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The Devonian in the Easternmost Variscides, Moravia: a Holistic Analysis Directed Towards Comprehension of the Original Context

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Czech Republic
Moravia
Bohemian Massif
Devonian
Variscides
Facies
Tectonics
Palaeomagnetism
Biodynamics

Contents

Das Devon von Mähren in den östlichsten Varisziden: Eine holistische Analyse zum Verständnis der ursprünglichen Zusammenhänge

Zusammenfassung

Ein Versuch einer holistischen Analyse der devonischen Gesteine von Mähren, dem östlichsten Teil des variszischen Orogens, wird nach Fazies, tektonischer Information, paläomagnetischen Daten und Biodynamik der Faunen unternommen.

Die Sedimente und Metasedimente des Moravischen Karstes, von Nemcice-Konice, Horni Benesov, Rymarov-Vrbno und der Tisnov-Fazies waren früher Teile eines weiten rhenotypen Beckens auf ausgedünnter Kruste, das im Zeitabschnitt Emsium bis Unterkarbon von einer dextralen Transtension erfasst wurde. Es stand mit anderen rhenotypen Becken in Verbindung, die entlang des Südrandes von Laurussia lagen. Es dürfte sich zur Devonzeit über mehrere Hunderte von Kilometern in Ost–West-Richtung erstreckt haben. Die überwiegende Anzahl an diastrophischen Sedimenten stammt aus dem späten Viséum. Zur Zeit des Viséum/Namurium kam es zur Beckeninversion wie das

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Nachlassen der diastrophischen Sedimentation widerspiegelt. Vormals voneinander entfernte Faziesbereiche wurden danach übereinandergeschoben. Die Fazies in verschiedenen Bereichen Westmährens-Schlesiens deuten auf die Existenz anderer Becken hin; jedoch zusätzliche Daten sind notwendig um ihr ehemaliges Vorhandensein zu bestätigen oder abzulehnen. Die givetischen Mestecko Trnavka-Schiefer mit ihrer Bedeckung von diastrophischen Sedimenten mögen auf eine Kollision im Givetium/Frasnium hinweisen, die sich im Wesentlichen in der Sudetenregion im nördlichen Teil des Böhmischen Massifs abspielte. Es wird vorgeschlagen, dass die Velke Vrbno-Fazies eine Barrandium-ähnliche Sequenz repräsentiert, die zur Devonzeit an einen Inselbogen angeschweisst wurde.

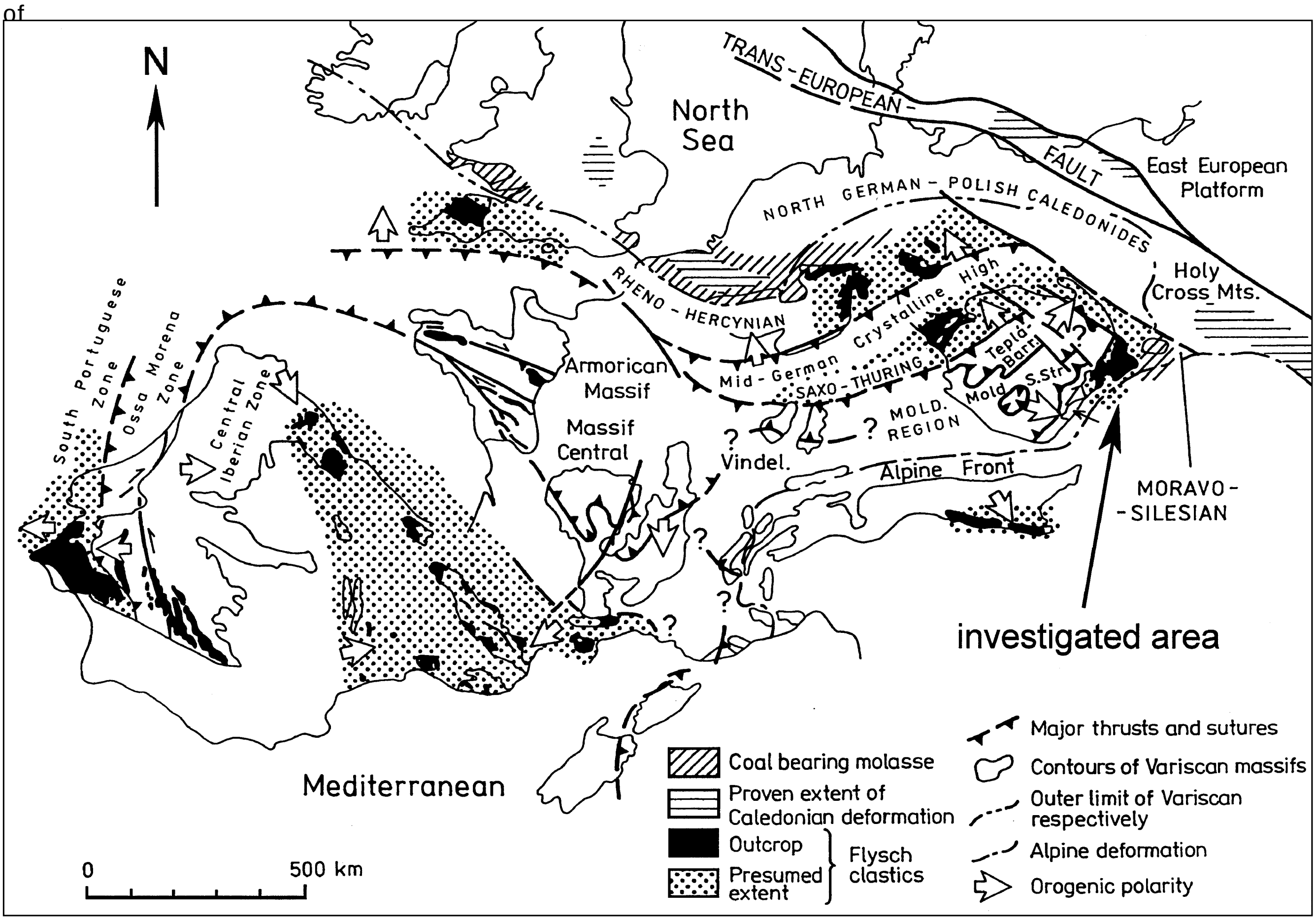
Wesentliche palinspastische Unterbrechungen von zehn bis Hunderten von Kilometern werden als „strike-slip wedging“ angesehen sowie als Aufarbeitung von Terranen unter der Kontrolle von Rotation im Uhrzeigersinn und Biegung des Orogens. Große Krustenblöcke wurden herausgehoben, zergliedert und letztlich vollkommen aus der Struktur gelöst.

Abstract

An attempt at holistic analysis of the Devonian rocks of Moravia is based on facies, tectonic information, palaeomagnetic data, and biodynamics of faunas in this easternmost part of the Variscan Orogen. Sediments and metasediments of the Moravian Karst, Nemcice-Konice, Horni Benesov, Rymarov-Vrbno and Tisnov facies were formerly parts of a large Rhenish-type basin developed on attenuated crust undergoing dextral transtension during the Emsian to Early Carboniferous. It communicated with other Rhenish-type basins along the southern Laurussian margin and, during Devonian times, may have been several hundred kilometres in length, oriented E–W. Most of the diastrophic sediments are Late Viséan. Basin eversion, reflected in cessation of diastrophic sedimentation, occurred during the Viséan/Namurian. Formerly remote facies-tracts were subsequently juxtaposed. Facies in various areas of western Moravia-Silesia suggest other basins, but additional data are needed to confirm or refute their former existence. The Givetian Mestecko Trnavka shale with its cover of diastrophic sediments may reflect Givetian–Frasnian collision occurring mainly in the Sudetic region in northern part of the Bohemian Massif. The Velke Vrbno facies is suggested as representing a Barrandian-like sequence accreted to a volcanic arc during Devonian times. Major palinspastic breaks of tens to hundreds of kilometres are explained by strike-slip wedging and reworking of terranes controlled by clockwise rotation and bending of the orogen. Large crustal blocks were uplifted, dissected and ultimately completely erased from the structure.

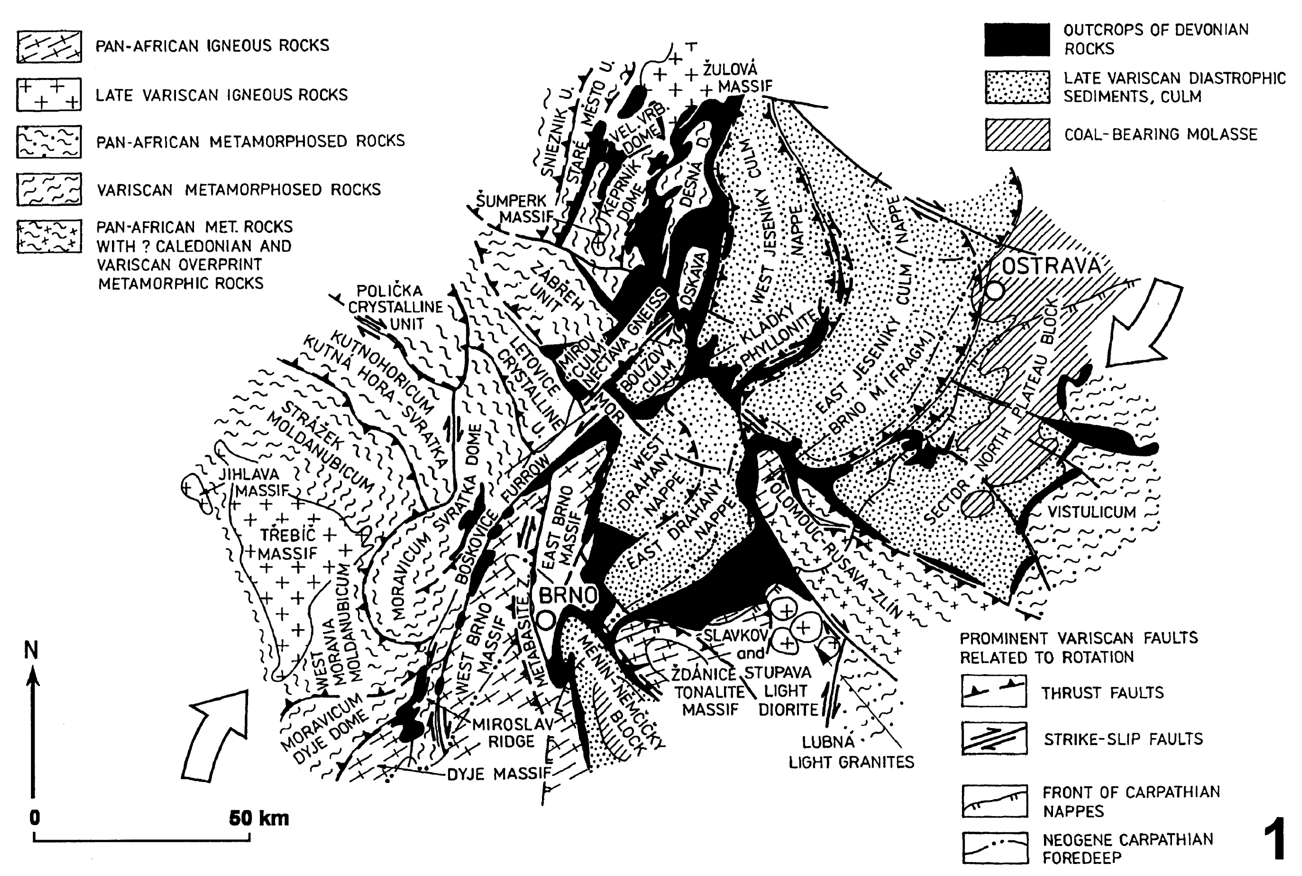
1. Current Concepts

There are numerous outcrops and much subsurface data bearing on the Devonian of Moravia and adjacent areas, a strongly deformed region where the eastern projection of the Variscan Orogen was reshaped by Alpine and Western Carpathian orogenesis (Text-Figs. 1–4). Improved resolution of lithologic and faunal-floristic data in recent de-

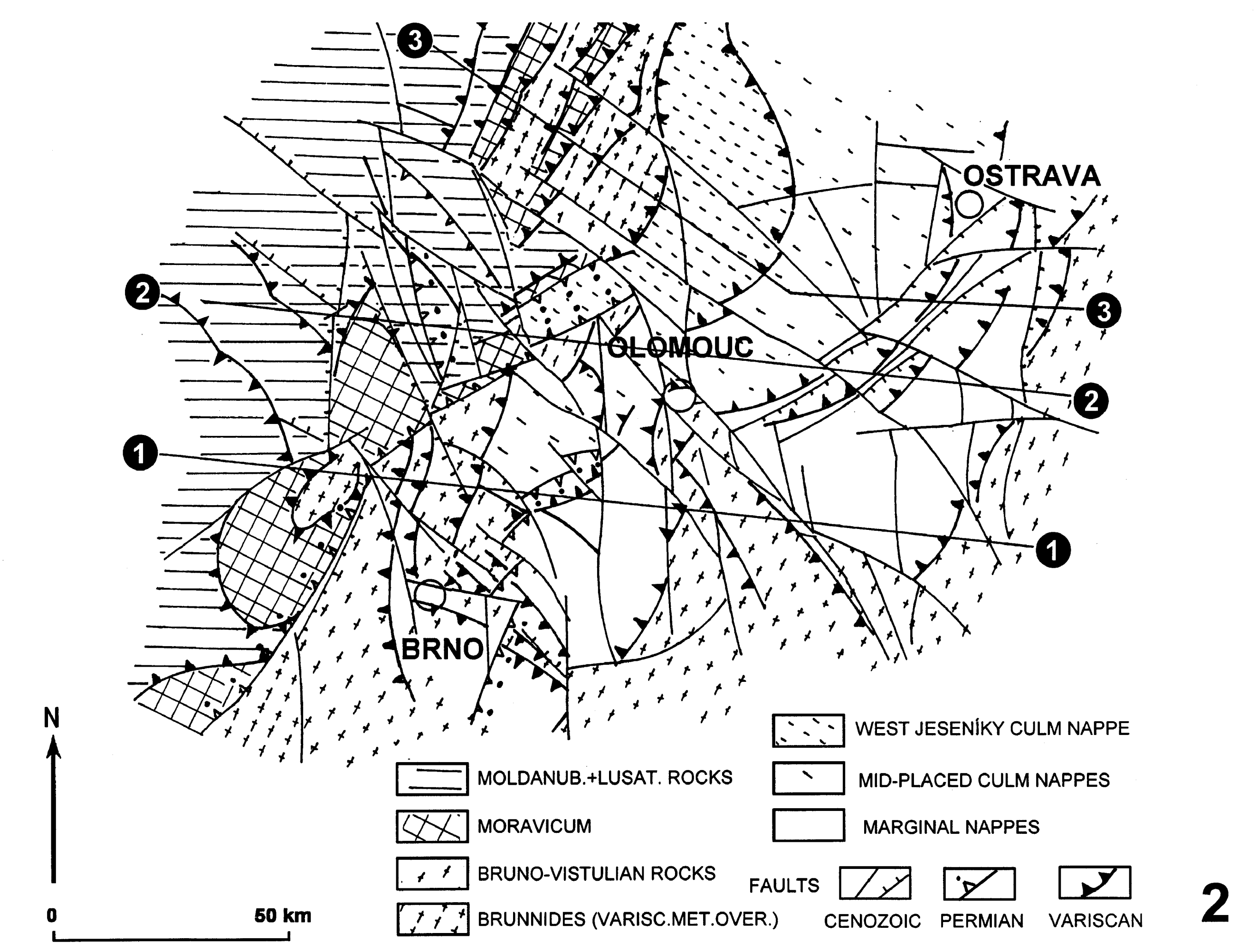


Text-Fig. 1. ▲△▲
Position of the Moravo-Silesian orocline on the eastern side of the Variscides according to Franke et al. (1995).

Text-Fig. 2. ►▷►
Bedrock geology of Variscan and pre-Variscan rocks in Moravia.
2/1: Variscan faults and Devonian outcrops emphasized.
2/2: Simplified map with post-Variscan faults (1–3 = geological sections).


PAN-AFRICAN IGNEOUS ROCKS
LATE VARISCAN IGNEOUS ROCKS
PAN-AFRICAN METAMORPHOSED ROCKS
VARISCAN METAMORPHOSED ROCKS
PAN-AFRICAN MET. ROCKS WITH ? CALEDONIAN AND VARISCAN OVERPRINT METAMORPHIC ROCKS
OUTCROPS OF DEVONIAN ROCKS
LATE VARISCAN DIASTROPHIC SEDIMENTS, CULM
COAL-BEARING MOLASSE
ŽULOVÁ MASSIF
SNIEZNIK U.
STARÉ MĚSTO U.
VEL. VRB. DOME
KEPRNÍK DOME
DESNÁ D.
WEST JESENÍKY CULM NAPPE
ŠUMPERK MASSIF
ZÁBŘEH UNIT
MÍROV CULM
NECTAVA GNEISS
OSKAVA
BOUZOV CULM
KLADKY PHYLLONITE
EAST JESENÍKY CULM NAPPE
BRNO M. (FRAGM.)
OSTRAVA
SECTOR NORTH PLATEAU BLOCK
VISTULICUM
POLIČKA CRYSTALLINE UNIT
KUTNOHORICUM
KUTNÁ HORA-SVRATKA
STRÁŽEK MOLDANUBICUM
LETOVICE CRYSTALLINE U.
SVRATKA DOME
MOR.
WEST DRAHANY NAPPE
EAST DRAHANY NAPPE
OLOMOUC-RUSAVA-ZLÍN
JIHLAVA MASSIF
TŘEBÍČ MASSIF
MORAVICUM
BOSKOVICE FURROW
EAST BRNO MASSIF
BRNO
WEST MORAVIA MOLDANUBICUM
WEST BRNO MASSIF
METABASITE Z.
SLAVKOV and STUPAVA LIGHT DIORITE
ŽDÁNICE TONALITE MASSIF
MENÍN-NĚMČICKÝ BLOCK
MORAVICUM DYJE DOME
MIROSLAV RIDGE
DYJE MASSIF
LUBNÁ LIGHT GRANITES
PROMINENT VARISCAN FAULTS RELATED TO ROTATION
THRUST FAULTS
STRIKE-SLIP FAULTS
FRONT OF CARPATHIAN NAPPES
NEOGENE CARPATHIAN FOREDEEP
N
0
50 km

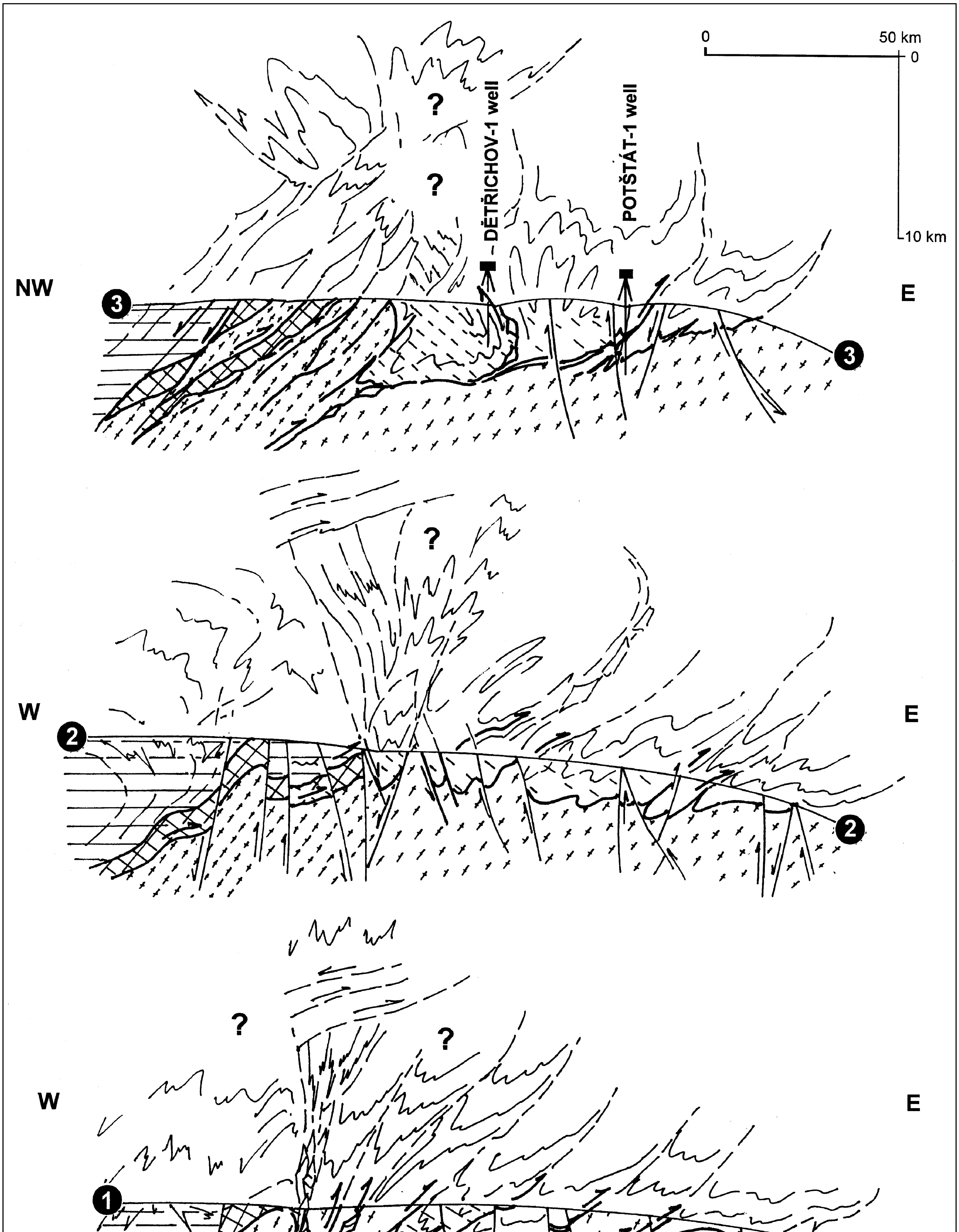
1


OSTRAVA
OLOMOUC
BRNO
1
2
3
N
0
50 km
MOLDANUB.+LUSAT. ROCKS
MORAVICUM
BRUNO-VISTULIAN ROCKS
BRUNNIDES (VARISC.MET.OVER.)
WEST JESENÍKY CULM NAPPE
MID-PLACED CULM NAPPES
MARGINAL NAPPES
FAULTS
CENOZOIC
PERMIAN
VARISCAN

2

Text-Fig. 3. ▲△▲
Distribution of the main types of the Devonian basin fills in Moravia.
Compare with the stratigraphic columns in Figure 6. The location of forty two small groups of sites allows comparison with other published data about the Devonian of Moravia:
1 = Mestecko Trnavka, shale, Givetian; 2 = Mohelnice Formation (Mirov), diastrophic sediment, ?Givetian, ?Devonian/Carboniferous; 3 = Zerotice, siliciclastics, platform carbonates, slightly metamorphosed, strongly folded, Givetian–Frasnian; 4 = Kadov, platform and slope carbonates, slightly metamorphosed, strongly folded, ?Givetian–Famennian; 5 = Lazanky n. Tisnov-Heroltice, siliciclastics, shale, platform and slope carbonates, metamorphosed, ?Eifelian–Famennian; 6 = Kvetnice n. Tisnov-Stepanovice, ?Praghian, ?Emsian–Frasnian; 7 = Vitosov, platform and slope carbonates, metamorphosed, Givetian; 8 = Branna, siliciclastics, carbonates, metamorphosed, Praghian, ?Givetian–Frasnian; 9 = Velke Vrbno, shale and slope carbonates, ?Early Devonian; 10 = Unicov, basinal volcanosedimentary sequence, shale, carbonate, basalt, ?Emsian–Famennian?; 11 = Ramzova, volcanosedimentary sequence, ?Devonian; 12 = Rejviz-Zlate Hory-Hermanovice, quartzite, shale, platform carbonate, Praghian–Frasnian; 13 = Rymarov, volcanosedimentary and sedimentary complexes, alkaline trachyte, siliciclastics, shale, carbonates; ?Praghian–Famennian; 14 = Sternberk, basinal shales, basalt, carbonates, Emsian–Famennian; 15 = Moravsky Beroun-Chabicov, basinal shales, basalt, carbonates, Emsian–Famennian; 16 = Horni Benesov, Emsian–Famennian; 17 = Krnov-Larysov, shale, Famennian; 18 = Sebetov-Boskovice, siliciclastics, slope and platform carbonates, Late Emsian–Famennian; 19 = Nectava, metamorphosed slope carbonates, ?Eifelian–Famennian; 20 = Konice-Javoricko, siliciclastics, shale, basalt, slope carbonates, late Emsian–Famennian; 21 = Mladec, siliciclastics, platform carbonates, ?Eifelian–Frasnian; 22 = Petrovice, Nemcice-Vratikov, shale, platform and slope carbonates, ?Lochkovian–Praghian, ?Emsian–Famennian; 23 = Pteni, Stinava-Repechy, basinal shale, Praghian–Emsian; 24 = Sovinec-Karlov, platform and slope carbonates, large clasts of phyllite and quartzite, Frasnian; 25 = Grygov-Krcman, siliciclastics, platform and slope carbonates, shale, Eifelian–Famennian; 26 = Prerov, Zeravice-Sobisky, Givetian–Famennian; 27 = Lesonice n. Miroslav, platform carbonate, tectonic breccia, Frasnian; 28 = Neslovice, ?siliciclastics and carbonates, ?Frasnian; 29 = Veverska Bityska-Chudcice, diastrophic siliciclastics and basinal carbonates, Eifelian, platform carbonates Givetian–Frasnian, ?Famennian; 30 = Cebin, siliciclastics and basinal carbonates, Eifelian, platform carbonates: late Eifelian, late Givetian and middle-late Frasnian, ?Famennian breccia; 31 = Ujezd, carbonates, Eifelian, Frasnian, ?Famennian; 32 = Cerna Hora, carbonates, siliciclastics, ?Frasnian–Famennian; 33 = Lelekovice, platform carbonates with quartz sand, strongly folded, slightly metamorphosed, Givetian; 34 = Uhrice-Jezov, siliciclastics, platform carbonates, late Eifelian–Famennian; 35 = Menin-Nemcicky, platform carbonates, late Eifelian–Famennian; 36 = Mokra-Horakov, platform siliciclastics and carbonates interleaved with calciturbidites of basinal depression, late Givetian–Famennian; 37 = Moravian Karst (Josefov, Macocha), platform siliciclastics and carbonates, late Eifelian–early Famennian, Famennian uplift (Brezina) or nodular limestone cover (Jedovnice); 38 = Celechovice-Slatinky-Hnevotin, platform and slope siliciclastics and carbonates, Eifelian–?early Famennian; 39 = Slavkov-Nitkovice-Rataje, platform siliciclastics and carbonates, Givetian–Famennian; 40 = Holesov, platform siliciclastics and carbonates, Frasnian; 41 = Hranice-Choryne, sliced platform siliciclastics and carbonates, late Eifelian–early Frasnian, late Frasnian drowning of reefs, Famennian slope facies; 42 = Jablunkov-Pisek, platform siliciclastics and carbonates, Frasnian–Famennian, open sea communication (on the E) in middle Frasnian.

Text-Fig. 4. ►▷►
Geological sections across the Moravia
For locations see Text-Fig. 2.


0
50 km
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?
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DĚTŘICHOV-1 well
POTŠTÁT-1 well
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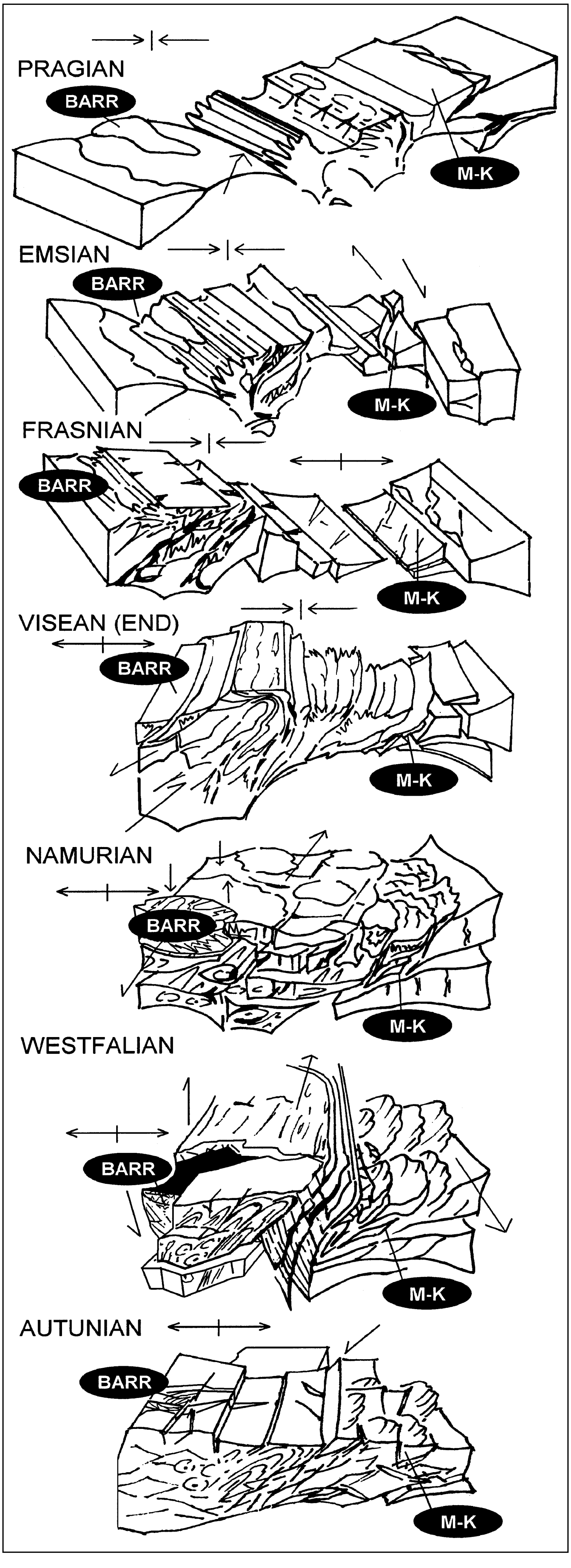
1

cades has enhanced understanding of Variscan orogenesis in this region; Devonian data, in particular, are important for clarifying how dismembered crustal segments have been emplaced.

Broad outlines of the tectonic scenario (Text-Fig. 5) reflect the following: Barrandian affinity of the peri-Gondwanan basins during the Early Devonian; presence of contemporaneous magmatic arcs as well as indications of older igneous rocks (Franke, 1997; Patocka & Hladil, 1997); docking of Barrandian precursors during the Givetian (Jaeger & Jaeger, 1988; Galle et al., 1995); extension of new back-arc basins, mostly within the south Laurussian margins (Ziegler, 1988; Chab et al., 1984; Franke et al., 1995; Hladil, 1996); initiation of Culm diastrophic sedimentation accompanied by nappe-stacking with inverted metamorphic zonation, followed by extensional collapse and lateral uplift of deep-crust Moldanubian rocks (Schulmann & Ledru, 1993; Zulauf et al., 1997; Otava, 1998) and then rotation culminating in superimposed northwards nappe-stacking (Hladil, 1991, 1995; Grygar & Vavro, 1994; Krs et al., 1995; Tait et al., 1996; Orel, 1997); emplacement of Viséan and Namurian plutons (Dorr et al., 1997; Holub et al., 1997); initiation of the Moravian shear zone and extension during Permian times (Melichar et al., 1995). Increased interaction of Barrandian basins during stepwise docking is considered in relation to new evidence of an Early Devonian magmatic arc(s) in the N of Moravia and NW of Bohemian Silesia (Patocka & Hladil, 1997) as well as the existence of Silurian arc rocks S of the Mid German Rise and Late Devonian arc plutonics in the Odenwald (Franke, 1997).

Whereas the Late Devonian is characterised by clastics on the Rhenohercynian foreland, and Laurussian segments were underplated towards the S, the Barrandian basins (Early and Middle Devonian) coming from Gondwana were docking with Laurussia, seemingly on a very obliquely consuming plate, with subsequent burial beneath siliciclastics, emergence, and then detachment from the consumed plate. It follows that this peri-Gondwanan plate was underplated towards the N. A possible hypothesis is that this partial arc had been inactive since the Frasnian when collision occurred with the old dissected arc of Silurian age. At that time it extended to areas where southward-directed consumption of marginal Laurussian (E-Avalonian) blocks was occurring. Closure of the Sudetic basins during the Middle-Late Devonian may reflect these processes. This view diverges from the hypothesis wherein the Laurussian plate was being continuously consumed – requiring relatively smooth and prolonged contact of the two super-plates (Finger & Steyrer, 1995). It agrees well with Berthelsen's (1992) scenario for docking of the Saxothuringian precursors. All recent palaeomagnetic, facies and faunal-floral data show that the Gondwanan-Laurussian gap was only slightly reduced during the entire span of Devonian time: the Rheic basins were closed, but the Rhenish-Harz basins became extended (Franke et al., 1995; Hladil et al., 1996). It is hypothesised that this gap included many small plates which were rotated and varied in the character of their sutures. Possible analogues for this situation are the recent Caribbean and eastern Mediterranean regions.



Text-Fig. 5.
Idealised scenario for evolution of the Variscan deformation of the crust in Moravia and adjacent areas of the Bohemian Massif.
BARR = approximate position of the Barrandian; M-K = approximate position of the Moravian Karst.

Important Early Devonian features were gradual thickening of the crust in the collision zone, especially after docking of the Moldanubian precursors, and major extension and deepening of basins in some pull-apart "windows" and half-grabens in the Rhenish-Moravian area, e.g. the central Moravian Konice segment (BABEK, 1996). This view again emphasizes right horizontal shear for the entire Gondwanan-Laurussian gap (ARTHAUD & MATTE, 1977); this allows for pull-aparts, alternation of extension and compression, and rotation of small plates. Increased thickening of the collided crust caused gravitational collapses in the region of the Bohemian Massif during latest Devonian and Early Carboniferous times (ZULAUF et al., 1996). Closing of the Rhenish-type basins started by accretion, wedging and renewed fault-slicing of terranes, followed subsequently by lateral uplift of underplated blocks of Moldanubian rocks. Clockwise rotation of Moravia during Viséan into Namurian and Westfalian times when NE-directed fault-slicing of already deformed Devonian–Culm basement structures took place; further modification was brought about by low-angle shear along the Moravian Shear Zone (HLADIL, 1991; STIPSKA et al., 1995; MELICHAR, 1995). Most of the Variscan plutonics were emplaced during Viséan and Namurian times (HOLUB et al., 1997); they mark extensionally attenuated areas. Gravitational collapse of the Barrandian segments from their Late Devonian–Early Carboniferous elevated position, resembling the contemporary Tibetan Plateau (ZULAUF et al., 1996, 1997) continued intermittently until Westfalian times when extensional potential occurred again during rotation of the orocline (Text-Fig. 5). The Westfalian Moravian Shear Zone (MELICHAR, 1995) produced a late but very profound reshaping of the orogen. The Moravo-Silesian Palaeozoics were affected mainly by recumbent folds and low-angle thrusts, e.g. near Valchov in central Moravia. Nappe segments underwent several phases of deformation. The geological map (Text-Fig. 2/1) displays the irregular shape of lenses intersected by the present erosion surface; the outcrop-tracts of Devonian rocks reflect the effects of Palaeozoic tectonics and delineate sutures between the larger blocks of crystalline and/or Culm rocks. Most of the Devonian rocks, being less competent, acted as "lubricant" between these more competent massifs (Text-Fig. 2/1). Thickening of the crust accompanied by detachment and rotation of crustal layers (Text-Fig. 5) is also suggested for the Late Carboniferous Brunovisticulum foredeep and foreland intruded by Variscan plutonic bodies (DUDEK, 1980; KLOMINSKY & DUDEK, 1994).

The Variscan structures were significantly re-shaped by later tectonics. Permian post-orogenic extensional thinning of the crust was expressed in grabens and listric faults (Text-Fig. 2/2); Cainozoic faulting was also significant (Text-Figs. 2/2 and 4). The brittle layer of the crust was probably detached from deeper crustal layers. This process reflected stress connected with the Alpine and Western Carpathian deformation fronts. Similar processes have been suggested for distant parts of the Bohemian Massif (ZULAUF & DUYSTER, 1997); the proximal Moravian parts were even more exposed to this stress. The upper crust seems to have moved toward the S, later to the E, and was affected by Neogene counter-clockwise rotation and horizontal shear; effects of this include inception of pull-apart basins, e.g. the Vienna Basin (HUBATKA & KREJCI, 1996). Structures were also modified by Pliocene–Pleistocene sags (e.g. Hana) and horsts in crystalline complexes (e.g. Jesenik and Svratka). Rejuvenation and inception of the so-called "transverse" faults characterise this phase; they are mostly oriented NW–SE (cf. Section 3: Tectonic Structures).

2. Dismembered Devonian Facies

The basic features of the Moravian facies were synthesised by CHLUPAC (1964, 1988) into:

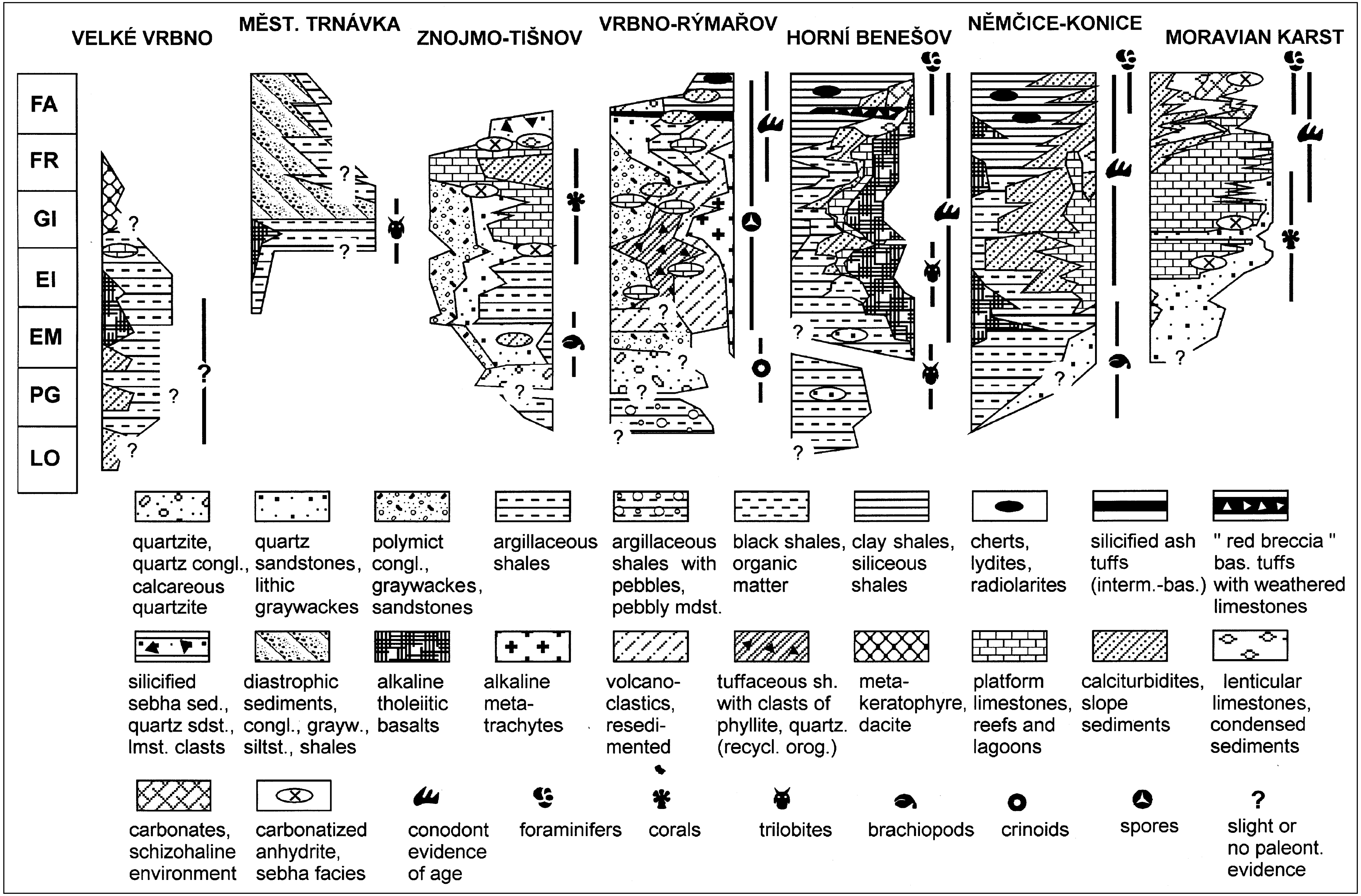
- platform facies of the Moravian Karst
- platform margin, slope and adjacent depressions with "transitional facies" and
- "basin facies" with open-sea to deep-water sediments.

2.1. Moravian Karst

(Text-Fig. 6)

These sequences rest on deeply eroded Late Proterozoic crystalline rocks (the Brunovistulian unit), locally covered by Early Palaeozoic sediments. At least part of the Old Red sediments are pre-Devonian in age; new analyses indicate an Early Cambrian age for some (JACHOWICZ & PRICHYSTAL, 1997).

The initial Devonian rocks are a thin arid deltaic-plain complex; its age is indicated by the first limestone intercalations with ?late Emsian, middle and late Eifelian coral faunas (HLADIL, 1985). Lochkovian and Praghian clasts may be present but there is no evidence of this. Deposition of near-shore siliciclastics continued until the Frasnian/Famennian boundary with thin prograding wedges developing during major falls in sea level, namely during the Eifelian–Givetian, basal Kacak at Lazanky-Zrcadla; late Givetian, ?pre-asymmetricus interval at Horakov; middle Frasnian, ?jamiae Zone at Sumbera near Brno; and latest Frasnian, basal Upper Kellwasser regression at Usti near Hranice. Thick acidic crystal-vitric volcanic tuffs occur in the Givetian; basic and intermediate tuffaceous layers occur in the late Frasnian (PRICHYSTAL, 1993). The Middle to Late Devonian stromatoporoid boundstones consist of several superimposed cycles. Growth of these banks culminated during late Eifelian, early middle Givetian, early middle Frasnian and late Frasnian. Four parasequences (main cycles) have been discriminated according to these maxima of growth. The platform cycles are characterised by change from dark clayey packstone to light coral-stromatoporoid reef banks which emerged and were karstified (HLADIL, 1983). However, the varying facies fabric and areally fluctuating subsidence indicate pull-apart or at least irregular subsidence in an extensional regime. From the late Frasnian, evolution of individual blocks differed. Blocks S of Ostrava and S and SE of Brno remained moderately elevated or were slightly uplifted into domes and horsts. They were profoundly affected by Famennian and Tournaisian eustatic falls causing major hiatuses, schizohaline environments and karstification. The southern part of the Moravian Karst (or Konice blocks) subsided rapidly (KALVODA et al., 1996; BABEK, 1996). Lenticular limestones covered the proximal slope; depressions were filled by fan and channel calciturbidites. The Moravian Karst is a huge disjunct Givetian–Frasnian platform forming part of the vast carbonate platforms which rimmed the northern coasts of the Rhenish-type basins from SW England to Moravia, or even to Romanian Dobrugea. The maximum thickness of these grey, predominantly micritic carbonate complexes is 1–1.3 km, mean thickness ca 0.3–0.4 km (ZUKALOVA, 1980; HLADIL, 1988). Rocks of Moravian Karst type are widespread in par-



Text-Fig. 6.
Stratigraphic columns of the main types of the Devonian basin fills in Moravia.

autochthonous and allochthonous situations in NE, E and SE Moravia. Their facies show major disjunctions in the drilled area at Koberice SE of Brno, in the Mokra area E of Brno, and near Prostejov or Olomouc in Hana (central Moravia). These disjunctions correspond to north-westerly oriented Namurian thrusts with dextral horizontal shear (HLADIL, 1991). In the N of Moravia, they dip under Culm nappes (CIZEK & TOMEK, 1991). Dismembered blocks with this type of sedimentary package continued towards the SW of Moravia where they are cut by the Boskovice Furrow. The most south-westerly projection is at Lesonice near Znojmo (tectonic breccia of middle Frasnian reef limestone). Pebbles of Hosteradice Viséan Culm near Znojmo contain limestone of Moravian Karst type, though there are no preserved southerly source areas for these limestones. These pebbles occur in association with other rocks (dolerites and other basics) not known in the field or subsurface.

2.2. Nemcice – Konice

(Text-Fig. 6)

Rocks of "Transitional Facies" are known from the vicinity of Konice (central Moravia), the Nemcice-Vratikov belt and locations scattered along the NW margin of the Brno Massif (HLADIL, 1994). They occur in strongly tectonised contexts in Viséan to Westfalian fault slices, traced as thin slivers along faults towards the NW where their metamorphosed relics rim the Nectava crystalline units (P. HANZL, unpublished data) and even to Vitosov near Zabreh (R. MORAVEK, unpublished data). Transitional Facies are characterised by presence of Early to Middle Devonian argillaceous shales (CHLUPAC, 1964; CHLUPAC & HLADIL, 1994). Palaeontologic data indicate rocks of ?Lochkovian age (HAVLICEK & MERGL, 1990), but most of the shales were deposited during the Emsian and Eifelian (CHLUPAC, 1964, 1988). The Emsian Ludmirov shales contain basaltic tuffs; the transgression surface of dark mud-supported quartz conglomerate and dark carbonaceous shale was found only in KDH boreholes in Konice. The basement, detached together with Devonian cover, is the Kladky Phyllonite, a pre-Variscan retrogressive metamorphic unit. The earliest biostromes and calciturbidites are late Emsian with partitus Zone conodonts high in the interval (BABEK, 1996; J. KALVODA, unpublished data). Although coral evidence indicates ages ranging from late Emsian to late Frasnian, the main development of coral-bearing rocks accumulated during the late Eifelian and early Givetian. Packstones to lime-mud supported rudstones predominate, with numerous styliolinids and chips of crinoid columnals. Two main Konice relict nappes – deep and upper slope – occur in many fault slices. Upward thinning and upward fining sequences of slope carbonates are typical (Eifelian to Tournaisian according to BABEK, 1996), but rocks from the proximal environments indicate great relief on the platform margin: truncated reefs, subaerial diagenesis, and deep sea valley sediments. The proximal slope was covered locally by lenticular limestones of Frasnian age (e.g. Vratikov). Condensed shales with radiolarians were deposited frequently during the Famennian (DVORAK, 1973).

2.3. Sternberk – Horni Benesov

(Text-Fig. 6)

Deep water basin facies was identified by occurrence of clayey shales with small blind trilobites (CHLUPAC, 1964, 1974). Deepening of the basin continued from Emsian to Givetian; most facies show Rhenish affinity (ROEHLICH, 1958). Sheet-flows and mounds of pillow lavas were succeeded in time by sea mounts with hyaloclastics and pepperite dominated rocks (PRICHYSTAL, 1993; HLADIL, 1994) cropping out in many places in the Sternberk-Horni Benesov belt. The Horni Benesov mine exposures and subsurface drilling have revealed numerous fault-slices with condensed deep water sequences (sedimentologically starved) with predominance of shales and siliceous shales interleaved with sediments derived as debris flows from the steep slopes of the volcanic elevations (GALLE et al., 1995). The Devonian intrabasinal elevations were, nevertheless, mostly tectonic klippen. The Givetian basaltic guyots with reef caps and breccia flows were the most rigid rocks in this context, tending to mobility in the condensed deep water shale "lubricant". The basin interiors were not entirely free of sialic crust. This is indicated by tholeitic basalts (PRICHYSTAL, 1993) as well as sporadic influx of non-volcanic quartz clasts during the late Emsian and subsequently during the late Famennian (DVORAK et al., 1983). Famennian drowning of Givetian–Frasnian guyots is indicated by red breccia (weathered reef clasts in tuffs) with pelagic cover. However the existence of "drowned" pumice of intermediate to acid composition as well as clasts of slightly metamorphosed Middle Devonian styliolinid shale indicate tectonic uplift in the SW (HLADIL et al., 1988).

2.4. Vrbno – Rymarov

(Text-Fig. 6)

The oldest unit of this group is dominated by quartzites and quartz conglomerates of "Siegenian" and Praghian–Emsian age (ROEMER 1865; CHLUPAC, 1989). The quartzites are mostly shallow water sediments with formerly around 5–30 % carbonate. Close proximity to dark plagioclase schists has been reported; these were probably shales with ?arc-related tuffs (J. CHAB, unpublished data). The upper part of the quartzite sequence displays fining upwards trends. Numerous boreholes in the vicinity of Rymarov have revealed Middle and Upper Devonian fault-slices. Two associations have been discriminated. A volcanic complex dominated by alkaline trachytes reflects continental rifting (CHAB et al., 1984; PATOCKA & VALENTA, 1990); it may have originated from one huge stratavolcano. The other association is a volcano-sedimentary complex dominated by siliciclastics of very diverse composition; sedimentary structures indicate megadunes formed in depressions and channels. Carbonate sedimentation occurred occasionally but was lithologically diverse. Specific layers have produced fauna and spores indicative of late Emsian to Famennian (HLADIL et al., 1988). Basic volcanic products continued to appear until Frasnian–Famennian times, when trachyte volcanism was reduced. Late Devonian evolution was more diverse. Part of the region foundered and was filled by a condensed sequence of silicified tuffs and shales; another part was emergent and covered by fringing reefs with angular clasts of phyllite and quartzite; a third part accumulated quartz sandstones with Late Devonian spores and plant debris.

2.5. Tisnov – Znojmo

(Text-Fig. 6)

Because its northern projections seem to be underlain by "Siegenian" quartzites, many authors linked this facies assemblage with the Vrbno facies (CHLUPAC, 1964); other authors, because it is underlain by a deltaic plain siliciclastic complex, linked it with the Moravian Karst (Dvorak, 1973; Bosak, 1983). The Tisnov facies assemblage nevertheless is readily discriminable from other areas of Early–Middle Devonian siliciclastics by being thicker and having a larger amount of immature clastics and black mudstones (Chlupac & Hladil, 1994). Carbonaceous lithic greywackes at Backovec Hill have produced Emsian brachiopods (V. Havlicek, unpublished data). The carbonate complex is Givetian–Frasnian; its platform rims were considerably smaller laterally and in thickness than those of the Moravian Karst. Algal precipitation of micrite was reduced; sabkha environments were frequent nearshore (Batik & Skocek, 1981; Koverdynsky & Hladil, 1985). A unique discovery of lenticular limestones of Frasnian/Famennian age at Lazanky n.T. has algal structures and purple clastic biotite, but is without conodonts. Also represented is a sequence of ?late Frasnian silicified sabkha laminites and fine-grained quartzites with dispersed limestone breccias (J. Dvorak, unpublished data; Chlupac & Hladil, 1994). The Late Devonian was a time of tectonic uplift and erosion. Sediments of the Tisnov platform and slope were faulted and intensely folded, and later re-folded; they now occur in several nappes paralleling the Moravian Shear Zone (Bosak, 1983, 1984).

2.6. Mestecko Trnavka-Mirov

(Text-Fig. 6)

Argillaceous shales with Givetian trilobites occur in several places near Mestecko Trnavka in west-central Moravia (Chlupac, 1961). These shales are overlain by sandstones and conglomerates with ripple marks and load casts (Otava et al., 1994). This discovery is of prime importance because it documents the onset of diastrophic sedimentation (Mirov “Culm“) having commenced in the Givetian. Shales, conglomerates and the Zabreh crystalline rocks were deformed in low-angle overturned folds associated with thrust faults. Apatite, oval zircons and tourmaline predominate. Garnets are rare and of spessartine-grossular almandine composition with less than 4 % pyrope; this composition recalls the Lugicum gneisses. This composition differs profoundly from other diastrophic Culm rocks of Moravia. It is suggested that the name Mirov “Culm” should be discontinued. A new name – Mohenice Formation – has been proposed (Otava & Sulovsky, 1997). Basic and intermediate tuffs have been found close to the Trnavka Shale, but their stratigraphic position remains problematic.

2.7. Velke Vrbno

(Text-Fig. 6)

This Devonian occurrence provides minimal precise data due to unusually strong polyphase deformation and metamorphism masking most primary structures, and a dearth of useful published information. The lower part of the sequence, prior to metamorphism, consisted of dark shales and calciturbidites. Most previous reports of fossils in the carbonates were based on metamorphic artifacts but the presence of dacryoconarids, cephalopods, echinoids and gastropods has been established; these have been interpreted as Early Devonian (Hladil & Cejchan, 1994). Confirmation and refinement of this age (Praghian) has come from crinoid columnals (Prokop & Koverdynsky, in preparation). A massive occurrence of graphitic shale suggests the possible presence of Silurian; also possible is Ordovician, represented by an interval of quartzites and sandstones, but both suggestions are without supporting biostratigraphic evidence. The upper part of the calciturbidite interval contains argillaceous shales and basic tuffs analogous to the widespread pattern associated with the Daleje Event. In the authors’ opinion, the reconstructed sequence is continued by light coloured carbonates, breccias and conglomerates culminating with metadacites and metarhyolites. A recent reconstruction suggests Givetian to Frasnian docking, fault-slicing of the accretionary prism, and subsequent magmatic arc conditions.

About 400 sections in Moravia, grouped into 42 broad localities (Text-Fig. 3), have been allocated to the above basin-fill types. Some of these sections display unique features (Boskovice Furrow [Hladil 1979, 1992; Hladil et al., 1994]; Moravian Karst [Isaacson & Galle, 1978; Dvorak et al., 1981; Dvorak & Novotny, 1984]). The complete Moravian Devonian bibliography consists of about 3200 publications, many sites tending to be referred to in the international literature.

3. Tectonic Structures

Young brittle tectonics involves both radial and thrust faults. Although often neglected or considered to be unimportant rejuvenation of Palaeozoic faulting, these faults are in fact important. Recent geodetic measurements indicate considerable movements of centimetre magnitude per annum (Vyskocil, 1991); seismic monitoring indicates activity on faults near Sternberk, Moravsky Beroun and Olomouc-Prerov (Havir et al., 1997). The Pliocene Upper Morava Graben came into being oriented NW–SE along contacts between the Drahany and Jeseniky parts of the Culm nappes. New SW dipping half-horsts of Cainozoic age appeared (e.g. Celechovice) and adjacent Culm margins became arched (Musil, 1993). The NW–SE faults of the Jeseniky Mountains are associated with basaltic outpourings; carbon dioxide emanations still mark these lines. That the late Miocene–early Pliocene uplift was very rapid is indicated by erosion of the Badenian foredeep-foreland sediments. Young faults cut the Miocene valleys on the western margin of Moravicum. During the Badenian, the outstretched Carpathian nappes became deeply depressed in E and central Moravia. Movements on faults in Variscan nappes during the middle Miocene reflect thrusting to the S and subsequently to the E, i.e. opposite to orientation of the Carpathian nappes (Hubatka & Krejci, 1996). NNW-directed sinistral strike-slips at Mokra and Lesni lom have their freshly striated fault surfaces overlain by early Miocene sediments.

The Late Cretaceous–Paleogene situation was different: deep canyons incised high elevated blocks. Cretaceous strata were faulted by NW and NNW grabens; southerly directed thrusts have been reported from the Byci skala Cave and near Kurim. The effects of Triassic–Early Cretaceous tectonics on the Variscan rocks have not been deciphered. Large Permian graben and listric faults reflect extension; they caused drops of a few kilometres (Text-Fig. 2/2). Young brittle tectonics are responsible for most of the “fresh” block structures in the Moravian Palaeozoics; faults should not be considered to have been Devonian synsedimentary faults (contra Dvorak et al., 1984). Profound “reworking” of Moravia during the Westfalian was connected with the extensive, gently inclined Moravian Shear Zone (Rajlich, 1974, 1990; Stipska et al., 1995; Melichar, 1995). This megastructure has associated large and small oblique, recumbent, faulted folds (Burinaek & Melichar, 1997; Melichar & Kalvoda, 1997). This dextral shear juxtaposed rather different parts of Moravia (W of the Boskovice Furrow and Jesenik town, and E of them). The western part is characterised by ductile deformation, whereas the eastern part is characterised by mainly brittle deformation (Schulmann, 1990). That Moravia is much more dissected on the W has been long known; Dvorak & Wolf (1979) were the first to point this out on the basis of organic matter in Devonian sediments. Magnetic anisotropy of the Culm sediments shows similar decrease in depth of deformation towards the SE (Hrouda, 1977).

Stipska et al. (1977), modeling rheological sections, found that the crust of Lugicum in NW Moravia had been doubled in thickness and had become more plastic after mantle melting above westward underplated Silesicum during middle/late Viséan (ca 340 Ma). Hladil et al. (1996) and Orel (1996, 1997) proposed more profound oroclinal bending accompanied by destruction of plate structure and pronounced rotation of the terranes. Strong clockwise rotation of wedged and re-fault-sliced terrane fragments was suggested for Moravia (90–120°); even stronger rotation was suggested for some parts in the centre of the Bohemian Massif. These processes culminated during the Namurian. Although faults of this age were effaced by strong Westfalian shear in western Moravia, structures obviously of that age were preserved in eastern Moravia in the Drahany and Jeseniky nappes (Text-Fig. 2/1), though they are strongly overprinted by later structures, e.g. the previously mentioned flat folding and thrusting towards the NE between Brno and Olomouc (Hladil, 1991) and at Valchov near the Boskovice Furrow (Melichar & Kalvoda, 1997).

Viséan and older seams among the units are so dismembered by this profound structural reorganisation that they can be appreciated only from lithologic and deformation data from individual sections, e.g. the events involved in thrusting during the Tournaisian can be inferred from alternating troughs, edge-cliffs and carbonate wildflysch breccias in south Moravian precursors of the late Variscan structures (Dvorak et al., 1984; lithological data from Mokra). Because of this very strong overprint, the Devonian tectonics cannot be readily discriminated by structural analysis. Moreover, the Devonian segments are profoundly dismembered; they represent samples originally from various parts of the basins. The most important information concerns the composition, isotopic data and biostratigraphic ages of the rocks. The tectonic setting (Patocka & Valenta, 1990; Patocka & Hladil, 1997), palaeogeography (Galle et al., 1995) and palaeomagnetism (Krs et al., 1995) provide the most compelling data, but the import of these data is considerably diminished due to the strong overprinting by subsequent deformation. The chemistry of the igneous rocks and composition of basin fill point to remnants of the Early Devonian volcanic arc, and closure of relict basins in W Moravia. More distant southerly sources detached from sequences of the Rheic sea may have been incorporated into the Moravicum and Svratka crystalline units, but there is no unequivocal evidence for this. Volcanic and sedimentary evolution in central and E Moravia provides evidence for Rhenish-type Middle to Late Devonian transtension and thinning of the crust (Hladil et al., 1994). Rare occurrences of unmetamorphosed Silurian and Early Devonian sediments and volcanites on Drahany Upland are aggregated along Namurian and Westfalian seams of Culm units (Kettner & Remes, 1935; Prichystal, 1996; Chadima & Melichar 1998). Composition of volcanites ranges from basalt to trachyte-andesite; geochemistry and REE distribution correspond to within-plate volcanic rocks of several different volcanic centres (Hanzl et al., 1998). Origin of these rocks is unknown; they may have been detached from the basement of distant basins (Ozclon, 1994), local basins (Hladil & Cejchan, 1994) or most likely slided from nappe stacks the same as Viséan–Namurian olistoliths.

4. Palaeomagnetic Data

Palaeomagnetic data derived from Carboniferous rocks of the Bohemian Massif show tectonic deformation (Birkenmajer et al., 1968; Krs 1978); pronounced tectonic deformation of Early and Middle Carboniferous rocks in the Hercynides of western Europe has also been reported (Edel, 1987). It has been shown that the Trans-European Suture Zone played a significant role in producing the pattern of pre-Variscan palaeomagnetic pole positions caused by palaeotectonic rotations of different magnitudes (Krs & Pruner, 1995). Devonian limestone units from the Moravian Zone were recently investigated by two palaeomagnetic teams, one from Prague, the other from Munich. The Czech team investigated 15 sites from 3 localities: Krtiny, Josefov and Celechovice; clockwise rotations of different magnitudes were found (Krs et al., 1995; Tait et al., 1996). Palaeotectonic rotations between 66 and 94° clockwise with respect to the Devonian palaeomeridian of stable Europe were demonstrated (Text-Fig. 7).

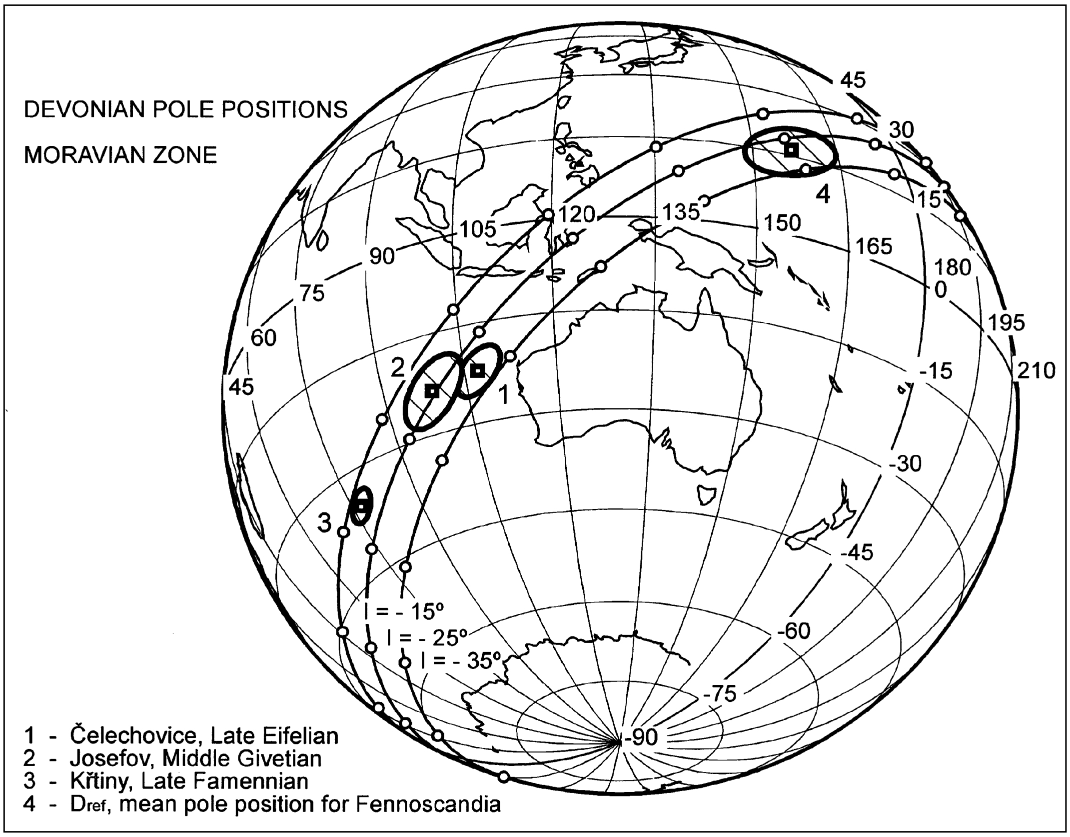
4.1. Site Group 1

(Text-Fig. 3)

Celechovice na Hane (Statni lom abandoned quarry) – location 49°31’56” N, 17°05’14” E, western margins of the Hana lowland 14 km SW of Olomouc; late Eifelian/early Givetian; upward deepening, strongly fluctuating environments corresponding to sabkha, lagoon and platform margin situations; prevalence of dolomitised limestones (dolomite 5–80 %); micrite predominating (60–70 volume-%) over bioclasts; flakes, laminae and micropetaloids indicate bacterial precipitation of part of the micrites; Fe-glauconite exceeds (1–12 weight-%) other smectite minerals. Rocks connected with transgression pulses are slightly dolomitised and dark in colour. Laminites with teepee structures are rich in organic carbon (up to 0.4, average 0.04–0.15 weight-%). The content of silica increases in beds 1–8 (originally quartz silt) and in beds 95 and 100 where iron-rich siliceous cemented coatings indicate emergence. Sulfides and thiospinels have been identified (approx. 0.01–0.2 weight-% EDA). Presence of microcrystalline magnetite has been ascertained, mostly as an accessory. The CAI of conodonts is $>$4.5, indicating maximum temperatures $>$250°C. Cainozoic weathering was avoided in sampling.

4.2. Site Group 2

Josefov-Habruvka: rocky outcrops between the Josefov road junction and Jedovnice Brook karst spring at 49°08’31“N, 16°41’28” E, Krtiny Creek in the Moravian Karst, 15 km NNE of Brno; lower part of the middle Givetian; inception of deepening of the large carbonate platform; mean sedimentation rate 30 m/Ma; rock types:



Text-Fig. 7.
Pole positions and ovals of confidence at the 95 %-probability level for Devonian limestone units of Moravia.
1 = Celechovice, latest Eifelian; 2 = Josefov – Habruvka, early Middle Givetian; 3 = Krtiny Marble Quarry, late Middle Famennian; 4 = D_{ref} reference Devonian pole position (for undeformed parts of Fennoscandia "stable Europe").
The theoretical distribution of pole positions due to palaeotectonic rotations was derived for rocks with inclination values of $I_p = -15°$, $I_p = -25°$ and $I_p = -35°$, respectively.
Pole positions representing the three localities are shown by small squares (solid lines).

packstone/floatstone predominating with 35 volume % amphipora wackestone. Quiet aggradation and early bacterial lithification was cyclic; massive storm re-deposition was subordinate (38 volume %). Moderate amounts of dolomite, Corg., Fe and S decrease upwards (EDA). The organic carbon content is 0.02–0.2 weight-%. Small crystals of Fe-oxides and pyrite are dispersed through the rock. Early diagenetic processes were almost undisturbed by emergence indicated by scarcity of fenestrae and vadose silt structures. The main decrease in relict porosity occurred when the Givetian limestones were buried beneath a few kilometres of Early Carboniferous sediments. Organic matter reflection values of 4–5 %Rmax (P. MUELLER, unpublished data 1987) correspond to maximum temperatures of 250°C. The late Variscan quartz-carbonate hydrothermal veins with Cu-minerals are 1 km to the W (CIZEK, 1977); they had no influence on this section.

4.3. Site Group 3

Krtiny: abandoned Krtiny marble quarry in Krtiny Creek in the Moravian Karst 17 km NE of Brno at 49°08'36"N, 16°44'02"E; Famennian *marginifera* to *praesulcata* conodont zones; deeper ramp environment; nodular limestones (originally lime muds) with occasional intraclastic or bioclastic beds. The interval reflects the global low-stand of sea level following the global Early *marginifera* Zone transgression. The low rate of sedimentation falls within the pelagic range of 2 m/Ma; this is reflected in abundance of phosphatic bioclasts, especially conodonts, but cephalopods, pelagic bivalves, brachiopods, trilobites and ostracods also occur. Re-sedimentation locally of nodules indicates early marine lithification of the lime muds. Layers suspected of having undergone synsedimentary sliding were avoided in sampling. The amount of clay minerals ranges from 8 to 13 w. %. The Al_2O_3/Na_2O ratio in the red matrix of the nodular limestones is unusually high, up to 159; this is interpreted as due to influx of Famennian lateritic soils from the karstified Frasnian platform (DVORAK et al., 1976). The %Rmax values for the eastern side of the Moravian Karst are 4–5 and CAI values 4.5, both indicating maximum temperatures >250°C.

4.4. Methods and Instruments

166 oriented samples were collected from which specimens were prepared for laboratory measurements at the Palaeomagnetic Laboratory of the Institute of Geology, Academy of Science of the Czech Republic, Pruhonice.

Remanent magnetisation and volume magnetic susceptibility were measured using JR-4 and JR-5 high sensitivity spinner magnetometers and a KLY-2 kappa-bridge respectively (JELINEK, 1966, 1973). The MAVACS (Magnetic Vacuum Control System) apparatus was used for progressive thermal demagnetisation (PRIHODA et al., 1980) in steps of 50° between 100° and 400° and steps of 25° between 400° and 500°; heating to 530° and over 530° were used only sporadically. Zijderveld plots of vectors of remanent magnetisation were constructed for all specimens investigated; the vectors were projected onto the horizontal and vertical N–S planes. The normalised values of remanent magnetic moments vs. temperature were plotted, $M_t/M_0 = F(t°C)$, where M_t is the modulus of remanent magnetic moment of the specimen at the specific temperature and M_0 denotes the modulus of remanent magnetic moment of the specimen in its natural state. To verify eventual phase changes of magnetically active minerals during laboratory thermal treatments, normalized values of volume magnetic susceptibility vs. temperature, $\kappa_t/\kappa_0 = f(t°C)$ were also investigated; κ_t denotes magnetic susceptibility of the specimen treated at the respective temperature and κ_0 denotes magnetic susceptibility of the

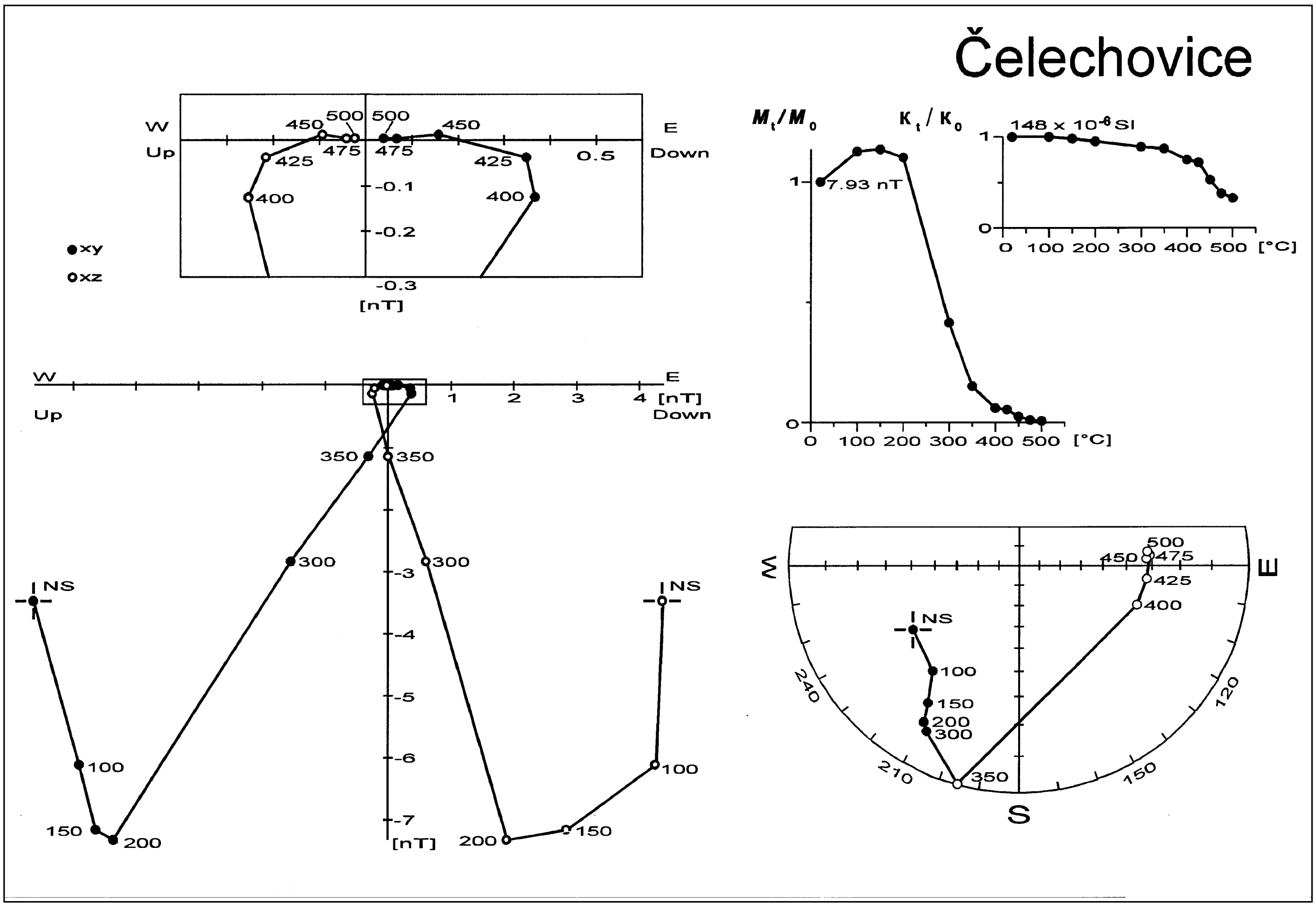
Table 1.
Mean directions of B- and C-components of remanence and corresponding pole positions derived from limestone formations (Moravian Karst facies). See KRS & PRUNER (1995).

The B-component reflects the late Variscan magnetic overprint. The palaeomagnetic directions of the B-components have not been corrected for the dip because the folding of the beds was older than this overprint. The C-component of the magnetic remanence originated during or soon after sedimentation. The latter component corresponds to magnetically unchanged relics of magnetite of probable bacterial origin. Palaeomagnetic directions derived from the Devonian C-component were corrected for dip of rocks.

φ [°] N = present latitude of the locality; λ [°] E = present longitude of the locality; mean palaeomagnetic directions calculated from the set of samples D [°]-declination and I [°]-inclination; α_{95} [°] = semi-vertical angle of cone of confidence at the 95 % probability level (FISHER, 1953); k = precision parameter; δm, δp = ovals of confidence; n = number of samples; calculated palaeopole positions; φ_p = palaeolatitude and λ_p = palaeolongitude.

locality and rock type	stratigr. age (cf. possible ages in millions of years *)	geographical coordinates		magnetic compo-nents	mean palaeomagnetic directions		α_{95} [°]	k	n	palaeomagnetic pole positions		ovals of confidence	
		φ [°] N	λ [°] E		D [°]	I [°]				φ_p	λ_p	dm [°]	dp [°]
Křtiny	Late Famennian	49.143	16.737	B	198.3	-9.9	2.9	83.3	30	43.20°S	8.67°W	2.93	1.48
nodular limestone	(? Approx. 369 Ma)			C	133.9	-19.1	5.8	25.9	25	35.17°S	77.03°E	6.05	3.15
Josefov	Middle Givetian	49.142	16.691	B	217.7	-7.4	2.0	69.5	70	34.44°S	31.03°W	2.01	1.01
Amphipora limestone	(? Approx. 384 Ma)			C	111.4	-24.4	6.0	11.7	52	23.58°S	98.89°E	6.43	3.44
Čelechovice	Eifelian / Givetian	49.532	17.087	B	221.9	8.7	2.6	45.8	66	25.06°S	30.23°W	2.62	1.32
dolomitic limestone	(? Approx. 395 Ma)			C	104.8	-31.1	4.0	39.2	34	22.24°S	107.17°E	4.47	2.5

(*) compared with: Tucker, R.D., Bradley, D.C., Ver Straeten, C.A., Harris, A.G., Ebert, J.R., and McCutcheon, S.R., in press, New U-Pb zircon ages and the duration and division of Devonian time. Earth & Planetary Science Letters. 1998.



Text-Fig. 8.
Thermal demagnetisation results exemplified by sample No. 7062A2, from Celechovice, latest Eifelian, Statni lom Quarry.
Left: Zijderveld plots; NS = natural state; Upper right: normalized values of remanent magnetic moment and volume magnetic susceptibility plotted against temperature t (°C); M_t = remanent magnetic moment of the specimen demagnetised at the temperature t; M_0 = remanent magnetic moment of the specimen in natural state; κ_t = volume magnetic susceptibility of the specimen demagnetised at the temperature t; κ_0 = volume magnetic susceptibility of the specimen in natural state.
Lower right: stereographic projection of directions of remanent magnetisation of the specimen in natural state (NS) and after progressive thermal demagnetisation.

specimen in its natural state. Three components of remanent magnetisation were derived using multi-component analysis of remanence (KIRSCHVINK, 1980), directions of separated remanence components and statistically evaluated mean directions (FISHER, 1953) were plotted in stereographic projection. The statistically calculated mean directions of separated remanence components were evaluated in combination with fold tests.

The limestones from Celechovice, Josefov and Krtiny are slightly magnetic rocks displaying three components of remanent magnetisation (A–C). The A-components of recent viscous origin are fairly low; these can be separated within the interval of temperatures from 20° up to 150–200°C. The B-components differ by having very shallow inclinations; these are typical for temperatures from 150–200° up to 350–400°C. Their declination values oscillate from approximately 200 to 220°; these directions indicate their Variscan origin. The most important C-components occurred at temperatures between 400–425°C and 500–530°; these components are less pronounced but readily separated – see typical results of progressive thermal demagnetisation (Text-Figs. 8 to 10; Table 1). The assumption that the C-component is primarily Devonian results from multi-component analysis, fold tests, rock composition and history. This early magnetisation is connected with small bacterial biocrystals of magnetite; the rocks are depleted in early diagenetic siderite, the usual "host" in deep slope deposits (ELLWOOD et al., 1988). Not all Devonian rocks in Moravia have this early C-component; data from the 3 localities are the best presented in the past decade.

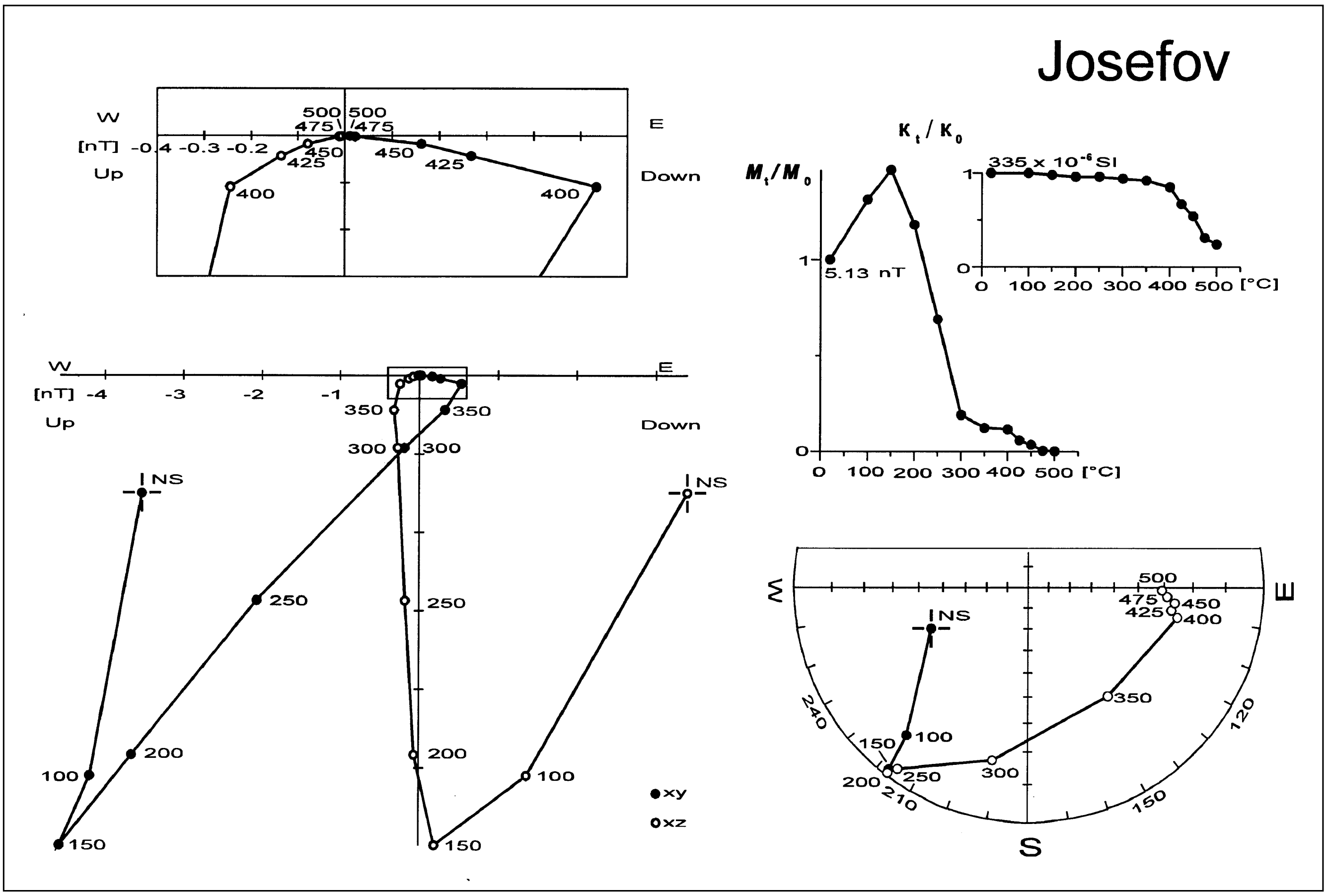
4.5. Results

The mean directions of the B- and C-components are characterised by good stability and narrow ranges within the dimensions of the sites (80 m bedding-parallel × 20 m in section). The B-components indicate a strong late Variscan overprint, the derived pole positions and their scatter indicating an overprint developed in the Late Carboniferous, possibly continuing into the Early Permian.

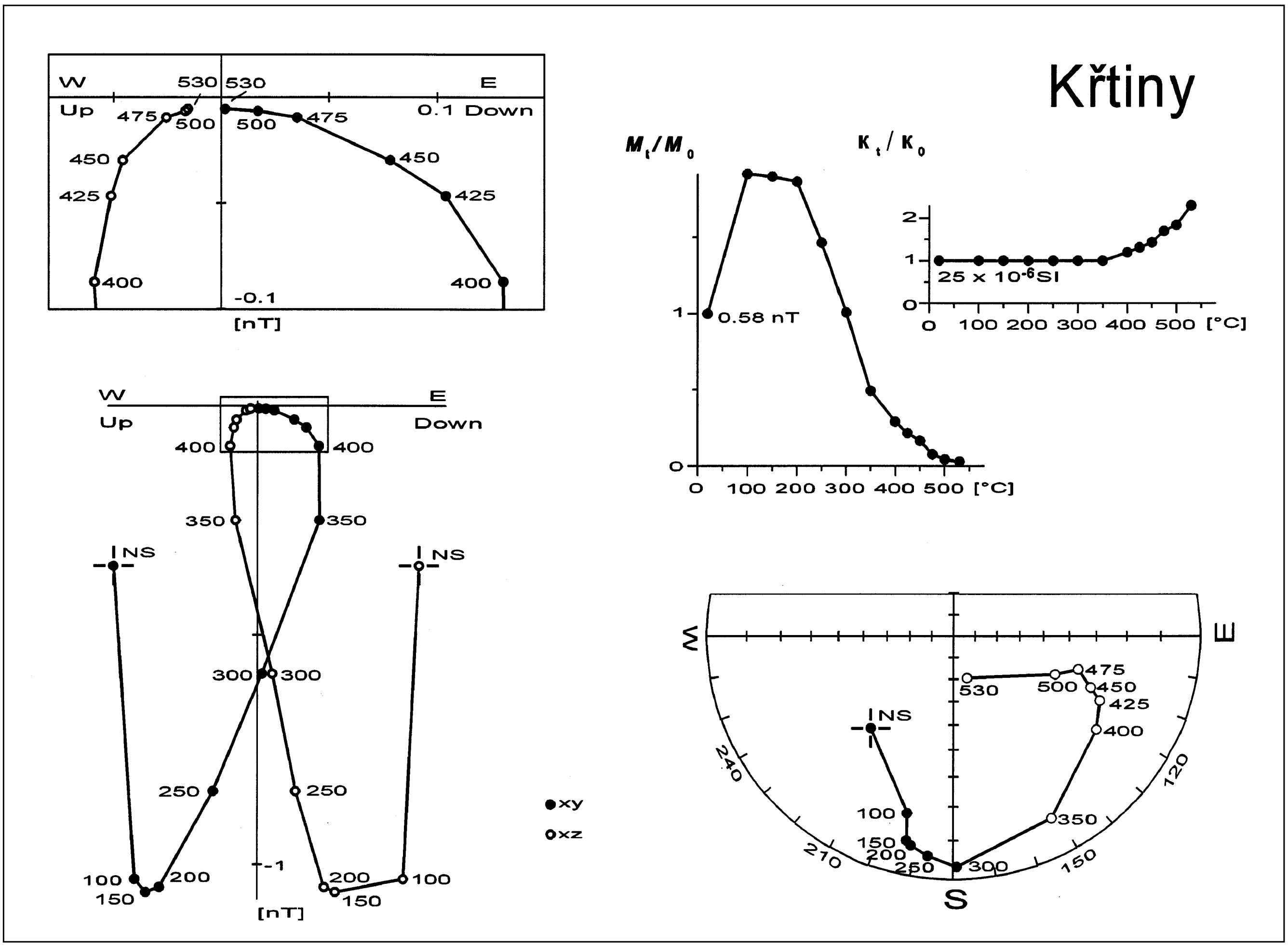
The C-components show pronounced palaeomagnetic declinations (D_p) indicating clockwise rotations. The values of D_p, the angle difference between the Devonian and Recent meridians, are 105° for the Eifelian–Givetian (Celechovice), 110° for the Middle Givetian (Josefov) and 134° for the Late Famennian (Krtiny). We stress that these sites are from different tectonic blocks and are different in age; the one feature in common is that they belong to the Moravian Devonian platform.

The palaeomagnetic measurements are consistent with the facies and tectonic models developed in the late 1980s. Maximum tectonic rotation occurred during the latest Devonian and Early Carboniferous (HLADIL et al., 1991). The discovery of dynometamorphosed pebbles of Early and Middle Devonian deep basinal shales in Viséan diastrophic sediments of the Drahany Upland (CHLUPAC & LANG, 1990) is consistent with this scenario.

The Early Permian palaeomagnetic pole positions calculated for the Bohemian Massif and its cratonised neighbourhood fall within a narrow interval (KRS, 1968). Values for the Piedmont basin, for example, are φ_p = 40.12°N, λ_p = 167.22° with the semi-vertical angle of confidence 5.3°.



Text-Fig. 9.
Thermal demagnetisation results exemplified by sample 7081A1 from Josefov near Habruvka, late middle Givetian section at Karst Springs of the Jedovnice Brook.
See caption for Figure 8.



Text-Fig. 10.
Thermal demagnetisation results exemplified by sample No. 7112A1, from Krtiny.
Late Middle Famennian, section in the abandoned Krtiny "Marble" Quarry. See caption for Figure 8.

Mean plate rotation values for the Early Permian cratonised Bohemian Massif are 25° by reference to the "stable" plate rotation from Early Permian to Recent. The pre-Permian rotations were calculated from the difference between the Devonian C-components and the mean Early Permian directions. Thus, the "total" Variscan clockwise rotations within the orogen are 80° for Celechovice, 86° for Josefov and 109° for Krtiny. These values consist of the tectonic rotation within the orogen and rotation of the plates on the globe, both from the Devonian to Early Permian.

Reference to the Devonian palaeogeographic net, based on "stable" cratonic northern Europe is necessary for calculation of "pure" Variscan palaeotectonic rotation. The reference Devonian pole position (Dref) is φ_p = 16.3°N, λ_p = 156.5° and α_{95} = 7.5°. The mean plate rotation values for the Devonian of this "stable" northern Europe are ca. 40° by reference to the "stable" plate rotation from Devonian to Recent. If this net of "stable" Devonian Europe is taken as reference, the "pure" tectonic rotations within the orogen, based on Devonian rocks, are 65° for Celechovice, 71° for Josefov and 94° for Krtiny, with error-bars of only a few degrees (Table 1).

Three theoretical paths of rotated pole positions were calculated for D_p from 0 to 360° in steps of ΔD_p = 20° for inclination values of I_p = –15°, I_p = –25° and I_p = –35°, respectively. The real pole positions calculated for the Moravian Karst match, within the range of statistical error, the distribution of theoretically derived pole positions.

The palaeogeographic latitudes were calculated from mean inclination values of the early magnetisation C-components. The late Eifelian rocks of Celechovice indicate 18.9°S, the middle Givetian of Josefov 14.8°S and the late Famennian of Krtiny 11.7°S. These Devonian palaeolatitudes are much farther south in the southern hemisphere than formerly assumed.

5. Devonian Biodynamics in Moravia

Most data concern marine faunas. In general, Praghian to early Eifelian coral associations were more endemic than during the Givetian and Frasnian (Pedder & Oliver, 1990). This, in our opinion, reflects mainly low sea levels during the Emsian (Morrow et al., 1995). Data from Hladil (1984), May (1995) and Sarnecka (1997) accord with Emsian to Frasnian thamnoporids migrating from the Urals and the Kuznetsk Basin along several seaways between the Gondwanan and Laurussian margins. Finger-like routes extended towards the peri-Gondwanan Cantabrians as well as along both shores of the Rhenish basins. During the Eifelian, this W-directed coastal migration was stronger in the N and was characterised by natalophyllids and coenitids; it extended from the S Urals and Kuznetsk Basin to the Holy Cross Mountains, Moravia and probably to the Eifel (Hladil, 1985; Sarnecka, 1997). During the Emsian–Eifelian transition, large favositids (e.g. *Favosites gilsoni*) started to dominate the Rhenish basins; they are also known from the Boskovice Furrow and Konice. Although many rugose and tabulate corals extended over large areas after the Givetian transgression, some widely distributed species (e.g. *Calceola sandalina* and the exclusively Givetian *Caliopora battersbyi*) preferred shelves of the Rhenish basins, including the Moravian Karst. Ibero-Maghrebian relations (Y. Plusquellec, pers. comm. 1997) commenced in the Praghian–Eifelian in both carbonate and clayey slope facies. *Kerforneidictyum* and *Pterodictyum* are typical of such faunas in Morocco, Spain and the Barrandian. Moravian pleurodictyids are in need of revision, but they appear to be closer to those from Rhenish rather than Barrandian facies. Different affinities are indicated for the caliaporid coral *Luciaella* (E. Fernandez-Martinez & Hladil, in preparation); it appears to have originated in the late Emsian of the Cantabrian region, reaching the Barrandian during the middle Eifelian possibly by a NE-directed current. This direction of immigration seems not to have occurred for Moravia. Frasnian alveolitids have two features: a pronounced differentiation across the shelf, and long migration routes along the coast. Devonian benthic faunas are in accord with a barrier between the Barrandian and Moravian basins, as well as differences between the Moravian Karst – Konice and Horni Benesov (Galle et al., 1995). Differences in corals have been noted for Tisnov and Vrbno, but data are still insufficient due to deformation and metamorphism of the host rocks.

Occurrences of the brachiopod *Tropidoleptus* are peculiar, linking the Praghian–Emsian of the Jeseniky Mountains with the Rhenish Massif, the Appalachians and Bolivia (Isaacson & Chlupac, 1984; P.E. Isaacson, pers. comm. 1997). This feature is not unique; the so-called Siegenian fauna spread to Spain (Garcia-Alcalde et al., 1990, and pers. comm. 1997). The Dalejan sea level rise produced an increase in similarity of brachiopod faunas in basinal clayey facies. The Horni Benesov assemblage has a high proportion of Bohemian as well as cosmopolitan species (Havlicek & Pek (1986). V. Havlicek (in Havlicek & Vanek, 1998) explains this as being a result of extension of Boucot's Urals Region fauna; these faunas are viewed as being linked by a common source rather than resulting from direct connenction. The "Bohemian" genera. *Plectodonta (Dalejodiscus), Holynatrya* and *Chynistrophia* are accompanied by undetermined chonetids and inarticulate brachiopods (V. Havlicek, pers. comm. 1996). The Horni Benesov assemblages are also linked to Rhenish–N Harz faunulae (Galle et al., 1995). A significant fauna from Petrovice in the Nemcice-Vratikov belt ranges from ?Lochkovian and Praghian to early Eifelian (Havlicek & Mergl, 1990). Rhenish genera dominated in this calm-water subtidal environment with abundant benthic faunas; Bohemian elements are rare (*Sieberella, Glossinotoechia*). The presence of *Arduspirifer mosellanus gracilis* and *Glossinotoechia henrici*, for example are Praghian species. Emsian brachiopod faunas are diverse, with dominance of fixosessile, quasi-infaunal, infaunal and free-living types (Havlicek & Mergl, 1990); assemblages show both Bohemian and Rhenish relationships. The Middle and Late Devonian trilobite genera determined from Moravia (Chlupac, 1966, 1969) may be similarly interpreted (Galle et al., 1995); trilobite occurrences, however, are strongly dependent on facies (Chlupac, 1983).

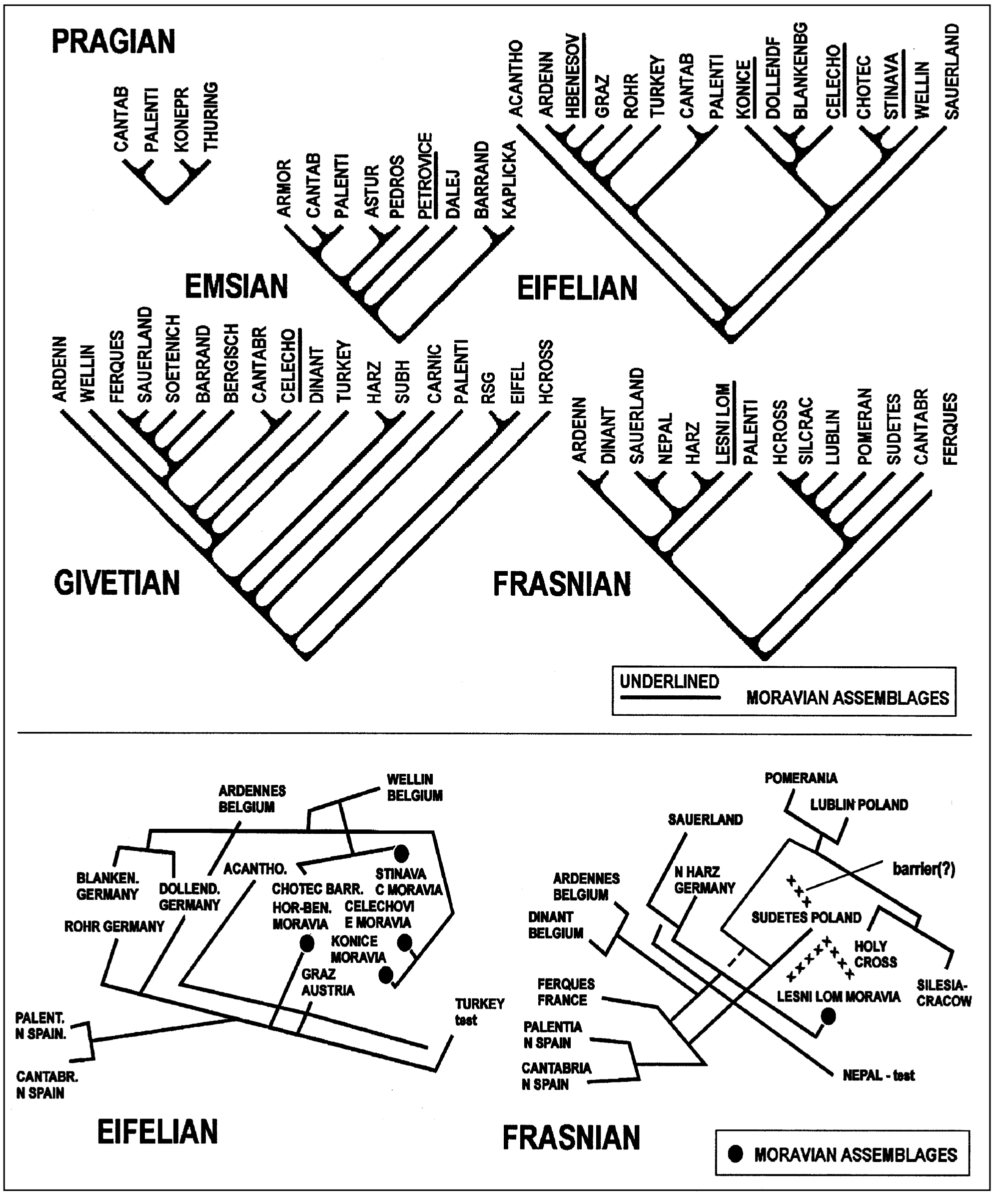
The oldest Moravian conodonts are from Ludmirov near Konice. This Emsian–Eifelian association includes *Polygnathus costatus partitus, Po. c. costatus, Po. angusticostatus, Po. trigonicus* and *Icriodus rectirostratus* (J. Kalvoda, unpublished data 1996). O. Friakova (in Dvorak et al., 1983) found another old association at Ridec in the Sternberk-Horni-Benesov belt: *Icriodus corniger leptus, I. rectirostratus* and *Po. bultyncki*. Conodonts diversified later except for the late Eifelian to early Givetian slope facies dominated by varieties of *Po. linguiformis* (Babek, 1996). The highest abundance and diversity of conodonts occurs in the lenticular cephalopod limestones of the Frasnian to Famennian cover of the former platform margins (Krejci, 1991). On the other hand, occasional Famennian deposits with many hiatuses in the platform interior, S of Ostrava and S of Brno, have light coloured, cross-bedded limestones. The Late Devonian fauna is mostly cosmopolitan or at least broadly correlated with regions in the neighbourhood; it is often accompanied by shark teeth (M. Ginter in Hladil et al., 1991). This supports ease of interchange of the conodonts between the Moravian Rhenish-type basin and the world ocean.

Moravian spore assemblages of continental plants are almost unknown for three reasons: Organic matter in many platform sediments was decayed and oxygenated; most of the rocks have been affected by tectonic shear; and there have been few studies focused on Moravian outcrops. Although these constraints exist, M. Vavrdova (in Hladil et al., 1988) documented several associations in JR-10 borehole at Rymarov in Vrbno facies: *Geminospora* spp. and ?*Samarisporites* spp. – Middle to Late Devonian; *Actinosporites acanthomammilatus* dominated assemblage – Middle Devonian; *Grandispora* spp., *Dibolisporites* spp. and *Geminospora* spp. – ?Late Devonian; *Apiculiretusispora minor, Retusotriletes rotundus* and *Emphanisporites novellus* – Middle/Late Devonian. *A. acanthomammilatus* and *E. novellus* link the Vrbno facies to the Rhenish and more generally Euramerica region. Spores and acritarchs from Rymarov in northern Moravia do not diverge in any significant way from those of the Ardennes-Rhenish region. Most surprising, however, is that the Barrandian Praghian to Givetian palynofloras are so similar, if not identical to those of the Ardennes-Rhenish region (J. Bek based on papers by Lele, 1972; McGregor, 1979; and Vavrdova, 1989). This similarity of spores contrasts with the fairly dissimilar marine faunas (Galle et al., 1995). It accords with some sort of barrier as regards the marine faunas, but ease of wind-driven transport of spores between coastal marshes.

Though many Moravian Devonian faunas have been recently revised, the database faunas are still rather incomplete. We have used only lists of genera of rugose and tabulate corals, stromatoporoids, brachiopods, trilobites, conodonts and foraminifers from a few tens of sites. Few Moravian and compared assemblages have been evaluated as to quality (necessary for improving reliability of computed relationships). This notwithstanding, we have used the PAUP program to obtain a heirarchical order of similarities for faunas of the European Variscides. Time-slices used were as long as stages. Faunal lists for comparison were extracted from literature, usually post-1980 and, where possible, confirmed by our own study or expertise. This is the reason for absence of some areas, particularly those in the former USSR. The database is available on request from A. Galle.

We are unable to make comparisons for the Lochkovian. Lists for the Praghian are still too "spotty" for computing. The Emsian site Petrovice in the Nemcice-Vratikov belt was compared with assemblages from the Barrandian, Armorica and the Iberian Peninsula. The last form a relatively homogeneous cluster distinct from the Barrandian assemblages. The Dalejan assemblage is clearly similar to the Iberian assemblage as regards bathymetry

Text-Fig. 11.
Interpration of results calculated by PAUP program for all fossil genera.
Eifelian and Frasnian. So-called Wagner trees inferred evolution of relationships under the principle of maximum parsimony. They are interpreted to dichotomizing diagrams (above) and “geographic” diagrams (below).



(both reflect the Dalejan Event). Eifelian localities in Moravia, the Barrandian, the Rhenish Massif, the Ardennes and the Carnic Alps were also examined. Diminishing differences between the peri-Gondwanan and Laurussian assemblages are characteristic for the Eifelian. Iberian localities still cluster together; the Moravian and Rhenish localities are close to each other but, on the other hand, Laurussian Horni Benesov, the Ardennes and the Rhur in the Rhenish area are close to the peri-Gondwana Carnic Alps and Turkey. In the Eifelian, the contrast between the Barrandian *Acanthopyge* Limestone and the Chotec Limestone is interesting. We explain these differences by differing bathymetry. The fauna from the *Acanthopyge* Limestone has interesting Givetian affinities, though the conodont data indicate it to be Eifelian – with the exception of its uppermost beds. If this fauna is compared with other Givetian assemblages, the *Acanthopyge* Limestone is not unusual. It is therefore inferred that for benthic faunas there was stepwise migration of European Givetian precursors into the Eifelian of the Barrandian; comparable forms arrived in Moravia during the Givetian (Text-Fig. 11).

Givetian assemblages from Moravia, the Rhenish Massif, the Ardennes, N France, the Harz and the Holy Cross Mountains, and the peri-Gondwanan Barrandian, Iberian Peninsula, Carnic Alps and Turkey have also been studied. Although most of the sites are Laurussian, the difference between peri-Gondwanan and Laurussian assemblages has disappeared. We interpret this to reflect tectonic shortening of the basins and increased ease of interchange between faunas rather than a simple effect of sea level rise.

Among Frasnian localities, Laurussian ones predominate: Moravia, the Rhenish Massif, the Ardennes, NE France, the Harz and several Polish localities. The occurrences cluster homogeneously on the resulting graphic “trees” due to the cosmopolitan nature of the assemblages; peri-Gondwanan and Laurussian differences are not apparent. Clustering of Polish sites is conspicuous, possibly indicating a tendency for the Frasnian sites of Moravia and Poland to separate (Text-Fig. 11). This is important in considering the palaeomagnetic data for tectonic rotation of the Moravian Karst as several discrete blocks (KRS et al., 1995; TAIT et al., 1996).

6. Conclusions – Outlines of Palinspastic Reconstruction

Lithofacies and fauna support the Laurussian affinities of the Moravian Karst, Nemcice-Konice, Horni Benesov, Rymarov-Vrbno and the Tisnov facies. The patterns of faunas and facies are consistent with interpreting them as parts of a formerly large but now tectonically dismembered Rhenish-type basin developed on thinned crust undergoing dextral transtension during the Emsian to Early Carboniferous.

A continental rift with shallow seas changed to a deep but segmented basin during the Middle and Late Devonian communicating with other Rhenish-type basins along the southern Laurussian margin. It appears to have extended several hundred kilometres E–W. Palaeomagnetic data indicate strong clockwise tectonic rotation and wedging of individual massifs. Closure of this Rhenish-type basin and cessation of diastrophic sedimentation occurred during the Viséan/Namurian; formerly distant facies-tracts became juxtaposed. Large palinspastic breaks sever the parautochthonous and alochthonous Devonian rocks in the Potstat-1 borehole and Konice sections. Profound lacunae in facies detach particularly the Vrbno, Horni Benesov and Moravian Karst facies.

Other basins are suggested by the facies of various outcrops in western Moravia-Silesia, but additional data are needed for confirmation or otherwise. The Givetian Mestecko Trnavka Shale with its cover of diastrophic sediments, the Mohelnice Formation, may be interpreted as documenting Givetian–Frasnian collision like in the Sudetic region in the northern part of the Bohemian Massif. The distance during the Givetian between the Mestecko Trnavka – Mirov and Tisnov facies is indicated by entirely different tectonic setting; the Tisnov facies was on a relatively stable block slightly reflecting cessation of a distant arc. Large segments of Devonian continental crust and ocean floor had been removed in relation to Variscan joining of these two facies. Significantly, the nearly Letovice ophiolite to the SSW is believed to have formed in an oceanic basin separating the Brunovistulian–Moravian and Moldanubian blocks (Hoeck et al., 1997). Velke Vrbno represents another situation: a Barrandian-like sequence accreted to a volcanic arc during the Devonian.

Large palinspastic breaks of several tens to a few hundred kilometres are explained by strong strike-slip wedging and reworking of terranes controlled by clockwise rotation and oroclinal bending. Large pieces of crust were uplifted, dissected and finally erased from the structure; large slices of former Devonian basins are absent, probably underplated or consumed in mantle.

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