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RELATION OF COAL DEPOSITS OF THE WEST CARPATHIANS TO THE DEEP STRUCTURE

(Figs. 1—2)

Abstract: The largest number of coal deposits of Tertiary age are bound to blocks with thinner crust on the inner side of the West Carpathians and to the contact of this crust with thicker orogenic crust. Both types of crust are divided by deep-seated faults into blocks with different tendency of movement. For the origin of deposits were suitable boundaries with contrasting moving blocks. The influence of block dissection is also shown in the Carpathian Neogene fore-deep, which is, however, poor in occurrences of coal deposits. The most productive megastructures are the Vienna and East Slovakian basins. Both belong to intermontane basins lying at the contact of megablocks. Of favourable influence on formation of coal deposits in these basins were the elevations near the Peripieninic lineament.

The small Inner Carpathian coal deposits are lying at the southern margin of the Fatra—Tatra block with crust 35 km thick. Of positive influence on their distribution was the north-southern Danube fault system (Central Carpathian lineament). The latter displayed features of a coal-forming lineament from the viewpoint of deposit.

Most productive from the blocks on a thinner crust is the South-Slovakian block, lying in continuation of the Balaton block, richest in coal resources in the Pannonian basin. The coal basin belong to the peripheral coal-bearing zone of the Pannonian mantle diapir. At its margin migration of coal-forming conditions took place from west to the east and radially from the inner part of the Carpathian arc to the Pannonian basin. Differential movements of segments inside the blocks induced also reversibility of migration of conditions favourable for the origin of coal seams.

Резюме: Самое бóльшое количество угольных местонохождений третичного возраста связано с блоками с более тонкой корой на внутренней стороне Западных Карпат и с площадью соприкосновения этой коры с более грубой орогенной корой. Оба типа коры является глубинными разломами расчисленными на блоки с различной подвижной тенденцией. Для возникновения месторождений подходили границы резко движущихся блоков. Влияние блокового расчленения проявилось и в карпатской неогенной предгорной впадине, которая все же бедна нахождением месторождений угля. Самой продуктивной мегаструктурой является венский и восточнословацкий бассейны. Оба бассейна относятся к междугорным депрессиям лежащим на границе соприкосновения мегаблоков. Благоприятное влияние на формирование месторождений угля в этих бассейнах оказивали элезации вблизи перипиенинского линеамента.

Небольшие внутреннекарпатские местонахождения лежат в южной окраине Фатро-татранского блока с корой мощностью в 35 км. Положительное влияние на их размещение имела своерно-южнодунайская система разломов (центрально-карпатский линеамент). Он имел черты углеобразующего глубинного разлома.

Среди блоков на тонкой коре самым продуктивным является югословацкий блок, лежащий на линии продолжения балатонского блока, самого богатого на запасы угля в паннонском бассейне. Угольные бассейны относятся к периферической зоне паннонского плащевого диапира. По краям этого диапира

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происходила миграция углеобразующих условий от запала к востоку и радиально от внутренней части карпатской дуги к панонскому бассейну. Дифференцированные движения глыб внутри самых блоков обусловили и возвращаемость миграции условий благоприятных для формирования угольных пластов.

Tertiary coal deposits of the West Carpathians are on the whole smaller in comparison with deposits of coal on the platform in the fore-land of the Carpathians. Already this simple comparison proves the first-rate influence of the intensity of tectonic movements and tectonic dissection of the basement of the basins on the quantity of coal resources and their areal extent. The position of the coal-bearing basins in the tectogene can be therefore one from the criterii of estimation of perspectiveness of the basin and incidental prognosis of the occurrence of new latent coal deposits. In my contribution I valuate relation of Tertiary sedimentary basins and the coal seams bound to these basins to the deep block structure indicated geophysically and geologically also from other aspects and closing I try to delimit the criterii of prognosis resulting from these relations. In advance I call attention that the concept of deep structure includes spatially the upper and lower part of the crust below the sedimentary basins.

1. *Geophysical indications of deep structure*

The total view of the geophysical problems was presented by F u s á n et al. (1971) and in the last time by B e r á n e k (1978) and I b r m a j e r (1978). Solving the given problem, I mainly set out from the following data.

a) The Carpathian fore-deep, which is poor in coal occurrences, is prevailingly characterized by a negative gravitational field and thick, Epivariscan-consolidated crust.

b) The West Carpathian basins lying on the outer side of the Peripieninic lineament occur in the negative gravitational field, the basins on the inner side of the West Carpathians — on the inner side of the lineament — in heterogeneous field conditioned by the contact of the regional positive and negative field. The South Slovakian basin lies in the field of positive gravitational anomalies (areally the largest basin). This field is a part of the extensive positive anomaly of the Pannonian lowland and geophysically is a genetic connection of the basis with this megastructure indicated here. The positive field correlates with thin crust 24—30 km thick. This increases in direction to the Outer Carpathians and so far at the profiles DSS the greatest throw in thickness is at the Peripieninic lineament. The values of crust thickness were determined more precisely by K v i t k o v i č and P l a n č á r (1975), who came to an equal conclusion. This lineament is a first-rate deep seismic active structure, separating various historically and dynamically developed crustal segments.

A very variable gravitational field is in the East Slovakian basin where the positive gravitational field and thin crust reach most widely into the Inner Carpathians. Geophysically this basin differs from the Vienna basin, with which it has many common features from the geologic-deposit aspect.

Differences in the geophysical picture of the sedimentary basins are correlated also with differences in deep temperatures. The region of the positive gravitational field is accompanied by a high heat flow (maximum in the East Slovakian basin), the zones of negative anomalies with low heat flow (Marušiak and Lizoň, 1976). An exception from this relation is, however, the Vienna basin where the high heat flow accompanies regions with high Tertiary subsidence mobility.

2. *Geophysical indications and their correlation with geophysical data*

Geologically and geophysically the neotectonic block structure and principal deep faults were defined by Fusán et al. (1971), Kvitkovič and Plančár (1975) and Kvitkovič et al. (1976). In my work I set out from their dissection into blocks with competent designation.

a) In the Carpathian fore-deep and in the Outer Flysch Belt of the Carpathians the Neogene basins developed as part of migrating fore-deep, longer sinking was bound to the zones of deep-seated faults of the basement: the Late lineament in the Hornomoravský úval depression, the Vienna basin and the autonomic block Weiss (1949), separated from the Brunnia block in conception of Zeman (1978) by the Lednice deep-seated line.

b) The Inner Carpathian basins have two kinds of relation to the deep structure:

1. Basins at the contact of the Fatra—Tatra block with Peripannonian block (Danube and South Slovakian) are in greater number, however, of small area.

2. Basins on blocks with thin crust: Danube, South Slovakian and East Slovakian are of large area and mostly with great mobility (Fig. 1).

From the view-point of relation of the basins to deep-seated faults is evident that the basins of the first type, at the deep-seated Přerov—Štiavnica fault, are not characterized by great mobility but by great tectonic dissection. Basins of the second type in the site of deep-seated faults or in place of their crossing have the most mobile partial depressions: the Gabčíkovo depression on the Vepor deep-seated fault, crossing with the Nesvačilka—Trnava line, as I shall mention in the next, or the central East Slovakian depression, the deepest part of which at the confluence of the Laborec and Ondava rivers lies at the contact of the Balaton and Szamos deep lines, Preneoid-activated. The deep-seated faults having distinct influence on mobility of basins were manifested in the thin crust in proximity of mantle activity only. In this regard it is possible to complement the conclusions of Buday (1961), who was the first to solve the Tertiary basins from the view-point of deep structure.

3. *Relations of basins to fundamental block structure.*

Before I come to solution of relation of the coal basins, I mention some new knowledge concerning generally Tertiary basins, to which the coal deposits and occurrences of coal are bound.

I already mentioned that smaller Neogene basins may be well correlated with their position with the boundary of positive and negative gravitational field, which is situated in agreement with the geological data as the boundary of the Fatra—Tatra block. The relatively largest basins of this group are bound to the partial Central Slovakian block, disturbed by deep-seated N — S faults of the Zázrivá—Revúca system of Kubíni (1962), designated by Štohl (1976) as the Central—Carpathian lineament. The basins are lying at the contact of the two principal deep-seated faults: of NW—SE direction, Přerov—Štiavnica system and NE — SW, Vepor. The contact of faults resembles a fault triplet, characteristic of volcanic-thermal vaults. In this area the Štiavnica volcanic centre with complicated graben and horst structure of the basement is such a vault (Fusán et al., 1971). The origin of basins was probably evoked by deep activity of diapir character (see also Vass, 1976).

An analogous interpretation results also from the analysis of the gravitational field in the East Slovakian basin, mainly the existence of an elliptical positive anomaly with maximum heat flow in Slovakia (Marušiak and Lizoň, 1976). The East Slovakian basin is lying at the contact of three megablocks: the West-Carpathian, East-Carpathian and Pannonian in neotectonic limits. It is a typical interblock basin with great mobility and great tectonic dissection. Here the contact of faults of NW—SE and NE—SW or NNW—SSE direction is also of triplet character, stressing a deep elavation

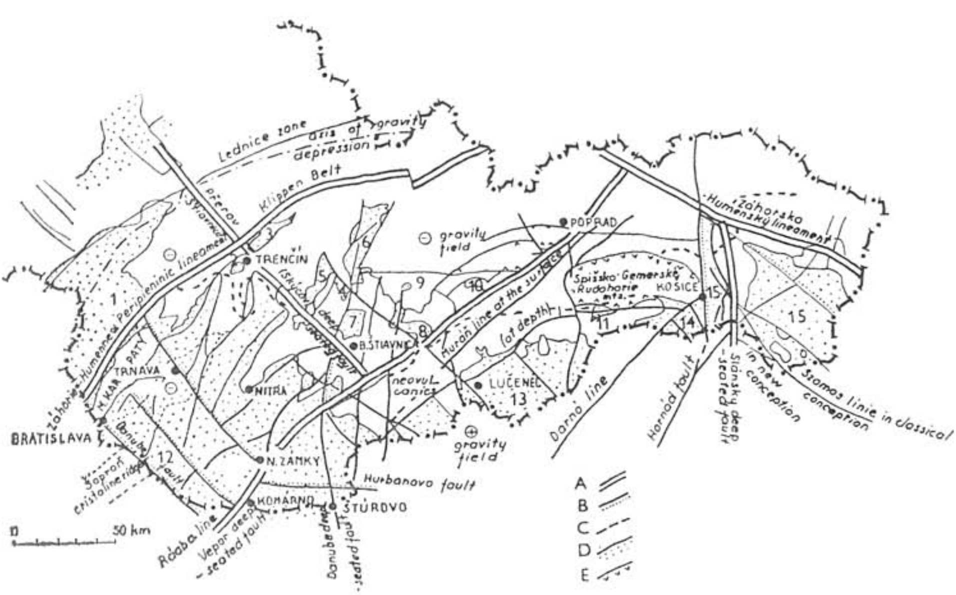

Fig. 1. Relation of Inner Carpathian basins of Slovakia to the deep structure of their basement.

Basins: 1 — Vienna basin; 2 — Trenčín basin; 3 — Ilava basin; 4 — Handlová basin; 5 — Upper Nitra basin; 6 — Turiec basin; 7 — Žiar basin; 8 — Zvolen basin; 9 — Banská Bystrica basin; 10 — Brezno basin; 11 — Rožňava basin; 12 — Danube basin; 13 — South Slovakian basin; 14 — Turňa basin; 15 — East Slovakian basin. A — deep-seated faults; B — active seismic faults; C — zero isoline separating + and — regional gravity anomalies for depth 12 km (according to Fusán et al., 1971); D — margins of basin; E — areas with abundant occurrences of Paleozoic basics. The deep-seated faults and their seismicity according to Fusán et al. (1979).

structure with ascending heat. A comparison to rift structures at the contact of lithospheric plates is offered here.

The Vienna basin shows similarly a complicated deep structure but of different character. Compared with the East-Slovakian basin its inner tectonic dissection is more influenced by the Peripieninic lineament contiguous to pre-Triassic faults of the basement of the basin of W—E and NW—SE directions. The great tectonic dissection was conditioned by renewal of movements at these faults by the influence of so far unclear dynamic at the contact of the Carpathians and Bohemian massif.

The extent of the Vienna basin is bordered by the already mentioned deep-seated faults: Lednice, Peripieninic and in the NE the system of faults of the Labe lineament. Inside the basin is divided into the NE stable and SW mobile part by a fault line of NW—SE direction shown in the Nesvačilka and Vranovice grabens NW of the Peripieninic lineament and SE of it in a deeply founded fault between Trnava and Nové Zámky. I designate this line as the Nesvačilka—Trnava line. This line separates in the Danube basin the SW mobile block (I designate it as the Danube—Zohor block) from the NE stable block with elevations of granitoids of the Považský Inovec and Tríbeč mts. The Danube and Vienna basins display similar fundamental dissection conditioned by faults, probably of Neogene age. The mobile block is transversely divided by an elevation zone accompanying the Peripieninic lineament. A part of the elevation are the Little Carpathians and Šoproň crystalline ridge. This elevation made possible suitable lithofacial coal-forming conditions, mainly NE of the Nesvačilka—Trnava line.

The Danuble block including also the Šoproň Precambrian is separated from the SE block by the Vepor deep seated fault linked with the Rába line. These faults border according to F u s á n et al. (1971) the South Slovakian block. From the view-point of deep structure toward SE the deep-seated Balaton fault is evident, approaching the Záhreb—Kulč deep zone west of the Danube (W e i n, 1969). The block between this line and the Rába line I designate as the B a l a t o n b l o c k, part of which is also the South Slovakian block. Both blocks have another common feature, an analogous type of crust, reaching as far as faults linked in strike to SE with the Přerov—Štiavnica deep-seated fault.

4. *Relation of basins to crust type*

According to the interpretation of the origin of thin crust in the Pannonian basin by S t e g e n a et al. (1975) the zone with thin crust would be a result of deep erosion of crust by mantle diapir. Deep drillings to the basement of the South Slovakian basin (see B i e l a, 1978) showed that metasediments and basic metavolcanics are prevailling here, representing areas of sinking as a consequence of weak or lacking inversion connected with ascending granitoids, giving rise to consolidated continental crust. In the area under study granitoids are rare, what can be cleared up by the existence of thin or discontinuous continental crust. The existence of volcanic depressions could be testified e.g. by borehole MV-12 SW of Bušimce. This type of crust was affected by weak Epivariscan consolidation (M a h e ľ, 1978) and liable to renewal of sinking. Composition of rocks in the South Slovakian block and zone NW of the Balaton line is similar and indicates competence to an equal block of nontypical continental crust.

The results of boreholes into the basement of the East Slovakian basin point to a similar type of rocks (including ultrabasic rocks) besides rocks of shelf type (Upper Paleozoic arcoses and limestones) belonging to the margin of continental crust.

The basement of the Vienna basin has not been known so far. The basin, however, is lying on a block af simatic type (Z e m a n, 1978), with sinking tendency, proving also the geological development of this area verified by deep drillings (B i e l a, 1978).

Large Neogene basins are evidently connected not only with blocks and their mobile parts or their crossing but also already with weakly Epivariscan--consolidated crust, with small portion of granite layer. This crust of suboceanic character was thinner and liable to repeating mobility and sinking already before the origin of basin. I do not consider S t e g e n a 's assumption of secondary deep erosion of crust after the analysis of crust type as substantiated.

The basement of small intramontane basins is typical in having occurrences of granitoids connected with thick continental crust, tectonically broken up by undeep faults.

5. *Coal basins and deep structure*

For creation of coal-forming conditions, besides tectonic activity, also paleogeographical configuration of the area is of great importance. Paleogeographical knowledge has not been complete so far. It is evident from up to present knowledge (G r o s s, 1978, G a š p a r í k, 1978) on development of the Tertiary that the Peripieninic lineament conditioning greater sinking in the northern part of the West Carpathians took part in division of marine sediments already in the Paleogene. On the contrary, in the southern part and mainly in the Pannonian basin development of continental crust was complemented by volcanic activity and uplifts suitable for formation of small coal-forming basins took place. In the Inner Carpathians sedimentation areas were tectonically dissected in dependence on tectonics of the basement of Paleogene basin and so a foundation to differentiated contrasting tectonic movements to the end of the Paleogene was laid, on the one hand favourable for coal-forming sedimentation, however, on the other hand unfavourable for the origin of deposit accumulations of coal. This is proved by a large number of occurrences of Paleogene coal without economic importance.

In the Miocene essential tectonic rebuilding took place and the boundary of sea with land migrated generally to the south. With this migration, however, already movements at block margins interfered, mainly at N—S faults, along which coal-forming conditions penetrated back, in northern direction toward the interior of the Carpathians. In the Pliocene movements were already strongly influenced by development of the individual blocks.

In the Carpathian fore-deep only local accumulations of coal formed, cyclically repeating coal-forming conditions were created at the Přerov—Štiavnica fault in the area of the Hornomoravský úval depression only.

In the Vienna basin favourable conditions were formed NE of the Nesvačilka—Trnava line in the stable sector of basin. Favourable conditions could have been formed by the elevation strip along the Peripieninic lineament.

The East Slovakian region is characterized by occurrences of coal at the margins of the mobile East Slovakian block (Slánsky deep-seated fault), favourable conditions were again at the Peripieninic lineament in the stable Humenné block. There is some analogue with the NW branch of this lineament. Important for creation of coal-forming conditions was the Hornád fault with the Slánsky deep-seated fault, at which favourable conditions repeated from the end of the Paleogene, throughout the Eggenburgian to the Sarmatian. In the Paleogene the Peripieninic lineament was manifested favourably in the line from Stará Ľubovňa to the Vihorlat mts. and farther to the territory of the USSR. Due to the influence of dense tectonic dissection equally as at the margins of the East Slovakian block, however, conditions for larger deposit concentration of coal have not been created. An exception was the mentioned Humenné block rising obviously under the influence of Vihorlat mts. volcanism as a consequence of formation of a deep magmatic elevation (possibly of secondary magmatic chamber).

The Vienna and East Slovakian basins have one common feature - great concentrations of occurrences of coal, including objects important as deposits and, moreover, concentration of the main gas deposits of Czechoslovakia over a relatively small area. Besides lithofacial conditions by the influence of great tectonic differentiation of sinking, it is mainly caused probably by the specific development of basins, conditioned by interblock position, tectonic exposition at the Peripieninic lineament at the contact with thin crust and with dynamic effects of the mantle diapir below the Pannonian basin.

Another group of deposits, which we range to the small Inner Carpathian basins, is distinctly bound to the Central Slovakian segment of the Fatra—Tatra block. The main deposits are situated at the SW margin of the block at the deep-seated Přerov—Štiavnica fault in the area of its crossing with the fault zone of the Central Carpathian lineament. Here is a second (see East Slovakian region) manifestation of N—S faults for areal concentration of coal occurrences and deposits (Handlová, Nováky, Badín). The manifestation of these faults may be also followed in the Danube block — localities Obyce, Hronský Beňadik and others and in the South Slovakian block localities with Lower Pliocene occurrences in the Hron valley, Štúrovo deposit. The zone of the Central-Carpathian lineament, probably formed in the Neogene, displays features of a coal-bearing lineament (Fig. 2).

The Fatra—Tatra block with a tectonically highly dissected continental crust, frequent alternation of elevation and depression strips, is the block richest in occurrences of coal and deposits of industrial interest. We may trace here coal-forming conditions from the Lower Eocene to the Middle Pannonian s.l. (Lower Pontian).

The Danuble block is poorest in coal occurrences and besides the locality of Beladice coal occurrences are bound to the mentioned N—S zone only. The great mobility of the block was the reason four inundation by sea in the Miocene, otherwise favourable for the origin of coal seams. The spatially restricted extension of the elevation was paleogeographically unfavourable for the origin of larger desposits in the Lower and Upper Pliocene. The areal prevalence of the depression conditioned long-lasting sea floods.

The South Slovakian block is of largest area. Coal deposits are found near Štúrovo and in the South Slovakian basin. The occurrences of coal coincide in time with the Eocene to Pliocene and indicate partial uplifting movements in this interval, which were the most extensive on Hungarian territory. The largest coal basins are also situated there. The position of the South Slovakian coal basin confirms again linking to the margins and proximity of deep-seated faults, in this case continuation of the Přerov—Štiavnica deep-seated fault, perhaps active also farther toward SE in the pre-Badenian period. The post-Badenian-formed block integrates six blocks with various inner structure. The blocks delimited by Fusán et al. (1979) also correspond to variously mobile units with reversible vertical movements. The largest number of coal occurrences and main deposits are situated in the Šahy block and here, besides the already mentioned continuation of the deep-seated Přerov—Štiavnica block, also in the N—S zone of the Central-Carpathian lineament.

The correlation of coal occurrences and coal basins with deep block structure shows:

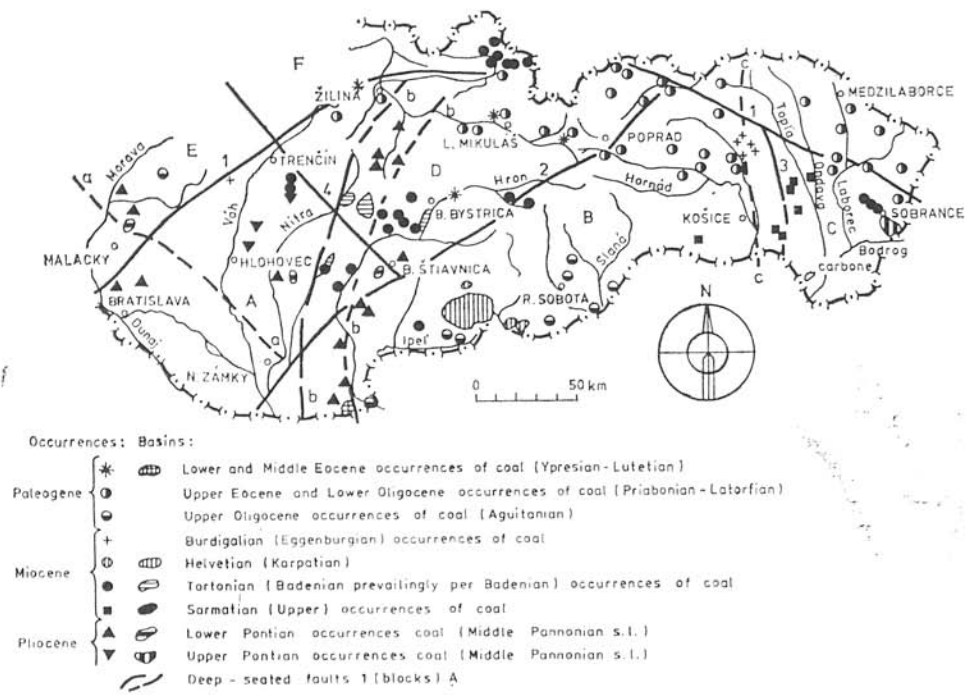

Fig. 2. Occurrence of coal and coal basins of Slovakia in relation to deep structure. Deep-seated faults: 1 — Peripieninic lineament; 2 — Vepor fault; 3 — Slánsky -fault; 4 — Přerov—Štiavnica fault; a — Nesvačilka — Trnava fault; b — Central—Carpathian fault; c — Hornád fault. Blocks: A — Danube block; B — South Slovakian block; C — East Slovakian block; D — Fatra—Tatra block; E — Slovakian—Moravian block; F — Slovakian—Silesian block.

a) Deposit concentrations of coal are bound to block margins, which were incorporated in the block structure formed in present-day form to the end of the Miocene.

b) The largest coal resources are concentrated to the Vienna and East Slovakian basins, which are of the position of interblock basins at the boundary of two megablocks: the Bohemian massif and West Carpathians, West and East Carpathians. Both basins, traditionally ranged to intramontane basins, are intermontane basins from the standpoint of deep structure.

c) Of analogous position are also coal deposits of the South Slovakian basin, which is lying on a thin weakly Prenoid-consolidated crust. This is part of the Pannonian megablock, its northern Balaton block. The coal deposits are bound to transition between thin and thick continental crust of the Inner Carpathians. Thus they are lying between two different crustal segments.

d) The Inner Carpathian coal deposits belonging to intramontane basins, on typical continental crust, are dynamically bound to margins of blocks or deep structures.

e) In distribution of coal deposits the N—S fault zone, which is an upper crustal manifestation of perhaps Neogene-founded and further developing lineament, is of so far underestimated importance. The lineament displays features of a coal-bearing lineament, as the Vardar zone (Čech — Zeman, 1979).

f) Favourable for the origin of coal deposits from the standpoint of deep structure were: block margins with different tendency of movements (neighbourhood of source area), tectonic dissection differentiating paleogeographical conditions, slow sinking, which was mainly predisposed by thin, Paleozoic- and Mesozoic — unconsolidated crust.

Factors unfavourable for the origin of larger volume of coal resources were: high tectonic disturbing and rapid changes in positive and negative movements, little tectonic dissection of mobile (weakly consolidated) crust.

6. *Remarks to prognostic regions*

The above mentioned criterii are also of prognostic character, however, it is necessary to consider in a complex way besides the tectonic factors also paleogeography. In this contribution I am limited only to criterii resulting from the analysis of relation of deposits to deep structure, without valuation of paleogeography, which has not been completely finished from synthetic side.

As least perspective appears the fore-deep zone and from the inner units the Danube block. The existence of the north-southern Central-Carpathian lineament delimits a prognostic area within the competent blocks to the strip between Levice and Krupina and a parallel strip between the rivers Nitra and Hron. From other prognostic structures only the Vienna and East Slovakian basins remain, mainly the zones along the Peripieninic lieament. In its eastern part the area around Kapušany, Vranov and in the western part the zone between the Hornád and Slánsky deep-seated fauls are concerned. Everywhere margins of blocks with interference of uplifting and sinking (at faults) movements are concerned. It will be possible to compile more detailed prognoses, however, after evaluation of paleogeographical development only. These works, however, should take into consideration tectonic knowledge.

Closing remarks to classification of Tertiary basins.

The tectonic classification of basins worked out by Buday (1961) was essentially confirmed. It is, however, necessary to complete it from the standpoint of deep structure and knowledge of thickness and type of crust.

a) The Vienna and East Slovakian basins I range to intermontane basins, the structure of which inherits the fault structure of adjacent large units.

b) Other basins on the inner side of the West Carpathians from the standpoint of crust development I divide into:

— basins on consolidated crust, with development of basins depending on migration of folding

and

— basins on weakly consolidated, mobile crust, with dynamic development, connected with development of the Pannonian mantle diapir. Both types of basins inherited mobility and structural dissection of the basement but the second type of basins has, moreover, the character of superimposed basins lying on various geological units forming the basement of basins. Foundation of basins proceeded along the Carpathian arc from west to east and from the inner to the outer side but differentiated movements of blocks directed these tendencies also in opposite direction. Mainly in the Pliocene sinking was intensified in the zone around the Panonian lowland and development of mobility was most probably connected with releasing of tension in crust above the mantle diapir.

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