The development of the Carboniferous accretionary wedge in the Moravian-Silesian Paleozoic Basin

Vývoj karbonského akrečního klínu v moravskoslezské paleozoické pánvi (Czech summary)

(15 text-figs.)

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A complicated development of the erosion remnant of the sedimentary part of the Carboniferous accretionary wedge in the Moravian-Silesian region of the Bohemian Massif is comprehensively analyzed on the basis of a great number of data. Results rest upon a lithologic analysis of the flysch and molasse formations, analysis of thicknesses, analysis of the chemical and lithologic composition of sediments of individual lithostratigraphic units, analysis of cannibalism phenomena and extensive resedimentation of Carboniferous siliclastics, and upon the structural-tectonic analysis. A review of remnant and foreland basins is given, and the influence of an oblique collision and prograding thrust fold belt upon the changing geometry of the basin and upon the composition and structure of the sedimentary part of the wedge is interpreted.

Key words: Foreland basins, oblique collision, thrust-fold belt, megafacies, flysch, molasse, turbidites, fans, cannibalism, redeposition, chemical composition, heavy minerals, tectonic reworking, retro wedge, stack wedge

Introduction

The sedimentary part of the Carboniferous accretionary wedge forms a post-erosional remnant of the filling of the Czech part of Moravian-Silesian Paleozoic Basin (Fig.1). This large basinal structure developed from the Devonian up to the Westphalian at the eastern border of the Bohemian Massif under the control of a collision of two plates of continental crust. In the west, the internal orogenic zones of the Bohemian Massif are interpreted as a hanging wall unit (Fritz et al. 1993). The eastern Cadomian block of the Brunovistulicum played the role of the footwall unit which gradually disintegrated and subsided (Kumpera 1988) during an oblique collision (Grygar 1992). The deeply eroded roots of the collision suture are located in the Silesicum and Lugicum crystalline units in the north and in the Moravicum and Moldanubicum units in the south (Kumpera – Foldyna 1992). The collision of two units of contrasting crustal character conditioned a rapid uplift in the central parts of the Bohemian Massif and the origin and development of subsiding and migrating foreland basins in the Brunovistulicum. This consequently led to the origin of a thick sedimentary accretionary wedge of a complex composition and structure. The preserved filling of the basin is a rather small denudation remnant of a far larger basinal structure.

The Moravian-Silesian Paleozoic Basin belongs to polyhistory basins (Klein 1987). It underwent the following stages:

- rift basin (Hladil 1988) of the Devonian – Tournaisian age,
- carbonate platform (Devonian – Viséan),
- remnant basin with flysch (mostly Viséan),
- foreland basin with flysch,
- foreland basins with marine (Viséan) paralic coal-bearing sediments and continental molasse sediments (Namurian-Westphalian).

Sediments of the Carboniferous accretionary wedge crop out only in the Drahany Upland (Drahany block) and in the Nízký Jeseník Hills (Jeseník block) (Fig. 1). The major parts of the Carboniferous wedge are covered by younger sediments in the Polish lowlands and the autochthone and nappes of the Outer Carpathians, and are here partly known only from deep mines and boreholes. The easternmost and southernmost parts of the basin are deeply immersed and unknown.

Materials and methods

In the paper, a great number of data, stored mostly in a computer data base, are summarized. The material comprises thicknesses, lithologic data, pebble analyses and chemical analyses of Carboniferous sediments, structural-tectonic observations and biostratigraphic determinations,

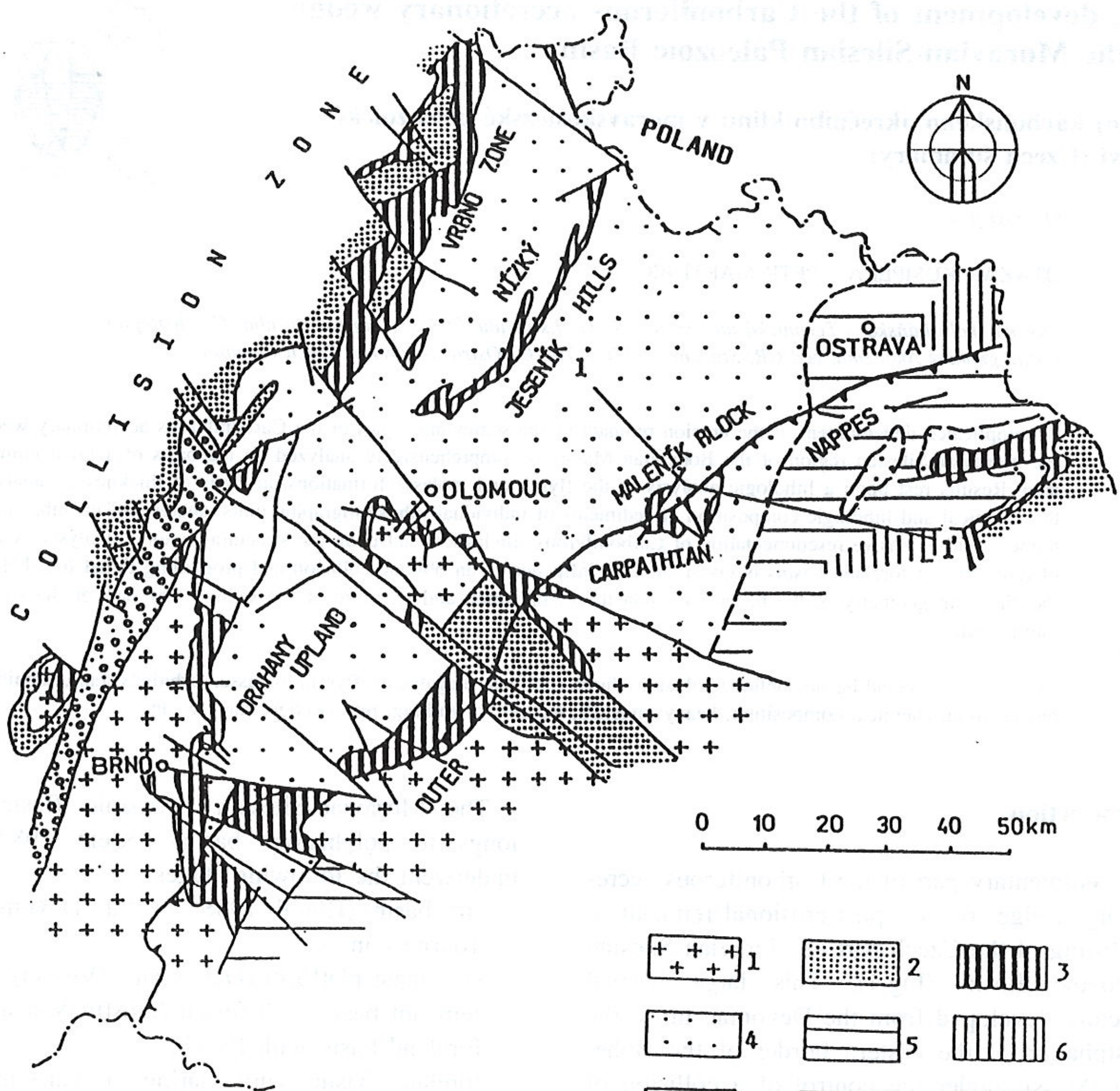


Fig. 1. Generalized geological map of the eastern part of the Bohemian Massif; constructed on the surface of the Epi-Variscan Platform (compiled after: M. Dopita – J. Dvořák – J. Foldyna – O. Kumpera)
1 – plutonic complex of Brunovistulicum basement (Upper Proterozoic); 2 – crystalline complex of Brunovistulicum basement (Upper Proterozoic); 3 – Devonian-Tournaisian (partly up to the Viséan) pre-flysch deposits; 4 – Viséan (partly uppermost Devonian – ?Tournaisian ?) flysch deposits; 5 – Namurian A – coal-bearing paralic molasse deposits; 6 – Namurian B – Westphalian, coal-bearing continental molasse deposits; 7 – Uppermost the Stephanian – Permian in the Boskovice Furrow; 8 – Outer Carpathian front; 9 – State boundary. 1-1' = line of the cross-section shown in Fig. 2

which were carried out especially via detailed geological mapping of the Carboniferous of the Moravian-Silesian area of the Bohemian Massif, for more than 30 years. The main working method is a brief synthesis of data and their relationships, on the basis of new knowledge from a basin analysis of dynamically developing remnant and foreland basins (Allen – Allen 1990).

Results

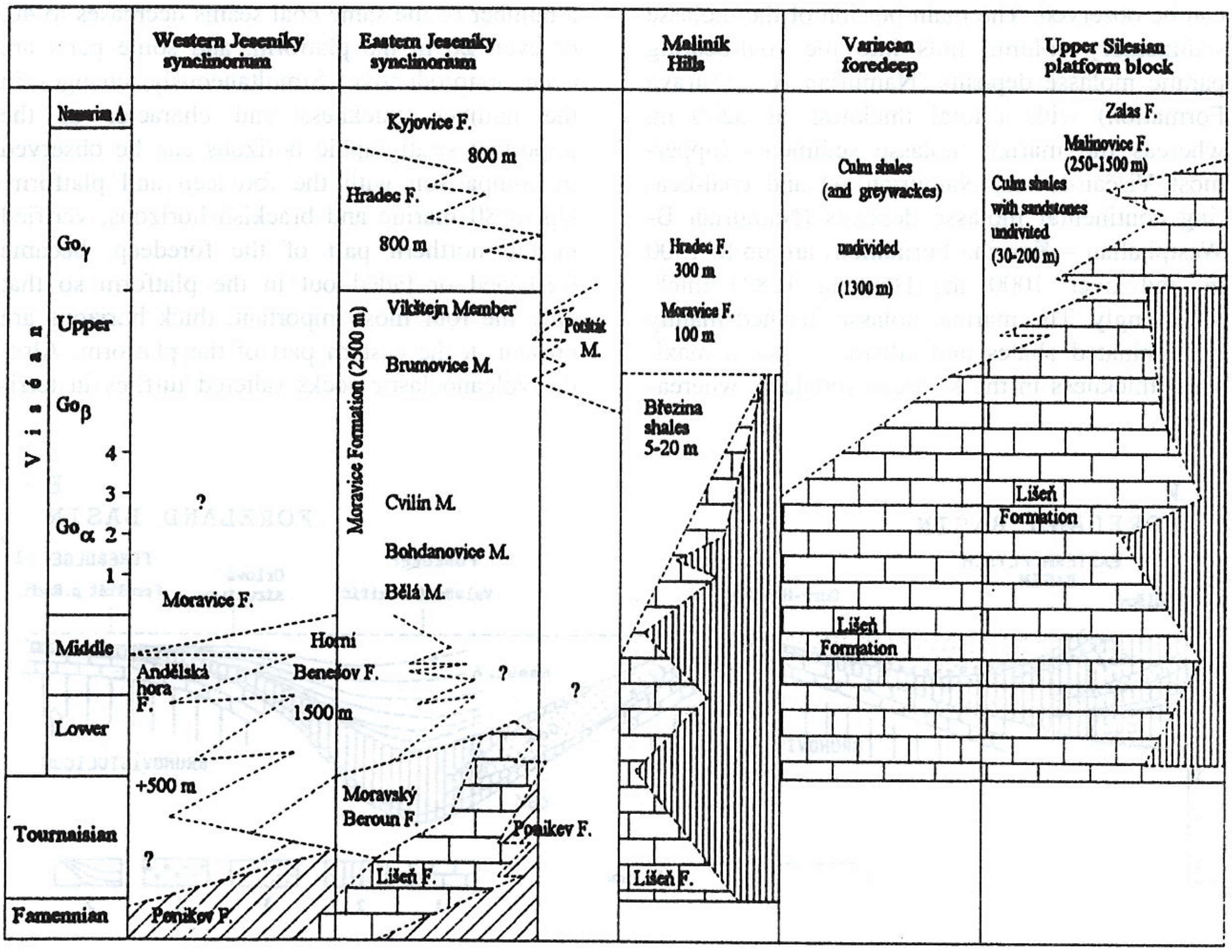
Thickness, rate of deposition, partial troughs

Not only the basin types, but also the basin geometry passed through great changes due to the gradual shifting of depocentre from the collision zone to the foreland (Kumpera 1971, Dvořák 1973). This is documented chiefly by the different thicknesses of the stratigraphic units.

The main portion of the sedimentary wedge falls upon siliciclastic flysch and molasse sediments, a smaller part belongs to platform carbonates and rift deposits (Table 1). The total thickness of the Carboniferous sedimentary wedge (after compaction) is more than 12 km. The average rate of sedimentation is therefore about 27 cm per 1000 years. The sediments of the accretionary wedge reach the greatest thicknesses in the west, in the vicinity of the collision zone, and above all in the north-west. The preserved thickness (including Devonian rock thicknesses) can be estimated at 8 km, as a maximum, whereas the total thickness decreases gradually to 200 m, in the extreme eastern parts of the basin. The decrease is not continuous, but the thickness distribution varies within the narrow partial troughs and forebulges which arose and ceased during the Carboniferous (Kumpera 1983).

Some of these troughs and elevations are proved conclusively by isopach studies. Two partial basins and forebulges, of different age, are well documented in the eastern part of the Paleozoic basin (Fig. 2). In the western trough, the thickness of the Upper Viséan flysch deposits is reduced from 2500 m, in the western part, to 100 m or less, in the eastern part. The easternmost, and latest trough of the foreland basin – the Variscan foredeep – is of the latest Viséan and Namurian A age. It is filled with marine and paralic molasse sediments where the thickness reaches up to 4500 m (evaluating the compaction, the thickness had to reach more than 6000 m) in the depocentre, whereas it decreases to 200 m or less

Table 1. Stratigraphy of Lower Carboniferous in Jeseník block of Moravian-Silesian Basin



(*white* – flysch deposits and partly marine molasse deposits, *oblique lines* – rift deposits, I– platform carbonates, *vertical lines* – stratigraphic breaks) in the easternmost platform forebulge. The thickness of sediments accumulated during one time span strongly varies, changing up to 25 times between troughs and elevations. Therefore, a marked fluctuation of the sedimentation rate must have occurred. Considering one trough, the deposition rate could be 25 cm to 35 cm per 1000 years in the Late Viséan flysch depression and surprisingly up to 90 cm per 1000 years in the Namurian A foredeep, while it decreased rapidly to zero in the platform forebulge. The schematic section (Fig. 2) shows the intensity of the Late Viséan-Namurian A subsidence of the foredeep. In this time span, also this part of the basement subsided to 6 km or more.

Evaluating the thickness of the molasse sediments, which are preserved in the external parts of the accretionary wedge, a similar picture can be obtained to that in the flysch sediments (Fig. 2). Continuous lateral and vertical transition between flysch and molasse deposits, as well as between marine and paralic coal-bearing molasse, can be observed. The main portion of the molasse sedimentary column falls into the coal-bearing paralic molasse deposits (Namurian A – Ostrava Formation) with a total thickness of 3200 m, whereas the marine molasse sediments (uppermost Viséan-lowest Namurian A) and coal-bearing continental molasse deposits (Namurian B-Westphalian – Karviná Formation) are up to 1300 m and over 1000 m (Havlena 1982) thick, accordingly. The marine molasse, formed mainly by laminated shales and siltstones, has a maximum thickness in the Variscan foredeep, whereas its thickness diminishes rapidly to less than 200 m in the platform.

The main feature of the coal-bearing paralic molasse deposition was a compensation of subsidence by the clastic supply. Nevertheless, the sedimentation was influenced by the contrasting subsidence activity of the foredeep and platform, (Fig. 2). Comparing both tectonic environments, the foredeep is characterized by a full subsidence compensation and the platform by a retarded subsidence. The foredeep and the platform differ not only in the thickness of the paralic molasse, but also in the number of coal seams and their thicknesses. In the foredeep, the thickness of the paralic molasse (Ostrava Formation, Namurian A) reaches up to 3200 m and decreases to about 100 m and less in the platform. Some platform blocks emerged as forebulges. The coal capacity decreases rapidly towards the platform (Dopita – Kumpera 1993). The Ostrava Formation consists of more than 170 coal seams with an average thickness of 73 cm in the foredeep, whereas a number of the same coal seams decreases to 40, or even 20 in the platform, and some parts are even nonproductive. Simultaneously, changes in the number, thickness and character of the important stratigraphic horizons can be observed in comparison with the foredeep and platform. Up to 80 marine and brackish horizons, verified in the northern part of the foredeep, became freshened or faded out in the platform so that only the four most important, thick horizons are present in the eastern part of the platform. Also, the volcanoclastic rocks (altered tuffites in terri-

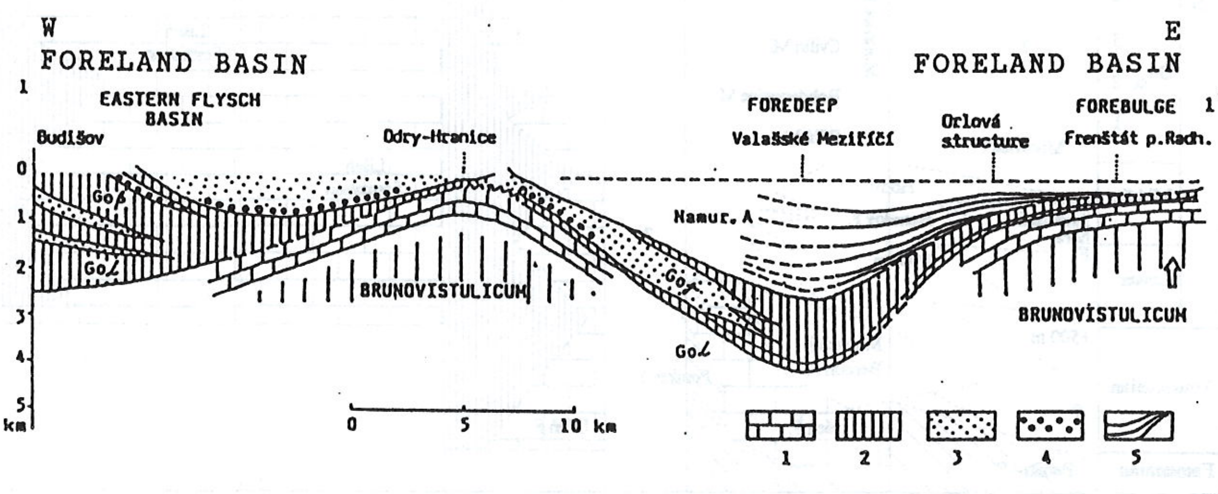


Fig. 2. Palinspathic cross section showing the thickness of stratigraphic units at the transition from foreland basin with flysch to foreland basin with molasse in the Moravian-Silesian Paleozoic Basin during Late Viséan ($Go_{\alpha-\beta}$) and Namurian A
1 – carbonates; 2 – predominantly shaly deposits; 3 – predominantly graywackes; 4 – conglomerates; 5 – coal-bearing paralic molasse. Location of the section 1-1' is shown in Fig. 1

genous siliclastic sediments, kaoline tonsteins in coal seams and kaolinized tuffites redeposed as „whetstone" rocks) disappear in the same direction, while changes in the cyclical structures of the Namurian A deposits are demonstrated. The thickness of cyclothemes, the grain size and number of sandstone and conglomerate layers increase to the southeastern part of the platform indicating a source area (Jansa 1967). Comparing the paralic molasse stage of evolution with older ones, we can see that contrasts between the foredeep and the platform reached their maximum during the Namurian A deposition.

After the deposition of the coal-bearing paralic molasse sediments, tectonic movments were under way at the end of Namurian A, and the significant seam Prokop, up to 14 m thick, was deposited in an extensive area. The following coal-bearing continental molasse sediments were deposited in a land-locked basin (Havlena 1982) surrounded by an elevated land, already under the platform conditions. The depositional area was displayed eastward. This part of the molasse sequence (Karviná Formation) is known in the limited erosion remnants, which do not enable a thickness analysis. The thickness of the remnants reaches 1000 m.

Paleocurrent systems and turbidite fans in the flysch stage

The flysch stage of the accretionary wedge evolution is typical of sedimentation and resedimentation by turbidity currents, mudflows and

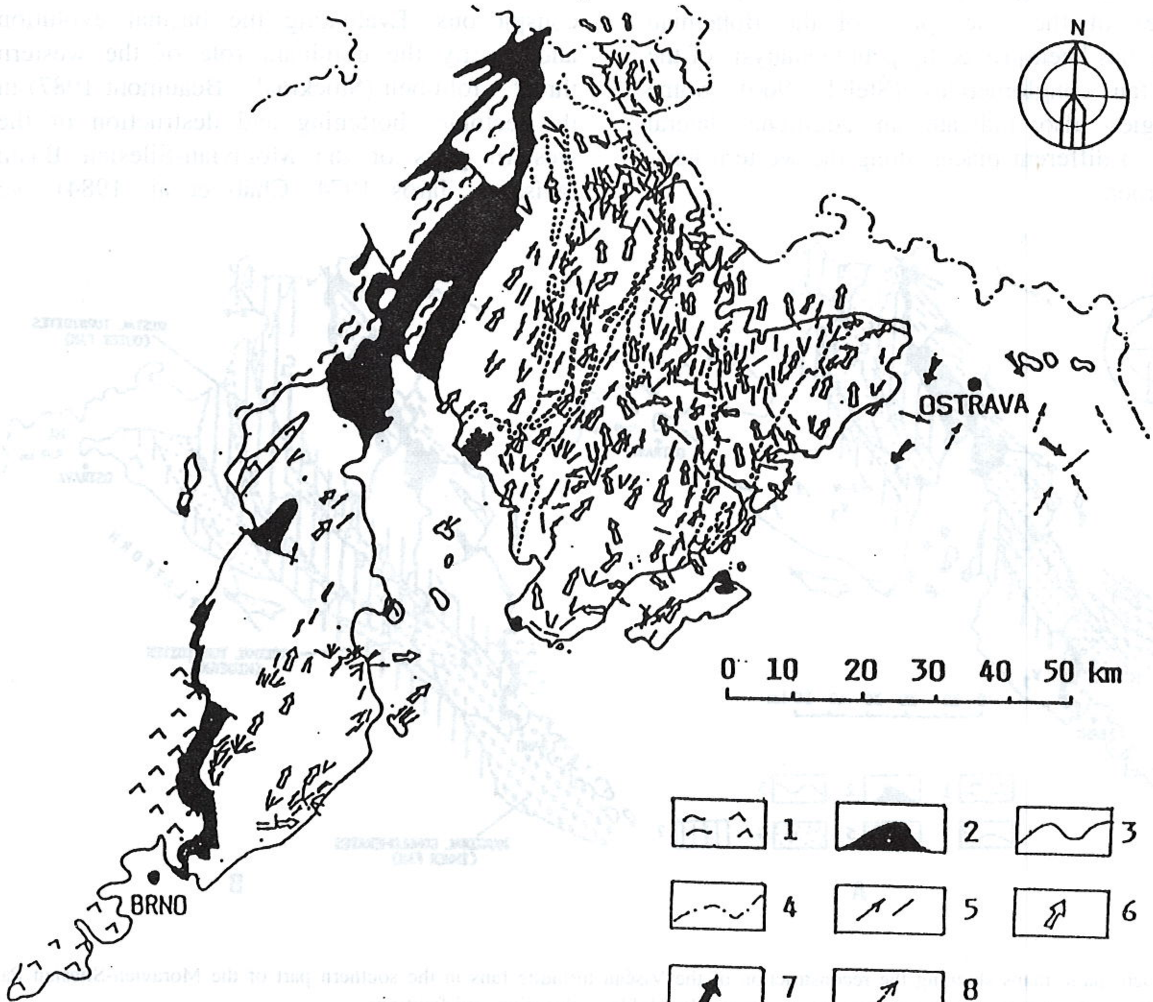


Fig. 3. Sole marks directions in Carboniferous flysch deposits and flow marks directions in coal-bearing molasse deposits in the Czech part of the Moravian-Silesian Paleozoic Basin
1 – crystalline rocks; 2 – pre-flysch deposits; 3 – outlines of the outcropping Carboniferous deposits; 4 – state boundary; 5 – sole marks directions (single measurements); 6 – sole marks directions (great numer of measurements); 7 – directions of the marine transgressions in paralic molasse deposits; 8 – flow marks directions in molasse deposits

sandflows (Kumpera 1971). The remnant and foreland basins with flysch, has been filled mainly with turbidites. Current directions, derived from numerous sole marks (flute casts, groove casts etc.), testify a longitudinal filling and the provenience of the paleocurrent systems from the southern parts of the basin (Fig. 3). The Upper Viséan flysch sediments, which are paleontologically well dated, show a clear lateral distribution of the turbidite megafacies, starting with marginal coarse conglomeratic beds in the southern part of the Drahany Upland, and continuing, step by step to the north with fluxoturbidites, proximal turbidites and distal turbidites. The last megafacies together with hemipelagic sediments, prevail in the northern parts of the preserved accretionary wedge.

A western supply, partly from the crystalline complex of the inner parts of the Bohemian Massif, has been proved by pebble analysis of the inner fan conglomerates (Štelcl 1960). Some lithologies also indicate an additional lateral supply in different places along the western basinal border.

A series of turbidite fans (Ricci-Lucci 1980) of different ages can be recognized in the Viséan flysch stage of evolution (Fig. 4). Only the Upper Viséan fans are entirely preserved.They include the whole megafacies succession starting with marginal coarse conglomerate beds in the southern part of the Drahany Uplan, which represent the sediments of the deep sea inner fan and midfan, and terminating with the fine-grained and fine rhythmical deposits of the outer fan in the northern parts in the Nízký Jeseník Hills (Fig. 4B). The older Viséan flysch sediments are not so well paleontologically dated as the Upper Viséan deposits. Nevertheless, a presumable reconstruction of the older Viséan turbidite fans can be submitted (Fig. 4A). The absence of the marginal coarse conglomerate beds, of both the inner fan and midfan of older Viséan fans, is conspicuous. Evaluating the basinal evolution and chiefly the dominant role of the western thrust – fold belt (Stockmal – Beaumont 1987) in the tectonic shortening and destruction of the western parts of the Moravian-Silesian Basin (Mísař – Jaroš 1974, Cháb et al. 1984), we

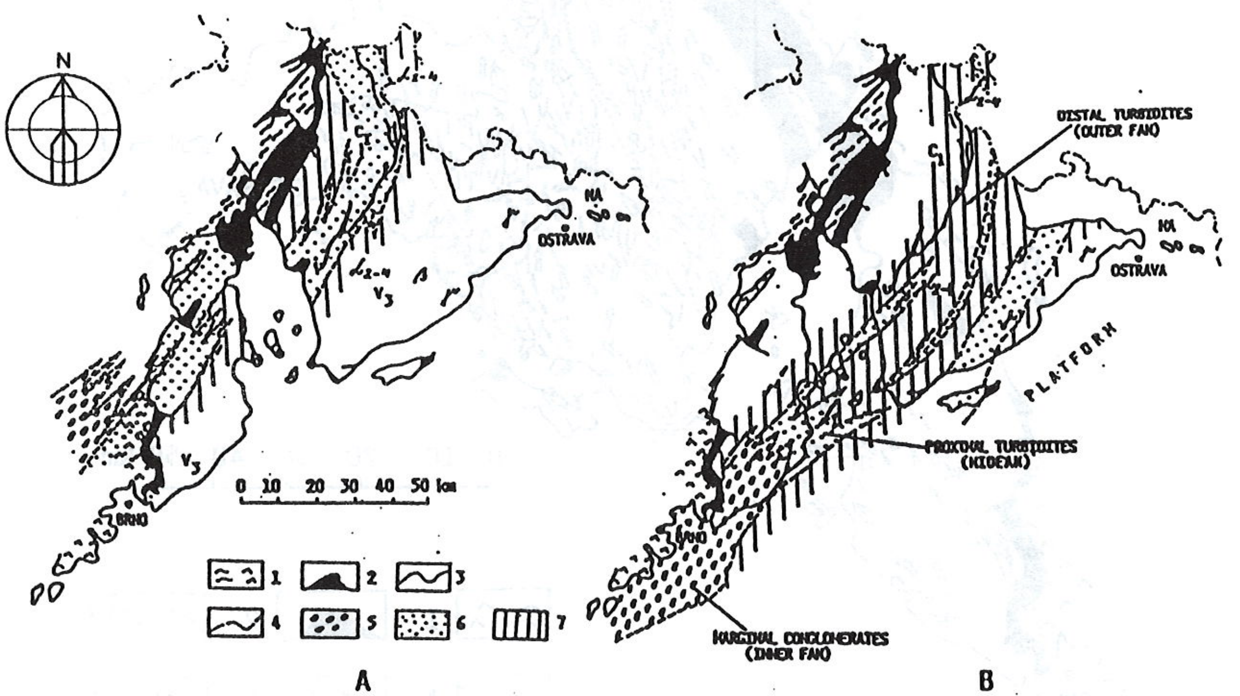


Fig. 4. Schematic maps showing the reconstruction of the Viséan turbidite fans in the southern part of the Moravian-Silesian Paleozoic Basin. Drawn in recent outcrops and position (after folding, thrusting and faulting)

A – Early Viséan (and Tournaisian ?) turbidite fans. Recent position; location of the inner fan and of a part of the midfan is hypothetical

B – Late Viséan turbidite fans with the entire megafacies succession well preserved. Explanation of symbols within the maps: C_1 – Viséan non divided, V_3 – Upper Viséan α, β, γ – position of Upper Viséan goniatite zones Go_α, Go_β, Go_γ, NA – Namurian A

1 – crystalline rocks; 2 – pre-flysch deposits; 3 – outlines of the outcropping Carboniferous deposits; 4 – state boundary; 5 – coarse and boulder conglomerates (inner fan megafacies); 6 – predominantly graywackes; 7 – predominantly shales and siltstones (black flysch of the outer fan)

suppose an erosion of the inner fan deposits and redeposition, or an absorption into the crust by the prograding thrust-fold belt occurred during Viséan. It is,for example, a metamorphism of denudation remnants of Devonian rocks (Chlupáč 1975), preserved whithin the thrust fold belt, reaching the staurolite zone and metamorphism of the Viséan sediment complex at the western border of the basin reaching the biotite isograde (Králík – Polický 1976) that prove the absorption of a part of flysch complexes in the crust during the shifting of this thrust-fold belt. The post-Variscan erosion of the remaining parts of the older Viséan inner fan deposits, together with the overthrusted rocks, can also be assumed. In general, the shaping of the turbidite fans led to the S-N lithologic polarity of the Carboniferous accretionary wedge. Transversal changes in lithologies are also evident. They were connected with the rapid W-E shifting of the depocentre in the Viséan owing to the prograding western thrust-fold belt and gradual destruction of the basement (Kumpera 1971, 1983, Dvořák 1973). These lithologic changes were influenced by the redeposition of formerly deposited flysch siliciclastics and by the gradual decreasing in relief energy in the source area during the closing stages of evolution.

Sedimentary expression of tectonic processes

The described longitudinal and transversal trends in the accretionary wedge evolution are in accordance with the trends of lithologic and chemical composition of the Carboniferous sediments.

Changing chemical composition of siliclastics

The changes in the chemical composition of the Carboniferous sediments are expressed partly by the oxide ratios, and partly by the recalculation of chemical analysis by Niggli's or the C.I.P.W. system. Only noncarbonate rocks (i.e. the rocks with less than 5% carbonates) has been taken into consideration. Aluminium content demostrated by the Al_2O_3/Na_2O ratio in claystones of different age, gradually increases from Devonian up to Upper Viséan and Namurian A strata and later decreases again (Fig. 5). Changes in the SiO_2/Al_2O_3 ratio indicate the increasing content of SiO_2 (as quartz) in the molasse deposits, with a clear peak in the youngest continental molasse deposits (Fig. 6). Changes in the K_2O/Na_2O ratio are conclusive in all siliclastics types (Fig. 6). In addition, the ratio manifest a marked enhancement in continental molasse sediments, which

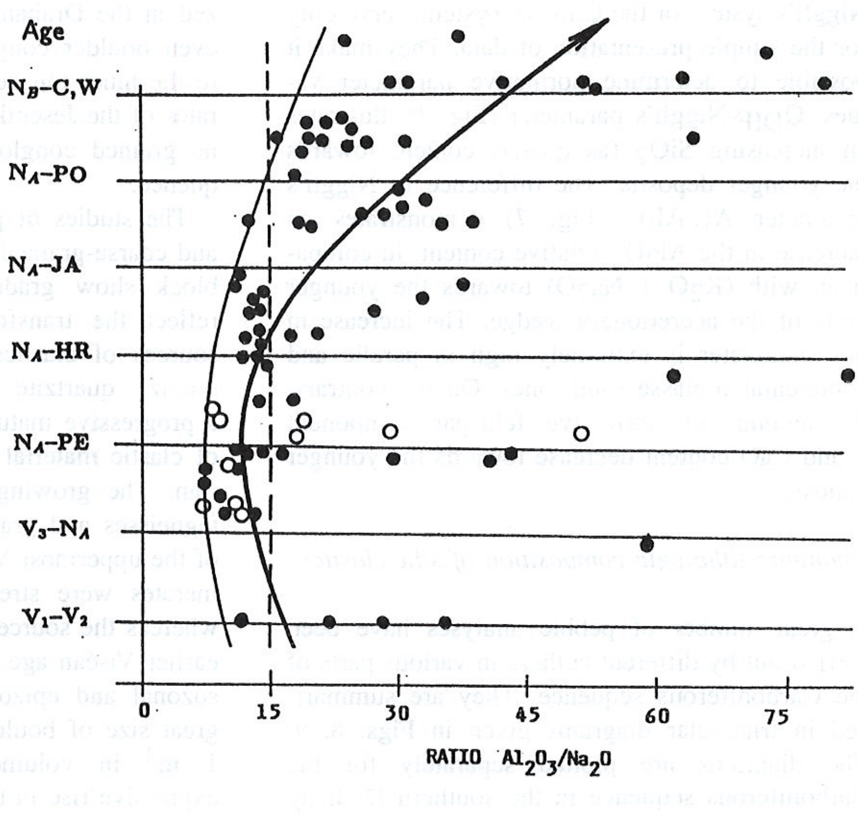


Fig. 5. Al_2O_3/Na_2O ratio values in the claystones from the eastern part of the Carboniferous accretionary wedge in the Moravian-Silesian region of the Bohemian Massif. *Dots* – values from the Ostrava region, *circles* – values from deep boreholes near Němčičky SE from Brno. *Arrows shows* the trend in ratio evolution. Stratigraphic position: V_1-V_2 – lower and middle part of Viséan; V_3 – Upper Viséan; N_A – Namurian A (Members of the Ostrava Formation: PE – Petřkovice Member, HR – Hrušov Member, JA – Jaklovec Member, PO – Poruba Member), N_{B-C} – Namurian B and C, W – Westphalian

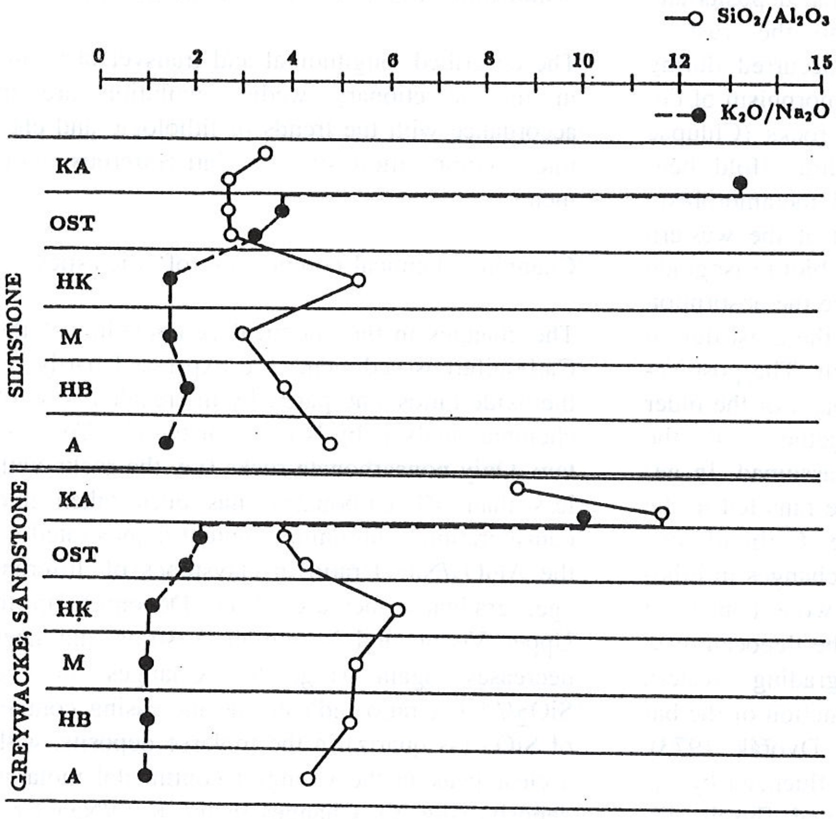


Fig. 6. Diagrammatic representation of the SiO_2/Al_2O_3 (96 analysis) and K_2O/Na_2O (117 analysis) mean values in the Carboniferous sequence in the Moravian-Silesian region of the Bohemian Massif
Stratigraphic units: A – Andělská Hora Formation, HB – Horní Benešov Formation, M – Moravice Formation, HK – Hradec – Kyjovice Formation, OST – Ostrava Formation, KA – Karviná Formation. Age of the formations is given in Table 1

corresponds with increasing detritic muscovite and K-feldspar contents in these young deposits.

Recalculations of the chemical analysis, by Niggli's system or the C.I.P.W. system, serve only for the simple presentation of data. They make it possible to determine normative parameter values. Q_{DIF}-Niggli's parameter (Fig. 7) illustrates an increasing SiO_2 (as quartz) content towards the younger deposits. The difference in Niggli's parameter AL-ALK (Fig. 7) demonstrates an increase in the Al_2O_3 relative content, in comparison with (K_2O + Na_2O) towards the younger parts of the accretionary wedge. The increase in this parameter is extremely high in paralic and continental molasse sandstones. On the contrary, the amount of normative feldspar component F and CaO content decrease towards the younger deposits.

Changing lithologic composition of siliciclastics

A great number of pebble analyses have been carried out by different authors in various parts of the Carboniferous sequence. They are summarized in triangular diagrams given in Figs. 8, 9. The diagrams are plotted separately for the Carboniferous sequence in the southern Drahany block and in the northern Jeseníky block, with respect to the different sizes of conglomerate pebbles in these two units. Conglomerates analyzed in the Drahany block are coarse grained, or even boulder conglomerates, and belong mostly to the inner fan deposits, whereas the conglomerates of the Jeseník block represent mostly the fine grained conglomerates of the outer fans sequence.

The studies of pebble assemblages in boulder and coarse-grained conglomerates in the Drahany block show gradual changes, which probably reflect the transforming of primary individual sources of clastics. The increasing amounts of quartz, quartzite and silicate rocks indicate a progressive maturity and a more distant source of clastic material during the Viséan and Namurian. The growing amounts of Moldanubic catagneisses and granulite pebbles in the direction of the uppermost Viséan coarse – grained conglomerates were stressed by Štelcl (1960, 1962), whereas the source areas of the conglomerates of earlier Viséan age are represented mainly by mesozonal and epizonal metamorphic schists. The great size of boulders (even boulders more than 1 m^3 in volume are present) confirms an expressive rise in the relief energy in the western

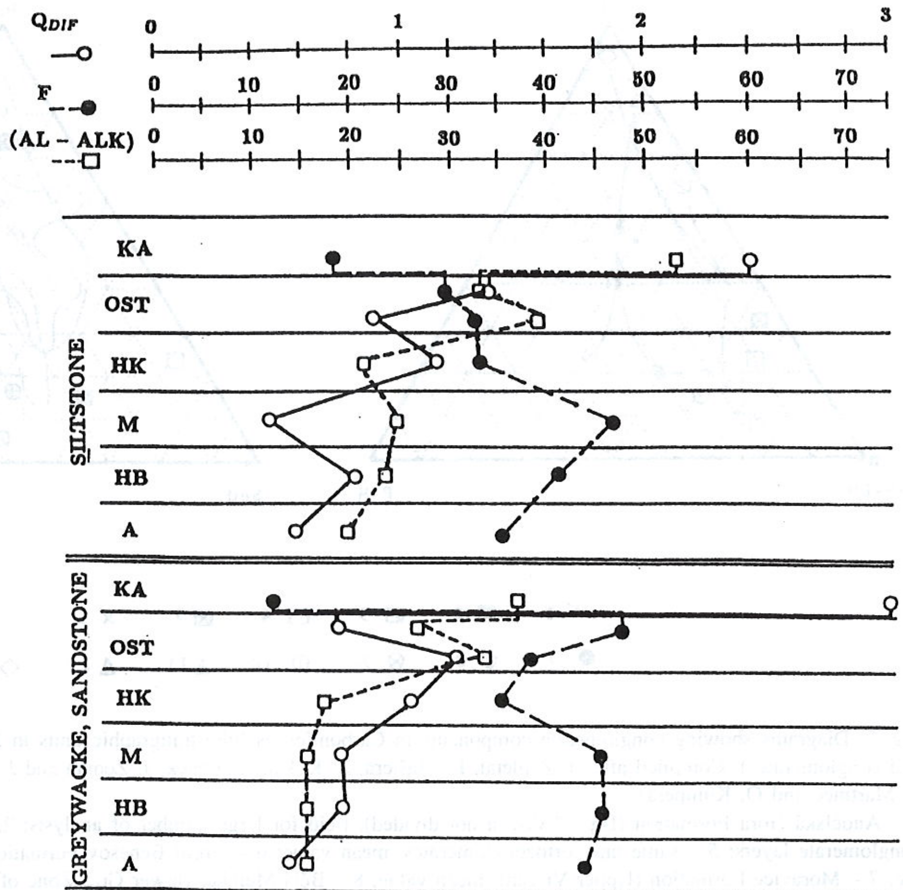
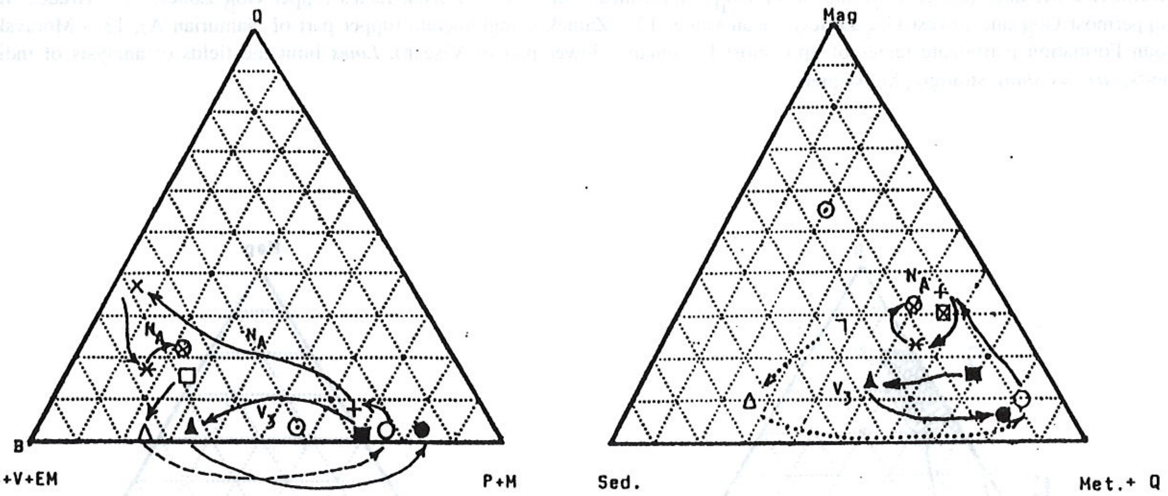


Fig. 7. Diagrammatic representation of mean values of the C.I.P.W. parameters Q_{DIF} (87 analysis) and F (91 analysis) and of the Niggli's difference AL – ALK (84 analysis) in the Carboniferous stratigraphic units in the Moravian-Silesian region of the Bohemian Massif. For stratigraphic units A – KA see Fig. 6



■ 1 ▲ 2 ● 3 ⊙ 4 □ 5 △ 6
○ 7 + 8 × 9 ✳ 10 ⊗ 11 ⊠ 12

Fig. 8. Diagrams showing conglomerate components in Carboniferous lithostratigraphic units of the Drahany Block; mostly coarse and boulder conglomerates (compiled after J. Štelcl, L. Maštera, J. Polický and V. Fialová)

1 – Kořenec Conglomerate (lower part of Viséan); 2 – Račice Conglomerate (Upper Viséan Go_{α} – lower Go_{γ}); 3 – Luleč Conglomerate (Upper Viséan – upper Go_{β},and Go_{γ}); 4 – Upper Viséan conglomerates in the Miroslav horst; 5 – the lowest part of Račice Conglomerate from Nesvačilka-3 borehole; 6 – upper parts of Račice Conglomerate from Nesvačilka-3 borehole; 7 – Luleč conglomerates in Nesvačilka-3 borehole; 8 – lowest Namurian A from Němčičky-2 borehole; 9 – middle part of Namurian A from Nemčičky-2 borehole; 10, 11, 12 – upper part of Namurian A from Němčičky-2 borehole. *Arrows show* the stratigraphic sequence Q – quartz, S, Sed – sedimentary rocks, V – volcanites, EM, – epizonal metamorphosed rocks, Met – all metamorphosed rocks, P – plutonic rocks, Mag – magmatic rocks

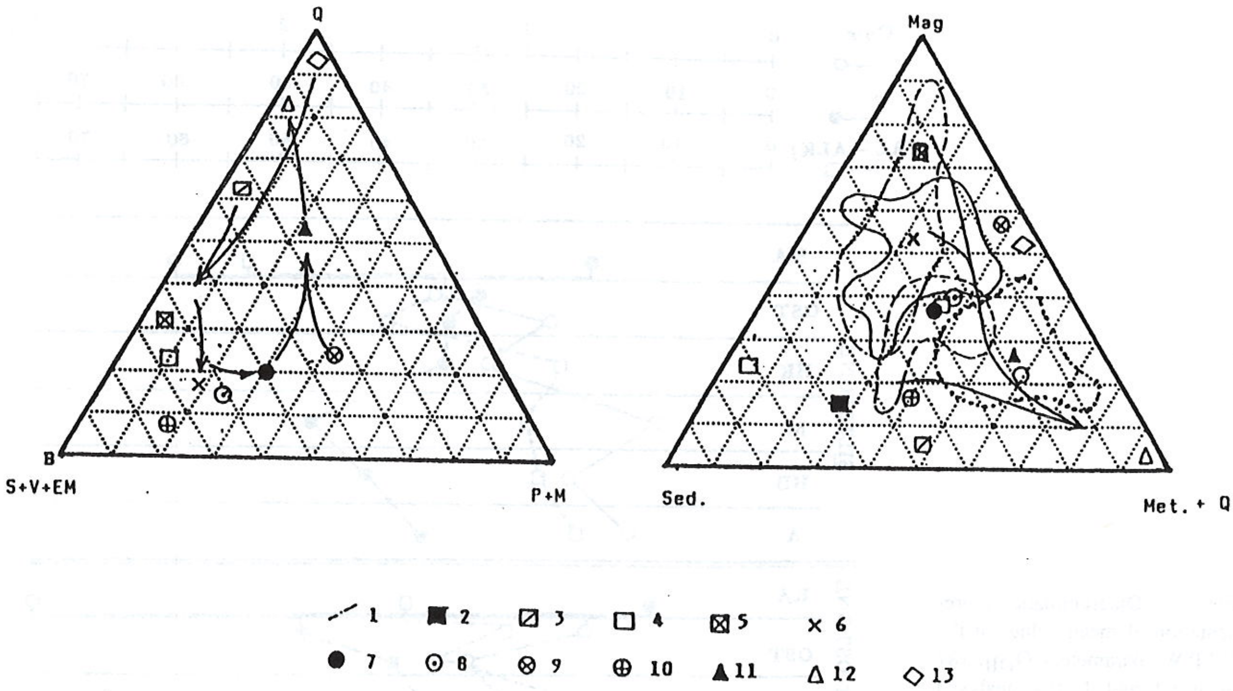


Fig. 9. Diagrams showing conglomerate components in Carboniferous lithostratigraphic units in Jeseníky block (mostly fine-grained conglomerates). Compiled after J. Zapletal, L. Maštera, Z. Kukal, J. Jiránek, J. Zeman and J. Kupka, J. Králík and J. Polický, P. Martinec and O. Kumpera)

1 – Andělská Hora Formation (D_3 – ?Viséan not divided), field for large number of analysis; 2, 3, 4 – same unit, various paraconglomerate layers; 5 – same unit, ortoconglomerates, mean value; 6 – Horní Benešov Formation (lower part Viséan), mean value; 7 – Moravice Formation (Upper Viséan), mean value; 8 – Bělá Member (lower Go_{α} Zone of Upper Viséan), mean value; 9 – Brumovice Member (upper Go_{α} and lower Go_{β} Zone), mean value; 10 – Potštát facies (upper Go_{β} Zone); 11 – Hradec Member (uppermost Go_{β} and lowest Go_{γ} Zones), mean value; 12 – Zámek Conglomerate (upper part of Namurian A); 13 – Moravský Beroun Formation (carbonate facies of uppermost Devonian – lower part of Viséan). *Lines* limit the fields of analysis of individual units, *arrows show* stratigraphic sequence

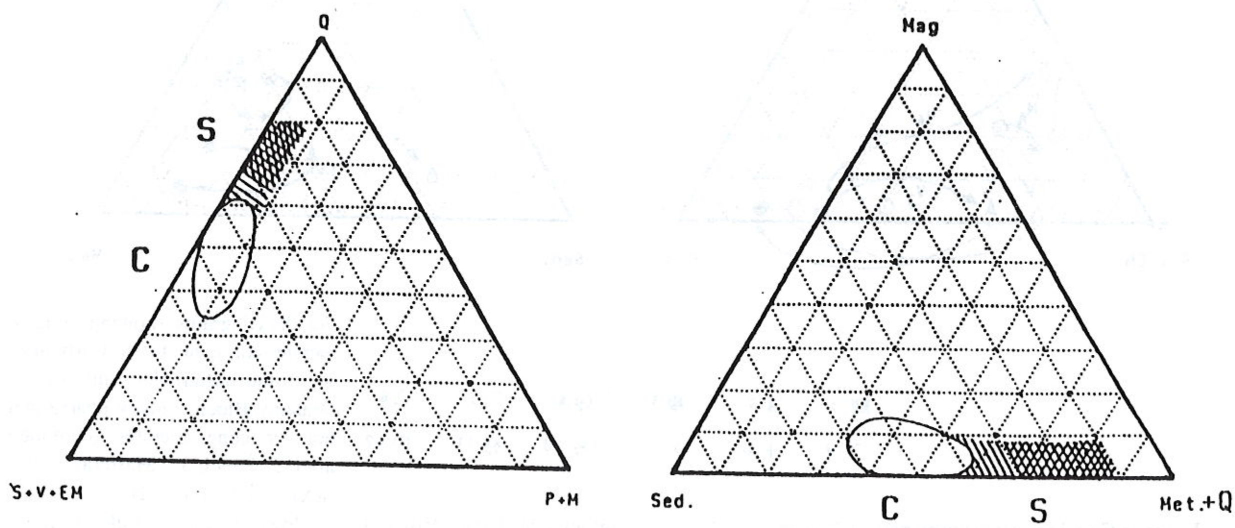


Fig. 10. Diagrams showing the main components of fine-grained conglomerates (field C) and sandstones (field S) in lower part of Karviná Formation (Namurian B) (Q, S, V, EM, P, M, MET see Fig. 8)

Fig. 11. Transparent heavy mineral assemblages of individual stratigraphic units in Jeseníky block (compiled after J. Otava, L. Jansa and P. Martinec)
1 – Saddle Member in thick sandstone layers/laminas; 2 – Poruba Member in thick sandstone/laminas; 3 – proximal turbidites; 4 – distal turbidites. Relative content of minerals: *large dots* – prevalent content > 60%, *large circles* – dominant, *small dots* – subdominant, *small circles* – not frequent. Heavy minerals: G – garnets, Z – zircone, A – apatite, T – tourmaline, R – rutile, D – disthene, E – epidote, S – staurolite, O – ore minerals, Ti – titanite, Am – amphiboles, An- anatas, Zo – zoisite

		TRANSPARENT HEAVY MINERALS												
Age	Unit	G	Z	A	T	R	D	E	S	O	Ti	Am	An	Zo
W	Karviná Form. sandstone	•	o	–	⊙	⊙	–	–	–	–	–	–	–	–
N_B	Karviná Form. sandstone[1)]	⊙	⊙	⊙	o	•	–	–	–	–	–	–	–	–
		●	o	o	o	o	–	–	–	–	–	–	–	–
N_A	Ostrava Form. sandstone[2)]	⊙	–	⊙	–	•	–	–	–	–	–	–	–	–
		o	●	•	–	⊙	–	–	–	•	?	–	–	–
$V_3\ Go_\gamma - N_A$	Kyjovice Mem. greywacke	•	●	⊙	•	⊙	–	–	–	–	–	–	–	–
V_3Go_γ	Hradec Mem. greywacke	●	⊙	⊙	–	–	–	–	–	–	–	–	–	–
V_3Go_β	Moravice Form. greywacke	⊙	⊙	⊙	–	–	–	–	–	o	–	–	–	–
								change						
$V_3\ Go_\alpha$	Moravice Form. greywacke	⊙	⊙	⊙	–	o	o	•	•	–	o	⊙	o	o
V_2 ?	Horní Benešov Form., greywacke[3)]	⊙	⊙	⊙	–	o	o	o	•	–	⊙	–	o	o
V_2 ?	Horní Benešov Form., greywacke[4)]	⊙	⊙	–	–	–	–	–	–	⊙	–	–	–	
D_3 ? – C_1	Andělská Hora Form.	–	●	⊙	⊙	o	–	–	⊙	–	⊙	⊙	–	–
D_3 ? – C_1	Moravský Beroun Form.	–	⊙	–	⊙	–	–	–	–	–	–	–	–	–

Fig. 12. Transparent heavy mineral assemblages of individual Carboniferous units in Drahany block (compiled after J. Štelcl and L. Svoboda, J. Polický and V. Fialová and J. Otava). For explanation see Fig. 11

		TRANSPARENT HEAVY MINERALS												
Age	Facies	G	Z	A	T	R	D	E	S	O	Ti	Am	An	Zo
N_A upper	arcose	●	•	–	–	–	–	–	–	–	–	–	–	–
								change						
N_A middle	arcose	•	•	⊙	o	o	–	–	–	•	–	–	–	–
N_A base	greywacke	●	⊙	–	•	–	–	–	–	•	–	–	–	–
								change						
V_3 upper	Myslejovice Form.	⊙	⊙	⊙	•	o	o	o	o	o	–	–	–	–
V_3 lower	Myslejovice Form.	⊙	⊙	⊙	•	o	–	o	–	⊙	–	–	–	–
V middle?	greywacke	⊙	⊙	⊙	•	•	–	o	o	⊙	–	–	–	–
V lower?	greywacke	•	⊙	⊙	o	o	–	–	–	•	–	–	–	–

trust-fold belt, which was the main source area of the Upper Viséan sediments. This is in accordance with the low Al_2O_3/Na_2O ratio in the Upper Visean claystones.

The sediments of the outer fans, exposed in the northern Jeseníky block, manifest a more complex relationship (Fig. 9). The fine-grained graywacke conglomerates analyzed, mostly by Kühnel 1967, Kukal 1970 and Zapletal 1989, show a very diverse material composition and great amounts of sedimentary pebbles, quartz and low-grade metamorphites in the lower Viséan strata. The portion of magmatic rocks increases in pebble assemblages towards the younger Viséan deposits. The magmatites are represented by acid plutonites and effusive rocks and by their amount. Among the sedimentary pebbles, the predeposited lower Viséan rocks, which often show metamorphism of a low degree, are common in the middle part of the Viséan sequence, but they are less frequent in the conglomerate layers of the higher stratigraphic positions (Maštera 1975). Then,the maturity increases strongly towards the Namurian and Westphalian molasse deposits, with the distinct maxima in the continental molasse sediments (Fig. 10).

In both regions, the conglomerate layers have a common increasing maturity of clasts assemblages towards the younger deposits, but changes in the Drahany block are not as conspicuous as in the Jeseníky block area.

The trends of transparent heavy minerals assemblages, studied especially by Otava (1985, 1988) and Štelcl and Svoboda (1962), indicate a similar evolution from stable associations in the Viséan carbonate platform deposits to polymict associations with the most unstable minerals. The more stable garnet and zircon assemblages in the Viséan flysch sediments up to stable and ultrastable assemblages in Namurian B, C and Westphalian deposits were found (Fig. 11). The changes in the Drahany block (Fig. 12) are not as significant as in the Jeseníky Hills area, but the trends are similar. The reason can be inferred from the more intensive reworking and redeposition of sediments in the more mobile northern part of the wedge.

Cannibalism

Numerous pebbly mudstone layers (Zapletal 1991, Jiránek 1993), rare olistolites and olistostromes and redeposed Devonian and Lower Carboniferous fauna are proof of the reworking, or cannibalization, of previously deposited sediments. Also, small clasts of the older Carboniferous sediments, which are even slightly metamorphosed and which were rede-

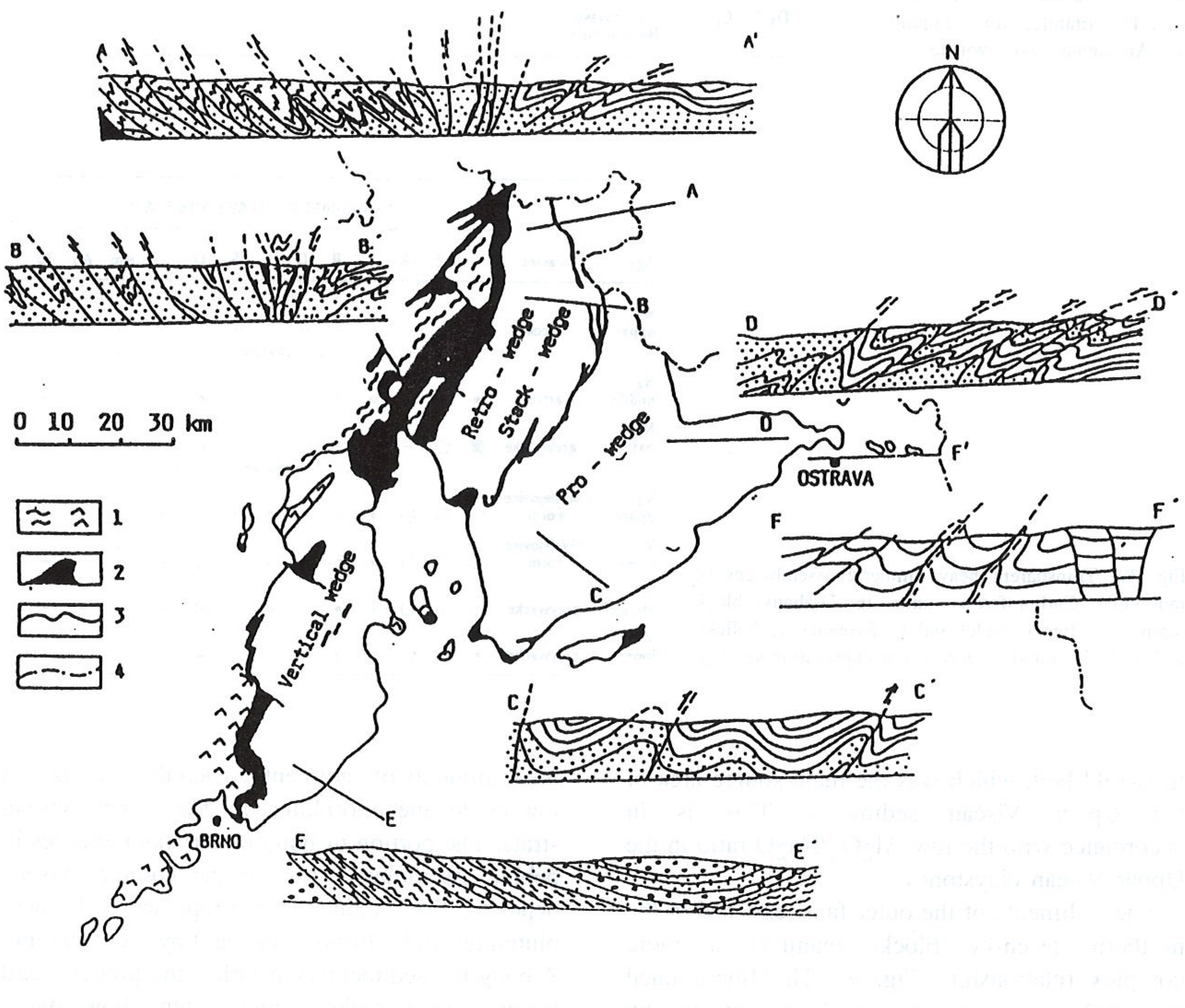


Fig. 13. Outline of the Carboniferous regions in the Moravian-Silesian Paleozoic Basin with schematic cross sections showing the different tectonic styles and shortening. Note the contrast between thin-skined tectonics in the north and simple folds in the south. A-F: sections lines; for 1-4 see Fig. 4

posed into the upper part of the wedge, are present (Zapletal 1989). These phenomena are frequent, especially in the outer fans and in older flysch sediments cropping out in the northern part of the wedge in the Nízký Jeseník Hills (Fig. 14). In addition to the mentioned phenomena, changing paleoslope orientation can be derived from the numerous slide scars, slump folds and slip bedding. These features can be observed only in some parts of the Viséan flysch sequence, whereas they are absent in some other thick flysch complexes. In general, the frequency of these phenomena decreases in the young deposits.

Tectonic reworking, shortening and a grade of metamorphism

The tectonic reworking of the Carboniferous deposits presents a similar picture, differing in intensity and style in different parts of the wedge (see Kumpera 1971, 1983). The wedge is divided into three parts (Fig. 13): – a retro-wedge (situated in the westernmost part of the wedge) near the roots of the collision zone, a pro-wedge (Willet – Beaumont 1993) situated far from the collision zone; the retro- and a the pro-wedge are divided by a stack-wedge which partly forms a narrow klippen zone (Kettner 1952) with the

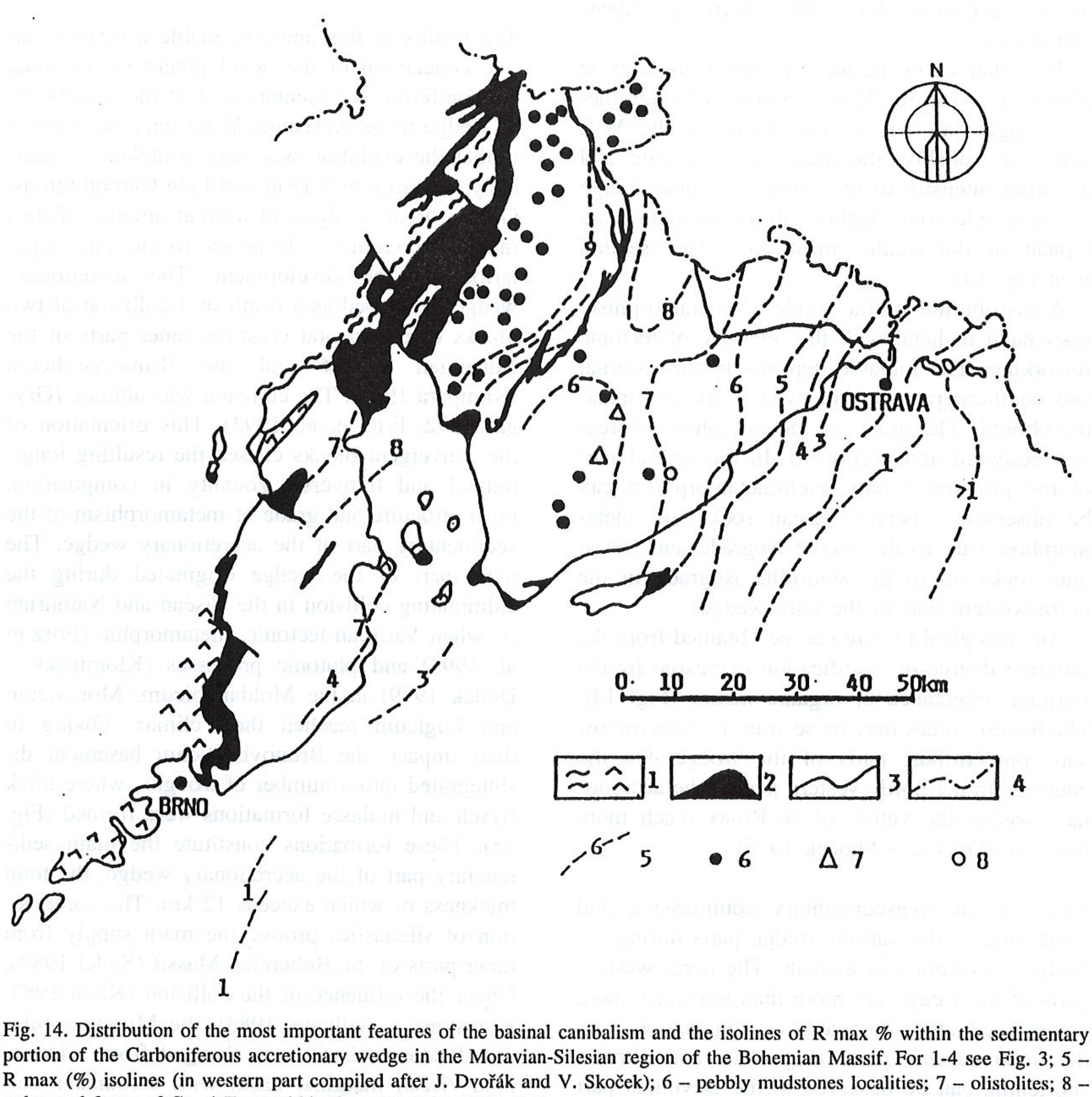


Fig. 14. Distribution of the most important features of the basinal canibalism and the isolines of R max % within the sedimentary portion of the Carboniferous accretionary wedge in the Moravian-Silesian region of the Bohemian Massif. For 1-4 see Fig. 3; 5 – R max (%) isolines (in western part compiled after J. Dvořák and V. Skoček); 6 – pebbly mudstones localities; 7 – olistolites; 8 – redeposed fauna of $Go_{\alpha}4$ Zone within the greywacke of $Go_{\gamma}1$ Zone

Devonian-Tournaisian rocks squeezed through the thick Lower Carboniferous sequence to the surface (Fig. 13, section A, B). A W-E polarity in the intensity of the tectonic reworking can be observed. The most intensive back-folding and back-thrusting (Silver – Reed 1988) connected with the origin of the metamorphic foliation and with superposed folds, can be seen in the western and especially in the northwestern part of the retro-wedge. The intensity of the tectonic reworking decreases to the east into the pro-wedge, the tectonic reworking of which is characterized by more broad, partly cleawage folds and short thrusts. The tectonic reworking became simpler to the eastern wedge periphery, where the paralic and contineta1 molasse deposits show only normal and strike-slip faulting, forming grabens and horsts.

The changes in the tectonic reworking can be observed also in the N-S direction. Although these changes are not so expressive as the W-E structural zonality, the decrease in folding and thrusting intensity to the south is evident. Large broad simple folds without thrust structures are typical of the southernmost areas (see section E in Fig. 13).

A distribution of the grade of metamorphism goes hand in hand with the intensity of tectonic reworking. The molasse deposits in the external and southern parts of the wedge are not metamorphosed. The grade of metamorphism increases westward and northward. In the central part of the pro-wedge only anchimetamorphism can be observed, whereas Viséan rocks are metamorphosed up to the biotite isograde and Devonian rocks up to the staurolite isograde in the north-western part of the retro-wedge.

An analogical picture can be obtained from the different degree of coalification expressed by the vitrinite reflectance of organic matter (Fig. 14). The lowest values may be seen in the easternmost and southernmost parts of the wedge. On the contrary, in the north-western part of the accretionary wedge the values of % Rmax reach more than 9% (Dvořák – Skoček 1975).

The different synsedimentary compression and shortening of the various wedge parts during the Variscan evolution is evident. The north-western parts of the wedge are more than ten times more compressed and shortened, in comparison with the south-eastern parts (Fig. 13). An extreme shortening can be observed in the Devonian part of the stack-wedge. Orel (1985, cit. in Hladil 1988) proposed that the original width of the Devonian basin was more than 200 km. The present width of the Devonian-Turnaisian klippen belt, although its original width had to be several tens of kilometers in the stack wedge, is several kilometers. A strong shortening can also be observed in the flysch deposits surrounding the Devonian-Tournaisian rocks in the stacke-wedge (see section A, B in the Fig. 13). The intensity of compression diminishes abruptly into the pro-wedge trending up to zero on its external borders. Also, the southern parts of all the wedge types show a decrease in the shortening of the original basinal width .

Discussion and conclusion

The results of this analysis enable a more dynamic conception of the development of the thick Carboniferous sedimentary part of the accretionary wedge to be presented. What must be stressed is that the evolution was very complex, dynamically changing in Viséan and Late Carboniferous. Only a broad analysis of a great amount of data makes it possible to do justice to the main regularities of the development. The accretionary wedge developed as a result of a collision of two blocks of continental crust-the inner parts of the Bohemian Massif and the Brunovistulicum (Kumpera 1988). The collision was oblique (Grygar 1992, Fritz et al. 1993). This orientation of the convergent blocks caused the resulting longitudinal and tranversal zonality in composition, inner structure and grade of metamorphism of the sedimentary part of the accretionary wedge. The main part of the wedge originated during the culminating collision in the Viséan and Namurian A, when Variscan tectonic, metamorphic (Fritz et al. 1993) and plutonic processes (Klomínský – Dudek 1979) in the Moldanubicum, Moravicum and Lugicum reached their climax. Owing to their impact, the Brunovistulicum basement disintegrated into a number of troughs, where thick flysch and molasse formations were formed (Fig. 15). These formations constitute the main sedimentary part of the accretionary wedge, the total thickness of which exceeds 12 km. The composition of siliclastics proove the main supply from inner parts of the Bohemian Massif (Štelcl 1982). Under the influence of the collision (Klein 1987, Kingstone – Williams 1983), the Moravian-Silesian Paleozoic basin was changed from a Devonian-Viséan marginal basin with carbonates and a Devonian-Tournasian rift basin to the remnant and foreland basin with flysch. At the same time, the flysch portion of the wedge budget covered and repressed the carbonate platform and rift deposits. This occured during the final stages of the development, forming a foreland basin with molasse (Einsele 1992).

The development of siliclastics, and the analysis of thicknesses, prove that the remnant and foreland basin gradually crumbled to a system of narrow longitudinal troughs (Fig. 15) and elevations, which arose and ceased during the sedimentation and synsedimentary tectonic reworking (Kumpera 1983). We have distinguished three principal partial troughs in the flysch basins – a western, middle and eastern flysch trough, and also the most external depression – the molasse foredeep. In the Viséan, a great amount of the clastics supplied the remnant and foreland basins, mainly from the prograding western thrust-fold belt. The high relief energy of this belt, during the Viséan is indicated by boulder conglomerates and low Al contents. The clastics entered the principal flysch troughs mainly near the southern part of the Drahany Upland in front of the submarine canyon, and were redeposited along the trough axis to the north forming large turbidity fans (Ricci-Lucci and Valmori 1980) – Fig. 4.

The sedimentary development was strongly influenced by the prograding western thrust-fold belt, the shifting of which caused a partial destruction of older turbidity fans and redeposition of their clastics into the younger flysch and molasse deposits.

We consider this process to be one of the main reasons for growing chemical (Figs. 5, 6, 7) and mineralogical maturity (Figs. 8-12), which is low in the older flysch deposits and culminates in the younger continental molasse deposits. The tectonic processes in the collision zone faded out in the later part of Namurian A. This is documented by an increase in the Al_2O_3 relative content, and also by the growing kaolinite input into the basin, which can be explained by the growing peneplanation of the source area. Dvořák and Maštera (1974) have explained more detailed differences in the composition of the Upper Viséan sediments, between the northern Jeseníky Hills area and the southern Drahany Upland, by means of the existence of two basins which were supplied from different source areas. On the contrary, much of the data indicates the existence of only one basin. When evaluating the difference in the siliclastics composition, the disparate grain size and position in the turbidite fans should be taken into account. Furthermore, it is evident that the northern parts of the basin developed as a consequence of the oblique collision, under more dynamic conditions. They were in a synsedimentary way, compressed and shortened more intensively so that a greater number of partial troughs originated and ceased in this part of the basin. In paleontologically well dated Upper Viséan deposits,

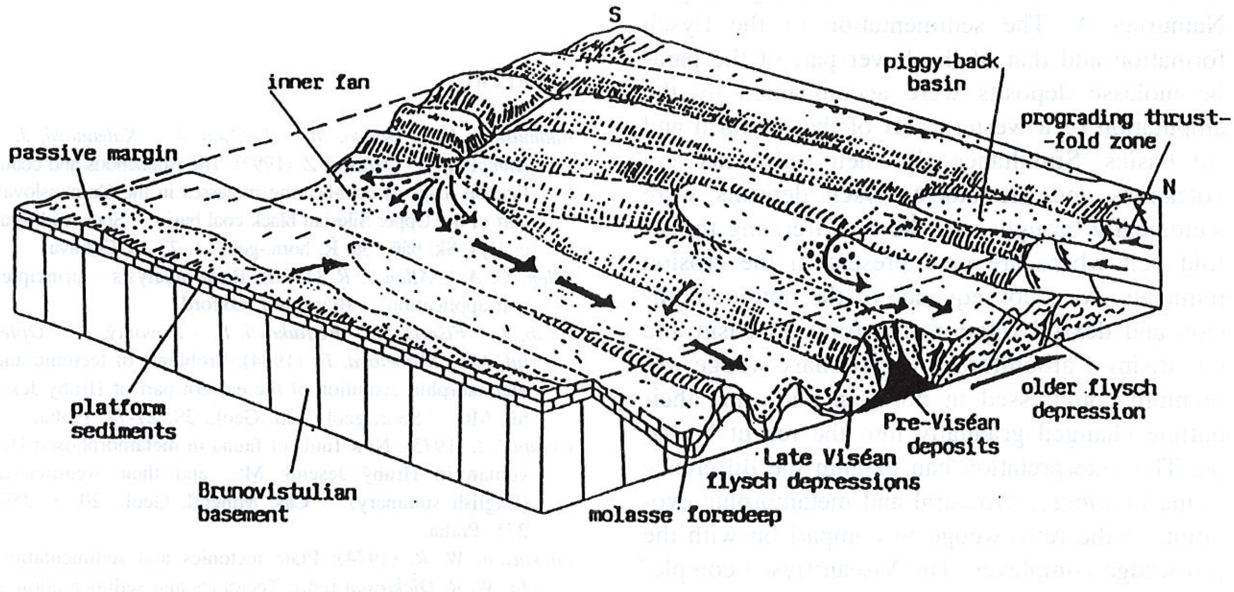


Fig. 15. Schematic conception of the partial flysch troughs and molasse foredeep and of the surrounding source areas in the Moravian-Silesian Paleozoic Basin during the Late Viséan stage of development

only one partial trough can be recognized in the southernmost part of the basin, whereas the development of three or even four partial troughs can be supposed in the northern Jeseníky Hills area. The more rapid eastward shifting of the depocentre led to the multiply redeposition, well documented by frequent features of intrabasinal cannibalism in this part of the basin. The extrabasinal clasts, derived from the western thrust-fold belt, were mixed here with redeposed clasts from the intrabasinal elevations. Also, the geometry of the accretionary wedge and the original contour of the foreland basins passed through great changes, mainly in the Viséan. First of all, the western parts of the basinal filling were amputated by the prograding thrust-fold belt. Two verified directions of the lithologic, structural and metamorphic polarity (transversal (W-E) and longitudinal (N-S)) made it possible to suppose an expressive synsedimentary rotation of the basin around vertical axis, in consequence to the oblique collision in the SW-NE direction. A similar rotation was already proved in younger basins (Kodama – Takeuchi – Ozawa 1993) and simulated by experiments (Schreurs 1994). Hladil (1988) documented the original orientation of the Devonian part of the carbonate platform basin and Devonian rift basin in the W-E direction, i.e. approximately perpendicular to the recent direction of Variscan structures in the Moravian – Silesian region. Considering our data, the main process of the amputation, reorientation and rotation of the basin and of the evolved wedge began in the Viséan, and culminated at the beginning of Namurian A. The sedimentation of the flysch formation and that of the lower part of the paralic molasse deposits were accompanied by the amputation of a western part of the platform and rift basins. Simultaneously, their sediments and volcanites and the oldest flysch deposits were tectonically brought into the N-S trending thrust-fold belt where are now present in the erosion remnants. As a consequence of the oblique collision and dextral rotation, the foreland basin and the arising Carboniferous accretionary wedge were more compressed in northern parts and their outline changed gradually into the recent V-shape. This interpretation can explain the difference in the lithologic, structural and metamorphic evolution of the retro-wedge in comparison with the pro-wedge complexes. The Viséan flysch complexes of the retro-wedge were deposited in the remnant basin on the more mobile and thinner crust of the pre-flysch rift basin, whereas the flysch complexes of the pro-wedge originated in the foreland basin located on the more stable older platform. Also a special and complex lithologic and structural evolution of the stack wedge with its Devonian – Tournaisian klippen belt are in keeping with this conception. The Devonian and Carboniferous complexes in the stack wedge were intensively compressed near the contact area between the mobile space of the Devonian-Tournaisian rift basin and the platform. The detailed structures of this klippen belt and stack wedge may be explained by the existence of a lateral ramp (Malugeta – Koyi 1987), divided these contrasting basins during the extreme shortening and rotation.

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Vývoj karbonského akrečního klínu v moravskoslezské paleozoické pánvi

Na základě analýzy karbonských sedimentů a jejich strukturně tektonických poměrů je v práci podán nástin vývoje zbytkové flyšové pánve, flyšové pánve předpolí a molasové pánve v předpolí variské kolizní zóny. Analýza se opírá o rozbor litologie flyšové a molasové formace, analýzu mocností, chemického a litologického složení hornin jednotlivých litostratigrafických jednotek, o rozbor jevů kanibalismu a rozsáhlé resedimentace karbonských klastik. Analýza strukturně tektonických poměrů ukazuje na velmi rozdílnou intenzitu zkrácení v různých částech původních pánví. Během vývoje mocného karbonského sedimentárního akrečního klínu se postupně nejen měnil obrys pánví a jejich vnitřní členění, ale současně také vrcholila jejich výrazná pravostranná rotace kolem svislé osy. Zejména z. části akrečního klínu byly hluboce denudovány již během variského vývoje a patrně též zčásti absorbovány do kůry progradujícími západními vrásovo-násunovými pásmy.