Stratigraphy, palaeoclimatology and palaeogeography of the Late Palaeozoic continental deposits in the Czech Republic

Stanislav OPLUŠTIL
Department of Geology and Palaeontology, Faculty of Science,
Charles University, Albertov 6,
128 43 Praha 2 (Czech Republic)
oplustil@mail.natur.cuni.cz

Jiří PEŠEK
Department of Geology and Palaeontology, Faculty of Science,
Charles University, Albertov 6,
128 43 Praha 2 (Czech Republic)

343
IUGS UNESCO IGCP

Opluštil S. & Pešek J. 1998. — Stratigraphy, palaeoclimatology and palaeogeography of the Late Palaeozoic continental deposits in the Czech Republic, *in* Crasquin-Soleau S., Izart A., Vaslet D. & De Wever P. (eds), Peri-Tethys: stratigraphic correlations 2, *Geodiversitas* 20 (4) : 597-620.

ABSTRACT
Numerous Late Palaeozoic continental basins were formed within the territory of the Czech Republic. Their sedimentary history began either in the Westphalian (central and western Bohemia, Brandov Basin and basins in Sudetic area) or in the late Stephanian (Blanice and Boskovice Grabens). The incompleteness of the floral record gives an evidence for several hiatuses the most important of which are those between the Bolsovian and Westphalian D and between the Stephanian B and C. During the deposition, an increase in sedimentary area, structural reworking and also considerable changes in source areas took place.

KEY WORDS
Peri-Tethys
Bohemian Massif,
Late Carboniferous,
Westphalian,
Stephanian,
Autunian,
continental basins,
palaeogeography.

RÉSUMÉ
La stratigraphie, la paléoclimatologie et la paléogéographie des dépôts continentaux du Paléozoïque supérieur de Bohème (République Tchèque). De nombreux bassins continentaux d'âge paléozoïque supérieur se sont formés sur le territoire de la République Tchèque. Leur histoire commence soit dans le Westphalien (Bohème centrale et occidentale, bassins de Brandov et des Sudètes) soit dans le Stéphanien supérieur (grabens de Blanice et de Boskovice). On n'y trouve pas toutes les biozones de paléoflore, ce qui montre la présence de plusieurs hiatus, dont les plus importants sont ceux entre le Bolsovien et le Westphalien D et entre le Stéphanien B et C. Pendant le dépôt, on note une augmentation de l'aire de sédimentation et du remaniement structural et aussi des changements considérables dans les sources d'apport.

MOTS CLÉS
Péri-Téthys
massif bohémien,
Carbonifère supérieur,
Westphalien,
Stéphanien,
Autunien,
bassins continentaux,
paléogéographie.

INTRODUCTION

Czech Republic (CR) occupies a relatively small area of Europe. Geological units are among the best explored areas of the European Variscides. During the Late Palaeozoic time, marine followed by paralic and continental sediments were deposited. Analysis of their spatial and temporal distribution should allow a better definition of the Early Carboniferous-Late Triassic interval which is critical for better understanding of the dynamic evolution of this part of Europe.
Sedimentation in some Late Palaeozoic basins is preceded by the Late Devonian sedimentation. Gradual consolidation of the Variscides during the middle Namurian to Triassic, characterized by general thickening of crustal granite layer of the Bohemian Massif (BM), resulted in an equalization of strongly imbalanced heat and strain conditions. Such consolidation followed by the development of further ocean basins in broader vicinity of the massif led to its collapse which resulted in the development of numerous grabens and horsts and also in splitting the plate along strike-slip faults. These Late Carboniferous and Permian processes initiated the origin, rapid development and relatively short existence of various types of basins (Figs 1-3). In this manner the mostly postcollisional intramontane basins of the Bohemian Massif became a trap for dominantly detrital material. The intramontane sedimentary basins (Fig. 3) grew larger during the late Westphalian time following an intra-Westphalian hiatus, however, the oldest continental deposits are of the late Visean and Namurian age. Formerly isolated depressions were interconnected and formed larger basins (Fig. 7). The sedimentation was interrupted several times. The hiatus approximately between the Stephanian B and C (*e.g.* Late Stephanian, Doubinger *et al.* 1995) was associated with changes in both the existing basins and in the source areas. These changes resulted in structural reconstruction of the central and western Bohemian basins, an increase in the area of sedimentation in central and western Bohemia and interrupted sedimentation in the eastern part of the Krkonoše-piedmont Basin as well as in the Intra-Sudetic Basin and elsewhere. In the source areas, new basins in the form of grabens were established (*e.g.* Blanice and Boskovice Grabens). Other important changes are connected with the Saalic phase of the Variscan orogeny. During the Saxonian to Triassic, these processes resulted in considerable and rapid subsidence in filled basins and in reduction of the sedimentation domain in which detrital material was brought in from gradually eroded and peneplained source areas (today's absence of sediments except the Lugicum, *i.e.* Sudetic basins). The deposition of the Variscan continental molasse within the Bohemian Massif ceased during the Triassic. These sediments cover only a negligible part of the area. The ideas mentioned in this paper are supported by recently compiled palaeogeographical maps (Figs 4, 6, 8) which represent an integral part of the Atlas of the Permo-Carboniferous of the Bohemian Massif (Pešek *et al.* 1998).

VOLCANISM

Considerable mobility of basinal basements as well as movements along the regional and local faults resulted in volcanic activitiy which accompanied sedimentary processes. Several volcanic cycles are represented by acid, intermediate and basic volcanism. The earliest Middle Devonian to early Westphalian cycle (Přichystal 1993) is supposed to reflect the onset of the Brunovistulicum (south-western projection of the Baltica terraine) subduction underneath the central part of the Bohemian Massif. This cycle gradually ceased in the late Namurian and early Westphalian (Kumpera & Martinec 1995). Another cycle is related to the Duckmantian/Bolsovian to early Stephanian interval. It is characterised by abundant acid volcanism the early products of which filled the central and western Bohemian basins. This cycle proves the drift of volcanic centers from Moravia into the western, central and NE Bohemia. The final volcanic cycle coincides with the late Stephanian and Autunian when extensive intermediate to basic effusive bodies originated in central and NE Bohemia. Products of acid volcanism are also abundant but considerably thinner (Pešek & Tásler 1979).

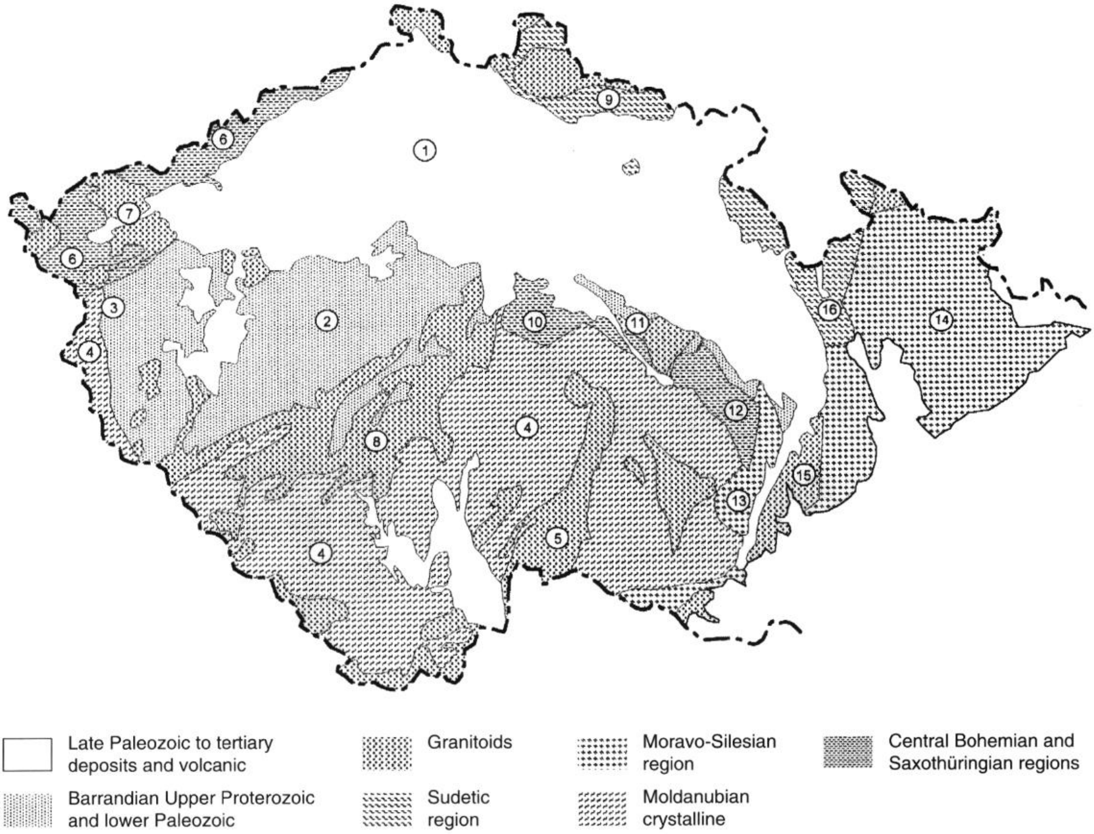


FIG. 1. — Crystalline rock units and the pre-Variscan Palaeozoic formations of the Bohemian Massif. Chlupáč-Vrána eds (1994), simplified. **1**, Late Palaeozoic to Tertiary deposits; **2**, Barrandian Upper Proterozoic and Lower Palaeozoic; **3**, Teplá Crystalline; **4**, Moldanubian Crystalline Complex; **5**, Moldanubian Pluton; **6**, Krušné hory Mts. Crystalline Complex; **7**, Krušné hory Pluton; **8**, Central Bohemian Pluton; **9**, Krkonoše-Jizera Crystalline Complex; **10**, Kutná Hora Crystalline; **11**, Železné hory Mts.; **12**, Svratka Crystalline; **13**, Moravicum; **14**, Silesicum and Moravo-Silesian Palaeozoic; **15**, Brunovistulicum; **16**, East Sudetes region (crystalline units).

CLIMATE

It is generally accepted that the climate during the Late Carboniferous and particularly during the Permian became warmer and consequently drier (Parrish 1995). However, various climatic conditions dominated in the different parts of the newly consolidated supercontinent Pangea, depending on latitude, altitude, topography and the position within the continent (Ruddiman & Kutzbach 1991; Ziegler 1990). Palaeomagnetic measurements (e.g. Krs & Pruner 1995) provide an evidence that the Bohemian Massif was situated between 4° and 6° N during the Late Palaeozoic. Since the middle Namurian it occupied interior position at a distance of several hundred kilometres from the northern coast of the Tethys (Scotese & McKerrow 1990). The Late Palaeozoic continental deposits of the Bohemian Massif exhibit several trends valid at least for the whole Variscan Europe: a decreasing in coal content since the Late Westphalian to the Permian and increasing abundance in the occurrence of red bed deposits. Stephanian sediments are typical by the alternation of thick grey and red units while during the Permian, mostly primary red beds were deposited. Similar alternation reported by Rowley *et al.* (1985) in the United States, is ascribed to variation in intensity of monsoons. Monsoons are proposed in various climatic models for the low latitude regions of the Pangea adjacent to the Tethys (Crowley *et al.* 1989; Kutzbach & Gallimore 1989; Nairn & Smithwick 1976; Parrish & Peterson 1988; etc.). It is expected that the monsoonal circulation with wet summers and dry winters began in the Latest Carboniferous and probably unevenly increased up to its maximum during the Triassic (Parrish *et al.* 1986). Similar conclusion was arrived at by Ziegler (1990) who studied a phytogeographic pattern of the Permian. The oldest evidence of the seasonal climate in the Late Palaeozoic continental deposits of the Bohemian Massif is represented by the laminated lake deposits of the Stephanian B age (lower part of the Forezian, Doubinger *et al.* 1995) covering an extensive area of several thousand square kilometres. Lamination consists of typical dark-light couplets reflecting seasonal variation in organic content (Skoček 1990). Similar lamination occurs in the Autunian deposits of the Rudnik Horizon in the Krkonoše-piedmont Basin as reported by Blecha *et al.* (1997), who also detected cyclic variations in boron content in lake deposits of another Autunian horizon. The origin of cycles may have been related to high frequency climatic changes with a periodicity of thousand or even tens of thousand years. Moreover, the occurrence of evaporites (Prouza *et al.* 1977) and the elevated contents of boron in the Late Palaeozoic sediments of the Bohemian Massif also argue for dry climatic conditions (Bouška & Pešek 1985).

In contrast, Becq-Giraudon & Van den Drissche (1994) proposed periglacial conditions at the altitude of nearly 5000 m for the deposition in Stephano-Permian basins of the Massif central. These authors give sedimentological and floristical evidences enhanced by geotectonic arguments.

Late Palaeozoic continental basins of the Bohemian Massif and the Massif central show the same geotectonic position, latitude, and in many cases comparable tectono-sedimentary history. Despite this, there has not been found any evidence for such a high relief or temperate climate in the Bohemian Massif during this period yet. Floristic records from Bohemia only confirm a rapid decrease in lycopsids plants at the end of the Westphalian and increasing frequency of Walchia during the Stephanian. As a whole, the Bohemian late Westphalian to Autunian floras are rich in species, most of which being known from NW Spain and other, formerly paralic basins of NW Germany, Belgium and N France.

BEGINNING OF THE LATE PALAEOZOIC CONTINENTAL DEPOSITION IN THE BOHEMIAN MASSIF

The oldest Carboniferous continental sediments of the Bohemian Massif are known from the Intra-Sudetic Basin, where purely continental conditions were established after a marine regression in the late Visean. First coarse grained sediments were deposited as alluvial fans in piedmont setting (Blazskow Conglomerates). They grade into marshy-fluvial, partly coal-bearing Walbrzych (Waldenburg) Formation of the early Namurian age. Above, they pass into fluvial deposits (Bialy Kamien Member). These sediments are known mainly from the Polish part of the Basin. In the Czech territory, sedimentation of the Žacléř Formation began around the Namurian/Westphalian boundary after an episodic Visean deposition of the Blazskow Conglomerates. Its lower part, the Lampertice Member consists of coal-bearing fluvial cycles with conglomerates at the base. This unit has yielded rich flora referring to the Langsettian (Westphalian A) age. *Neuralethopteris schlehanii* (Stur) and *Lonchopteris conjugata* (Goeppert) dominate, while *Lonchopteris rugosa* Brongniart, typical for Duckmantian (Westphalian B), is still missing (Kotasowa & Migier 1995; Šetlík 1977). Sediments of the Lampertice Member pass into the Doly Žd'árky Member of the Duckmantian (Westphalian B) age either continuously or after a short hiatus at SW margin. In the Late Silesian Basin, the non-marine deposition took place from the middle Namurian and with several hiatuses lasted until the Stephanian in the Polish part.

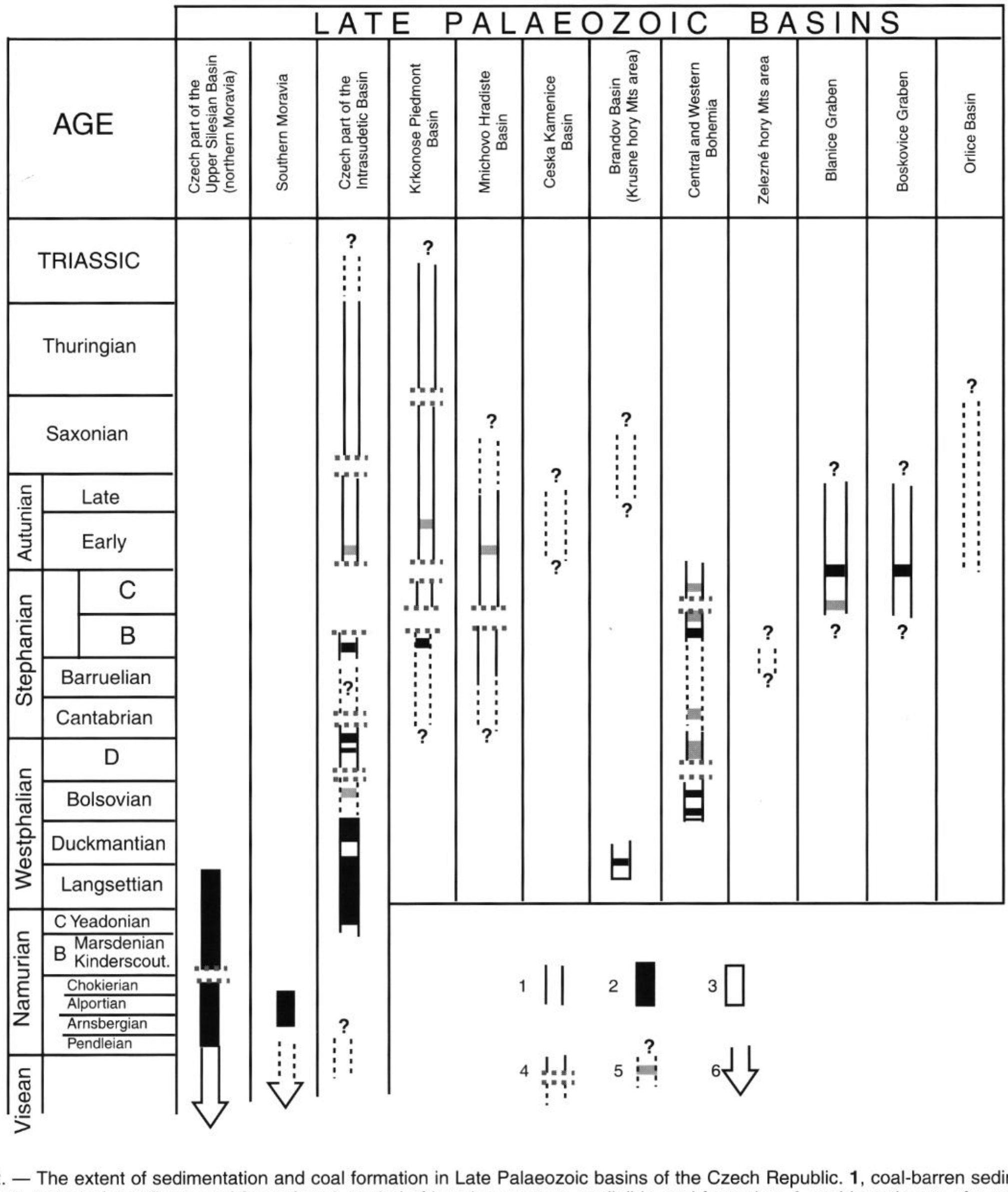


FIG. 2. — The extent of sedimentation and coal formation in Late Palaeozoic basins of the Czech Republic. **1**, coal-barren sedimentation; **2**, period of significant coal formation; **3**, period of less important to negligible coal formation; **4**, problematic age of a unit; **5**, break in sedimentation; **6**, the given interval preceded by an early sedimentation.

DUCKMANTIAN AND BOLSOVIAN (WESTPHALIAN B AND C)

Sediments of the unit studied were deposited in several isolated regions in the Intra-Sudetic Basin, Krušné hory Mountains and in the central and western Bohemia. It is supposed that sedimentation in the Czech part of the Late Silesian Basin continued at least till the Duckmantian. However, these youngest deposits have been later eroded.

Duckmantian and Bolsovian deposits in the

Intra-Sudetic Basin successively filled the basement depressions. The maximum subsidence shifted from the NW to the SE. Detrital material transported to the basin from the SW, W and SE, is represented by talus, alluvial fans and fluvial to fluviolacustrine deposits containing less coal than the overlying unit. The source area which supplied the Intra-Sudetic Basin with detrital material is thought to have had mountaineous relief as suggested by the occurrence of fanglomerates. The present distribution of Duckmantian and Bolsovian sediments seems to be similar to their original extent. Mechanical weathering is thought to have been the dominant process during the Duckmantian and Bolsovian (Tásler *et al.* 1979). Duckmantian and Bolsovian sedimentation was accompanied by gradually increasing volcanic activitity (Mašek 1973). The center of acid volcanism is believed to have been located in the vicinity of the Polish Walbrzych.

Duckmantian and Bolsovian sediments of the Brandov Basin in the Krušné hory Mountains (Fig. 9) were deposited in a narrow, NW-trending depression including Late Palaeozoic basins between the towns of Olbernhau and Flőha in the Flőha river valley, Germany. The SE alignment of these basins possibly trends farther to the Slaný-Třtěno depression marked by acid synchronous volcanism between Peruc and Třtěno in central Bohemia.

The Krušné hory Mountains Carboniferous sediments were deposited on a rugged basement of the Krušné hory crystalline complex (Fig. 1). Sporadic data indicate that the preserved detrital sediments containing abundant local material, were transported for a short distance in streams flanked occasionally by alluvial plains covered with vegetation.

Sediments of the Radnice Member were deposited in the central and western Bohemia (Fig. 5) on an alluvial plain during a period of higher mobility of the basin's basement and associated with extensive volcanic activity. These sediments initially filled two depositional centers which were later connected. The eastern depositional center includes approximately an area of the eastern part of the Kladno-Rakovník Basin including isolated small remnants to the S. The Rakovník, Radnice and Plzeň regions, including remnants in their southern and eastern vicinities, represent the western depositional center. The latter center is thought to have been drained toward the SW into Bavaria whereas the eastern center is believed to have been connected with the sea of the West European foredeep through the Krušné hory and Flőha Basins. The western depositional center might have been drained in this direction during deposition of the upper Radnice Member. Duckmantian and Bolsovian sediments originally did not cover the entire area of the central and western Bohemian basins. Low, NE-trending ridges of mostly Proterozoic basement served as a source of gravity-induced fanglomerates and short debris-flows.

The Late Carboniferous central and western Bohemian basins contain locally very coarse detrital sediments deposited by ephemeral streams. Large peat bogs were formed on broad alluvial plains during warm and humid climate. Coal-forming vegetation is thought to have rapidly expanded into abandoned meanders during stream migration. Numerous volcanic centers were formed in several basins and their broad vicinity.

A major N-S trending stream, parallel to the axis of the Plzeň Basin, transported detritus from the north where an extensive dry land existed during the Duckmantian and Bolsovian. This stream prevented coal formation during the deposition of the lower Radnice Member. At the same time similar stream flowed from Rakovník to Radnice. The fluvial deposition resulted in splitting of coal seams or in their absence in the broad vicinity of the above mentioned towns. Yet another major stream flowed from the SW into an intensively subsiding NW-SE trending depression between Slaný and Třtěno. This stream is assumed to have continued toward Brandov and further into Germany (see above).

Alluvial plain of the Radnice Member subsided along the central Bohemian deep-seated fault (Mísař *et al.* 1983) flanked probably by a zone of piedmont sedimentation. The main sourceland represented by the central Bohemian pluton is supposed to be located S of this fault. Local sourcelands were scattered throughout the alluvial plain. The source areas adjacent to the Carboniferous basins and the remaining area of

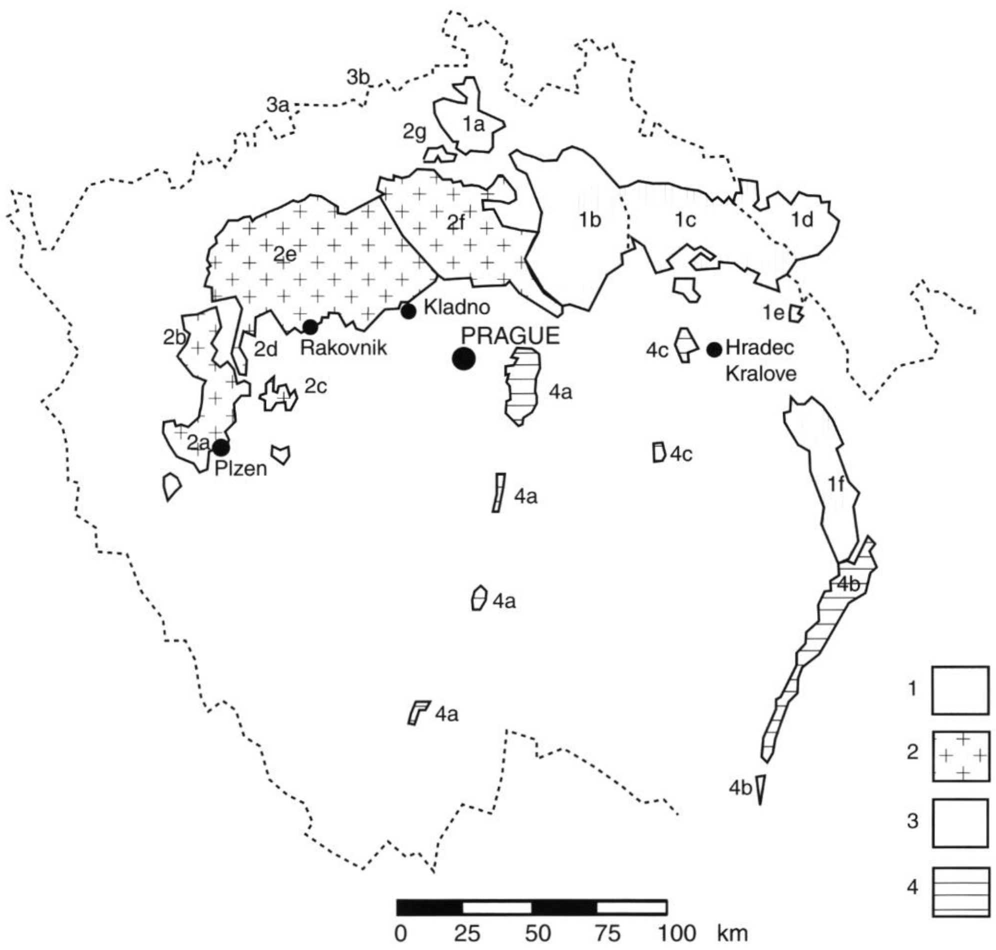


FIG. 3. — Late Carboniferous and Permian continental deposits of the Bohemian Massif. Chlupáč-Štorch eds (1992). **1**, Sudetic Late Palaeozoic: **1a**, Česká Kamenice Basin; **1b**, Mnichovo Hradiště Basin; **1c**, Krkonoše-piedmont Basin and occurrences near Zvičina and at the Hořice elevation; **1d**, Intra-Sudetic Basin (Czech part); **1e**, Permian formations in the Orlické hory Mountains; **1f**, Orlice Basin. **2**, central and western Bohemian Late Palaeozoic deposits: **2a**, Plzeň Basin; **2b**, Manětín Basin; **2c**, Radnice Basin; **2d**, Žihle Basin; **2e**, Kladno-Rakovník Basin; **2f**, Mšeno-Roudnice Basin; **2g**, Kravaře occurrence. **3**, Late Palaeozoic of the Krušné hory Mountains: **3a**, Brandov occurrence; **3b**, Mikulov occurrences. **4**, Late Palaeozoic sediments of the graben structures: **4a**, Blanice Graben (from north to south): Český Brod region, Vlašim occurrence, Tábor occurrence, České Budějovice region; **4b**, Boskovice Graben with Miroslav occurrence in south; **4c**, Jihlava Graben (Železné hory Mountains and Hradec Královė occurrences).

the Bohemian Massif are thought to have displayed deeply levelled mountain relief. Sedimentation in all basins took place in depressions between adjacent ridges that exercised considerable control upon sediment distribution. Thicker coal seams originated in their "sedimentary shadow" (Pešek 1968) being protected from considerable supply of detrital material.

The Duckmantian and Bolsovian sedimentation was accompanied by relatively abundant volcanic activity. Warm and humid climate was favourable to the formation and preservation of coal seams. Diversified Duckmantian and Bolsovian flora contains the following stratigraphically important species: *Sphenophyllum myriophyllum* Crépin, *Sphenophyllum cuneifolium* (Sternberg), *Lepidodendron simile* Kidston, *Laveineopteris loshi* (Brongniart) and *Laveineopteris tenuifolia*

(Schlotheim). On the other hand *Pecopteris penaeformis* (Brongniart) is a typical element of the Radnice Member. *Lonchopteris rugosa* Brongniart is common in the Doly Žd'árky Member but it is extremely rare in the lower part of the Radnice Member in central and western Bohemia. The presence of *Annularia sphenophylloides* (Zenker), *A. stellata* (Schlotheim) and *Sphenophyllum emarginatum* (Brongniart) is characteristic of the upper part of the Bolsovian succession in the Intra-Sudetic Basin (Petrovice Member) but these species are very rare in the Radnice Member. The total assemblage of the Radnice Member is indicative of either late Duckmantian or early Bolsovian (Wagner 1977). The age of the Doly Žd'árky Member is mostly Duckmantian, but flora in its upper part is very similar to that of the Radnice Member. However the following unit, the Petrovice Member, is already of the late Bolsovian age.

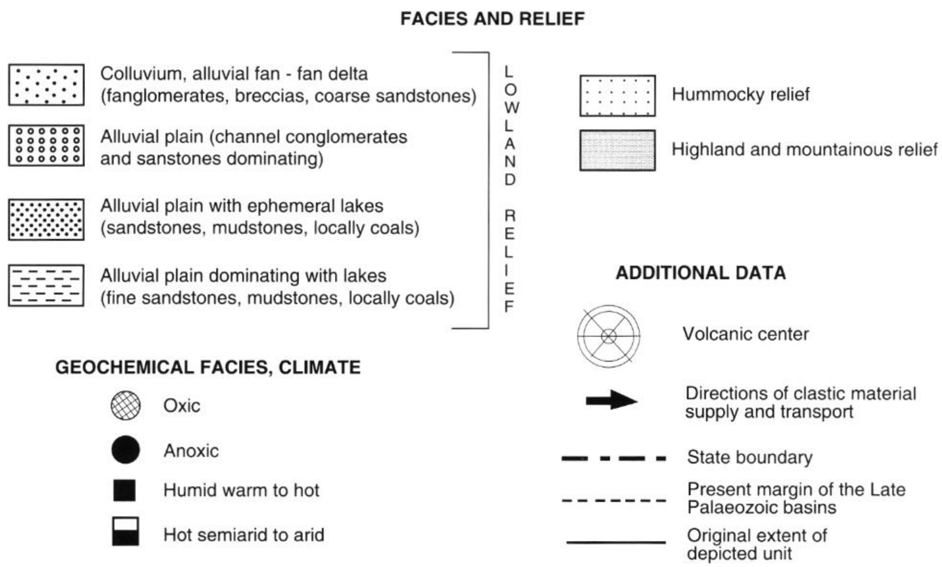
WESTPHALIAN D-CANTABRIAN

The facies pattern of this stratigraphical interval indicates a continuous sedimentary domain extending from the Manětín and Plzeň basins in the west as far as the Intra-Sudetic Basin in the east. This is in contrast to the earlier period when two separate sedimentary basins existed. Havlena & Pešek (1980) believe that the central Bohemian and Sudetic basins formed an arch open to the south at this time.

Westphalian D to Cantabrian sediments in limnic basins of the Bohemian Massif were deposited after a hiatus related to the Leonian phase defined in Northern Spain by Wagner (1965). According to Wagner (1977) differences in floristical assemblages between the Radnice and the lower part of the Nýřany Member provide good evidence of stratigraphical gap comprising the late Bolsovian and substantial part of the Westphalian D. Comparable stratigraphic gap occurs also in the Carboniferous sediments of the Late Silesian Coal Basin (Kotasowa & Migier 1995).

During the Westphalian D period, not only substantial increase in the area of sedimentation occurred but also additional NW-SE trending depressions formed. The extension of sedimentary basin further to the east and the marked increase in thickess of the Nýřany Member, compared to the Radnice Member are also due to Leonian orogenic phase.

Uneven subsidence of the basin's basement governed the pattern of detrital sedimentation at the onset of deposition of the Svatonovice



LEGEND (Figs 4, 6, 8)

Duckmantian and Bolsovian (Westphalian B and C)

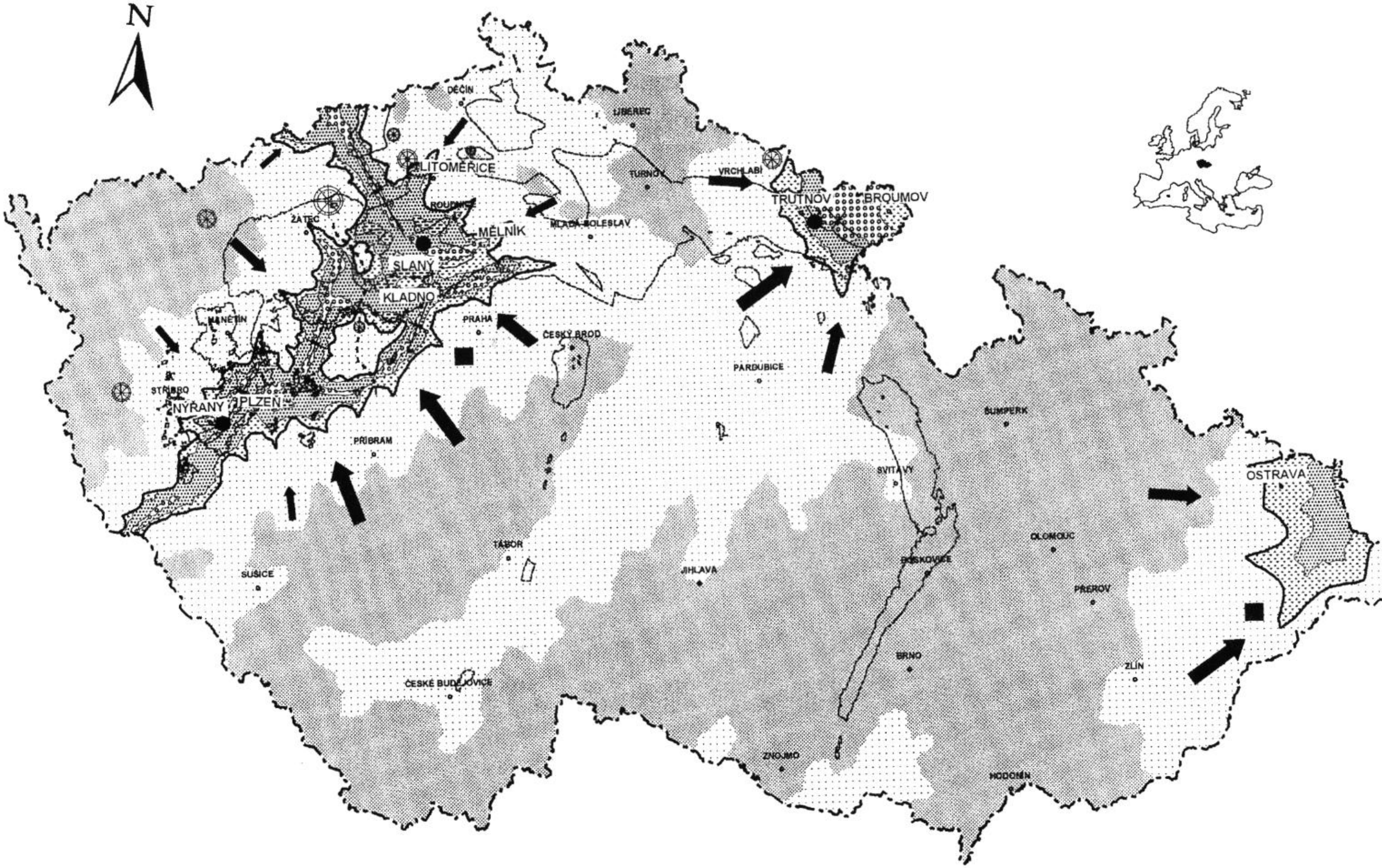


FIG. 4. — Palaeogeography of the Czech Republic during the Duckmantian and Bolsovian.

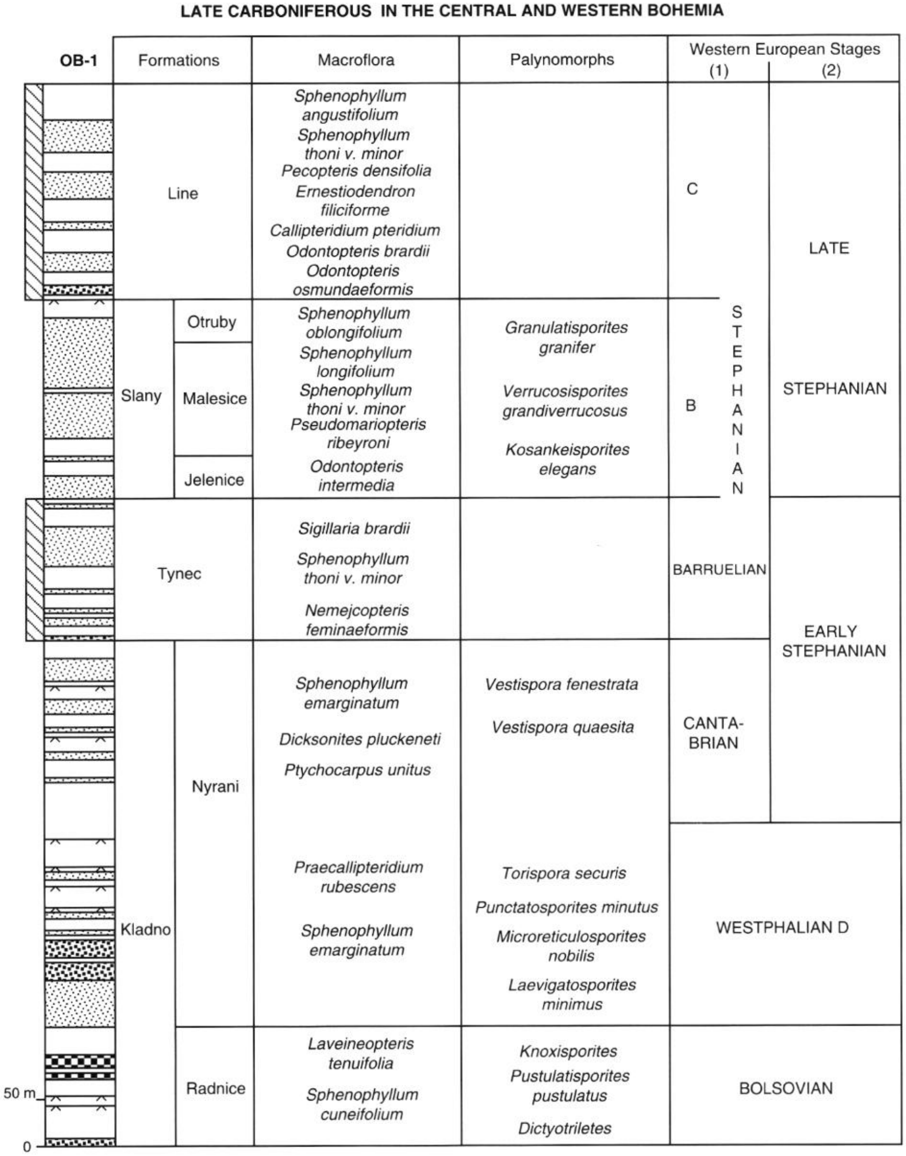


FIG. 5. — Lithology and biostratigraphy of the central and western Bohemian Late Palaeozoic deposits on an example of the borehole Ob1 (Otruby) in the eastern part of the Kladno-Rakovník Basin, Czech Republic, 14°06'E - 50°15'N. **1**, Opluštil & Pešek (this volume); **2**, Doubinger *et al.* 1995.

Member (Figs 7, 12) in the Intra-Sudetic Basin (Tásler *et al.* 1979). Deposition of this unit to the NW and SE of the south-western (*i.e.* Czech) flank of the basin started after a hiatus as evidenced by the kaolinization of rhyolite tuffs, by the redeposition of pebbles of the Petrovice Member to the NW, and by a considerable reduction of the thickness of the Svatoňovice Member to the

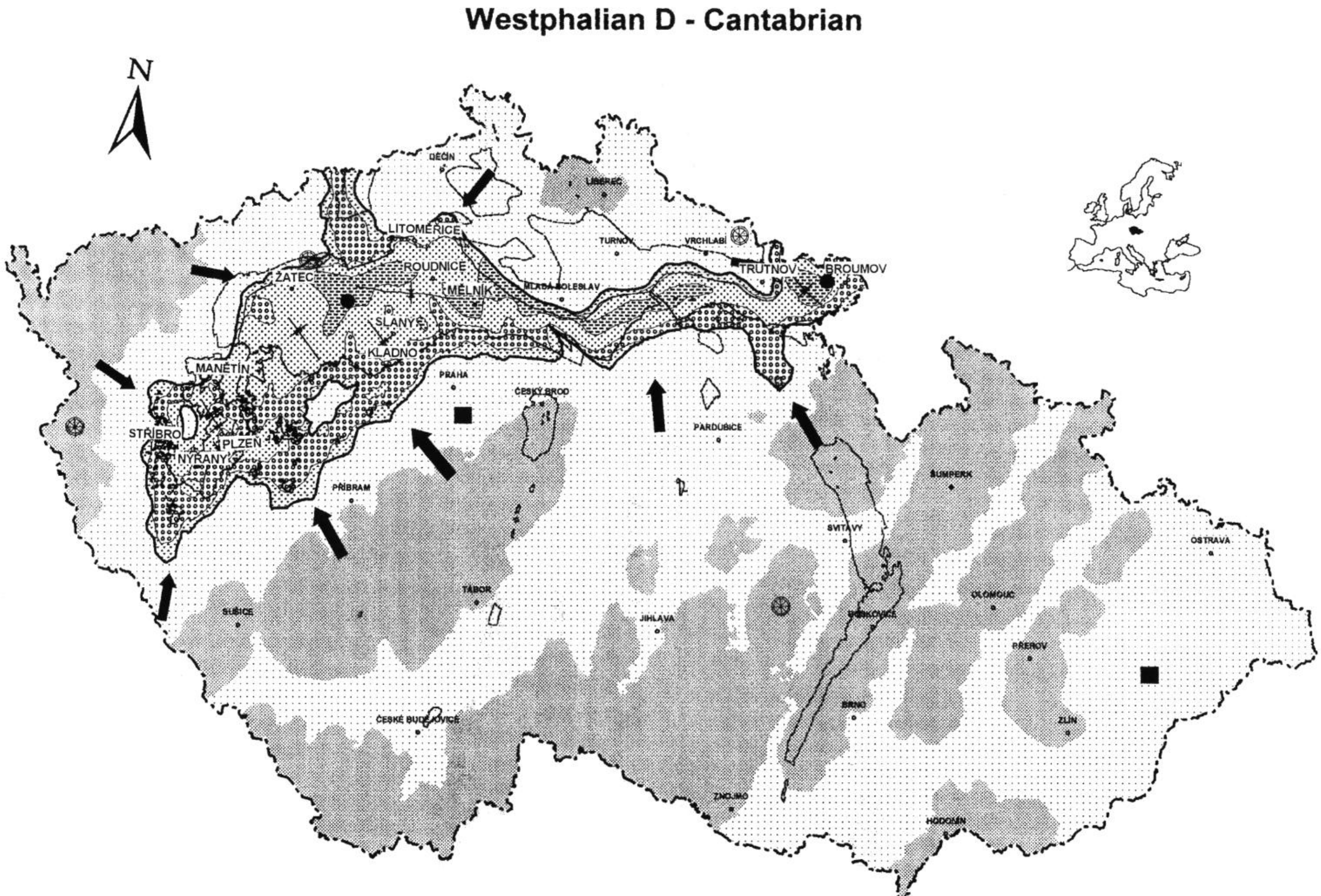


FIG. 6. — Palaeogeography of the Czech Republic during the Westphalian D - Cantabrian (see legend Fig. 4).

SE (Tásler *et al.* 1979). Compared with the Petrovice Member, the alluvial and alluvial-fan deposits are less abundant while the alluvial and intermittent lake fine-grained deposits are thicker. This resulted from higher morphological maturity of the source areas compared to the earlier period of the Petrovice Member deposition and to a decreased energy of streams. A major change took place in the lithological character of conglomerates, arkoses and sandstones. Pebbly and sandy clasts of the lower Svatoňovice Member, transported from the W (*i.e.* adjacent Krkonoše-Jizerské hory Mountains crystalline complex), were deposited in a much reduced basin surrounded by weathered and eroded areas. The sedimentation of the Svatoňovice Member was terminated by extrusion of low viscosity andesitic lavas forming laterally extensive but rather thin body. Deposition of lacustrine and fluvio-lacustrine sediments accompanied by periodic growth of peat followed this andesitic extrusion. Further deposition of the Svatoňovice Member extended over the pre-Carboniferous basement in the vicinity of Bernartice (NW part of the Intra-Sudetic Basin) and around Hronov (SE part). The filling of the Krkonoše-piedmont and Mnichovo Hradiště basins probably began at this time (Fig. 7).

The areal distribution of the Nýřany Member in central and western Bohemia is more extensive than that of the underlying Radnice Member. However, some low structural highs trending NE-SW locally and initially prevented the deposition of the Nýřany Member. Higher structural highs are thought to have existed only in the area of the Křivoklát-Rokycany Volcanic Complex and perhaps even south of the Manětín Basin. Changes in source areas and also in extent of sedimentary basins took place during the break in sedimentation. A system of NW-SE to NNW-SSE trending grabens and horsts was formed prior to, or at the same time as sedimentation of the Nýřany Member began. The earliest deposits of the Nýřany Member occur in the SE part of the Plzeň Basin, in the area of the River Ohře and in the Mirošov Carboniferous relic. Variegated detritus produced by weathering of the Late Proterozoic rocks in the west and the surficial detritus from granitoid massifs was transported into the basin. The size of sedimentary basin was rapidly enlarged and the upper part of the Nýřany Member covered much of the Mšeno-Roudnice Basin. Lithology of the Nýřany Member (Fig. 5) deposited on the alluvial plain varies considerably comparing with the Radnice Member sediments. Whereas in the western Bohemian basins fluvial deposits prevailed, the central Bohemian basins were partly dominated by lacustrine sediments deposited in several intermittent lakes elongated in the E-W direction and located in the central part of the region. Lacustrine sediments are flanked by alluvial fans toward the south and locally even toward the north. Low transporting competence of streams flowing into these lakes was controlled by the velocity and extent of flash floods. Coal seams originated between the channels and abandoned meanders, in intermittent lakes and marshes. Periodical influx of coarse detrital material considerably reduced the early formation of coal seams as peat bogs were not protected from the detrital material by elevations of crystalline basement as in the underlying unit (Pešek 1968). Sedimentation of the Nýřany Member was accompanied by weak, largely acid volcanics.

Detrital material was brought into the central and western Bohemian basins from sources in the S and SE (particularly from the central Bohemian pluton – see Kukal 1983; Pešek 1994). Some other granitic massifs also served as sources of weathered material. Material from weathered metamorphic complexes was washed into the basin, too.

The character and dynamics of the water regime in which these sediments were deposited is poorly understood. We are of the opinion that the central and western Bohemian Carboniferous basins may have been drained into Saxony, Federal Republic of Germany. However, hypothetical drainage in part of the central Bohemian basins through Sudetic basins into N Sudetic Basin in Poland cannot be excluded. The topography of the Bohemian Massif remained almost unchanged as compared with the deposition of the previous unit. Some levelling of the relief probably existed although local occurrences of coarse detritus are indicative of uplifted blocks yielding largely mechanically weathered material.

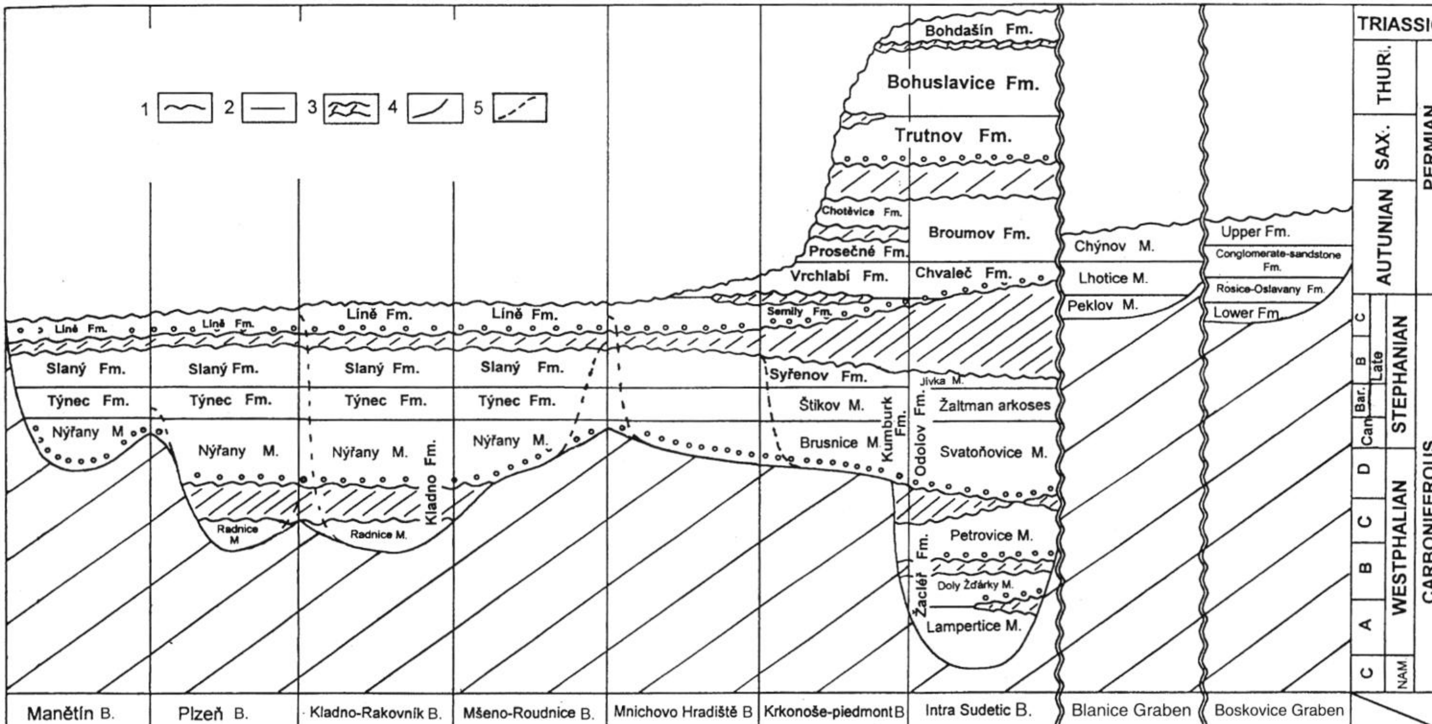
The deposition of Westphalian D-Cantabrian sequence took place under similar climatic and orogenic conditions as those prevailing during the underlying unit, *i.e.* under warm and humid climate which was favourable for the growth of rich vegetation. The Nýřany Member flora contains two successive assemblages (Šetlík 1977; Wagner 1977). The older one is of the late Westphalian D while the younger one, containing *Sphenophyllum oblongifolium* (Germar & Kaulfus) and *Pecopteris lepidorhachis* Brongniart refers to the Cantabrian. A little younger seems to be the flora of the Svatoňovice Member in the Intra-Sudetic Basin (Wagner 1977) which contains also *Praecallipteridium jongmansi* (Bertrand) and *Odontopteris cantabrica* Wagner.

THE STEPHANIAN IN THE LATE PALAEOZOIC BASINS OF THE CZECH REPUBLIC

It is generally accepted that the Late Palaeozoic continental basins of the Czech Republic contain sedimentary records comprising most of the Stephanian (Havlena 1974; Šetlík 1977; Pešek 1994; etc.). Thus the Westphalian D to Early Cantabrian age is assumed for the Nýřany and Svatoňovice Members in the central and western Bohemia and in the Sudetic area respectively. Similarly, Barruelian (Stephanian A) is supposed for the Týnec Formation (with *Neuropteris ovata* Hoffman), Stephanian B for the Slaný Formation and Stephanian C for the Líně Formation and their lateral equivalents in the Sudetic area (Fig. 7). Lithologically and floristically proved hiatuses of the basinal range are recorded only from the Late Bolsovian to the Late Westphalian D and between Late Stephanian B to the Early Stephanian C (within the Late Stephanian of Doubinger *et al.* 1995). The range of the latter extends up to the Autunian in the Intra-Sudetic Basin. On the other hand, Wagner (1977) proposed another long-lasting hiatus between the Nýřany Member and the Týnec Formation in the central and western Bohemia and adequate units in the Sudetic region. This hiatus comprises most of the Cantabrian, Barruelian and Stephanian B. The Late Stephanian B is therefore proposed for the Týnec and Slaný Formations and their equivalent in the Sudetic area by this author. Continuous floristic succession seems to be present from the the Late Westphalian D to Early Cantabrian and from the Late Stephanian B to Stephanian C. This hiatus is deduced mainly by the presence of *Lilpopia raciborskii* (Lilpop) and *Nemejcopteris feminaeformis* (Schlotheim) from the Týnec Formation and their absence in the top of the Nýřany Member. Only the part occurring above the hiatus between the Stephanian B and C has been selected to present Stephanian palaeogeography in this contribution.

STEPHANIAN C-AUTUNIAN

Stephanian C and Autunian sediments in limnic basins of the Bohemian Massif were deposited after a hiatus related to an intra-Stephanian phase of the Variscan orogeny which is responsible for remarkable changes in the geology of sedimentary basins and source areas. The distribution and abundance of deposits of the studied interval suggest these two stages should be described separately.
Stephanian C and Autunian sediments in the central and western Bohemia as well as in the Sudetic region consist mostly of unfossiliferous red beds in which flora is recorded mainly from several grey horizons accompanied by thin coals or bituminous shales with vertebrates. In the Blanice and Boskovice Grabens the uppermost Stephanian C contains mineable coal seams accompanied by rich flora. Whereas the presence of *Sphenophyllum angustifolium* Germar is typical for the Stephanian C, rich *Callipteris* flora including *Autunia conferta* (Sternberg) dominates in the Autunian deposits.
Recently, the Stephanian was revised in the Saint-Étienne Basin by Doubinger *et al.* (1995). They propose to subdivide the Stephanian into an Early Stephanian (the Barruelian, equivalent to the former Stephanian A), and a Late Stephanian (the Forezian, equivalent to the former Stephanian B and C).
Basic features of the Stephanian C (Havlena & Pešek 1980), can be summarized as follows: an



Formation = Fm.
Member = M.

FIG. 7. — Lithostratigraphic division and correlation of the most important Late Palaeozoic limnic basins in the Czech Republic. **1**, erosional unit boundary; **2**, unit boundary; **3**, hiatus; **4**, a boundary between the Carboniferous/Permian formations and the underlying unit regardless of its age and petrographic composition; **5**, increase in the area of sedimentation over the basement in different basins.

Stephanian C - Autunian

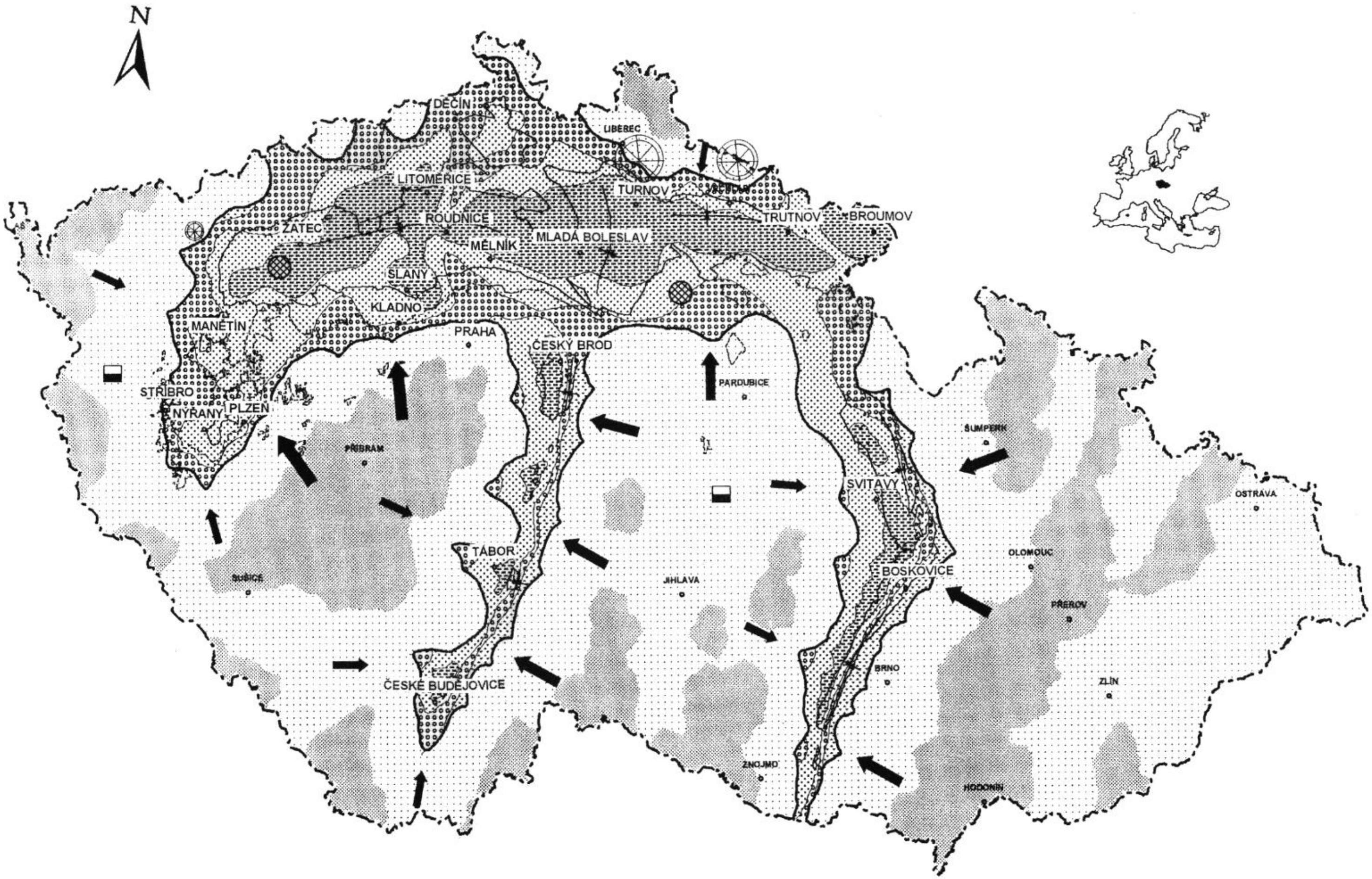


FIG. 8. — Palaeogeography of the Czech Republic during the late Stephanian (Stephanian C) - Autunian (see legend Fig. 4).

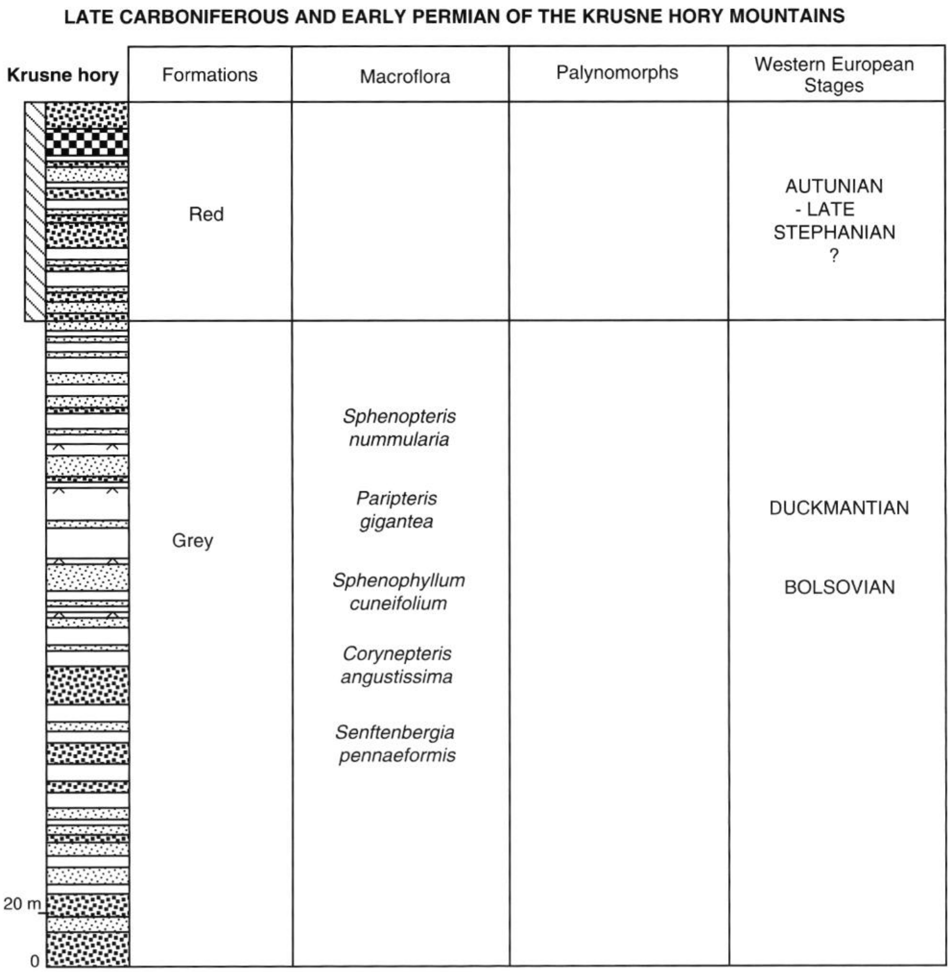


FIG. 9. — Lithological scheme of the Late Palaeozoic sediments of Brandov relic in the Krušné hory Mountains region, Czech Republic, 13°24'E - 50°37'N.

extensive subsidence occurred during which extremely thick sediments were accumulated in the central Bohemian basins as a part of a consistent central Bohemian-Sudetic area. In contrast, much less sediments accumulated in the Sudetic part of this area, or sedimentation may have been interrupted (*i.e.* Intra-Sudetic Basin). During the intra-Stephanian hiatus, a substantial part of Stephanian B sediments was eroded from the Intra-Sudetic Basin but a rather smaller part of these deposits was removed in the Mnichovo Hradiště and Krkonoše-piedmont Basins (Fig. 10). The subsidence and sedimentation in both Grabens (Boskovice and Blanice) as well as in the Česká Kamenice Basin started probably during the Early Stephanian C. The deposition of Stephanian C sediments was also renewed near Brandov in Krušné hory Mountains (Fig. 9) after a long hiatus.

Stephanian C sediments were deposited in a basin extending from western Bohemia as far as to the Krkonoše-piedmont Basin. The sedimentation took place only in the Mnichovo Hradiště and Krkonoše-piedmont Basins due to the

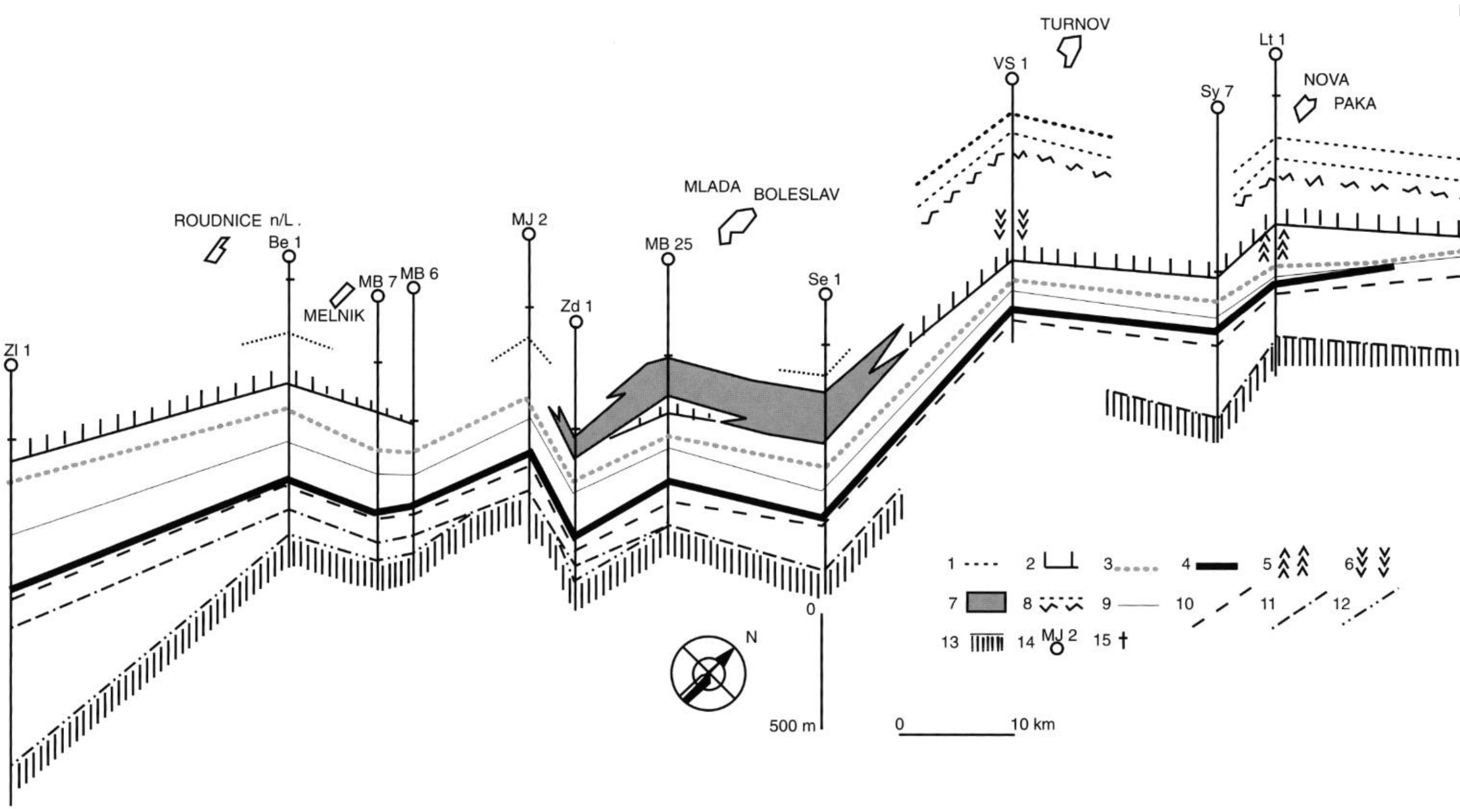


FIG. 10. — Correlation of lithostratigraphical units in parts of the Kladno-Rakovník Basin, Mnichovo Hradiště Basin and Krkonoše-piedmont Basin. Modified after Havlena & Pešek (1980). **1-3**, variegated aleuropelites of the Líně Formation (central Bohemian basins), and/or Semily Formation (Sudetic region): **1**, Stránka Horizon; **2**, thickness of the Klobuky Horizon and/or upper Ploužnice Horizon; **3**, thickness of the Zdětín and/or lower Ploužnice Horizon. **4**, Mšec Member and its black claystones equivalent of the Syřenov Formation. **5**, **6**, volcanites: **5**, intrusive rocks; **6**, extrusive rocks. **7**, sediments with conglomerate interbeds of the Barrandien type (Zikmundová-Holub 1965). **8-12**, formation boundary: **8**, base of the Libštát Formation; **9**, base of the Líně Formation and its equivalent; **10**, base of the Slaný Formation and its equivalent; **11**, base of the Týnec Formation and its equivalent; **12**, base of the Kladno Formation. **13**, Late Palaeozoic basement. **14**, borehole collar. **15**, borehole data of the Late Palaeozoic strata.

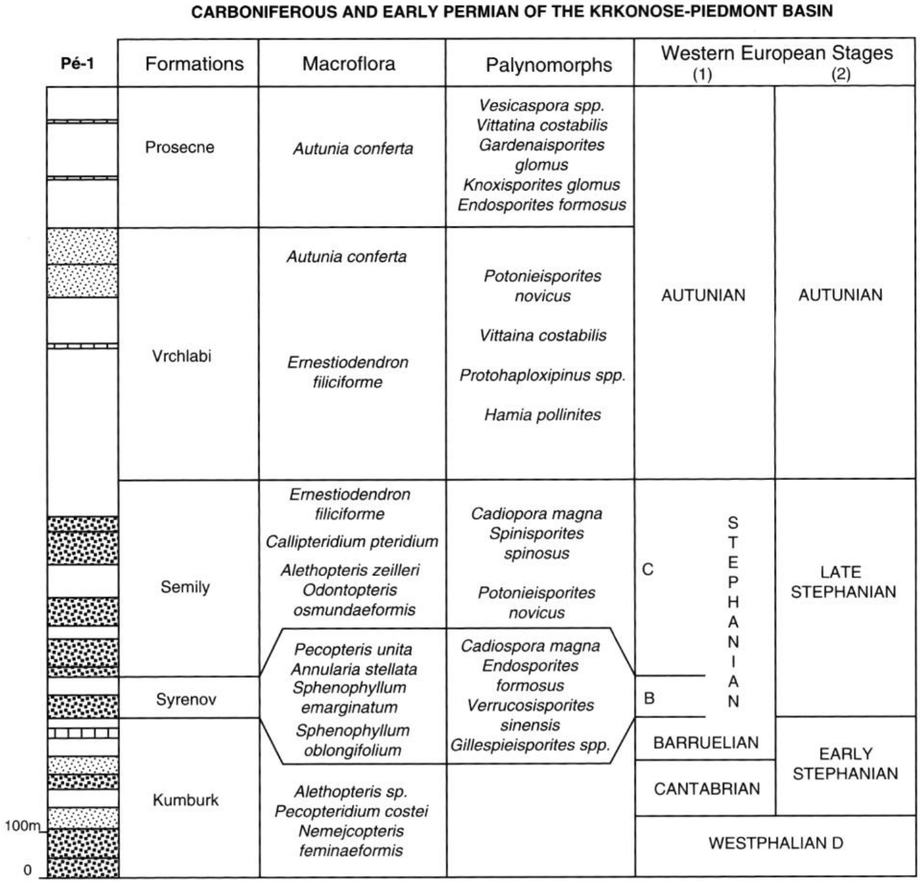


FIG. 11. — Borehole Pé1 (Prosečné) from the central part of the Krkonoše-piedmont Basin, Czech Republic, 15°41'E - 50°34'N. **1**, Martinek (this volume); **2**, Doubinger *et al.* 1995.

arching of the eastern segment of the latter basin and of the entire Intra-Sudetic Basin in particular. The Krkonoše-piedmont Basin was probably interconnected with the Česká Kamenice Basin. The central Bohemian basins were possibly also connected with the Late Palaeozoic relics near Brandov and Český Brod.

An ephemeral lake existed in west and central Bohemian and some Sudetic basins. The extent of this lake was comparable to the lake existing earlier. However, the area of the basin alternately increased or decreased depending on the volume of coarse material supplied. Minor streams also transported mud and rubble from weathered rocks from the N. Kollert *et al.* (1975) and Holub *et al.* (1981) believe that substantial volume of sediments is also of aeolian origin. Shallow water-filled depressions were locally overgrown by vegetation. After the deposition of the Klobuky horizon, a short break in sedimentation perhaps occurred in the eastern part of the Mšeno-Roudnice Basin. Early Palaeozoic rocks in source areas were exposed during this break. Deposits of this age are also known from the Carboniferous basement in the SE part of this basin. The Silurian and Devonian limestones were eroded and their fragments were transported into the basin from the south (Zikmundová & Holub 1965).

The deposition of sediments took place during

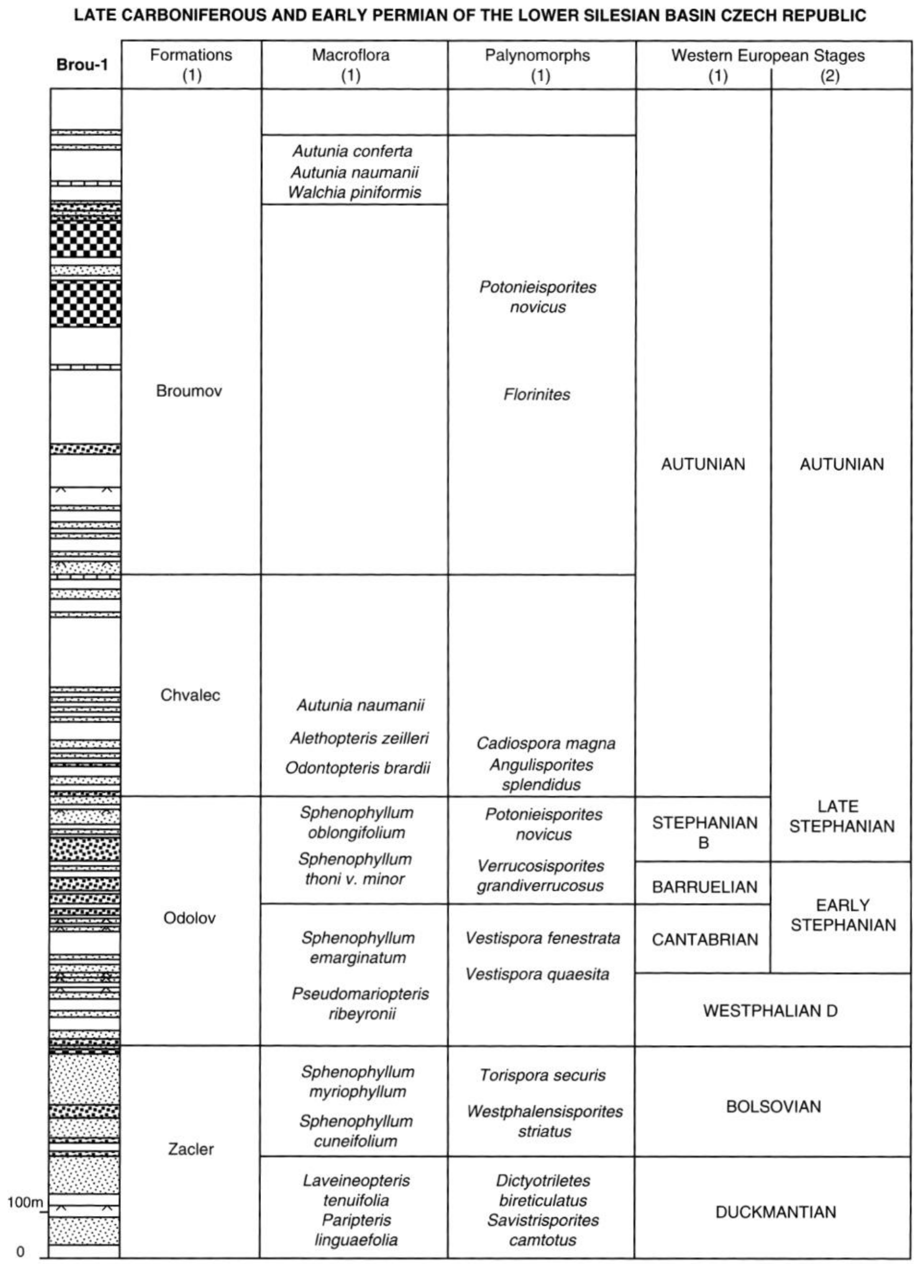


FIG. 12. — Borehole Brou 1 (Broumov) from the central part of the Intra Sudetic Basin, Czech Republic, 16°21'E - 50°35'N, lithology and biostratigraphy. **1**, Opluštil & Pešek (this volume); **2**, Doubinger *et al.* 1995.

intense acid and basic volcanic activity. The volcanic centers existed outside the central and western Bohemian basins and also inside the Kladno-Rakovnik basin in the Žatec area. Detrital material was probably derived from sources which already supplied the underlying units.

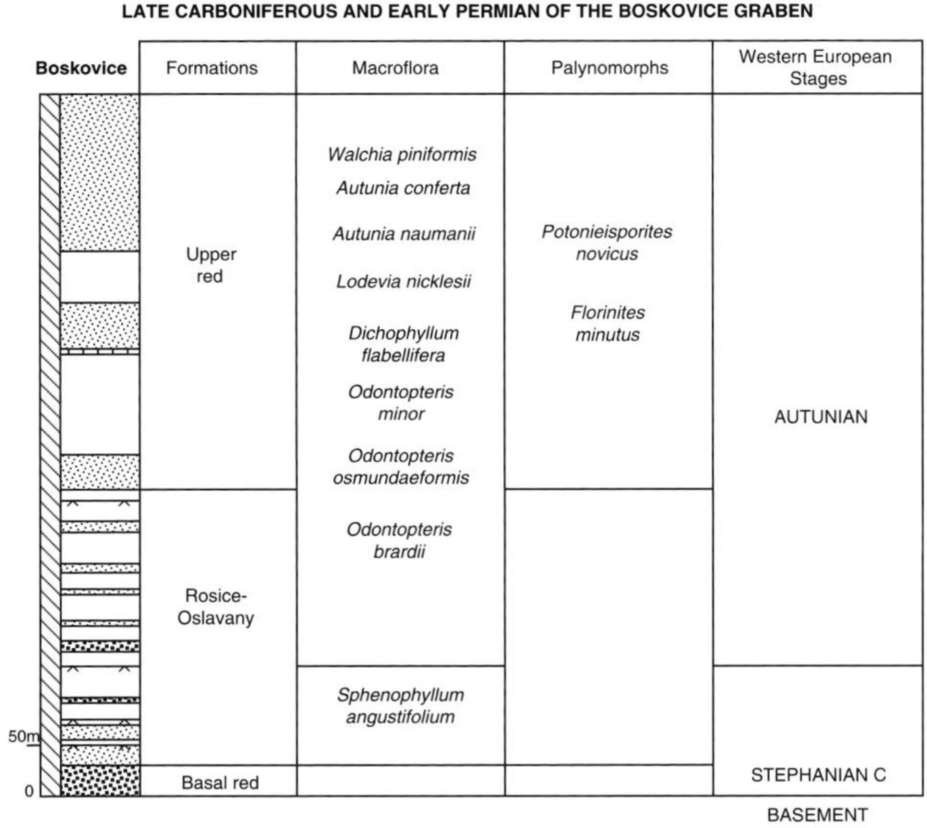


FIG. 13. — Boskovice Graben, Czech Republic, 16°25'E - 49°10'N, lithological and biostratigraphical scheme.

However, the Late Proterozoic metamorphites and Early Palaeozoic rocks of the Barrandian area seem to have played a more important role as a source. In addition, the occurrence of conglomerates containing pebbles of Silurian and Devonian carbonates indicates that some new source areas of detrital material must have existed. Crystalline complexes of the Teplá, Krušné hory Mountains and Lugicum in particular probably also played an important role as source areas.

The Semily Formation (Fig. 11) together with yet unnamed units of the same age constitute Stephanian C sediments in the remaining Sudetic basins. The sedimentary domain of the most important Sudetic basins, the Mnichovo Hradiště and the Krkonoše-piedmont Basins, was surrounded by source areas to the south, east and north. The alluvial plain of the Sudetic basins was connected with the central Bohemian alluvial plain to the West. Both plains share the fluviolacustrine and lacustrine deposits. Lacustrine sediments in these basins pass in fluviolacustrine to fluvial deposits toward the margins of the alluvial plain. Small peat bogs in the Krkonoše-piedmont Basin were formed during the period of reduced sediment supply. The deposition was locally accompanied by contemporaneous intermediate to basic volcanism. It is possible that the Sudetic, central and western Bohemian basins were drained by several streams through the area of present Krušné hory Mountains into Saxony.

Individual, small basins elongated NNE-SSW and supplied with clastics from the west and mainly from the E probably existed in the Blanice Graben near České Budějovice and Tábor. The area near Český Brod may have been connected with the central Bohemian alluvial plain in the N (Havlena & Pešek 1980). A marked zone of piedmont sedimentation with alluvial fans and talus was formed along an arched source area E of Český Brod. Minor coal-forming vegetation locally grew in small shallow lakes.

A narrow basin was formed in the Boskovice Graben (Fig. 13) W of the large arched block of the Brno Massif. Morphologically marked boundary of this block was rimmed by a zone of thick talus deposits and alluvial fans. Minor fluviolacustrine and lacustrine sediments were deposited contemporaneously with piedmont sediments west of this area. Organic deposition was restricted only to the Rosice-Oslavany area. Minor contemporaneous volcanic activity was recorded here.

Autunian sedimentation in the Bohemian Massif probably occurred over a large area interconnecting all limnic basins of the Czech Republic. Gradual cessation of deposition was due to arching of the western and central parts of basins in western and central Bohemia. Consequently, higher thicknesses of sediments were deposited in the Mšeno-Roudnice Basin only. This basin and the Sudetic basins constituted a newly formed basin which also included the newly formed Orlice Basin and the Boskovice and Blanice Grabens. In contrast to the Stephanian C, the extensive subsidence during the Autunian time shifted into the Sudetic basins and also in the Boskovice and Blanice Grabens where sedimentation reached its peak.

Autunian sedimentation in the Intra-Sudetic Basin (Fig. 12) includes deposits of alluvial fans and sediments brought probably by ephemeral streams (Vernéřovice Member). The upward decrease in grain size indicates an extensive denudation of source areas which resulted in the prevalence of alluvial plain and lacustrine sediments over fluvial channel deposits. Sedimentation of the Bečkov Member (Chvaleč Formation) in particular was accompanied by strong volcanic activity west of the Intra-Sudetic Basin. However, in the Intra-Sudetic Basin itself, only pyroclastics occur. Similar development of the sedimentary filling is also known from the Krkonoše-piedmont Basin (Fig. 11) but its latest Autunian unit (Chotěvice Formation) includes a large proportion of evaporites (Prouza *et al.* 1977).

The development of the Blanice and Boskovice Grabens reached its peak during the Autunian. Both basins are characterized by extensive subsidence along the eastern boundary of permanently uplifting blocks. Margins of those blocks were source areas for sediments of alluvial fans and talus deposits. Fluviolacustrine sediments occurring in central and eastern parts of both grabens originated in source areas located east of these basins (Fig. 13). These areas were gently arching and formed morphologicaly low relics. Fluviolacustrine sediments which are in heteropic relation to marginal sedimentation in the east, passed gradually toward the north into similar sediments in the Mšeno-Roudnice Basin and/or in the Sudetic sedimentary domain. Sedimentation in the Boskovice Graben was accompanied by a weak volcanic activity. Autunian and Saxonian sediments preserved along the Lužice fault in northern Bohemia provide an evidence for the connection of the Bohemian basins with similar basins in Saxony. These basins may have been also drained into the North Sudetic Basin in Poland.

The deposition of dominantly fine detrital material indicates continuing denudation of the Bohemian Massif. Several formerly buried units were uplifted and exposed to erosion as evidenced for example by pebbles of Early Palaeozoic carbonates in the Mšeno-Roudnice Basin.

The deposition of sediments of both stages studied took place in a warm to hot climate which gradually became arid.

CORRELATION OF THE CZECH LATE PALAEOZOIC CONTINENTAL BASINS WITH SIMILAR BASINS IN EUROPE

Various types of continental basins occur in the Bohemian Massif. Despite their comparable geotectonic position with similar continental basins

of Variscan Europe, they usually differ in stratigraphic range of their sedimentary records and in size and architecture. Such differences occur even within the Bohemian Massif. On the opposite, there is a strong resemblance of the Blanice and Boskovice Grabens with similar basins in the French Massif central. In both areas, narrow half-grabens with a high subsidence rate developed during the Stephanian and Permian. Their genesis is related to wrench faulting connected with Variscan orogeny (Ziegler 1986).
Stratigraphic range of the basins in central and western Bohemia and Sudetic area has probably no exact equivalent in any other basin of Europe. Some hiatuses traceable in different basins of the Variscan chain and its foredeep may have been of correlative value. The important hiatus proved in the basins of the central and western Bohemia and poorly developed in the Sudetic area is related to the Leonian phase defined in NW Spain. This hiatus has been also recognized in the Late Silesian Basin in Poland as well as in the Krušné hory Mountains Basin (in German literature the Erzgebirge Becken) and NE part of the Saale Basin in Halle-Delitzsch district (Schneider *et al.* 1994) in Germany. In the W European foredeep this hiatus corresponds with the termination of paralic deposition and onset of non-marine sedimentation.

CONCLUSION

The internal parts of the European Variscides including the Bohemian Massif contain a number of the Late Palaeozoic continental basins whose initiation and development are related to final phases of Variscan orogeny. The dominant role of strike-slip faulting was emphasized by many authors (Arthaud & Matte 1977; Ziegler 1986). In the Bohemian Massif the role of wrench faults was recently demonstrated by Pašek & Urban (1990) on an example of the Pilsen Basin.
Continental basins of the Bohemian Massif were formed in two periods: in the Namurian-Westphalian period and in the late Stephanian period. During the Namurian but mainly in the Westphalian, the basins of central and western Bohemia and Sudetic area were formed. In the late Stephanian only a few kilometres wide but tens of kilometres long half-grabens (Blanice and Boskovice Grabens) of NNE direction were originated.
In the middle Westphalian the deposition took place in two separated areas – in western and central Bohemia and in the Sudetic area. Basal sediments of both depocentres infilled erosively or tectonically established river valleys. SW-NE trending morphological depressions contrast with nearly N-S narrow graben-like tectonical valleys, described from the Plzeň and Kladno-Rakovník Basins (Pašek & Urban 1990; Pešek 1994), the direction of which is comparable with that of the Blanice and Boskovice Grabens.
During the Westphalian D and Cantabrian an extensive increase in sedimentary area resulted in connection of central and western Bohemian depocentre with the one in the Sudetic area around the Westphalian-Stephanian boundary. Another substantial widening took place after a hiatus in the Stephanian C when the sedimentary area reached its maximum due to newly established grabens which were connected with basins of the Sudetic area.
Sedimentary record in most of the Czech Late Palaeozoic continental basins is interrupted by several hiatuses. In the Westphalian and Stephanian two important interruptions have been proved on the basis of floristical and lithological changes. The first one, ranging from the Late Bolsovian to the Early Westphalian D is also detectable in some other basins in Poland and the eastern part of Germany. The second hiatus is dated to the Early Stephanian C. During both hiatuses significant reworking of tectonic and structural plans of basins and their basement resulted in changes of sourcelands and an extensive widening in sedimentary area accompanied by shifting of the axis of maximum subsidence after a hiatus. Another, however, only floristically evidenced gap is supposed by Wagner (1977) from Late Cantabrian to Early Stephanian B. Tectonic activity was connected with intensive volcanism concentrated mostly into middle Westphalian and to the Stephanian C-Autunian. For the Westphalian, humid and probably warm climate is assumed. Since the Late Stephanian (Forezian) a seasonal climate with respect to rain-

fall fluctuation has been evidenced. Primary red beds predominate in the Late Stephanian and Permian sediments as a consequence of gradual increase in aridity to the end of the Palaeozoic.

Acknowledgements
We would like to express sincere thanks to J.-F. Becq-Giraudon and A. Izart for their critical reviews of the manuscript. We thank P. Vízdal for his assistance in computer processing and construction of maps. We are also grateful to K. Martínek for construction of the borehole Pé 1 Prosečné section, Z. Šimůnek for providing us with valuable information on phytopalaeontology of the Boskovice Graben, the Krkonoše piedmont and the Intra-Sudetic Basins, and A. Izart for computer plotting of Figs 5, 9, 11, 12 and 13. Elaboration of the manuscript was made possible by financial support of projects No. 205/93/0699 and No. 205/96/1231 provided by the Grant Agency of the Czech Republic.

REFERENCES

Arthaud F. & Matte, P. 1977. — Late Paleozoic strike-slip faulting in southern Europe and northern America: result of a rightlateral shear zone between the Appalachians and the Urals. *Geological Society of America Bulletin*, New York 88: 1305-1320.

Becq-Giraudon J.-F. & Van den Drissche J. 1994. — Dépôts périglaciaires dans le Stéphano-Autunien du Massif central: témoin de l'effondrement gravitaire d'un haut plateau hercynien. *Comptes Rendus de l'Académie des Sciences*, Paris 318 (II): 675-682.

Blecha M., Martínek K., Drábková J., Zajíc J., Šimunek Z. 1997. — *Paleoenvironmental changes on the Carboniferous-Permian boundary. Final report to grant 205/94/0692.* Grant Agency of the Czech Republic, Praha, 352 p. [in Czech].

Bouška V. & Pešek J. 1985. — Boron in the aleuropelites of the Bohemian Massif: 147-155, *in 5th Meeting of the European Clay Groups, Praha 1983.* Charles University, Praha.

Crowley T. J., Hyde W. T. & Short D. A. 1989. — Seasonal cycle variations on the supercontinent of Pangea: implications for Early Permian vertebrate extincions. *Geology* 17: 457-460.

Doubinger J., Vetter P., Langiaux J., Galtier J. & Broutin J. 1995. — La flore fossile du bassin houiller de Saint-Étienne. *Mémoires du Muséum national d'Histoire naturelle,* Paris, 164, 356 p.

Havlena V. 1974. — Stephanian series and Cantabrian stage in the central Bohemian Basin, Czechoslovakia. *Folia Musei Rerum Naturalium Bohemiae Occidentalis, Geologica* 2: 1-18.

— 1977. — Remarks on the Cantabrian Stage: 409-416, *in* Holub V. M. & Wagner R. H. (eds), *Symposium on Carboniferous Stratigraphy. IUGS Subcomm. Carb. Strat. (SCCS), Field and General Meeting, Czechoslovakia, 1973.* The Geological Survey, Praha.

Havlena V. & Pešek J. 1980. — Stratigrafie, paleogeografie a základni strukturní členěni limnického permokarbonu Čech a Moravy. *Sbornik Příroda Plzeň* 34: 1-144 [in Czech with English summary].

Holub V., Skoček V. & Tásler R. 1981. — Nová litostratigrafická jednotka permokarbonského staří v permokarbonu středočeské oblasti. *Věstnik Ústředního Ústavu geologického,* Praha 56: 193-201 [in Czech with English abstract].

Kollert A., Bylová I., Ditrichová A., Hnízdilová E., Lang M., Mašek J., Pešek J., Pradáčová M., Stibitz Vl., Šetlík J., Valterová P., Žáková B. & Žbánek J. 1975. — *Ložisková studie kladensko-rakovnické pánve (KRP)- surovina: černé uhlí.* Unpublished paper, Geofond, Praha: 1-418 [in Czech].

Kotasowa A. & Migier T. 1995. — Macroflora: 56-64. *in* Piatkowska E. (ed.), *The Carboniferous System in Poland.* XIII International Congress on Carboniferous and Permian, Warszawa.

Krs M. & Pruner P. 1995. — Palaeomagnetism and palaeogeography of the Variscan formations of the Bohemian Massif, comparison with other European regions. *Journal of the Czech Geological Society*, Praha 40: 3-46.

Kukal Z. 1983. — Granitoidní plutony byly hlavním zdrojem živců permokarbonských sedimentů. *Časopis pro mineralogii a geologii,* Praha, 29, 2: 423-428 [in Czech with English abstract].

Kumpera O. & Martinec P. 1995. — The development of the Carboniferous accretionary wedge in the Moravian-Silesian Palaeozoic Basin. *Journal of the Czech Geological Society*, Praha 40: 47-64.

Kutzbach J. E. & Gallimore R. G. 1989. — Pangean climates: Megamonsoons of the megacontinent. *Journal of Geophysical Research* 94: 3341-3357.

Mašek J. 1973. — Volcanic products of the central Bohemian Carboniferous. *Sborník geologických Věd, Geologie*, Praha 24: 73-104 [in Czech with English abstract].

Nairn A. E. M. & Smithwick M. E. 1976. — Permian paleogeography and climatology: 283-312, *in* Falke H. (ed.), *The Continental Permian in Central, West, and South Europe.* Reidel, Boston.

Parrish J. T. 1995. — Geologic evidence of permian climate: 54-61, *in* Scholle P. A., Peryt T. M. & Ulmer-Scholle D. S. (eds), *The Permian of Northern Pangea*, Volume 1: *Paleogeography, Paleoclimates, Stratigraphy.* Springer, Berlin.

Parrish J. M., Parrish J. T. & Ziegler A. M. 1986. — Permian-Triassic paleogeography and climatology and implication for therapsid distributions: 109-132, *in* Hotton N. H. III, MacLean P. D., Roth J. J. & Roth E. C. (eds), *The Ecology and Biology of Mammal-like Reptiles*. Smithsonian Press, Washington DC.

Parrish J. T. & Peterson F. 1988. — Wind directions predicted from global circulation models and wind directions determined from eolian sandstones of the western United States – a comparison. *Sedimentary Geology* 56: 261-282.

Pešek J. 1968. — Geologická stavba a vývoj sedimentů plzeňské černouhelné pánve. *Sborník Příroda* 2: 1-109 [in Czech].

— 1994. — *Carboniferous of central and western Bohemia (Czech Republic)*. Czech Geological Survey, Praha.

Pešek J. *et al.* 1998. — *Paleogeographic Atlas: Late Paleozoic and Triassic Formations, Czech Republic.* Czech Geological Survey, Praha 1-53.

Pešek J. & Tásler R. 1979. — Volcanism and volcanogenic rocks in the Upper Palaeozoic limnic basins of the Bohemian Massif. *Folia Musei Rerum Naturalium Bohemiae Occidentalis, Geologica* 30: 1-55.

Prouza V., Skoček V. & Tásler R. 1977. — Evaporites in the Lower Permian of the Krkonoše-piedmont Basin. *Věstník Ústředního Ústavu geologického*, Praha 52: 367-369 [in Czech with English abstract].

Rowley D. B., Raymond A., Parrish J. T., Lottes A. L., Scotese C. R. & Ziegler A. M. 1985. — Carboniferous palaeogeographical, phytogeographic, and paleoclimatic reconstructions. *International Journal of Coal Geology* 5: 7-42.

Ruddiman W. F. & Kutzbach J. E. 1991. — Plateau uplift and climatic change. *Scientific American* 264 (3): 66-75.

Schneider J. W., Rössler R. R. & Gaitsch B. G. 1994. — Time lines of the Late Variscan volcanism – a holostratigraphic synthesis. *Zeitblatt für Geologie und Paläontologie* I: 477-490.

Scotese C. R. & McKerrow W. S. 1990. — Revised world maps and introduction, *in* McKerrow W. S. & Scotese C. R. (eds), *Paleozoic paloegeographhiy and biogeography*, Memoir – Geological Society of London 12: 1-21.

Skoček V. 1990. — Stephanian lacustrine-deltaic sequence in central and north-eastern Bohemia. *Sborník geologických věd, Geologie,* Praha 45: 91-122 [in Czech with English summary].

Šetlík J. 1977. — Results on recent investigation on the Carboniferous flora of Bohemia: 315-340, *in* Holub V. M. & Wagner R. H. (eds), *Symposium on Carboniferous Stratigraphy. IUGS Subcomm. Carb. Strat. (SCCS), Field and General Meeting, Czechoslovakia, 1973.* The Geological Survey, Praha.

Tásler R. *et al.*, 1979. — *Geologie české části vnitrosudetské pánve* Ústřední Ústav geologický, Praha, 292 p. [in Czech with English summary].

Wagner R. H. 1965. — Palaeobotanical dating of Upper Carboniferous folding phases in NW Spain. *Memorias del Instituto geológico y minero de España*, Madrid 66: 1-169.

— 1977. — Comments on the Upper Westphalian and Stephanian floras of Czechoslovakia, with particular reference to their stratigraphic age: 441-455, *in* Holub V. M. & Wagner R. H. (eds), *Symposium on Carboniferous Stratigraphy. IUGS Subcomm. Carb. Strat. (SCCS), Field and General Meeting, Czechoslovakia, 1973.* The Geological Survey, Praha.

Ziegler A. M. 1990. — Phytogeographic patterns and continental configurations during the Permian period, *in* McKerrow W. S. & Scotese C. R. (eds), *Paleozoic palaeogeography and biogeography*, Memoir – Geological Society of London 12: 363-379.

Ziegler P. 1986. — Geodynamic model for the Palaeozoic crustal consolidation of Western and Central Europe. *Tectonophysics*, Amsterdam 126: 303-328.

Zikmundová J. & Holub V. 1965. — Pebbles of Silurian and Devonian limestones in the Permo-Carboniferous of the Mladá Boleslav area. *Věstník Ústředního Ústavu geologického*, Praha 40: 185-188. [In Czech with English abstract].

Submitted for publication on 1 March 1997; accepted on 15 December 1997.