SUMMARY

Contrary to the pre-flysch sedimentation, the flysch development differs geochemically: while during the preceeding periods intensively chemically weathered clastic material had been deposited, at the beginning of the flysch development the situation changed abruptly - a fresh, chemically unweathered detritus was transported down from rapidly ascending median mass. This serves as a proof of a relatively fast uplift of some blocks of median mass which were exposed to those climatic levels in which mechanical disintegration of rocks prevailed over chemical. The climatic anomaly did not extend over the entire region, however. In the remaining part of the basin intensively chemically weathered sediments with high Al_2O_3/Na_2O ratio (up to 100) were deposited simultaneously with the flysch development. The ascending mountain range attracted abundant precipitation which generated a rapid transport of clastic material into the basin. Terrestrial volcanism (CO_2 production) along with tropical climate considerably affected the vegetation growth in swamps of the marine basin margins. Terrestrial flora fragments in the flysch formations prevailed towards the overlying rocks. The process culminated by coal seams formation in paralic molasse. The oldest flysch formations lack the goniatite and pelecypod macrofaunas which both gradually adapted themselves to the new life environment. The macrofauna development commenced first during the Upper Viséan. Rivers transported clastic material from the ascending median mass in the west perpendicularly to the longer axis of the basin which extended in the NNE-SSW direction. Around the river mouth a clastic fan was formed from which the detritus was redistributed within a zone of maximum subsidence by sea currents as well as by gravitational currents mainly from the SSW to the NNE. Along the axis of this zone the marine environment was the deepest. In the transverse section towards the east the basin had an ascending tendency. The sedimentary environment of the Ponikev Formation (siliceous shales containing silicites) was characterized as shallow-water deposits - currents did not transport a coarse clastic detritus to this part of the basin. From the west towards the east the thicknesses of the individual layers of clastic sediments increase at first, and then they thin out laterally passing to other facies. Along the axis of the zone of maximum subsidence coarse-grained clastics are present while at the western shore in the sedimentation shade clayey and silt clastic sediments were deposited. In some places at the clastic fan margin lenticles of shallow-water limestones with abundant fauna have been preserved if this part of the sedimentary formations was not denuded already during the Lower Carboniferous. This is documented by quite frequent pebbles of nearly contemporaneous limestones preserved in gravitational slide bodies or in conglomerates near the centre of the basin.

The clastic fans are least developed in the oldest Andělská Hora Formation and best in the Moravice Formation and in the Hradec-Kyjovice Formation. The clastic material deposition was rapid but most likely episodic. This has also been documented by thin

intercalations of fine black tuffaceous shales which prove a very slow deposition of fine oozy material at the time when almost no clastic material came into the basin. The oldest flysch formations show the most graded bedding. This characteristic type of bedding fades out towards the overlying formations.

If the recent considerable spatial reduction of original basins as well as the western margin denudation are considered, the depositional space width of the flysch development in individual stages did not exceed 50 km. The western margin of the flysch development has always been of regressive character (advancing clastic wedges) while the eastern one of transgressive character. The fill of the maximum subsidence zones exhibits an imbricated structure. The sediments of the individual zones of maximum subsidence have maximum estimated thicknesses from 1 500 to 2 000 m. A false thickness of the fill can be even twofold as a result of horizontal space reduction.

Zones of maximum subsidence migrated still faster from the median mass to the foreland as a consequence of more intensive compressional processes. Deposition of clastic material was also faster which had been preconditioned by faster ascent of progressively more extensive source area. The above described processes are reflected in an increased diameter of the largest pebbles in conglomerate intercalations with no respect to the increased length of transport.

An ascent of some blocks of median mass was accompanied by intrusions of vast Variscan granitoids at depth and by an associated subsequent acid volcanic activity at the top of the mountain ridge. It has first been known in the Upper Frasnian where it formed thin intercalations of tuffites containing volcanic quartz, apatite, zircon, and biotite. The beginning of the subsequent terrestrial volcanism was contemporaneous with the beginning of the flysch development. Its existence is manifested not only by intercalations of tuffs and tuffites in sediments but also by pebbles and minute clasts of acid volcanites and their tuffs distributed in conglomerates and greywackes of the flysch development.

The beginning of the Horní Benešov Formation deposition and the shift of the maximum subsidence zone towards the east was accompanied by intensive eruptions of terrestrial volcanism. The faster deposition of coarser material was due to more rapid ascent of the source area where, besides granodiorites and phyllites, also metamorphites of higher metamorphic grade occurred. The amount of pebbles of acid volcanites and their tuffs containing biotite is higher.

During the deposition of the Andělská Hora and the Horní Benešov Formations, the Desná Dome and mainly the elevation structure of the Proterozoic basement between the Vrbno Group and the Šternberk-Horní Benešov belt gradually subsided. The blocks situated east of the Šternberk-Horní Benešov belt were elevated at this time. The level of west-vergent folds then originating was sloping westwards.

Due to gradually increasing compression of the whole basin, volcanites were pushed diagonally up together with the sediments of the Šternberk-Horní Benešov belt during the Lower and Middle Viséan, and along with the Horní Benešov Formation they were integrated into a complex fan-shaped anticlinorium. The height of the pushed up anticlinorium exceeds 3 000 m. This is documented by low-grade thermal metamorphosis of organic matter in Lower Devonian to Lower Carboniferous sediments in the apical part of the anticlinorium of the Šternberk-Horní Benešov belt as compared with the adjoining deep synclinorial structure in the west filled prevailingly with the rocks of the Horní Benešov Formation. As it was proved by the borehole Dětřichov-1, the metamorphosis of the Lower Viséan rocks at the bottom of this borehole at the depth of 2 400 m belongs to a transition from anchizonal to epizonal grade. In the west the synclinorium adjoining the

Šternberk-Horní Benešov belt rapidly subsided in the Lower and Middle Viséan having been filled with a relatively coarse-grained clastic material. In the same time, the sediments were metamorphosed by an upward propagating heat, gradually folded, and subjected to cleavage-producing processes. The Horní Benešov HB-SV-2 borehole documents that the basic initial effusive volcanism had continued in the subsiding zone at the foot of the Šternberk-Horní Benešov belt till the Middle Viséan, i.e. longest in the entire Nízký Jeseník Mts. The basic initial volcanism producing material ascending along deep faults directly from the mantle documents that in the Lower Viséan the subsiding and melting of granite layer blocks has not yet been commenced in the vicinity of the Šternberk-Horní Benešov belt. The blocks in the vicinity of the Vrbno zone and westward of it where the initial volcanism had terminated already at the beginning of the Famennian were underthrust and melted.

The deep synclinorium at the western margin of the Šternberk-Horní Benešov anticlinorium is a result of a collision of two blocks of the Proterozoic basement. The original sedimentary space was syndepositionally reduced. Hot hydrothermal solutions ascending along trending dislocation zones thermally metamorphosed both sediments and volcanites. The anticlinorium was thrust over the synclinorium along listric surfaces.

During the Upper Viséan the zone of maximum subsidence was transferred eastwards of the Šternberk-Horní Benešov belt. Here the subsidence reached up to 1 500 m. The small block of volcanites with cleavage dipping towards the east was thrust over the structures with eastern vergency of the entire belt margin during the final formation stage of the fan-shaped anticlinorium. The west-vergency part of the anticlinorium is older than its east-vergency part in the east.

During the deposition of the lower part of the Moravice Formation, the western margin of the basin extended to the present Šternberk-Horní Benešov belt position. It is documented also by fragments of calcareous sandstones and limestones of Middle to Upper Viséan age, redeposited in slump conglomerates after a short-distance transport. The folded and metamorphosed cover of the Desná Dome gradually became a source of clastic material. This documents the ascent of the Desná Dome as well as the termination of the main folding and deformation processes in this part of the former basin during the Upper Viséan. At that time the dip of the level of folds also changed in the western part of the Nízký Jeseník Mts. to the present dip towards the east.

During the deposition of the lower part of the Moravice Formation the fold structures had different vergencies in different transversal blocks. There exists a variegated mosaic of blocks exhibiting west or east vergencies of fold structures. A geological environment with a variety of structure vergencies ends frequently at dislocations which were likely active not only during the sedimentation but also during a plastic deformation of deposited layers. The different vergencies of fold structures were due to different dips of blocks of the Proterozoic basement already during the deposition of the Moravice Formation. The Šternberk-Horní Benešov belt represents a boundary line between two different vergencies - on its west side west-vergency structures prevail while on its east side there is a belt of structures with various vergencies. Only the structures at the eastern margin of the present occurrence of the Moravice Formation show strictly eastern vergency.

In the uppermost Viséan, during the deposition of the Hradec-Kyjovice Formation, the zone of maximum subsidence shifted far to the east. At that time the Desná Dome and its surroundings as well as the structures located west of it were to a large extent a source region. Extensive, kilometres in size, overturned folds in the Hradec-Kyjovice Formation are disrupted by overthrusts showing an expressive east vergency which indicates a general dip of the fold level to the east.

The present foredeep of the Variscan tectogene (west part of the upper Silesian Basin) represents the zone of maximum subsidence which is located most easterly. Around the Viséan-Namurian boundary a volume of 1 300 m thick sediments was deposited before the actual start of paralic sedimentation of the Ostrava Formation. The marine sediments which had filled the foredeep before the actual beginning of the paralic sedimentation do not show flysch character any more.

The transition from the marine to paralic sedimentation commenced at the time when the subsidence in the foredeep was the fastest within the whole period of the Variscan tectogenesis. The transition took place at the time when sedimentation was faster than subsidence, i.e. when the basin was filled-up. The Ostrava Formation was still being gently folded. The Prokop coal seam corresponding to the upper half of the Namurian A and to the lower part of the Namurian B (thus approximately to a twice longer period during which the 3 000 m thick Ostrava Formation was deposited) delimits a termination of the main stage of the Variscan tectogenesis. At that time deformation of folds in the whole tectogene was terminated - the sediment deposition has been transferred further to the east onto the platform part of the Variscan foreland where terrestrial sediments of the Upper Namurian and Westphalian have already shown smaller thicknesses and where they have not been folded.

The most rapid tectonic activity was under way during the lower half of the Namurian A when the foredeep subsided most rapidly and when the folded tectogene was uplifted most progressively. Intensive volcanic activity was associated with tectonic activity, which is documented by thick intercalations of tuffites in the Ostrava Formation. A stagnation then occurred during a deposition of the Prokop seam which delimited a qualitative step from the period of marine geosynclinal bains (depressions) to the formation of completed tectogene elevations.

The tectogenesis of the European Variscides was part of the Gondwana collision with Laurasia in the circumequatorial zone (Dvořák 1985). The forelands played an active role having been thrust under the tectogene. Due to a considerably steep temperature gradient the underthrust blocks of the continental crust of the forelands were melted. The melt penetrated beneath the median mass where it intruded in the form of low-density granitoids. This extraordinarily fast progressing development was reflected in the flysch stage.

While the formation of the oldest Andělská Hora Formation took approximately 20 million years and of the Horní Benešov Formation about 15 million years, the Moravice Formation was formed only in about 3 million years and the Hradec-Kyjovice Formation (including the more than 1 300 m thick fill of the last zone of maximum subsidence below the Ostrava Formation) in ca. 2 million years. The flysch sedimentation is in a causal relation to the rapid uplift of the median mass and thus to the intrusion of granitoids and to the subsequent volcanism. It has formerly been assumed that pluton intrusions were contemporaneous with the Variscan molasse.

While in Moravia and Silesia the blocks of the foreland were underthrust in the ESE-WNW direction, on the Earth's surface the zones of maximum subsidence migrated in the opposite direction from the median mass to the foreland, i.e. from the WNW to the ESE. Individual flysch troughs (i.e. the zones of maximum subsidence) marked the places of underthrusting of individual blocks (subduction). The termination of prevailingly basic initial volcanism points to the beginning of this process: in the Vrbno Group it commenced in the Famennian, while in the Šternberk-Horní Benešov belt it commenced in the Middle

Viséan. It resulted in a significant spatial reduction of the original sedimentation area. Due to the melting of the granite part of the Earth's crust at depth, however, no increase in thickness of the Earth's crust is observed now. This has been indicated by an extensive regional positive anomaly of the gravity field as well as by the preserved small thickness of the Earth's crust, i.e. less than 30 km (Blížkovský et al. 1977).

Explanation to text-figures

1. Synoptic geological map of the Nízký Jeseník Mts. 1 - pre-flysch formations and volcanics of the Vrbno and Šternberk-Horní Benešov zones, 2 - limestone formations of Devonian and Lower Carboniferous age near Hranice and in the surroundings, 3 - Andělská Hora Formation (Famennian and Tournaisian), 4 - Horní Benešov Formation (Lower and Middle Viséan), 5 - Moravice Formation (Upper Viséan, Go alfa and beta zones), 6 - greywackes, 7 - shales and siltstones with greywacke intercalations (6, 7 - Hradec-Kyjovice Formation - Upper Viséan, Go gama zone and the base of the Namurian A), 8 - Ostrava Formation (lower half of the Namurian A), 9 - neovolcanism, 10 - Neogene.

2. Map of the Nízký Jeseník Mts. with the situation of the boreholes mentioned in the text.

3. Stratigraphic table of the Carboniferous of the Nízký Jeseník Mts. and surroundings. Vertical hatching - stratigraphic gap.

4. Schematic section illustrating the facies relations in the Andělská Hora Fm.: flysch facies, siliceous shales - silicite facies and carbonate facies. Also bathymetric conditions are illustrated. Not to the scale. 1 - flysch, 2 - siliceous shales with silicites, 3 - carbonates, 4 - direction of transport of clastic material, 5 - maximum subsidence, 6 - maximum uplift.

5. Stratigraphic correlation scheme of Horní Benešov (HB), Andělská Hora (AH), Ponikev (PO) Formations and the "Na výsluní" Facies west of Moravský Beroun. 1 - calcareous sandstones and limestones ("Na výsluní" Facies), 2 - greywackes, 3 - shales and siltstones, 4 - quartz conglomerates and coarse-grained sandstones (Moravský Beroun Formation), 5 - siliceous shales, silicites (Ponikev Formation), 6 - basic volcanites (Devonian), 7 - crystalline rocks of Proterozoic age, 8 - occurrence of volcanic quartz, 9 - Tournaisian/Viséan boundary.

6. Section through the Dětřichov 1 borehole. 1 - fine-grained petromictic conglomerates, 2 - greywackes, 3 - alternating shales, siltstones and very fine-grained greywackes, 4 - black shales (thickness enlarged). 1-4 - Horní Benešov Formation (Lower and Middle Viséan).

7. Schematic map of clastic wedges of the Moravice and Hradec-Kyjovice Formations. A - presumed coast in the time of deposition of the lower part of the Moravice Formation, B - clastic wedges, C - present extent of the Hradec-Kyjovice Formation. Numbers in clastic wedges: 1 - Osoblaha promontory, 2 - Bělkovice valley, 3 - east of Horní Benešov, 4 - Kopeček-Pohořany, 5 - NW of Lipník, 6 - Staré Oldřůvky-Lublice, 7 - Cvilín, 8 - Hrabůvka, 9 - Potštát, 10 - Klokočov-Spálov, 11 - Hranice, 12 - Vítkov-Domoradovice (1-4 - age of the lower part of the Go alfa zone, 5-7 - Go alfa 4 zone, 8-10 - Go beta zone, 11, 12 - Go gama zone. 1 - 10 - Moravice Formation, 11, 12 - Hradec-Kyjovice Formation).

8. Distribution of greywackes and conglomerates of the clastic wedge in the Moravice Formation NW of Lipník (geologic map without Quaternary deposits). 1 - thick Neogene and Quaternary, 2 - sediments of Go beta zone age, 3 - greywackes with interbedded conglomerates, 4 - alternating shales, siltstones and fine-grained greywackes (3, 4 - Moravice Formation, upper part of the Go alfa zone), 5 - Vilémovice Limestone (Frasnian).

9. Kružberk dam. Top: present position of the olistolith of laminated shales in the slumping conglomerate bed within the greywackes of the Moravice Formation. Bottom: an attempt to reconstruct the movement of the olistolith within a slumping body.

10. Lithology of the base of the Hradec-Kyjovice Formation in the Maleník block, outcrop SW of Hranice. 1 - coarse to fine-grained greywackes, 2 - very fine-grained conglomerates, 3 - fine-grained conglomerates, 4 - medium-grained conglomerates with some pebbles up to 20 cm in size.

11. Lithology of the base of the Hradec-Kyjovice Formation north of Hranice near Jindřichov. 1 - conglomerates, 2 - coarse-grained greywackes, 3 - medium- to fine-grained greywackes, 4 - siltstone shales, 5 - rhythms with graded bedding.

12. Schematic palinspastic section through the eastern part of the sedimentary basin at the end of the Upper Viséan. Not to the scale - horizontally markedly reduced. The map illustrates the relation of thick flysch formations in

the western part of the basin to the carbonate platform development in the east on the Variscan foreland. M - Moravice Formation, H-K - Hradec-Kyjovice Formation. 1 - conglomerates, 2 - greywackes, 3 - siltstones and shales, 4 - shales, 5 - limestones of the Líšeň Formation (Hády-Říčka and Křtiny Limestones - Famennian to Upper Viséan age), 6 - sandstones of Upper Viséan age overlying the Macocha Formation, deposited after a long time gap, 7 - reef-carbonates of the Macocha Formation (Givetian to Frasnian), 8 - gneiss of Proterozoic age, 9 - Go beta/Go gama goniatite zone boundary.

13. Stratigraphic-facies scheme of flysch and molasse and its relation to pre-flysch formations of the same age in the Nízký Jeseník Mts. AH - Andělská Hora Formation, HB - Horní Benešov Formation, M - Moravice Formation, HK - Hradec-Kyjovice Formation, O - Ostrava Formation, K - Karviná Formation, P - Ponikev Formation (siliceous shales with silicites), L - Líšeň Formation (biodetrital and micritic nodular limestones). AH to HK - flysch, O - paralic and K - terrestrial molasse.

14. Schematic map and section illustrating the distribution of flysch sediments according to their grain size and thickness within the zone of maximum subsidence. Sediments of the clastic wedge are distributed due to sea currents parallel to the elongated basin axis. 1 - conglomerates, 2 - greywackes, 3 - siltstones and shales, 4 - lenses of dark grey biodetrital limestones, 5 - inclination of the paleoslope, 6 - clastic wedge, 7 - axis of the maximum subsidence zone, 8 - main direction of currents in the basin, 9 - cross section line.

15. Diagram illustrating the accelerated deposition of clastic material in the individual zones of maximum subsidence and transition to paralic and terrestrial molasse.

16. Schematic map of the axes of maximum subsidence during the deposition on flysch and molasse in the Nízký Jeseník Mts. and their surroundings. 1 - in the Famennian, 2 - in the Tournaisian, 3 - in the Lower and Middle Viséan, 4 - in the Upper Viséan (Go alfa zone), 5 - in the Upper Viséan (Go beta zone), 6 - in the Upper Viséan (Go gama zone), 7 - in the lower part of the Namurian A, 8 - in the Upper Namurian and Westphalian A.

17. Diagram illustrating the accelerated shift of the zone of maximum subsidence during flysch and molasse development from the median mass to the foreland.

18. Synoptic map of structures in the broad surroundings of the Nízký Jeseník Mts. VS-D - Intrasudetic depression, S-M - Góry Sowie Mts., K-M - Góry Kaczawskie Mts., ŽGM - Žulová granitoid massif, OK - Orlice-Klodzko dome, K - Keprník dome, D - Desná dome, B-Z - Branná zone, Čs-Z - Červenohorské sedlo zone, V-Z - Vrbno zone, Š-HB-Z - Šternberk-Horní Benešov zone, Z-K - Zábřeh crystalline complex, OB - Osoblaha block, MB - Maleník block, ZH-K-D - Zlaté Hory-Krnov dislocation.

19. Palinspastic section through the Šternberk-Horní Benešov structure in the northern surroundings of Moravský Beroun near the Middle/Upper Viséan boundary. It illustrates the synsedimentary development of the structure during the collision of two blocks of crystalline complexes of Proterozoic age. The western one was subducted below the eastern one. Without scale. 1 - Horní Benešov Formation (Lower and Middle Viséan), 2 - Andělská Hora Formation (Famennian and Tournaisian), 3 - Ponikev Formation (Upper Frasnian to Tournaisian), 4 - limestones (Middle-Upper Devonian), 5 - volcanic rocks and tuffs (Emsian and Middle Devonian mainly), 6 - shales with some sandstone intercalations of the Stínava-Chabičov Formation, the Basal Clastic Formation of Lower Devonian age at the base, 7 - high-grade metamorphosed rocks of Proterozoic age.

20. Schematic map of the eastern part of the Nízký Jeseník Mts. with marked eastern and western vergencies of the structures in the Moravice Formation. 1 - Devonian and lowermost Carboniferous of the Šternberk-Horní Benešov zone, 2 - Hradec-Kyjovice Formation, 3 - structures of eastern vergency, 4 - structures of western vergency, 5 - structures lacking vergency (in the south), 6 - area lacking detailed investigation, 7 - axis of the Mladecko anticline.

21. Schematic palaeocurrent map in the Moravian Basin in the Upper Viséan (Go alfa zone).