deposits are separated by an angular unconformity.

Middle Cretaceous structure of the Transdanubian Range

The Mesozoic basement of the Pelso (Transdanubian Range) Unit is made up by Triassic basin- and Ladinian–Rhaetian platform-carbonate facies (Haas 1988). The uniform Late Triassic carbonate platform disintegrated in Jurassic and was subjected to differentiated subsidence reflected by pelagic sediments of high facies diversity (Fülöp 1975, Galácz *et al.* 1985). The multitude of Liassic neptunian dikes bears witness to extension. In the Gerecse Mountains and its wider surroundings in the Early Jurassic based on the strike of the Liassic neptunian dikes a stress field with NE–SW tension was identified (Bada *et al.* 1996).

Various facies of the Lower Cretaceous developed on dissected shelf margins and slopes (Fogarasi 1995). On the basis of ophiolite-like debris this series is assumed to have been formed in the vicinity of the obductive nappe front of the Vardar Ocean (Császár & Árgyelán 1994, Árgyelán 1995).

The most typical feature of the general setting of the Transdanubian Range is its synclinal structure known in the Bakony and Vértes Mountains. In contrast to the Bakony, the elements of the synclinal structure are much less distinct in the Gerecse Mountains and the Dorog Basin. Nevertheless, the setting of Cretaceous facies provides clear evidence of the synclinal aspect (Császár & Árgyelán 1994). Its formation can be attributed to the Aptian–Turonian interval, corresponding roughly to the Middle Cretaceous.

Some authors consider the nappe structure of the TR being controlled by several geophysically proved reverse faults (Rumpler & Horváth 1988, Pogácsás *et al.* 1991). Balla (1994) considered the reverse faults as features of imbricated structures of the northern limb of the TR.

The syncline structure is particularly distinct in the Buda Hills (Wein 1977). Its axis strikes NNW–SSE. The gradual rotation of the formation strike provided the clue upon which Szentes (1934) and Vigh & Szentes (1952) discovered the structural buckling. On the basis of the position of Senonian alkaline rock dikes Balla & Dudko (1989) suggested that the buckling may have occurred prior to the Senonian.

However, recent structural analyses raised some doubts concerning the buckling's existence (Bada *et al.* 1996).

Since the fault tectonics of the basement was strongly affected by post-Cretaceous movements, only folded elements and reverse faults have been distinguished among the Middle Cretaceous features. These structural elements correspond to a defined stress field. In the Vértes Mountains, in the surroundings of Vitány castle Maros (1988) identified Middle Cretaceous N–S compression. In the Gerecse Mountains and its wider surroundings Bada *et al.* (1996) established two stress fields for the Cretaceous — an older one with N–S and a younger one with WSW–ENE oriented compression axes, respectively.

Palaeogene structure of the Transdanubian Range

The origin and opening of the Palaeogene basin in the north-eastern part of the TR area is explained with a pull-apart mechanism after the compressional or transpressional tectonic regime (Báldi & Báldi-Beke 1985, Báldi 1986, Tari *et al.* 1993, Fodor *et al.* 1992, 1994).

The Middle Eocene sedimentary series is made up of clastic, coal bearing formations as well as carbonate ones (Báldi & Báldi-Beke 1985, Báldi *et al.* 1984, Gidai 1972, 1989).

During the Early Oligocene a major part of the TR was intensively uplifted and eroded (infra-Oligocene denudation, Telegdi Roth 1927, Gidai 1972).

The Hárshegy Sandstone was formed in the related areas. During the Late Oligocene clastic fluvial and deltaic sediments were deposited (Korpás 1981, Nagymarosy 1990, Nagymarosy & Báldi-Beke 1988). The end of the formation of Egerian sediments passing slightly even into the earliest Miocene is the final event of the Palaeogene cycle.

In this area the sediments are arranged in three, roughly W–E striking belts (Fig. 1). One of the principal lines of the TR — the Vértessomló–Nagykovácsi Line (42,) passes along the southern margin of the southernmost Eocene belt. It is also a boundary between the Gerecse and Vértes Mts. On its western end at Vértessomló, along the boundary of the Dachstein Limestone Formation a 6 km sinistral, whereas on its eastern end in Buda Hills a 16 km dextral strike-slip movement can be observed. Reverse-fault-like structures are postulated along that line (Triassic pushed on Oligocene) (Végh-Neubrandt *et al.* 1987) suggesting its compressive–transpressive nature after the Oligocene.

On the basis of detailed sedimentological and tectonic investigations according to Fodor *et al.* (1992, 1994) dextral shear was still active in the Eocene along that line. Eocene partial basins (Tatabánya — Tb, Nagyegyháza — Ne, Csordakút — Csk, Mány — Ma and Zsámbék — Zs) became opened by normal as well as strike-slip faults. Some more important faults are: Tatabánya (43), Vértesszõlõs (44), Vértestolna–Bicske (46), Szomor (47), Zsámbék (48), associated with the Vértessomló–Nagykovácsi Line (Figure 1). Towards the N the basins are bordered by normal faults (Bada *et al.* 1996, Maros 1988). Left-handed transverse faults are associated with the right-handed Vértessomló–Nagykovácsi strike-slip fault that can be interpreted as the conjugated pair of the left-handed ones.

It was along the so-called Buda Line in Buda Hills that Báldi & Nagymarosy (1976) suggested a facies jump in the Kiscellian. In spite of the presence of the Kiscell Clay Formation westwards from this line in the Dorog Basin, it was formerly traced from Buda Hills into Börzsöny Mountains (Báldi & Nagyné Gellai 1990). Most recently, the illustration of the line has been limited to Buda Hills as Buda (or János Hill) anticline having acted as major facies boundary (Fodor *et al.* 1992, see the Map,

Fig. 1. Eocene and Palaeogene–Miocene fault lines in the DANREG area

Geological formations: 1 = younger than Eocene, 2 = Eocene, 3 = older than Eocene. *Fault lines:* 4 = lateral displacement, 5 = normal fault, 6 = code of a major fault line in the Tectonic Map, 42 Vértessomló–Nagykovácsi, 44 Vértesszõlõs, 45 Bajna, 46 Vértestolna–Bicske, 52 Jászfalu, 55 Pilis, 56 Ferenc-hegy annex?). The line presumably associated with the right-handed strike-slip zone traversing along the whole length of the southern margin of the TR is supposed to have developed above blind faults and reverse faults biting upwards from the basement towards the surface. Some smaller Eocene reverse faults are also postulated. In the Buda Hills two main stress fields have been revealed by a number of authors including BERGERAT (1989), FODOR *et al.* (1992, 1994): a WNW–ESE or NW–SE compression and perpendicular tension in the Palaeogene — Early Miocene.

South of the Nagykovácsi Line two additional lines appear. One of them, the Ferenc Hill Line (56) has been proved by detailed analyses (BENKOVICS & DUDKO 1992). BALLA & DUDKO (1989) suggested left-handed character and Miocene age of the Vértessomló–Nagykovácsi (42) and Bajna lines (45) bordering the northern Eocene belt (including the Dorog Basin) from the south. Beside sinistral movements dextral ones have also been proved by microtectonic measurements suggesting that they were active like the Vértesszõlõs Line (44) in both Eocene and Miocene times.

From the south and north the Dorog Basin (Do) is limited by the E–W striking Dorog fault (53) and a segment of Rába–Hurbanovo–Diósjenõ Line (25) of similar orientation, respectively. The roughly NW–SE striking faults and E–W (EEN–WWS) dextral strike-slip faults formed as a result of NW–SE compression and related perpendicular tension in compliance with the Eocene stress field.

Miocene structure of the Gerecse–Pilis Mts–Buda Hills

BALLA (1989a) and BALLA & DUDKO (1989) suggested that the Early Miocene basin evolution in the Transdanubian Range was associated with the progressive approach of the South Pannonian Unit towards the North Pannonian one and their subsequent collision and counter-clockwise rotation (CCW.)

They suppose that longitudinal sinistral strike-slip faults along former Palaeogene lines occurred at the same time in the NE part of the area (*e.g.* sinistral movements along the Vértessomló– and Hurbanovo–Diósjenõ Lines (BALLA 1989a; 1989b), VASS *et al.* 1993).

The Middle Miocene (Karpathian–Badenian) roughly N–S compression and E–W extension are associated with the formation of the transtensional Budajenõ (Zsámbék) Basin west of the area, as well as the resumption of longitudinal right-handed lines. NW–SE striking right-handed faults, like the Pilis Line (55) or Kesztõlc Line (54) were presumably brought about also in this period.

Börzsöny–Dunazug volcanic belt

In the Börzsöny and Dunazug Mts, Lower Badenian volcanic formations have in the pre-volcanic substratum Oligocene–Lower Miocene rocks and they are covered by Middle Badenian ones. Both mountains have a stratovolcanic structure preserving their respective collapsed calderas, and some separate small volcanic centres (BALLA & KORPÁS 1980a, 1980b). The structural evolution of the area testifies to multiple repetition of' tectonic events. In the eastern part of the volcanic belt the onset of volcanic activity in the Late Eggenburgian–Early Ottnangian is indicated by the Gyulakeszi Rhyolite Formation. Both the Börzsöny and Dunazug palaeovolcanoes developed in the Early Badenian. These volcanics are overlain by the Middle Badenian Rákos Limestone Formation still bearing some andesite tuffs and lava banks at its base (KORPÁS & CSILLAGNÉ TEPLÁNSZKY 1982) indicating the end of volcanism.

Sarmatian clastic-carbonate deposits overlie Badenian and elsewhere older formations (*e.g.* in the southeastern foreland of the Gerecse Mts). The Sarmatian is overlain in turn by friable Pannonian clastics (JÁMBOR 1980).

Phenomena inferring E–W extension can often be observed in the area. The most common orientation of dikes occurring in the Nagymaros region is N–S (DARIDÁNÉ TICHY *et al.* 1989). Quite similarly, roughly N–S striking (partially synsedimentary) faults have been identified in the sediments underlying the volcanic complex in the Börzsöny Mts. Also cracks in Dachstein Limestone at Vác filled with Oligocene sediments are equally N–S oriented. So before and during volcanism the tectonics of Dunazug Mts partly were controlled by a paleeostress field with oriented E–W extension.

In the Nagymaros region dextral strike-slip faults can be observed (BENCE *et al.* 1991; DARIDÁNÉ TICHY *et al.* 1989). They affect the dikes as well, thus they originated after the extensional regime. Strike-slip movements can also be observed in the Middle Miocene Rákos Limestone Formation at Zebegény occurring thus after the Middle Badenian. These phenomena indicate a palaeostress field with NW–SE compression. It is not clear whether this palaeostress field depends on local block rotation only or has a regional character.

Following the strike-slip regime, normal faulting became again the predominant feature in the structural evolution of the Nagymaros area.

Ipel'ská kotlina Basin (IKB)

Only the western part of the IKB belongs to the DANREG area, together with the SW spur of the Krupinska planina Mts built up by Badenian andesite volcanics. The IKB itself is filled by siliciclastic deposits with coal and some volcanoclastics, Oligocene to Karpathian in age. The basement of the basin is built up by crystalline schists of the Veporicum Unit. The schists underwent a strong regional Variscan metamorphism. They are represented by gneiss, mica schist, amphibolite with some features of retrograde metamorphism. Negative gravity anomalies indicate the presence of some light bodies, probably granitoids in the deeper crust. The crystalline schists are partly covered by Mesozoic sediments of the Föderata or Struzeníka sequence.

The Tertiary development of the IKB differs essentially from that of the Danube Basin. The IKB is filled by the sediments of three overlapping basins. The oldest is the Buda, or the Hungarian Palaeogene Basin, but in the IKP only Late Palaeogene *i.e.* Oligocene and Egerian sediments are present. To explain the origin and opening of the basin, a pull-apart mechanism (Báldi & Báldi-Beke 1985, Báldi 1986) has been proposed.

It should be mentioned that there is no evidence of a pull-apart mechanism governing the filling of the IKB and other Palaeogene basins in Southern Slovakia.

The Buda Palaeogene Basin vanished at the end of Egerian stage. This is evidenced by remnants of prograded deltas (*e.g.* Opatová delta; ˇutovská-Holcová *et al.* 1993).

At the beginning of the Eggenburgian a new basin was opened, the Fil'akovo–Pétervásara Basin (Vass 1995) of a smaller areal extent than the Buda Basin opened. The mechanism of this basin opening may have been similar to that of the Buda Basin. The basin existed relatively shortly — some 2 Ma (22.0–20.0 Ma B.P.).

For the vanishing and closing of the Fil'akovo/Pétervására Basin the terminal Eggenburgian regional uplift was responsible. The uplift affected the entire Pannonian realm (Vass 1995). Witnesses of uplift are the terrestrial deposits as well as the evidence of subaerial erosion. The uplift was caused by an asthenosphere rise.

Crustal heating was responsible for the generation of crustal magmas and for the activation of areal rhyolite-rhyodacite volcanism, widespread throughout the Pannonian region (Pantó *et al.* 1966, Szabó *et al.* 1992, Lexa *et al.* 1993). All these events fall within the Late Eggenburgian–Early Ottnangian period (20–19 Ma B.P.).

Traces of continental sedimentation and products of rhyodacite explosive volcanism are also preserved in the Ipel'ská kotlina depression (Bukovinka Formation).

The generation and development of the third, youngest partial basin in the IKB as well as in Southern Slovakia and Northern Hungary —the Novohrad/Nógrád Basin— was controlled by an ongoing process of rifting, kept in motion by rising asthenosphere.

The pressure release is evidenced also by the measured ductile deformations (Vass *et al.* 1993, Fodor in Márton & Fodor 1995) resulted in horizontal rotation of crustal fragments.

Since the Pelso Megaunit was in sinistral motion along the Rába–Hurbanovo–Diósjenõ (Rapovce–Pleπivec) Line the block rotation was to the left (CCW), in accordance with observations of Terres & Sylvester (1981) and Allen & Allen (1992). The rotation took place in two pulses: the first by 50° at the end of Ottnangian, the second by 30° to the end of Karpathian and/or in the Early Badenian (Márton *et al.* 1995, 1996, Márton E. & Márton P. 1996).

The second rotation was preceded by regional uplift causing regression and deep erosion. The new extension resulted in the Badenian transgression, but after a relatively short period the intensive andesitic volcanic activity pushed out the sea from the IKB. The sea never entered the IKB and the territory of S Slovakia any more.

At the end of the Palaeogene and at the beginning of the Early Miocene the tectonics in the IKB and in the Krupinská planina Mts were controlled by a palaeostress field with maximum compression oriented NE–SW (recent coordinates, Vass *et al.* 1993). Within this stress field the normal faults striking NE were either generated, or reactivated, including the faults of the ˇahy–Lysec Volcanotectonic Zone (27). Those faults are epigenetically disrupted by younger transversal faults, active in Badenian time. The junctions of both fault systems facilitated the rising of andesite magma.

During the Early Miocene, a NE–SW oriented extension became the prevailing kinematic phenomenon. Within such a stress field originated and were active the normal, NW–SE striking faults. Those faults border the buried Dacov Lom Graben (Vass *et al.* 1979).

The recent structure of the IKB is controlled by faults striking NNW–SSE. They originated during the Early Badenian as normal faults within a stress field with NNW–SSE oriented compression. These faults disturb the IKB forming a graben-and-horst structure (Vass *et al.* 1979). Only the Pribelce–Plachtince elevated blocks (a horst) of the Vinica Graben [the two units of which are separated by the Selany fault (26)] and the Levice–Turovce Horst [separated from the Vinica Graben by the eastern Santovka–Turovce-E fault (22)] belong to the DANREG area.

Malé Karpaty (Little Carpathian) Mts

The Malé Karpaty Mts consist of several superposed nappe units. The Tatricum Superunit constitutes the lowermost part of structure. Four tectonic units were recently distinguished in the Tatricum (Plaπienka *et al.* 1991): the Tatric pre-Alpine basement nappes (the Modra and the Bratislava nappes) and the Mesozoic subautochthonous units (the Borinka and Oreπany units). The Borinka Unit shows some features of Penninic affinity. The Fatricum Superunit represents the Vysoká nappe. This unit palaeogeographically belongs to the northern part of the Fatricum, in close proximity of the southern Tatricum.

The Hronicum superunit is tectonically separated into several nappe units (the Veterlín Nappe and the Havranica–Jablonica Nappe). Therefore they are correlated with the Alpine nappes (the Göller Unit, the Schneberg and Mürzalpe nappes) (Plaπienka *et al.* 1991).

The Tertiary tectonic development is characterised by Early Miocene transpression with backthrusting and strike slip faulting. Middle Miocene transpression with strike-slip and normal faulting, Late Miocene to Pliocene transtension and extension tectonic regime. Faults bordering NW of the Malé Karpaty horst belongs to the seismoactive sinistral Mur–Mürz–Leitha fault system.

Vienna Basin

Only a part of Vienna Basin interferes with the NW corner of the DANREG area. The pre-Neogene basin basement is built up by East Alpine and West Carpathian nappe units, outcropping in Leitha Mts, Sopron Hills and

Hainburg Mts as it was mentioned in paragraph "Sopron area".

In the Hainburg Mts there are the crystalline core rocks: micaschists, paragneisses, granitic and granodioritic intrusive rocks. These are Palaeozoic in age and much less metamorphosed than the Lower Austroalpine complexes of the Sopron Hills. (The sedimentary cover comprises Permian clastics and Middle Triassic carbonates). The Hainburg Mts seem to be an along-strike continuation of the Austroalpine Leitha Hills to NE. They may be considered as a part of West Carpathian Tatric Unit. Their separation from and displacement against the Alpine units is due to a fault system striking NW–SE *i.e.* subperpendicular to the general strike of the Vienna Basin. One of the faults is the fault cutting of the Hainburg Mts from the Malé Karpaty Mts. Presumably more important faults are hidden by the Neogene–Quaternary filling of the Vienna Basin. The faults developed as a consequence of differential movements during Alpine thrusting with the Carpathian nappe system passing into the Alpine one.

The Vienna Basin itself covers the pre-Neogene basement composed of Alpine and West Carpathian Nappe units. Its whole arrangement depends on the Alpine movements against the southern spur of the Bohemian Massif, overthrusting the crystalline rocks of the Bohemian Massif and its Mesozoic cover over large distances. In the Austrian part of the basin the upwards following pile contains (from bottom to top) the southernmost (marginal) Molasse, the Flysch and the Austroalpine units, comprising the Northern Calcareous Alps, the Greywacke Zone and the crystalline basement including locally preserved Permo-Mesozoic remnants. From abundant drilling record it is known that the structural pattern of the basement shows the same assemblage as the exposed Alpine region farther southwest. Thrusting ended here in the Alpine part (west of the Vienna Basin) in Oligocene or Early Miocene time but was going on in the Carpathians. Contemporaneously with the overthrusting of the Alpine nappes upon the Molasse Zone, the Vienna Basin began to open as an extensional and piggyback basin at the beginning of the Miocene. It is filled mostly by siliciclastic deposits of Eggenburgian to Pliocene age. Distinct tectonic and palaeogeographic changes occurred during its development and, as a result, two tiers (structural horizons) can be observed in the basin. The younger Vienna Basin reaches as far as the area under study. Its formation started when the Central Carpathian and Alpine blocks finished their CCW rotation (Kováè & Túnyi 1995) to bring about the inversion of the basin at the end of the Early and beginning of the Middle Miocene.

From the Karpathian the basin opened by means of pull-apart mechanism in a palaeostress field with S–N compression. The faults responsible for its opening, neither penetrated deeper into the crust, nor did they intersect the crust, respectively (thin-skinned pull-apart; Royden 1985). The majority of the NE running synsedimentary faults generated during the Miocene have beside the sinistral horizontal component also a vertical one.

The part of the Vienna Basin shown on the Tectonic Map of the DANREG area is disrupted by a Badenian NE striking system of faults generated in NE–SW oriented extension (Kováè *et al.* 1989; Nemèok *et al.* 1989). The faults confine blocks from E to the W as follows: the Malé Karpaty Mts or Bratislava Horst bordered towards the W by the Litava–Engelhartstetten fault (2) and the Kopfstetten fault (30) The Zohor Graben (Mitterndorf Graben) is bordered ed towards the W by the Láb–Malacky fault (1).

A postsedimentary phase of tectonism started after the Late Pannonian, producing especially on the Austrian territory a considerable number of new faults, cutting up the Miocene sedimentary sequence. Their effect is characterized by approximately equal thickness of the sedimentary cover on top of the (former) heights and lows within the basin. In many cases these faults have been active up to the Holocene, as it is shown by the faults forming the Mitterndorf Graben with its Quaternary filling or the main faults (*e.g.* Engelhartstetten) terminating the Vienna Basin towards southeast, where recent seismicity is proved by seismic measurements. These younger faults are also of economic interest as the blocks separated by them use to bear some of the main hydrocarbon deposits of the oil and gas fields in the Vienna Basin.

The existence of a conjugated fault system striking northwest–southeast (more or less perpendicular to the one mentioned above) can be postulated. Probably following the depressions and therefore hidden by the young sedimentary cover, it can be deduced from the left-lateral displacement within the Alpine–Carpathian Mountain Range as well as from the differences of the accompanying sediments. Since even the most recent ones seem to be affected, the tectonic movements connected with these faults are assumed being quite obviously still active.

The Mattersburg Basin

The Mattersburg (also called Eisenstadt) Basin is located between the Leitha Mountains in the north, the Sopron Hills in the south and closed towards the east by the Rust Heights. It may be considered eastern appendix of the Vienna Basin, since their Neogene development is closely interconnected. It shows a less intensive subsidence and therefore has a less thickness sedimentary filling. Sedimentation started with the limnic–fluviatile, coal bearing Brennberg series in the southern part alongside the Sopron Hills, thinning and ending towards the north, while the younger sediments of Badenian up to Pannonian extended to the borders of the basin.

According to the sedimentary and palaeontologic record, the connection to the Vienna Basin via the so-called "Wiener Neustadt Gate" was interrupted several times and was closed finally at the turn from Miocene to Pliocene, probably in relation to (mainly lateral) movements along the fault system bordering the southeastern Vienna Basin and general elevation of the surroundings, probably also causing the north-south striking faults bordering the basin to the east (Rust Heights).

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Autor(en)/Author(s): Pistotnik Julian, Elecko Mihal, Vass Dionyz, Hok Jozef, Vozar Jozef, Nagy Alexander, Sefara Jan, Dudko Antonyina

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