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Neogene Tectonics and Paleostress Changes in the Czechoslovakian Part of the Vienna Basin

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With 16 Figures

ČSSR
Wiener Becken
Neogen
Tektonik
Paläostress

Contents

Zusammenfassung

Eine geodynamische Rekonstruktion der neogenen Geschichte des NE-Teils des Wiener Beckens und der angrenzenden Teile der Kleinen Karpathen auf der Basis von ökostratigraphischen, sedimentologischen und strukturellen Daten wird vorgestellt.

Die tektonische Entwicklung des Gebietes und die Sedimentation wurden durch wechselnden Paläostress kontrolliert. Die Achse des maximalen Kompressions-Stresses war in einer subhorizontalen Ebene wirksam und rotierte schrittweise von NW–SE nach NE–SW.

Im Unter-Miozän wurde die Falten- und Überschiebungstektonik abgelöst von Blattverschiebungen mit maximaler Kompression in NW–SE-Richtung.

Das Mittel-Miozän war charakterisiert durch ausgedehnte Blattverschiebungen mit NE–SW-Kompression.

Während des Ober-Miozäns und Pliozäns herrschte Zerrungs-Tektonik mit einer NW–SE-gerichteten Achse maximaler Dehnung vor.

Abstract

The geodynamical reconstruction of the Neogene history of the NE part of the Vienna Basin and of adjacent parts of the Malé Karpaty Mts. is based upon ecostratigraphical, sedimentological and structural data.

The tectonical development of the area and sedimentation were controlled by changing paleostress. The axis of the maximum compressional stress was effective in a subhorizontal plane and rotated gradually from NW–SE to NE–SW.

In the Lower Miocene time the fold-overthrust tectonics was followed by strike-slip faults with the NW–SE maximum compressional stress.

The Middle Miocene stage was characterized by extensive strike-slip faults with the NE–SW maximum compressional stress.

During the Upper Miocene and Pliocene the extension tectonics with the NW–SE maximum extension axis prevailed.

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1. Introduction

The purpose of the geodynamical reconstruction of the Neogene history of the NE part of the Vienna Basin and adjacent parts of the Malé Karpaty Mts., of the Brezovské pohorie Mts. and Myjavská pahorkatina upland is the elucidation of the genesis of intramontane depressions of the Western Carpathians. The depressions formed in the area affected by fading subduction of the North-European platform beneath the overriding system of Carpathian–Pannonian blocks (the subduction passed into a continent–continent type collision), and by the elevation of the asthenosphere in the Pannonian region.

In the Neogene time the formation of basins and deposition were controlled by regional faults whose kinematic regime reflects the stress field of particular stages. The stress formed the faults or controlled the kinematic regime of older faults. This led to the so called kinematic fluctuation of faults (MONTENAT et al., 1987). Tectonic activity of regional significant faults has been derived on the basis of the study of mesoscopical structures at representative localities (Fig. 1).

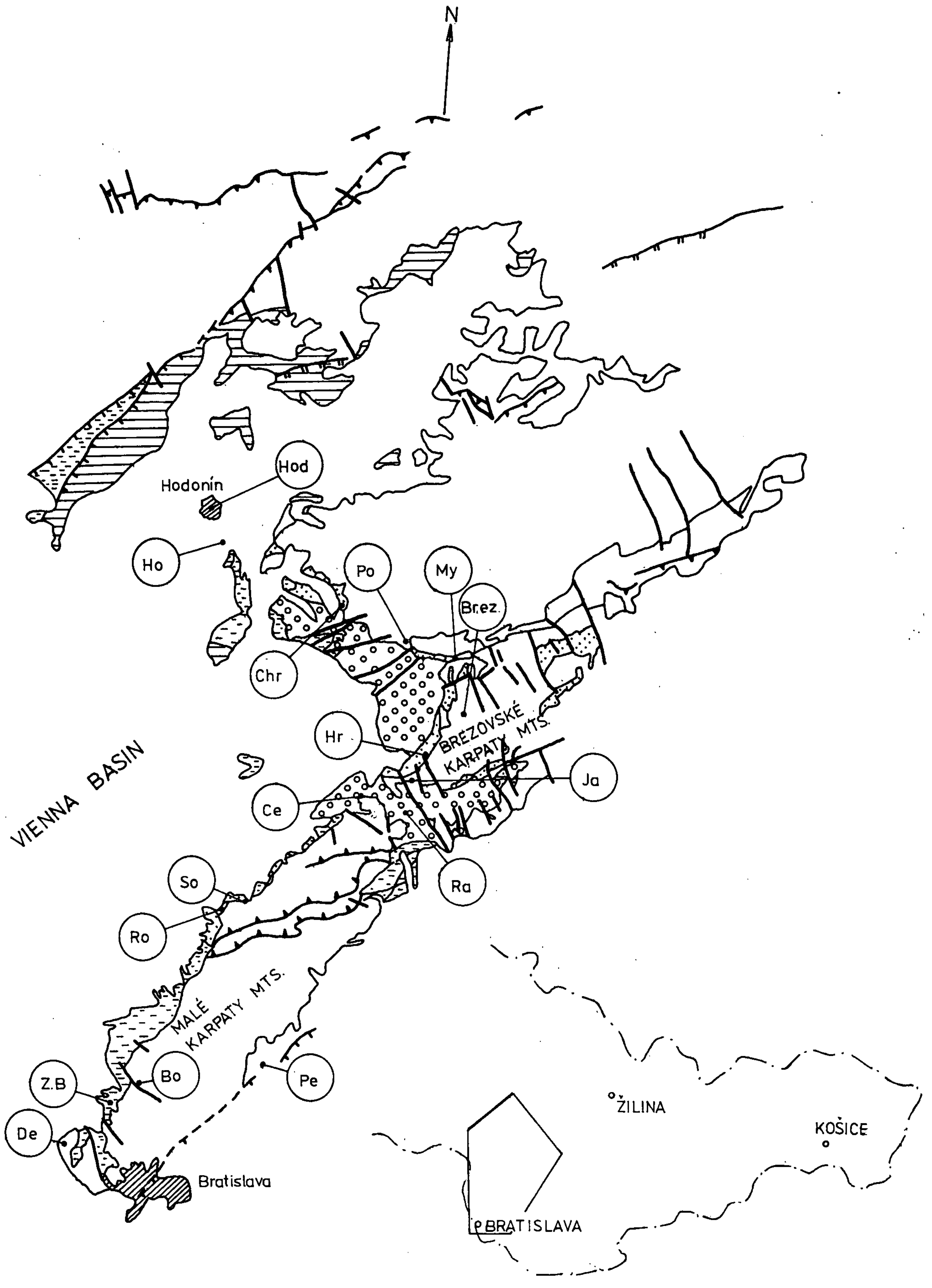


Fig. 1.
Scheme of localities studied.
Bo = Borinka; Brez = Brezová pod Bradlom; Ce = Cerové-Lieskové; De = Devínska Nová Ves; Ho = Holíč; Hod = Hodonín; Hr = Hradište pod Vrátom; Chr = Chropov; Ja = Jablonica; My = Myjava-Belanský; Pe = Pezinok; Po = Podbranč; Ra = Raková; Ro = Rohožník; So = Sološnica; ZB = Záhorská Bystrica.

The study was based on the properties of the lithosphere behaving as an elastic layer transferring the stress over a distance of several hundreds of km (Turcotte & Schubert, 1982). Besides large faults the stress also generated minor structures distributed in the earth's crust. Mesozoic, Paleogene, Eggenburgian, Karpatian, Badenian, Sarmatian and Pannonian rocks were studied and the predominant paleo-stress in the Neogene stages was found out by the method of elimination.

Shear and tension faults whose movement planes were constructed and whose stress tensors were found out, have been analyzed at the representatvie localities.

In ideal cases (Fig. 2), i. e. with subvertical and subhorizontal vectors, Hoeppner's (1955) and Jaroszewski's (1972) projections were applied, in more complicated cases we used Angelier-Mechler's (1976) and Alexandrowski's (1986) projections.

Sometimes several movement phases might have been distinguished in the field on the basis of lineation relations on tectonic slickensides in other cases on the basis of statistical evaluation of data on fault planes and movement direction on them (Alexandrowski, 1986).

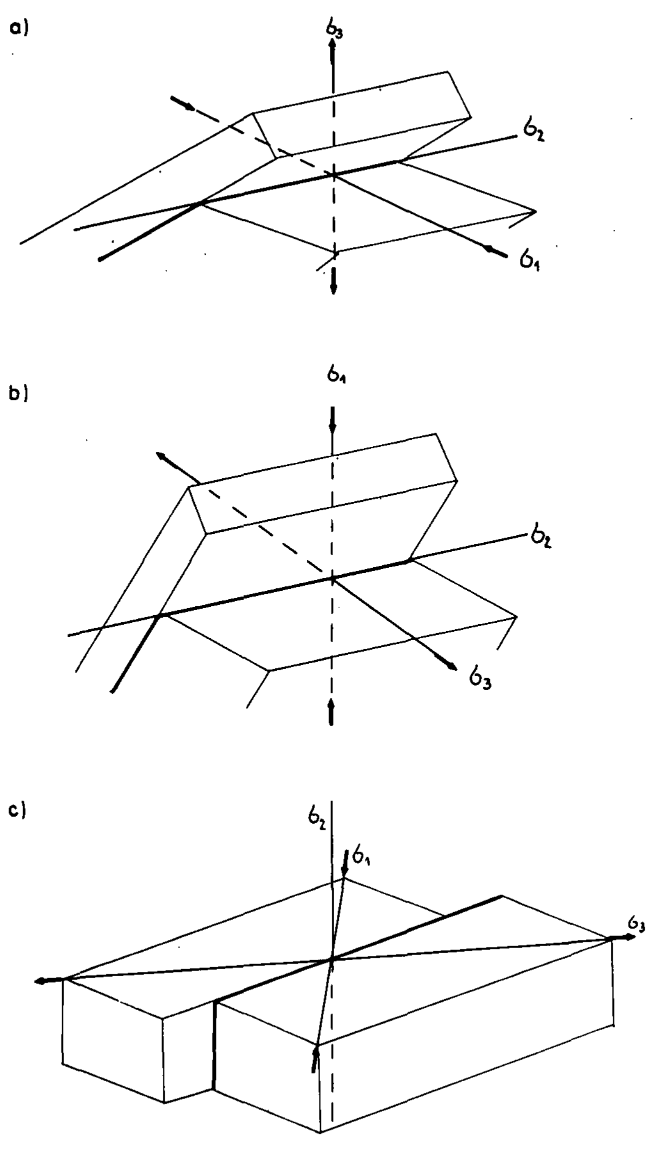


Fig. 2.
Relation between stress tensor and ideal shear faults (Anderson, 1951).
σ_1 = maximum compressional stress; σ_2 = intermediate stress; σ_3 = minimum compressional stress (relative extension).
a = reverse fault; b = normal fault; c = strike-slip fault.

Four principal phases with regional paleo-stress tensor of variable orientation have been distinguished. Sometimes their accurate delimination was difficult because of the more or less continuous rotation of the stress tensor direction. In the area of study there were besides ideal faults also other variants whose origin had been due to not only the paleostress but also to the pre-existing anisotropy. Structural analysis was complemented with sedimentological data.

2. The Lower Miocene Time

The earliest paleostress field had an axis of maximum compressional NW–SE-oriented stress. Its existence is closely connected with the overriding of the Western Carpathians orogene over the North European Platform. The direction of the maximum compressional stress is in accordance with the movement of the West Carpathian block. A presumption of the northvergent movement of the orogene is based upon direct paleomagnetic evidence (Kováč et al., 1988) and indirect structural evidence. In the course of the consequent overthrust the movement in SW part of the West Carpathians takes a sinistral turn to its present positon, i. e. NW-wards.

The age range of this phase is Eggenburgian – Lower Badenian, the lower boundary being limited by the age of the Neogene sediments studied. On the basis of deformations in the western part of the Western Carpathians (Stráník et al., 1979; Kováč et al., 1984; Steininger et al., 1984; Vass et al., 1983; Jiříček, 1979, 1985, 1987) and the present conception of the development of the Flysch Belt, the lower boundary of the effective paleostress may be dated as Paleogene.

The relatively long phase is distinctly reflected at the localities studied. Fig. 3 shows interpretations of the maximum compressional stress and of the minimum compressional stress (relative extension). Evidently the maximum compression component in particular areas varied around the maximum in NW–SE direction. There are several causes of the course dispersion:

1) The dispersion caused by the stress field axis deviation in the marginal parts of the accretion prism. The dispersion was found out by Angelier et al. (1986) (Fig. 4) and explained by a simple model of viscous material.
2) The change of stress field orientation in the evolution of the accretion prism and its deformation (-Knipe-Needham, 1986; Dewey et al., 1986).

In the area of study the phase was identified in Mesozoic rocks at the localities Devínska N. Ves, Záhorská Bystrica, Borinka, Hradište pod Vrátnom, in Paleogene Rocks near Sološnica, in Eggenburgian sediments near Podbranč, Chropov, Myjava–Belanský, Hradište pod Vrátnom, in Karpatian sediments near Cerové – Lieskové. Up to the Eggenburgian the phase was chracterized preferably by fold-reverse fault tectonics, during the Eggenburgian by formation of reverse fault zones (Fig. 5).

The Eggenburgian depositional area was formed in a stress field whose compression component might have

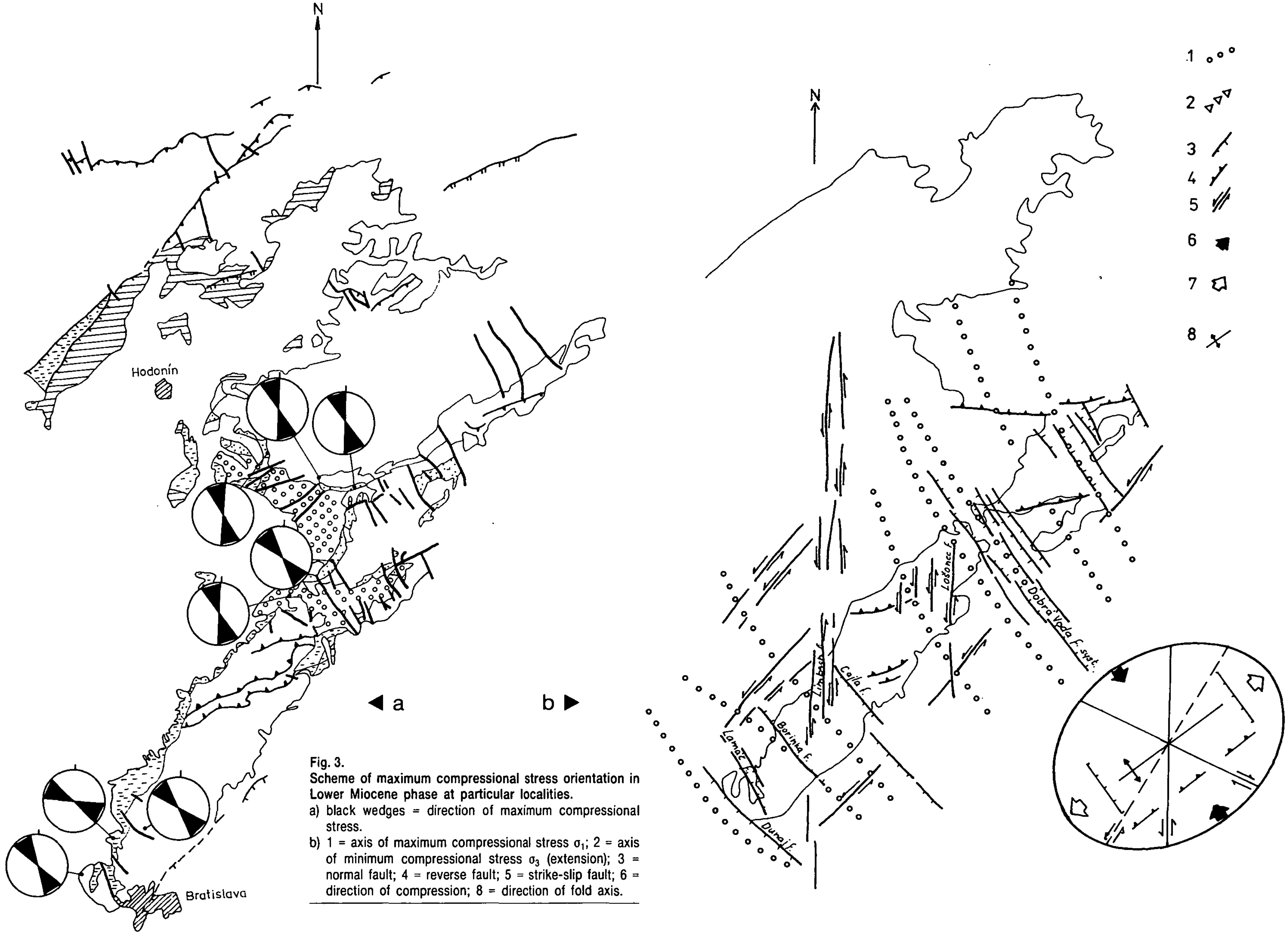


Fig. 3.
Scheme of maximum compressional stress orientation in Lower Miocene phase at particular localities.

a) black wedges = direction of maximum compressional stress.

b) 1 = axis of maximum compressional stress σ_1; 2 = axis of minimum compressional stress σ_3 (extension); 3 = normal fault; 4 = reverse fault; 5 = strike-slip fault; 6 = direction of compression; 8 = direction of fold axis.

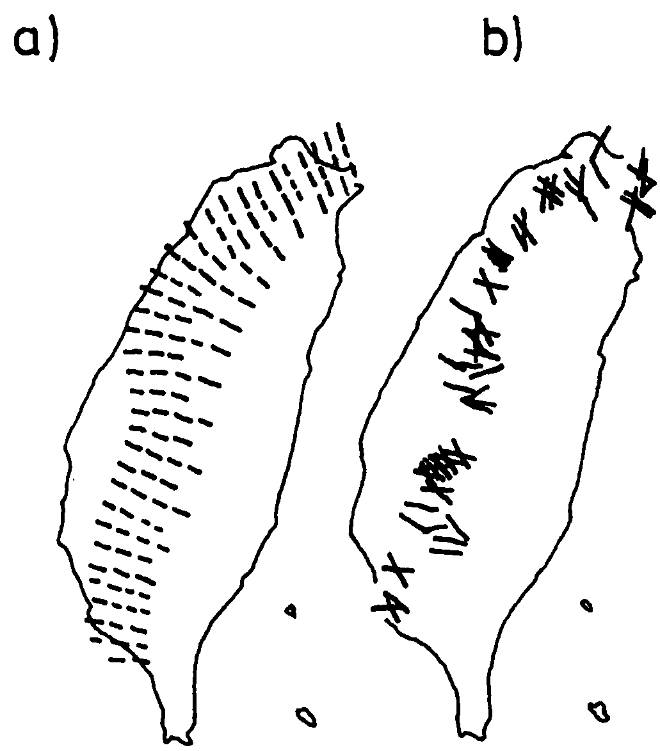


Fig. 4.
Maximum compressional stress direction in Taiwan during collision process (ANGELIER et al., 1986).
a) Directions determined by fold analyses.
b) Directions determined by fault population analyses.

been effective in N–S course. Sea transgression from the foredeep crossed the fronts of flysch Carpathian nappes and advanced to the Paleoalpine-consolidated part of the orogene.

There in the shear zone strained by sinistral strike-slip faults an intramontane depression formed along the inner margin of the Klippen Belt (KOVÁČ et al., 1988). Partial depressions separated by the basement elevations were generally E–W to ENE–WSW striking in both the area of flysch nappes and the area of the Central Western Carpathians (JIŘÍČEK. 1979; KOVÁČ et al., 1988). In the area studied the deposition commenced with basal conglomerates forming large alluvial fans on the periphery of the depositional area. At the beginning, the clastic material transport direction was from S, SE to N, NW, later on the longitudinal transport direction with the NE–SW depression axis prevailed. Denudation remnants of sediments preserved are indicative of both the lateral and the vertical facies changes. An upward transition of conglomerates and sandstones into pelites is evident. Synsedimentary activity of faults is indicated by fluxoturbidites mainly in the area of flysch nappes.

The sedimentation retreat from the Klippen Belt area proceeded during the Ottnangian time. Sediments of the Eggenburgian – Ottnagnian depositional cycle occurred mainly in the area of the present Vienna Basin on the basement built up of flysch nappes (JIŘÍČEK & TOMEK, 1981).

In the Lower Miocene time the advance of orogene on the platform and the space shortening resulted in accumulation and increasing thickness of the frontal part of the orogene. It caused a rapid increase of lithostatic pressure and preferred formation of strike-slip faults (Fig. 6). During the Karpatian the maximum compressional axis of the paleostress was effective in the NW–SE direction.

The change in the tectonic regime during the Karpatian is indicated by the character of sedimentation and by changing paleogeographic extension of the basin

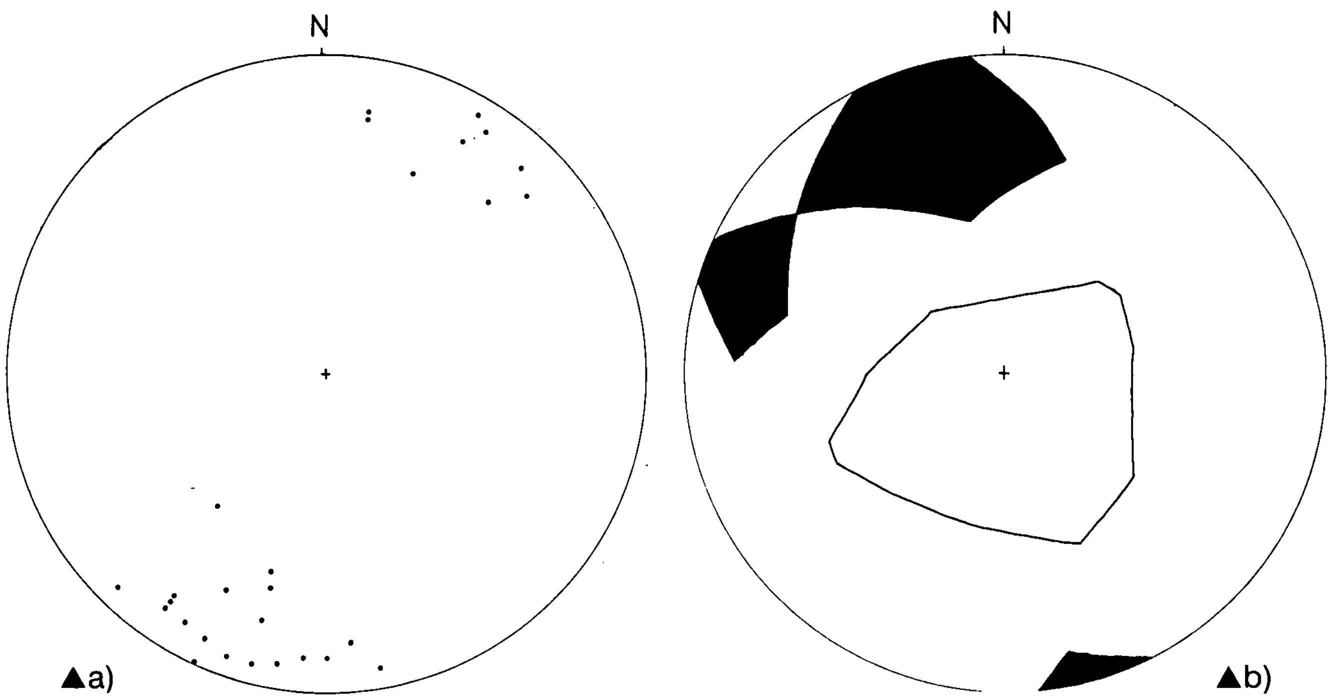


Fig. 5.
a) Shortening of Eocene rocks at Sološnica in section perpendicular to B-axes of folds.
● = B-axes of folds.
b) Tectonogram of analyses of reverse faults in Eggenburgian rocks at locality Podbranč.
Black cutting = maximum compressional stress orientation; white cutting = relative extension orientation.

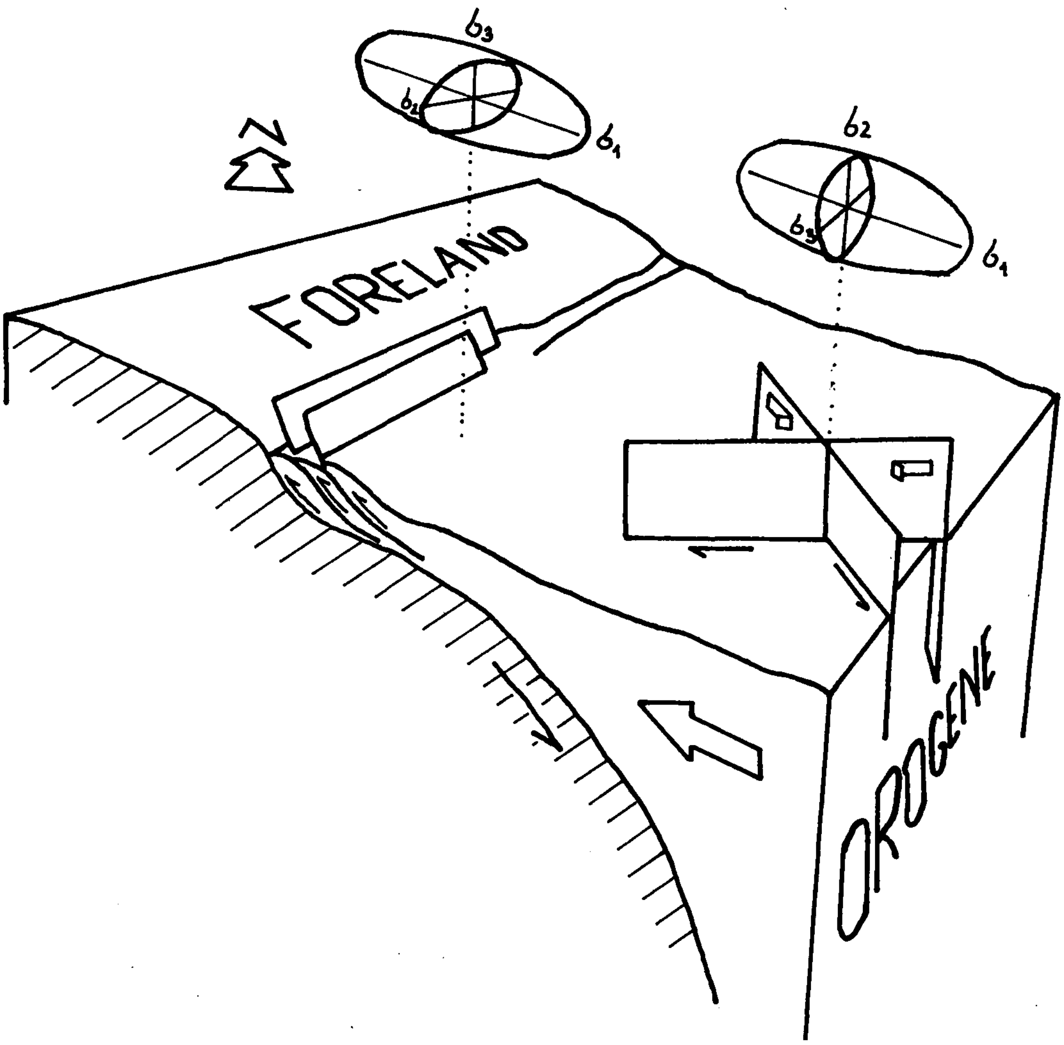


Fig.6.
Ellipsoids of stress tensors.
σ_1 = maximum compressional stress; σ_2 = intermediate stress; σ_3 = minimum compressional stress.

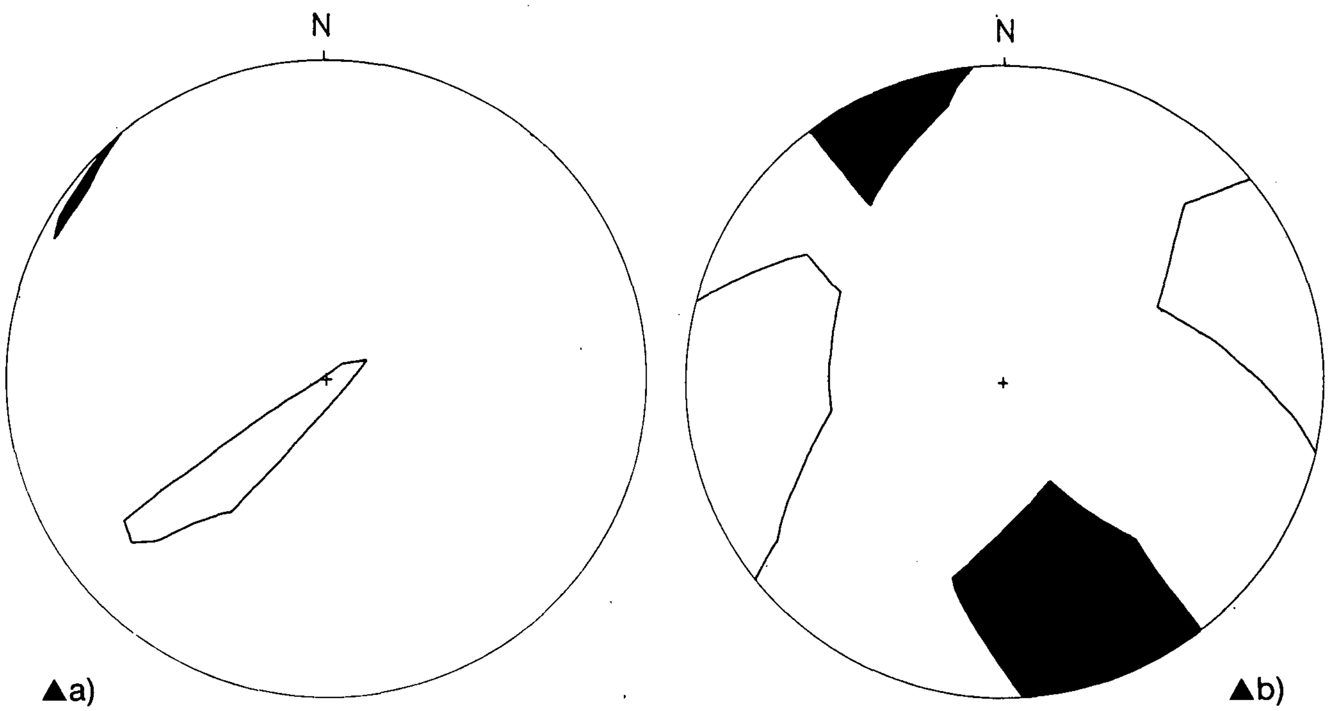


Fig. 7.
Tectonograms of Lower Miocene phase at locality Myjava–Belanský.
a) Orientation of stress-producing earlier revrese fault population.
b) Orientation of stress-producing later strike-slip fault population.
Black cuttings = maximum compressional stress; white cuttings = relative extension.

with the depositional centres migrating southeastwards. The alluvial-delta fan of the Jabonica conglomerates and sandstones was formed in the area studied. The conglomerates and sandstones passed vertically and laterally into the basinal "schliers" facies. Clastic material was transported from SW, i. e. from the area of the present Malé Karpaty Mts., adjacent basement of the present Vienna Basin and the Danube lowlands. In the area of the NE part of the present Vienna Basin the sedimentation documents basin formation in the strike-slip zone (Kováč, 1985). Quick facies and sedimentary thickness changes, angle discordances are striking. Synsedimentary fault activity is indicated by slump bodies (Buday, Cícha & Čtyroký, 1959) and high sedimentation rate (Vass & Čech, 1983).

Activity of ENE–WSW striking reverse faults in the Malé Karpaty Mts. and in the Brezovské Karpaty Mts. is evidenced by talus cones forming during the Eggenburgian in a belt extending from Rozbehy through Dobrá Voda to Čachtice. At the individual localities the layers of breccia and poorly sorted conglomerates alternate with layers of well-rounded conglomerates and sandstones. They are regarded as products of the calm periods between tectonically active stages. Reverse faults with a vergency towards the inside of the Carpathians were described by Michalík (1984, 1987) as active in the Savian–Styrian phase and affected the Mesozoic rocks.

In that time the sinistral strike-slip faults of N–S direction (Limbach, Lošonec) were particularly significant in the Malé Karpaty Mts. These strike-slip faults enabled the northward shift of the Baďurka Massif. During the Karpatian the NW–SE striking normal faults control the basinal sedimentation. The Dobrá Voda fault system (Plančár, 1979) controlled the formation of a depression between the Brezovské Karpaty Mts. and the Pezinské Karpaty Mts.

The eastward rotation of the orogene movement trajectory in the area studied is evidenced by the data resulting from the structural analysis of Eggenburgian sediments at the locality Myjava–Belanský (Fig. 7) affected by reverse faults and younger strike-slip faults. Fig. 8 shows helicoidal Riedel shears crossing the strike slip zone in Karpatian clays at the locality Cerové-Lieskové. According to their orientation the Karpatian – Lower Badenian extension joints in the Stockerau lime pit near Devínska N. Ves, described by Mišík (1980), may also be ranged to this phase.

3. The Lower to Middle Miocene Transition Period

In this period the paleostress field reflects the continuous W–E termination of movements in the front of the orogene (Stráník et al., 1979; Kováč et al., 1984; Oszczypko & Slaczka, 1985).

The maximum compressional axis of the stress culminated in N–S direction (Fig. 9) in that phase. It was active in the interval of the end of the Karpatian – Lower Badenian. Because of the lack of data from the Lower Badenian rocks it is partly identical with the former phase. According to its intensity at individual localities we regard the activity as short. Middle Badenian rocks were not deformed by the activity of the phase. The area studied was then so far from the sutural collision zone that only strike-slip faults arose there. Reverse and normal faults only occurred as compensation structures of movements in strike-slip faults.

The Lower Badenian phase is represented by a uniform depositional cycle in the sense of Špička & Zapletalová (1964), denoted as the "Lanzendorf serie". In paleogeographical respect the deposition areas in the SW part of the West Carpathians display a closer affinity to Karpatian deposition areas than to the distribution of basins during the Middle and Upper Badenian. In the Czechoslovak part of the Vienna Basin the maximum thicknesses of pelites of the basinal "tegel" facies are associated with the transversal depression in the continuation of the Leváre–Pernek depression (Špička, 1969). Conglomerates with pelite layers underlying the Devínska N. Ves Member containing calcareous nannoflora of the Zone NN5 (Vass et al., 1988) are regarded as the marginal facies of Lower Badenian sediments in the area studied. The pebble material comprises frequent Mesozoic carbonates and sporadically granites. The Čupy gravels (Buday, 1956) with the pebbly material mostly composed of flysch rocks of the Biele Karpaty unit are regarded as the marginal facies in the northern part of the area.

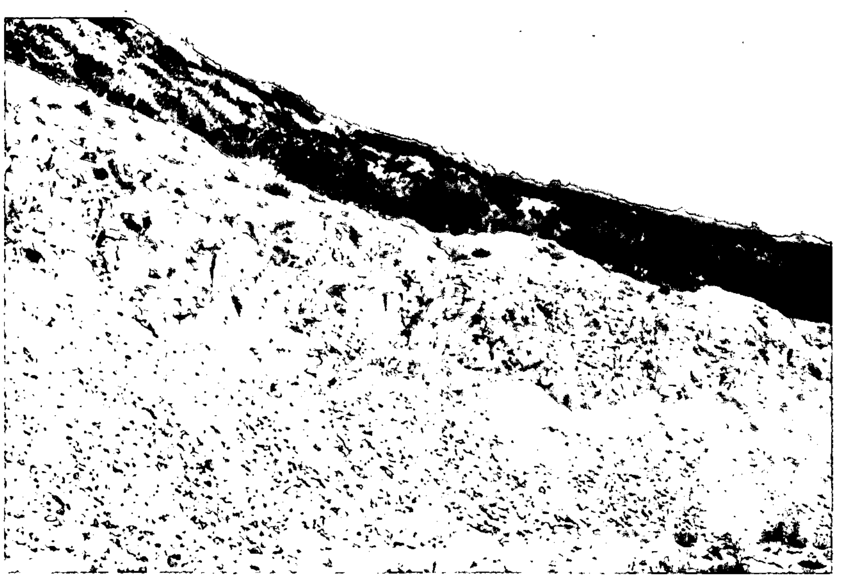
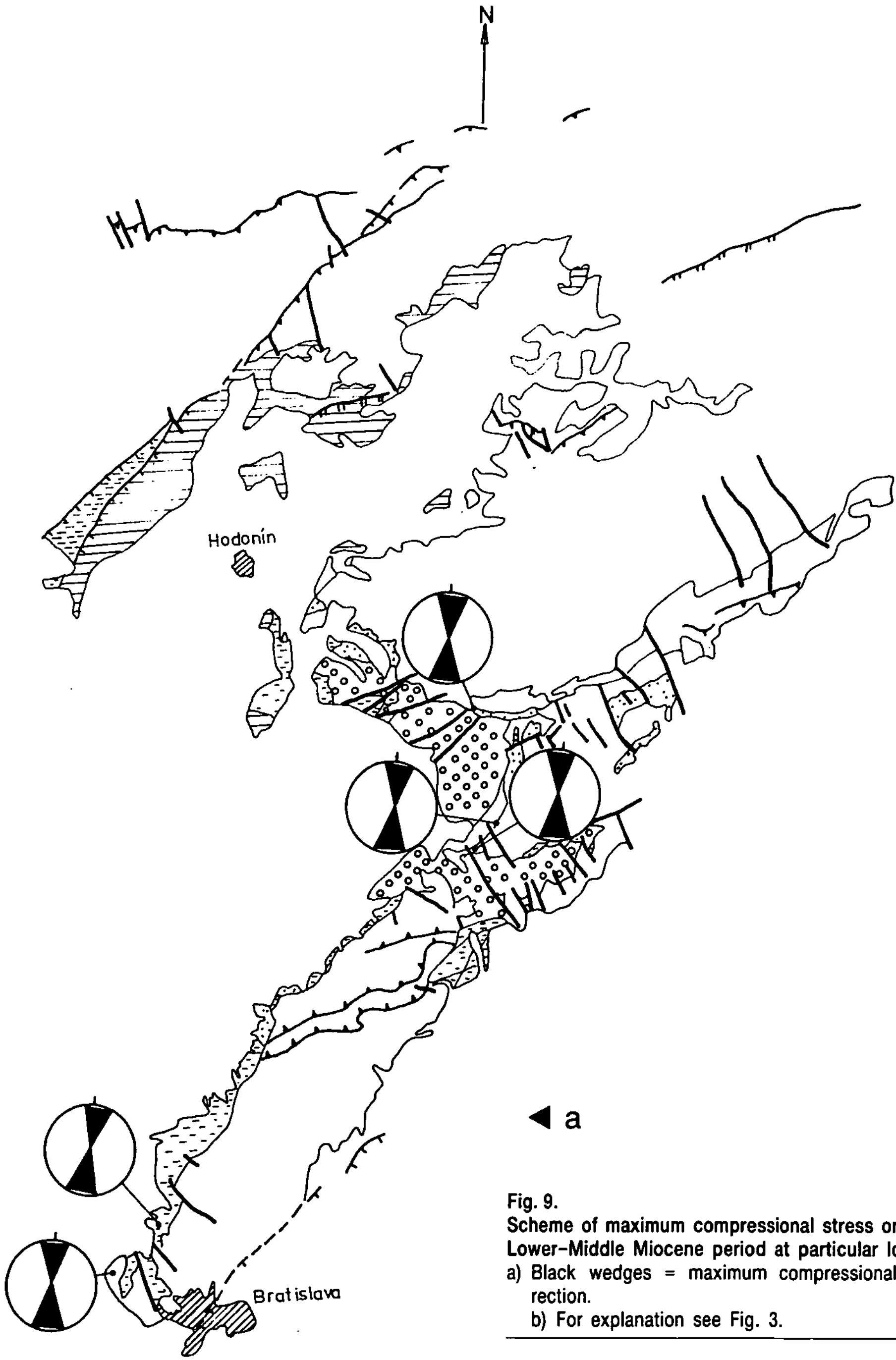


Fig. 8.
Riedel shears of strike-slip fault zone at locality Cerové-Lieskové.



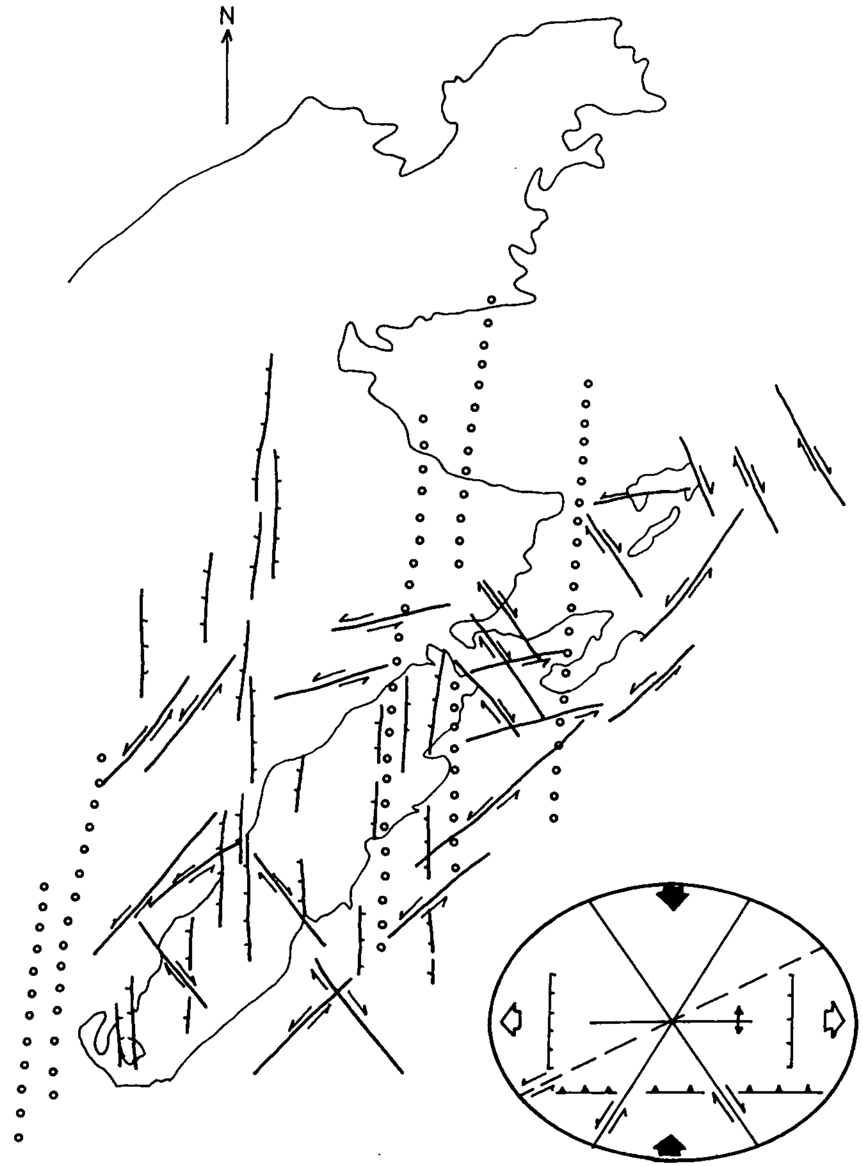


Fig. 9.
Scheme of maximum compressional stress orientation in Lower-Middle Miocene period at particular localities.
a) Black wedges = maximum compressional stress direction.
b) For explanation see Fig. 3.

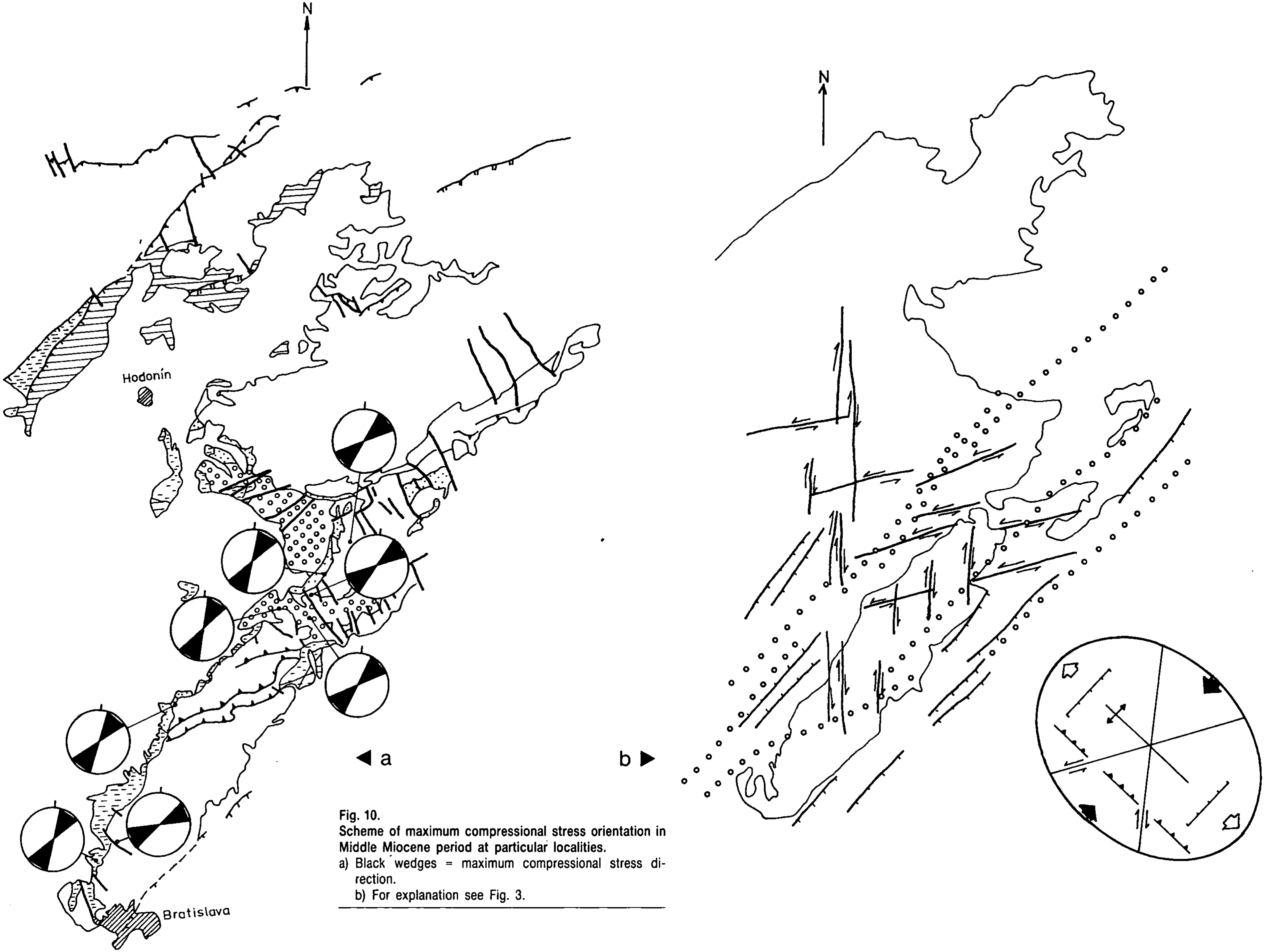


Fig. 10.
Scheme of maximum compressional stress orientation in Middle Miocene period at particular localities.
a) Black wedges = maximum compressional stress direction.
b) For explanation see Fig. 3.

This phase is evidenced by deformed Mesozoic rocks at the localities Jablonica, Záhorská Bystrica with more general orientation of stress tensors, and at the localities Devínska N. Ves, Hradište pod Vrátnom with more ideal orientation of stress tensors. Eggenburgian rocks are deformed at the localities Podbranč and Hradište pod Vrátnom. Fig. 9 shows the activated faults of this phase. The N–S striking normal faults and sinistral NE–SW strike-slip faults were most effective. Along them the partial blocks were shifted northeastwards and controlled the general extension of the Neogene basins in that part of the Carpathians.

This phase preceded the subsidence mechanism of the pull-apart basin s. l. in the Vienna Basin.

4. The Middle Miocene Period

Middle Badenian rocks are only affected by deformation of the phase with the NE–SW maximum compressional stress (Fig. 10). Besides structural evidence it is indicated by sedimentary pattern of the Middle and Upper Badenian documenting a changing kinematic regime in the area of the Vienna Basin (Fig. 11).

Rejuvenation of tectonic activity is indicated by coarse clastics on the slopes of the Malé Karpaty Mts., denoted in the general map of Czechoslovakia 1 : 200.000 as Lower Badenian (BUDAY et al., 1962) and ranged to the Tortonian (Middle Badenian) by ŠPIČKA (1969). The determination of the Middle Badenian age of the Devínska N. Ves beds (VASS et al., 1988) with the character of coarse-clastic debris apron mostly composed of poorly rounded granite material, is in accordance with ŠPIČKA'S opinion. The coarse-clastic bodies occur between the village Lozorno and Devínska N. Ves. They are a marginal equivalent of the Jakubov beds (Middle Badenian) as also indicated by less rounded to angular rock clasts from the Malé Karpaty Mts. in sandstone bodies of the Jakubov beds (DLABAČ, 1970).

The Middle Badenian sedimentation is also characterized by lithotamnia bioherms and reefs known from the area between Láb and Malacky and from the surroundigs of Stupava and Rohožnik. They are presumed to have been generated on tectonically uplifted blocks of the eastern basin periphery. The blocks sank as early as the Middle Badenian and were covered with a monotonous sedimentation of the zone of agglutinates (DLABAČ, 1970). The Middle Badenian basinal sedimentation passed continuously into the Upper Badenian. The Studienka beds of the bolivina-bulimina Zone were deposited, partly brackish in the NW part of the Basin (ŠPIČKA, 1966).

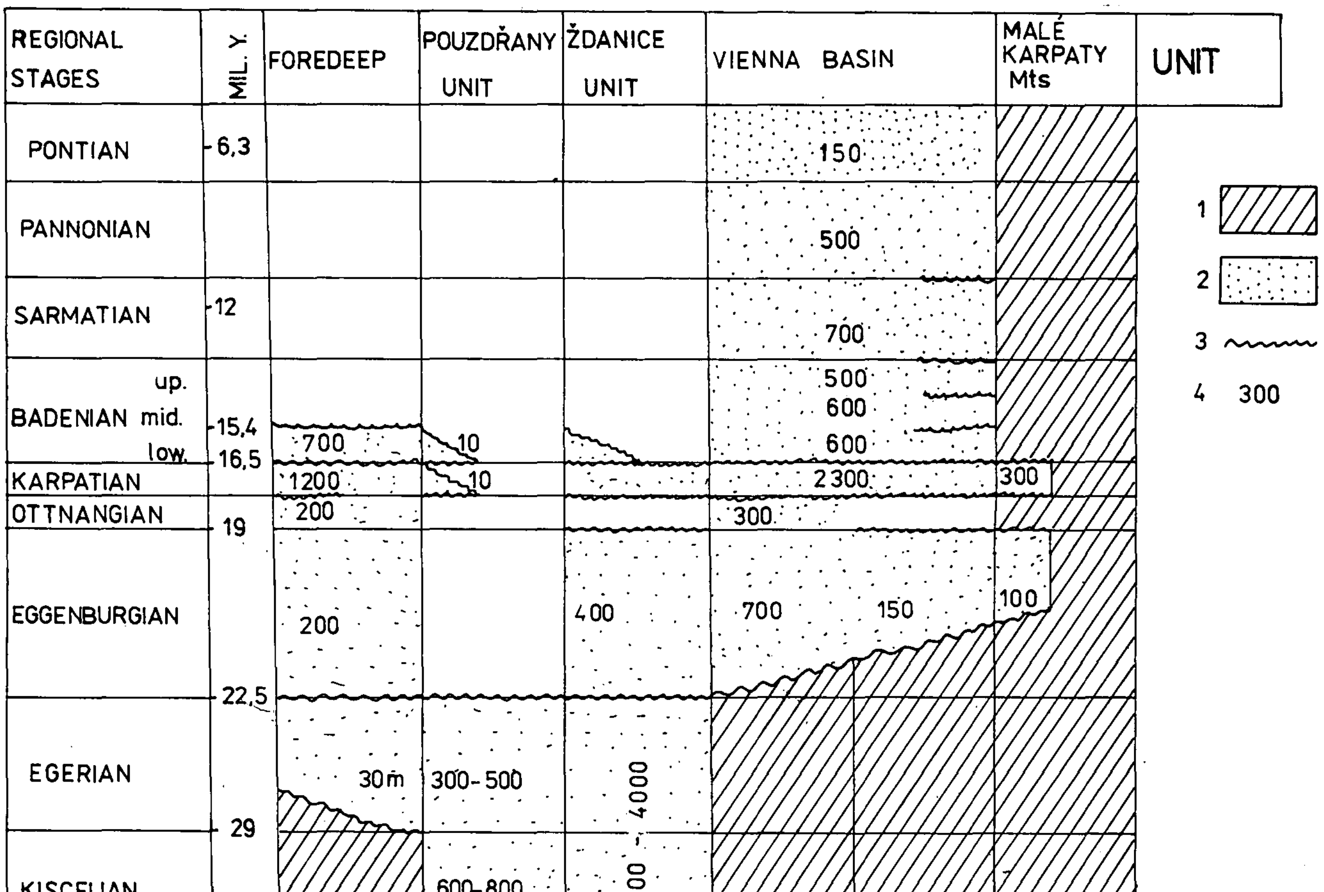


Fig. 11.
Scheme of Neogene sedimentation in SW part of West Carpathian Mts. and thickness of sediments preserved.
1 = basement of Neogene sediments; 2 = Neogene sediments; 3 = angular discordance or erosional contact; 4 = thickness of sediments [in metres].

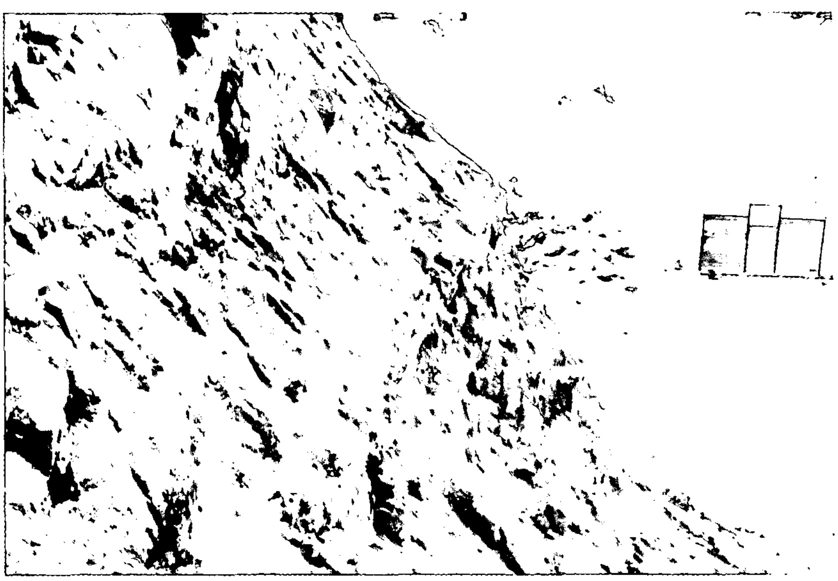


Fig. 12.
Riedel shears at Hradište.
They are linked up with principal displacement zone in the centre of the figure.

The Middle and Upper Badenian sedimentation was mostly controlled by SSW-NNE fault tectonics well identifiable in the present structure of the Vienna Basin. As the mobility of the eastern margin is indicated by lower Badenian coarse-detrital facies, mobility of the flysch basement in this period is evidenced by transgression extending northwards (ŠPIČKA, 1969).

The deformations generated in this phase, are preserved in Mesozoic rocks at the localities Hradište pod Vrátnom, Záhorská Bystrica, Brezová pod Bradlom, Borinka. Fig. 12 shows the deformation of Eggenburgian rocks at the locality Hradište pod Vrátnom – a system and a type of shears forming a strike-slip fault zone. The setting of shear types (WILCOX et al., 1973; BARTLETT et al., 1981; NAYLOR et al., 1986) and the extent and mode of shifting in the zone show that the local strike-slip faults form actually the transtension zone. The Karpatian sediments affected by this stress field are exposed on locality Cerová-Lieskové. Fig. 13 shows the interpration of the stress tensor according to the conjugated couple of strike-slip faults in the Karpatian conglomerates at the locality Raková. The Middle Badenian rocks at the locality Rohožník are affected by strike-slip faults of the first order.

We presume that the movement amplitudes on dextral N–S strike-slip faults were not as large as in the Lower Miocene period when they were sinistral strike-slip faults.

In fact, the later dextral movements did not wipe off the sinistral component which is still conspicuous. Scarce reverse faults were generated on strike-slip fault.

Frequent normal faults are indicative of transtensional tectonics.

In that period the sinistral ENE–WSW strike-slip faults associated with NNE–SSW to NE–SW striking normal faults were frequent as shown by remote sensing photographs (POSPÍŠIL et al., 1986). In that phase the NE–SW margins of the Malé Karpaty horst got more prominent, and depositon in the Vienna Basin proceeded in a "pull-apart" basin s. l. Significant strike-slip faults are besides ROYDEN'S (1985) data (subsidence and thermal analyses) and our mesostructural information also proved by geological cross sections (WESSELY, 1983; KRÖLL et al., 1981; WACHTEL & WESSELY, 1981), by the results of sedimentological-stratigraphical study of foothill slump bodies and cones of the Devínska N. Ves beds (VASS et al., 1988), and by the migration from N to S of depositional centres of the basin in the Karpatian – Middle Badenian period (JIŘÍČEK, 1979, 1985).

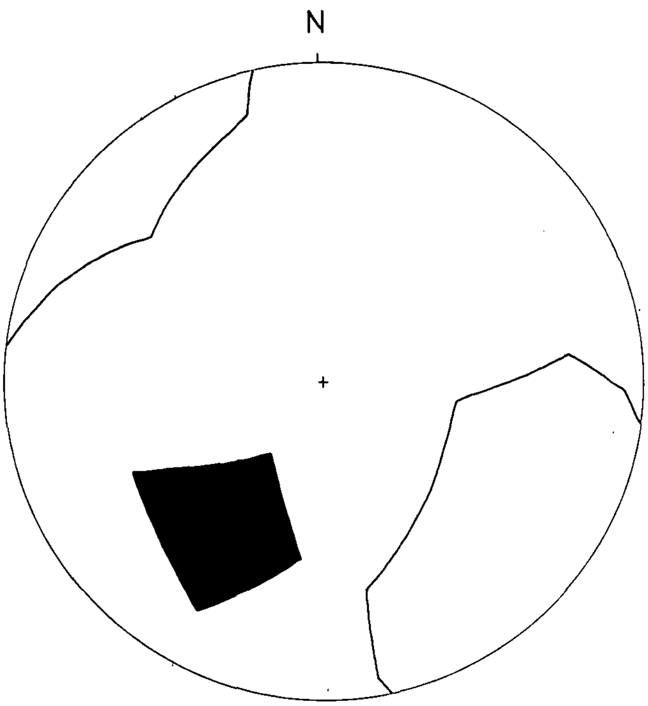


Fig. 13.
Tectonogram of stress in conjugated couple of strike-slip faults of Middle Miocene phase at locality Raková.
Black cutting = maximum compressional stress orientation; white cutting = relative extension orientation.

5. The Upper Miocene to Pliocene Period

The gradually fading subduction along the Carpathian front from W to E caused that during the Sarmatian period the suture zone was so far as to cause extension in the SW part of the West Carpathians. The extension resulted from the retreat of the subduction

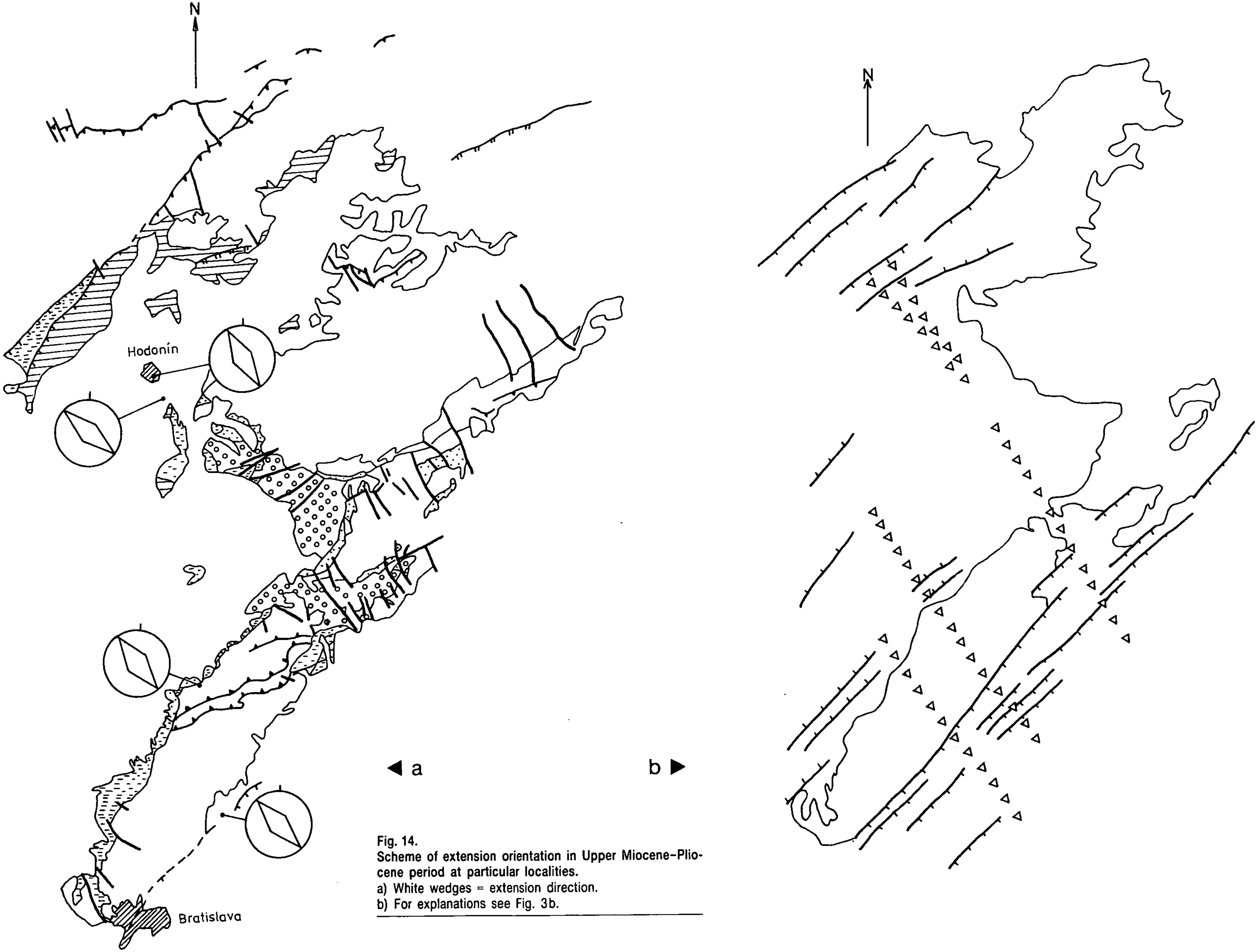


Fig. 14.
Scheme of extension orientation in Upper Miocene–Pliocene period at particular localities.
a) White wedges = extension direction.
b) For explanations see Fig. 3b.

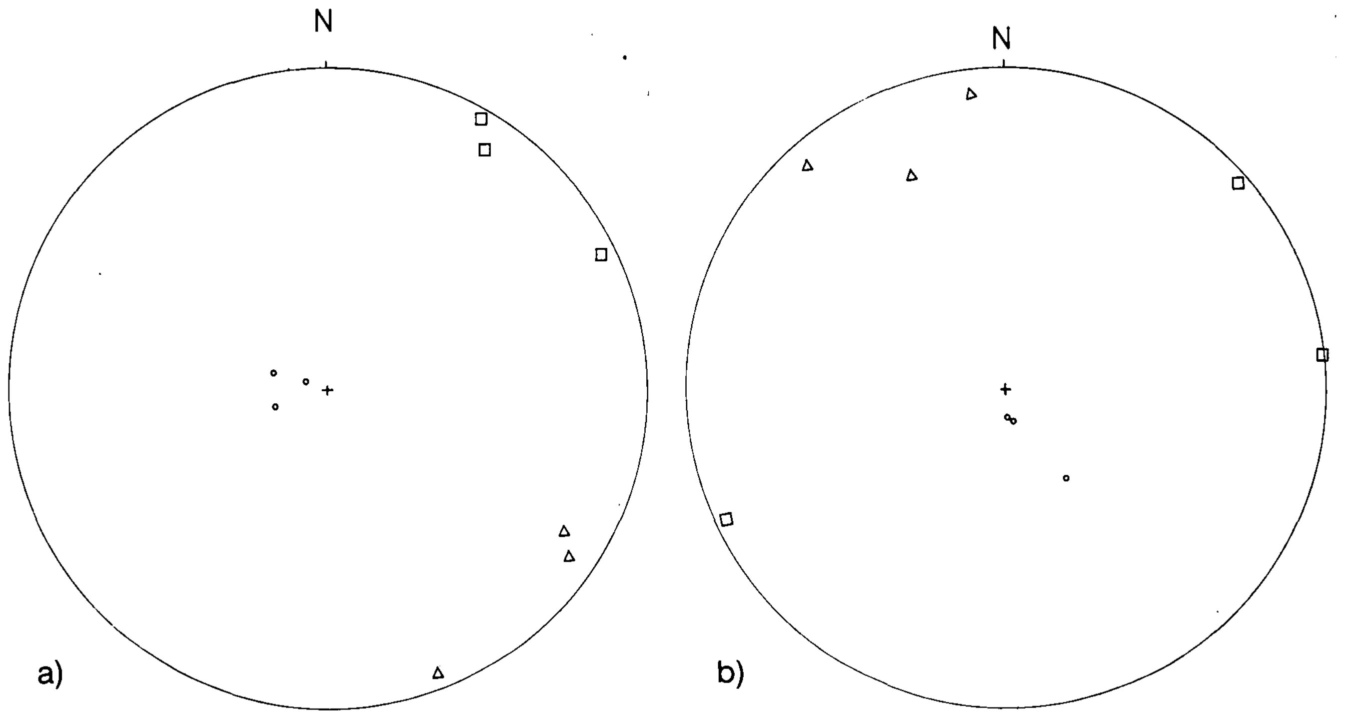


Fig. 15.
Tectonograms of latest phase at particular localities.
□ = maximum compressional orientation; ○ = intermediate stress orientation; △ = minimum stress orientation.
a) Pezinok.
b) Hodonín.

zone (TURCOTTE-SCHUBERT, 1982; HAMILTON, 1979) in the East Carpathians (ROYDEN et al., 1982, 1983) and the mantle diapir (STEGENA et al., 1973, 1975; LEXA & KONEČNÝ, 1974) in the Pannonian region.

Fig. 14 shows the NW–SE direction of the extension.

In contrast to the Badenian period the Sarmatian subsidence is more gentle and fades from the base towards the overlier. Like in the Badenian time, the depositional area of the Vienna Basin is controlled mainly by SSW–NNE-striking faults. The area of flysch nappes is still mobile and the transgression advances northwards to the Hradište graben (ŠPIČKA, 1969). Sands and clays with plentiful macrofaunal remains forming occasional lumachelles mainly deposited in the eastern part of the area studied. In the area of Devínska N. Ves the nubecularian limestones were deposited. Basinwards mostly clays with variable Ca-content and with the upward increase of sandy intercalations and sand layers occur.

The transgressive character of the Pannonian is proved by the reactivation of the extension tectonics resulting in the deepening of the depositional area of sediments ranging to 500–600 m in thickness. The fading of the extension tectonics and gradual filing up of the depositional area are presumed on the basis of coal sedimentation (the Kyjov lignite seam). In the Pontian period the deposition only continues in the central parts of depressions. Like in the Pannonian the fading tectonic activity is indicated by lignite seams (the Dubňany lignite seam).

Among structural phenomena characterizing this phase are tension joints in Sarmatian rocks at Hilíč, the listric normal faults at Sološnica and extension features of Pannonian rocks at Hodonin and Pezimok (Fig. 15). At Sološnica we have found out vertical amplitudes of neotectonic movements caused by extension of NW–SE direction (Fig. 16).

6. Conclusions

In the present sedimentary sequences of the area studied the traces of several tectonical phases have been preserved. The earliest, pre-Neogene and Lower Miocene phase was characterised by the NW–SE striking maximum compressional stress. In this phase the folding and thrust of the flysch zone and of the Lower Miocene molasse over the foreland took place. During this phase the dynamic conditions were changing to such an extent that instead of folds and overthrusts the reverse faults and overthrusts were generated. In the Karpatian period strike-slip faults were dominant.

The end of this Lower Miocene phase is characterised by indications of the eastward fading of the collision activity. In the Lower Badenian period the direction of the last nappes overthrust was oriented like the maximum compressional stress i. e. in N–S direction. Strike-slip faults were dominant again and the mechanism of the "pull-apart" s. l. in the Vienna Basin commenced.

In the Middle Badenian period the compression caused by collision migrated in the NE–SW direction. In the Vienna Basin it formed the transtension conditions for the "pull-apart" basin s. l. type sedimentation. During the next eastward migration of fading of the collision activity in the front of the Western Carpathians during the Upper Sarmatian – Pannonian period the Vienna Basin was in the area of extension conditions preserved up to the Recent.

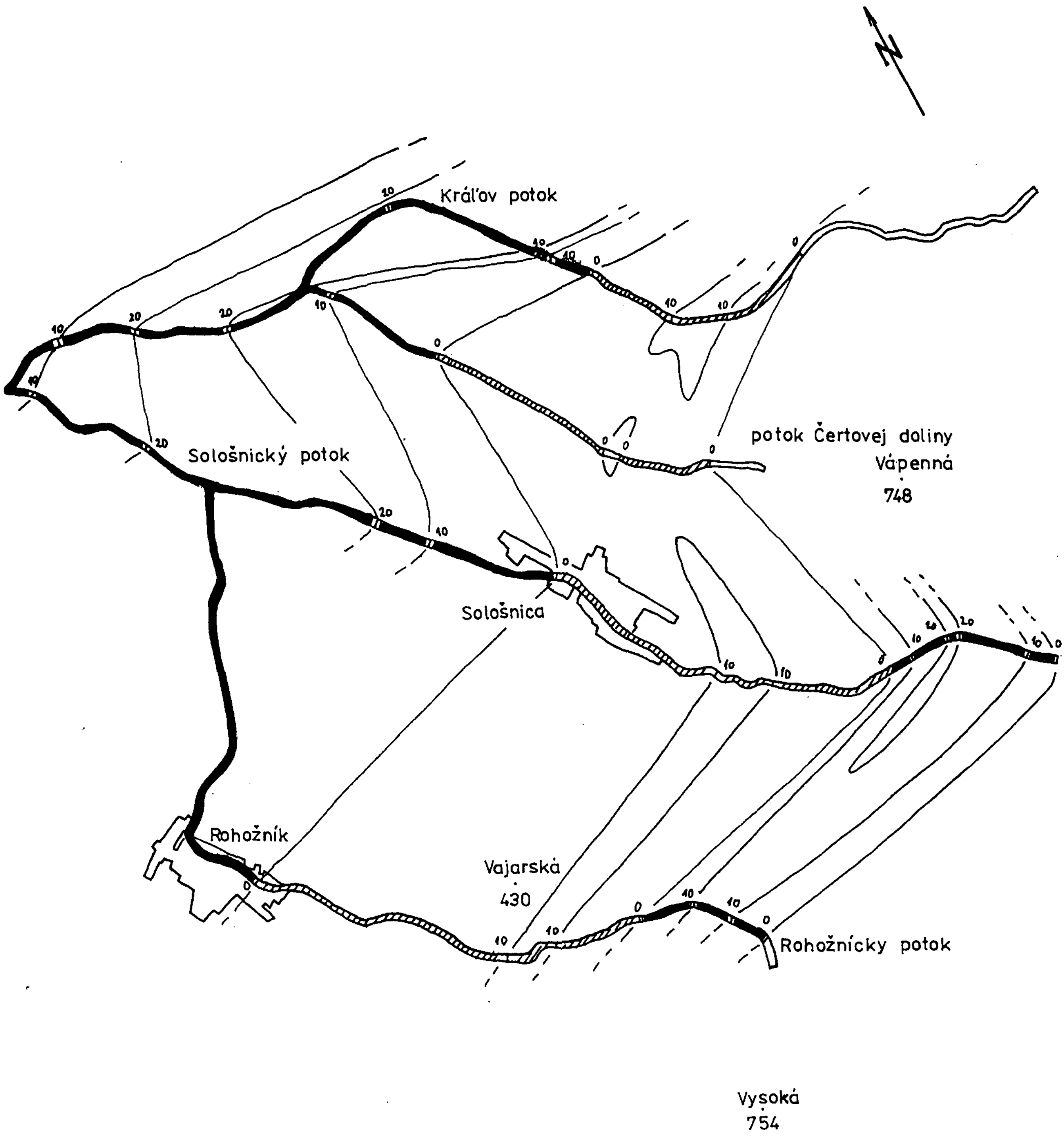


Fig. 16.
Vertical movements at locality Sološnica, caused by recent extension.
Black line = areas of normal fault movements [in metres]; hachure = areas of uplift movements [in metres]; white line = areas of zero movements.

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