Microfacies analysis of Devonian to Lower Carboniferous carbonates and its impact on the interpretation of internal architecture of the Konice-Mladeč Belt, Moravia, Czech Republic

Mikrofaciální analýza karbonátových hornin devonu a spodního karbonu a její dopad na interpretaci vnitřní stavby konicko-mladečského pruhu, Morava, Česká republika (Czech summary)

(6 text-figs., 1 plate)

ONDŘEJ BÁBEK

Přírodovědecká fakulta Univerzity Palackého, Tř. Svobody 26, 771 46 Olomouc, Czech Republic

Devonian to Lower Carboniferous carbonate sediments of the central and southern parts of the Konice-Mladeč Belt are composed of 15 microfacies types. The microfacies have been grouped into 4 microfacies associations according to their spatial and temporal relationships. The microfacies associations originated in specific depositional environments: microfacies association A represents distal fore-reef carbonates; microfacies association B represents fore-reef slope to basin plain carbonates; microfacies association C represents distal carbonate slope deposits and basin plain carbonates, and microfacies association D represents proximal carbonate slope deposits. The carbonate complex of the central part of the Konice-Mladeč Belt (Transitional Development) is composed of succession of microfacies associations A and B. Succession of microfacies associations B, C and D constitute the carbonate complex of the southern part of the Konice-Mladeč Belt (Basinal Development). In our opinion both the areas represent originally separated units consolidated during the Variscan orogeny along a significant tectonic line running inside the Konice-Mladeč Belt.

Key words: Devonian, Carboniferous, deep-water carbonates, microfacies analysis, depositional environment, facies disjunction, tectonic boundary, Konice-Mladeč Belt, Bohemian Massif

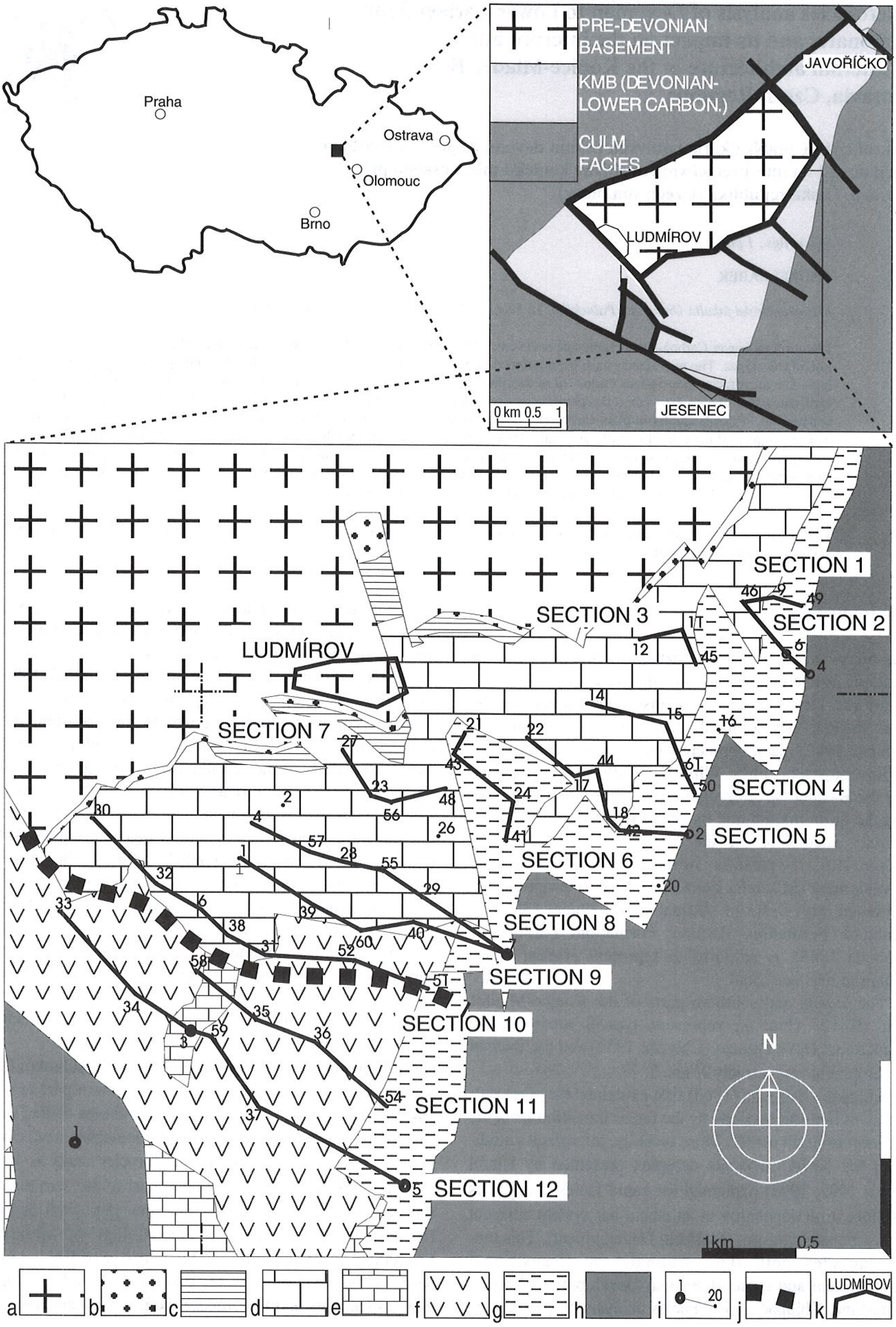
1. Introduction

The moravian pre-flysch paleozoic system has been subdivided into three basic stratigraphic successions - "Platform Development", "Transitional Development" and "Basinal Development" (see review in Zukalová - Chlupáč 1982), each characterized by a typical sequence of litostratigraphic units. While the Platform Development and the Basinal Development are considered as representing the basin margin and its center respectively, the sedimentary succession of the Transitional Development, where litostratigraphic units typical of Platform Development (Macocha Formation, Líšeň Formation) are combined with those of Basinal Development (Stínava-Chabičov Formation, Ponikev Formation) (Chlupáč - Svoboda 1963), is assumed to represent gradual facies transition between them.

The central and southern parts of the Konice-Mladeč Belt (KMB) (Fig. 1) represent typical areas of the Transitional Development (Chlupáč 1959) and the Basinal Development respectively (Figs. 2, 3).

Chlupáč - Svoboda (1963) first explained the close proximity of both successions by the facies transition from the platform to basin center. More recently, microfacies studies of the KMB carbonate complex presented by Hladil (1986, 1992, 1993) explained the rapid facies changes as resultant from deposition in an island-bar system adjacent to a carbonate platform (Platform Development). This model includes both the carbonates of Transitional Development and those of Basinal Development (Jesenec Limestone, Chlupáč 1964). Facies analysis of several carbonate sections in the Transitional Development area, supported by conodont biostratigraphy, revealed a deepening upward succession from distal fore-reef through base-of-slope into pelagic basin-floor environments (Bábek 1996). The carbonate complex was deposited on the slopes of the extensive carbonate platform covering for a substantial time span the area of the Platform Development. In contrast, facies succession of the Jesenec Limestone, as well as its stratigraphic range, significantly differ from the carbonate stratigraphies visible in Transitional Development, suggesting that the carbonate sedimentation was controlled by different factors in both areas (Bábek 1995). Carbonates of the central and southern part of the KMB display significant discrepancies. Although Chlupáč - Svoboda (1963) and Hladil (see above) believed that the different stratigraphies could be explained by lateral facies changes, the very different overall stratigraphic frameworks and different age ranges of the limestones in both areas do not allow for a simple, continuous basin margin - basin center facies transect to be imagined over such a small distance.

In an attempt to disclose the internal architecture of the carbonate complex in the central and southern part of the KMB, thin sections from numerous boreholes drilled during the long-term survey for building materials were evaluated. Despite its limitations, microfacies analysis was chosen as the basic approach since most of the core material is lost. The thin sections are now deposited at the Department of Geology and Paleontology of Masaryk University, Brno. The aim of this paper is twofold: 1) to describe the basic microfacies types and related microfacies associations and to compare them with facies and fa-


Praha
Ostrava
Olomouc
Brno
PRE-DEVONIAN BASEMENT
KMB (DEVONIAN-LOWER CARBON.)
CULM FACIES
JAVOŘÍČKO
LUDMÍROV
JESENEC
0 km 0.5 1
SECTION 1
SECTION 2
SECTION 3
SECTION 4
SECTION 5
SECTION 6
SECTION 7
SECTION 8
SECTION 9
SECTION 10
SECTION 11
SECTION 12
LUDMÍROV
N
1km 0,5
a b c d e f g h i j k

← Fig. 1. Simplified geological map of central and southern parts of the Konice-Mladeč Belt
a - basement (Kladky Unit); b - Devonian basal siliciclastics; c - marine siliciclastics (Stínava-Chabičov Formation); d - carbonates of the Transitional Development (Macocha Fm., Líšeň Fm.); e - Jesenec Limestone; f - volcanites; g - radiolarian shales and silicites (Ponikev Formation); h - flysch siliciclastics (Culm facies); i - transverse sections (see text) with black points marking shallow mapping boreholes (LV boreholes with appropriate number), and rings marking deep boreholes (KDH boreholes with appropriate number); j - tectonic line separating Transitional and Basinal Development (see text); k - village. Adopted from Dvořák et al. (1993) and modified

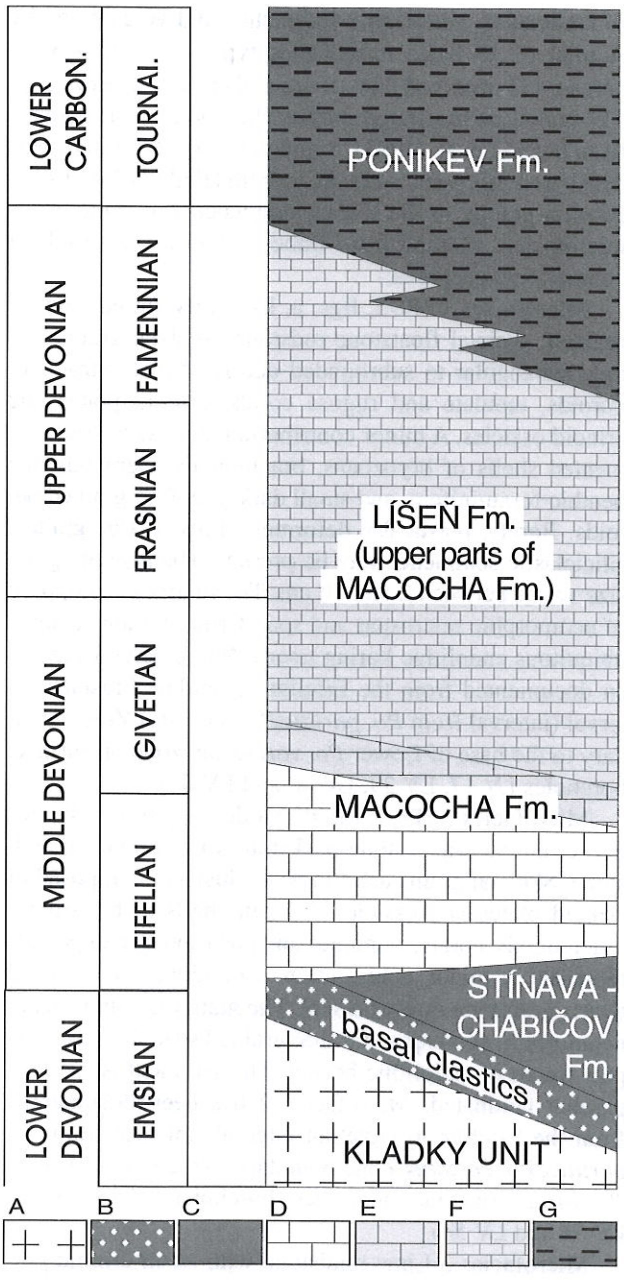


Fig. 2. Stratigraphy of the Transitional Development in the central part of the Konice-Mladeč Belt
A - basement (Kladky Unit); B - terrestrial and marine siliciclastics; C - marine siliciclastics; D - distal fore-reef carbonates; E - upper slope carbonates; F - carbonate slope to basin plain deposits; G - radiolarian shales and silicites

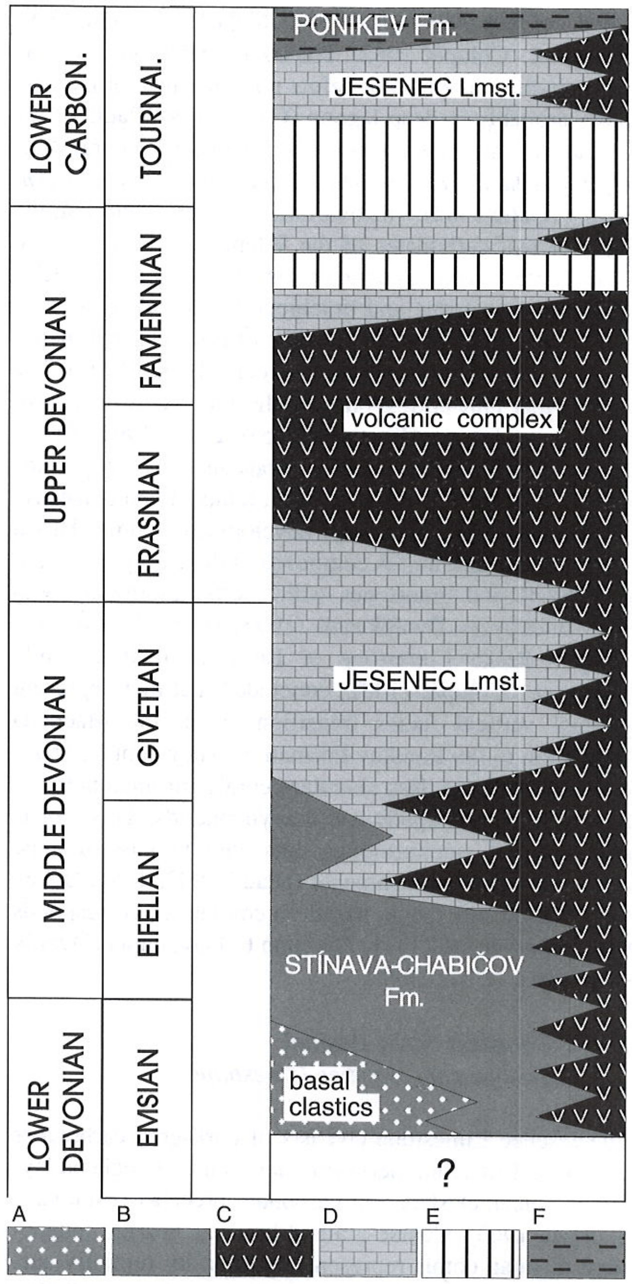


Fig. 3. Stratigraphy of the Basinal Development in the southern part of the Konice-Mladeč Belt
A - marine (? and terrestrial) siliciclastics; B - marine siliciclastics; C - volcanic rocks; D - carbonate slope deposits; E - hiatus; F - radiolarian shales and silicites

cies associations previously described from the surface occurences in the KMB, and 2) to reconstruct the microfacies associations in boreholes in a 3D model with emphasis on disclosing the position and nature of the boundary between both the carbonate stratigraphies.

1. 1. Carbonates of the Transitional Development

The vertical succession of carbonates in the Transitional Development area resembles succession of litostratigraphic units typical of the Platform Development. These include Macocha Formation and Líšeň Formation (Fig. 2). The lowermost unit, composed of dark-grey biomicrites with abundant fauna of thick-walled brachiopods, tabulate and rugose corals, stromatoporoids, bryozoans and echinoderms (Galle 1995, Hladil 1986, 1992, 1993), has been assigned to "*Stringocephalus* Limestone" (Josefov Lmst.) of Macocha Formation (Chlupáč - Svoboda 1963, Zukalová - Chlupáč 1982). The coral- and stromatoporoid fauna indicate deposition below normal- and storm wave-base, probably in deep lagoon (Galle 1988, Hladil 1992). The age of this assemblage is the Late Eifelian coral Zone *Cyatophyllum (Acantophyllum) dianthus - Calceola sandalina* (Galle 1982). The overlying unit represents equivalents of reef carbonates of the Vilémovice Limestone of Macocha Fm. with tabulate corals, stromatoporoids, echinoderms, bryozoans and brachiopods. The alternation of these two main facies is indicative of fore-reef talus deposited in a distal fore-reef environment (Bábek 1996). The age of this unit corresponds to the interval from Lower Eifelian to Lower Givetian (Bábek et al. 1994, Bábek 1996). Very abundant tabulate corals and stromatoporoids can be correlated with the Eifelian faunal assemblages typical of early stages of reef development (comp. Hladil 1986a). The third unit is composed of dark-grey, thin-bedded, biodetrital limestones with cherts, alternating with shale interlayers. Dvořák et al. (1993) assigned them to the Hády - Říčka Limestone of Líšeň Formation, while Zukalová - Chlupáč (1982) concluded that they represent gradual vertical facies transitions from the Macocha Formation to the Ponikev Formation. They contain abundant echinoderms, less abundant corals, stromatoporoids, bryozoans, brachiopods and dacryoconarids. This unit is composed of calciturbidites deposited in base-of-slope and basin-plain environments (Hladil 1993, 1994, Bábek 1996). Their age range, based on conodonts, corresponds to the interval from Early Givetian to Famennian (Dvořák et al. 1993, Bábek 1995).

1. 2. Carbonates of the Basinal Development - Jesenec Limestone

The Jesenec Limestone consists of dark-grey carbonates with abundant echinoderm fragments and intercalated layers of volcaniclastics and carbonate breccias (Chlupáč - Svoboda 1963). Coarse-grained breccias bearing redeposited frasnian corals represent high density turbidity current deposits and debris flow deposits (Bábek 1995a). Microfacies and facies analysis of the Jesenec Limestone suggest deposition in a carbonate slope environment distinctly influenced by the volcanism. Based on conodonts, the age range of the Jesenec Limestone is within the interval from Late Eifelian to Late Tournaisian (Bábek et al. 1994) (Fig. 3). The microfacies characteristics of the Devonian part of succession is similar to that of the youngest carbonate deposits of the Transitional Development (Hladil 1986). The Lower Carboniferous limestones are separated from the Devonian ones by a non-depositional and/or erosional hiatus.

2. Microfacies analysis

2. 1. Description of microfacies and their stratigraphic range

The borehole material included almost 600 thin sections of carbonates, siliciclastic sediments, and volcanic rocks. A total of 15 basic microfacies types were recognized among 452 observed thin sections of carbonate sediments. The conodont biostratigraphy of the boreholes is adopted from Dvořák et al. (1993). Supplementary biostratigraphic data based on corals, were taken from Hladil (1986, 1994). Biostratigraphy of the surface equivalents of some of the microfacies, adopted from Bábek (1995), were used for comparative purposes.

Microfacies 1 (Pl. I, figs. a, b) Poorly sorted, coarse-grained, skeletal floatstone-rudstone. Skeletal grains include subangular to subrounded debris of platy stromatoporoids, tabulate and rugose corals, crinoid plates and crinoid ossicles. A minor contribution is provided by fragmented shells of bryozoans, brachiopods, ostracods and benthic foraminifera, and small dark grey fine-grained peloids. Rarely, plastically deformed chips of fine-grained siliciclastic sediments may be present. The average grain size varies between 2 and 10 cm. The matrix is composed of neomorphic microspar and spar. Crinoid grains display ubiquitous endolithic boring traces. Microfacies 1 has been documented from the Eifelian to Middle Frasnian interval (interval from *Po. partitus/Po. costatus* Zone boundary to the base of Lower *Po. varcus* Subzone on surface; boreholes LV 17, LV 29, LV 46 and LV 51).

Microfacies 2 (Pl. I, fig. d) Moderately to poorly sorted, crinoidal wackestone-packstone to fine-grained rudstone. Skeletal grains are almost exclusively composed of crinoid plates and ossicles. Broken shells of bryozoans, brachiopods, corals, ostracods and gastropods, and peloids represent a minor contribution. Conodonts and detrital quartz grains are rarely present. The matrix is composed of neomorphic microspar and fine-grained spar. Crinoids display traces of endolithic boring. The sediment is sparsely parallel laminated. Microfacies 2 has been documented from the Eifelian to Givetian interval (interval from *Po. partitus/Po. costatus* Zone boundary to the base of Lower *Po. varcus* Subzone on surface; boreholes LV 18, LV 29, LV 51 and LV 54).

Microfacies 3 Lime mudstone with small crinoid grains. Conodonts and detrital quartz grains are sparsely present. The matrix is composed of neomorphic microspar and spar. The rock contains thin stringers of sericite and chlorite. Microfacies 3 has been documented from Middle Devonian with no closer age determination (boreholes LV 22 and LV 47).

Microfacies 4 (Pl. I, fig. i) Moderately to well sorted, crinoidal/peloidal wackestone-packstone. Grains are represented by crinoids and plastically deformed, elongate peloids. Small contribution is also provided by conodonts, echinoid spines and detrital quartz grains. Crinoid grains display endolithic borings. The matrix is composed of strongly recrystallized neomorphic spar. Parallel lamination, sharp basal bed boundaries and bioturbation have been sparsely observed. Microfacies 4 has been documented from the Givetian to Tournaisian interval (*Pa. marginifera, Pa. expansa* and *Si. praesulcata* Zones on surface; boreholes LV 46, LV 47, KDH 7).

Microfacies 5 (Pl. I, fig. f) Poorly sorted floatstone-rudstone with skeletal grains and intraclasts. Skeletal grains include crinoids, corals, stromatoporoids, bryozoans, brachiopods and rarely conodonts. Nonskeletal grains include peloids and abundant subangular to subrounded intraclasts, composed of microfacies types 2, 4, 7, 9, 10, 11 and 13. Noncarbonate grains include detrital quartz grains, volcanic rocks, siliciclastic sediments, radiolarian shales and phosphorites. Nonskeletal grains represent volumetrically dominant part of the rock. The matrix is composed of neomorphic microspar and spar with disperged organic matter. Microfacies 5 has been documented from Eifelian to Middle Tournaisian interval (*Po. varcus* to *Po. asymmetricus* Zone interval and *Si. isosticha*-upper *Si. crenulata* Zone on surface; boreholes LV 33, LV 51, KDH 7).

Microfacies 6 Moderately sorted, skeletal wackestone-packstone with intraclasts. Skeletal grains are composed of crinoids, stromatoporoids, brachiopods and molluscs. Nonskeletal grains include plastically deformed, elongate peloids and intraclasts, composed of microfacies types 2 and 3. Conodonts, well sorted, subangular, detrital quartz grains and grains of fine-grained siliciclastics are sparsely present. Matrix is composed of neomorphic microspar and spar. Microfacies 6, which is comparable to the Givetian MF 8-2 of Hladil (1994), was documented from borehole KDH 7.

Microfacies 7 Poorly sorted, skeletal floatstone-rudstone with benthic and pelagic fauna. Benthic fauna include crinoids, tabulate corals and probably stromatoporoids. Pelagic components are represented by dacryoconarids (mainly styliolinids) by 5 volume percent in average. Plastically deformed peloids and grains of fine grained siliciclastics form a minor contribution. Crinoids display endolithic borings. Matrix is composed of neomorphic microspar and spar. Microfacies 7 has been documented from the Eifelian to Givetian interval (boreholes LV 18 and LV 44).

Microfacies 8 Poorly sorted packstone to floatstone-rudstone with benthic and pelagic skeletal grains and intraclasts. Skeletal grains include fragmented stromatoporoids, corals, bryozoans, gastropods, algae, brachiopods, crinoids and pelagic dacryoconarids. Intraclasts are composed of microfacies 3, 9, 10, 11 and 13. Peloids, grains of volcanic rocks and detrital quartz grains form a minor contribution. Conodonts are rare. Crinoid fragments display endolithic boring. The matrix is composed of neomorphic microspar and spar with disperged organic matter and pelitic material. Microfacies 8 has been documented from the Givetian (borehole LV 54). It is comparable to MF 8-3 of Hladil (1994).

Microfacies 9 (Pl. I, fig. e) Moderately sorted, crinoid/dacryoconarid wackestone-packstone. Grains include abundant crinoid plates and crinoid ossicles, styliolinids, sculptured dacryoconarids and peloids. A minor grain contribution is provided by fragmented shells of brachiopods and bryozoans, rare foraminifers, conodonts, radiolarians and calcispheres. Intraclasts and detrital quartz grains are sparsely present. Delicate shells of dacryoconarids are often strongly fragmented, even when emplaced in matrix supported wackestones. Crinoids display traces of endolithic boring. The matrix is composed of neomorphic microspar and spar. Parallel lamination, graded bedding and sharp basal bed boundaries are typical of this microfacies. Microfacies 9 has been documented from the Eifelian to Frasnian interval (*To. australis* to *Po. ensensis* Zone interval, *Po. varcus* Zone, *Po. asymmetricus* to *A. triangularis* Zone interval on surface; boreholes LV 15, LV 46 and LV 54).

Microfacies 10 (Pl. I, fig. e) Moderately sorted, fine grained wackestone with abundant crinoids and pelagic skeletal grains. Skeletal grains are composed of crinoids, dacryoconarids, ostracods, trilobites, radiolarians and conodonts. Well sorted, detrital quartz grains are sparsely present. Crinoids often display endolithic borings. The matrix is composed of neomorphic microspar with disperged organic matter and pelitic material. Parallel lamination is frequent. Microfacies 10 has been documented from the Eifelian to Frasnian interval (*Po. partitus/Po. costatus* Zone boundary, *To. australis* to *Po. ensensis* Zone interval, *Po. varcus*, *Po. asymmetricus* and *Pa. gigas* Zones on surface; boreholes LV 46, LV 54, KDH 1, KDH 5 and KDH 7).

Microfacies 11 (Pl. I, fig. c) Lime mudstone with crinoids and pelagic organisms. The pelagic components are represented by styliolinids, and less abundant calcispheres and radiolarians. Detrital quartz grains are sparsely present. Crinoids display sparse traces of endolithic borings. Styliolinids are rarely fragmented. The matrix is composed of neomorphic microspar with disperged organic matter and pelitic material. Parallel lamination and slight bioturbation are frequent. Microfacies 11 has been documented from the Givetian to Frasnian interval (*Po. varcus* to *Po. asymmetricus* Zone interval on surface; borehole LV 46).

Microfacies 12 Coarse-grained, intraclastic breccia (rudstone). Large, nonskeletal grains include grains of radiolarian shales, radiolarian phosphorites and grains of structureless recrystallized spar. Intergranular spaces are filled with micrite and microspar with densely packed styliolinid and sculptured dacryoconarid shells. This extremely rare microfacies type (1 sample) is documented from the Frasnian (borehole KDH 5).

Microfacies 13 (Pl. I, fig. h) Skeletal lime mudstone-wackestone with pelagic organisms. Skeletal grains include delicate shells of trilobites, filamentous bivalves, sponge spicules, radiolarians, ostracods and dacryoconarids. The matrix is composed of pure micrite or fine-grained microspar. Microfacies 13 has been documented from the Givetian to Frasnian interval (boreholes LV 54 and KDH 5).

Microfacies 14 (Pl. I, fig. g) Pure dacryoconarid lime mudstone-wackestone. Skeletal grains are represented by mostly unfragmented shells of both sculptured dacryoconarids and styliolinids. Matrix is composed of micrite and microspar with disperged pelitic material. Parallel lamination is frequent. Gradual transitions between microfacies 14 and microfacies 9 were observed in thin sections. Microfacies 14 has been documented from the Givetian to Frasnian interval (boreholes LV 46 and KDH 5).

Microfacies 15 (Pl. I, fig. j) Coarse-grained, peloidal/crinoidal wackestone-packstone to grainstone. Skeletal grains are composed of crinoids, echinoid spines and sparse foraminifers. Nonskeletal grains include abundant plastically deformed peloids and partially micritized ooids. Detrital grains of volcanic rocks and phosphorites, sometimes bearing radiolarians, are less abundant. The matrix is composed of neomorphic microspar and spar. Microfacies 15 has been documented from the Middle- and Upper Tournaisian (*Si. crenulata* to Upper *Gn. typicus* Zone interval on surface, borehole KDH 7).

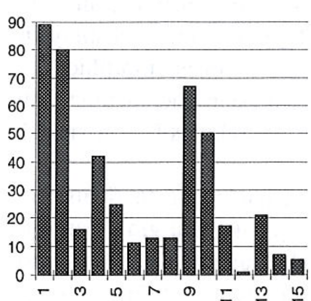
2. 2. *Origin of carbonate and noncarbonate grains*

The observed carbonate and noncarbonate grains can be divided into three main groups: 1) benthic, mostly shallow-water skeletal grains; 2) pelagic (mostly planktonic) and "deeper-water" benthic skeletal grains; and 3) nonskeletal grains derived from different environments. 1) Benthic organisms include platy stromatoporoids, rugose and tabulate corals, echinoderms, bryozoans, brachiopods, molluscs and benthic foraminifers. Diverse stromatoporoids, tabulate and rugose corals, common in the Eifelian, Givetian and Frasnian, indicate growth in an extensive, mostly shallow-water reef environment (see Hladil 1993). In the Devonian the tabulate corals and platy stromatoporoids were restricted to the reef margin and reef flat environments (see Playford 1980). Crinoids, brachiopods and bryozoans indicate a marginal slope environment during the Devonian and Carboniferous (Playford 1980, Armstrong - Mamet 1977). Depth differentiation between stromatoporoids as shallow-water dwellers and crinoids living in deeeper water, has been suggested by Tucker (1969). Stromatoporoid-coral-crinoidal faunal assemblages are typical of a Devonian microfacies association H of Hladil (1994), which indicate the frontal margin of a reef complex. Molluscs, benthic foraminifers and ostracods contribute less significantly to the total volume of this group. 2) Pelagic organisms include dacryoconarids, radiolarians, calcispheres and conodonts, that are abundant in the Lower Paleozoic pelagic (see review in Franke - Walliser 1983) or basinal (Playford 1980) carbonate facies. Delicate, thin-shelled trilobites are also included in this group. Cephalopods are surprisingly absent in the area studied. The planktonic dacryoconarids are represented predominantly by styliolinids. The styliolinids inhabited surface waters just a few metres or few tens of metres in depth. In a rock record, they are most abundantly associated with brachiopods and trilobites, indicating the offshore settings (Yochelson - Lindemann 1986). Styliolinids are typical components of Devonian pelagic carbonates of the variscan Belt (e.g. Tucker 1973). 3) The third group is composed of nonskeletal grains and grains of noncarbonate rocks. Nonskeletal grains include peloids and intraclasts. Strong recrystallization of the peloids prevents from determination of their origin (faecal pellets, micritized carbonate grains, pseudopellets or intraclasts). The biogenic origin of the peloids is supported by the frequently observed different stage of evolution of micritic envelopes in many skeletal grains (mainly crinoids). In this case the oval shapes, normally typical of faecal pellets, result from plastic deformation of micritic grains in response to tectonic shear. Carbonate intraclasts, composed of microfacies types 2, 3, 4, 7, 9, 10, 11 and 13, represent another nonskeletal grain group. Grains of noncarbonate rocks occur frequently. They comprise pelagic radiolarian shales, radiolarian phosphorites, volcanic rocks and fine-grained siliciclastics. Abundant intraclasts and noncarbonate grains indicate significant erosion and mixing of lithified or semi-lithified particles of sediment derived both from relatively shallow-water environment (microfacies 2, 3, 4) and typical basinal environment (microfacies 11, 13, 14, radiolarian shales).

2. 3. *Relationships between microfacies, microfacies associations*

The frequency of the occurence of an individual microfacies type strongly varies. The total number of described samples of particular microfacies type is shown in Table 1.

Table 1. Table and chart of a total number of samples of each microfacies type



	number (total 457)	%
microfacies 1	89	19.47
microfacies 2	80	17.51
microfacies 3	16	3.5
microfacies 4	42	9.19
microfacies 5	25	5.47
microfacies 6	11	2.41
microfacies 7	13	2.84
microfacies 8	13	2.84
microfacies 9	67	14.66
microfacies 10	50	10.94
microfacies 11	17	3.72
microfacies 12	1	0.22
microfacies 13	21	4.6
microfacies 14	7	1.53
microfacies 15	5	1.09

The most abundant are the microfacies 1 (17.95 %), microfacies 2 (16.02 %), microfacies 9 (13.49 %), microfacies 10 (10.07 %), microfacies 4 (8.47 %), microfacies 5 (5.04 %), microfacies 13 (4.22 %), microfacies 11 (3.43 %) and microfacies 3 (3.23 %). Total of microfacies 6, 7, 8, 12, 14 and 15 make up less than 10 %.

The microfacies are distributed in specific associations, determined pursuant to their spatial and temporal relationships. In all boreholes, each sample was examined with respect to the adjacent underlying and overlying sample. The pairs of vertically adjacent samples were counted (see Table 2).

Table 2. Counts on pairs of vertically adjacent microfacies samples in an idealized borehole

borehole XY (vertical succession of samples)	depth	part of adjacent microfacies	counts
microfacies 9	↓	13-9 =	2
microfacies 13		=9-13	
microfacies 9		5-9	1
microfacies 5		5-5	1
microfacies 5		1-5	1
microfacies 1			

The counts of all possible microfacies pairs in all boreholes are displayed in half-matrix (Tab. 3a).

The counts were then divided by half of the sum of total numbers of both the appropriate microfacies types (1). The resulting number is called the frequency parameter (F). Giving a relative frequency of common occurence of every microfacies pair the frequency parameter equals

$$F = 2 \, . \, n(a\text{-}b) \, / \, n(a) + n(b) \qquad (1)$$

where n(a-b) is number of neighboring microfacies a and microfacies b, n(a) is total number of microfacies a, and n(b) is total number of microfacies b. Frequency parameter values are subject of considerable error due to differences in sample distribution in boreholes. In average, one sample per 7.7 m of borehole length occured. In some boreholes, however, the occurence drops to a level of 1 sample per 25 m. Therefore only frequency parameter values higher than 100 were taken into consideration. Frequency parameter values are figured in a half matrix (Table 3b) and surface chart (Fig. 4).

The higher the frequency parameter the more frequently the two microfacies in question occur in association. Local extremes of frequency parameter values (peaks in the surface chart) match microfacies pairs occuring in association most frequently. These are 1/1, 1/2 and 15/15 (frequency parameter equal to or higher than 300) 9/9 and 11/15 (frequency parameter between 200-299) 7/8, 9/10, 12/13 and 13/13 (frequency parameter between 150-199) 1/9, 1/10, 2/2, 2/5, 4/4, 5/6, 5/7 and 8/9 (frequency parameter between 100-149). These microfacies pairs create headstones of the four

Table 3. Counts on vertically adjacent microfacies pairs from all boreholes, displayed in a half matrix (a). Frequency parameter values for all possible microfacies pairs calculated from all boreholes, displayed in a half matrix (b)

3a

	microfacies 1	microfacies 2	microfacies 3	microfacies 4	microfacies 5	microfacies 6	microfacies 7	microfacies 8	microfacies 9	microfacies 10	microfacies 11	microfacies 12	microfacies 13	microfacies 14	microfacies 15
microfacies 1	33	29	3	5	5	1	2	4	9	7	4	0	0	0	0
microfacies 2	0	9	3	3	6	1	2	2	5	6	1	0	0	1	0
microfacies 3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
microfacies 4	0	0	0	6	3	0	1	1	3	3	1	0	1	1	0
microfacies 5	0	0	0	0	1	1	2	1	4	1	2	0	2	1	1
microfacies 6	0	0	0	0	0	1	0	0	1	3	0	0	0	0	0
microfacies 7	0	0	0	0	0	0	0	2	3	2	0	0	0	0	0
microfacies 8	0	0	0	0	0	0	0	0	4	2	1	0	1	0	0
microfacies 9	0	0	0	0	0	0	0	0	19	10	4	0	3	3	0
microfacies 10	0	0	0	0	0	0	0	0	0	3	3	0	2	1	0
microfacies 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
microfacies 12	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
microfacies 13	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0
microfacies 14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
microfacies 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

3b

	microfacies 1	microfacies 2	microfacies 3	microfacies 4	microfacies 5	microfacies 6	microfacies 7	microfacies 8	microfacies 9	microfacies 10	microfacies 11	microfacies 12	microfacies 13	microfacies 14	microfacies 15
microfacies 1	370	323	57	76	87	20	39	78	115	101	75	0	0	0	0
microfacies 2	0	113	63	49	114	22	43	43	68	92	21	0	0	23	0
microfacies 3	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0
microfacies 4	0	0	0	143	90	0	36	36	55	65	34	0	32	41	0
microfacies 5	0	0	0	0	40	111	105	52	87	27	95	0	87	63	67
microfacies 6	0	0	0	0	0	91	0	0	26	98	0	0	0	0	0
microfacies 7	0	0	0	0	0	0	0	154	75	63	0	0	0	0	0
microfacies 8	0	0	0	0	0	0	0	0	100	63	67	0	59	0	0
microfacies 9	0	0	0	0	0	0	0	0	284	171	95	0	68	81	0
microfacies 10	0	0	0	0	0	0	0	0	0	60	90	0	56	35	0
microfacies 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	273
microfacies 12	0	0	0	0	0	0	0	0	0	0	0	0	182	0	0
microfacies 13	0	0	0	0	0	0	0	0	0	0	0	0	190	71	0
microfacies 14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
microfacies 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400

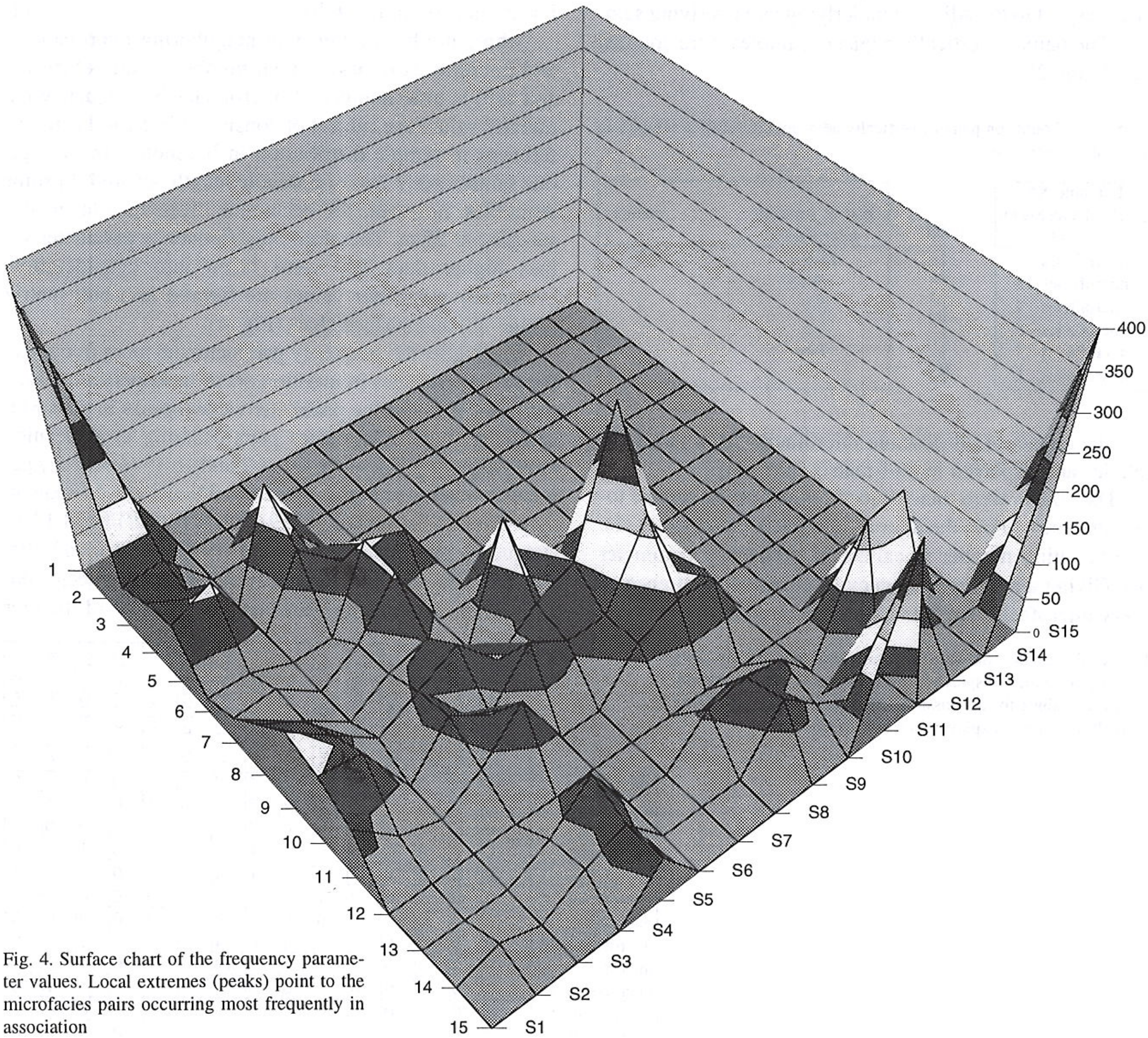


Fig. 4. Surface chart of the frequency parameter values. Local extremes (peaks) point to the microfacies pairs occurring most frequently in association

microfacies associations recognized. The differences in time distribution of microfacies over the central and southern part of the KMB is shown in Fig. 5.

The following microfacies associations were distinguished:

Microfacies Association A. (M.A. A) It is composed of microfacies 1, 2, 3, 7 and 10. Microfacies 1 and 2 are the most abundant. This association is typical of the Eifelian to Early Givetian interval in the Transitional Development area. M.A. A is comparable to the Josefov Limestone and Vilémovice Limestone of Macocha Formation.

Microfacies Association B. (M.A. B) This association includes microfacies 1, 2, 5, 6, 7, 8, 9, 10, 11, 13 and 14. Microfacies 9 and 10 are the most abundant. This association is typical of the Givetian to Frasnian interval in the Transitional Development area. M.A. B is comparable to the uppermost part of Macocha Formation (Vilémovice Limestone) and/or the Hády-Říčka Limestone. In the Basinal Development area this microfacies association is typical of the Late Eifelian to Early Frasnian interval. It is comparable to the lower parts of Jesenec Limestone.

Microfacies Association C. (M.A. C) This association is composed of microfacies 2, 4, 5 and 10. Microfacies 4 and 5 are the most abundant. This microfacies association is typical of the Late Frasnian to Early Famennian interval in the Transitional Development area. It is comparable to the Hády-Říčka Limestone. In the Basinal Development area this association is typical of the Late Frasnian to Late Famennian interval. It is comparable to the upper parts of Jesenec Limestone.

Microfacies Association D. (M.A. D) This association is composed of microfacies 5, 11 and 15. Microfacies 15 is the most abundant. This association is typical of the Middle to Upper Tournaisian interval in the Basinal Development area. It is comparable to the uppermost parts of Jesenec Limestone.

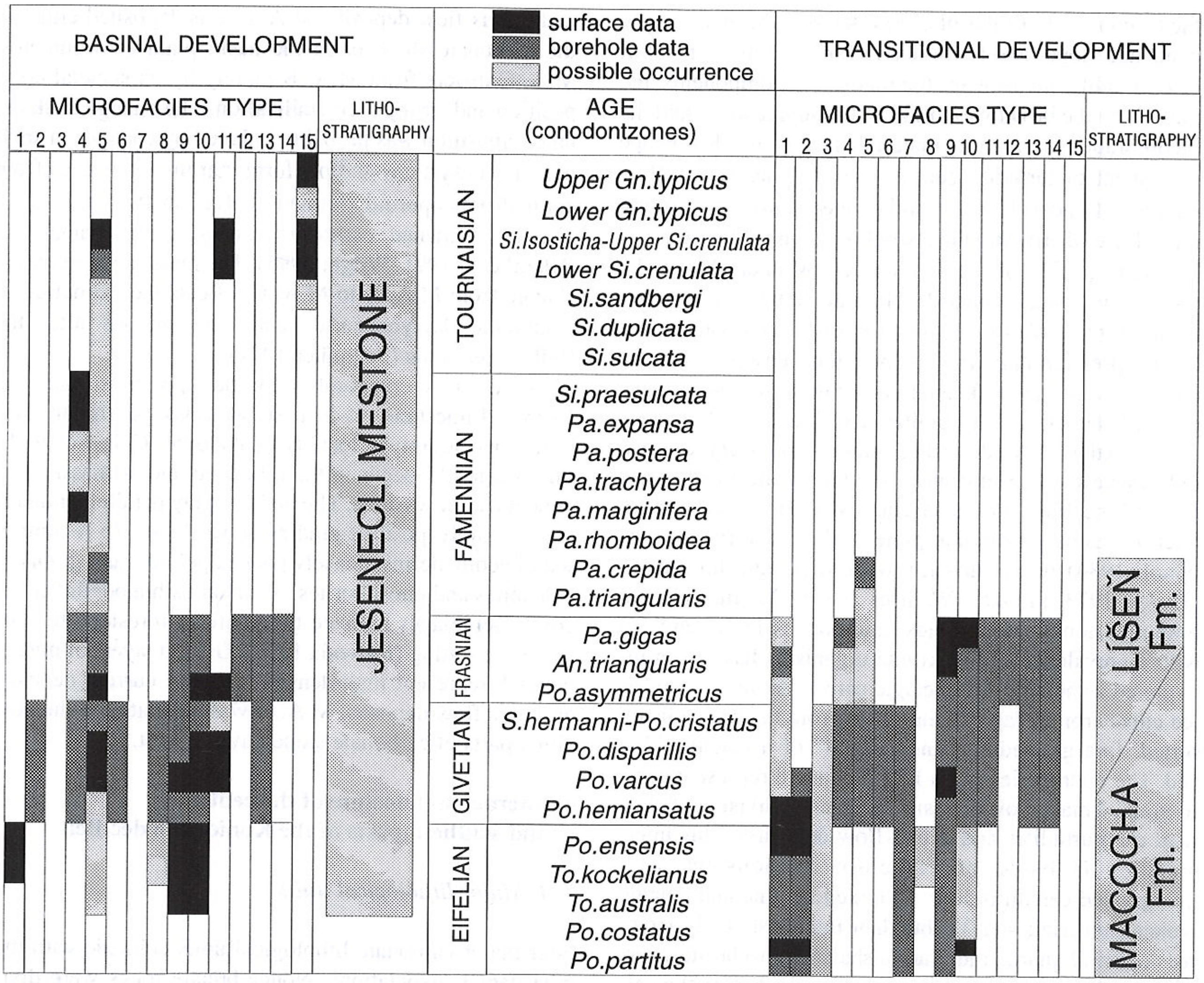


Fig. 5. Time distribution of microfacies. Age determinations from boreholes (grey) and from surface occurrences (black) are figured separately for the central part of the KMB (left) and its southern part (right). Possible occurrence of microfacies (not documented) is figured by light grey colour

3. Correlation with surface occurrences and interpretation of depositional environment

M.A. A is comparable to the Macocha Formation in the Transitional Development area. It is composed of up to several tens of metres thick layers of massive stromatoporoid, coral and crinoid rich floatstone-rudstone breccias (microfacies 1, 2, and 7) alternating with the dark grey, thin-bedded, platy micritic limestones and shale interlayers (microfacies 3, 10). Breccias with reef-derived material, closely associated with skeletal lime sands and dark lime mudstones, typically occur in both ancient and modern fore-reef slope environments creating fore-reef talus deposits (Enos - Moore 1983). The rapid grain size decrease, from the breccias to the lime muds, is typical of modern distal fore-reef environments (Hine - Mullins 1983). The thin-bedded dark grey lime mudstones are comparable to the fore-reef slope hemipelagic muds - periplatform ooze (see Cook - Mullins 1983). The mixing of skeletal remains of typical reef dwellers, such as corals and stromatoporoids, and typical upper slope inhabitants, such as crinoids and bryozoans, supports the interpretation of fore-reef slope environment.

M.A. B is comparable to the upper parts of Macocha Formation and/or the Hády-Říčka Limestone in the Transitional Development area. In the Basinal Development area it is comparable to the lower parts of Jesenec Limestone. Microfacies 9 and 10 often show parallel lamination, sharp bed bases and tops and ocassionally graded bedding. In outcrop they typically form dark grey, thin bedded, platy limestones with sharp bed bases and tops. Sedimentary structures include parallel lamination, low-angle cross stratification and simple and/or multiple grading. They are interpreted as fine-grained calciturbidites displaying the upper divisions of the Bouma sequence. On the surface, the calciturbidite succession comprises a range of microfacies from lime mudstones with pelagic fauna through crinoidal calcarenites to the coarse-grained skeletal/intraclastic rudstones. M.A. B is composed essentially of the same microfacies. The microfacies contain both the platform-derived skeletal components and slope- and basin-derived ones. Being typical of calciturbiditic microfacies the mixture of components displays both the broad variability of the source areas and the incorporation of bottom material during the downslope movement of turbidity current (see Reijmer et al. 1991, Herbig - Bender 1992). Another mechanism controlling microfacies distribution in a single calciturbidite bed is the hydraulic sorting of grains (Herbig - Mamet 1994). The crinoid- and dacryoconarid-rich, mud supported carbonates are typical of the Devonian basinal carbonate facies. Living preferentially in the fore-slope environment the crinoids were major skeletal contributors to some examples of Paleozoic calciturbidites (e.g. Tucker 1969, Davies 1977). Lütke (1976) described crinoid- and dacryoconarid rich wackestones-packstones from the calciturbidite sequence of the Flinz facies in Harz Mts. However, similar microfacies have been interpreted either as storm deposits (Gnoli 1984) or as current-reworked pelagic limestones (Tucker 1973, Franke - Walliser 1983). The fine-grained lime-mudstones-wackestones (microfacies 11, 13 and 14) with a prevalence of planktonic organisms have been interpreted as hemipelagic-pelagic carbonate oozes, deposited either from pelagic "rainfall" or from the hydraulicaly sorted, fine grained suspension "tail" of a calciturbidite bed. The microfacies types 1, 2, 5, 7 and 8 represent coarse-grained mass-flow deposits (Ta Bouma division of classical calciturbidites and debris-flow deposits). This interpretation is based on: 1) close relationships with fine-grained calciturbidites; 2) mixed benthic and pelagic skeletal material; and 3) abundant intraclasts and extraclasts (detrital quartz, radiolarian shales, phosphorites, carbonates). Similar sediments were described from the calciturbiditic Flinz Limestone of the Rheinisches Schiefergebirge (Eder et al. 1983). M.A. B was deposited either in the distal parts of carbonate slope or in basin-plain environments.

M.A. C is comparable to the Hády-Říčka Limestone in the Transitional Development area. In the Basinal Development area the M.A. C is comparable to the upper parts of Jesenec Limestone. On the surface the microfacies 2, 4 and 10 form strongly recrystallized, light-grey, thin-bedded platy limestones with interlayers of radiolarian shales. Skeletal carbonate grains include essentially benthic echinoderms and conodonts. In the Basinal Development area the Famennian limestones yielded abundant *Palmatolepis* dominated conodont assemblages that are typical of pelagic environment (e.g. Sandberg et al. 1988). The carbonate beds represent probably event-deposits of mixed more shallow-water (echinoderms) and pelagic (palmatolepid conodonts) skeletal material on a background of pelagic radiolarian shales. The sedimentary structures are generally disguised by strong recrystallization. On the surface the soft-sediment deformation and brecciation resulting probably from downslope creep and slumping, were rarely observed. Microfacies 5 represents mass-flow deposits (Ta Bouma division of calciturbidites and debris-flow deposit). M.A. C was deposited either in the carbonate slope or in the basin plain environments. M.A. C differs from M.A. B mainly by its skeletal composition and strong recrystallization. The change in skeletal composition was probably induced by changes in shelf benthic ecosystems and platform margin geometries from coral-stromatoporoid rimmed shelves in the Frasnian to distally steepened carbonate ramps in the Famennian (Hladil et al 1991, Wright 1995). The major compositional change from M.A. B to M.A. C reflects the extinction of planktonic dacryoconarids and cricoconarids after the Kellwasser crisis (Schindler 1992).

M.A. D is comparable to the uppermost parts of Jesenec Limestone. It is best preserved at the Jesenec Limestone stratotype locality (Zukalová - Chlupáč 1982). Microfacies 15 occur in thick-bedded and/or massive sedimentary successions. The beds display parallel lamination and, rarely, positive grading. Microfacies 15 is composed of echinoderms, densely packed peloids, and grains of volcañites and phosphorites. Abundant sihonodellid conodont assemblages indicate the platform foreslope to starved basin setting (Kalvoda 1994). Graded layers of microfacies 5 represent high-density turbidity current deposits or debris flow deposits. M.A. D was deposited in the proximal parts of carbonate slope environment.

4. Internal architecture of the central and southern parts of the Konice-Mladeč Belt

4. 1. Major lithological units

Four major carbonate lithological units coincide with the microfacies associations. Noncarbonate rocks were divided into another 4 main facies: 1) siliciclastics (Devonian basal siliciclastics and marine Stínava-Chabičov Formation); 2) volcanites (volcanic complex); 3) pelagic radiolarian shales and silicites (Ponikev Fm.) and 4) siliciclastic flysch sediments of the Culm facies (Protivanov Fm.). The subsurface material comprise 53 boreholes. The boreholes were described in terms of the vertical succession of carbonate microfacies associations and noncarbonate facies. The boreholes were linked to create 12 sections running approximately perpendicular to the mean strike (see Fig. 1). The distribution of major lithological units in boreholes and in sections is shown in Fig. 6.

4. 2. Lithostratigraphic succession of central part of the Belt

The following stratigraphic succession has been derived from boreholes in the central part of the Konice-Mladeč Belt. The Devonian sedimentary complex started by deposition of basal siliciclastic sediments overlying the crystalline rocks of the Kladky Unit. Their maximum thickness never exceeds 20 m and, in places, this unit may be missing (Fig. 6 section 8, LV 29 section 9, LV 40), as was already suggested by Chlupáč - Svoboda (1963). The ba-

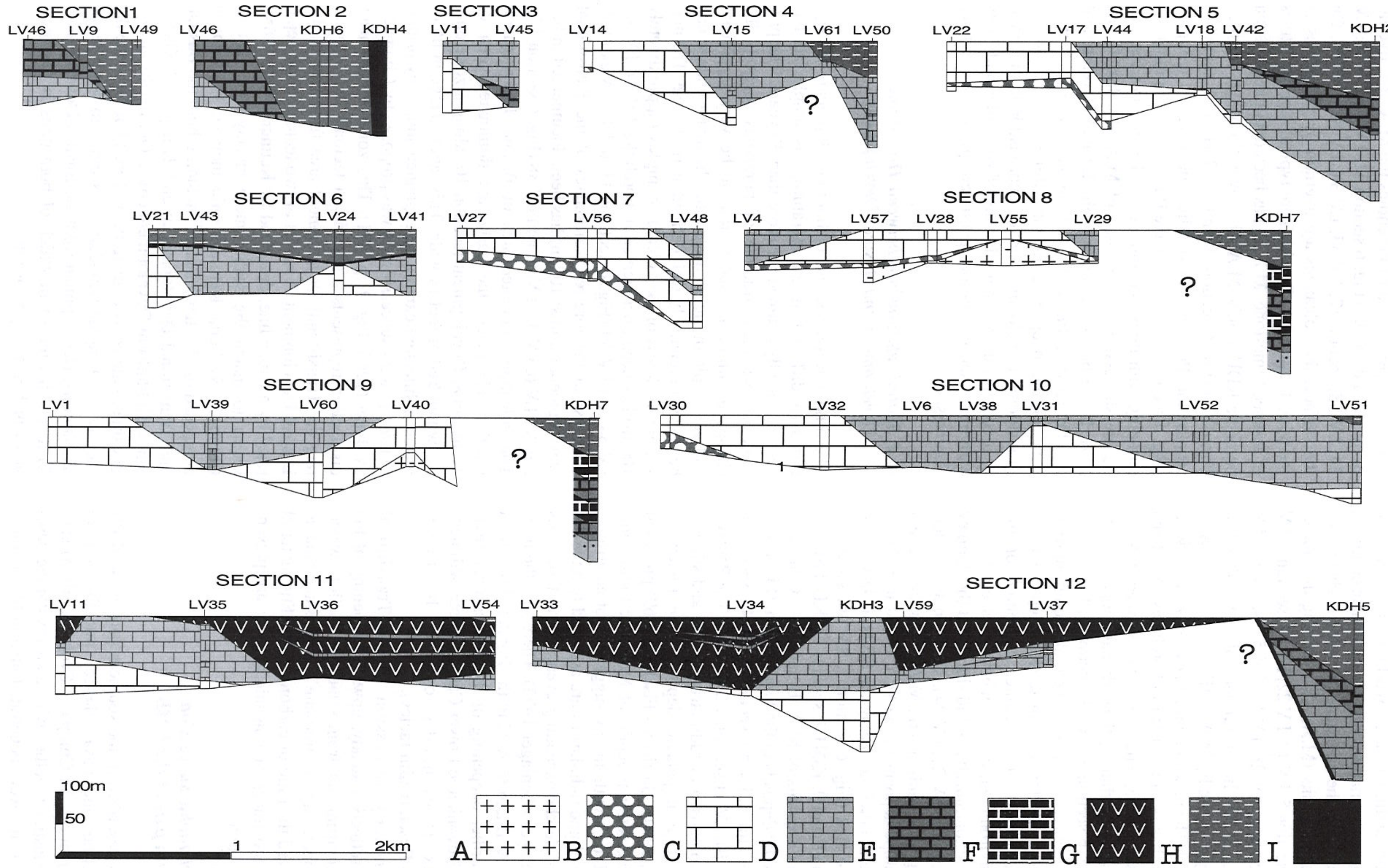


Fig. 6. Interpretation of depositional systems in the transverse sections
a - basement (Kladky Unit); b - Devonian basal clastics and Stínava-Chabičov Fm. (terrestrial and marine siliciclastics); c - microfacies association A (fore-reef talus deposits); d - microfacies association B (fore-reef slope to basin plain carbonates); e - microfacies association C (carbonate slope to basin plain deposits); f - microfacies association D (proximal carbonate slope deposits); g - volcanic complex; h - Ponikev Fm. (pelagic shales and silicites); i - Culm facies (siliciclastic flysch). Strongly vertically exaggerated

sal siliciclastic sediment are overlain either by the Stínava-Chabičov Formation or by the carbonate complex.

In its lower parts, the carbonate complex is characterized by fore-reef deposits (M.A. A), overlying the siliciclastics (Fig. 6 section 5, LV 17, LV 22, LV 44, section 7, LV 27, LV 56, section 8, LV 28, LV 55, LV 57, section 9, LV 40, section 10, LV 30). In several boreholes, the siliciclastics are directly overlain by M.A. B (Fig. 6 section 8, LV 4, section 8, LV 29. The maximum thickness of M.A. A (80 m approximately) has been recorded in boreholes LV 32 and LV 38 (Fig. 6 section 10). The fore-reef carbonates of M.A. A are conformably overlain by the carbonate slope deposits of M.A. B (Fig. 6 section 3, LV 11, section 5, LV 44, section 9, LV 60, section 10, LV 51). The transition from fore-reef deposits to mass-flow carbonate slope deposits is interpreted as a record of a distinct deepening of the depositional environment. In several boreholes, the M.A. A is overlain by radiolarian shales and silicites of the Ponikev Fm (Fig. 6 section 6, LV 21, LV 24). This contact is interpreted as being of tectonic origin. M.A. B can be overlain by carbonate slope deposits of the M.A. C distributed irregularly in several boreholes along the SE boundary of the Konice-Mladeč Belt (Fig. 6 section 1, LV 46, section 5, KDH 2, section 8 and 9, KDH 7, section 12, KDH 5).

Upward, the deposits of M.A. B and M.A. C are gradually replaced by deposits of the Ponikev Fm. (Fig. 6 section 1, LV 9, section 4, LV 50, section 5, LV 42, section 6, LV 43, section 10, LV 51 section 12, KDH 5). The Ponikev Formation is composed of radiolarian shales and silicites that represent typical pelagic deposits (see review in Dewever et al. 1994). Garrison - Fischer (1969) proposed a near CCD depositional depths of Mesozoic radiolarites of the alpine Tethys without any suggestion of an absolute deph. Some alpine radiolarites are assumed to have been deposited in depths exceeding even several thousands of metres (Schlager - Schlager 1973). Therefore, the transition from M.A. B and M.A. C to the Ponikev Formation represents a further deepening of the depositional environment. The Devonian to Lower Carboniferous sedimentary complex is eventually overlain by Lower Carboniferous flysch (Culm facies).

The sedimentary succession of the Transitional Development reflects a steady, upward deepening of the depositional environment from relatively shallow water, fore-reef carbonates up to carbonate compensated pelagic deposits. Upward the ratio of carbonate to pelitic material decreases and no traces of volcanic activity are present throughout the area.

4. 3. Litostratigraphic succession of southern part of the KMB

The boreholes described in the southern part of the KMB penetrated neither the basal clastics nor the Stínava Chabičov Formation. As Chlupáč - Svoboda (1963) showed the siliciclastics together with their crystalline basement (Kladky Unit) were penetrated also in the southern part of the KMB. In most boreholes the M.A. B is overlain by volcanic rocks (Fig. 6 section 11, LV 35, LV 36, LV 54, LV 58, section 12, LV 33, LV 34, LV 37, LV 59). On the surface, the volcanites are overlain by carbonates of the M.A. C and M.A. D, which are typical representatives of Jesenec Limestone. M.A. D has been documented from borehole KDH 7 only. M.A. D is overlain by the Ponikev Formation (Fig. 6 sections 8 and 9, KDH 7). In some boreholes the Ponikev Fm overlies the volcanic complex (Fig. 6 section 11, LV 54). In the Basinal Development, alternating with thick accumulations of volcanites the carbonate succession is composed of M.A. B, M.A. C and M.A. D. Carbonate complex of the Basinal Development is different from that of the Transitional Development in that: 1) the deepening upward trend, typical of the Transitional Development area, is not visible in this area; 2) it contains thick accumulations of volcanites and 3) its carbonate sedimentation persisted up to the Upper Tournaisian.

4. 4. Spatial relationships between Transitional Development and Basinal Development

The lithologic successions of both developments are significantly different. In the literature, this simple fact has been repeatedly claimed for more than 30 years. The presented facies reconstruction of boreholes suggests the change in lithofacies successions to be very significant and very rapid in lateral direction. The major change can be placed in relatively well defined, narrow zone. The maximum thickness of the volcanic complex (approximately 100 m) has been documented in boreholes LV 34, LV 36, LV 54 and LV 59 (Fig. 6 sections 11 and 12). Maximum thickness of the fore-reef carbonates of the Transitional Development (almost 100 m) has been documented in boreholes LV 6, LV 31, LV 32 and LV 38 (Fig. 6 section 10). The volcanite dominated area of Basinal Development (section 11) meets the carbonate dominated area of Transitional Development (section 10) along a zone only a few hundred of metres wide. This rapid change in lithofacies architecture can not be explained simply by primary lateral facies succession, as was proposed by Chlupáč - Svoboda (1963, Fig. 1, p. 271). This zone of lithofacies disjunction represents a significant tectonic line, separating the Transitional Development area from that of the Basinal Development. A model of two tectonic units separated by a nappe line, described by Kettner (1949, 1965), seems to match the reality more closely than that of Chlupáč - Svoboda. Kettner's units include: 1) basement composed of "Drahany facies" including both the Basinal and Transitional Developments; and 2) nappe of Kladky unit with Platform Development cover. Our results are applicable to the concept of Kettner (1965) but for some departures: 1) tectonic boundary is assumed to separate the Transitional Development from the Basinal Development; 2) it remains uncertain which of both units is basement and which is of nappe origin.

5. Conclusions

Total of 15 microfacies were recognized in carbonates of the KMB. They are divided into 4 microfacies associations according to their temporal and spatial relationships. Each microfacies association represents a product of specific depositional environment.

Central part of the KMB is determined by the thick carbonate complex overlying the older basal clastics and Stínava-Chabičov Formation, and overlain by younger Ponikev Formation. This succession is typical of the Transitional Development (Chlupáč 1959). The carbonate complex itself shows an upward deepening trend. During the Givetian, the M.A. A, deposited in distal fore-reef environment, is replaced by M.A. B and M.A. C, deposited mainly by gravity-flow processes in carbonate slope and basin plain environments. During the Frasnian and Famennian, the mass-flow carbonates were gradually replaced by pelagic, carbonate compensated, radiolarian shales and silicites. The deepening of the depositional environment, derived from subsurface data as it has been, is in accordance with the thinning and fining upward trend, described from several surface sections in the central part of the Konice-Mladeč Belt (Bábek 1996).

In contrast, carbonates from the southern part of the KMB, assigned to the Jesenec Limestone of Basinal Development, display different microfacies characteristics. The Jesenec Limestone is composed of M.A. B, M.A. C and M.A. D alternating with thick accumulations of volcanites. M.A. D is restricted solely to the Basinal Development. It represents the only Lower Carboniferous carbonates known in the KMB. Furthermore, carbonate succession in the Basinal Development area displays no deepening upward trend.

From the lithofacies point of view, the carbonates of the central part of KMB differ from those of its southern part. The major differences include their microfacies characteristics, age range, content of volcanic intercalations and overall evolution of depositional environments. In map, both the extremely different areas are lying in very close vicinity to one another. Their boundary coincide with a zone of major lithofacies disjunction, which is only several hundred meters wide. The zone is assumed to represent a surface projection of significant tectonic boundary, which separates two tectonic units; one composed of lithostratigraphic succession of Transitional Development and another composed of that of Basinal Development.

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Mikrofaciální analýza karbonátových hornin devonu a spodního karbonu a její dopad na interpretaci vnitřní stavby konicko-mladečského pruhu, Morava, Česká republika

Devonské a spodnokarbonské karbonáty střední a jižní části konicko-mladečského pruhu zahrnují 15 mikrofaciálních typů, které jsou na základě vzájemných časoprostorových vztahů rozděleny do 4 mikrofaciálních asociací. Tyto mikrofaciální asociace vznikaly ve specifických depozičních prostředích: mikrofaciální asociace A reprezentuje distální předútesové karbonáty; mikrofaciální asociace B zahrnuje karbonáty předútesového svahu až pánve; mikrofaciální asociace C zahrnuje distální svahové karbonáty a karbonáty pánve a mikrofaciální asociace D zahrnuje proximální svahové karbonáty. Karbonátový komplex střední části konicko-mladečského pruhu je tvořen sukcesí mikrofaciálních asociací A a B. V jižní části konicko-mladečského pruhu (pánevní vývoj) převažují karbonáty tvořené sukcesí mikrofaciálních asociací B, C a D. Oba areály dle našeho názoru představují původně oddělené jednotky, sblížené během variské orogeneze podél významné tektonické linie, probíhající uvnitř konicko-mladečského pruhu.

Plate I ⇒

a) Microfacies 1, M.A. B. Skeletal rudstone with large tabulate coral fragment (left) and conspicious biogenic objects (right). Note strong recrystallization in all samples. "Na Srdéčku" Quarry near Ponikev
b) Microfacies 1, M.A. A. Skeletal float - rudstone with crinoid ossicles and stromatoporoid fragments. "Ludmírov" Quarry
c) Microfacies 11, M.A. B. Microsparitic lime mudstone with delicate dacryoconarid shells. Vojtěchov, "Samota Skalka"
d) Microfacies 2, M.A. B. Crinoidal wackestone. Note syntaxial neomorphic rims (top) and distinct foliation. "Na Srdéčku" Quarry near Ponikev.
e) Microfacies 9 and 10, M.A. B. Sharp base of turbidite bed composed of crinoidal/dacryoconarid packstone (right) eroding the upper part of another bed composed of crinoidal/dacryoconarid wackestone (left). Borehole LV 45, depth 37.5 m
f) Microfacies 5, M.A. C. Rudstone with intraclast composed of microfacies 13 (left). Borehole KDH 7, depth 144.4 m
g) Microfacies 14, M.A. B. Dacryoconarid wackestone. Note syntaxial rims around dacryoconarid shells (left centre). Ladín
h) Microfacies 13. Intraclast of lime mudstone - wackestone with tiny fragments of trilobite shells (top, centre) and crinoids (upper left). Borehole KDH 7, depth 144.4 m
i) Microfacies 4, M.A. C. Wackestone - packstone with echinoderms (left centre) and peloids. Original fabric is obscured due to severe neomorphic recrystallization. Vojtěchov
j) Microfacies 15, M.A. D. Peloidal wackestone - packstone with crinoid ossicles overgrown by syntaxial sparry *rims*. Jesenec

O. Bábek: Microfacies analysis of Devonian to Lower Carboniferous carbonates and its impact on the interpretation of internal architecture of the Konice-Mladeč Belt, Moravia, Czech Republic (Pl. I)