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MOLASSE BASINS AND VOLCANIC ACTIVITY IN WEST CARPATHIAN NEOGENE — ITS EVOLUTION AND GEODYNAMIC CHARACTER

(Figs. 21)

Abstract: Opening of the Inner Carpathian Neogene basins took place in a shear zone, formed as a result of the oblique convergence of the North European Platform and Carpathian-Pannonian block. The sedimentation in back deep was controlled by the formation and development of the Pannonian asthenolith. The temporal and spatial distribution of volcanism documents the process of the Carpathian arc formation, it exhibits affinity to a subduction zone and proves the existence of mantle diapirism.

Резюме: Образование неогеновых бассейнов внутренних Западных Карпат проходило в зоне смятия, образованной вследствие косовой конвергенции североевропейской платформы и карпато-паннонского блока. Осадконакопление тыловых бассейнов было обусловлено образованием и развитием паннонского астенолита. Распределение вулканизма по времени и пространстве подтверждает процесс образования карпатской дуги, обнаруживает сходство с зоной субдукции и доказывает наличие мантийного диапиризма.

Since the 1970's there accumulate new data that have considerably changed the original views on the age and development of the Neogene sedimentary basins and volcanism. The submitted model of the West Carpathian geodynamic development generalizes the present-day knowledge and at the same time outlines new trends in further research.

The main phenomena that controlled the Neogene development of the West Carpathians are:

— subduction of the North European Platform under the Carpathian—Pannonian block, which changes into a continent-continent type collision in the Miocene;

— oblique convergence of the collided plates;

— formation and development of the Pannonian asthenolith.

The final, stage of subduction in the area of the folded Outer West Carpathian units is characterized by the following events:

— closing of flysch troughs in the Outer West Carpathians;

— folding and thrusting of nappes over the subducting plate. Termination of the overthrust in the Carpathian front migrates from the W to E (compare Buday, 1959, 1961; Buday et al., 1965, 1967; Jiříček, 1979 and others);

— formation of the Miocene foredeep.

The present configuration of the suture zone and arc shape of the Carpathians suggest that the relative movement of the colliding places - subducting North European and overriding Carpathian—Pannonian - was oblique (Fig. 1). By

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oblique convergence according to D e w e y's (1980) model the movement of the upper plate was more rapid than retreat of the dounbending of the subducted plate (Fig. 2). This type of lithospheric plate collision results in compression oblique to the convergent margin and produces shear stress along it. In the case of the Carpathians, the oblique convergence led to bending and final formation of the present Carpathian arc. Shear stress along the convergent margin in the Klippen Belt and Inner West Carpathian areas generated pull-apart type basins in broader sense (shear basins).

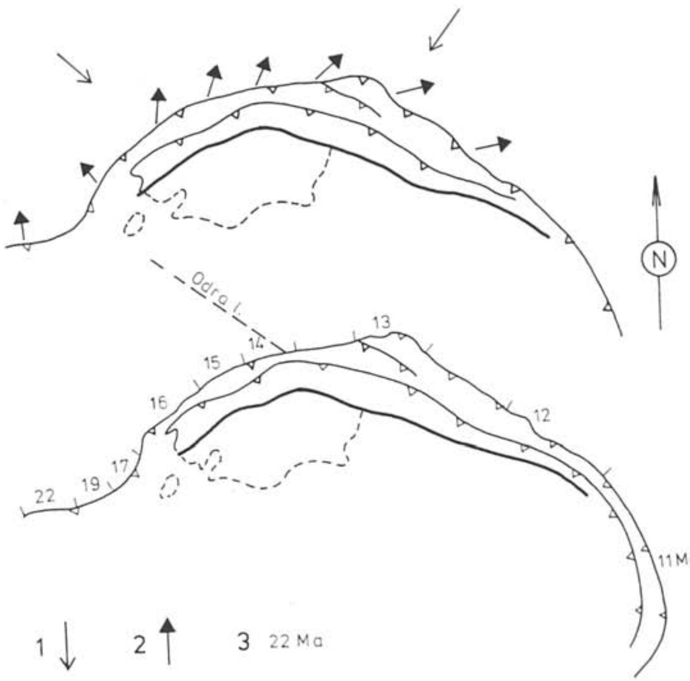


Fig. 1. Development of the West Carpathian front units in the Neogene.
Explanatory notes: 1 — subduction of the platform; 2 — direction of the overriding of the Outer Carpathian nappe fronts; 3 — age of the last nappe overridings onto the foredeep (after B u d a y 1965; J i ř í č e k 1979).

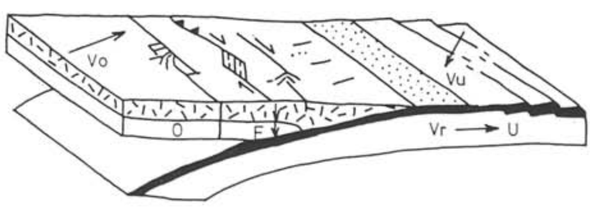


Fig. 2. Model of oblique convergence of lithospheric plates (D e w e y, 1980).
Explanatory notes: Vo — velocity of overriding plate O, Vu — velocity of underriding plate U, Vr — velocity of migration of subduction hinge, F — frontal (forearc) part of arc.

In the Lower Miocene (Eggenburgian—Karpatian, 22.0—16.5 Ma), in the front of the Carpathians foredeep sedimentation took place on the margin of the subducting North European Platform, in the foreland basins position. The foredeep was formed partly from the original flysch troughs (flysch sedimentation replaced by molasse one) and gradually extended towards the foreland. On the other hand the transgression from the foredeep extended on the fronts of the folded and thrust sheets of flysch nappe units. In the area of the present Vienna Basin, on the outer margin of the Klippen Belt, piggy back basin was formed. In addition to the transversal fault activity, this basin is characterized by active movement of its basement - Magura Group nappes (K o v á č et al., 1986). The contact of obliquely converging plates was more or less linear in the Lower Miocene. The frontal part of the Inner West Carpathians is likely to have been shaped into its present-day arc form as late as in the Miocene, which can be confirmed, among other evidence, by paleomagnetic measurement results in the Malé Karpaty Mts. area (T ú n y i, 1988). In the Miocene, the Malé Karpaty rotated in an anti-clockwise direction by 30° (Fig. 3).

	n	D°	I°	k	α_{95}°
E_g	8	325.8	67.3	576.3	2.31
K_1	63	329.9	71.0	16.0	4.61
K	74	341.2	58.6	25.9	3.30

✳ PRESENT GEOMAGNETIC DIRECTION

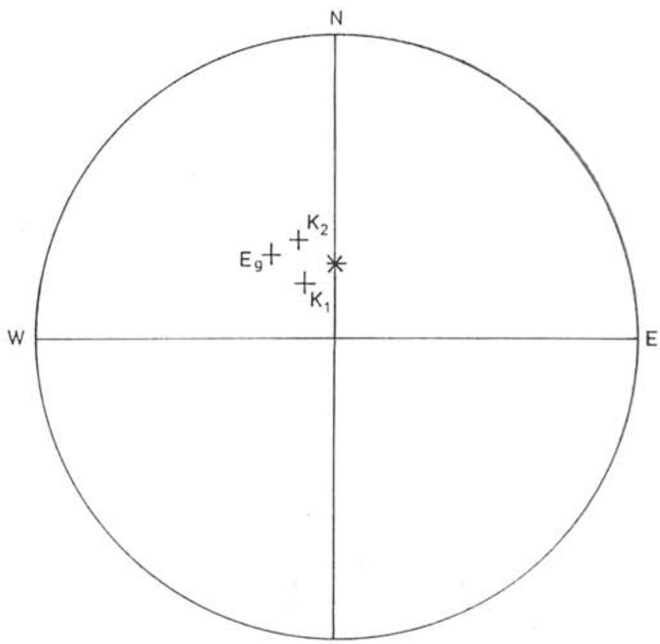


Fig. 3. Stereoprojection of paleomagnetic directions for Eggenburgian and Karpatian. Samples taken from Malé Karpaty Mts. by T ú n y i, 1987.

The relative oblique movement of the lithospheric plates generated shear stress in the convergence zone and this resulted in left-lateral strike slips in the Klippen Belt area and peri-klippen zone. In the Eggenburgian, a longitudinal intramountain depression originated on the Klippen Belt inner margin in the

NE part of the present Vienna Basin, in the Brezovské Karpaty Mts., Čachtické Karpaty Mts. and in the central Váh River valley (Fig. 4). A similar narrow, shear basin was formed along the Klippen Belt on the northern margin of the present Transcarpathian Basin (Fig. 5).

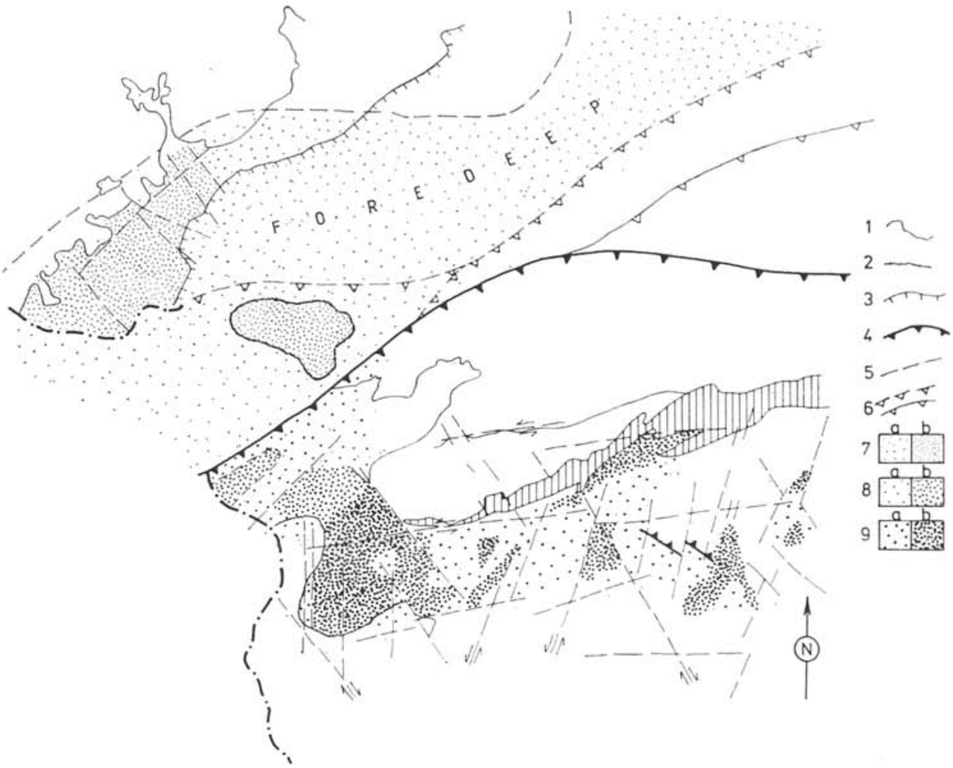


Fig. 4. Geodynamic, palinspastic reconstruction of Eggenburgian basins in SW part of the West Carpathians.
Explanatory notes: 1 — boundaries of geological units; 2 — denudation remnants of Eggenburgian sediments; 3 — present nappe front; 4 — active nappe front in the Eggenburgian; 5 — supposed margin of the foredeep; 6 — fronts of folded nappe units; 7 — foredeep a — present-day extent of sediments, b — supposed extent of sedimentation areas; 8 — piggy back basin a — present-day extent of sediments, b — supposed extent of sedimentation areas; 9 — longitudinal intramountain depression, a — present-day extent of sediments, b — supposed extent of sedimentation areas.

During the Ottnangian, these initial shear basins were degraded. Their extent and intensity of subsidence diminished, the latter continuing only in the deepest parts of the Vienna Basin and in the Bánovská kotlina Basin (B r e s t e n s k á, 1980). No Ottnangian sediments are known in eastern Slovakia.

In the Karpatian, tectonic activity increased. The sedimentation areas opened by shearing mechanism partly follow the Eggenburgian ones, but the individual basins were formed in a different stress field and their depocentres migrated southward (K o v á č, 1986). The maximum sedimentation rate occurs in the area of the present Vienna Basin (on Inner Carpathian basement) where the Karpatian sediment thickness attains up to 2300 m.

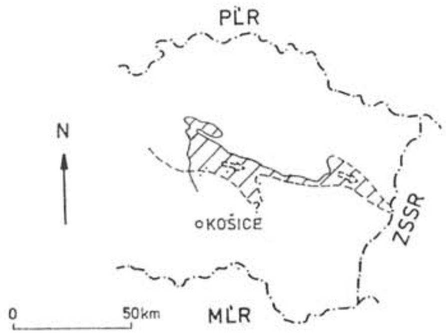


Fig. 5. Extent of Eggenburgian sediments in the East Slovakian Basin.

In the Karpatian, a new shear basin opened in eastern Slovakia, in which, after the deposition of a salt-bearing formation (Soľná Baňa Formation), the change of the compressional regime results in areal widening of the basin and considerably accelerated subsidence. In comparison with the Eggenburgian, the subsidence centre migrated to the SE.

In the Lower Miocene, backland basins (e.g. Novohrad Basin) were very impersistent in time and space (episodic basins — V a s s, 1981). The subsidence intensity in the backland basins on the Pannonian Block seems to have been considerably lower than that in intramountain basins along the convergent margin. In the Upper Eggenburgian, when rhyodacite volcanism culminated (20—21 Ma), the sea even retreated from the backland basin area and sedimentation continued in continental environment (Bukovinka, Zagyvapalfa, Szaszvár and Gyulakész Formations). Some authors speculate about the opening of these basins on strike-slip faults (B á l d i — B á l d i - B e k e, 1985; B á l d i, 1986 and others). Nevertheless, no typical manifestations of this mechanism have been observed on the Slovak territory.

The backland area development was considerably controlled by the origin and development of the Pannonian asthenolith. Lower Miocene acid rhyolite and rhyodacite volcanism (22.5—20 Ma) in southern Slovakia and northern Hungary is regarded as a product of partial melting in the lower crust heated by the ascending Pannonian mantle diapir (K o n e č n ý — L e x a, 1974).

In the Middle Miocene (16.5—11.0 Ma), the oblique convergence of lithospheric plates of the North European Platform and Carpathian—Pannonian blocks continued. The fact that the collision came gradually to its end is documented by the last overriding of the nappe fronts onto the foredeep as well as migration of depocentres of the foredeep from the W to E.

The West Carpathian arc has acquired its present shape in this period. It is noteworthy that the Carpathian arc formation and shear stress took part in the final stage of the structural formation of the Klippen Belt. Despite strong shear stress, the Klippen Belt, apart from small transversal dislocations, has preserved its continuity, although its width (reduced also by Miocene shear stress) is sometimes, less than 1 km and its inner structure bears features of tensile stress.

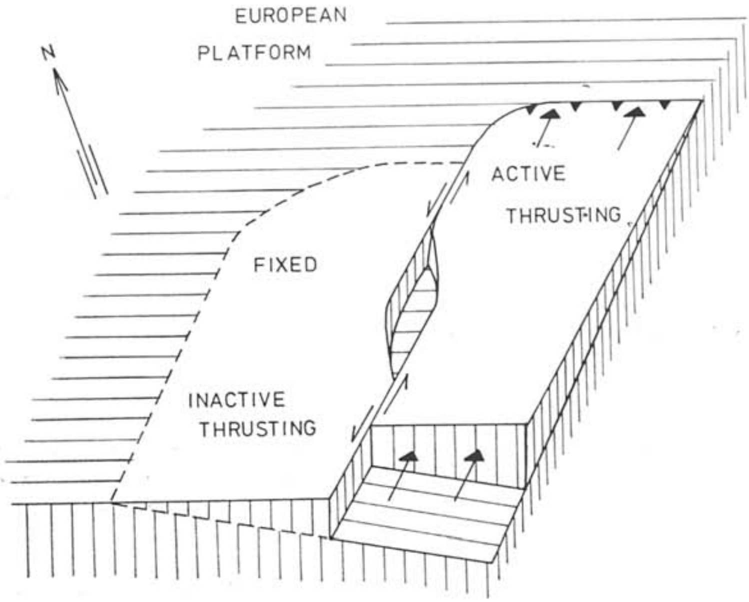


Fig. 6. Openning of the Vienna Basin (after Royden, 1985).

The direction of shear stress in the convergence zone during the Middle Miocene was not the same throughout the Carpathian arc. In the western part of the Carpathians the direction of the lateral movement remained unchanged relative to the Lower Miocene one, i.e. left-lateral. In the eastern part of the West Carpathian segment the direction changed to right-lateral.

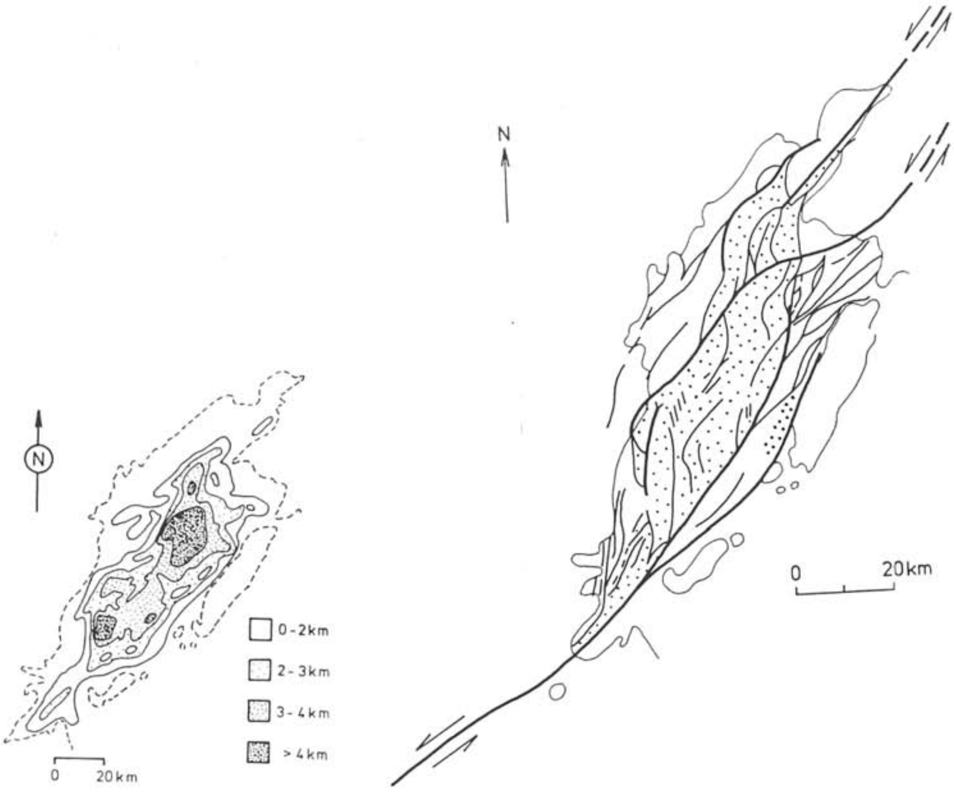
The left-lateral strike slip in the western part of the Carpathians opened the Vienna Basin (Roth, 1980; Royden, 1985). Compared to the pre-Badenian one, this basin (Vienna Basin s.s., Andrusov, 1938) was formed according to a new structural plan. After the overthrust of the underlying flysch nappes, the basin began to open along NE, NNE trending faults (Fig. 6). Royden (1985) proves the pull-apart nature of the basin's opening by the following facts:

— rhombohedral shape of the basin, with at least two subsidence centres (Fig. 7).

— "en echelon" arrangement of the basin's major faults (Fig. 8).

— migration of subsidence centres and rapid subsidence, in the Badenian (Figs. 7, 9).

These characteristic of a pull-apart type basin may be supported by manifestations of the existence of steep relief on the basin's margin, debris apron-, debris flow- and olistostrome-type accumulations, rapid replacement of the coarse marginal facies by fine-grained basinal ones. The Devínska Nová Ves Member — coarse clastic beds of Middle Badenian age on the eastern margin of the basin is more than 300 m thick (V a s s et al., 1988; Fig. 10).



Figs. 7., 8. Vienna Basin.

The Vienna Basin is a special case of a pull-apart basin denominated "thin skinned pull-apart basin" by R o y d e n (1985). According to this work it differs from typical pull-apart basins in the following:

— the basin is deposited immediately on a relatively thin "set" of nappe units (thin skinned thrust belt);

— the basin's opening concerns predominantly allochthonous units immediately underlying the basin, their thickness being reduced by up to 50 % (normal thickness of the nappes west of the basin is 6—8 km, under the basin it amounts to only 3—4 km);

— no dismatch in the structure of the immediate allochthonous basement caused by strike-slip movements can be observed, because the major strike-slip faults are parallel with the structural trend of the nappes and/or trend of their fronts;

— strike-slip faults generating the basin do not penetrate the autochthonous basement, i.e. under the detachment surface of the nappes beneath the basin and therefore no geologically unrelated units occur side by side in the autochthonous basement, structure;

— the basin's opening coincides with active folding in the adjacent part of the Outer Carpathians (in the Flysch Belt). This fact solves partly the "pull apart" spatial problem. The basin's widening was compensated by the overthrust of the flysch nappe fronts onto the North European Platform (Fig. 6). In the region between Kroměříž and Tarnów towns, the last overthrusts are dated at 16—14 Ma (Fig. 1), i.e. they coincide with energetic opening of the Vienna Basin;

— no thermal anomaly originated in the crust underlying the basin. On the contrary, the Vienna Basin is cold with a low heat flow of 40—60 mW/m^2 and decreased thermal gradient value of 34 °C/km. Both the values are lower

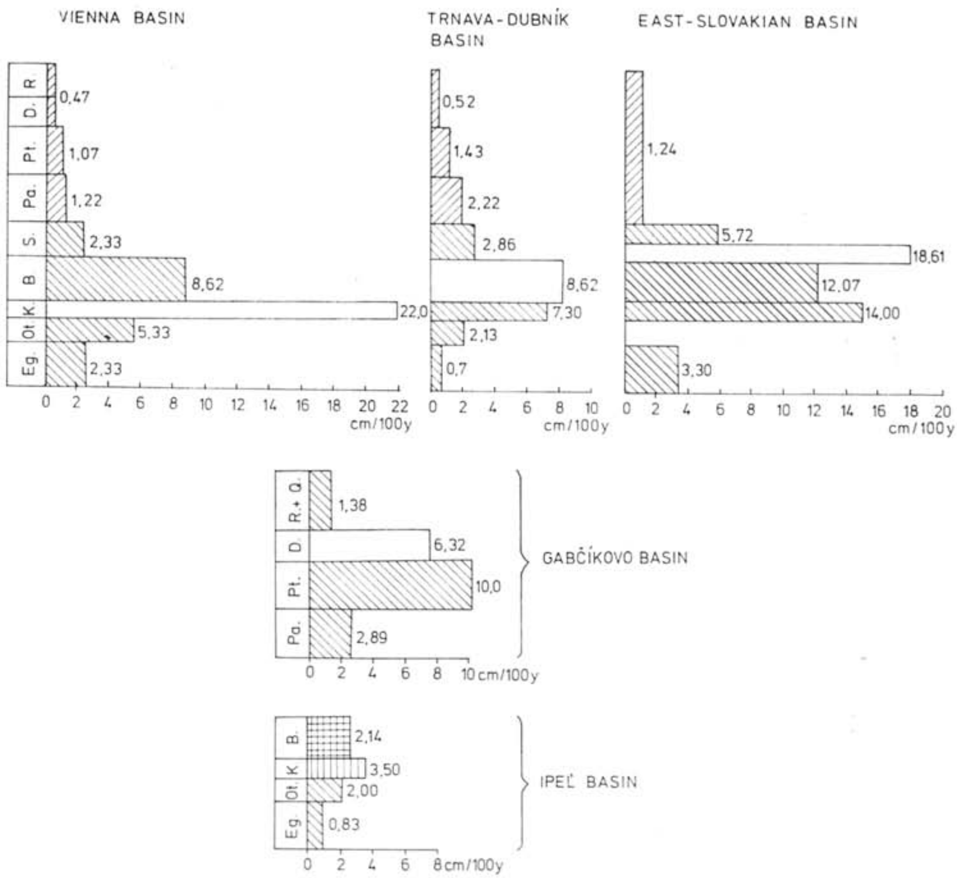


Fig. 9. Sedimentation rate in West Carpathian Neogene basins.

than those observed in numerous Miocene extension basins including, e.g., the East Slovakian Basin, see below.

E and NE of the Vienna Basin, in the northern part of the present-day Danube Lowland, left-lateral strike slip opened narrow depressions. The subsidence in these depressions, "embayments" of the Trnava—Dubnica Basin culminated during the Middle and Upper Badenian (Vass, 1981; Vass — Čech, 1983).

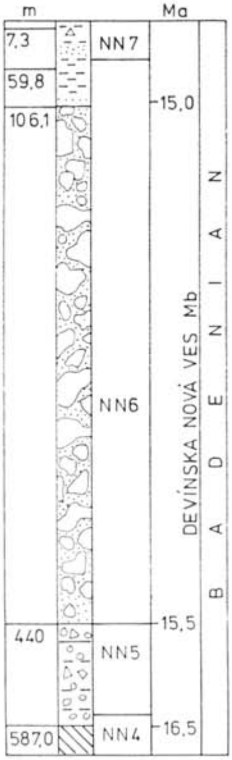


Fig. 10. Schematic profile of the Devínska Nová Ves Member in DNV-1 borehole, position of under- and overlying layers dated biostratigraphically.

The Middle Miocene East Slovakian Basin (as part of the Transcarpathian Basin) opened on the eastern flank of the West Carpathian segment. In comparison with the Lower Miocene, an important structural re-arrangement took place here. The zone of maximum subsidence migrated from the Lower Miocene direction (ESE) to SE. The lateral movements along the major faults changed from left-lateral to right-lateral ones. This change was due to an important re-structuring of the convergent Carpathian margin. Both convergent components: the North European subducting plate roughly west of the Odra River line, as well as W part of the overriding Carpathian-Pannonian plate,

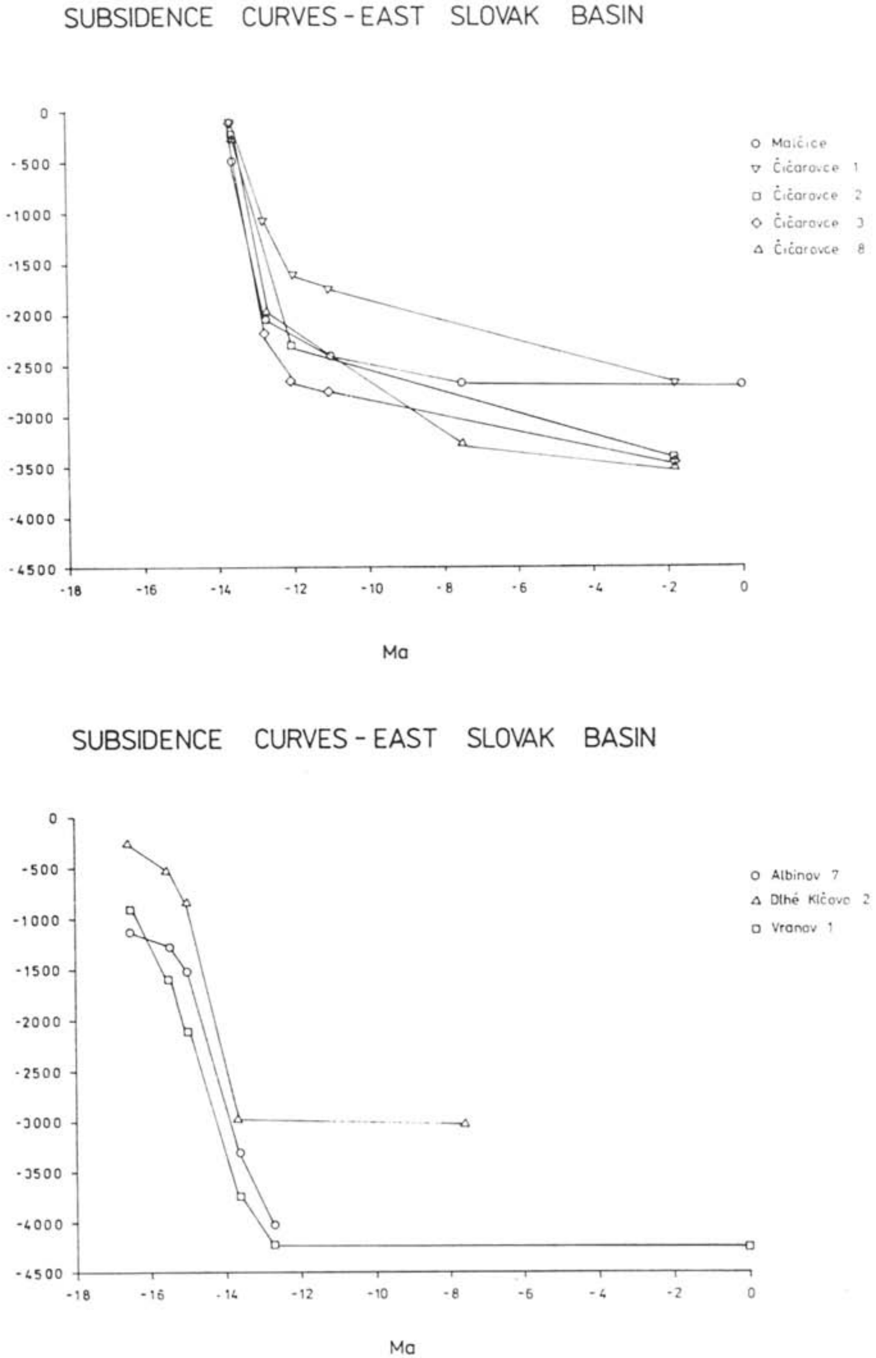
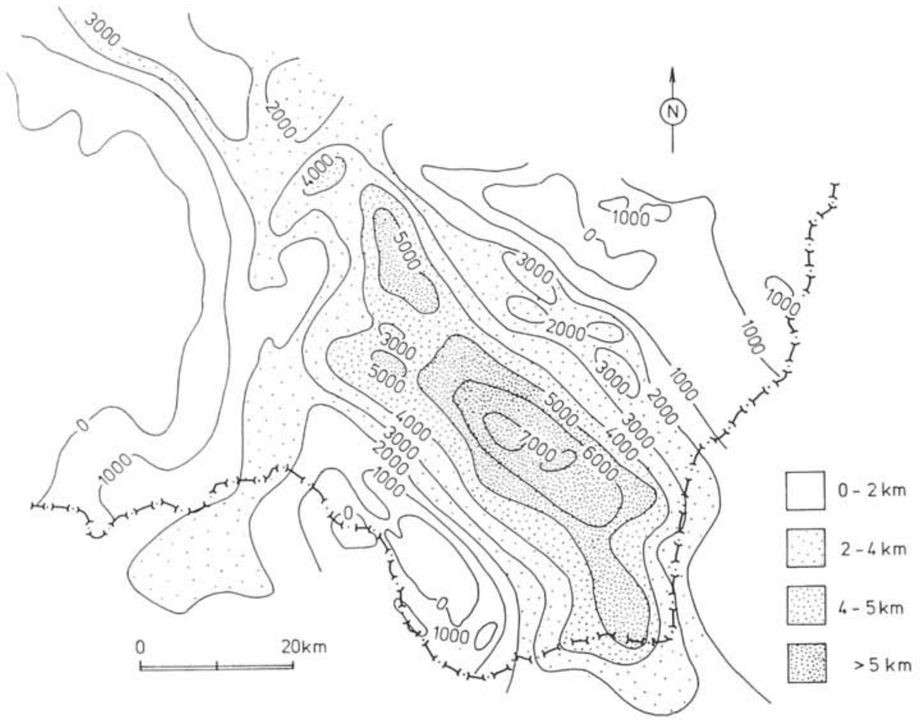
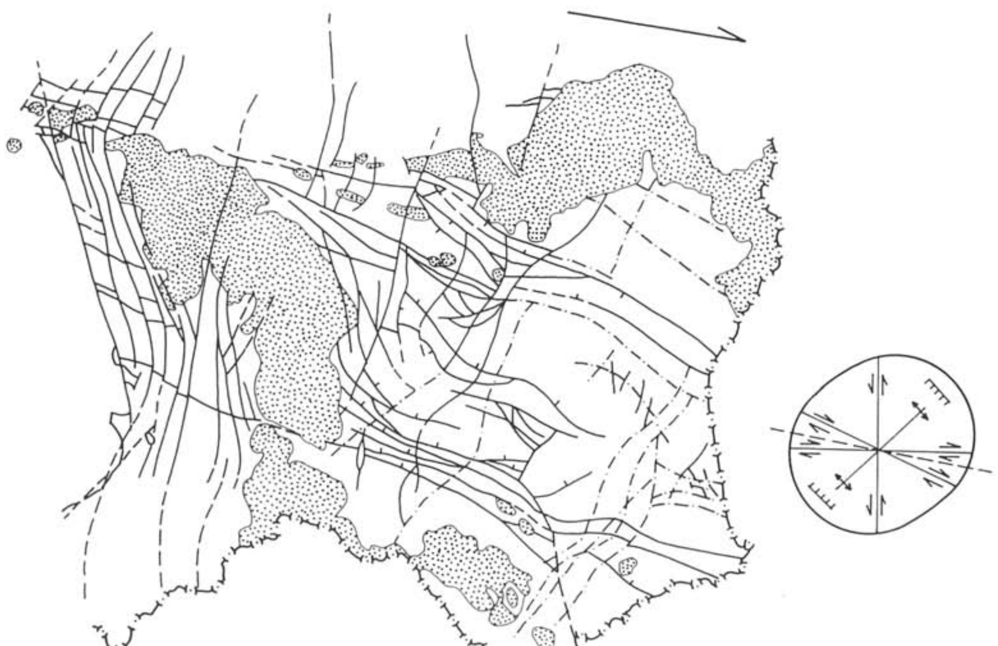


Fig. 11. Subsidence curves — East Slovakian Basin.



Figs. 12., 13. East Slovakian Basin.



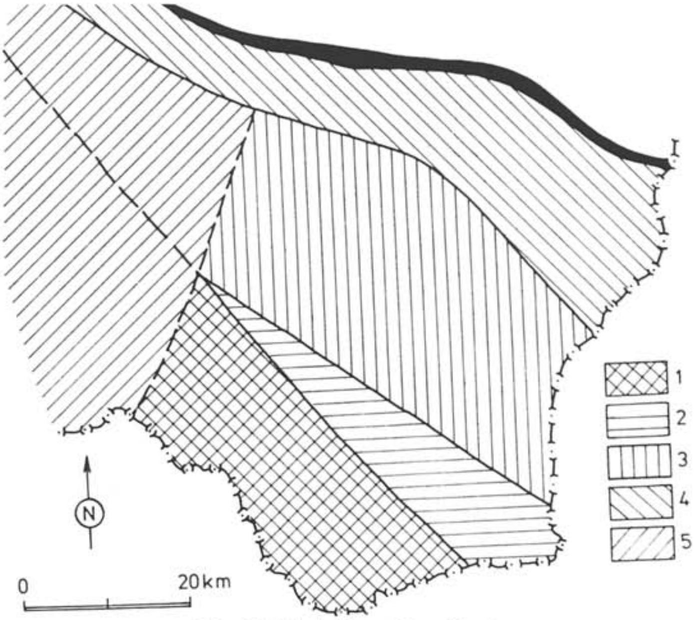


Fig. 14. East Slovakian Basin.
Legend: basement of East Slovakian Basin: 1 — Zemplín unit; 2 — Ptrukša block; 3 — Iňačovce-Pozdišovce block; 4 — Humenné Mesozoic; 5 — Čierna Hora Mesozoic and Gemeric Paleozoic.

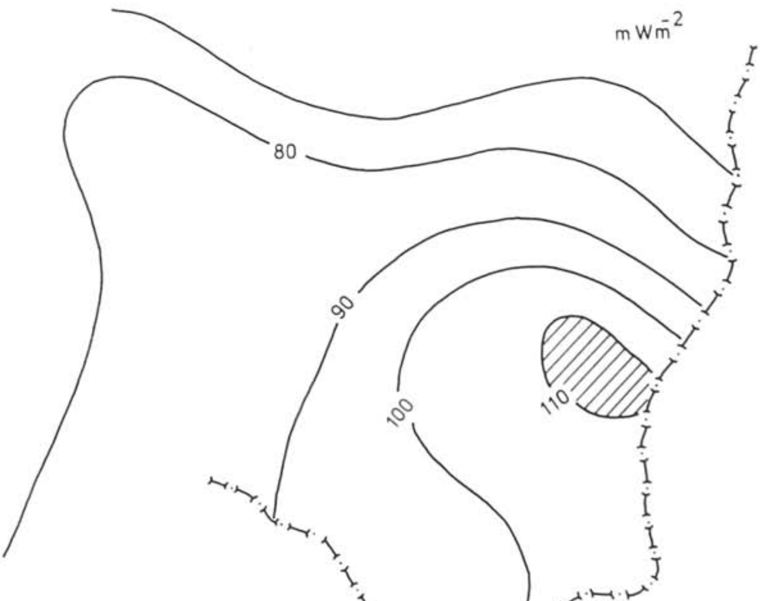


Fig. 15. East Slovakian Basin (Isohyps of geothermal gradient, Kráľ et al., 1985).

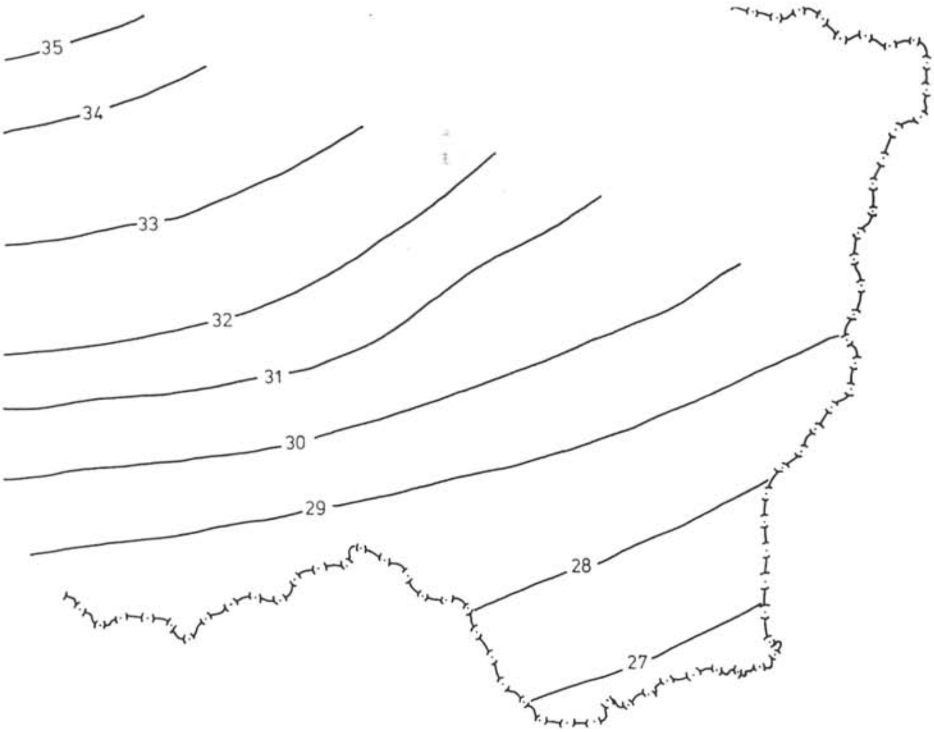


Fig. 16. East Slovakian Basin (Isohyps of MOHO depth, Šefara et al., 1987).

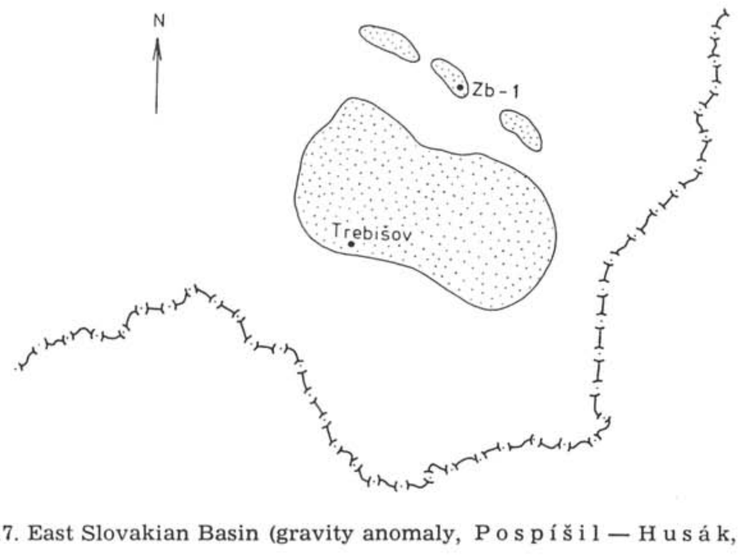


Fig. 17. East Slovakian Basin (gravity anomaly, Pospíšil — Husák, 1985).

after the last overthrust of the outer flysch nappes, became stabilized. The rest of the convergent Carpathian margin remained still active.

A basin which has all principal features of typical basins in shear zone (pull-apart type s.l.) (compare Reading in Ballance; Reading, 1980; Christie — Blick — Biddle, 1985) was opened by right-lateral movements along the major NW-SE trending faults in eastern Slovakia. Our supposition is confirmed by the following present-day geological data:

— rhombohedral shape (Fig. 12);

— migration of subsidence centres, which is illustrated by some maximums of sediments accumulations on the maps of thicknesses of the sedimentary filling (Fig. 12);

— rapid subsidence, especially during the Upper Badenian and Lower Sarmatian (Figs. 9, 11);

— distinct asymmetry in cross-section;

— "en echelon" arrangement of the fault system (Čverčko, 1977, Fig. 13);

— flover structures mainly in one of the main fault zones of Močarany—Topľany faults (Fig. 18);

— inverse tectonics in the basin identified from seismic sections. The manifestations of the inverse tectonics are evident in the Upper Sarmatian, i.e. in the period when the basin began to degrade (Fig. 18);

— dismatch in the structure of the basin's basement. In addition to the West Carpathian units, the basement is built up also of units unrelated to the West Carpathians (Iňačovce—Pozdišovce block, Zemplín unit with Pstrukša block (Fig. 14);

— deposition of sediments in the direction of the contemporaneous maximum subsidence axis of the basin (e.g. filling of the basin with delta sediments of the Klčov Formation from the NW to SE in the Upper Badenian);

— existence of mass flow deposits, pebbly mudstones and other marginal coarse-clastic sediments that quickly pinch out towards the basin;

— high heat flow and high geothermal gradient (101 mW/m, 53 °C/km, respectively, Kráľ et al., 1985; Rudinec, 1984; Fig. 15);

— the basin is underlain by a thinned crust (Fig. 16), intensive volcanic activity including volcanoes buried in the basin filling (Malčice, Beša, Čičarovce and other stratovolcanic structures);

— during the basin's energetic widening the thinned crust might have been disrupted allowing mantle masses to penetrate into the crust or/even onto the bottom of the basin. This possibility is suggested by a remarkable gravity anomaly coinciding with a conspicuous magnetic anomaly in the basin's central part (Pospíšil — Husák, 1985). In the area of a smaller magnetic anomaly under Karpatian sediments, the Zbudza-3 drillhole has discovered a peridotite layer overlying the Mesozoic. The peridotites may be traces of mantle masses penetrated onto the bottom of the basin (Fig. 17);

— opening of the East Slovakian Basin was compensated by the overriding of the Outer Carpathian nappes in the area between Tarnów and Rzesow (Stebnik, Borislaw-Pokut and Marginal Fault units) onto the North European Platform.

The dimensions of the East Slovakian Basin - length of about 100 km, width of about 50 km, correspond to several pull-apart type basins described in literature. The basin itself is only an autonomous part of the more extensive

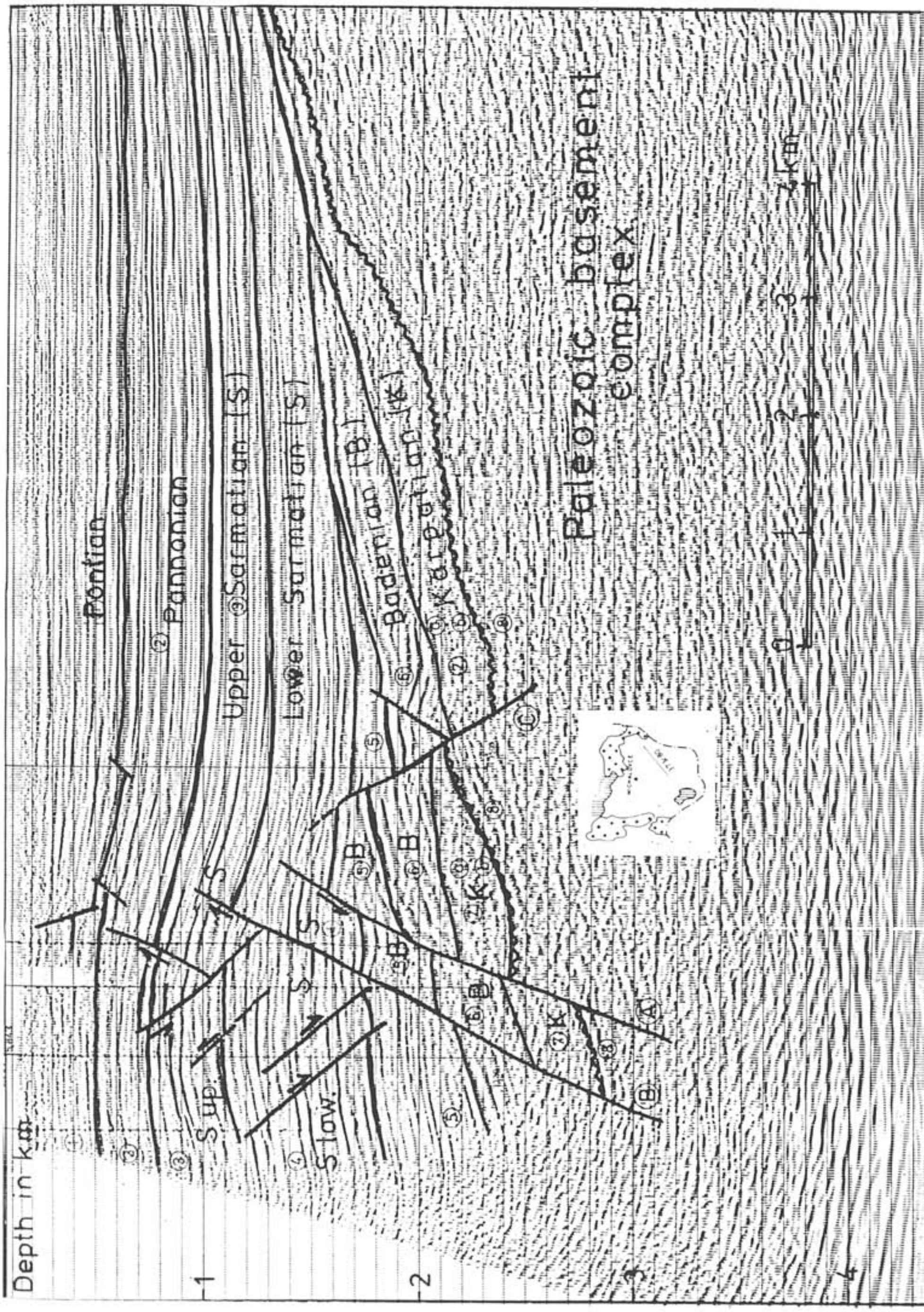


Fig. 18. Močarany-Toplany faults in East Slovakian Basin.

Transcarpathian Basin. The basin's autonomous position was partly due to the transversal Seredne ridge (R u d i n e c, 1982).

In the U p p e r M i o c e n e and P l i o c e n e (11.0—1.8 Ma), the collision of the North European Platform and Carpathian—Pannonian block comes to its end. The last overthrusts in the West Carpathian front in the region between Tarnów-Przemysl terminated during the Lower Sarmatian (approximately 13 Ma) and in the East Carpathian front in the period between the Middle and Upper Sarmatian (approximately 12 Ma).

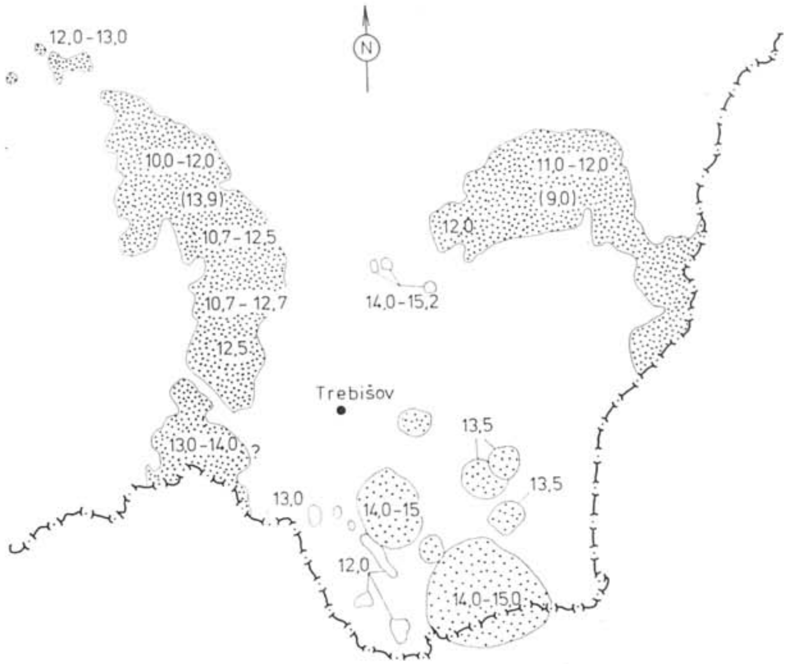


Fig. 19. Volcanism and its age in East Slovakian Basin.

In the peri-klippen zone as well as Inner West Carpathians, shear stress and related pull-apart mechanism of basin opening was finished. E.g., the change in stress field in the East Slovakian Basin resulted in tectonic inversion in the Sarmatian. Some normal faults became reverse ones (Fig. 18). Moreover, the subsidence rate decreased rapidly and the basin degenerated gradually. The sedimentary sequences acquired distinct regressive character, the basin reduced its extent and depth. Sedimentary environment became progressively fresh-water. The basin stopped to exist at the end of the Pliocene. Other intramountain basins (basins formed under shear-stress conditions along the Carpathian convergent margin: Vienna Basin, Trnava—Dubnica Basin etc.) had a similar fate — their existence also terminated at the end of the Pliocene.

In the Upper Miocene—Pliocene, subsidence controlled by the Pannonian asthenolith took place in the Carpathian backdeep. In the Lower and mainly Middle Miocene (20—11 Ma), crust stretching and corresponding crust thinning accompanied by the upwelling of the asthenosphere and core subsidence (initial subsidence) took place. In the Upper Miocene and Pliocene, second so-called thermal subsidence appeared. Compared to the initial stage, this phase of subsidence was slower and passive. It was not accompanied, or only to a small extent, by fault activity in the West Carpathians. The backdeep basins extended areally. The ascending asthenolith gradually cooled due to heat conductivity (S c l a t e r et al., 1980; H o r v á t h, 1987).

Fig. 20. Volcanic occurrences and their age in West and East Carpathians.

In the deepest parts of the Pannonian Basin the process of crust thinning even accelerated in the Upper Miocene. The crust thinning accompanied by its spreading gave rise to a new initial stage of subsidence (about 4 km), that was replaced by thermal subsidence as early as during the Pannonian (approx. 8 Ma, H o r v á t h, 1987).

V o l c a n i c a c t i v i t y i n t h e N e o g e n e in the West Carpathians area was associated with:

— subduction of the North European Platform under the Carpathian—Pannonian block;

— existence of mantle diapirism in central Slovakia and Pannonian Basin.

Volcanic products in eastern Slovakia exhibit spatial affinity to, the subduction zone. In the East Slovakian Basin and its continuation to Transcarpathia on the Soviet territory there are two belts of calc-alkaline volcanics, predominantly of andesite character. Their trend is more or less parallel to the convergent Carpathian margin and/or Carpathian subduction zone. Relatively less differentiated pyroxene basaltoid andesites prevail, especially in the northern volcanic belt, e.g. in the Vihorlat Mts. They are less contaminated by crust material than central Slovakian andesite volcanic rocks. Fig. 19 illustrates that the belt more distant from the convergent margin and partly buried beneath sediments (Tokaj Mts. on the Hungarian territory and Slánske vrchy Mts.) is older (15—13 Ma), whereas the belt situated closer to the convergent margin (Vihorlat-Popriečny Mts., their continuation to the Soviet and Rumanian territory — Guti-Calimani-Hargita) is younger (12.5—13 Ma). Both the volcanic belts became progressively younger towards the E and SE thus pursuing the direction of the migration of the last overthrustings in the Outer Carpathian front (Fig. 20).

All the above-mentioned facts suggest that the volcanic rocks of both belts (arcs) correspond more or less to the model of volcanic arcs of subduction zones. That is why the East Slovakian Basin seems to have been an intraarc basin approximately since the Middle Sarmatian.

The Central Slovakian volcanics (Štiavnica stratovolcano, Poľana stratovolcano, volcanics of Fabova hoľa, Kremnické vrchy Mts., Vtáčnik Mts., Pohronský Inovec Mts. and Krupinská planina plateau as well as the Börzsöny Mts.) and volcanics buried in the filling of the Danube Lowland Basin (Šurany, Kráľová, Gabčíkovo?, Rusovce) can be more or less mechanically joined together thus forming a belt that, with regard to its spatial relations to the West Carpathian subduction zone, appears as an island arc. But their chemical composition as well as some other facts given in further text indicate their genetic relationship to the processes of mantle partial melting and crust contamination.

The andesite volcanism origin in the central Slovakian area can be derived from the processes of partial melting in the upper mantle due to the subduction process and subsequent manifestations of diapirism. In the course of their ascending, magmatic masses differentiated (predominantly by fractional crystallization) and were contaminated by crust material, which is reflected by increased Al, K and incompatible element contents. From the petrographic viewpoint, the volcanic products are characterized by great variability — in addition to intermediate andesites also basaltoid andesites, acid andesites to dacites and rare rhyodacites are present.

The Pannonian asthenolith was a regional phenomenon controlling the West Carpathian development in the Neogene. The existence of mantle diapirism in the Pannonian and central Slovakian areas is suggested by the following facts:

— regional uplift of the folded orogeny backland in the Upper Eggenburgian accompanied by an extensive rhyodacite-rhyolite volcanism. We regard this acid volcanism preceding andesite one (during the Middle Miocene both kinds of volcanism were synchronous) as a product of intracrustal melting caused by the thermal effect of the initial stage of the mantle diapir ascending;

— formation of horst-graben structures under extension conditions contemporary with the andesite volcanism (Badenian—Sarmatian) indicates lateral expansion of the diapir. This expansion is reflected by the migration of the volcanic activity from the Pannonian Basin area towards the orogenic zone;

— thinned crust proved by geophysical methods (Stegena et al., 1975);

— increased heat flow and thermal escape evidenced by a thermal model and subsidence in the Pannonian Basin and adjacent area in the Badenian (Royden — Sclater, 1981);

— alkali basalt volcanism in central and southern Slovakia regarded as a final manifestation of the mantle diapirism. Temporal and spatial distributions of volcanic products document:

— double origin of volcanic products

— processes of tectonic strain and their succession in the West Carpathian area (formation of the West Carpathian arc in a shear zone due to oblique convergence).

The acid rhyodacite-rhyolite volcanism in the Pannonian Basin and southern Slovakia became active after disappearance of the Buda Paleogene Basin. In the Lower Miocene "episodic" basins (e.g. Novohrad basin) impersistent in time and space were formed in this area. The explosive activity culminates at the end of the Eggenburgian — at a time of regional uplift (volcanic products deposited in continental environment) and continues less intensively in the Karpatian and Lower Badenian. The eruptive centres of this period were situated in the Pannonian Basin area.

Younger occurrences of acid sialic volcanism in the central Slovakian area between the Upper Sarmatian and Pannonian are related to fault systems of meridional direction (N-S) in association with block movements of considerable vertical amplitudes (1500—2000 m). The volcanism was predominantly eruptive-effusive. In comparison with the main explosive stage in northern Hungary of Lower Miocene age when colossal volumes of pyroclastic material were produced, the Sarmatian extrusive-effusive volcanism in central Slovakia appears to have been lateral fading out of the activity on meridional-trending faults. From time and spatial viewpoints, we may state migration of the activity from the central parts of the Pannonian Basin towards its margins.

The andesite volcanism in central Slovakia became active in the Lower Badenian and continued in the Sarmatian and Pannonian, its bimodal character (represented by rhyodacites and acid andesites in one side and basaltoid andesites on the other side) was stressed. The explosive-effusive activity gave rise to the formation of large stratovolcanoes with differentiated intrusive complexes and manifestations of hydrothermal activity in the central volcanic zones. The volcanic activity is accompanied by the desintegration of the territory into a system of horst-graben structures with large vertical movement amplitudes predominantly of asymmeric character (partial rotation of blocks), corresponding to extension conditions. In the eastern part of the region, NE-SW trending faults accompanied by NW-SE trending ones dominate by the formation of the horst-graben structures, whereas in the western part of the region there prevails a NNE-SSW to meridional fault system which became active mainly in the period Sarmatian to Pannonian.

The change in the orientation of the fault systems may have resulted from stress field changes due to continuing convergence in the shear zone and partly block rotation. The migration of the volcanic activity from the central parts of the Pannonian Basin towards its margin, i.e. towards the orogenic zone, together with gradual disintegration of the territory into horst-graben structures corresponds to the supposed expansion of the asthenolith.

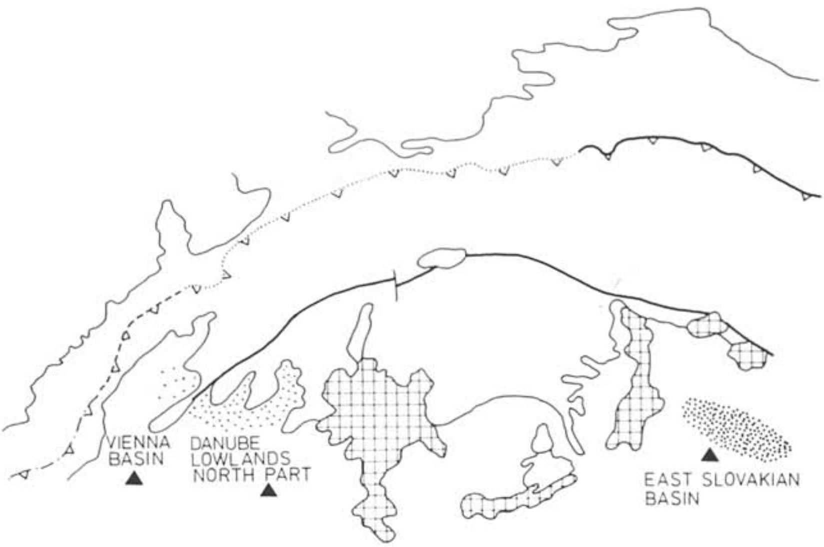


Fig. 21. W-E migration of the maximum Neogene subsidence in intramountain basins can be well correlated with termination of nappe overridings in the West Carpathian front (compare Figs. 1 and 9).

The structural-tectonic relationship and character of the eastern Slovakian volcanism are markedly different. The acid rhyodacite-rhyolite volcanism predominantly of explosive character accompanies the formation of the subsidence area of the East Slovakian sedimentation basin since the Eggenburgian and culminates in the Lower Badenian (Hrabovec Tuffs) when spatial expansion of the East Slovakian Basin took place. The supply systems are probably bound to marginal NW-SE trending faults. Besides the dominant explosive activity, also extrusions and effusions of viscose lavas take place. The volcanic activity sporadically continues to the Upper Sarmatian.

The initial manifestations of the andesite volcanism are associated with block movements near the NE margin of the Zemplín horst (15 Ma, Middle Badenian) and in the northern part of the Slánske vrchy Mts. where a number of stratovolcanoes originated (Zlatá Baňa). The formation of the volcanic belt related to the desintegration of the western margin of the sedimenetation area into a system of horst-graben structures finished in the Sarmatian. The andesitic volcanic activity manifestations are accompanied by synchronous sporadic activity of rhyolite volcanism till the Upper Sarmatian.

The formation of an other andesite stratovolcanic belt closer to the Vihorlat-Popriečny subduction zone is relatively younger — Middle to Upper Sarmatian. The spatial distribution of the volcanoes in the eastern part of the NW-SE trending belt (Morské oko, Diel, Popriečny) indicates a fault system parallel to the graben in the southern part of the belt continuing to the territory of the U.S.S.R. Smaller sized volcanoes in the western part of the belt (Vihorlat-Sokolský potok, Kyjov) situated at the intersection of the main system with transversal NE-SW trending faults seem to be parasitic ones.

Conclusions

The Neogene development and geodynamic character of the West Carpathian sedimentation areas and volcanism were controlled by the ending subduction of the North European Platform under the overriding Carpathian—Pannonian block system and existence of the Pannonian asthenolith.

The time and spatial distributions of the calc-alkaline volcanism in the East Slovakian Basin area exhibit affinity to the subduction zone. The central Slovakian volcanism, as well as volcanism of the West Carpathian backland area (Pannonian Basin) were related to the processes of partial mantle melting and crust contamination due to the subduction process and subsequent manifestations of mantle diapirism.

Shear basins (pull-apart type basins s.l.) opened due to oblique convergence in the West Carpathian suture zone.

In the Eggenburgian, a longitudinal intramountain depression opened in a left-lateral strike-slip zone in the peri-klippen belt area. In the backland area, sedimentation took place in "episodic" basins controlled by the formation and development of the Pannonian asthenolith.

The development of the Carpathian arc since the Karpatian was associated with the opening of the intramountain basins. In the western part this happened along left-lateral, mostly NE-SW trending strike slip (Karpatian—Badenian), in the eastern part of the West Carpathians (Karpatian—Lower Sarmatian) along right-lateral NW-SE trending strike slip. The mechanism of basin opening affected also manifestations of volcanic activity. In the central Slovakian volcanic area, in the western part, movements along NE-SW trending faults prevailed.

The volcano-tectonic activity in the central Slovakian volcanic area in the western part took place predominantly along NE-SW trending faults. In the Sarmatian and Pannonian, NNE-SSW to meridional faults dominated. This change in the orientation was due to advanced convergence in the West Carpathian shear belt. Besides the dominant NE-SW trending faults also those of NW-SE strike are present. The spatial distribution of volcanoes in the East Slovakian Basin area suggests a NW-SE trending fault system.

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REFERENCES

ANDRUSOV, D., 1938: Karpathen Miozän und Wiener Becken. Petroleum, Berlin, 34.

BÁLDI, T., 1986: Mid-Tertiary stratigraphy and paleogeographic evolution of Hungary. Akadémiai Kiadó. Budapest, pp. 1—201.

BÁLDI, T. — BÁLDI-BEKE, M., 1985: The evolution of the Hungarian Paleogéne Basins. Acta Geol. Acad. Sci. Hung. (Budapest), 28, 1—2, pp. 5—28.

BRESTENSKÁ, E., 1980: Geologická mapa a vysvetlivky k regiónu Bánovskej kotliny 1 : 50 000. Manuscript, Geofond, Bratislava.

BUDAY, T., 1959: Přehled vývoje neogenu Západních Karpat. Čas. Mineral. Geol. (Praha), 4/4, pp. 456—468.

BUDAY, T., 1961: Der Tektonische werdegang der Neogenbecken der Westkarpaten und ihr baustil. Geol. Práce, Zoš. (Bratislava), 60, pp. 87—106.

BUDAY, T. — CÍCHA, J. — SENEŠ, J., 1965: Miozän der Westkarpaten. Geol. Inst. of D. Štúr, Bratislava, pp. 1—295.

BUDAY, T. et al., 1967: Regionální geologie ČSSR II. — 2. Academia, Praha, pp. 1—651.

ČVERČKO, J., 1977: Zlomy vo východoslovenskej neogénnej oblasti a jej tektonický vývoj. Manuscript, Geol. Inst. of D. Štúr, Bratislava.

DEWEY, J. F., 1980: Episodicity, sequence, and style at convergent plate boundaries (Stangway, D. W. ed.). The continental crust and its mineral deposits. Geol. Assoc. Can. Spec. Paper 26, pp. 553—573.

CHRISTIE-BLICK, M. — BIDDLE, K. T., 1985: Deformation and basin formation along strike-slip faults. In: Strike-slip deformation basin formation, and sedimentation (Biddle, K. T. — Christie-Blick, M. eds.). Soc. Econ. Paleont. Mineral. Spec. Publ., Tulsa, Oklahoma, U.S.A., 37, pp. 1—34.

JIŘÍČEK, R., 1979: Tektogenetický vývoj karpatského oblouku během oligocénu a neogénu. Tektonické profily Západních Karpat. Geol. Inst. of D. Štúr, Bratislava, pp. 203—220.

HORVÁTH, F., 1984: Neotectonics of the Pannonian basin and the surrounding mountain belts: Alps, Carpathians and Dinarides. Ann. Géophys. (Paris), 2, 2, pp. 147—154.

KOVÁČ, M., 1986: Lower Miocene sedimentation in the area of Jablonica depression — a model bounds to oblique-slip mobile zone. Geol. Zbor. Geol. carpath. (Bratislava), 37, 1, pp. 3—15.

KOVÁČ, M. — KRYSTEK, I. — SENEŠ, J. — VASS, D., 1986: Origin, migration and disappearance of West Carpathians sedimentary basins in the Lower Miocene. G. Geol. (Bologna), 3, 48/1—2, pp. 317—322.

KRÁL, M. — LISOŇ, J. — JANČÍ, J., 1985: Geotermický výskum SSR. Záverečná správa čiast. štát. úlohy S-52-537-106-02 za roky 1981—1985. Manuscript, Geofyzika, Brno.

LEXA, J. — KONEČNÝ, V., 1974: The Carpathian volcanic arc-discussion. Acta Geol. Acad. Sci. Hung. (Budapest), 3—4, pp. 279—293.

POSPÍŠIL, L. — HUSÁK, Ľ., 1985: Príspevok geofyziky k poznaniu stavby východoslovenských neovulkanitov a ich podložia. Západ. Karpaty, Sér. Geol. (Bratislava), 10, pp. 197—219.

READING, H. G., 1980: Characteristics and recognition of strike-slip fault system. In: Sedimentation in oblique-slip mobil zones (Ballance, P. F. — Reading, H. G., eds.). Inter. Assoc. Sedim. Spec. Publ., Boston, Melbourne, 4, pp. 7—26.

ROTH, Z., 1980: Západní Karpaty — terciérní struktura střední Evropy. Knihovna Ústř. Úst. geol. (Praha), 55, pp. 1—128.

ROYDEN, L. H., 1985: The Vienna Basin. A thin-skimmed pull-apart basin. In: Strike-slip deformation, basin formation, and sedimentation (Biddle, K. T. — Christie-Blick, M. eds.). Soc. Econ. Paleont. Mineral. Spec. Publ., Tulsa, Oklahoma, U.S.A., 37, pp. 319—338.

RUDINEC, R., 1982: Schéma paleogeografického vývoja transkarpatskej depresie v neogéne. Manuscript, MND Michalovce.

RUDINEC, R., 1984: Teplotno-tlakové problémy vo flyšových oblastiach a bradlovom pásme na východnom Slovensku a ich vzťah k ropoplynonosnosti. Miner. slov. (Spišská Nová Ves), pp. 467—483.

SCLATER, J. G. — ROYDEN, L. — HORVÁTH, F. — BURHFIEL, B. C. — SEMKEN, L. C. — STEGENA, L., 1980: The formation of the intra-Carpathian basins as determined from subsidence data. Earth Planet. Sci. Lett. (Amsterdam), 51, pp. 139—162.
STEGENA, L. — GÉCZY, B. — HORVÁTH, F., 1975: Late Cenozoic evolution of the Pannonian Basin. Tectonophysics (Amsterdam), 26, pp. 71—91.
ŠEFARA, Š. et al., 1987: Štruktúrno-tektonická mapa vnútorných Západných Karpát pre účely prognózovania ložísk, geofyzikálne interpretácie. SGÚ, Bratislava, 267 pp.
THÚNYI, I.: 1988: In: Stratigrafická a paleogeografická korelácia vývoja egenburských sedimentov SV časti malých Karpát, Trnavskej tabule a Považia. (K o v á č, M. et al. eds.). Manuscript, Geofond, Bratislava, 221 pp.
VASS, D. — ČECH, F., 1983: Sedimentation rates in molasse basins of the West Carpathians. Geol. Zbor. Geol. carpath. (Bratislava), 34, 4, pp. 411—422.
VASS, D. — NAGY, A. — KOHÚT, M. — KRAUS, I.: Devínsko-novoveské vrstvy: hruboklastické sedimenty na juhovýchodnom okraji Viedenskej panvy. Miner. slov. (Bratislava), 2, pp. 109—122.

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