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FRANTIŠEK ČECH* — JAROSLAV ZEMAN**

GENESIS OF MESO—CENOZOIC SEDIMENTARY BASINS OF BOHEMIAN MASSIF IN ALPINE-CARPATHIAN FORELAND

(Figs. 3)

Abstract: There are Meso—Cenozoic graben basins at the southern and southeastern margins of the Bohemian Massif in the Alpine-Carpathian foreland. In terms of plate tectonics the basins might be associated with strike-slips along transcurrent faults. In the foreland of the convergent contact the "pull-apart" basin may be considered. No strike-slip faults nor other characters of the pull-apart basins have been proved by the analysis of geologic structure of the basement and basin surroundings. The genesis of the basins is still associated with normal faults. The basins in the foreland of the West Carpathian nappes can possibly have the character of the continental margin structures.

Резюме: У южного и юговосточного краев Чешского массива в альпийско-карпатском форлянде находятся мезо—кайнозойские сбросовые бассейны. В терминах плитовой тектоники бассейны можно связивать с ложными сбросами транскурентного типа. В форлянде концентрического контакта это может быть бассейн пулапартового типа. Анализ геологического строения основания и окрестности бассейнов не доказал ложные сбросы, ни другие признаки, характерные для пулапартовых бассейнов. Образование бассейнов в форлянде связывается постоянно с нормальными сбросами. Бассейны в форлянде западнокарпатских покровов могут иметь характер структур окраин континента.

Sedimentary basins on the pre-Mesozoic basement of the Bohemian Massif in the foreland of the East Alps and West Carpathians are genetically associated with tectogenic movements in the orogens mentioned. South-Bohemian basins have been forming since the Upper Cretaceous time. Basins in the foreland of the West Carpathians, the Vranovice and Nesvačilka nappes and the Upper Moravian graben mostly developed in the Tertiary time. The origin of the basins is associated with movements along pre-Tertiary and perhaps partly Precambrian faults. Genesis of the basins as tectonic grabens was explained by subsidence of basement blocks along faults. The Vienna Basin situated at the boundary of the Bohemian Massif and West Carpathian megablocks has a specific position. In respect of pre-Neogene structural levels it is an interblock (intermontane) basin of a long evolution (Čech, 1982, 1984).

General problems concerning basin genesis in foreland of orogens

At present most attention is paid to the mechanism of movements along faults of the platform foreland of tectogens. Geodynamic models based on plate tectonics prefer strike-slip faults as the main cause of the origin of

* Prof. Ing. F. Čech, DrSc., Department of Economic Geology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava.
** RNDr. J. Zeman, CSc., Civil Engineering Geology, nat. ent., Gorkého nám. 7, 110 00 Praha 1.

sedimentary basins (shear basins according to G r e e n, 1977) of the graben character (B u r k e — D e w e y, 1973). The models are based on the idea that in the front of the convergent contact between plates or microplates the horizontal stress and pressure are transported over hundreds of km to the

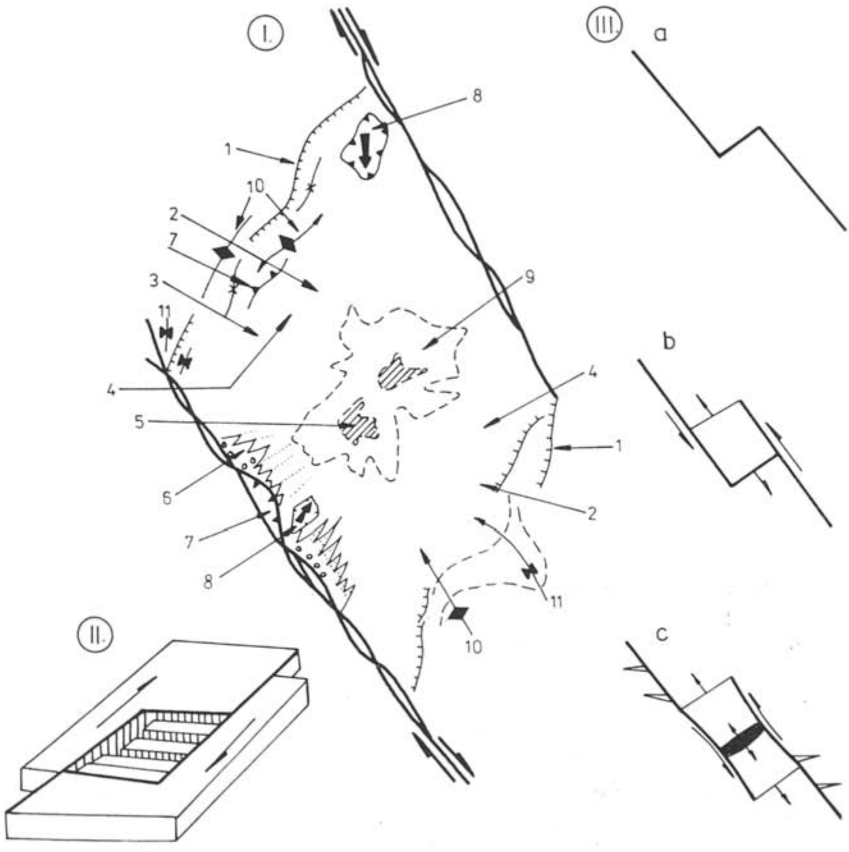

Fig. 1. Formation of "pull-apart" basin by strike-slip fault on uneven fault.
Legend: I — Model prototype of basin (modified after C r o w e l l, 1974): 1 — faults with subsidence, 2 — zone of crustal stretching and thinning, 3 — formation of discordances and transgressive deposition of sediments in deeper part of basin, 4 — original, now detached sediments, 5 — relics of marginal rocks of basin bottom in new-formed volcanic bottom (9), 6 — zone of proluvial cones and rapid facies changes, 7 — smaller overthrusts, 8 — gravity-displaced blocks (arrow-head marks transport course), 9 — new-formed volcanic bottom, 10 — compression anticlines, 11 — extension synclines.
II — Blockdiagram of genesis of "pull-apart" basin. Maximum subsidence is perpendicular to marginal faults (simplified, after M i a l l, 1984).
III — Scheme of genesis of "pull-apart" basin in strike orientation identic with orientation of South-Bohemian basins: a) original uneven discontinuous fault, b) sinistral strike-slip fault should open box-shaped area, c) further strike-slip faults should cause crustal stretching and opening and subsidence in basin centre perpendicular to course of stretching; W-E faults should open.

foreland of the forming tectogen-orogen and that the formation of basins on the platform foreland is controlled by strike-slip motion on geologically older faults, transcurrent to the plate margins (Bally — Snelson, 1980; Kingston et al., 1983; Miall, 1984; Reading, 1978). This dynamics was applied on the Vienna Basin by Royden et al. (1982), Wessely (1984) a. o. The problem of the application was discussed by Čech (1984).

The type basin denoted as the "pull-apart basin" is the theoretical basis of geodynamical ideas and reconstructions. Crowell (1974 - Fig. 1) described the "pull-apart" basin in the southern part of the Gulf of California for the convergent plate contact modified by transcurrent and eventual transform faults. The basin exhibits some typical features like fault termination, box form (Fig. 1, II) but also fold structures and volcanic bottom (spreading centre) reminding of the new-formed oceanic crust. The basin in the southern part of the Gulf of California is associated with a high heat flow density. Sometimes the basins of this type as proto-type are compared to small oceanic basins not generated by divergent movements. But Klemme (1980) placed the basins of this type also on the divergent margin of the Atlantic Ocean. Reading (1978) and other authors assume the formation of basins on transform faults extending from the ocean behind the divergent continent margin. Some authors ignore the complexity of basin features and range the basins to the "pull-apart" type only on the basis of their existence and the shape of faults (cf. Royden et al.; Wessely, l. c.).

When from the complex of features we only consider for example the rhomboid shape of the basin in the map, and the fault termination, then besides the South-Bohemian basins also the Cheb basin, the Upper Moravian graben and even the Upper Cretaceous Bohemian basin can be ranged to the "pull-apart" basins.

Aulacogens and rifts represent another problem concerning the classification of basins on the southeastern margin of the Bohemian massif. The problem was discussed from the general view by Čech (1985, 1985b). From the view of geophysics the aulacogens and rifts show identic features like thinned crust beneath depressions and elevation of the active asthenosphere (e. g. Zbořil et al., 1986). There is a problem of how to denote the grabens on divergent continent margins. Grabens extending to the ocean, are sometimes denoted erroneously (Miall, 1984) as aulacogens. Curtis (1980) admits at most the term pseudoaulacogen. The original term "failed or dead rift arm" (Burke and Dewey, 1973) should be right. According to Shatsky (1955) aulacogen is a depression on a platform in the foreland of orogen to which it is diagonal or partly perpendicular. So aulacogen cannot be on the divergent margin of the continent plate (Curtis l. c.).

Geologic structure of basement of South-Bohemian basins

Strike-slip faults bordering the South-Bohemian basins can only be proved by a comparison of geologic structure inside and outside the basin, in its basement. The first new information on the geologic structure of the basement is offered by the Tectonic map of ČSSR 1 : 500 000 (Mahel' et al., 1984). However, the data mostly differ from information offered by boreholes in the basin basement performed in the sixties, for the exploration of uranium occurrences, and from data resulting from hydrogeologic wells realized in the second half of the seventies and at the beginning of the eighties. The boreholes for the Uranium prospection occupy the most part of the Třeboň basin. For the reconstruction of the basement 16 boreholes denoted as A, 8 boreholes denoted as P, 11 as N and 43 as TP could have been used. Geological interpretation of boreholes was done by RNDr. B. Houska from Uranium Survey Příbram. The boreholes were drilled in profiles, in variable distances (from 0.5 to 1 km and to 2.5 km). The exploration was concentrated near Veselí n. Lužn., Lomnice n. Lužn., Suchdol n. Lužn. (the max. number of TP boreholes), Trhové Sviny, Nové Hrady and České Velenice. The map in Fig. 2 only shows

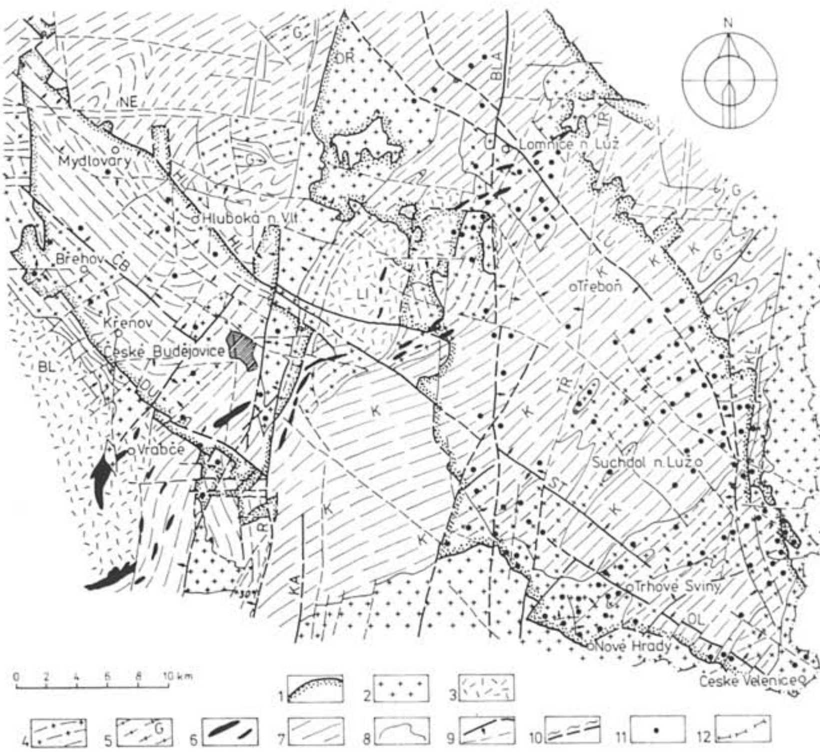

Fig. 2. Exposed geological map of South-Bohemian basins (without platform sediments). *Legend:* 1 — Upper Cretaceous boundary; 2 — granitoids; 3 — granulites: BL — Blanský les, (L) — Lišov body; 4 — migmatites; 5 — orthogneisses and rocks of such appearance; 6 — amphibolites and ultrabasic rocks in granulites; 7 — paragneisses (K — Kaplice complex); 8 — boundaries of rock complexes; 9 — faults established inferred; 10 — faults with mylonites; 11 — boreholes in basin basement; 12 — state frontiers.

Fault names: BLA — Blaník zone, ČB — České Budějovice fault, DU — Dubné fault, HL — Hluboká f., KA — Kaplice f., NE — Netolice f., R — Rudolfov f. in Budějovice basin, DR — Drahotěšice f., KL — Klikov f. (fault zone), LU — Lužnice f., OL — Olešnice f., ST — Stropnice f., TŘ — Třeboň f. in Třeboň basin.

some selected holes. It was impossible to present all the holes. Further regional exploration was performed by Civil Engineering Geology (Stavební geologie n. p.) Praha. In the basement of the Třeboň basin they drilled 22 TJ boreholes and 6 HP boreholes near the basin periphery (V r á n a, 1978, 1982). 12 HP boreholes (P e t r, 1978) reached the basement in the České Budějovice basin. The boreholes offered new data on the trend of course and areal extent of paragneisses and migmatitized gneisses. They proved the extent of the Ševetín granodiorite, the southwestern margin of the Moldanubic pluton and the extent of cordierite migmatites with biotite $\pm$ sillimanite (Fig. 2). Fault tectonics was reconstructed on the basis of the deep drilling data. Numerous corrections, mainly of data on the extent of granulites, granitoids and basic bodies taken over to the map by F i a l a et al. (1982), were necessary in comparison to geophysical interpretation of the basin basement (K a d l e c et al., 1978). It was also necessary to correct the fault tectonics because, for example, it was impossible to prove the presumed W-E-striking fault crossing the Třeboň basin and running near Trhové Sviny (M a l e c h a et al., 1977 b).

Drilling cores from the crystalline basement showed that migmatites in paragneisses formed layers ranging from dm to m in size, alternating with non-migmatitized. Similar cases also occurred in the Kaplice gneiss complex. For this reason the migmatites were only marked in areas where they were revealed by more boreholes. In the northern part of the Budějovice basin it is the continuation of the Podolí complex, in the Třeboň basin — cordierite migmatites in the mantle of the Moldanubic pluton. When the light-coloured layers ranged from dm to several m in thickness, also leucocratic migmatites were described as orthogneisses. In some cases leucocratic rocks were denoted as migmatites in the map in Fig. 2.

Tectonics of South-Bohemian basins

On the presumption about uneven surface and according to data on the depth of crystalline complexes the isohypses of the surface of crystalline complexes were constructed in a preliminary map 1 : 100 000. Uneven parts or greater linear gradients of isohypses between boreholes were explained by faults.

Basical structure of crystalline complexes is monoclinic, with parallel foliation (metamorphic and bed schistosity) on the basin periphery. Foliation dips 20—30° prevailed, 40° and 60—70° were scarce in boreholes. Great dips are characteristic of the surroundings of the Lužnice fault and of some other faults. Perhaps there are rather flexures than folds presumed by M a l e c h a et al. (1977a). Folds are an exceptional phenomenon mostly associated with migmatites.

Most conspicuous faults with stable strike in the České Budějovice basin are the Hluboká fault, the fault running across the basin centre denoted as the České Budějovice fault, the Rudolfov and the Drahotěšice faults. They border the Rudolfov NNE-SSW grabenformed on the extension of the Ševětín granodiorite. The southern termination of the graben is so far unknown. The NW-SE-striking České Budějovice fault extends southeastwards to the Kaplice gneisses; the Rudolfov fault is part of the Kaplice—Rodel fault zone (Z e m a n et al., 1986).

In the Třeboň basin the fault division of the NW-SE Stropnice graben has been precised. Inverse movements of underlying blocks (M a l e c h a et al., 1977 b) are indicated by depth oscillation of the basement on both sides of the Olešnice and Stropnice faults (divergent arrow-heads at fault in the map in Fig. 2). The Stropnice fault is the strike continuation of the Hluboká fault with the reverse course of dips and subsidences. The two faults delineate the deepest sagged blocks in the basins.

The eastern periphery of the Třeboň basin is bordered by the Klikov fault zone (cf. M a l e c h a et al., 1977b). The zone is wider and consists of more faults than it was known before. We have denoted a new conspicuous regional NW-SE fault as the Lužnice fault. The Blaník fault and the convergent fault running across Třeboň, denoted as the Třeboň fault, extend into the basin. The two faults are marking out the superimposed tectonic graben of the Blaník trench.

In relation to the structure of crystalline complexes the two South-Bohemian basins are superimposed basins, but the České Budějovice basin shows features of a synclinal graben in its northwestern part, because in the crystalline basement a syncline with the NW-SE axis may be presumed in respect of the multidirectional structure outside the basin periphery. Any association with the Jáchymov deep fault can only be admitted for the line of the Stropnica and Hluboká faults. Its continuation northwestwards to the Písek crystalline complexes cannot be geologically proved.

Possible existence of strike-slip faults

Correlation of structural courses and rock complexes inside and outside the basin did not show any indications of strike-slip fault on marginal faults or on the Blaník fault zone. In the České Budějovice basin the strike-slip fault is prevented by the continuous course of the Ševětín granodiorite, in the Třeboň basin by the course of migmatites and Kaplice gneisses. The outcrops of crystalline complexes and granitoids near basin margins did not show conspicuous or dominant shear joint systems either. There are NW-SE (ac - joints) tension joints in gneisses. In granitoids the N-S and S-E joints predominate.

Meso—Cenozoic tectonic grabens on SE margin of Bohemian Massif

The pre-Mesozoic basement of NW-SE grabens consists of Late Paleozoic sediments in its SW part, and of Cadomian granitoids and pre-Devonian metamorphites in its NE part. The Vranovice and Nesvačilka grabens are on the Brno block, the Upper Moravian graben rests as an interblock depression on the contact with the Silesian block; according to F u s á n et al. (1979) - between the Slovak—Moravian and Silesian—Slovak blocks. The Nesvačilka graben was predisposed by the deep Nesvačilka—Trnava fault (Č e c h, 1982).

Pícha (1979) denoted the Nesvačilka and Vranovice grabens as aulacogens extending into the sea. E l i á š (in S u k et al., 1984) presumes the existence of the Morava strait extending from the margin of the Moravian carbonate platform northwestwards beneath the Bohemian Cretaceous. E l i á š did, however, not describe the nature of the strait.

On the SE the Nesvačilka and Vranovice grabens link up with the N-S

Kúty graben in the Vienna Basin. Č e c h (1984), basing upon the analysis of geophysical data and orientation of gravity- and magnetic linear anomalies, regards the grabens as geophysically indicated in a deeper structure (Fig. 3).

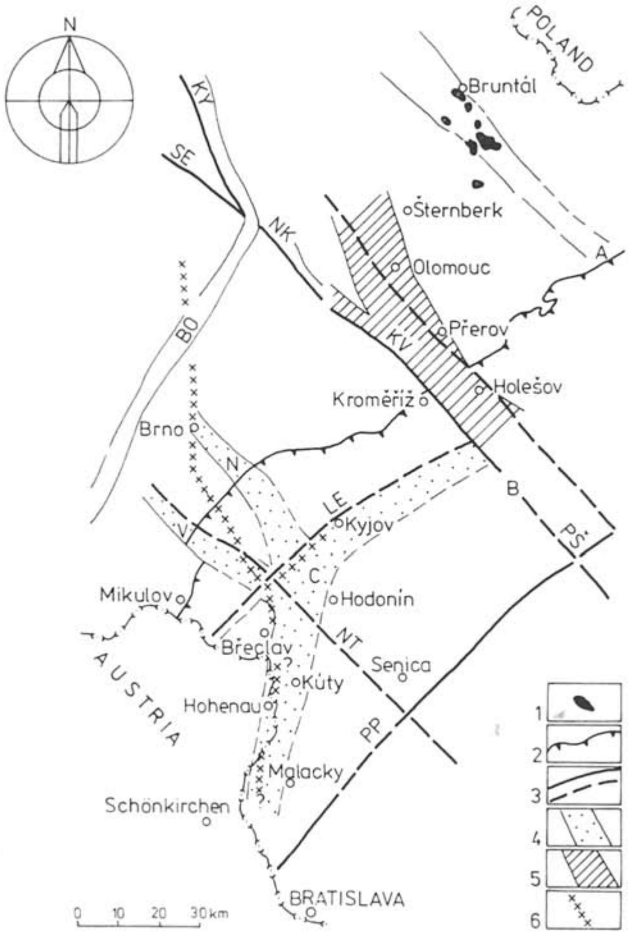

Fig. 3. Tectonic grabens on contact of Bohemian Massif and West Carpathians on Czechoslovak territory.

Legend: 1 — neovolcanics; 2 — front of Out-Carpathian nappes; 3 — geologically proved, presumable and geophysically indicated faults of variable geotectonic significance; 4 — presumable triple junction rift pattern (Jurassic ?), beneath Vienna Basin in autochthonous basement; 5 — graben with features of aulacogen; 6 — zones of basic rocks and positive magnetic anomalies.

G r a b e n s: A — Silesian initial rift, B — Upper Moravian graben, C — presumable paleorift with failed arms — Vranovice (V) and Nesvačilka (N) grabens.
D e e p f a u l t s: LE — Lednice, NT — Nesvačilka-Trnava, PP — peri-Pieninian, PŠ — Přerov-Štiavnica (equivalent of Labeg).
S i g n i f i c a n t f a u l t s: KY — Kyšperk f., SE — Semanín, NK — Nectava-Konice, KV — Kvasice f., BO — faults of Boskovice trench.

The Upper Moravian graben is a geologically young structure with 100 m of Quaternary sediments (Z e m a n et al., 1980) in the fill. A fault zone with Tertiary and Quaternary basalts extends from the Nízky Jeseník to the Morava gate. The NW-SE zone exhibits tectonical and geomorphological features of an initial depression of the graben type.

Possible application of new geodynamic models of sedimentary basins on Meso—Cenozoic grabens on margins of Bohemian Massif

The origin of basins during the Upper Cretaceous and Tertiary on S and SE margins of the Bohemian Massif was formerly associated with the compression by the East-Alpine and West-Carpathian nappes. At present this concept is also postulated by S c h e n k et al. (1986). There is no tectonic evidence of the transparency of the consolidated Bohemian Massif for compressions or formation of new shear tension inside the Massif. If the fronts of nappes compressed the crystalline massif, the new tension would concentrate mostly on the massif margin next to the nappes.

The existing data on the structure of the basement of frontal nappes deny their extensive outer deformational effects. Deep drilling on the southern margin of the Bohemian Massif revealed Middle and Upper Cretaceous unfolded sediments beneath the East-Alpine molasse and nappes (F u c h s et al., 1984). The West-Carpathian outer nappes did not fold the sediments of the Neogene Carpathian Foredeep. Its formation by compression (K o v á č et al., 1987) is speculative. Compression did not affect the platform foreland and it is hardly possible to associate the origin of tectonic grabens in the foreland of the West Carpathians with compression. Reflection seismic data (T o m e k, 1985) also indicate the traction movements of flysch nappes with deformation effects upon the basement.

The origin and transport of compressions from the East Alps to the inside of the Bohemian Massif are denied by the fact that in the South-Bohemian basins there is no evidence of strike-slip faults on marginal faults and the faults do not extend south-eastwards beneath the fronts of the Alps. According to geological reconstruction (F u c h s et al., 1984) the autochthonous Cretaceous sediments beneath the fronts of the East Alps filled the sea basin extending from Regensburg to Linz and from Munich to Salzburg. So the origin of horizontal compression from the Alpine tectogen can at the margin of the Bohemian Massif not be ranged to the Upper Cretaceous time when the marine sedimentation was proceeding on crystalline complexes of the Bohemian Massif. Synsedimentary disquietude in South-Bohemian basins resulted then in cyclic sedimentation of the Upper Cretaceous deposits. The disquietude was associated with intermittent subsidence of the basin bottom. In the Tertiary - when the East Alps should have had compressed the Bohemian Massif crystalline complexes, mostly pelitic sedimentation in a calm lacustrine environment proceeded in the South-Bohemian basins. The South-Bohemian basins cannot be regarded as "pull-apart" basins forming on transcurrent faults far in the foreland of convergent movements. The model is also opposed by the fact that blocks with the maximum subsidence in basins do not exist in their axis and their course is not NE-SW (Fig. 1, III). If the basins were opening by sinistral NW-SE strike-slip fault, the maximum-sagged blocks would be NE-SW-striking. Neither the volcanic bottom - one of the typical features according to C r o w e l l (1974) - nor folds in sediments have been found in the basins. The South-Bohemian basins resulted from normal faults. This mechanism is proved by the variable mutual relationships among movements on faults - as shown by variable relative ages of faults (M a l e c h a et al., 1977 a, b). Other causes of fault-predisposed basin subsidence are unknown. The movements might have been associated with the oscillating surface of asthenosphere in the foreland of the Alpine mobile zone, or with advection- and diapirical rock (granulites?) displacement in the shallower level of the Bohemian Massif crust.

As for aulacogens, the authors of new basin classification forget that S h a t s k y (1955) characterizes aulacogens by long life on paleolineaments, by variegated endogenous processes and inversion of movements. So they cannot be identified solely according to their orientation to tectogen. The Upper Moravian graben may show some features of aulacogen (foundation on a deep fault, indications of inversion, orientation to tectogen) but it is in no case a typical aulacogen.

The Nesvačilka and Vranovice grabens could be failed arms of triple junction rift pattern as far as the linear magnetic anomalies reflect the pre-Tertiary, Mesozoic (?) basic rocks. Repeated graben trends in the Hradiště graben during the Quaternary and Holocene times (Z e m a n et al., 1982) and in the Kúty graben during the Quaternary time may indicate the heredity of movements in the paleorift pattern. The south-eastern margin of the Bohemian Massif might have had and may still have in some recent movements indications of divergency (Č e c h, 1988a, 1988b).

Neovolcanics of the Silesian area may be regarded as an indication of an initial continental rift. It is denoted as the Silesian initial rift. It is likely that geological evolution of the rift will continue.

On the eastern margin of the Bohemian Massif are further graben structures active at the end of the Paleozoic and with rejuvenated movements in the Tertiary time. This concerns the neotectonic to subrecent graben character of the Boskovice trench and the Orlice Basin. In respect of dynamics in the evolution of the area the neotectonically proved dome movements with bending strain were predominant. Evidences of strike-slip faults towards the Carpathians, and of the opening of the Ohře rift in association with speculative subduction (P o s p í š i l — V a s s, 1983) are missing. The basement of the Ohře rift is known from hundreds of boreholes but no traces of crustal opening have been found.

Conclusion

The South-Bohemian Meso—Cenozoic basins were not formed by diagonal strike-slip faults bordering the sedimentary filling. The faults cannot be regarded as transcurrent, active during convergent movements of the East Alps. The basins cannot be denoted - in terms of plate tectonics - as "pull-apart" basins, although their outer features like their rhomboid shape are similar. The basins were formed before the fronts of Alpine nappes reached the margins of the Bohemian Massif.

The basins on the SE margin of the Bohemian Massif have not resulted from diagonal strike-slip fault owing to the pressure caused by the thrusting

West-Carpathians nappes. The nappes did not form any deformations in the basement and in the foreland either. Tectonic grabens in the foreland of the West Carpathians show identic NW-SE orientation. The Vranovice and Nesvačilka nappes are not aulacogens but rather failed arms of the triple junction rift pattern whose existence is presumed in the Mesozoic on the Lednice deep fault and on the Nesvačilka—Trnava deep fault. The trend of graben subsidence continued in the Quaternary and locally in the Holocene.

The Upper Moravian graben shows some features of aulacogen but it is not a typical aulacogen. Recently the Silesian initial rift with Silesian neovolcanoes was distinguished.

The formation of grabens on the SE margin of the Bohemian Massif was not associated with transcurrent faults and their dynamics before the nappe fronts.

Subsidence was most likely due to uplift movements in the eastern part of the Bohemian Massif, resulting in the renewal of subsidence on old faults predating the post-Paleozoic time. The relation between the genesis of Meso—Cenozoic sedimentary basins on the southern and southeastern margin of the Bohemian Massif and the processes forming the Alpine-Carpathian tectogen is not in the mechanistic explanation - like long-distance transport of strike forces - but in subcrustal or crustal processes activated also in the platform foreland of the tectogen.

Translated by E. Jassingerová

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