Bulletin of Geosciences, Vol. 80, No. 1, 67–78, 2005

Hiatuses between the base of the Pennsylvanian and the base of the Triassic in the Bohemian Massif (Czech Republic)

Jiří Pešek

Charles University, Faculty of Science, Albertov 6, 128 43 Praha 2, Czech Republic. E-mail: ir@natur.cuni.cz

Abstract. A number of hiatuses can be distinguished in the Carboniferous and Permian of the Bohemian Massif. They can be subdivided into three categories. The most important ones are represented by breaks in deposition on a regional scale, such as between the Early and Middle (locally even Late) Namurian in the Upper Silesian Basin, Bolsovian and Westphalian D, and between Stephanian B and C in northeastern, central, and western Bohemia, and between Autunian and Saxonian in the Krkonoše Piedmont and the Intra-Sudetic basins. The presence of hiatuses at these levels has been also reported from a number of European Late Paleozoic basins. The second category of such breaks in deposition occurs only in parts of certain basins. It includes hiatuses in the Bolsovian of the Kladno-Rakovník Basin, between Stephanian C and Autunian, and in the Autunian within the Intra-Sudetic and/or Krkonoše Piedmont basins. The sharp boundary between Permian and Triassic deposits in the Intra-Sudetic and Krkonoše Piedmont basins is also related to this category. The third category includes the presumed (Wagner 1977) but hitherto unproven hiatus between the Westphalian D and the Late Stephanian B in central and western Bohemia.

Key words: Bohemian Massif, Late Carboniferous, Permo-Triassic, break in sedimentation

Introduction

A hiatus is a break or interruption in the continuity of the geologic record, such as the absence in stratigraphic sequences of rocks that would normally be present, but either were never deposited or were eroded before the deposition of overlying beds. A hiatus is also understood as a lapse in time, such as a missing time interval at an unconformity. The term unconformity is often used instead of hiatus in such cases (Jackson, ed. 1997).

A number of such breaks in deposition exist in the Late Paleozoic of the Bohemian Massif, as documented by some 2000 boreholes reaching to the basement. Apart from diastems, which lie beyond the scope of this contribution, hiatuses and their evidence from the base of the Pennsylvanian to the Triassic are discussed. These discontinuities in the fossil record can be subdivided into regionally significant and local hiatuses on the basis of importance. Regionally significant hiatuses are defined as breaks in deposition encountered in at least several basins in the territory of the Bohemian Massif, and are able to be correlated with similar phenomena in other Late Paleozoic basins of Europe. Local hiatuses are defined here as breaks in the sedimentary record documented from at least one basin in the Czech Republic.

Hiatuses can be identified:

- in well exposed terrain on extensive outcrops,
- in surface or deep mine works crossing at least two stratigraphically different units lying not too far from each other,
- in regions documented by deep boreholes that have reached at least one marker horizon over a larger area,
- from geological maps and cross-sections based on data from deep boreholes, possibly in combination with stratigraphically defined outcrops,
- possible breaks in deposition that were never geologically documented in the field due to generally flat angles of deposition and poor exposure, but may be interpreted from gaps in the floral or faunal record.

Namurian hiatuses

A sudden change in the floral assemblage of the Prokop Seam (lowermost seam of the Saddle Member) and in the overlying sediments was noted by Gothan (1913). This change is sometimes called “Gothan’s floral jump”. The base of this seam is marked by the disappearance of index floral elements of the Ostrava Formation dated to the Pendlian and Arnsbergian, i.e. Early Namurian (Figs 1 and 2). According to Dopita (1988), an interval of dark to beige quartzose sandstones, and quartzites or black sandy carbonate (siderite) penetrated by stigmarian appendices (with a maximum thickness of tens of centimetres), has been found below the Prokop Seam at the base of the Saddle Member of the Karviná Formation at many places in the Czech part of the Upper Silesian Basin. Dopita (1988) suggested that these rocks are a fossil weathering crust formed during a hiatus prior to the Prokop Seam formation, and compared it with ganister known from Late Carboniferous basins in Britain (i.e. Northumberland Basin, Havlena 1965). Interbeds of the Prokop Seam and its hanging-wall are marked by the appearance of the Karviná-type assemblage, i.e. of Middle to Late Namurian and Langsettian (i.e. Westphalian A) flora. While the uppermost beds of the Poruba Member of the Ostrava Formation are attributed to the goniatite Subzone E_2, flora of the Prokop Seam and the whole Saddle Member corresponds to the goniatite Subzone R_1 of the Belgian Carboniferous (Purkyňová 1976, 1977). This means that sediments of the goniatite Zone H are missing in

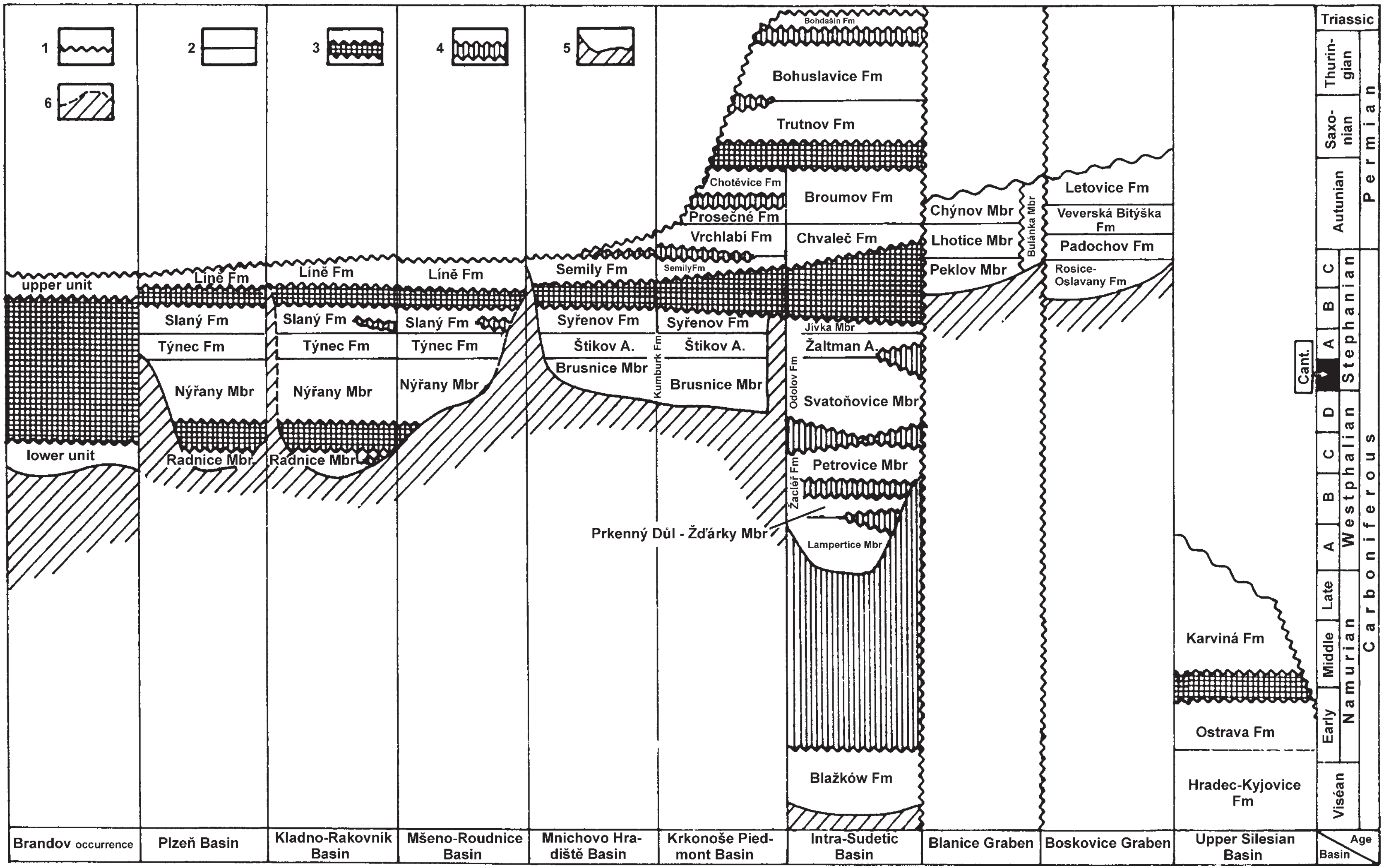

Figure 1. Lithostratigraphic classification and correlation of Late Paleozoic and Triassic units in selected basins of the Czech Republic. J. Pešek et al. (2001), completed and modified.
1 – erosional limit of the unit, 2–4 boundaries of lithostratigraphic units: 2 – conventional, 3–4 hiatus: 3 – regionally significant, 4 – local; 5 – boundary between the Late Paleozoic and Late Proterozoic–Early Paleozoic basement, 6 – as above, for part of the basin (indicates the gradual extension of sediments in time and space), Westphalian: A – Langsettian, B – Duckmantian, C – Bolsovian, Stephanian A: Barruelian.

the footwall of the Prokop Seam. A prominent change in the composition of the floral assemblage is also evidenced by the palynological studies of P. Valterová (in Dopita et al. 1997). A sudden change in the coal-petrographic composition of seams, represented by a marked increase in the proportion of inertinite at the base of the Saddle Member, was also observed by Malán (1966). Signs of this regionally important hiatus also include the abundant occurrences of coal clasts from eroded seams of the Ostrava Formation, especially in the Saddle Member of the Karviná Formation (e.g. Kožušníková et al. 1999; Martinec and Kožušníková 2002).

A break in deposition at this level is also suggested from the Polish part of the Upper Silesian Basin. Deposition of the areally restricted Jejkowice Member is assumed to be part of this interval by only a few Polish geologists (Zdanowski and Żakowa 1995). An interruption in the stratal succession at the same level, i.e. between the Early and Middle Namurian, has been reported by Dęmbowski and Porzycki (1988) from the Lublin Basin and from the same level of the Polish part of the Intra-Sudetic Basin (Walter et al. 2001).

An analogous, considerably longer, though local break in deposition probably also occurred in the Czech part of the Intra-Sudetic Basin. Such a break is documented by a hiatus between the Blażkow Formation (Late Viséan or Early Namurian) and the Žacléř Formation (Late Namurian to Bolsovian = Westphalian C). Sediments of the Wałbrzych Formation were deposited on the Polish side at that time. This hiatus was followed by a change in the configuration of the basin, resulting in a prominent enlargement of the depositional area and a change in the character of the sedimentary fill (onset of coal-bearing units in the Czech territory). A brief interruption between the Biały Kamień and Žacléř Formations has been reported by Walter et al. (2001) from the Polish part of the Intra-Sudetic Basin.

A break in deposition between the Early and Late Namurian, or Langsettian, has been described by Wills (1956) from several British basins (Figs 3 and 4). It has been reported also from some basins in the Cantabrian Mts. from NW Spain (Wagner 1970). Most of the Namurian is absent also in the Saar Basin (Littke et al. 1995).

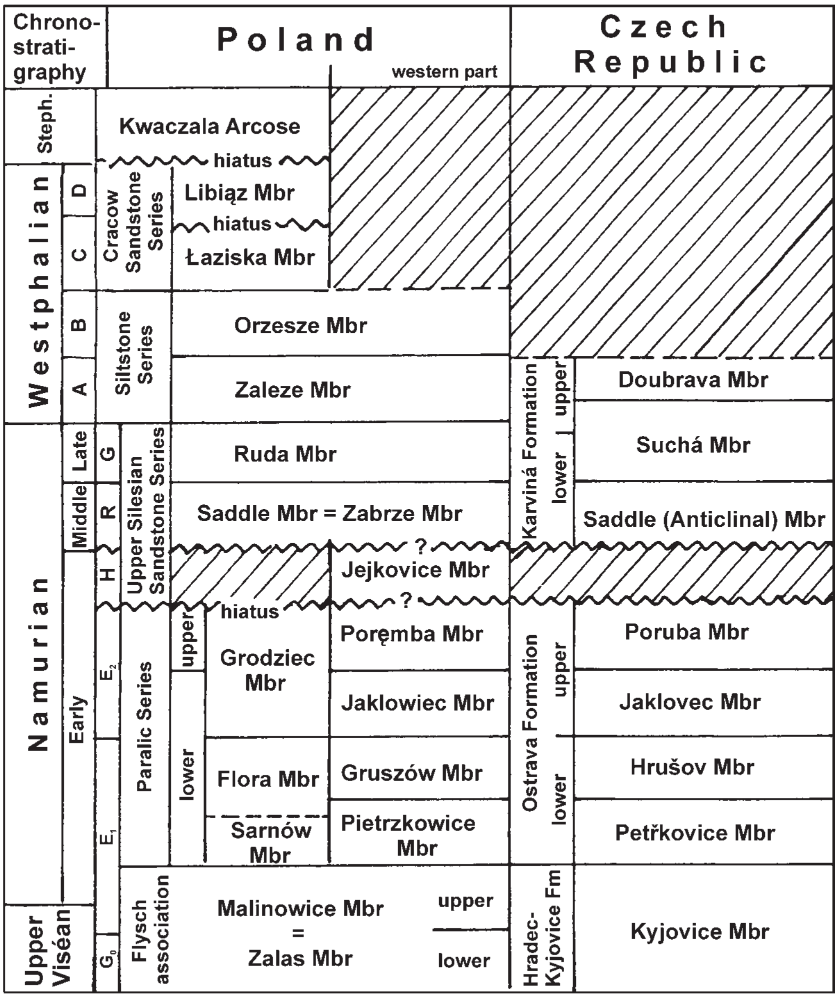

Figure 2. Lithostratigraphic classification of the Carboniferous sediments in the Czech and Polish parts of the Upper Silesian Basin. Dopita et al. (1997), completed and modified.

Westphalian hiatuses

Shorter depositional breaks in the Duckmantian (i.e. Westphalian B), connected with the prominent rejuvenation of relief in the area of the Intra-Sudetic Basin, may be associated with distinct erosional boundaries between the Lampertice and Prkenný Důl-Žďárky members and the Prkenný Důl-Žďárky and Petrovice members of the Žacléř Formation. A marked enlargement of the Prkenný Důl-Žďárky Member and its transgression over the crystalline basement is particularly conspicuous.

In Slovakia, sediments of mostly marine origin were deposited in the northern Gemericum in the Langsettian, after a hiatus between the Early Namurian and Langsettian during which the pre-Westphalian sediments were folded (Vozárová and Vozár 1988). The break in deposition between the Langsettian and Duckmantian has been reported from a number of basins in the Cantabrian Mts. (Moore et al. 1971) and from the Saar Basin (Littke et al. 1995). A hiatus has also been noted from the Duckmantian of the Asturian Basin (Moore et al. 1971). The unconformable resting of Westphalian D on Namurian limestones has been documented in NW Spain by Wagner (1970).

A marked enlargement of the depositional area at the expense of source areas occurred at the Duckmantian/Bolsovian boundary, or in the Early Bolsovian when Late Carboniferous sedimentation began in the Brandov occurrence (Krušné hory Mts.) and in western and cen-

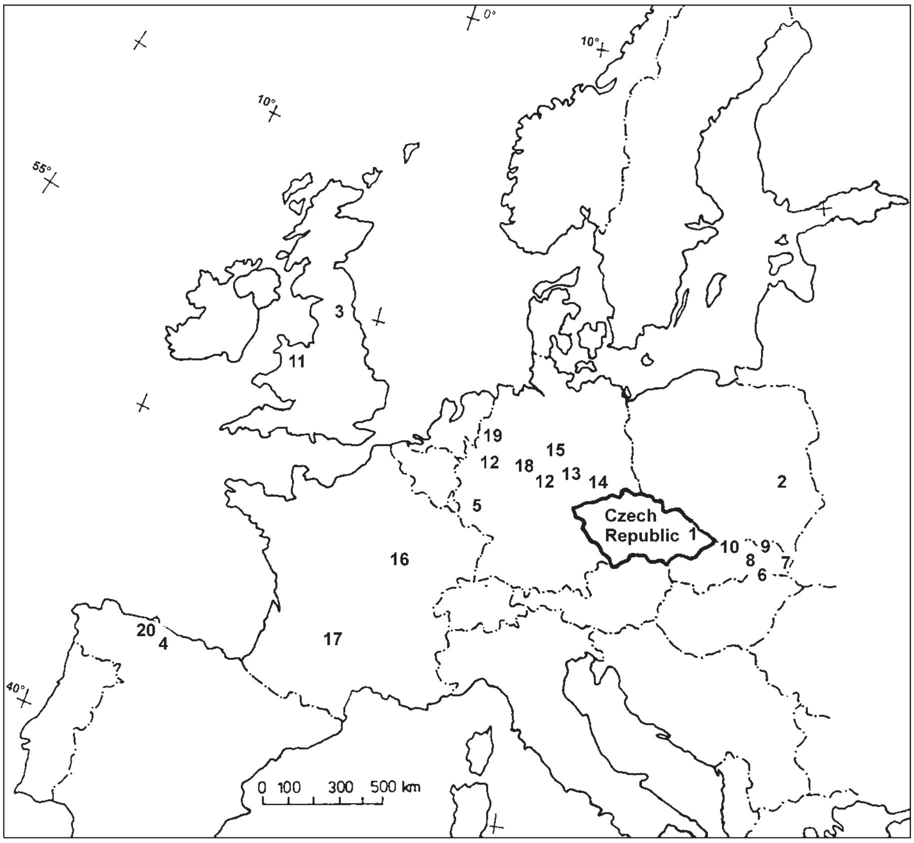

Figure 3. Location of basins and structural-tectonic units mentioned in the text.
1–3 basins: 1 – Upper Silesian, 2 – Lublin, 3 – Northumberland-Durham, 4 – Cantabrian Mts., 5 – Saar Basin, 6 – Gemericum, 7 – Zemplinicum, 8 – Veporicum, 9 – Hronicum, 10 – Tatricum, 11–14 basins: 11 – North Stafford, 12 – Ruhr, 13 – Hainichen-Borna, 14 – Krušné hory Mts., 15 – Harz Mts., 16–17 basins: 16 – Autun-Épinac, 17 – Decazeville, 18 – Thüringer Wald, 19 – Ibbenbüren, 20 – Asturian Basin .

tral Bohemia. Continental clastic sediments, mostly coal-bearing, began to be deposited in the Plzeň, Radnice, and Kladno-Rakovník basins (Pešek et al. 1998).

At about the same level, a major change in the character of sedimentary fill occurred in basins of the West European foredeep, stretching from northern France, across Belgium and the Netherlands, into Germany. The last marine sediments were deposited at the Duckmantian/Bolsovian boundary. From this time on, these basins were filled only with continental clastic sediments. With only one exception (North Stafford Basin – Havlena 1965) a similar change also occurred in all basins in Great Britain. A hiatus between Duckmantian and Westphalian D deposits has been described from part of the Ruhr Basin (Teichmüller 1962) associated with folding of the pre-Late Westphalian fill, a shift of the deposition towards the north, and with the transgression of Westphalian D on rocks of various ages.

A locally developed hiatus between the Lower and Upper Radnice members (Bolsovian) is documented by erosion of the Main Kladno (= Upper Radnice) Seam in several mines in the Kladno-Rakovník Basin (Fig. 5).

Westphalian sedimentation was interrupted by another hiatus of regional significance, which is observed not only in the central and western Bohemian Late Paleozoic basins, but also in the Intra-Sudetic Basin. This hiatus lies at the Early(?) Bolsovian / Late(?) Westphalian D boundary, i.e. at the boundary between the Radnice and Nýřany members (e.g. Frič 1883, Purkyně 1913, Čepek 1926, Němejc 1932). It is also evidenced by the erosion of the Upper Radnice Seam in several mines in the Plzeň Basin (see Figs 21 to 25 in Pešek 1978), and by the erosion of part of the succession of the Upper Radnice Member as documented in several deep boreholes (Fig. 6) in the Kladno area (cf. also Havlena and Pešek 1980). Equally significant is the change in the composition of macro- and microflora of the Radnice and Nýřany members (e.g. Šimůnek et al. in Pešek et al. 2001). The existence of this hiatus is also indicated by other lines of evidence. In basins where the Radnice Member had already been deposited, the Nýřany Member marked a prominent enlargement of the depositional area (cf. Appendices Nos. 34 and 35 in Pešek et al. 1998). Moreover, sedimentation in several other basins of central and western Bohemia started with this unit of Westphalian D to Cantabrian age: in the Manětín Basin, and in most of the Žihle and Mšeno-Roudnice basins. NW-SE elongated depressions, often rapidly subsiding, developed during the hiatus or soon after the onset of sedimentation of the Nýřany Member. The Central Bohemian Pluton probably became exposed to the surface and functioned as a major source of medium- and coarse-grained clastic material, especially for the central Bohemian Carboniferous (Pešek 1996).

The break in deposition between the Bolsovian and Westphalian D has also been reported from the Czech part of the Intra-Sudetic Basin, where the existence of a hiatus is documented by kaolinization of the Křenov rhyolite tuffs and by the presence of rock pebbles of the Petrovice Member near the base of the Odolov Formation (Tásler et al. 1979, Spudil and Tásler in Pešek et al. 2001). The above mentioned phenomena are related to the spread of deposition to the west of the Intra-Sudetic Basin, i.e. to the onset of deposition in the Krkonoše Piedmont Basin and probably also in the Mnichovo Hradiště Basin. Late Westphalian sediments either covered a major part of the two basins or filled only local depressions in the basin floor. The central Bohemian–Sudetic complex of basins was established either in Westphalian D or in the Early Stephanian. These basins formed an arc open to the south, which Havlena and Pešek (1980) interpreted as the first response of continental sedimentation to the Variscan arc structure in the Bohemian Massif (Fig. 7).

The existence of a local hiatus between the Bolsovian and Westphalian D in Poland was documented by the occurrence of petromictic conglomerates NE of the Wałbrzych Formation, and/or by the overlap of a unit considered to be an equivalent of the Svatoňovice Member over the latter (Havlena 1965). A hiatus from about the same level has been described from a number of neighbouring basins. In the Polish part of the Upper Silesian Basin a hiatus (see Fig. 2) has been documented between the Łaziska and Libiąz members (e.g. Zdanowski and Żakowa 1995).

A break in the deposition between the lower (Westphalian) and upper (Stephanian C or even Permian) units has been reported from the Late Paleozoic occurrence near Brandov (e.g. Purkyně 1930; Spudil in Pešek et al. 2001).

A hiatus at the Bolsovian/Westphalian D boundary, during which the pre-Late Westphalian fill was folded, has been described from an areally limited basin in the Borna and Hainichen area of Germany. This break was followed by the spread of deposition on the northern (Saxonian) side of the Krušné hory (Erzgebirge) Mts., and formation of the so-called Krušné hory basins (e.g. Daber et al. 1968). Sediment deposition in the Hronicum in Slovakia started during Westphalian D or even in Late Stephanian (Vozárová and Vozár 1988).

Stephanian hiatuses

A hiatus immediately following the Nýřany Member (Westphalian D to Cantabrian) in central and western Bohemia was contemplated by Wagner (1977). The same author placed the subsequent unit (Týnec Formation), mostly considered Barruelian (i.e. Stephanian A) in age, to the Late Stephanian B. This solitary opinion was opposed by Holub (1977). Boundary beds between these two units are exposed in the Plzeň area in a relatively long outcrop series between Plzeň and Radčice. No marked erosion or weathering effects in rocks on top of the Nýřany Member have been registered at this outcrop or in the more than 100 boreholes to the basement documented by the present author from the 1960s to the 1990s.

A break in the deposition at the Westphalian/Stephanian boundary has been documented, for example, in the Saar Basin in Germany (Littke et al. 1995). A similar hiatus has been reported at places such as the eastern margin of the Harz Mts. (Daber et al. 1968), the Polish part of the Upper Silesian Basin (Dopita et al. 1997), and the Asturian Basin in Spain (Wagner 1963). Truncation of Westphalian D and an unconformity at the base of the overlying Autunian have been confirmed in the NW part of the Zwickau-Oelsnitz Basin in the Krušné hory Mts. (Pietzsch 1962). In Slovakia, several basins were formed in the Zemplinicum and southern Veporicum in the Cantabrian (Vozárová and Vozár 1988). The Early or Middle Stephanian also marks the onset of sedimentation in most of the basins in central France (Vetter 1968).

A short, local break in deposition can be inferred at places in the Slaný Formation (Stephanian B), between the

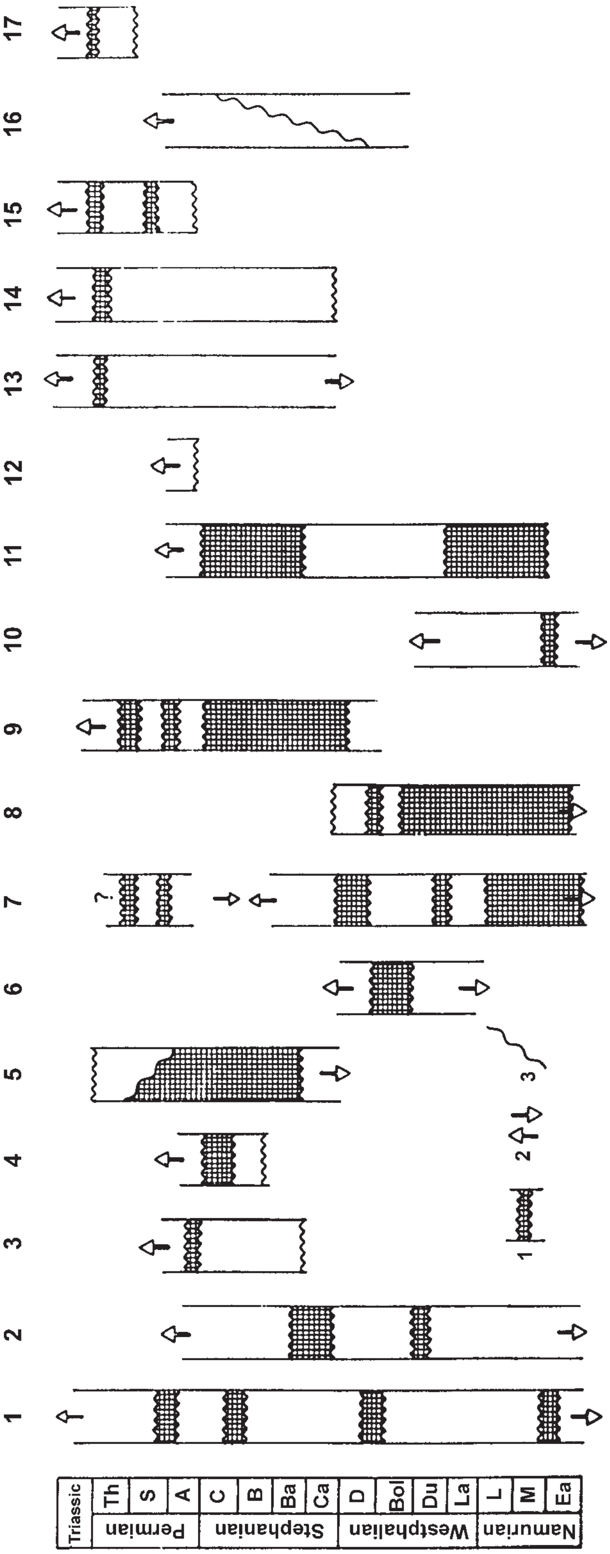

Figure 4. Important hiatuses in the Late Carboniferous and Permian deposits of the Bohemian Massif and in basins and structural-tectonic units mentioned in the text.
1 – break in deposits, 2 – deposits continue either up or down, 3 – erosional boundary. Numbers above the columns: 1 – basins of the Bohemian Massif, 2–10 basins: 2 – Asturian, 3 – Decazeville, 4 – Autun-Épinac, 5 – Ems, 6 – Ruhr, 7 – Saar, 8 – Borna-Hainichen, 9 – Krušné hory (Erzgebirge), 10 – Lublin, 11–17 structural-tectonic units: 11 – North Gemericum, 12 – South Gemericum, 13 – Zemplinicum, 14 – South Veporicum, 15 – North Veporicum, 16 – Hronicum, 17 – Tatricum.

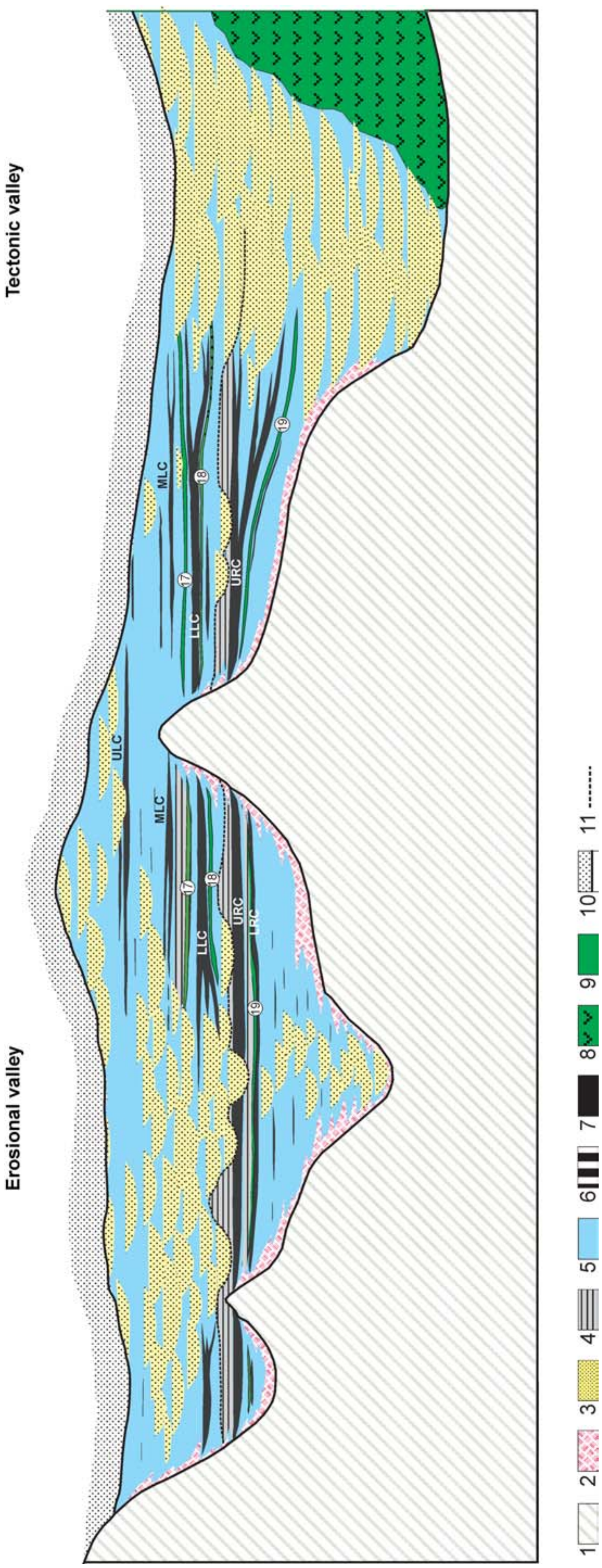

Figure 5. Schematic cross section of the Radnice Member in the Kladno-Rakovník Basin, implying the synsedimentary wedging-out of seams of the Lubná Group of Seams, and erosion of the Upper Radnice (Main Kladno) Seam. S. Opluštil (2000).
1 – basement, 2 – colluvial sediments, 3 – fluvial channel sediments, 4 – lacustrine and lacustrine deltaic sediments, 5 – flood plain clastics, 6 – carbonaceous shales, 7 – coal seams, 8 – rhyolite, 9 – tuffs and tuffites, 10 – base of the Nýřany Member, 11 – base of the Upper Radnice Member.
Coal seams: 12 – ULC: Upper Lubná Seam, 13 – MLC: Middle Lubná Seam, 14 – LLC: Lower Lubná Seam, 15 – URC: Upper Radnice Seam, 16 – LRC: Lower Radnice Seam, 17 – Upper volcanic horizon, 18 – Middle volcanic horizon, 19 – Lower (Whetstone) volcanic horizon.

Malesice and Ledce members, as documented by the weathering of pyrite concretions from cores at the top of the former unit in central Bohemia and occasionally also in western Bohemia.

An exceptionally significant break in deposition occurred in all Bohemian Late Paleozoic basins between Stephanian B and C. This intra-Stephanian hiatus has been supported by a number of observations, including the occurrence of weathering products on top of the Slaný and Syřenov formations in deep boreholes drilled in the Mšeno-Roudnice and Krkonoše Piedmont basins. It is also evinced by the erosion of part of the Slaný Formation (eastern Mšeno-Roudnice Basin) and most of the coeval Syřenov Formation in the Mnichovo Hradiště and Krkonoše Piedmont basins (cf. Fig. 19 in Havlena and Pešek 1980), and of the Jívka Member in the Intra-Sudetic Basin. The existence of a hiatus at this level in the Polish part of the basin has been documented by Sawicki (1995). Fluvial paleochannels (Fig. 8) filled with Late Stephanian clastics have been found at this level in the Mšeno-Roudnice Basin (Skopec et al. 2000). During the intra-Stephanian hiatus, the axes of maximum subsidence in the central Bohemian basins and in the Krkonoše Piedmont Basin shifted to the north (Pešek 1994). A transgression of the Líně Formation across the basement has been reported, e.g. from the northern part of the Kladno-Rakovník Basin.

Sedimentation in the Brandov occurrence in the Krušné hory Mts. was probably also reactivated after this time interval. Sediments of the so-called upper unit (Stephanian C?), the rocks of which are sometimes attributed to the Autunian age, were deposited there (Spudil in Pešek et al. 2001).

Significant changes also occurred in the source areas. Stephanian C marked the onset of sedimentation on a limited area. This occurred not only in the markedly elongated basins, mostly called furrows in the Czech literature (Blanice and Boskovice grabens), but also in the Česká Kamenice Basin, among others (Holub in Pešek et al. 2001). In Stephanian C and likely in the Autunian time, Late Paleozoic sediments and volcanics probably reached their maximum areal extent in the Bohemian Massif (see Appendix 38 in Pešek et al. 1998).

The hiatus between Stephanian B and Autunian has been reported from the Autun-Épinac Basin, and that between Stephanian C and Autunian also from the Decazeville Basin in central France (Vetter 1968). An angular unconformity within Stephanian B, or a transgression of units of this age and Stephanian C age across rocks of different ages, has been documented by Wagner (1970) from a number of basins in the Cantabrian Mountains and their foothills. In Late Stephanian, deposition of sediments also started in the southern Gemericum of Slovakia (Vozárová and Vozár 1988).

Autunian hiatuses

A more extensive, though local hiatus known from the southern segment of the Krkonoše Piedmont Basin is placed to the boundary between Stephanian C and Autunian. The basal sandstones of the Vrchlabí Formation (Autunian) truncate the deposits of the Semily Formation (Stephanian C), locally even down to the level of the Ploužnice Horizon (Prouza and Tásler in Pešek et al. 2001). No such situation has been observed in other Bohemian basins. A break in deposition has also been reported from the Autunian of the Krkonoše Piedmont Basin between the Prosečné and Chotěvice formations. Much like the previously mentioned hiatus, this break also does not have a basin-wide extent (Prouza and Tásler in Pešek et al. 2001). The Autunian also marks a prominent spread of the area of deposition, especially in the Blanice and Boskovice grabens (Holub, Jaroš, and Malý in Pešek et al. 2001). This was probably also the period of incipient filling of the Orlice Basin (Pešek et al. 1998).

In Slovakia, Autunian sedimentation starts in the northern Veporicum. In addition, sediments were deposited in the northern Gemericum after a hiatus between the Cantabrian and Late Stephanian (Vozárová and Vozár 1988).

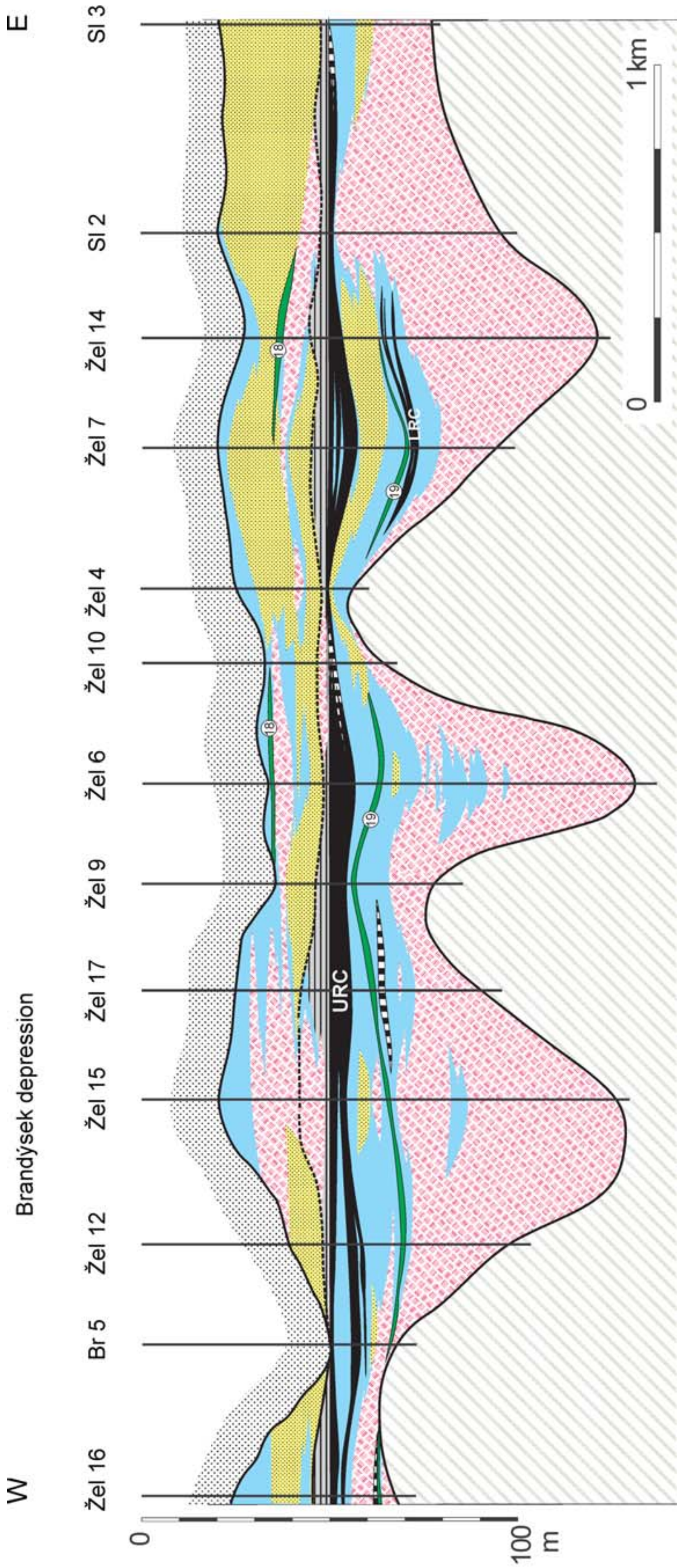

Figure 6. A cross section of the Brandýsek depression in the eastern part of the Kladno-Rakovník Basin. It implies the erosion of the Radnice Member (Bolsovian) down to the level of the Radnice Group of Seams and unconformable resting of the Nýřany Member (Westphalian D). Opluštil (2000). For explanations see Fig. 5.

A regionally significant break in deposition has been confirmed in the Krkonoše Piedmont Basin, and in the Polish and Czech parts of the Intra-Sudetic Basin. In these bas-

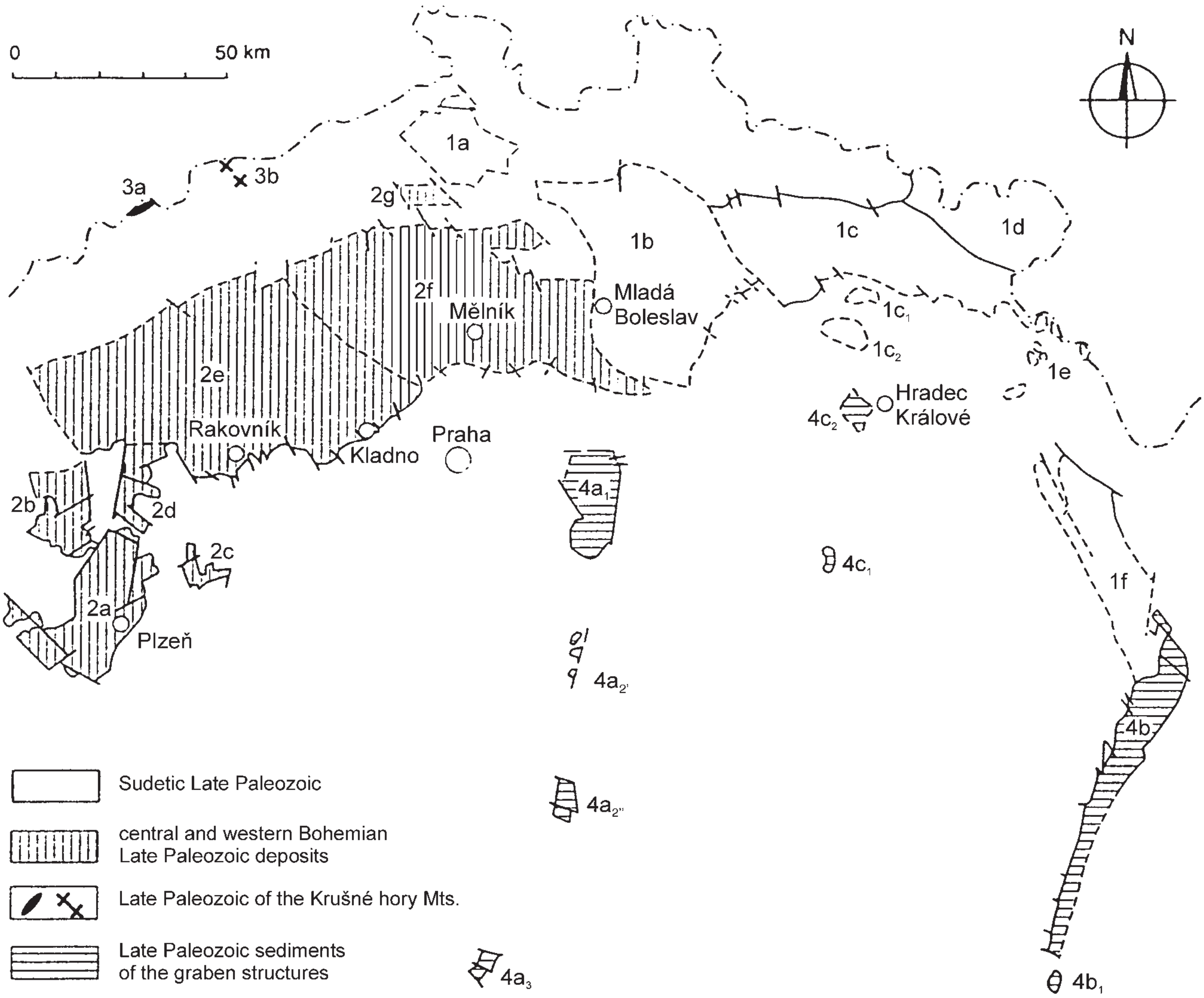

Figure 7. Late Carboniferous and Permian continental deposits of the Bohemian Massif. From Chlupáč and Štorch (1992), modified.
1 – Sudetic Late Paleozoic: 1a – Česká Kamenice Basin, 1b – Mnichovo Hradiště Basin, 1c – Krkonoše Piedmont Basin [occurrence near Zvičina ($1c_1$) and at the Hořice elevation ($1c_2$)], 1d – Intra-Sudetic Basin (Czech part), 1e – Permian in the Orlické hory Mts., 1f – Orlice Basin, 2 – central and western Bohemian Late Paleozoic basins: 2a – Plzeň, 2b – Manětín, 2c – Radnice, 2d – Žihle, 2e – Kladno–Rakovník Basin, 2f – Mšeno–Roudnice Basin, 2g – Kravaře occurrence, 3 – Late Paleozoic of the Krušné hory Mts.: 3a – Brandov occurrence, 3b – Mikulov occurrences, 4 – Late Paleozoic sediments of the graben structures: 4a – Blanice Graben: $4a_1$ – northern section (Český Brod area), $4a_2$ – central section: $4a_{2'}$ – Vlašim occurrence, $4a_{2''}$ – Tábor occurrence, $4a_3$ – southern section (České Budějovice area), 4b – Boskovice Graben, $4b_1$ – Miroslav occurrence, 4c – Jihlava Graben: $4c_1$ – Železné hory Mts. occurrence, $4c_2$ – Hradec Králové occurrence.

ins, the Trutnov Formation (Saxonian) and its Polish equivalent overlie, with a distinct angular unconformity, sediments of the Broumov and Słupiec formations (Autunian) in Poland, older units in the Intra-Sudetic Basin, and various Autunian formations in the Krkonoše Piedmont Basin. The Trutnov Formation, however, locally transgresses over the crystalline basement. Basal sediments of this unit evidence a prominent rejuvenation of the source areas (Prouza and Tásler in Pešek et al. 2001).

In Slovakia, a short break in deposition occurred in the northern Veporicum between the Autunian and Saxonian. At the same time, deposition of a siliciclastic complex started in the Tatricum (Vozárová and Vozár 1988). The hiatus at the Autunian/Saxonian boundary has also been documented in most of the basins in Germany, i.e. in the Thüringer Wald, on the eastern margin of the Harz Mts., and in basins of the Krušné hory (Erzgebirge) Mts. (Katzung and Pfeiffer 1968). The Zechstein deposits transgress over the Stephanian W near the border between Germany and the Netherlands (e.g. Schuster 1962). Moreover, the unconformable resting of Zechstein or Rotliegend deposits on Westphalian D has been described from the Ems Basin by Fabian and Müller (1962). The unconformity between the Autunian and Saxonian has also been reported from most of the basins in central France and from NW Spain (Wagner 1970).

Hiatus at the Permian/Triassic boundary

Sediments of the Bohdašín Formation (Triassic) conformably overlie the Bohuslavice Formation (Thuringian?), though with a distinct erosional boundary. As the age of the two units has been relaibly paleontologically determined in neither the Intra-Sudetic Basin nor the Krkonoše Piedmont Basin, the exact position of this possible hiatus is merely speculative (Prouza and Tásler, Spudil and Tásler in Pešek et al. 2001).

In Slovakia, a break in deposition has been described in the Zemplinicum, southern and northern Veporicum, and in the Tatricum between Thuringian and Triassic deposits (Vozár and Vozárová 1988).

Hercynian orogeny and the effects of its phases in the Late Carboniferous and Permian in the Bohemian Massif

The Hercynian orogeny was subdivided by Frech (1905), Stille (1920, 1924), and Kosmatt (1927) into six phases, from the oldest Bretonian phase placed to the Devonian/Carboniferous boundary by Stille (1920), to the youngest Pfalzian phase (Tab. 1) at the Permian/Triassic boundary (Stille 1924). Stille recognized in the 1920s that the Variscan orogeny was almost a constant process, continuing without interruption. For this reason he subdivided the Bretonian phase into three subphases (age Upper Devonian to Mississippian – Lower Carboniferous), which were designated as Early Variscan folding by Stille (1927).

As for the Carboniferous in the Bohemian Massif, a more or less general agreement exists on the placement of the Sudetic phase *sensu* Frech (1905) to the Viséan/Namurian boundary (e.g. Buday et al. 1961; Dvořák and Růžička 1972; Petránek 1993), i.e. to the uppermost Viséan to Lower Namurian (e.g. Havlena 1964; Mišík et al. 1985). Marked differences exist in the understanding of the Erzgebirgian and Asturian phases. While Buday et al. (1961) and Petránek (1993) placed the Erzgebirgian phase to the Namurian/Westphalian boundary (similarly to Kossmat (1927)), Havlena (1964) placed this phase to the Middle to Late Namurian. Svoboda (1983) and Mišík et al. (1985) consider this phase to be Middle or Late Namurian to Langsettian in age. Even more disagreement exists in the conception of the Asturian phase. Svoboda (1983) placed this phase to the Westphalian/Stephanian boundary, in agreement with Stille (1924). Mišík et al. (1985) dated it to the Late Westphalian, or to the Westphalian/Stephanian boundary. Buday et al. (1961) ranked the Asturian phase to the Late Stephanian. In a completely different conceptualisation, Havlena (1964) subdivided the Asturian phase into Early Asturian (Langsettian to Duckmantian) and Late Asturian phases (Bolsovian to Barruelian). Moreover, Havlena (1964) also defined an Intra-Stephanian phase in Stephanian B and C, which has not been identified by other authors. The Saalic phase was placed to the Early/Late Rotliegend boundary, i.e. between the Autunian and Saxonian, by Stille (1920). It was understood similarly by Svoboda (1983) and Petránek (1993). Havlena (1964) and Mišík et al. (1985) dated the Saalic phase to the Autunian and Saxonian, while Buday et al. (1961) and Holub (in Pešek et al. 2001) suggested its Late Autunian age passing to the Autunian/Saxonian boundary. The effects of the Pfalzian phase were identified at the Permian/Triassic boundary by Stille (1924). This phase is understood similarly by Svoboda (1983) and Mišík et al. (1985). In contrast, this phase was placed to the Saxonian to Lower Triassic by Buday et al. (1961), to the Late Permian to Triassic by Havlena (1964), and to Late Thuringian by Petránek (1993).

Prominent breaks in the deposition in the Bohemian Massif occurred in the Upper Silesian Basin between the Lower and Middle Namurian, and especially in central and western Bohemia between Early (?) Bolsovian and Late (?) Westphalian D. The hiatus between Stephanian B and C is highly visible in all continental basins. The significant break between Autunian and Saxonian has been identified in the Intra-Sudetic and Krkonoše Piedmont basins. On the other hand, the hiatus between the Early(?) Bolsovian and

Table 1. Classification of phases of Hercynian orogeny in the Carboniferous and Permo-Triassic of the Bohemian Massif according to different authors, and their original dating according to Frech (1905), Stille (1920, 1924) and Kossmat (1927)

Phase	Dating (author)
Pfalzian	**Permian/Triassic boundary** (**Stille 1920**, Dvořák and Růžička 1972, Svoboda 1983, Mišík et al. 1985) **Late Rotliegend to Triassic** (Buday et al. 1961) **Late Thuringian** (Petránek 1993)
Saalic	**Early/Late Rotliegend boundary** = Autunian/Saxonian (**Stille 1920**), Dvořák and Růžička 1972, Svoboda 1983, Petránek 1993) **Autunian to Saxonian** (Havlena 1964, Mišík et al. 1985) **Late Autunian to the Autunian/Saxonian boundary** (Buday et al. 1961, Holub in Pešek et al. 2001)
Intra-Stephanian	**Stephanian B to C** (Havlena 1964)
Asturian	**Westphalian/Stephanian boundary** (**Stille 1924**, Dvořák and Růžička 1972, Petránek 1993) **Late Westphalian/Stephanian** (Mišík et al. 1985) Early Asturian: **Langsettian to Duckmantian**, Late Asturian: **Bolsovian to Barruelian** (Havlena 1964) Stephanian (Buday et al. 1961)
Erzgebirgian	**Namurian/Westphalian boundary** (**Kossmat 1927**, Buday et al. 1961, Petránek 1993) **Middle and Late Namurian** (Havlena 1964, Dvořák and Růžička 1972) **Middle Namurian to Westphalian** (Svoboda 1983) **Late Namurian to Early Westphalian** (Mišík et al. 1985)
Sudetic	**Viséan/Namurian boundary** (**Frech 1905**, Buday et al. 1964, Dvořák and Růžička 1972, Petránek 1993) **Late Viséan to Early Namurian** (Havlena 1964, Mišík et al. 1985)

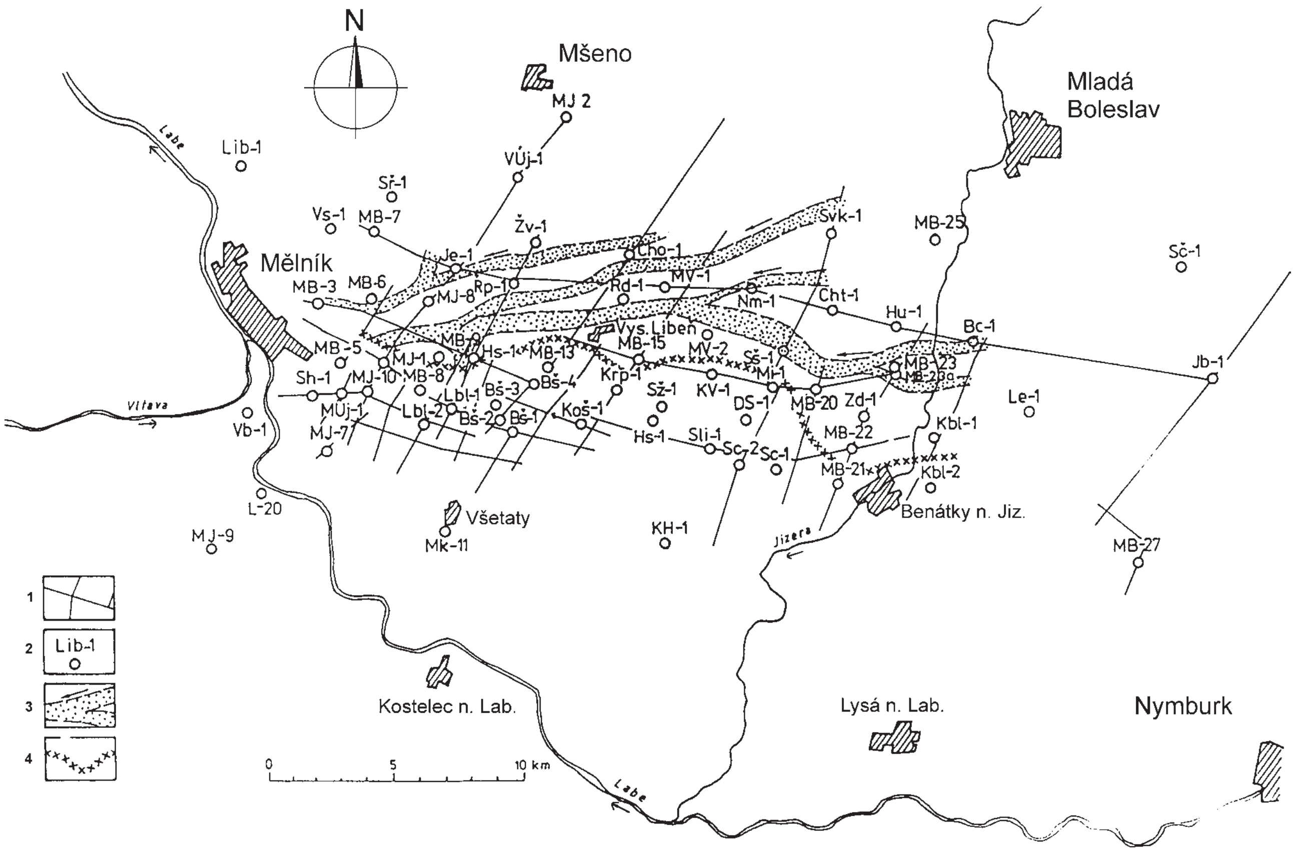

Figure 8. Schematic map of axes of fluvial channels at the top of the Slaný Formation (Stephanian B) in the Mšeno-Roudnice Basin. J. Skopec et al. (2000), completed and modified.
1 – seismic profile, 2 – borehole, 3 – presumed course of streams, 4 – southern limit of the Líně Formation (Stephanian C) at present.

Late (?) Westphalian D is rather of local significance in the Intra-Sudetic Basin. Other short-term interruptions in deposition are apparent from Table 1.

Considering, for example, that the most significant breaks in deposition in the Cantabrian Mts. (Wagner 1970) occurred in the Duckmantian (Palentian phase), in Upper Westphalian D (Leonian phase) and in the Barruelian (Asturian phase), it must be admitted that the Hercynian Orogeny within the present confines of Europe is not conceived uniformly. It seems to have been a period of ongoing unrest ranging from Late Devonian to the Permian/Triassic boundary, showing variable intensities in different areas and at different times (i.e. Stille 1951). This orogeny was locally manifested by intensive folding, such as in the Ruhr Basin (Teichmüller 1962) and in the basin near Borna and Hainichen in Germany (Katzung and Pfeiffer 1968), the pre-Late Westphalian fills of which were folded during a hiatus between the Duckmantian and Westphalian D, and between the Bolsovian and Westphalian D, respectively. By contrast, only the prominent brittle deformation of deposits or a hiatus occurred over larger or smaller areas of the Bohemian Massif (e.g. central and western Bohemia). The youngest folded sediments in the Bohemian Massif are Langsettian deposits in the Orlová structure (Havlena in Mísař et al. 1983). Other fold structures are understood as products of taphrogeny sensu Aubouin (1962).

Conclusions

Several breaks in deposition have been documented in the Late Paleozoic basins of the Czech Republic. They were formed mostly as the response of the more-or-less consolidated Bohemian Massif to the Hercynian orogeny. These breaks can be subdivided into the following categories according to their significance:

a) Hiatuses that can be documented in several basins in the Czech Republic and usually in other countries of Europe as well. These breaks in deposition generally led to major re-arrangements in the source areas. This category includes the depositional break at the Early/Middle Namurian boundary in the Upper Silesian and Lublin basins, and in many basins in Great Britain. This category of hiatus also includes the depositional break between the Early(?) Bolsovian and Late(?) Westphalian D known from the central and western Bohemian basins, the Intra-Sudetic Basin, and from the Polish part of the Upper Silesian Basin. Another break falling to this category is that between Stephanian B and C documented in central Bohemia and some of the Sudetic basins. Establishment of the graben-type basins and the formation of the Česká Kamenice Basin are placed to the same time interval. A major break in deposition from this period has also been reported from several basins in central France and a number of basins in NW

Spain. The depositional break from the Autunian/Saxonian boundary is also ranked to this category because of its significance; it has been documented from the Intra-Sudetic and Krkonoše Piedmont basins from most of the basins in Germany and central France, and from NW Spain.

b) Hiatuses that are present only in part of a particular basin, i.e. sharp boundaries between units. This category includes the depositional breaks between the Early and Late (?) Namurian in the Czech part of the Intra-Sudetic Basin, between the Lower and Upper Radnice members in the Kladno-Rakovník Basin (Bolsovian), between the Semily and Vrchlabí formations and the Prosečné and Chotěvice formations in the Krkonoše Piedmont Basin (Autunian), and the sharp boundary between the Bohdašín and Bohuslavice formations in the same basin and in the Intra-Sudetic Basin.

c) The depositional break between Westphalian D and Late Stephanian B remains problematic. The existence of this break was interpreted by Wagner (1977) as between the Nýřany Member and the Týnec Formation in central and western Bohemia.

Furthermore, the Hercynian orogeny should be understood as a period of major tectonic unrest ranging from the Late Devonian to the Early Triassic, showing variable intensity in different areas and periods. It caused intensive folding in some areas, and the mere brittle deformation of basin fill in other areas at the same time.

Acknowledgements. This study originated partly due to financial support from the Research Plan CEZ J 13/98: 113100006 and projects Nos. A3111103 and A3013903 of Grant Agency of the Academy of Sciences of the Czech Republic.

References

Aubouin J. (1962): Geosynclines. Elsevier, Amsterdam.

Buday T., Kodym O. st., Mahel' M., Máška M., Matějka A., Svoboda J., Zoubek V. (1961): Tektonický vývoj Československa. Nakl. Čs. akad. věd, Praha (in Czech).

Čepek L. (1926): Geologie jižní části plzeňské pánve kamenouhelné. Prometheus, Praha (French summary).

Chlupáč I., Štorch P. (Eds) (1992): Regionálně geologické členění Českého masívu na území České republiky. Čas. Mineral. Geol. 37, 257–275 (in Czech).

Daber R., Katzung G., Pfeiffer H. (1968): Siles. In: Grundriss der Geologie der Deutschen Demokratischen Republik. Akademie Verlag, Berlin, pp. 189–198.

Dęmbowski Z., Porzycki J. (Eds) (1988): Karbon lubelskiego zagłebia węglowego. Prace Inst. Geol. 122 (English and Russian summaries).

Dopita M. (1988): Sedlové vrstvy ostravsko-karvinského revíru. MS Vys. šk. báň. Ostrava (in Czech).

Dopita M., Aust J., Brieda J., Černý I., Dvořák P., Fialová V., Foldyna J., Grmela A., Grygar R., Hoch I., Honěk J., Kaštovský V., Konečný P., Kožušníková A., Krejčí B., Kumpera O., Martinec P., Merenda M., Müller K., Novotná E., Ptáček J., Purkyňová E., Řehoř F., Strakoš Z., Tomis L., Tomšík J., Valterová P., Vašíček Z., Vencl J, Žídková S. (1997): Geologie české části hornoslezské pánve. Min. živ. prostř., Praha (English summary).

Dvořák J., Růžička B. (1972): Geologická minulost země. St. Nakl. techn. lit. – ALFA, Praha, Bratislava (in Czech).

Fabian H. J., Müller G. (1962): Zur Petrographie und Alterstellung präsalinarer Sedimente zwischen der mittleren Weser und der Ems. Forschr. Geol. Rheinld. Westf. 3, 3, 1115–1140.

Frech F. (1905): Der Eifluss der geologischen Vorgeschichte auf die spätere Entwicklung. Geol. Zeitschr. 11, 4, 218–227.

Frič A. (1883): Fauna der Gaskohle und Kalksteine der Permformation Böhmens. I. Fr. Řivnáč, Prag.

Gothan V. (1913): Die oberschlesische Steinkohlenflora, I.T., Farne u. farnähliche Gewächse. Abh. Preuss. Geol. Landesanst., N. F. 56, 1–278.

Havlena V. (1964): Geologie uhelných ložisek 2. Nakl. Čs. akad. věd, Praha (in Czech).

Havlena V. (1965): Geologie uhelných ložisek 3. Nakl. Čs. akad. věd, Praha (in Czech).

Havlena V., Pešek J. (1980): Stratigrafie, paleogeografie a základní strukturní členění limnického permokarbonu Čech a Moravy. Sbor. Příroda 34, Západočes. Muz. Plzeň (English summary).

Holub V. M. (1977): Discussion to the article: Wagner R.H.: Comments on the Upper Westphalian and Stephanian floras of Czechoslovakia, with particular reference to their stratigraphic age. In: Holub V. M., Wagner R. H. Symposium on Carboniferous Stratigraphy. Ústř. úst. geol., Praha, 445–457.

Jackson J. A. (ed.) (1997): Glossary of geology. American Geological Institute, Alexandria.

Katzung G., Pfeiffer H. (1968): Der Rotliegendes. In: Grundriss der Geologie der Deutschen Demokratischen Republik, Akademie Verlag, Berlin, 189–198.

Kossmat F. (1927): Gliederung des variszischen Gebirgsbaues. Abh. Sachs. Geol. L.-A. 1, 1–39.

Kožušníková A., Martinec P., Pešek J., Valterová P. (1999): Coal clasts in the Carboniferous sediments of the Upper Silesian basin. Bull. Czech Geol. Surv. 74, 109–114.

Littke R., Buker C., Hertle M., Karg H., Stroetman-Heinen V., Oncken O. (1995): Heat flow evolution, subsidence and erosion in Rhens-Hercinian orogenic wedge of central Europe. In: Franke W. et al. (Eds) Orogenic process: Quantification and modeling in the Variscan belt. Geol. Soc. Spec. Publ. 179, 231–255.

Malán O. (1966): Výskyt pyritu a inertinitu v OKR a možnosti jejich využití pro korelaci a identifikaci slojí. Uhlí 14, 6–9 (in Czech).

Martinec P., Kožušníková A. (2002): Uhelné klasty ve svrchnokarbonských sedimentech české části hornoslezské pánve – prostředí, rychlost transportu, alterace a diagenetická historie v sedimentu. Documenta Geonica 2002, 167–176 (in Czech).

Mísař Z., Dudek A., Havlena V., Weiss J. (1983): Geologie ČSSR I. Český masiv. Stát. Pedagog. Nakl., Praha (in Czech)

Mišík M., Chlupáč I., Cicha I. (1985): Stratigrafická a historická geológia. Slov. Pedagog. Nakl., Bratislava (in Slovak).

Moore R. L., Neves R., Wagner R. H., Wagner-Gentis C. H. T. (1971): The stratigraphy of Namurian and Westphalian rocks in the Villamanin area of Northern León, N.W. Spain. Trabajos Geol. 3, 307–363.

Němejc F. (1932): Stratigrafické výzkumy konané z hlediska paleobotanického v uhelných revírech jižní části plzeňské kamenouhelné pánve v letech 1928–1932. Horn. Věst., 14–33, 417–421, 450–453, 483–485, 500–503 (in Czech).

Opluštil S. (2000): Radnické vrstvy kladenské části kladensko-rakovnické pánve. Unpublished Report Přírod. fak. UK, Praha. (in Czech)

Pešek J. (1978): Erosion and clastic dikes in coal seams of the Central Bohemian Basins and their significance for determination of plant substance coalification. Folia Mus. Rer. Natur. Bohem. Occident. 12, 1–34.

Pešek J. (1994): Carboniferous of central and western Bohemia (Czech Republic). Czech Geol. Surv. Prague.

Pešek J. (1996): Geologie pánví středočeské svrchnopaleozoické oblasti. Český geologický ústav, Praha (in Czech).

Pešek J., Holub V., Jaroš J., Malý L., Martínek K., Prouza V., Spudil J., Tásler R. (2001): Geologie a ložiska svrchnopaleozoických limnických pánví České Republiky. Czech Geol. Surv. Prague.

Pešek J., Opluštil S., Kumpera O., Holub V., Skoček V. (1998): Paleogeographic Atlas, Late Paleozoic and Triassic formations, Czech Republic. Czech Geol. Surv., Prague.

Petránek J. (1993): Malá encyklopedie geologie. JIH, České Budějovice (in Czech).

Pietzsch K. (1962): Abriss der Geologie von Sachsen. Deutsche Verlag Wissensch. Berlin.

Purkyně C. (1913): Geologie okresu Plzeňského. Okresní výbor v Plzni, 1–127 (in Czech).

Purkyně C. (1930): Brandovská kamenouhelná (antracitová) pánev v Rudohoří. 1. část geologická. Čes. Akad. Věd Umění, II., Palaeontogr. Bohemiae 14., 5–29 (in Czech).

Purkyňová E. (1976): Makrofloristická korelace svrchnonamurských vrstev v podbeskydské pánvi (hornoslezská pánev). Čas. Slez. Mus., A 25, 185–189 (English summary).

Purkyňová E. (1977): Namurian flora of the Moravian part of the Upper Silesian coal basin. In: Holub V. M., Wagner R. H. Symposium on Carboniferous Strafigraphy, Ústř. úst. geol. Praha, 289–303.

Sawicki L. (1995): Geological map of Lower Silesia with adjacent Czech and German territories 1 : 100 000. Panstw. Inst. Geol. Warszawa, 1–64.

Schuster A. (1962): Das Stefan in der Bohrung Wielen 1. Fortschr. Geol. Rheinl. Westf. 3, 3, 1097–1108.

Skopec J., Pešek J., Kobr M. (2000): Fosilní říční síť na svrchu slánského souvrství v mšensko-roudnické pánvi. Uhlí Rudy Geol. Průzk. 5, 3–11 (English summary).

Stille H. (1920): Ueber Alter und Art der Phasen variszischer Gebirgsbildung. Nachr. Ges. Wiss. Goettingen math.-phys. Kl., 218–224.

Stille H. (1924): Grundfragen der vergleichenden Tektonik. Borntraeger, Berlin.

Stille H. (1927): Die oberkarbonisch-altdyadischen Sedimentationsräumen Mitteleuropas in ihrer Abhängigkeit von der variscischer Tektonik. In: Congr. Stratigr. Carbon. (Heerlen 1927), Liège, 697–730.

Stille H. (1951): Recent deformations of the Earth's crust in the light of those of earlier epochs. Geol. Soc. Spec. Pap. 62, 171–191.

Svoboda J., ed. (1983): Encyklopedický slovník geologických věd, 1 a 2. Academia, Praha (in Czech).

Tásler R., Čadková Z., Dvořák J., Fediuk F., Chaloupský J., Jetel J., Kaiserová-Kalibová M., Prouza V., Schovánková-Hrdličková D., Středa J., Střída M., Šetlík J. (1979): Geologie české části vnitrosudetské pánve. Ústř. úst. geol. (English summary).

Teichmüller R. (1962): Entwicklung der subvariscischen Saumsenke nach dem derzeitigen stand unserer Kenntnis. Forschr. Geol. Rheinld. Westf. 3, 3, 1237–1254.

Vetter P. (1968): Géologie et paléontologie des bassins houillers de Decazeville, de Figeac et du Détroit de Rodez, T 1. Aurillac.

Vozárová A., Vozár J. (1988): Late Paleozoic in West Carpathians. Geol. úst. D. Štúra, Bratislava.

Wagner R. H. (1963): A general account of the Paleozoic rocks between the rivers Porma and Bernesga (León, NW Spain). Bol. Inst. Geol. Min. Espagna 74, 171–331.

Wagner R. H. (1970): An outline of the Carboniferous stratigraphy of Northwest Spain. Colloque sur la Stratigraphie du Carbonifére, Liège, 429–463.

Wagner R. H. (1977): Comments on the Upper Westphalian and Stephanian floras of Czechoslovakia, with particular reference to their stratigraphic age. In: Holub V. M., Wagner R. H. Symposium on Carboniferous Stratigraphy, Ústř. úst. geol. Praha. 441–455.

Walter H., Prouza V., Cymerman Z., Kozdrój W. (2001): Upper Carboniferous-Lower Permian. In: Kozdrój W., Krentz O., Opletal M. (eds) Comments on the geological map Lausitz-Jizera-Karkonosze (without Cenozoic sediments) 1 : 100 000. Sächsische Landesamt, Państwowy Institut Geologiczny, Český geologický ústav, Freiberg, Warszawa, Praha, 35–39.

Wills L. J. (1956): Concealed coalfieldes. Blackie & Sons, Ltd., London, Glasgow.

Zdanowski A., Żakowa H. (1995): The Carboniferous System in Poland. Prace Państw. Inst. Geol. 148, 1–215.