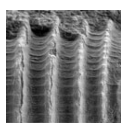


High-resolution tentaculite biostratigraphy and facies development across the Early Devonian Daleje Event in the Barrandian (Bohemia): implications for global Emsian stratigraphy

LENKA FERROVÁ, JIŘÍ FRÝDA & PAVEL LUKEŠ



The long-term activities of the International Subcommittee on Devonian Stratigraphy have been focused on the division of the Emsian into two new substages. The different stratigraphic levels, close to the Daleje Event, have mostly been discussed as their boundary. The latter event was first recognized in the Barrandian and defined as a bioevent, connected with a pronounced transgression. Its present conception has been inferred from studies of its appearance in deeper environments, with deposition of the calcareous Daleje Shale. We analysed its appearance in shallower environments, with predominantly carbonate sedimentation, using precise qualitative and quantitative biostratigraphic, paleoecological, and sedimentological methods. Our data revealed that the mid-Emsian had a more complex transgression-regression history than previously described. Evaluation of the stratigraphic distribution of more than 1250 newly collected dacryoconarid shells has resulted in the proposal of a new tentaculite biozonation, providing a much higher stratigraphic resolution than the existing biozonations, which are based on goniatites and conodonts. Quantitative analysis of the newly gathered paleoecological data suggests a distinct faunal turnover at the level of the first occurrence of the dacryoconarid tentaculite *Nowakia elegans*. In addition, our study revealed that the Daleje transgression (and thus the Daleje Event) started at the same time, and that it was preceded by a distinct regression. For these reasons, we propose the first occurrence of the worldwide and easily determinable dacryoconarid *Nowakia elegans* as a biostratigraphic indicator of the boundary level for the new Emsian substages. • Key words: Early Devonian, Daleje Event, Palaeozoic, new tentaculite biostratigraphy, facies analysis.

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The Early Devonian marine ecosystem was strongly influenced by several global changes, which were linked with restructuring of the marine food webs. The increased input of organic matter into the ocean, which was caused by the rise of land plants, dramatically changed the chemistry of the ocean surface waters (Algeo & Scheckler 1998). This eutrophication gave rise to plankton blooms, and opened up a new food source for many marine swimming organisms. Subsequently, the new food source structures caused changes in ontogenetic strategies and/or radiation of some groups of invertebrates and vertebrates (e.g., Signor & Brett 1984; Bambach 1999; Nützel & Frýda 2003; Klug

& Korn 2004; Klug *et al.* 2008, 2010; Monnet *et al.* 2011a, De Baets *et al.* 2012, and references therein). In addition, repeated and lasting events of anoxia caused selections in favour of non-benthic and demersal life styles (e.g., Klug *et al.* 2010; Manda & Frýda 2010). Klug *et al.* (2010) showed that during the Devonian, demersal and nektonic modes of life were probably initially driven by competition in the diversity-saturated benthic habitats, together with the availability of abundant planktonic food. Fundamental evolutionary changes in the Devonian marine water column were linked with the rapid rise of nekton (i.e., “Devonian nekton revolution”, Klug *et al.* 2010). On the other hand, increasing

predation pressure on the new Devonian planktonic groups (*e.g.*, Berkýová *et al.* 2007) as well as the new food sources influenced evolution in the majority of marine invertebrates (Klug *et al.* 2010). For example, three of the five living gastropod orders, which form the most diversified of all living marine invertebrate groups, probably originated during the Early Devonian (Bandel 1997; Nützel 1998; Frýda 2012; Frýda *et al.* 2008a, 2009; Frýda & Blodgett 2004; Nützel *et al.* 2007a). Increasing predation pressure and the existence of new food sources in the ocean surface waters is also linked with the extensive changes in gastropod protoconch morphology and adaption of some new groups on larval planktotrophy (Nützel & Frýda 2003; Nützel *et al.* 2006, 2007a, b; Frýda *et al.* 2009; Seuss *et al.* 2012).

Taken together, the Early Devonian marine ecosystem was quickly developing and changing in all of its environments (see review in Klug *et al.* 2010, and references therein). For an understanding and analysis of the Early Devonian evolutionary processes and the evolution of the marine environments, a very precise dating of Lower Devonian sedimentary successions is needed. However, the recent state of biostratigraphic zonation of the Early Devonian is too inaccurate for many evolutionary, ecological, and biogeographic analyses.

Long-lasting activities of the International Subcommission on Devonian Stratigraphy (ISDS) have been focused upon improving the precision of the Devonian biostratigraphic zonation. In recent years, one of the most discussed topics at the ISDS is about splitting the Emsian into two substages (see review in Becker 2007, Becker *et al.* 2010, Carls & Valenzuela-Ríos 2007, Kim *et al.* 2012). The main reason for this is the extremely long duration of the Emsian, in comparison with other Devonian stages. Its duration is estimated to be about 17 Ma by Kaufman (2006), or about 10 Ma according to the International Stratigraphy Chart (2011); this would be more than twice the duration of the other Early Devonian stages – Lochkovian (6 Ma or 5 Ma) and Pragian (3 Ma or 4 Ma), respectively. Additionally, the extremely long duration of the Emsian has been negatively influenced by the present definition of its lower boundary (see Carls *et al.* 2008 for details). The ISDS has suggested splitting the Emsian into two substages, the duration of which will be the same (or even longer) as that of two other Early Devonian stages (*i.e.*, Lochkovian and Pragian). The reason for calling them substages (except for the efforts to save the historical name Emsian) is not clear, and they could be really be named as stages.

The boundary of the regional Zlíchovian and Dalejan stages (established in the Barrandian), or the stratigraphic level close to their boundary, have mostly been discussed as time levels for the boundary of the new global substages (stages) of the Emsian (see details in Chlupáč & Lukeš

1999, also in Becker 2007). The Zlíchovian and Dalejan were established for practical reasons during a period of field mapping several decades ago. The whole Emsian succession of the Barrandian (Fig. 1) is mostly formed by carbonates (with the only exception in the middle of the Emsian). At that time, an interval of calcareous shales (the Daleje Shale) was deposited in most of the environments. The latter stratigraphic unit was recognized almost 200 years ago (*e.g.*, Barrande 1846a, b), but formalized much later by Krejčí (1877). During an intensive mapping period (1946–1960) and the associated biostratigraphic research after the Second World War (Svoboda & Prantl 1947–1951, Chlupáč 1954–1960), as well as during later activities focused on the proposal of the Early/Middle Devonian boundary in the Barrandian (Chlupáč *et al.* 1978, 1998; Chlupáč & Lukeš 1999 and references therein), huge amounts of new sedimentological, biostratigraphic, and palaeontological data was gathered from many Barrandian sections. All of these activities resulted in a redefinition of the Zlíchovian and Dalejan, which have been used since that time not only as regional stages, but also as internationally useful chronostratigraphic units (*e.g.*, De Baets *et al.* 2010). However, for somewhat obscure reasons, they were not accepted as international stages or substages. In 2003, the International Subcommission on Devonian Stratigraphy decided to divide the Emsian into two substages named as the Lower and Upper Emsian (SDS Newsletter 19). Names were selected; but no definition of their boundary exists so far.

As summarized by Becker (2007): “There is general agreement that the substage boundary should lie close to the Zlíchovian/Dalejan boundary of the Bohemian succession (Chlupáč 1976, Chlupáč & Lukeš 1999), which is characterized by the supposedly global and transgressive Daleje Event (House 1985)”. The Daleje Event was defined by House (1985) as an “extinction event”, which is connected with the Dalejan transgression. Thus, the Daleje Event was defined as a bioevent based on the extinction of some groups of early goniatites (*i.e.*, some *Mimosphinctidae* and the *Auguritidae*). However, Chlupáč & Kukal (1988, p. 125) used this term for an event having “a global character and manifests itself by a gradual rise of sea level, deepening of basins which were often accompanied by clay deposition at the expense of carbonate sediments”. Chlupáč & Kukal (1988) thus used the term “Daleje Event” for a transgressive event (also see Becker & Kirchgasser 2007). Unfortunately, such terminological chaos is rather common for some Palaeozoic events (*e.g.*, Silurian/Devonian boundary events; Manda & Frýda 2010), and has resulted in some complicated scientific discussion. In the present paper, we use the term “Daleje Event” in the sense of Chlupáč & Kukal (1988) because this usage has prevailed in the published scientific papers. It is noteworthy that the Daleje Bioevent was based by House (1985) on the

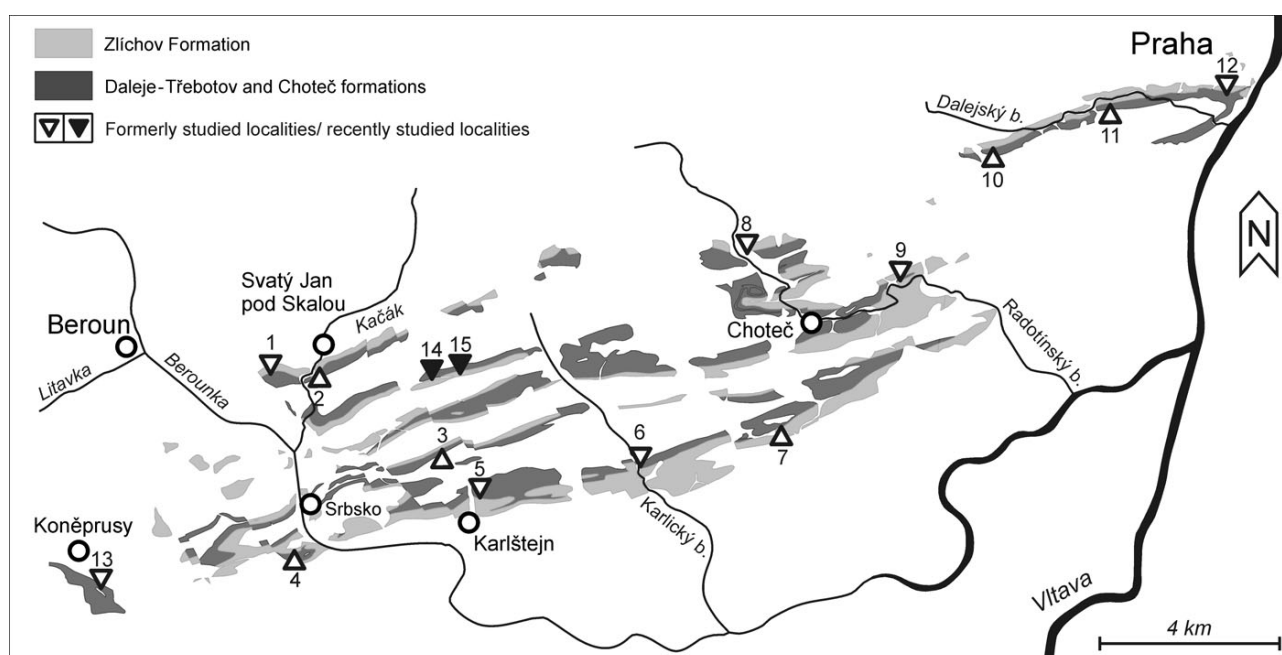


Figure 1. Map showing geographic distribution of Zlíchov, Daleje-Třebotov, and Choteč formations in the Barrandian, as well as the position of the most important localities. 1 – Macháčkův lom near Hostím; 2 – Kačák Valley; 3 – Amerika quarry; 4 – Císařská rokle near Srbsko; 5 – Karlštejn – V Hlubokém Valley; 6 – Karlík Valley; 7 – Pekárkův mlýn near Solopisky; 8 – Rážův mlýn; 9 – Kominická rokle; 10 – Zabitá rokle; 11 – Klukovice; 12 – Švagerka; 13 – Červený lom near Suchomasty; 14 – Čerínka hillside; 15 – Čerínka quarry.

supposedly coeval extinction of the family Auguritidae and some Mimosphinctidae, which in total represents the extinction of six genera of goniatites, according to House (1989). Nevertheless, there is no doubt that the period close to the Zlíchovian/Dalejan boundary is linked with a fast faunal turnover, as has already been noted by many earlier scientists (e.g., Chlupáč & Lukeš 1999).

Regardless of the usage of the term “Daleje Event”, the Barrandian is a classical area where this Emsian event was first recognized and defined (see House 1985, Chlupáč & Kukal 1988). However, its appearance was primarily studied in areas with the deposition of the calcareous Daleje Shale. The main focus of the present study is to evaluate facies development across the Daleje Event in carbonate-dominated environments of the Barrandian (Bohemia) and to improve the biostratigraphic zonation based on the dacryoconarid tentaculites of this interval, as well as to discuss the implications for global Emsian stratigraphy.

Lithostratigraphic units at the Daleje Event interval

More than 200 years of investigation of the Emsian successions, as well as their faunas in the Barrandian, have brought forth several hundred published and unpublished studies, written mainly in Czech, English, French, and German. In addition, during such a long time, the names of the

localities as well as of the lithostratigraphic units were changed several times, along with their definitions and usage. Therefore, orientation within the published data is very difficult (or nearly impossible) for foreign scientists. Because of this, an overview of the basic data on the main lithostratigraphic units at the Early Devonian Daleje Event interval is presented here.

As previously mentioned, the Daleje Event was first established as a bioevent; however, this term is mostly used as an equivalent for a distinct transgression that occurred in the middle of the Emsian. The Daleje Event occurs close to the boundary of the Zlíchov and Daleje-Třebotov formations. The older Zlíchov Formation forms two lithological units – the Zlíchov Limestone and Chýnice Limestone. For the purposes of this paper, the Chýnice Limestone is described separately from the Zlíchov Limestone, although Chlupáč (1981) had considered the Chýnice Limestone to be a member of the Zlíchov Limestone. The younger Daleje-Třebotov Formation includes three lithological units – the Daleje Shale plus the Třebotov and Suchomasty limestones. The stratotypes of these lithological units are described by Chlupáč (1957) and in Chlupáč *et al.* (1998). In the following section, we briefly summarize the basic information on all lithostratigraphic units described from this stratigraphic interval in the Barrandian, as well as describing the usage of these terms in the present paper. The lithostratigraphic units are listed in their stratigraphic order.

Zlíchov Limestone

In his paper, Kettner (1917) described the geology of the Zlíchov Limestone of the southern suburb of Prague as the first recognized independent sedimentological cycle in the upper half of the so-called Braník limestone (the “Bande gl” of Barrande). Later, Kodým (1919) as well as Kettner & Kodým (1919) introduced the name Zlíchov Limestone for this lithological unit. Lithological developments of the Zlíchov Limestone were studied and described in detail by Svoboda & Prantl (1948a, b) as well as Chlupáč (1957). The latter author slightly modified the usage of this term, and in 1981, he noted that the term Zlíchov Limestone should be considered as a valid synonym to the Zlíchov Formation. In some areas, the uppermost portion of the Zlíchov Limestone reaches to the stratigraphic level of the Daleje Event.

Generally, the facial differentiation of the Zlíchov Limestone is low. The predominant volume of this lithological unit is formed by thin bedded, dark to light grey, fine detrital to micritic limestones with abundant black cherts along with minor intercalations of calcareous shales. The majority of micritic layers and most of the shale intercalations are burrowed by *Chondrites* (Chlupáč 1957). In the lowermost part of the Zlíchov Limestone in the NE and SE areas of the Barrandian, the so-called “Chapel Coral horizon” described by Kettner (1917) is developed; for more details on the informal “Kaplička” unit or “Chapel horizon” see Svoboda & Prantl (1948a), Chlupáč & Lukeš (1999), and Chlupáč *et al.* (1998). Chlupáč & Lukeš (1999, p. 80; Chlupáč *et al.* 1998) used the term “Chapel Member” or “Chapel Coral Horizon” for this unsorted, coarse sedimentary breccia, and Hladil *et al.* (2010, p. 391) used a genetic term of channelized breccia flow deposits.

There are two basic types of transitions of the Zlíchov Limestone to younger lithological units: to (a) the Chýnice Limestone and (b) the Daleje Shale. A typical feature of the uppermost part of the Zlíchov Limestone is the disappearance of (or the very low occurrences of) dark cherts. This trend had already been observed by Kettner (1917) in the southern suburb of Prague, and later documented in all studied sections of the Barrandian (*e.g.*, Svoboda & Prantl 1947–1951, Chlupáč 1957, Chlupáč *et al.* 1979, Chlupáč & Lukeš 1999). The upper layers of the Zlíchov Limestone in the SE and S parts of the Barrandian are developed as grey, well-bedded, *Chondrites*-bearing limestones without cherts, intercalated with subordinate layers of dark shales (Chlupáč *et al.* 1979, Chlupáč & Lukeš 1999). In this area, the number of calcareous shale beds gradually increases upwards, and the stratigraphically higher shales predominate over the limestone beds (a gradual transition of the Zlíchov Limestone to the Daleje Shale). However, in the NW part of the Barrandian, the upper part of the Zlíchov Limestone is formed by grey to light-grey micritic and

finely detrital, well bedded, *Chondrites*-bearing limestones without cherts. Compared with the underlying beds, the amount of biotritus increases slightly upwards, containing mainly trilobite, ostracod, and brachiopod fragments (*e.g.*, Chlupáč *et al.* 1979). These layers gradually, but rapidly, change into a rosy, coarsely grained Chýnice Limestone.

Chýnice Limestone

In 1948, Svoboda & Prantl published the results of their geological mapping in the neighbourhood of the village of Chýnice (SE of Prague), where they found rose or red coarse-grained limestones overlying the Zlíchov Limestone, and named these the Chýnice Limestone. Svoboda & Prantl (1948) discussed the geographic distribution of the Chýnice Limestone and noted their occurrence in many sections of the NW, N, and NE parts of the Barrandian. Their later mapping activities (Svoboda & Prantl 1948–1951) revealed that the Chýnice Limestone was not developed only in the SE and S parts of the Barrandian, where a gradual transition of the Zlíchov Limestone into the Daleje Shale is developed.

In general, the Chýnice Limestone is lithologically rather variable in the ratio of coarse-grained bioclastic to finer bioclastic or micritic components. Their colour also varies from rosy to dark red brown, depending on the content of iron oxides. The lower boundary of the Chýnice Limestone with the Zlíchov Limestone is often gradual, but always rather sharp (the thickness of the transition interval is usually only a few centimetres – *e.g.* Fig. 2B, C). Development of the lower and upper parts of the Chýnice Limestone differs (Chlupáč 1957, Chlupáč *et al.* 1979, Havlíček & Vaněk 1996); however, a detailed sedimentological analysis has never been done. The lower part mainly consists of light to rosy granular biotrititic limestones with abundant diversified trilobites, ostracods, and other fauna. On the other hand, in the upper part of the Chýnice Limestone, the amount of the micritic component is high and gradually increases upwards and they become darker (red to red-brown). The lower beds of this more richly micritic upper part bear a rich and diversified benthic fauna, mainly comprising corals, trilobites, and brachiopods (*e.g.* Čeřínka hillside and Zabitá rokle localities).

The upper boundary of the Chýnice Limestone is typically formed by a gradual transition to the Daleje Shale. However, in the vicinity of village of Svätý Jan pod Skalou (Bubovice, Boubová Hill, Stydlé vody, Kačák Valley near Hostim, Mramorka Hill), the Chýnice Limestone gradually and very slowly changes into the Třebotov Limestone of the Daleje-Třebotov Formation (see discussion below). The thickness of the Chýnice Limestone reaches maximal values (up to 15 m) in areas where the Daleje Shale is not

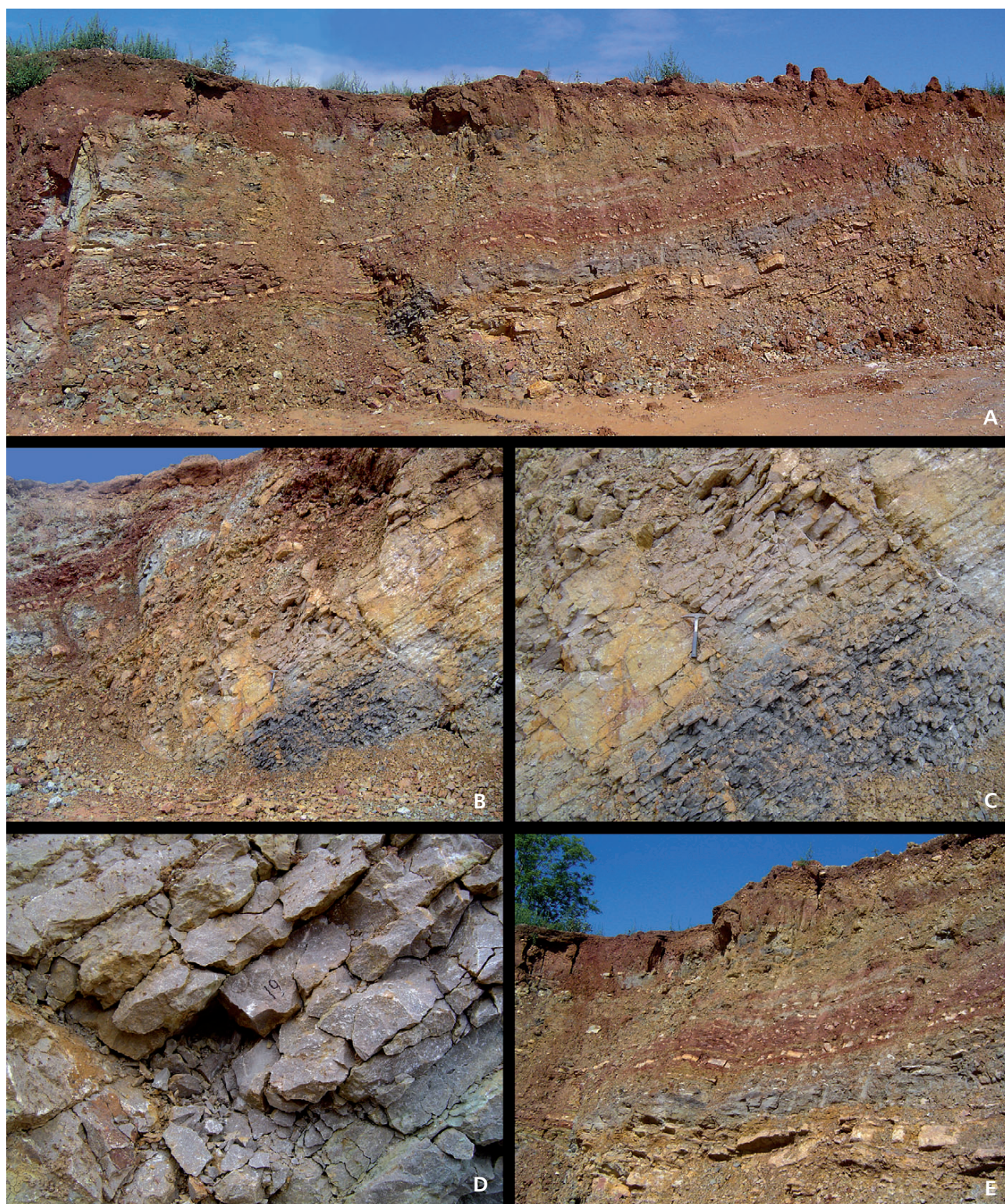


Figure 2. Čerínka quarry section. • A, B – view of the section, including the upper part of the Zlíchov Limestone, Chýnec Limestone, and Daleje Shale. • C – transition from the Zlíchov Limestone (dark grey colour) to the Chýnec Limestone (pink colour). • D – detail of picture C. • E – transition from the Chýnec Limestone (light reddish colour) to the Daleje Shale (grey to red colour).

developed, and gradually decreases toward the S, SE, E, and NE.

The original stratotype of the Chýnice Limestone was established by Svoboda & Prantl (1948) near the village of Chýnice. Unfortunately, this locality ceased to exist, and for that reason, a new lectostratotype was established in the Macháčkův lom near Hostim by Chlupáč (1957). In this area, however, it is difficult to define the upper boundary of this unit using lithological features (see discussion below).

Daleje Shale

Krejčí (1877) was the first who formally named the Daleje Shale (his “Daleje Band”). Usage of this lithological name was later redefined by Chlupáč (1959). The Daleje Shale is typically developed as greenish or dark grey-green calcareous shales. The colour of the Daleje Shale gradually changes to red or dark red in the uppermost parts. It is commonly bioturbated (*Chondrites* burrows), and in some sections, it contains grey micritic limestone concretions or thin beds. Krejčí did not establish the stratotype of the Daleje Shale and thus, the outcrop at the road “Ke Hřbitovu” in Praha-Hlubočepy was selected as the new lectostratotype (Chlupáč *et al.* 1998). Chlupáč (1959) defined the level at which shales predominate over limestones (Zlíchov or Chýnice limestones) as the lower boundary of the Daleje Shale unit. The distribution of the Daleje Shale varies across the Barrandian. The maximal thickness (more than 50 m) is developed in the SW vicinity of Prague (*e.g.* Praha-Hlubočepy, Třebotov; Chlupáč *et al.* 1998). A detailed description of their lithology, geographic distribution, and chemistry may be found in Kodým (1924), Petránek (1951), Svoboda *et al.* (1957), Chlupáč (1959), and Chlupáč *et al.* (1998).

Třebotov Limestone

The term Třebotov Limestone was introduced by Svoboda and Prantl (1947) for the red coloured mostly micritic limestones forming the lower part of the so-called Hlubočepy limestones. Later, Chlupáč (1959) redefined the usage of this lithological name and united the younger grey micritic limestones with the underlying red coloured Třebotov limestones of Svoboda & Prantl (1947) under his Třebotov Limestone. This definition of the Třebotov Limestone is still in use.

The Třebotov Limestone is typically represented by well-bedded, nodular, red, micritic limestones gradually

changing colour upwards into a light grey. Volcanic activity within this member is documented in the vicinity of Chýnice and Choteč (Fiala 1946, Svoboda & Prantl 1948). Further detailed information on their geology and faunas can be found in Svoboda & Prantl (1947–1951), Chlupáč (1959, 1998), Chlupáč *et al.* (1998), and Vodrážková *et al.* (2012). The “Nad tratí” quarry section at Praha-Hlubočepy was selected as the lectostratotype of this lithostratigraphic unit (Chlupáč 1959, 1981). The boundary of the Třebotov Limestone with the underlying Daleje Shale is gradual, and was defined by Chlupáč (1959) as the “level where the amount of limestones predominates over shales”. However, the definition of the lower boundary of the Třebotov Limestone with the underlying Chýnice Limestone is unclear in those areas with missing shale sedimentation such as in the vicinity of the village of Hostim (see discussion below).

Suchomasty Limestone

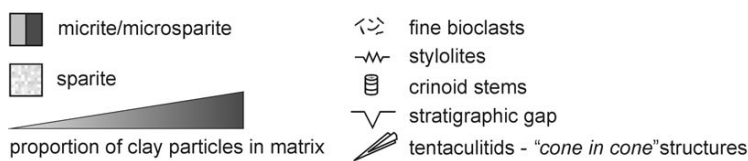
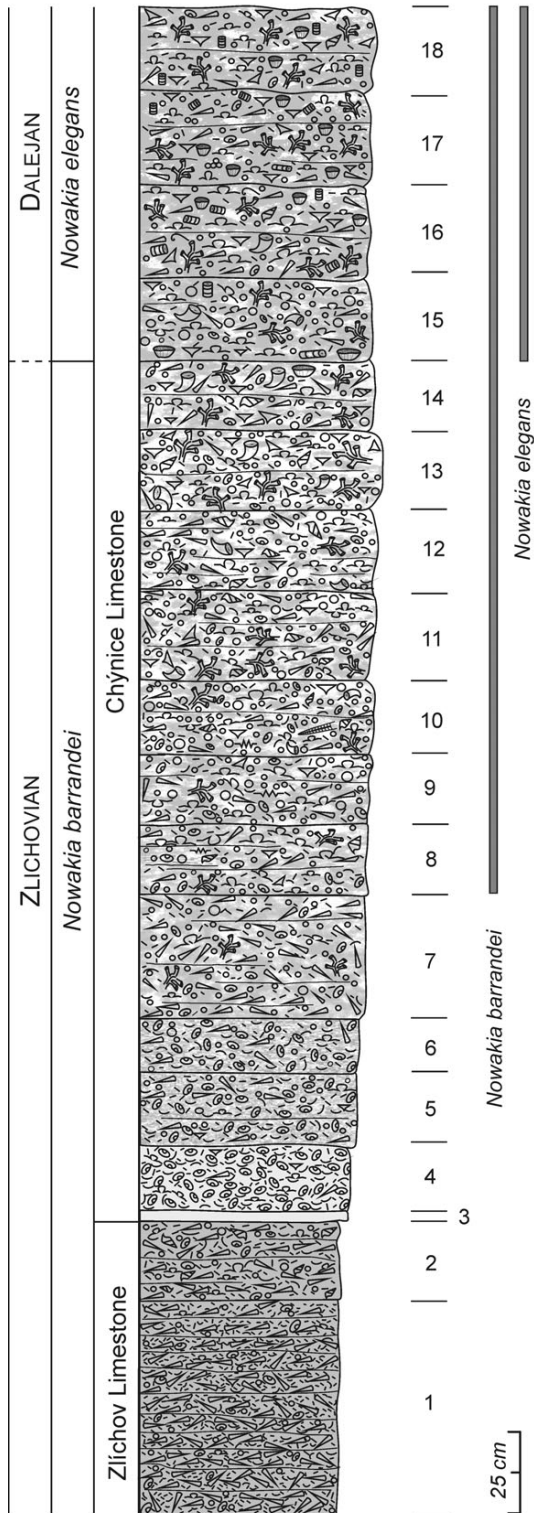
The term Suchomasty Limestone was formally introduced by Chlupáč (1957) for coarse red crinoidal to micritic limestones, only occurring in the Koněprusy area. The dominant colour of the Suchomasty Limestone is dark red, with its thickness reaching up to 30 m. These limestones were deposited on top of the Koněprusy Limestone (Praha Formation, Pragian) after a long period of emersion and erosion, being equivalent to the lower Emsian (Zlíchovian). The lower part of the Suchomasty Limestone also includes the filling of Neptunian dykes (Chlupáč 1954, 1996). The Suchomasty Limestone represents a partial equivalent of the Chýnice Limestone, and the full equivalent of the Třebotov Limestone (for further detailed information see Chlupáč 1954, 1996; Havlíček & Kukal 1990). The Červený lom near Koněprusy was selected as the lectostratotype of the Suchomasty Limestone by Chlupáč (1981).

Methods

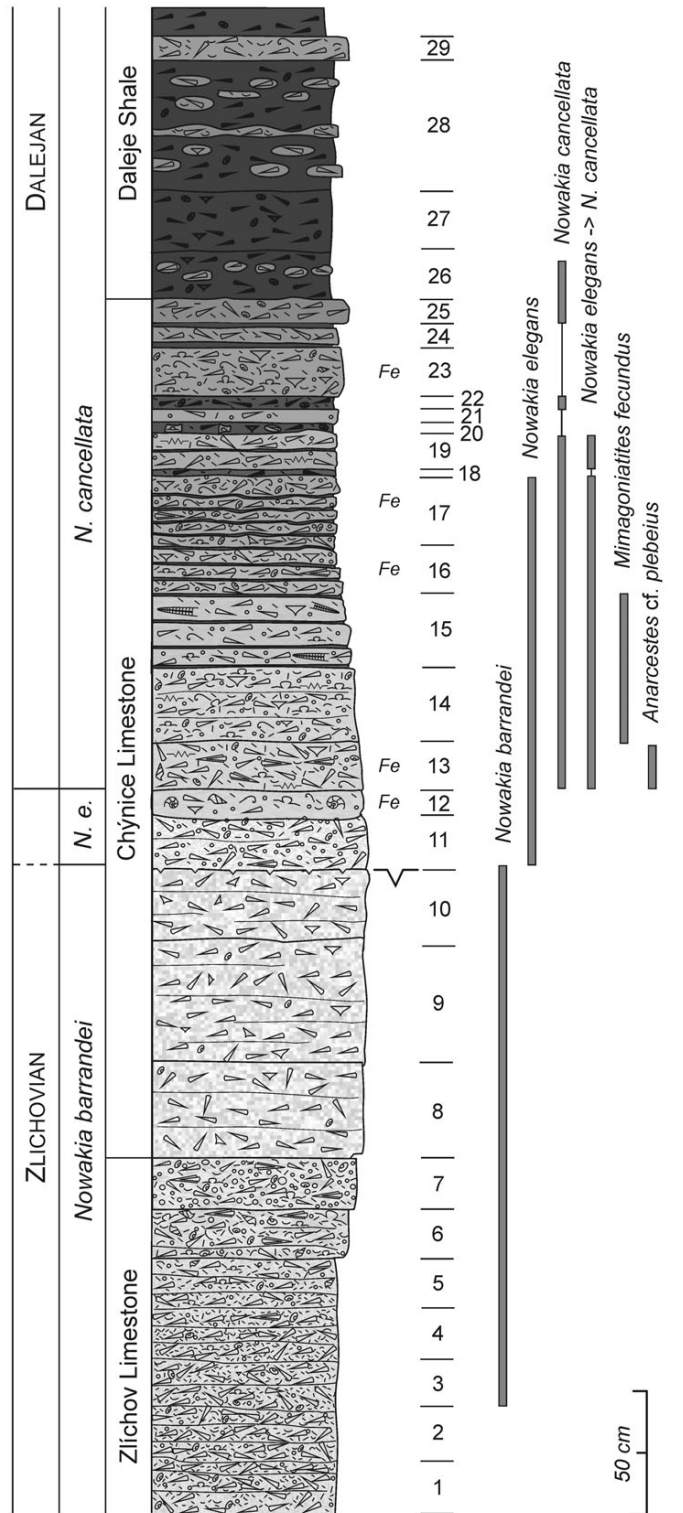
A review of all of the published data was used to select the sections, which are the most suitable for analysis of the appearance of the Daleje Event in successions with predominantly carbonate sedimentation. Two sections, the Čerínka hillside and the Čerínka quarry, were selected for the present study. The first locality had been partly studied in the past (see references in Havlíček & Vaněk 1996); however, the second section was discovered by one of us (JF) in 2006 during field research. Since 2006, both sections have been

Figure 3. Čerínka hillside and Čerínka quarry sections showing the lithology, biostratigraphy, and bed (interval) numbers. Dashed line – newly proposed lower boundary of Dalejan.

Čeřínka hillside section



Čeřínka quarry section



intensively studied for the masters and later for the doctoral project of the senior author of this paper. The Čeřinka hillside was opened with a 25 m long trench, which makes the collection of large rock samples possible. For practical reasons, the section was divided into short intervals having thicknesses of 20 to 25 cm and numbered in stratigraphic order. Rock samples (about 20 kg) from each interval were taken to the laboratory for palaeoecological, biostratigraphic, and sedimentological analysis, where also all the contained fossils were determined and counted. Only the data from the first 4.5 m of the Čeřinka hillside section were used for the present study (the remainder of the samples are currently being studied by Lenka Ferrová).

The limestone succession at the Čeřinka quarry section makes the study of very fresh limestone beds possible (Fig. 2). For this reason, the entire section was not divided into artificial stratigraphic intervals as at the Čeřinka hillside section and bed-by-bed-sampling was used. The thickness of the studied intervals was determined according to the lithological features of the individual beds, with their thicknesses ranging from several cm to several dm. The different thicknesses of the sampled intervals resulted in a different sampling strategy than at the Čeřinka quarry section. The sample size was determined according to the interval thickness. From each 10 cm of thickness, a sample of 3 kg was taken, in order to maintain approximately the same sample density across the section. Samples coming from the Čeřinka quarry section were processed in the laboratory as were those from the Čeřinka hillside section. Because of the fresh nature of the samples coming from the Čeřinka quarry section, about 35 samples were analysed for their isotopic composition of carbonate carbon. A few milligrams of rock powder (preferably micrite) were recovered with a dental drill from rock samples. Carbonate samples were decomposed in a vacuum by 100% phosphoric acid at a temperature of 25 °C. The carbon and oxygen isotopic composition of the released CO₂ was measured with a Finnigan Mat 251 mass spectrometer. All values are reported in ‰ relative to V-PDB by assigning a $\delta^{13}\text{C}$ value of +1.95‰ and a $\delta^{18}\text{O}$ value of 2.20‰ to NSB 19. Accuracy and precision were controlled by replicate measurements of laboratory standards and were better than $\pm 0.1\%$ for both carbon and oxygen isotopes.

The lithology of both sections was studied by the method of microfacial analysis, using thin sections of 3 × 4 cm and 2 × 4 cm in size. The quantitative data on all fossil taxa were summarized by Ferrová (2010), and have been prepared for publication. For numerical evaluation of the newly gathered data, the Past 2.15 software package was used (Hammer *et al.* 2001).

In the present paper, only the data on dacryoconarid tentaculites are used for improvement of the biostratigraphic resolution at the particular studied interval. Herein, the basic data on the stratigraphic distribution of all newly

found tentaculites in the Daleje Event interval at both of the studied sections are briefly summarized, together with a list of all of published as well as hitherto unpublished (dataset of Pavel Lukeš) occurrences in the Barrandian. We stress that the newly gathered data represents the first quantitative dataset on the stratigraphic distribution of dacryoconarid tentaculites across the studied interval. All previously published biostratigraphic data were only collected qualitatively (*i.e.*, an absent/present dataset). The latter approach resulted in a much lower stratigraphic resolution than the quantitative approach, because the biostratigraphic information for many (or even most) stratigraphic levels was inferred from a single occurrence of index tentaculite species within a particular bed. In addition, many levels lack biostratigraphic information (see Chlupáč *et al.* 1979). The newly gathered quantitative data on tentaculites makes a new proposal of biozonation within the studied interval possible. Comparison of the new and published sedimentological data as well as the application of the new high-resolution biozonation has resulted in a more detailed model of the transgression-regression history across the Daleje Event interval in the Barrandian, and introduced new implications for global Emsian stratigraphy.

Key sections across the Daleje Event interval

There is many tens of sections across the Daleje Event interval in the Barrandian, but only a few of those were studied with sufficient biostratigraphic resolution for the purposes of the present study (Fig. 1), which is focused on the appearance of the Daleje Event in carbonate-dominated environments. Classical sections such as Švagerka, Praha-Klukovice, Pekárkův mlýn near Solopisky, and Císařská rokle at Srbsko represent successions where the Chýnec Limestone are either undeveloped or where their equivalents form only a few limestone beds. In carbonate-dominated environments, there are only two sections that were well-studied biostratigraphically, Bubovice and Macháčkův lom near Hostim. However, in both of these sections, only the uppermost part of the Chýnec Limestone was studied (see Chlupáč *et al.* 1979). Additionally, biostratigraphic data from all of the above-mentioned sections had been collected qualitatively (*i.e.*, generally after finding of the first specimen of a biostratigraphically significant tentaculite taxon in a particular bed, the study was finished, and the next bed or stratigraphic interval was sampled). Some intervals were even left without any biostratigraphic datum. However, it should be mentioned that this approach was the standard biostratigraphic method at the time these sections were studied (Chlupáč *et al.* 1979, Chlupáč & Lukeš 1999, and partly also Schindler *et al.* 2003).

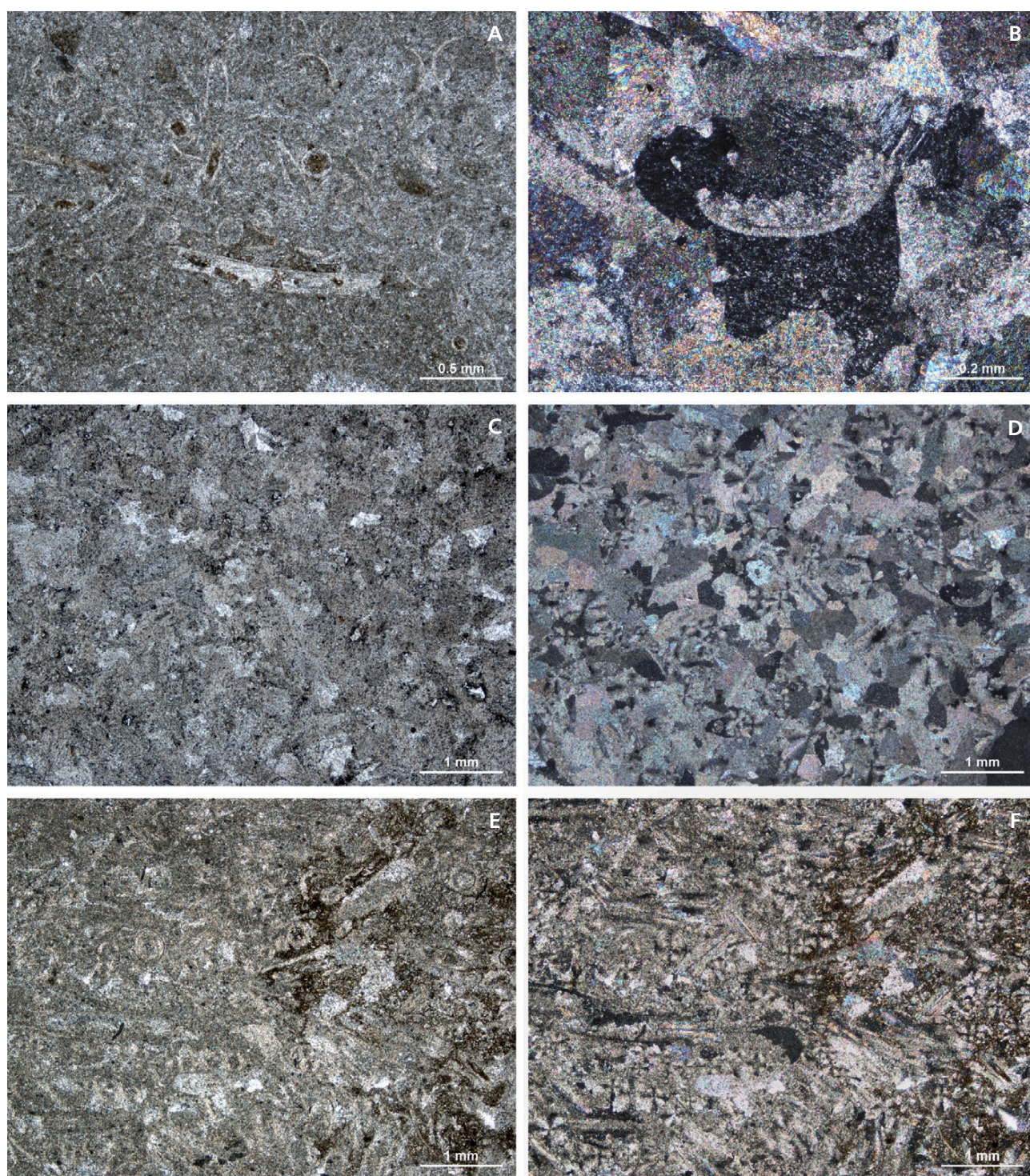


Figure 4. Čeřínka quarry section – thin sections. • A – homogenous tentaculite packstone with calcisiltite matrix and partly bioeroded bioclasts, interval 6, Zlíčov Limestone. • B – recrystallized fragment most likely of an ostracod carapace in polarized light, interval 8, lower part of the Chýnice Limestone. • C, D – completely recrystallized limestones (grainstones) in normal (C) and polarized (D) light (black crosses represent shells of tentaculite shells), interval 8, lower part of Chýnice Limestone. • E, F – tentaculite packstone with highly recrystallized calcisiltite matrix, normal (E) and polarized (F) light, interval 11, upper part of the Chýnice Limestone.

The section in the Červený lom near the village of Koněprusy, being completely developed in its carbonate facies, was studied in the needed biostratigraphic resolution (Chlupáč *et al.* 1979), as only some sections of that stratigraphic level were rather densely sampled for conodonts (Klapper 1977, Klapper *et al.* 1978). Unfortunately, due to the long stratigraphic gap in the Koněprusy area, the sedimentary record at the Červený lom, being the equivalent to the Zlíchovian, is missing.

Before the present study, there was no section in any carbonate-dominated environment of the Barrandian at the Daleje Event interval that had been studied with a sufficient biostratigraphic resolution. To fill this gap in our knowledge, two sections in the NW part of the Barrandian were studied – the Čeřinka hillside and Čeřinka quarry sections. In the following paragraphs, the new sedimentological and biostratigraphic data on these sections are summarized.

New data from carbonate dominated environments

Both of the newly studied sections, Čeřinka quarry and Čeřinka hillside (Fig. 1), are located south of the village of Bubovice (20 km SW of Prague), with a geographic distance of about 400 m. The first section was never studied before. The second section, the Čeřinka hillside section, is located to the east of those sections investigated by Chlupáč (1959) and Chlupáč *et al.* (1979), separated from them by about 20 m and 100 m, respectively.

Čeřinka quarry section

This section is located in the NE corner of the Čeřinka quarry (E of the village of Bubovice). This outcrop was created in 2006 by continuing mining in the Čeřinka quarry. Since 2008, it has been systematically studied by the senior author of this paper (Ferrová 2010). An approximately 5 m long section has been studied bed by bed (see Methods). Due to the non-weathered character of the limestones (Figs 2, 3), it was hard to extract all of the macrofossils from the rock. For this reason, the section was primarily studied for the collection of sedimentological and quantitative data on tentaculite biostratigraphic distributions.

Facies development

The uppermost part of the Zlíchov Limestone, through the entire Chýnec Limestone to the lower part of the calcareous shales (representing transitional layers between the Daleje Shale and the Třebotov Limestone) was studied in detail at the Čeřinka quarry section (Figs 2, 3).

Intervals 1 to 7 of the section, having a total thickness of about 1 m (Fig. 3), belong to the upper part of the Zlíchov Limestone, which is formed by grey, homogenous, and well-bedded beds of tentaculitid wackestone/packstone with a calcisiltite matrix (Fig. 4A). A typical feature of this succession is the slightly increasing amounts and sizes of the biotrititic content upwards toward the younger beds (to interval 7). Together with the tentaculites, crinoids and ostracods were determined as the most frequent components of the biotrititic materials. The sediment was distinctly bioturbated. Bioerosion of clasts occurs rather rarely. Fragments of corals were found at the top of interval 7 (Radek Labuša, personal communication).

Intervals 8–10, having a total thickness of about 1.2 m, represent the lower portion of the Chýnec Limestone. The transition between the Zlíchov and Chýnec limestones is rapid and rather sharp (Figs 2B–D, 3). The limestone beds of the lower part of the Chýnec Limestone differ from the underlying beds of the Zlíchov Limestone in their lithology. The beds are thicker, and formed by white to light rosy, completely recrystallized limestones (grainstones) (Fig. 4C). The faunal content in thin section is clearly visible, but only determinable using the crossed-nicoles mode (Fig. 4B, D). The preserved small fauna is mainly comprised of tentaculites and ostracods. Pseudosparite forms the main part of these beds.

The upper part of the Chýnec Limestone (Figs 4–6), including intervals 11 to 25, has a total thickness about 2.3 m. The lithological features of the basal bed (interval 11) differ distinctly from the underlying beds of the lower part of the Chýnec Limestone in their lack of dominant pseudosparite. The basal bed (interval 11, Figs 4E, F and 5A) is formed by rosy calcisiltite tentaculite packstone, with a high degree of recrystallization. Columnals of crinoids are frequent (some of them are bioeroded). Several fragments of corals were also found, but in general, the diversity of macrofossils is rather low. The following three beds (intervals 12–14, Fig. 5B–D) are formed by red tentaculite packstones with calcisiltite matrix (locally recrystallized). Except for tentaculites, other small fauna is mainly represented by fragments of crinoids and less frequently by ostracods, trilobites, bivalves, gastropods, cephalopods, brachiopods as well as rare rugose corals. Cone-in-cone structures of tentaculite shells are abundant. They were reported by Koptíková (2011, pp. 101, 102) also from upper part of the Třebotov Limestone. Bioerosion of the bioclasts of crinoids, trilobites, and other shells occur very commonly, also in analogy to the Třebotov Limestone (Hladil 2004). Abundant stylolites are surrounded with iron oxides.

Yellow to red coloured, tentaculite wackestone with partly recrystallized bioclasts, is characteristic of interval 15 (Fig. 5E). A decrease of the overall diversity and abundance of fossils is evident in comparison with the

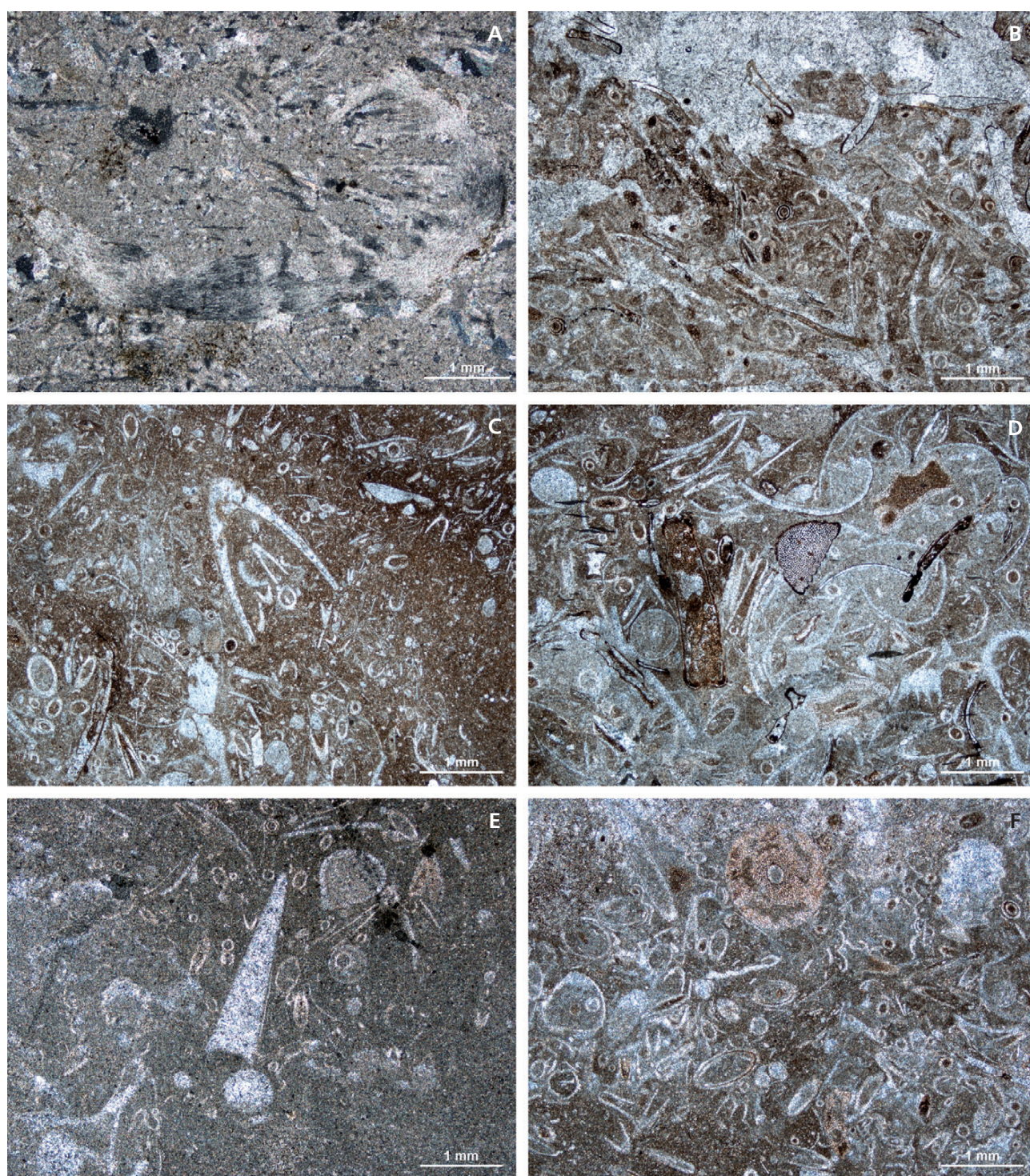


Figure 5. Čerínka quarry section – thin sections. • A – fragment of coral in polarized light, interval 11, upper part of the Chýnice Limestone. • B – partly recrystallized tentaculite packstone with calcisiltite matrix and “cone-in-cone” structures, interval 13, upper part of the Chýnice Limestone. • C, D – tentaculite packstone with calcisiltite matrix and partly bioeroded fragments of crinoids, ostracods, brachiopods and molluscs, interval 14, upper part of the Chýnice Limestone. • E – tentaculite wackestone, interval 15, upper part of the Chýnice Limestone. • F – tentaculite packstone with bioeroded fragment of crinoid, common “cone-in-cone” structures, partly recrystallized, interval 16, upper part of the Chýnice Limestone.

underlying intervals 12 to 14. The only exceptions are cephalopod fragments, which are more abundant than in the other intervals. Beds of tentaculite packstones, separated from one another by very thin 2 to 5 mm thick intercalations of barren shales, represent intervals 16 to 17 (Fig. 5F). Fragments of crinoids, ostracods, trilobites, and bivalves represent the greater part of the bioclasts. Cone-in-cone structures are common. Interval 18 is formed by a 3 cm thick layer of grey, strongly calcareous, soft shale. It contains numerous shells of poorly-determinable tentaculites, brachiopods, and ostracods.

Intercalations of homogeneous, tentaculite wackestone/packstone and calcareous shales are typical features of intervals 19 to 22 (Fig. 6A). Except for the tentaculites, other fossils are rather rare. The limestones are partly recrystallized. Cone-in-cone structures are present. Interval 23 is formed by a distinct, 20 cm thick bed of dark red packstone (Fig. 6B). The fossil assemblage of this limestone bed is diversified – including abundant fragments of tentaculites, ostracods, trilobites, and crinoids. Rarely, hyolith shells and fragments of crustaceans were also found, as well as a bryozoan zoecium in life-like positions (attached upon a clast; Fig. 6C, D). Bioerosion of trilobite and crinoid fragments are common, as well as cone-in-cone structures. The sediment was bioturbated. One interesting point is that the diversified assemblage, seen in the thin sections, was not possible to extract by hammering (by this method, only a few carapaces of ostracods were acquired). The limestone beds of interval 24 and 25 represent the end of sedimentation of the Chýnice Limestone. A typical feature of these highly recrystallized tentaculite wackestone/packstone beds, intercalated with thin layers of calcareous shale, is the low abundance and overall diversity of the macrofossils.

The final part of the section (intervals 26 to 29, Fig. 6F) consists of compacted calcareous shales, with subordinate amounts of red micritic limestones beds and lenses, forming the transition between the Daleje Shale and the Třebotov Limestone (compare with Chlupáč *et al.* 1979). Both limestones and shales contain tentaculite fauna.

Carbon isotopes

Thirty five samples collected at the Čeřinka quarry section for isotope analyses of the carbonate carbon include an interval from the upper Zlíčov Limestone to the top of the Chýnice Limestone (Fig. 7). Measured values (Table 1) from the upper Zlíčov Limestone and the lower part of the Chýnice Limestone (intervals 1 to 10) have a rather uniform development. However, the value from interval 11 (the first bed of the upper part of the Chýnice Limestone) and from the stratigraphically younger beds are suddenly and distinctly lower and reach even negative values (Figs 7, 8).

Notes on overall biodiversity

Investigation of the Čeřinka quarry section mainly focused on the study of carbonate petrology and quantitative tentaculite biostratigraphy. As a side product of the laboratory processing and separation of all determinable tentaculite shells, a rather large collection of other faunal elements was produced. The fauna from the Čeřinka quarry section includes trilobites, ostracods, bivalves, gastropods, cephalopods, brachiopods, anthozoans, rostroconchs, and hyolithes; aside from the more than 1250 determinable shells of tentaculites. In total, this fauna represents (without tentaculites) more than 50 different taxa, and will be further evaluated in the coming years.

Čeřinka hillside

The Čeřinka hillside section is situated SE from the village of Bubovice, and has been a well-known palaeontological locality of the Chýnice Limestone for more than 50 years. A list of fossils from this locality (often called Bubovice) was published by Chlupáč (1957, 1959), Chlupáč *et al.* (1979, 1998), and Havlíček & Vaněk (1996). Newly described taxa from the Čeřinka hillside section include inarticulate brachiopods, trilobites, and gastropods (Vaněk 1998; Frýda 2001; Frýda *et al.* 2008b, 2009; Budil *et al.* 2009; and Mergl & Ferrová 2009). During the years 2006 to 2010, this section was intensively studied by Lenka Ferrová. The section was exposed in an approximately 25 m long trench, which included the upper part of the Zlíčov Limestone, the entire Chýnice Limestone, and transitional layers between the Daleje Shale and the Třebotov Limestone. The dip of the limestone beds in the entire studied section was uniformly about 30° to the NW.

Facies development

The first two intervals (1, 2) have a total thickness of about 80 cm (Fig. 3) and represent the upper part of the Zlíčov Limestone. It consists here of light grey, homogeneous, and well-bedded beds of tentaculite wackestone/packstone without cherts, but with a calcisiltite matrix bearing a poor macrofaunal content (mostly fragments of trilobites and brachiopods; Fig. 8A). Fragments of crinoids, ostracods, and tiny gastropod shells were also observed as a subordinate faunal component. The sediment in these intervals was distinctly bioturbated. Indefinite edges between burrows and the enclosing sediment suggests that bioturbation had already started in the semi-lithified sediment. There is an increase from the base of interval 1 to the top of interval 2 in both the abundance and diversity of the bioclasts, as well as in the amounts of broken shells.

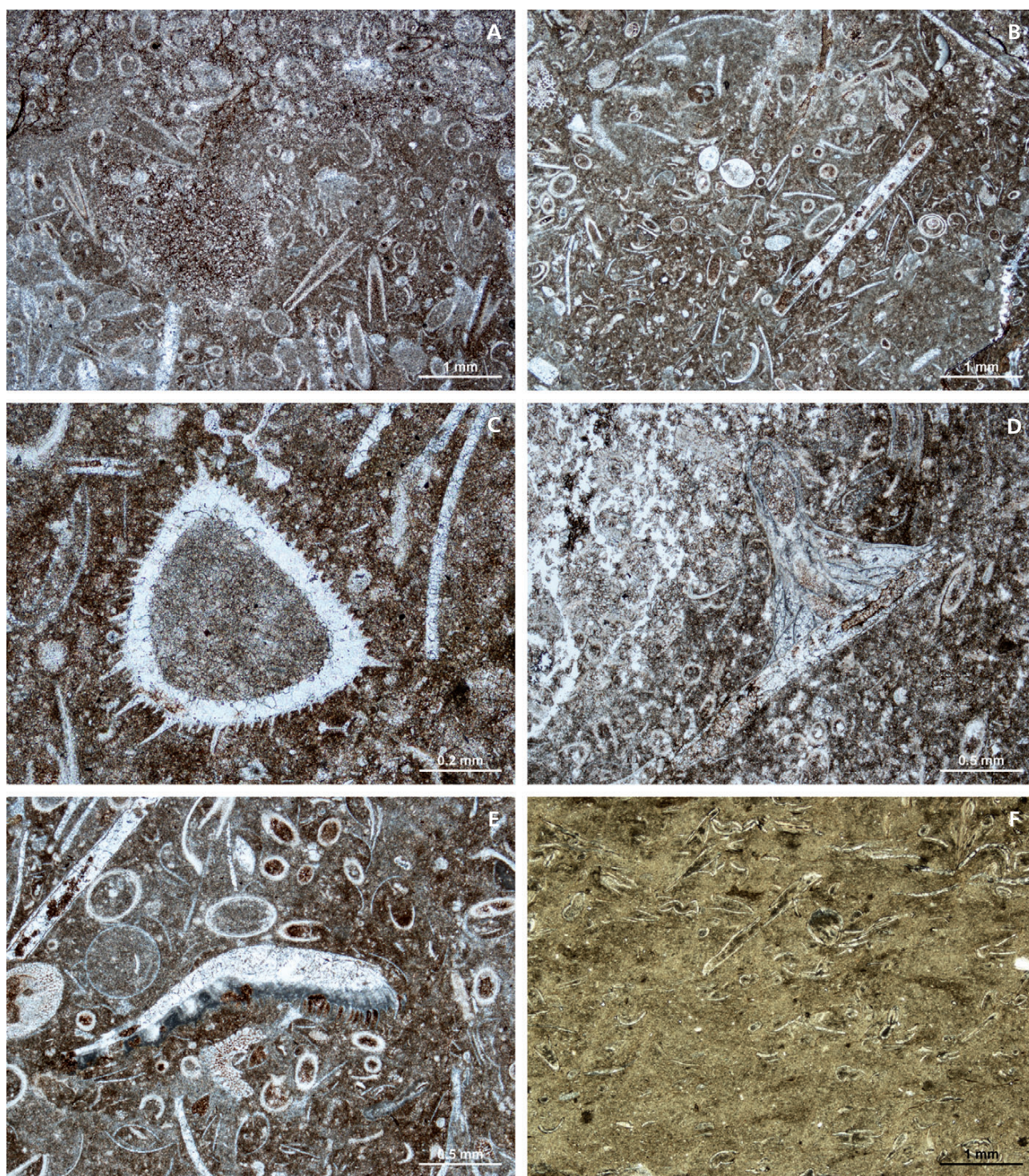


Figure 6. Čeřínka quarry section – thin sections. • A – partly recrystallized tentaculite packstone, interval 19, upper part of the Chýnec Limestone. • B–E – thin sections from interval 23, upper part of the Chýnec Limestone. B – packstone with diversified and partly bioeroded bioclasts of tentaculites and other molluscs, crinoids, and ostracods; C – cross section of a hyolithid (?) shell; D – small bryozoan zoecium attached on a bioclast; E – well-preserved fragment of a crustacean carapace. • F – calcareous tentaculite shale, lower part of the Daleje Shale.

Table 1. Isotope composition of carbonate carbon from the Čeřinka quarry limestone samples. Sampling covers much wider stratigraphic interval of the Čeřinka quarry section than biostratigraphic sampling. Table shows a position of each sample relative to stratigraphic intervals.

Scale (cm)	Interval	$\delta^{13}\text{C}$ (‰ PDB)	$\delta^{18}\text{O}$ (‰ PDB)
0		0.34	–3.29
18		0.64	–3.03
53		0.76	–2.64
76		0.62	–2.86
93		0.44	–2.97
107		0.45	–2.96
107		0.72	–2.81
129		0.69	–2.68
147		0.70	–2.71
169		0.75	–2.73
187		0.87	–2.15
204		0.73	–2.53
209	1	0.70	–3.28
222	2	0.71	–2.32
240	3	0.29	–2.95
255	3	0.50	–2.46
265	4	0.60	–2.28
275	4	0.71	–2.10
295	5	0.71	–2.58
315	6	0.75	–2.63
315	6	0.78	–2.67
335	7	0.71	–2.63
355	8	0.65	–2.57
375	8	0.58	–2.76
395	9	0.50	–2.50
423	9	0.44	–2.78
451	10	0.61	–2.50
451	10	0.66	–2.42
474	11	–0.24	–2.81
502	13	–0.64	–3.35
524	14	–0.18	–3.23
547	15	–0.06	–3.85
569	16	–0.19	–4.15

Intervals 3 to 14, with a total thickness of 2.5 m, represent the lower part of the Chýnice Limestone (Figs 8B–F, 9A, B). The transition between the Zlíčov and Chýnice limestone is rather sharp. Sedimentation of the Chýnice Limestone begins with an approximately 5 cm thick layer of weathered, totally recrystallized grainstone (size of the calcite grains about 1 to 2 mm). Because of this, a determination of the primary sedimentological features of this interval is impossible. The following beds are formed by white to light rosy neomorphized limestones (grainstones)

bearing fragments of ostracods, tentaculites, small trilobites, brachiopods, and locally abundant spicules (Fig. 8B–D). Sometimes, the bioclasts are micritized. Microsparite is often concentrated in the fillings of convex shells and the shells of tentaculites. Pseudosparite forms approximately 40% of the rock volume. A typical feature of the following intervals (5 and 6) is a gradual upwards increase in the amount of crinoidal fragments.

The lower part of the Chýnice Limestone (intervals 7 to 14; Fig. 3) show a gradual change from rosy unsorted floatstones with calcisiltite matrix, through poorly washed crinoidal packstones with pelletoids, to rosy crinoidal grainstones in the upper part (Figs 8E, F, 9A, B). Apart from crinoidal detritus, numerous fragments of different trilobites, corals, tentaculites, and ostracods were documented. Less frequent faunal elements include gastropods, cephalopods, rostroconchids, and bivalves. Traces of bioerosion are rare within all of these intervals (7–14).

The upper part of the Chýnice Limestone is formed by coarsely bedded limestone beds of a grey to red-brown colour. Intervals 15 to 18 represent unsorted floatstones with umbrella structures and pluricolumnals of crinoids to coral bindstones (Fig. 9C–F). The most abundant fauna are crinoids, trilobites, corals, tentaculites, and brachiopods.

The following succession also contains limestone beds formed by *in situ* benthic organisms (mainly corals). The top of the Chýnice Limestone and its boundary with the calcareous shale layers, forming the transition between the Daleje Shale and the Třebotov Limestone, is quite fast, yet gradual. This interval was studied by Chlupáč *et al.* (1979) at a very close section (named as Bubovice). Generally, the amount of fine grained carbonate particles, as well as of fine siliciclastic materials, gradually increases as the biotrititic component decreases (Chlupáč *et al.* 1979, and in our data). The uppermost part of the section has not yet been studied in detail, and will be one of the goals of the ongoing project.

Notes on overall biodiversity

Investigation of the Čeřinka hillside section mainly focused on the palaeoecology of the taxa occurring in the Chýnice Limestone. Since 2008, systematic research of this section was performed by Ferrová (2010). More than 2,100 fossil specimens belonging to 84 species were collected in the lower part of the Chýnice Limestone (intervals 7 to 14 with a total thickness of about 2.5 m). The upper part of the Chýnice Limestone, with an even higher diversity, is currently studied by the senior author. Publications evaluating the entire fauna are in preparation; three short papers based on these newly collected materials have already been published (Frýda *et al.* 2008b, 2009; Mergl & Ferrová 2009).

Tentaculite biostratigraphy

The stratigraphic distributions of all species of tentaculites (dacryoconarid, as well as true tentaculites) were examined at both newly studied sections, the Čeřinka hillside and Čeřinka quarry. Quantitative data, representing more than 1250 determined specimens are plotted in Figs 10 and 11 together with the results of rarefaction analyses (Fig. 12), which verified a good sampling density at the Čeřinka quarry section. Fourteen tentaculite species were documented at both of the studied sections. In addition, several important biostratigraphic observations have been made. Irrefutable co-occurrences of *N. barrandei* and *N. elegans* (Figs 3, 11) as well as irrefutable co-occurrences of *N. elegans* and *N. cancellata* have been discovered.

Careful evaluation of more than 800 tentaculite shells belonging to the species *N. barrandei*, *N. elegans*, and *N. cancellata* reveals numerous occurrences of transitional forms between *N. elegans* and *N. cancellata* (see discussion below), but not between *N. barrandei* and *N. elegans*.

In the following section, the basic data on all of the tentaculites found are summarized together with a list of all their occurrences in the Barrandian area, based on published papers as well as on the unpublished data of Pavel Lukeš. The terms Zlíčovian and Dalejan are used in the following taxonomic portion in the traditional sense (*i.e.*, the Dalejan starts with the first occurrence of *Nowakia cancellata*). The character “+” means that the mentioned taxa occur together.

Tentaculitids found at the Čeřinka sections

Order Tentaculitoidea Lyashenko, 1957
Family Tentaculitidae Walcott, 1886

Genus *Dicricococonus* Fisher, 1962
(= *Heteroconus* Lyashenko, 1955)

***Dicricococonus* sp.**

Čeřinka sections. – 7 incomplete shells from the Čeřinka quarry section (upper part of Chýnice Limestone – layers with *N. elegans* and *N. elegans* + *N. cancellata*).

Other occurrences in the Barrandian. – Voskop quarry (Koněprusy area): lowermost part of the Suchomasty Limestone (the filling of Neptunian dykes) without dating by index dacryoconarid tentaculites.

Stratigraphic range. – Uppermost Zlíčovian–lower Dalejan, Emsian.

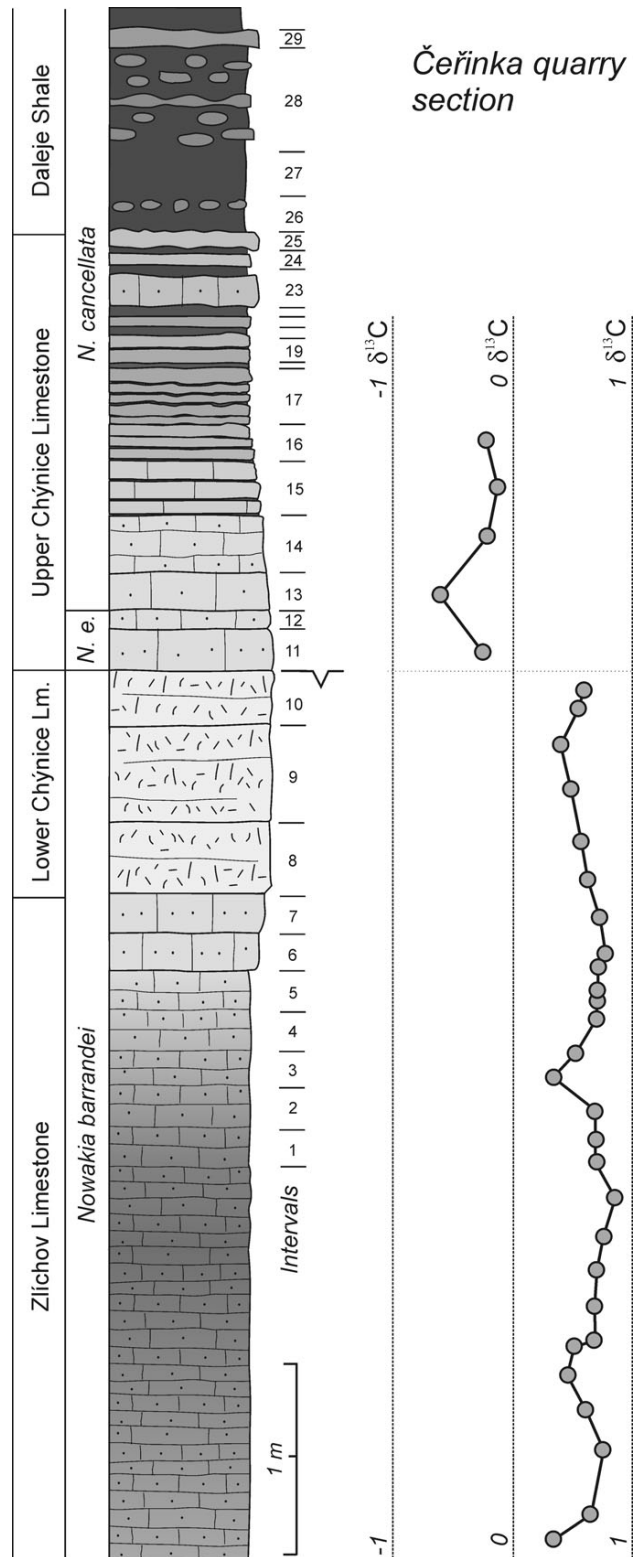


Figure 7. Čeřinka quarry section showing isotope composition of carbonate carbon from individual stratigraphic intervals. Note the sudden change in $\delta^{13}\text{C}$ values at the sequence boundary (boundary of intervals 10 and 11).

Remarks. – Incomplete shells 2 to 4 mm long without proximal part do not allow precise species determination. Nevertheless a thick body wall with fine dense rings and conspicuous protuberant mounds place these shells into genus *Dicricoconus*.

Order Homoctenida Bouček, 1964
Family Homoctenidae Lyashenko, 1955

Genus *Homoctenus* Lyashenko, 1955

***Homoctenus hanusi* (Bouček, 1964)**

Holotype. – Specimen figured by Bouček (1964) on pl. 40, fig. 1; Coll. NM L 6287a.

Type locality. – Praha-Hlubočepy, outcrop near the upper viaduct.

Type horizon. – Daleje Shale with *N. cancellata* (upper Emsian).

Čeřinka sections. – Tens of shells, all preserved without the proximal part, from the Čeřinka quarry section (upper part of the Zlíchov Limestone and the Chýnec Limestone – almost continuous occurrence from layers with *N. barrandei* to those with *N. cancellata*) and from the Čeřinka hillside section (Chýnec Limestone – layers with *N. barrandei* and *N. barrandei* + *N. elegans*).

Other occurrences in the Barrandian. – Švagerka section (bed No. 26, upper part of Zlíchov Limestone with *N. barrandei*); Klukovice section (lower part of the Chýnec Limestone with *N. barrandei*); Pekárkův mlýn section (upper part of Zlíchov Limestone to lower part of Daleje Shale – layers with *N. barrandei* and *N. elegans*); Macháčkův lom near Hostim (lowermost part of the Třebotov Limestone – dating by index dacryconarid species was not available). Bouček (1964) noted several additional occurrences: Karlštejn – V Hlubokém Valley (Daleje Shale); Holyně (Třebotov Limestone); Dolní Roblín (Eifelian Choteč Limestone).

Stratigraphic range. – Upper Zlíchovian–Dalejan, Emsian, and ?Eifelian (Bouček 1964).

Remarks. – Detailed description of this species is given by Bouček (1964, pp. 144–146).

Subclass Dacryconarida Fisher, 1962
Order Nowakiida Lyashenko, 1955

Genus *Nowakia* Gürich, 1896

***Nowakia* (*Nowakia*) *barrandei* Bouček & Prantl, 1959**

Figures 13D–F, 14A–C, K–O, 15B, C

Holotype. – Specimen figured by Bouček (1964) on pl. 8, fig. 2, Coll. NM L6185, National Museum, Prague.

Type locality. – Choteč (Barrandian area, Czech Republic).

Type horizon. – Upper layers of the Zlíchov Limestone, Zlíchovian (lower Emsian, Devonian).

Čeřinka sections. – Tens of very well preserved shells from the Čeřinka quarry section (uppermost part of the Zlíchov Limestone and lower part of Chýnec Limestone) and from the Čeřinka hillside section (lower part of Chýnec Limestone and in basal beds of upper part of Chýnec Limestone together with *N. elegans*).

Other occurrences in the Barrandian. – Švagerka section (uppermost part of the Zlíchov Limestone and lowermost part of the Daleje Shale – documented co-occurrence with *N. elegans*); Pekárkův mlýn section (upper part of the Zlíchov Limestone); Klukovice section (Chýnec Limestone); Císařská rokle section (upper part of the Zlíchov Limestone and the Chýnec Limestone); Lukeš (1977) noted additional occurrences: Chýnec “Ve mlýnci”; Praha-Holyně; Kominická rokle near Choteč.

Stratigraphic range. – Upper Zlíchovian (lower Emsian, Devonian).

Remarks. – Detailed description of was given by Bouček (1964, pp. 74–77), Lardeux (1969, pp. 96–99), Lukeš (1977, p. 20) and Alberti (1993, pp. 33, 34).

***Nowakia* (*Nowakia*) *elegans* (Barrande, 1867)**

Figures 13A–C, 14D–J, 15A,D

Holotype. – Specimen figured by Barrande (1867) on pl. 14, figs 20–24 and by Bouček (1964) on pl. 11, fig. 1, Coll. NM L6206; National Museum, Prague.

Type locality. – Vávrův mlýn in the Radotín Valley (= “Wawrowitz”), Prague, Czech Republic.

Type horizon. – The uppermost layers of the Zlíchov Limestone and lowermost part of Daleje Shale, uppermost Zlíchovian (Emsian, Devonian).

Čeřinka sections. – Tens of very well preserved shells from the Čeřinka quarry section (upper part of the Chýnec

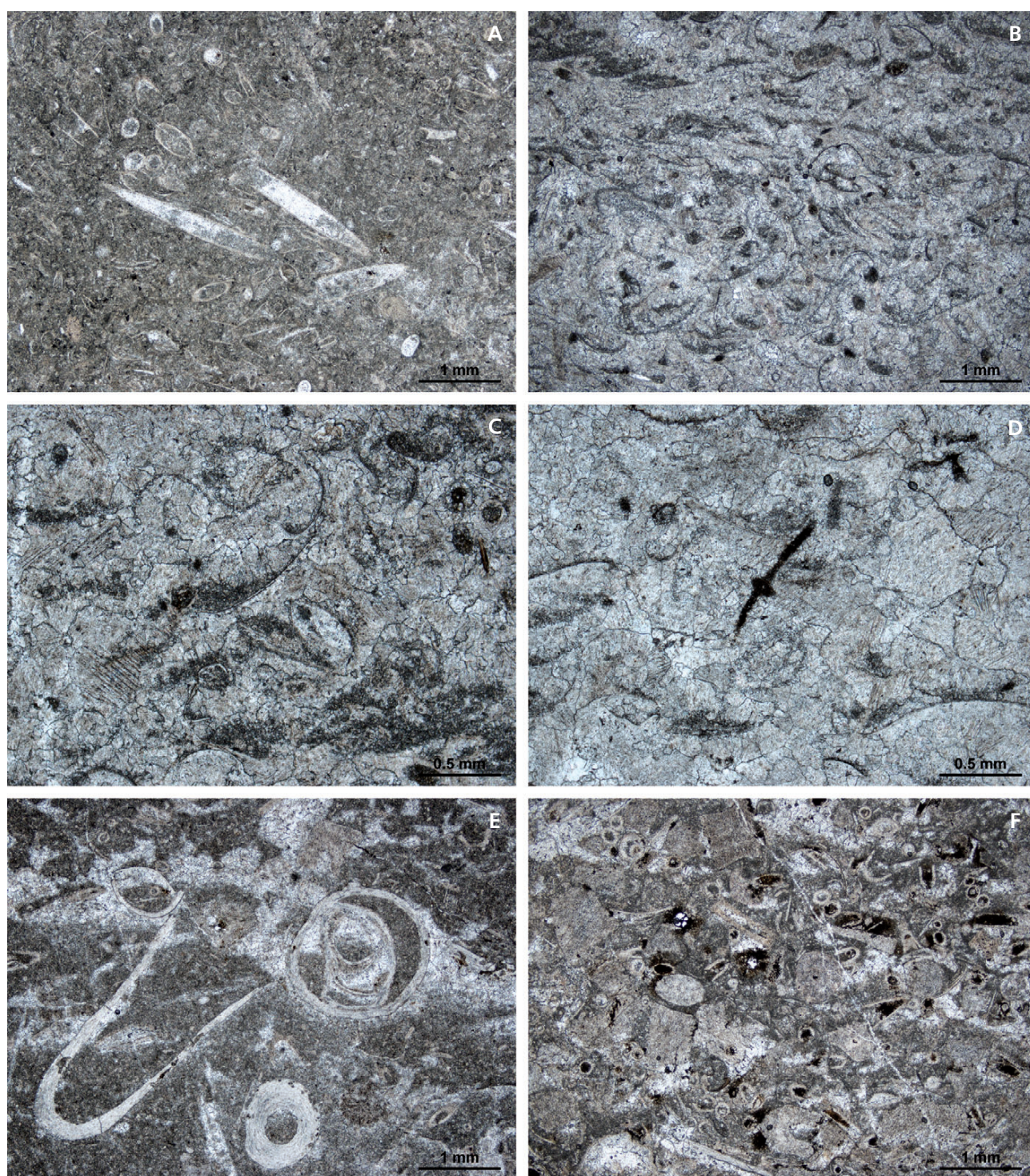


Figure 8. Čerínka hillside section – thin sections. • A – homogenous tentaculite packstone with calcisiltite matrix, interval 1, uppermost part of the Zlíčov Limestone. • B–D – interval 4, lower part of the Chýnice Limestone. B – recrystallized limestone (grainstone) containing of tentaculite shells and fragments of ostracods partly filled with microsparite (dark coloured); C – detail view of partly micritized ostracod carapace filled with microsparite (middle of the figure); D – detail view of black coloured spicule. • E – floatstone with fragments of corals, crinoids, ostracods, brachiopods, tentaculites and other molluscs, interval 7, lower part of the Chýnice Limestone. • F – crinoidal-tentaculite packstone, shells are partly recycled (fillings of tentaculite shells are different from the matrix), interval 8, lower part of the Chýnice Limestone.

Limestone also together with *N. cancellata*) and from the Čeřinka hillside section (upper part of the Chýníc Limestone together with *N. barrandei*).

Other occurrences in the Barrandian. – Švagerka section (uppermost part of the Zlíčov Limestone and lower part of the Daleje Shale also together with *N. barrandei*); Klukovice section (uppermost part of the Chýníc Limestone and lower part of the Daleje Shale); Pekárkuv mlýn section (uppermost part of the Zlíčov Limestone and lower part of the Daleje Shale); Císařská rokle section (Chýníc Limestone); Červený lom (lower part of the Suchomasty Limestone). Lukeš (1977) noted additional occurrences: Praha-Holyně and Kominická rokle.

Stratigraphic range. – Uppermost Zlíčovian and lowermost Dalejan (Emsian, Devonian).

Remarks. – Detailed description is given by Lukeš (1976, pp. 20–23), Salah (1976, pp. 29–39) and by Alberti (1993, pp. 37, 38).

***Nowakia (Nowakia) elegans (Barrande, 1867) →
Nowakia (Nowakia) cancellata (Richter, 1854)***

Čeřinka sections. – Tens of well-preserved shells from the Čeřinka quarry section (upper part of Chýníc Limestone together with *N. elegans* and *N. cancellata*).

Remarks. – Transitional forms between *N. elegans* and *N. cancellata* (in sense of Lukeš 1977) were first recognized by Alberti (1993), who figured them on table 17 (figs 5–11). Material newly collected at the Čeřinka hillside section revealed several different types of “transitional” forms. The most noticeable form has proximal parts of juvenile shell with a “*cancellata*-like” shape and ornamentation. However, the adult part of the shell bears an “*elegans*-like” shape and ornamentation. Large and well-preserved new material needs further detailed study using numerical methods.

Stratigraphic range. – Uppermost Zlíčovian to lowermost Dalejan (Emsian, Devonian).

Other occurrences in the Barrandian. – Pekárkuv mlýn section (lower part of the Daleje Shale together with *N. elegans*); Karlštejn – V Hlubokém Valley (lower part of the Daleje Shale together with *N. cancellata*); Císařská rokle section (Chýníc Limestone together with *N. elegans*).

Nowakia (Nowakia) cancellata (Richter, 1854)

Holotype. – Specimen figured by Richter (1854) on pl. 3, figs 10–13.

Type locality. – East Thuringian Highland (original locality unknown, Germany).

Type horizon. – “Schiefer der Tentaculitenschichten” (original designation of R. Richter), lower Dalejan, upper Emsian (Devonian).

Čeřinka sections. – Hundreds of complete shells preserved in limestones as well as in shales from the Čeřinka quarry section (upper part of the Chýníc Limestone and lower part of transitional layers between the Daleje Shale and the Třebotov Limestone together with *N. elegans*) and from the Čeřinka hillside section (Daleje Shale).

Other occurrences in the Barrandian. – Klukovice section (Daleje Shale – 9 m above the boundary with the Chýníc Limestone); Pekárkuv mlýn section (Daleje Shale – 12 m above the boundary with the Zlíčov Limestone); Karlštejn (lower part of the Daleje Shale); Císařská rokle section (lower and middle part of the Daleje Shale); Macháčkuv lom near Hostim (lowermost part of the Třebotov Limestone in about 1 m thick interval); Červený lom (lower part of the Suchomasty Limestone). Lukeš (1977) noted additional occurrences: Chýníc “Ve mlýnci” and Kominická rokle.

Stratigraphic range. – Lower Dalejan (upper Emsian, Devonian).

Remarks. – Detailed description is given in Salah (1976, pp. 40–48, table 3, figs 1–10), Lukeš (1977, pp. 23–24, table 1, fig. 3, table 5, figs 1–7, table 7, figs 1–3), Alberti (1993, pp. 335–336, table 13, fig. 13, table 19, figs 1–16, text-fig. 9).

Genus *Viriatellina* Bouček, 1964

***Viriatellina hercynica* Bouček, 1964**

Holotype. – Specimen figured by Bouček (1964) on pl. 17, fig. 6, Coll. NM S1830; National Museum, Prague.

Type locality. – Zorge, Harz (Germany).

Type horizon. – Upper layers of the “Tentaculitenknollenkalk”; Dalejan (upper Emsian, Devonian).

Čeřinka sections. – Tens of very well preserved shells from the Čeřinka quarry section (upper part of the Zlíčov Limestone and Chýníc Limestone together with *N. barrandei*, *N. elegans* and *N. cancellata*) and from the Čeřinka hillside section (Chýníc Limestone – in layers with *N. barrandei* and *N. barrandei* + *N. elegans*).

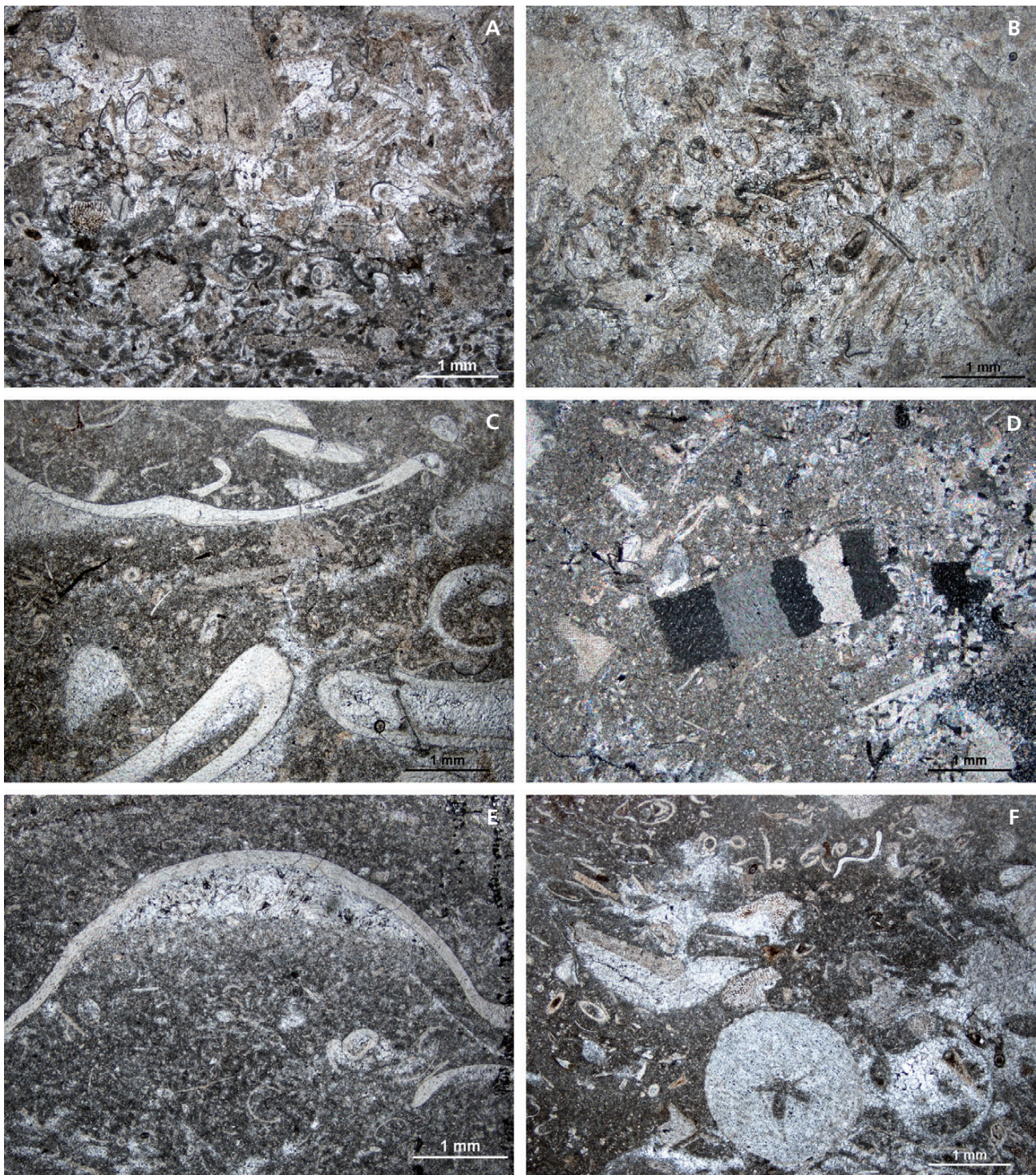


Figure 9. Čeřínka hillside section – thin sections. • A – recrystallized limestone with micritic pelletoids and altered (micritized) and non-altered shells (lower part of view) and crinoidal grainstone (upper part of view) separated by stylolitic boundary, interval 8, lower part of the Chýnice Limestone. • B – crinoidal grainstone, interval 13, lower part of the Chýnice Limestone. • C – unsorted floatstone with diversified bioclasts. • D – pluricolumnal of crinoid, E – umbrella structure (fragment of trilobite shell). C–E – interval 15, upper part of the Chýnice Limestone. • F – crinoidal unsorted floatstone with fragments of tentaculites, corals and other fossils, interval 17, upper part of the Chýnice Limestone.

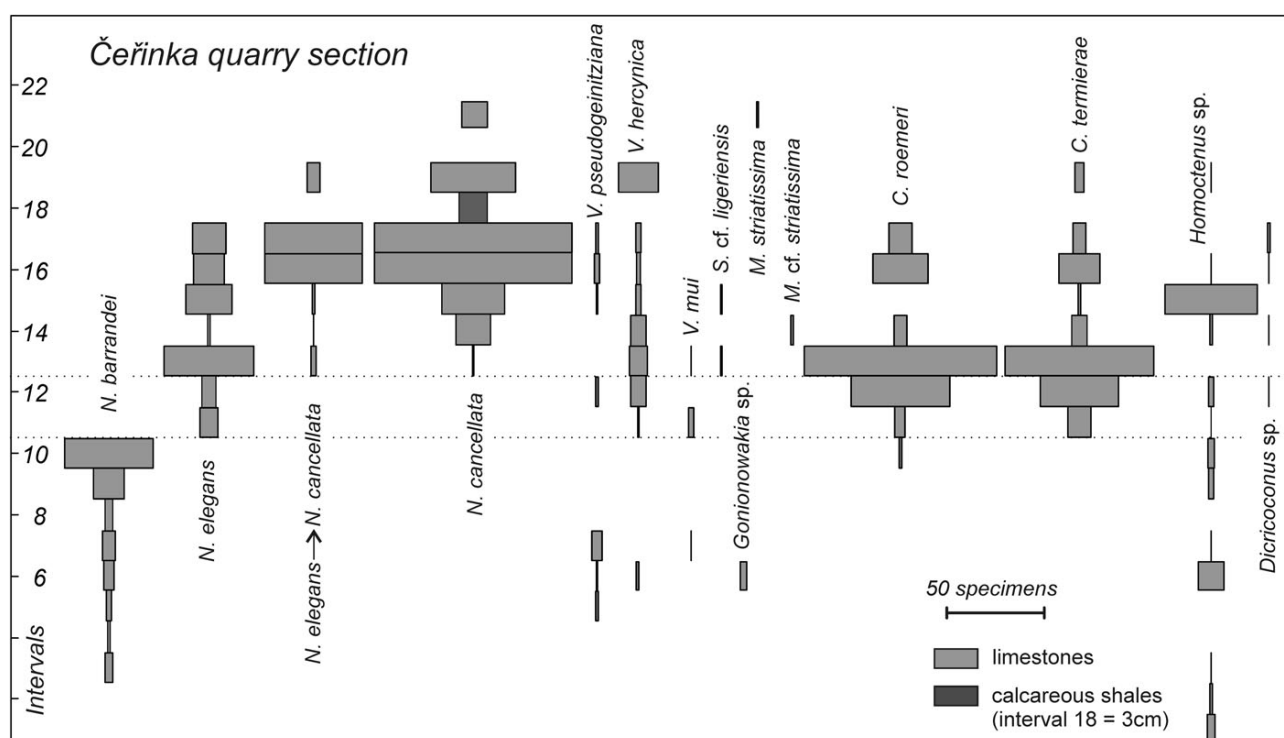


Figure 10. Čeřinka quarry section – quantitative data on the stratigraphic distribution of tentaculites.

Other occurrences in the Barrandian. – Švagerka section (upper part of the Zlíčov Limestone to lower part of the Daleje Shale in layers with *N. barrandei* and *N. barrandei* + *N. elegans*); Klukovice section (Chýnice Limestone with *N. barrandei*); Pekárkův mlýn section (upper part of the Zlíčov Limestone and lowermost layer of the Daleje Shale – layers with *N. barrandei* and *N. elegans*); Karlštejn – V Hlubokém Valley (upper part of the Zlíčov Limestone); Císařská rokle section (upper part of the Zlíčov Limestone and the Chýnice Limestone with *N. barrandei* and *N. elegans*).

Stratigraphic range. – Upper Zlíčovian to lower Dalejan (Emsian, Devonian).

Remarks. – Detailed descriptions in Bouček (1964, pp. 95, 96, table XVII, figs 3–7), Lardeux (1969, pp. 126–128, figs 95–96). Alberti (1998) introduced new several taxa closely resembling *V. hercynica*.

***Viriatellina pseudogeinitziana* Bouček, 1964**

Holotype. – Specimen figured by Bouček (1964) on pl. 18, fig. 1; Coll. NM L6212, National Museum, Prague.

Type locality. – Choteč (Barrandian, Czech Republic).

Type horizon. – Uppermost layers of the Zlíčov Limestone; uppermost Zlíčovian (lower Emsian, Devonian).

Čeřinka sections. – About 26 shells from the Čeřinka quarry section (upper part of the Zlíčov Limestone and the Chýnice Limestone with *N. barrandei*, *N. elegans* + *N. cancellata*) and from the Čeřinka hillside section (Chýnice Limestone with *N. barrandei* and *N. barrandei* + *N. elegans*).

Other occurrences in the Barrandian. – Švagerka section (upper part of the Zlíčov Limestone with *N. barrandei*); Klukovice section (Chýnice Limestone with *N. barrandei*); Pekárkův mlýn section (upper part of the Zlíčov Limestone with *N. barrandei*); Císařská rokle section (upper part of the Zlíčov Limestone with *N. barrandei*). Lukeš (1977) noted also Kominická rokle.

Stratigraphic range. – Upper Zlíčovian to lower Dalejan (Emsian, Devonian).

Remarks. – Detailed descriptions is given by Bouček (1964, pp. 96–99) and Lardeux (1969, pp. 134–136). *V. pseudogeinitziana* occurs commonly together with *V. hercynica* but former species has bigger and more robust shell with higher number of longitudinal ribs than *V. hercynica*. *V. pseudogeinitziana* has in comparison with *N. barrandei* just undulated surface of the shell.

Viriatellina mui Alberti, 1993

Holotype. – Specimen figured by Alberti (1993) on pl. 43, fig. 2, Coll. SMF 48696.

Type locality. – Gara Mdouard SW Erfoud (Tafilalt, Morocco).

Type horizon. – Biodebitic limestone with *Nowakia barrandei* (lower Emsian, Devonian).

Čeřinka sections. – About ten mostly incomplete but well-preserved shells from the Čeřinka quarry section (uppermost part of the Zlíchov Limestone to upper part of the Chýnec Limestone with *N. barrandei* to *N. elegans* + *N. cancellata*).

Other occurrences in the Barrandian. – Švagerka section (upper part of the Zlíchov Limestone with *N. barrandei* + *N. elegans*); Klukovice section (Chýnec Limestone, bed no. 39 with *N. barrandei*).

Stratigraphic range. – Upper Zlíchovian (lower Emsian, Devonian).

Remarks. – Detailed description is given by Alberti (1993, pp. 72, 73). Morphological characters of *V. mui* resemble those in *Stylionowakia ligeriensis* Lardeux, 1969. The latter species occurs also in layers with *N. barrandei*. Shells of *V. mui* are longer, more robust and bearing transversal mounds in middle and apical part of the shell. In *S. ligeriensis* transversal mounds occur in apertural part. However it is difficult to determination incomplete shells.

Genus *Stylionowakia* Lardeux, 1969

Stylionowakia ligeriensis Lardeux, 1969

Holotype. – Specimen figured by Lardeux (1969) on pl. 47, fig. 1; Institut de Paléontologie du Muséum d'Histoire naturelle de Paris.

Type locality. – La Grange near Chalonnes (Armorican Massif).

Type horizon. – La Grange Limestone (lower Emsian, Devonian).

Remarks. – See remarks of *V. mui*.

Čeřinka sections. – Several incomplete but well preserved shells from the Čeřinka hillside section (lower part of the Chýnec Limestone with *N. barrandei*).

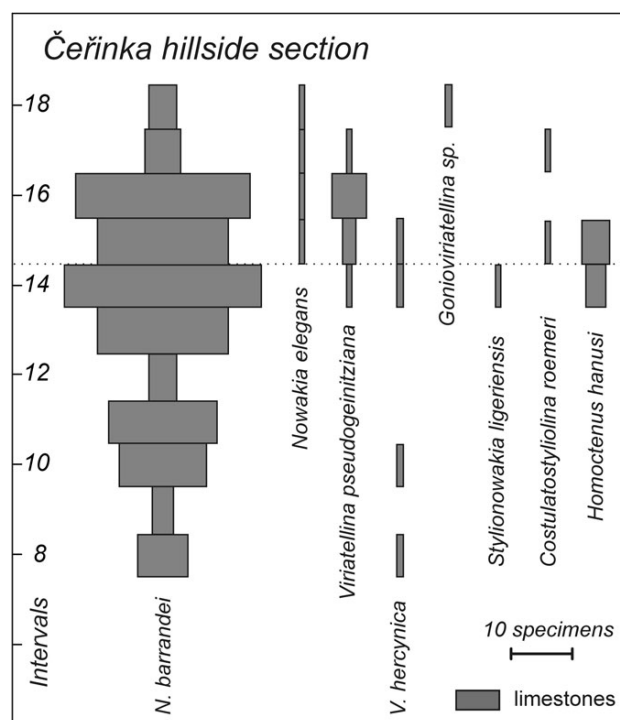


Figure 11. Čeřinka hillside section – quantitative data on the stratigraphic distribution of tentaculites.

Other occurrences in the Barrandian. – Klukovice section (Chýnec Limestone with *N. barrandei*); Pekárkův mlýn section (upper part of the Zlíchov Limestone, bed No. 16 with *N. barrandei*).

Stratigraphic range. – Upper Zlíchovian (lower Emsian, Devonian).

Genus *Metastylolina* Bouček & Prantl, 1961

Metastylolina striatissima Bouček & Prantl, 1961

Holotype. – Specimen figured by Bouček (1964) on pl. 37, fig. 8; Coll. NM L6273.

Type locality. – Švagerka near Zlíchov (Praha-Hlubočepy, Czech Republic).

Type horizon. – Daleje Shale (upper Emsian, Devonian).

Remarks. – Detailed description is given by Bouček (1964, pp. 142, 143).

Čeřinka sections. – Six shells from the Čeřinka quarry section (uppermost part of the Chýnec Limestone and lower part of the Daleje Shale with *N. cancellata*).

Other occurrences in the Barrandian. – Císařská rokle section (the Daleje Shale and upper part of the Třebotov Limestone – layers with *N. cancellata* and *N. richteri*); Bouček (1964) noted also following localities: Praha-Holyně (Choteč Limestone with *N. sulcata*); Chýnec – Spodní mlýn (Choteč Limestone with *N. sulcata*); Vysoký Újezd (abandoned quarry – the Choteč Limestone with *N. sulcata*).

Stratigraphic range. – Upper Zlíchovian (Emsian) to lower Eifelian.

Genus *Costulatostyliolina* Lardeux, 1969

***Costulatostyliolina roemeri* (Bouček, 1964)**

Holotype. – Specimen figured by Bouček (1964) on pl. 37, fig. 2; Coll. NM L6268.

Type locality. – Holyně – abandoned quarry (Prague, Czech Republic).

Type horizon. – Lower part of the Třebotov Limestone (Dalejan, upper Emsian).

Čeřinka sections. – Tens of well-preserved complete shells from the Čeřinka quarry section (upper part of the Chýnec Limestone with *N. barrandei*, *N. elegans*, and *N. cancellata*) and from the Čeřinka hillside (upper part of the Chýnec Limestone with *N. barrandei* + *N. elegans*).

Other occurrences in the Barrandian. – Klukovice section (Daleje Shale with *N. elegans*); Pekárkův mlýn section (upper part of the Zlíchov Limestone with *N. barrandei*); Macháčkův lom near Hostim (Chýnec Limestone).

Stratigraphic range. – Upper Zlíchovian (Emsian).

Remarks. – Detailed description made by Bouček (1964, pp. 134–136).

***Costulatostyliolina termierae* Lardeux, 1969**

Holotype. – Specimen figured by Lardeux (1969) on pl. 50, fig. 1; Institut de Paléontologie du Muséum d'Histoire naturelle de Paris.

Type locality. – La Grange, near Chalonnes (Armorican Massif).

Type horizon. – La Grange Limestone (lower Emsian, Lower Devonian).

Čeřinka sections. – Tens of well-preserved shells (but none with protoconch) from the Čeřinka quarry section (upper part of the Chýnec Limestone with *N. elegans* and *N. cancellata*).

Other occurrences in the Barrandian. – Chlupáč (1978) noted its occurrence in the Zlíchov and Chýnec limestones in his list of fossils but without any other locality information.

Stratigraphic range. – Upper Zlíchovian to lower Dalejan (Emsian).

Remarks. – Detailed description is given by Lardeux (1969, pp. 176–178). *C. termierae* differs from closely related *C. roemeri* by its sparse longitudinal ribs.

Order Styliolinida Lyashenko, 1955

Genus *Styliolina* Karpinsky, 1884

Type species. – *Styliolina nucleata* Karpinsky, 1884.

***Styliolina* sp.**

Čeřinka sections. – Hundreds of shells with different kinds of preservation; abundant through entire Čeřinka sections.

Other occurrence in the Barrandian. – Abundant through the whole Zlíchov and Daleje-Třebotov formations.

Remarks. – Straight smooth mostly conical shells disallowed any precise taxonomical identification and can contain more taxa together. At present state of knowledge specimens of this genus have no importance to detailed biostratigraphical research. For this reason shells of *Styliolina* sp. were not evaluated in presented analysis.

Order Gonionowakiida Lardeux, 1969

Genus *Gonionowakia* Ruan & Mu, 1983

Type species. – *Gonionowakia hexagona* Ruan & Mu, 1983.

***Gonionowakia* sp.**

Čeřinka sections. – Several incomplete well-preserved shells from the Čeřinka quarry section (upper part of the Zlíchov Limestone with *N. barrandei*).

Other occurrences in the Barrandian. – Švagerka section (upper part of the Zlíchov Limestone with *N. barrandei*); Pekárkův mlýn section (upper part of the Zlíchov Limestone

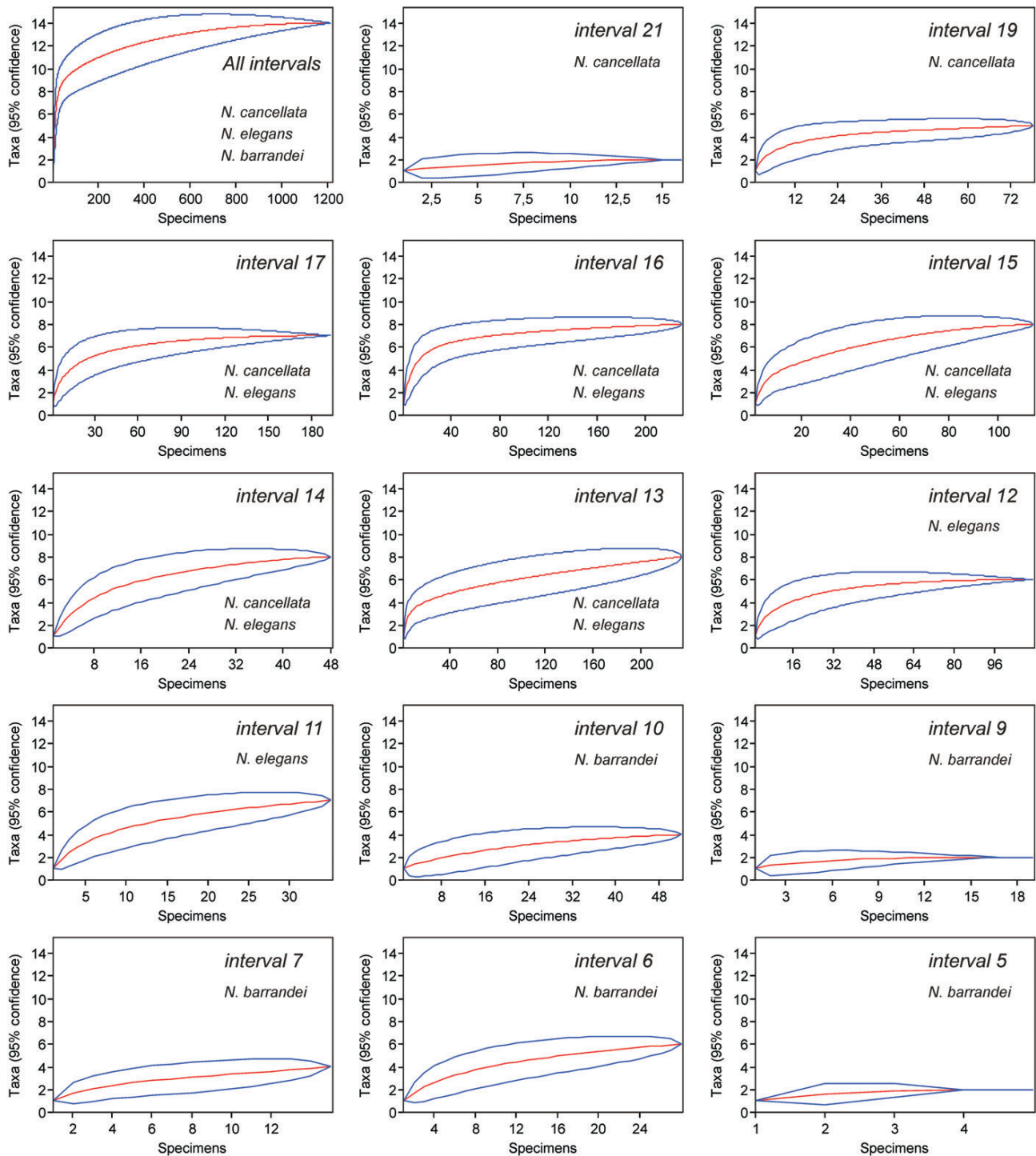


Figure 12. Čerínka quarry section – comparison of taxonomic diversity in 15 tentaculite samples (intervals 5–21), using rarefaction analysis. By extrapolation, the curves indicate if further sampling would have increased the number of tentaculite species. The curves also show how many tentaculite species we would expect to find if the number of specimens in the sample were lower. Standard deviations are also shown.

with *N. elegans*); Císařská rokle section (upper Zlícho-
vian).

Stratigraphic range. – Upper Zlícho-
vian.

Remarks. – According to Ruan & Mu (1983), fine shell
with polygonal transverse section, sparse longitudinal ribs
and sharp-ridged transverse rings characterize the genus
Gonionowakia.

Genus *Gonioviriatellina* Ruan & Mu, 1983

Type species. – *Gonioviriatellina cancellosa* Ruan & Mu, 1983.

Gonioviriatellina sp.

Čeřinka sections. – Several incomplete, but well-preserved shells from the Čeřinka quarry section (upper part of the Zlíchov Limestone with *N. barrandei*).

Other occurrences in the Barrandian. – Karlštejn – V Hlubokém Valley (upper part of the Zlíchov Limestone).

Stratigraphic range. – Upper Zlíchovian (Emsian).

Remarks. – Ruan & Mu (1983) characterized this genus by fine shell with polygonal transverse section, sparse longitudinal ribs and undulated transverse rings.

Proposal for a new tentaculite biostratigraphy

The biostratigraphic correlation within the stratigraphic interval close to the Daleje Event (roughly corresponding to the boundary interval of the regional stages Zlíchovian and Dalejan) was traditionally based upon tentaculite biostratigraphy (Bouček 1964, Lukeš 1977). Tentaculite biostratigraphy has provided precise relative dating and correlation of disconformities, unconformities, hiatuses, and sedimentological changes among the Lower and Middle Devonian sections of the Barrandian. Within the stratigraphic interval around the Daleje Event, the tentaculite biostratigraphy provides a much higher stratigraphic resolution than biozonation, based on conodonts or goniatites. It is highly unlikely to considerably increase the stratigraphic resolution of goniatite biostratigraphy in the future, simply due to the fact that the goniatites generally occur rather rarely, and it will be impossible to find them in all of the studied beds. In contrast, it is easily possible to collect numerous determinable tentaculite shells in every limestone or shale bed. However, it has to be noted that the full potential of conodont biostratigraphy has not hitherto been evaluated in the Barrandian, and this is one of the main targets of the ongoing project.

Previously published tentaculite biozonal charts for the Barrandian area were composed of taxon-range zones (Bouček 1964). All beds close to the Daleje Event bear rich and diverse tentaculite assemblages (Figs 10 and 11). Species of the genus *Nowakia* Gürich, 1896 belong to the most abundant and easily determinable taxa; for this reason, they have been used for biostratigraphic correlations. Here, we review the existing biozones, and define one new subzone.

All of these biozones are defined here as interval zones. The main reason for this definition is the fact that new, more detailed biostratigraphic research has revealed co-occurrences of adjacent index biozones (e.g., *N. barrandei* + *N. elegans*; *N. elegans* + *N. cancellata*). An interval zone is much less affected by widespread and confusing overlaps and gaps among zonal index taxa. Here, each of redefined interval zones is applied in accordance with the stratigraphic “rules” proposed by the second edition of the International Stratigraphic Guide (Salvador 1994) and the third edition of Czech Stratigraphic Code (Chlupáč & Štorch 1997). These biozones are defined by two bounding biohorizons, and named after the most significant traditional index species. Each biozone is further typified by a distinct tentaculite assemblage and its type section. This is just the first step in a redefinition of the tentaculite biozonal charts for the Barrandian area.

Taken together, usage of the biozones mentioned below as interval zones are the same as those mentioned by several authors (e.g., Lütke 1979, Kim 2011) but our usage differs from their common usage as range zones. In the following paragraphs, the basic data on the newly proposed tentaculite biostratigraphy of the Daleje Event interval are summarized. All of the biozones are listed in stratigraphic order.

Nowakia barrandei Biozone

This interval biozone is named after the characteristic species *Nowakia barrandei* Bouček & Prantl, 1959, which is an internationally recognized zonal index fossil (Bouček 1964, Alberti 1993). The base of the *barrandei* Biozone is placed at the first appearance of *N. barrandei*, and its top at the first appearance of *N. elegans* (Barrande, 1867) in sense of Lukeš (1977). Several additional tentaculite species occur within the *N. barrandei* Biozone – *Viriatellina pseudo-geinitziana* Bouček, 1964, *V. hercynica* Bouček, 1964, *V. mui* Alberti, 1993, *Costulatostyliolina roemeri* (Bouček, 1964), *Stylianowakia* cf. *ligeriensis* Lardeux, 1969, *Gonionowakia* sp., as well as the homoctenid *Homoctenus hanusi* (Bouček, 1964). The type section of the *barrandei* Biozone is at the Švagerka section.

Nowakia elegans Biozone (including the *barrandei*–*elegans* Subzone)

This interval biozone is named after the characteristic species *Nowakia elegans* (Barrande, 1867), which is a widely distributed zonal index fossil (Alberti 1993). The base of the *elegans* Biozone is placed at the first appearance of *N. elegans*, and the top of this biozone at the first appearance of *N. cancellata* (Richter, 1854) in sense of Lukeš (1977).

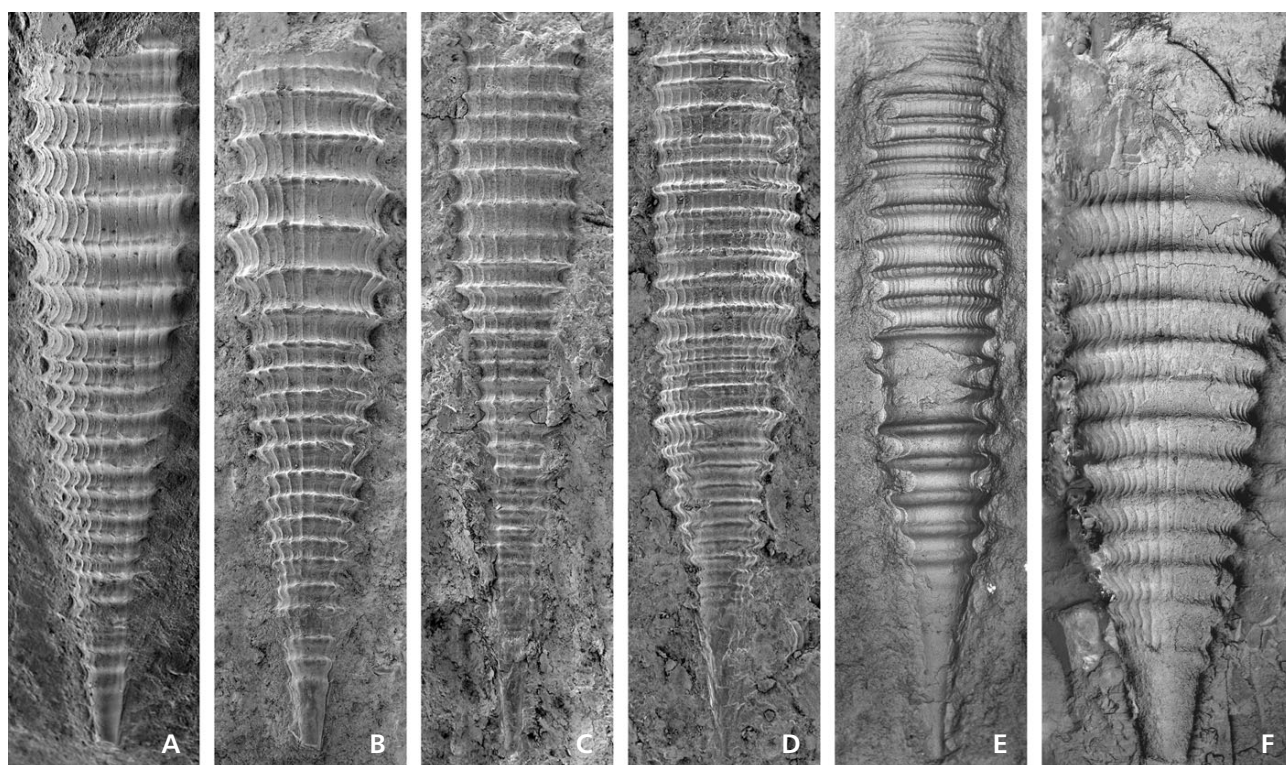


Figure 13. Shells of *Nowakia elegans* (A–C) and *Nowakia barrandei* (D–F). • A, B – oblique lateral and lateral views of specimen PL333, Bubovice, Chýnec Limestone. • C – lateral view of specimen LF001, Čerínka quarry, interval 17. • D – lateral view of specimen PL3719, Pekárkuv mlýn. • E – lateral view of specimen PL12, Choteč, Zlíčov Limestone. • F – lateral view of specimen LF002, Čerínka hillside, interval 13. A, B $\times 20$; C $\times 20$; D $\times 22$; E $\times 17$; F $\times 30$.

The lower part of the *elegans* Biozone is marked by its common occurrences of *N. elegans* and *N. barrandei*. Here, this level is established as a new *barrandei–elegans* Subzone within the *N. elegans* Biozone. Its base is also identical with the base of the *elegans* Biozone, and its top at the last appearance of *N. barrandei*. Several additional tentaculite species were found in both biozones; *Costulatostyliolina roemeri* (Bouček, 1964), and *C. termierae* Lardeux, 1969, are the most common species, together with the zonal index species within the *elegans* Biozone above the *barrandei–elegans* Subzone. However, *C. roemeri* also occurs in the *barrandei–elegans* Subzone and the underlying *barrandei* Biozone (Figs 11 and 12). *Viriatellina pseudogeinitziana*, *V. hercynica*, *V. mui*, *Homotenus hanusi*, *Dicricoconus* sp., and *Gonioviriatellina* sp. are less frequent species of the *elegans* Biozone. The species *C. termierae* did neither occur in the *barrandei–elegans* Subzone nor in the underlying *barrandei* Biozone. The type section of the *barrandei–elegans* Subzone and the *elegans* Biozone is the Švagerka section; it is also well documented at the Čerínka hillside section (Fig. 3), as well as some other regions (Spain, Pamir Mts). Lütke (1979) also mentioned the co-occurrence of *N. elegans* and *N. barrandei*; however, he did not make any formal conclusions.

Nowakia cancellata Biozone

This interval biozone is named after the characteristic species *Nowakia cancellata* (Richter, 1854) *sensu* Lukeš (1977), which is an internationally recognized zonal index fossil (Bouček 1964, Alberti 1993). The base of the *cancellata* Biozone is placed at the first appearance of *N. cancellata* (in sense of Lukeš 1977), and the top of this biozone at the first appearance of *N. richteri* Bouček & Prantl, 1959. The typical feature of the lower part of the *cancellata* Biozone is marked by the co-occurrences of *N. cancellata* and *N. elegans*. In the future, this level has good potential for the establishment of a new *elegans–cancellata* Subzone within the *N. cancellata* Biozone. However, very frequent occurrences of transitional forms (see above) between *N. elegans* and *N. cancellata* (Richter, 1854) in sense of Lukeš (1977) makes the definition of this subzone problematic before a detailed morphological analysis of all of these forms. Such an analysis must be based on a large amount of material (many tens or hundreds of well-preserved shells), which has to be collected with the greatest stratigraphic resolution at several sections, in order to eliminate the influence of possible very short gaps in the sedimentation. At the current time, such material exists from only one section, as a by-product of the present study.

The most common species in the *cancellata* Biozone, with the exception of the index taxon, are *Costulatostyliolina roemeri* and *C. termierae*. Their abundance is highest at the boundary of the *elegans* and *cancellata* biozones (Fig. 10). *Viriatellina pseudogeinitziana*, *V. hercynica*, *V. mui*, *Stylianowakia* cf. *ligeriensis*, *Metastyliolina striatissima*, *Homotenus hanusi*, and *Dicricoconus* sp. are less frequent species of the *cancellata* Biozone. The type section of the *cancellata* Biozone is at the Císařská rokle near Srbsko.

Features of new tentaculite biostratigraphy

Redefinition of the tentaculite biostratigraphy of the Daleje Event interval is based on very large amounts of new materials (more than 1250 species determined) from two sections in the Bubovice area (Čeřínka quarry and Čeřínka hillside sections). The method used for the collection of this biostratigraphic data makes their quantitative evaluation possible. Results of rarefaction analyses of tentaculite occurrences in each of the studied beds (Fig. 12) suggest a rather good sampling density (*i.e.*, there is a low probability that the studied beds contain significantly more tentaculite species). Collection of such a large amount of fossil materials revealed wider stratigraphic ranges for some tentaculite species. *Costulatostyliolina roemeri*, *Viriatellina hercynica*, *V. mui*, and *V. pseudogeinitziana* were first found in the *Nowakia cancellata* Biozone. The latter species, *V. pseudogeinitziana*, was also first recorded from the *Nowakia elegans* Biozone (also including the *barrandei–elegans* Subzone). The occurrence of *C. termierae* at the Čeřínka quarry section represents the first well-documented occurrence of this species in the Barrandian.

The most important result of the quantitative collection of tentaculites is not the improvement of the stratigraphic ranges of rare taxa, but an improvement of the tentaculite biostratigraphy. All previously published tentaculite biostratigraphic data are only based on a qualitative approach to the data collection. This qualitative approach, producing an absence/presence dataset, provided a much lower biostratigraphic resolution than the quantitative approach does, because many (or even most) of the data are only inferred from a single occurrence of a particular dacryoconarid species in any given bed. In addition, biostratigraphic data were not collected from all beds (see sections in Chlupáč *et al.* 1979). Our results clearly provide evidence for the co-occurrence of *N. elegans* and *N. barrandei*, making the definition of a new subzone possible. The new subzone was also recognized at South Tien Shan (Kim *et al.* 1978, 2011; Frýda, unpublished data) and in Spain (Montesinos & Truyols-Massoni 1987, García-Alcalde *et al.* 1988). Lack of densely sampled sections within

this stratigraphic interval, as well as the low number of tentaculite specialists are probably the main reasons for the missing records of co-occurrences of *N. elegans* and *N. barrandei* from other areas of the world. The duration of the *barrandei–elegans* Subzone was probably rather short, judging from a comparison of its thickness with those of other Emsian biozones.

Discussion of transgression-regression history and faunal changes

The present study is focused on the lithological appearance of the Daleje Event in areas with predominantly carbonate sedimentation. Application of the new high-resolution tentaculite biozonation to the newly gathered sedimentological data has resulted in a more detailed model of the transgression-regression history and faunal changes across the Daleje Event interval in the Barrandian. The latter model is discussed in detail in the following section.

Nowakia barrandei Biozone

In the Čeřínka area, the Zlíčov Limestone is typically developed as thin bedded, dark to light grey calcisiltites, with the characteristic abundant black cherts containing minor intercalations of calcareous shales almost throughout the entire thickness. Characteristic black cherts disappear a few meters below the boundary with the Chýnec Limestone, and the limestones become lighter and coarse. The uppermost part of the Zlíčov Limestone again becomes darker (increase in organic matter), but still with an increase in the amount of bioclasts (Fig. 2). This darker interval, belonging to the *barrandei* Biozone, was not documented at the Čeřínka hillside section; probably because of the more weathered state of the Zlíčov Limestone, which has caused oxidation of the organic matter. About 2 m below the boundary with the Chýnec Limestone (*i.e.*, just below above-mentioned dark interval), the Zlíčov Limestone bears a rich trilobite community dominated by *Reedops decorus* (Hawle & Corda, 1847) and *Zlichovaspis* (*Zlichovaspis*) *auriculata* (Dalman, 1826) – determined by Petr Budil (see more detail on the stratigraphic distribution of both species in Chlupáč 1977, 1983; Budil *et al.* 2009). Recently, František Hörbinger (Prague) found additional trilobite species – *Nephranomma modesta* (Barrande, 1872), *Crotalocephalus sternbergi sternbergi* (Boeck, 1827), *Harpidella* (*H.*) *kobayashii* Příbyl & Vaněk, 1981, *Sculptoproetus sculptus sculptus* (Barrande, 1846), *Zlichovaspis* (*Z.*) *vaneki* Budil, Hörbinger & Mencl, 2009, *Koneprusia* (*K.*) *aff. chynicensis* Vaněk & Pek, 1987, *Tropidocoryphe hermon* (Šnajdr, 1977), *Phacops* (*Pedinopariops*) *degener* Barrande, 1852, and *Lobopyge* sp. (all

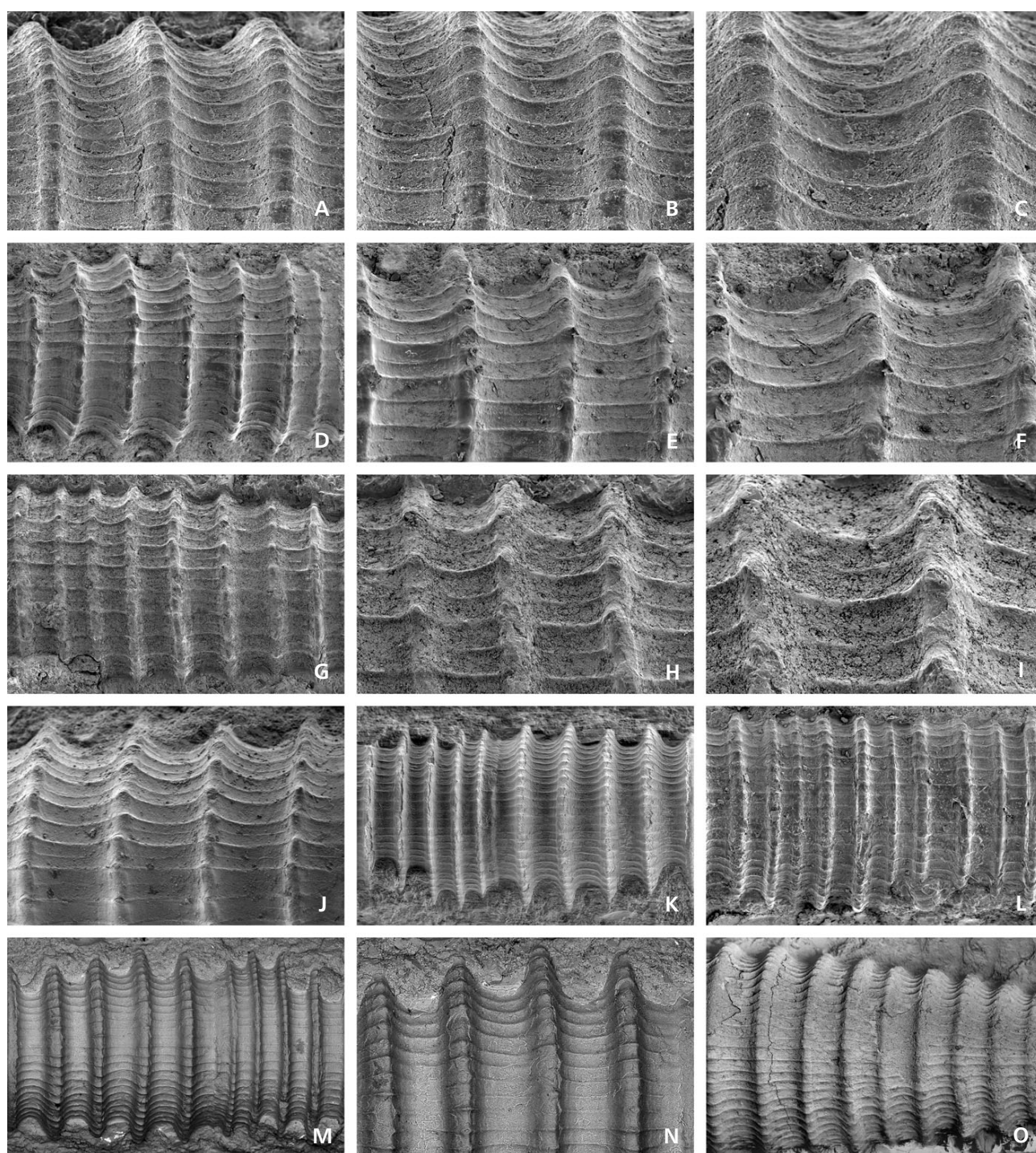


Figure 14. Detail views of shell ornamentation in *Nowakia barrandei* (A–C, K–O) and *Nowakia elegans* (D–J). Note secondary order ribs inserted between first order longitudinal ribs bearing nodes at crossing with transversal rings in *Nowakia elegans*. • A–C – *Nowakia barrandei*, specimen LF002, Čefinka hillside, interval 13. • D–F – *Nowakia elegans*, specimen PL333, Bubovice, Chýnice Limestone. • G–I – *Nowakia elegans*, specimen LF001, Čefinka quarry, interval 17. • J – *Nowakia elegans*, specimen PL333, Bubovice, Chýnice Limestone. • K, M, N – *Nowakia barrandei*, PL12, Choteč, Zlíčov Limestone. • L – *Nowakia barrandei*, specimen PL3719, Pekárkuv mlýn. • O – *Nowakia barrandei*, specimen LF002, Čefinka hillside, interval 13. A × 90; B × 105; C × 160; D × 31; E × 58; F × 92; G × 42; H × 100; I × 165; J × 50; K × 27; L × 35; M × 30; N × 55; O × 38.

determined by F. Hörbinger) – within these strata. This trilobite-rich horizon has been found in the same position at several other sections of Boubová Hill and the Kačák Valley areas (Frýda, unpublished data).

At the Čefinka quarry section, the lower boundary of the Chýnice Limestone, with underlying Zlíčov Limestone, is gradual but rather sharp (thickness of the transition interval is only a few centimetres; Fig. 2). The lower part of the Chýnice Limestone at this section is formed by thick layers of white to light rosy recrystallized limestone beds (interval 8 to 10; Figs 3, 7). A very similar lithological development was documented at interval 4 at the Čefinka hillside section (Fig. 3). The facies changes gradually from rosy unsorted floatstones with a calcisiltite matrix via poorly washed crinoidal packstones with pelletoids to rosy crinoidal grainstones. This was documented within the *barrandei* Biozone at the Čefinka hillside section (interval 8–14, lower part of the Chýnice Limestone; Fig. 3).

Occurrences of coarse-grained Zlíčov Limestone, or the transition to the lower part of the Chýnice Limestone in the *barrandei* Biozone, were recorded on all studied sections of the Barrandian area. At the Klukovice section (SW Prague; see Fig. 1), several beds of organoclastic, grey to pink limestones, with a total thickness of about 2 meters bear a rather rich trilobite fauna (Příbyl 1967, Šnajdr 1980, Chlupáč *et al.* 1979) together with the index tentaculite *N. barrandei*. Chlupáč *et al.* (1979) interpreted this stratigraphic interval as the “easternmost tongue of the Chýnice Limestone”. New data from the Čefinka sections are evidence that these fossil-rich beds are equivalent to the lower part of the Chýnice Limestone in the Čefinka area. The same development as at the Klukovice section has been documented (Prantl & Svoboda 1950, Chlupáč *et al.* 1979, Chlupáč & Lukeš 1999) at the Císařská rokle near Srbsko (see Fig. 17). The absence of cherts, as well as the occurrences of coarse-grained grey or pink-coloured limestones, are typical for the *barrandei* Biozone at the latter section. These limestone beds are also equivalent to the lower part of the Chýnice Limestone in the Čefinka area.

The Chýnice Limestone is not developed in the SE part of the Barrandian area. The Švagerka section at Praha-Zlíčov and Pekárkův mlýn near Solopisky are the best studied sections with such development (Kettner 1917; Kodym 1919; Kettner & Kodym 1919; Chlupáč 1959; Chlupáč *et al.* 1979, 1998; Chlupáč & Lukeš 1999). The characteristic cherts are missing at the top of the Zlíčov Limestone, and occurrences of the coarsely-grained limestone beds are typical for the *barrandei* Biozone of both sections (Fig. 17). However, the occurrence of calcareous shale has already been documented within this stratigraphic interval (Chlupáč *et al.* 1978, 1979). Coarse-grained as well as micritic limestone beds of the *barrandei* Biozone are rather fossiliferous. These beds at the Švagerka section are known as Barrande’s “Schwagerka” locality, which provided rich

coral and trilobite faunas (see history of this section in Kříž 1999 and stratigraphic data in Chlupáč 1957 and Chlupáč *et al.* 1979). It is noteworthy that the corral fauna of this level is *in situ* and does not show any traces of transport (Chlupáč 1957). The latter author interpreted its occurrence as a biostrome formed at the appearance of the Chýnice Limestone in this part of the Barrandian.

The following stratigraphically significant conodonts and goniatites were documented within the *barrandei* Biozone: *Polygnathus perbonus* (Švagerka, Císařská rokle and Pekárkův mlýn sections; Chlupáč *et al.* 1979); *Polygnathus gronbergi* (Císařská rokle; Chlupáč *et al.* 1979); *Erbenoceras solitarium* (Barrande, 1865) (Pekárkův mlýn sections; Chlupáč *et al.* 1979). The conodont fauna of the *barrandei* Biozone of the Barrandian was hitherto not studied in detail, and the study of its stratigraphic distribution from the *barrandei* to *cancellata* biozones is one of main topics of this on-going project.

Lithological developments within the *barrandei* Biozone at both of the studied sections, Čefinka hillside and Čefinka quarry, is interpreted here as evidence for an upwardly shallowing trend, with an increasing intensity of sediment washing. Also, all available lithological data – *i.e.* the disappearance of cherts and occurrences of coarse-grained Zlíčov Limestone with local developments of coral biostrome, gradual increases of the amount of rosy, unsorted crinoidal biosparite in the lower part of the Chýnice Limestone – from other Barrandian sections fits well with the latter interpretation.

***N. barrandei*–*N. elegans* Subzone**

Lithological development within the newly established *barrandei*–*elegans* Subzone of the *Nowakia elegans* Biozone can be studied at the Švagerka and Čefinka hillside sections.

The uppermost Zlíčov Limestone, intercalated by calcareous shales at the Švagerka section (beds 30 to 36 of Chlupáč *et al.* 1979), belongs to the *barrandei*–*elegans* Subzone. These beds provided a rich corral fauna in the past (Chlupáč 1957). In addition Chlupáč *et al.* (1979) mentioned a distinct faunal change at this level, where the typical Zlíčovian fauna (known at this section from beds 1 to 30) disappears. The discovery of biostratigraphically significant goniatite *Palaeogoniatites lituus* comes from the base of the *barrandei*–*elegans* Subzone at the Švagerka section (Chlupáč *et al.* 1979, Chlupáč & Turek 1983).

On the other hand, typical lithological types of the *barrandei*–*elegans* Subzone, occurring at the Čefinka hillside section (intervals 15–18), include coarsely-bedded limestone beds formed mainly by unsorted floatstones, with umbrella structures and pluricolumnals of crinoids and limestone beds formed by *in situ* benthic organisms

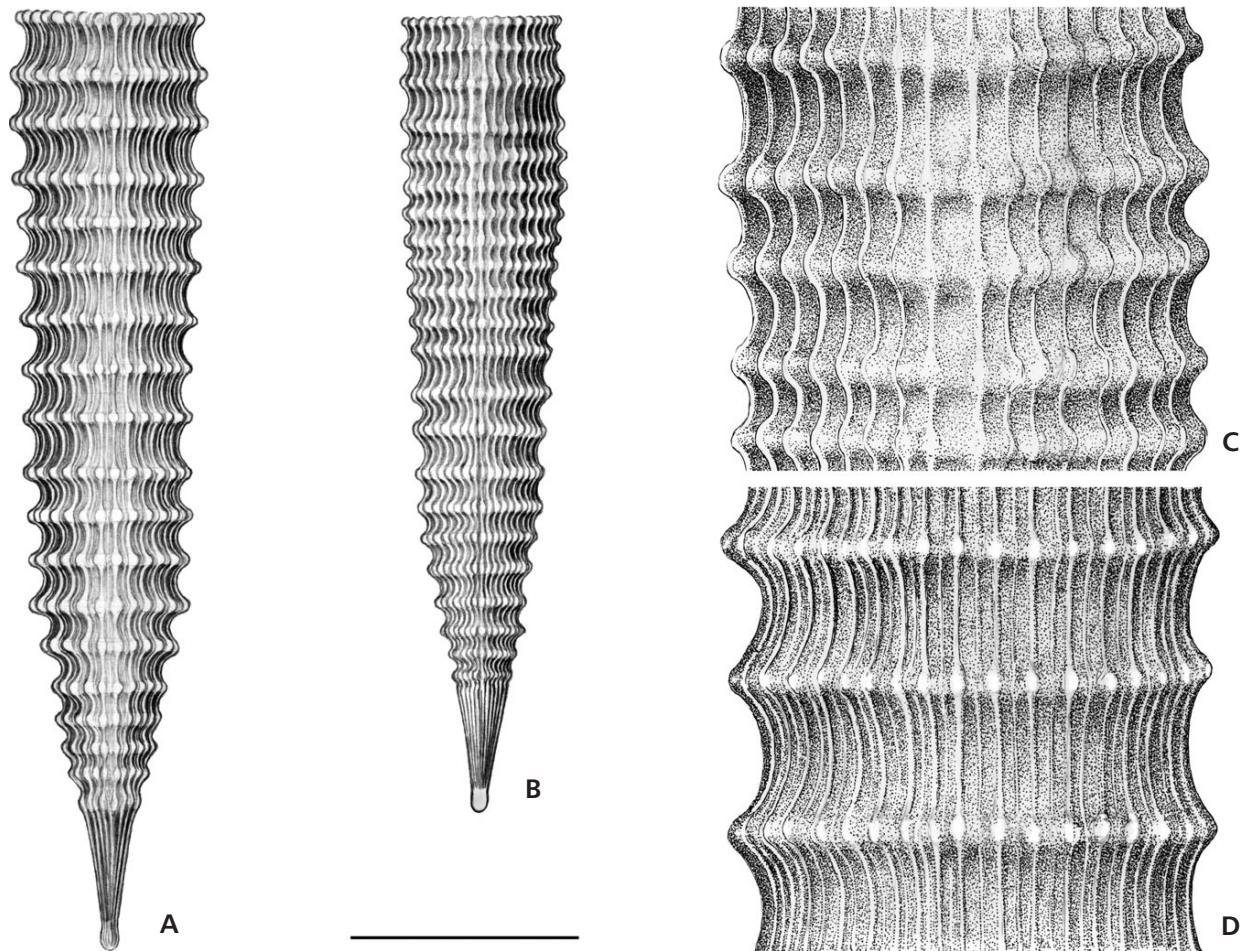


Figure 15. Reconstruction of shells in *Nowakia elegans* (A, D) and *Nowakia barrandei* (B, C). Details (C and D) show distinguishing character of the both species (note secondary order ribs inserted between first order longitudinal ribs bearing nodes at crossing with transversal rings in *Nowakia elegans*). Scale equals to 0.6 mm for A, B and to 0.2 mm for C, D.

(mainly corals). The fauna of this stratigraphic level is common and very highly diversified including trilobites, brachiopods, corals, cephalopods, gastropods, bivalves, and ostracods (Ferrová 2010, Ferrová *et al.* 2012). Numerical analysis of more than 2100 specimens belonging to more than 80 species of the *barrandei* and *elegans* biozones (collected by the senior author at the Čeřinka hillside section) also revealed a distinct faunal change close to boundary of the *barrandei* and *elegans* biozones (Ferrová 2010, Ferrová *et al.* 2012, and Fig. 16; in prep.). The latter results are robust and statistically significant, and they support the earlier observations from deeper water environments made by Chlupáč *et al.* (1979).

There is no sedimentological record for the *barrandei*–*elegans* Subzone at the Čeřinka quarry section (Figs 3 and 7). The first bed bearing *Nowakia elegans* is bed 11, which significantly differs from the underlying beds formed by light rosy neomorphized recrystallized limestones of the *Nowakia barrandei* Biozone (Figs 4 and 5). Sudden change in the isotopic composition of the

carbonate carbon was also recorded just below the first occurrence of *N. elegans* (Ferrová 2010; Fig. 7). The absence of any common occurrence of *N. elegans* and *N. barrandei*, and the sharp lithological and geochemical changes just below the first occurrence of *N. elegans* at the Čeřinka quarry section (Figs 3 and 17) are interpreted as evidence for a sedimentological gap (and thus also a distinct sequence boundary) including at least the whole *barrandei*–*elegans* Subzone. Comparison of the lithology and thicknesses of the Chýnice Limestone at two geographically close sections, Čeřinka quarry and Čeřinka hillside sections, suggests that the above-mentioned gap probably also includes the upper part of the *Nowakia barrandei* Biozone at the Čeřinka quarry section (Fig. 3).

The occurrence of beds of the *barrandei*–*elegans* Subzone at the Klukovice and Císařská rokly sections could not be tested due to the lack of biostratigraphic data at the boundary of *N. barrandei* and *N. elegans* biozones (Fig. 17). The occurrence of beds belonging to the *barrandei*–*elegans* Subzone at the Pekárkuv mlýn section is

presently under investigation. At this section, the first occurrence of *Nowakia elegans* was recorded at interval 18 (Chlupáč *et al.* 1979), just above the beds with the last shell of *Nowakia cf. barrandei*. Whether the *barrandei–elegans* Subzone is really missing at the Pekárkův mlýn section, or whether it is a sampling artefact (see methods section) will be revealed in the on-going research.

The present study revealed that the upper Zlíchovian regression culminated at the *barrandei–elegans* Subzone. Rich and highly diversified faunas connected with small bioherms are known from that time interval. Rich faunas and coral bioherms occurred not only in areas where the Chýnec Limestone was deposited (*i.e.*, Bubovice area), but also in deeper environments (*e.g.*, coral beds at the Švagerka section). The stratigraphical gap, including the whole *barrandei–elegans* Subzone (and likely also the top of the *barrandei* Biozone at the Čerínka quarry section) is the result of the culmination of the regression. It is noteworthy that this is the first evidence for a distinct stratigraphical gap in the Emsian succession of the Barrandian outside of the Koněprusy area.

Here, the lithological features within the *barrandei–elegans* Subzone are interpreted as the culmination of a regression trend, which is followed by a subsequent transgression from the top of the *barrandei–elegans* Subzone. Development of rich and highly diversified coral biostomes, newly documented at the Čerínka hillside section, as well as the existence of a sedimentologic gap at the Čerínka quarry section, strongly support this interpretation.

***Nowakia elegans* Biozone above the *barrandei–elegans* Subzone**

The beginning of a transgression was documented in the *barrandei–elegans* Subzone. From that time, increasing depositions of the Daleje Shale in deeper environments, as well as more micritic red-coloured limestones of the upper part of the Chýnec Limestone in shallow environments are recorded. Sedimentation of calcareous Daleje Shale at this stratigraphic level was documented at the Švagerka, Pekárkův mlýn, Císařská rokle, and Klukovice sections (see Fig. 17; for details see Chlupáč 1959, Chlupáč *et al.* 1979, and Chlupáč & Lukeš 1999). In the Koněprusy area, sedimentation of red crinoidal limestones, called the Suchomasty Limestone, started after a long hiatus including the whole lower Emsian (see Fig. 17; for details see Chlupáč 1959, Chlupáč *et al.* 1979). Here, the beginning of the deposition of the Suchomasty Limestone is dated to the *elegans* Biozone, but above the *barrandei–elegans* Subzone (Červený lom – Chlupáč *et al.* 1979; Voskop quarry – Lukeš in Frýda 1992).

The following stratigraphically important conodonts and goniatites were documented within the *elegans* Bio-

zone above the *barrandei–elegans* Subzone: a transitional form of *Polygnathus gronbergi* and *Po. laticostatus* (Císařská rokle gorge; Chlupáč *et al.* 1979); *Latericriodus b. beckmanni* (Pekárkův mlýn; Chlupáč *et al.* 1979); *Polygnathus laticostatus* and *Po. inversus* (Červený lom; Chlupáč *et al.* 1979); *Po. cf. inversus* (Bubovice; Chlupáč *et al.* 1979); *Mimosphinctes zlichovensis* (Švagerka, Pekárkův mlýn; Chlupáč *et al.* 1979); *Anetoceras* sp. (Švagerka; Chlupáč *et al.* 1979); and *Ivoites cf. hunsrueckianus* (Erben, 1960) (Pekárkův mlýn section; Chlupáč *et al.* 1979, De Baets *et al.* 2009).

The lithological features of the *elegans* Biozone above the *barrandei–elegans* Subzone are interpreted as evidence for a continuous transgression trend.

***Nowakia cancellata* Biozone**

During the *cancellata* Biozone, sedimentation was influenced by a continuous transgression which resulted in an increase of micrite and siliciclastic materials. A typical feature of the transgressive succession of the *elegans* to *cancellata* Biozones is the increase of both organic matter and iron oxides in the shales and carbonates.

Yellow to red coloured beds of unsorted tentaculite packstones intercalated with very thin calcareous shale layers (having a thickness of less than 1 cm) typify the basal part of the *cancellata* Biozone at both Čerínka sections. After this, a *ca* 1 m thick succession with a distinctly increasing trend in the amount of calcareous shales intercalating with homogeneous, unsorted, tentaculite wackestones to packstones is documented. The dominant fauna includes numerous tentaculites, brachiopods, and ostracods. Calcareous shales containing micritic nodules and thin nodular limestone beds represent the dominant lithological type, starting about 2 metres above the base of the *cancellata* Biozone and continuing upwards within this biozone. The term “transitional layers” between the Daleje Shale and Třebotov Limestone would be the best lithological term for this portion of the upper part of the *cancellata* Biozone, as was already noted by Chlupáč *et al.* (1979), who studied these stratigraphic levels in the Bubovice area.

The calcareous Daleje Shale forms the dominant lithological type everywhere in the NE, SE, and S parts of the Barrandian (*e.g.*, Švagerka, Klukovice, Pekárkův mlýn, and Císařská rokle). However, in the areas N, W, and SW of the village of Bubovice, the Daleje Shale is not developed (Kodym 1924, Prantl & Svoboda 1948, Chlupáč 1959). In this area, micritic beds belonging to the upper part of the Chýnec Limestone gradually change into the exclusively micritic and red-coloured Třebotov Limestone. Typical facies of the lower part of the Chýnec Limestone (as that found at both Čerínka sections) reaches up to much

higher levels stratigraphically. At the Macháčkův lom area (see Chlupáč *et al.* 1979, fig. 12), as well as at Boubová Hill and the Kačák Valley area it is not possible to select any useful lithological feature for a definition of a boundary between the Chýnec and Třebotov limestones because of their slow and gradual transition.

Lithological development of the Suchomasty Limestone, belonging to upper part of the *elegans* Biozone (*i.e.*, above the *barrandei–elegans* Subzone), up to the *cancellata* Biozone in the Koněprusy area is basically the same as in those areas mentioned above. The term Suchomasty Limestone is somewhat unnecessary, and it has been kept only as a geographic name for the equivalent of the Chýnec and Třebotov limestones in the Koněprusy area. Chlupáč (1957) recognized this problem quite well, and placed the lower part of the Suchomasty Limestone to the facies of the Chýnec Limestone (Chlupáč 1957, p. 61: “K facii chýnických vápenců čítám i spodnější partie červenavých mramorů suchomastských a bezprostředního nadloží svrchních koněpruských vápenců...”). The term Suchomasty Limestone is used even though it can only be defined by its geographic position. The distance to any area with Suchomasty Limestone from the nearest occurrence of the Chýnec and Třebotov limestones is about 2 km, which is of the same range as the distances amongst many sections of the Chýnec and Třebotov limestones. Nevertheless, any redefinition of all of the above-mentioned lithostratigraphic names has to wait for a modern evaluation of facies distributions of all of the Emsian sections of the Barrandian.

The following significant conodonts and goniatites were documented in the Barrandian area within the *cancellata* Biozone: *Latericriodus b. beckmanni* (Hostim; Chlupáč *et al.* 1979); a transitional form of *Polygnathus laticostatus* and *Po. gronbergi* at the base of the *cancellata* Biozone, and *Po. laticostatus* at the top of the latter biozone (Císařská rokle; Chlupáč *et al.* 1979); *Po. laticostatus* and *Po. inversus* (Červený lom; Chlupáč *et al.* 1979); *Gyroceratites gracilis*; *Mimagoniatites fecundus*; *Teicherticeras discordans* (Pekárkův mlýn; Chlupáč *et al.* 1979, Chlupáč & Turek 1983, Chlupáč & Lukeš 1999); and *Mim. fecundus* (Čeřinka quarry).

The lithological development of the *cancellata* Biozone is interpreted as evidence for a continuous transgression trend.

Implications for global Emsian stratigraphy

Evaluation of the newly gathered palaeontological and sedimentological data from the Emsian successions of the Barrandian has some implications for the global Emsian stratigraphy. Becker (2007) summarized the results of the long-term activities of the International Subcommittee

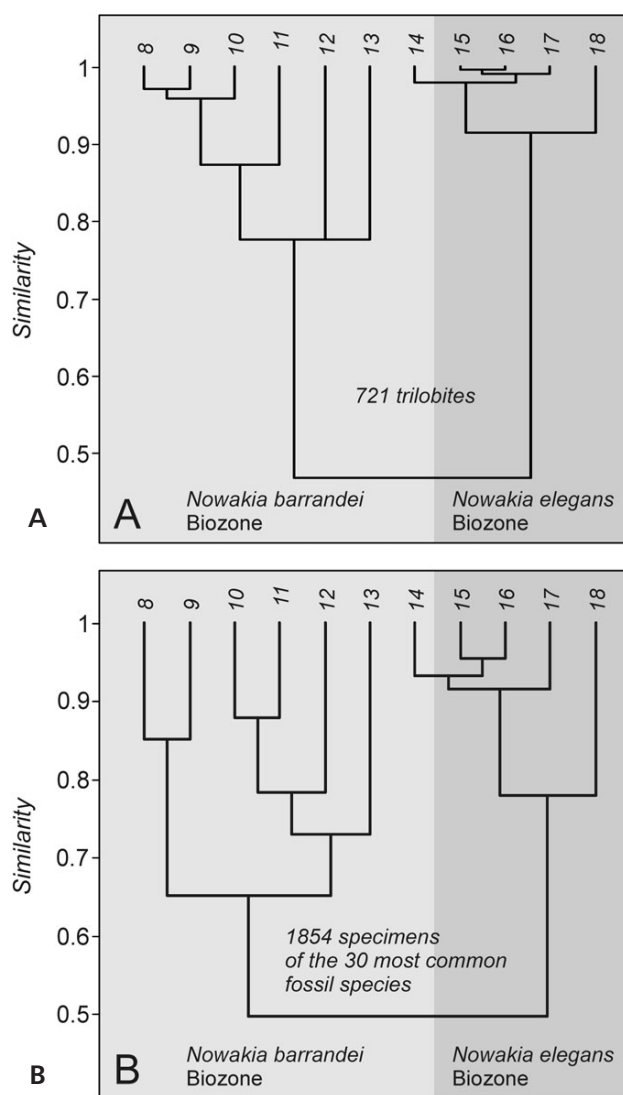


Figure 16. Čeřinka hillside section – stratigraphic intervals 8–18. Dendrogram based on clustering of Morisita's similarity index for abundance data using unweighed pair-group average algorithm. • A – clustering of 721 occurrences of the three most common trilobite species [*Phacops (Pedinopariops) degener* (Barr.), *Orbitoproetus chynicensis* (Příbyl) a *Scabriscutellum (Cavetia) furcifera* (Hawle & Corda)]. • B – clustering of 1854 occurrences of the 30 most common fossil species (ex Ferrová 2010, and in preparation).

on Devonian Stratigraphy, focused on the division of the Emsian into two substages. This comprehensive report, together with some additional data on the stratigraphic ranges of “stratigraphically useful” groups such as the conodonts, goniatites, and tentaculites (see *Subcommission on Devonian Stratigraphy Newsletters*; <http://unica2.unica.it/sds/>) fully describe the problems of the Emsian substages or stages. In the following sections, we briefly comment on some of these problems, and propose some solutions which are based on the insights obtained from the present study.

What group to select for the boundary?

This question could be changed to the question whether it is better to follow the tradition, or whether it would be preferable for the definition of the substage (stage) boundary to use any index fossil group, which provides the best stratigraphic resolution and is widely distributed. When we compare the three groups most commonly used as index fossils in the marine Devonian, *i.e.* conodonts, goniatites, and tentaculites, which have been discussed as the best potential groups for a splitting of the Emsian, we face the first problem – the ability to increase the biostratigraphic resolution in the future. There is no doubt that the Emsian goniatites represent a quickly evolving group of the Emsian invertebrates (De Baets *et al.* 2009; Klug *et al.* 2008, 2010; Monnet *et al.* 2011a, Korn & Klug 2012), but their abundance is generally much lower than that of microfossils such as conodonts and dactyloconarid tentaculites. For a future increase in stratigraphic resolution, we suggest the selection of a group, which could be relatively easily found in almost every layer of many mid-Emsian successions. Undoubtedly, more sporadic occurrences of mid-Emsian goniatites create a preference for use of conodonts and dactyloconarid tentaculites as more useful groups for a definition of a substage (stage) boundary within the Emsian. The near facies independence of dactyloconarids makes them a stratigraphically very useful group, which has been somewhat neglected in the past years and deserves much more scientific attention.

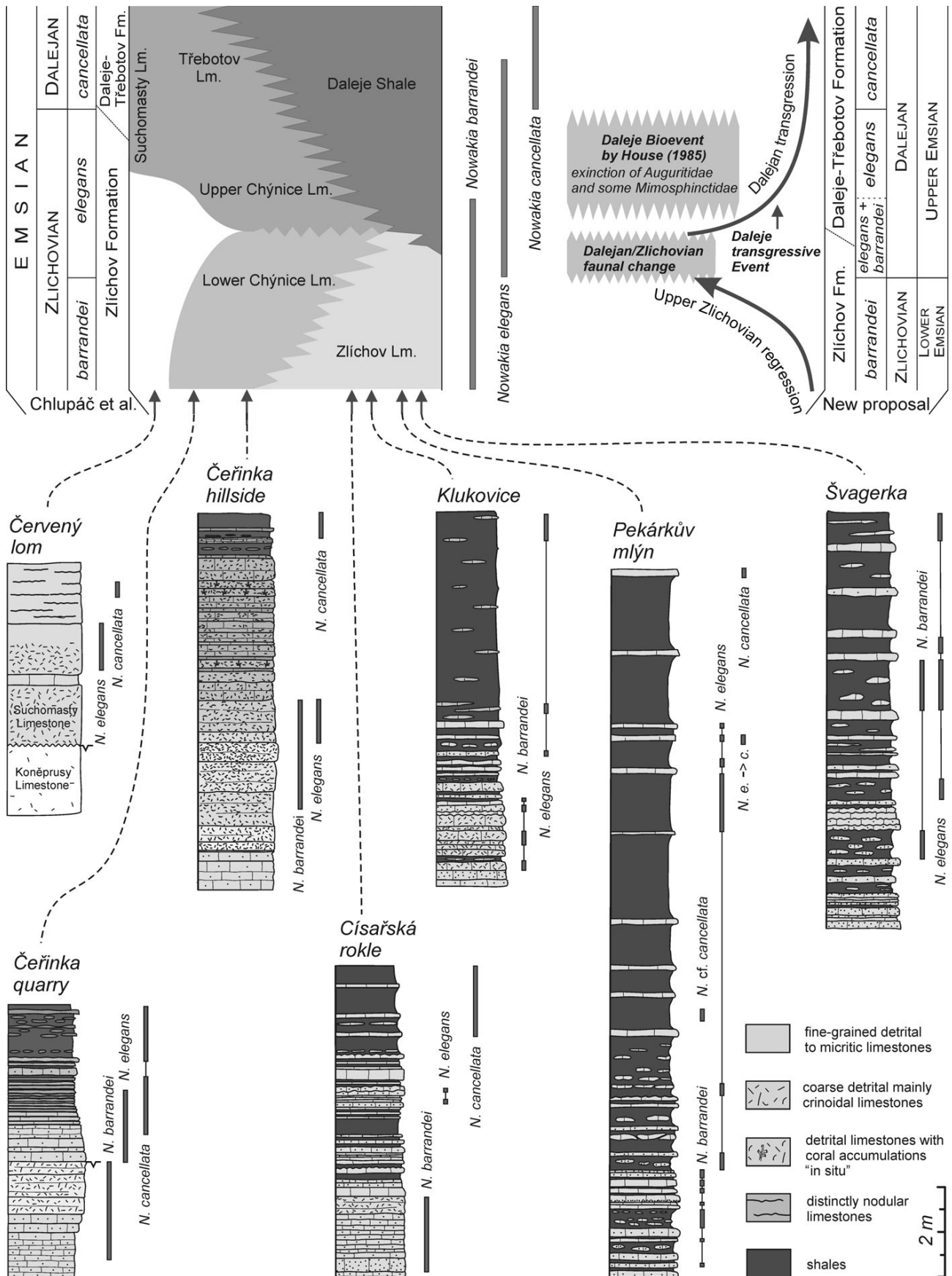
On the other hand, any definition of biostratigraphic level just on the first appearance (FAD) of any species is a fundamental problem because the FADs of species are always diachronic. The diachronicity should be generally low and less than the stratigraphic resolution within small geographic areas, but it always exists. For this reason, usage of the FAD of single species for a definition of global biostratigraphic correlations seems to be problematic. In contrast to that, associations (co-occurrences of species) suffer much less from diachronicity (*e.g.* Monnet *et al.* 2011b). In this context, here proposed level for splitting the Emsian (base of the *barrandei–elegans* Subzone) should be slightly better solution than previously proposed level (base of the *cancelata* Biozone), because the proposed boundary is based on co-occurrence of two tentaculite species with rather short duration. Nevertheless, in the future a

biostratigraphic scheme combining various groups like tentaculites, conodonts and goniatites would be really desirable for a stable Emsian biozonation.

Relationship between the substage boundary and extinction events

Many major stratigraphic boundaries were selected at levels of distinct faunal turnover, typically at the level of the radiation of a new group of marine organisms. In this context, it should be noted that a radiation event is a much better biostratigraphic marker than an extinction event. The main reason for this is the fact that the abundance of most marine species is generally higher just after their origins than before their extinction (*e.g.*, Signor–Lipps effect; Signor & Lipps 1982). Graptolites are a very good example illustrating this “rule”. The level of extinction of the so-called *Anetoceras* fauna is very frequently used as quite important for testing of the suitability of any biostratigraphic marker for a definition of a mid-Emsian substage (stage) boundary (*e.g.*, Chlupáč & Lukeš 1999, p. 96; Becker 2007). Becker (2007, p. 30) stated, referring to this issue, that “Unfortunately, even this polygnathid [...] is well below the upper *Anetoceras* faunas”. Here, we see several basic problems. First, according to our knowledge, there is currently no published evidence that the extinction of the so-called *Anetoceras* fauna (or the Daleje Bioevent by House 1985) represents a single synchronous event. This analysis will be complicated by the fact that some anetocerids have a very limited geographic distribution, and the fossil record of the *Anetoceras* fauna is not generally as rich as that of the conodonts or tentaculites. Additionally, Ockam’s razor can be applied to this issue, *i.e.*, it is not really possible to properly prove the exact stratigraphic position of the extinction level. Secondly, there is no data evidencing that the extinction rate and intensity during the crisis of the *Anetoceras* fauna were higher than that in the case of the Zlíchovian faunal turnover (*barrandei–elegans* Biozone boundary). Taken together, we suggest abandoning the use of the relationship between the *Anetoceras* fauna extinction and the stratigraphic position of any useful mid-Emsian biostratigraphic marker as an important criterion for the evaluation of its suitability for a definition of a mid-Emsian substage boundary.

Figure 17. Schematic model (upper left) showing the biostratigraphic position and geographic relationship of the lithological units of the Daleje Event interval in the Barrandian. All biostratigraphically well-dated sections are figured in the lower part of the figure, as well as their positions in the schematic model. In the upper right part of the figure a new proposal for the biostratigraphic and lithostratigraphic divisions is given. Recent data suggests inclusion of the lithologically distinct “Upper Chýnec Limestone” into the Daleje–Třebotov Formation, because this lithological unit is the product of a new sedimentary cycle started by the Daleje Event transgression. However, formal redefinition of the lithostratigraphic units of the Daleje Event interval must not be done until after a full re-evaluation of all available sections in the Barrandian. Future analysis will show if the unit informally named here (*i.e.*, the “Upper Chýnec Limestone”) should be formally established, or whether it belongs to the Třebotov Limestone of the Daleje–Třebotov Formation.



Nowakia elegans and the substage (stage) boundary

Originally, the lower Dalejan boundary was proposed at the first appearance of *Nowakia cancellata* (see Chlupáč 1976, 1982; Chlupáč & Lukeš 1999). The use of *N. cancellata* for a definition of a mid-Emsian substage boundary has been discussed by several authors (see Chlupáč & Lukeš 1999, and Becker 2007 for both advantages and disadvantages of this choice). Evaluation of the new biostratigraphic data from the Barrandian leads us to redefine the lower Dalejan boundary (FAD of the *N. elegans*) as well as to propose the base of the *Nowakia elegans* Biozone as a better level for the definition of the Emsian substage (stage) boundary (*i.e.*, the lower/upper Emsian boundary). The advantages and disadvantages of this choice are summarized in the following paragraphs. We consider this level to be a good choice for the following reasons:

1. There is a general agreement that the substage boundary should lie close to the level of the supposedly global transgressive Daleje Event (Becker 2007, p. 29). As shown by the present study, the upper Zlichovian regression culminates at the base of the *Nowakia elegans* Biozone (within the *barrandei–elegans* Subzone). The beginning of the Daleje transgression is just above the lower boundary of the *Nowakia elegans* Biozone, and thus is much older than the base of the *Nowakia cancellata* Biozone. The Barrandian is the type area for the Daleje Event.

2. *Nowakia elegans* is easily distinguishable from the older *Nowakia barrandei*: These two species differ by a qualitative morphological characteristic, namely the absence or presence of secondary ribs (Figs 14 and 15). In contrast to the younger *N. cancellata*, there are no known transitional forms between *N. barrandei* and *N. elegans*. This fact was not only corroborated by the study of a large amount of specimens gathered by the senior author over the last few years, but also by a study of all available collections from the Barrandian area, made over the past 40 years by Pavel Lukeš. Similar results were obtained by Kim (personal communication to JF, 2008), who has studied large tentaculite collections from the Tien Shan.

3. It is noteworthy that the co-occurrence of *Nowakia barrandei* and *N. elegans* was also recorded at Tien Shan (Kim 2011) and in Spain (Montesinos & Truyols-Massoni 1987, García-Alcalde *et al.* 1988), which indicates the likely high usefulness of this newly proposed subzone for intercontinental correlation. Additionally, co-occurrences of index species enhance the stratigraphic reliability of stratigraphic units.

4. *Nowakia elegans* is a widely distributed species (as is *N. cancellata*), and it occurs in both the carbonate as well as the clastic dominated environments, which increases its usefulness for global stratigraphic correlations. Also, in the

Barrandian, *N. elegans* is known to occur in both of the above-mentioned environments.

5. *Nowakia elegans*, as with all planktonic organisms, is very abundant and can generally be found in most sediment layers. This feature will be helpful for the future need to increase the biostratigraphic resolution.

6. The base of the *Nowakia elegans* Biozone is close to the boundary of the conodont biozones (*Polygnathus nothoperbonus* Mawson, 1987 and *Polygnathus inversus* Klapper & Johnson, 1975; see data in Mawson 1987; Mawson & Talent 2003; Kim *et al.* 2008, 2012), which increases the usefulness of both the conodont and tentaculite levels for global stratigraphic correlations. Additionally, this yields the possibility of independent testing by using the two different fossil groups.

7. The base of the *Nowakia elegans* Biozone appears to be close to the level of a distinct faunal turnover (end of the Zlichovian fauna; see the discussion above), which was recorded in benthic as well as planktonic and nektonic groups.

8. The stratigraphical range of *Nowakia elegans* is much shorter than that of the conodont and goniatite species, which have been suggested as markers for a definition of the Emsian substage boundary.

The main disadvantages of using the base of the *Nowakia elegans* Biozone as a possible level for any definition of an Emsian substage (stage) boundary are the following:

1. Although *Nowakia elegans* is a widely distributed species, there are not many detailed studies on its stratigraphic ranges in relationship to other biostratigraphically “significant” taxa. One exception is Tien Shan, where rather dense biostratigraphic data for different groups have recently been published (Kim 2011, Sennikov 2011).

2. At the present time, there is very little information on conodont biostratigraphy of the majority of Emsian sections in the Barrandian, which complicates any improvement of the composite conodont-tentaculite biostratigraphy. Nevertheless, detailed conodont studies of mid-Emsian sections in the Barrandian are one of the main topics of this on-going project, together with the addition of goniatite data.

3. FADs of species always suffer from their diachronicity. Associations of species are more reliable and should be preferred for the definition of (sub-)stage boundaries. Therefore, the combination of stratigraphic data of tentaculitids, conodonts and ammonoids are the most promising approach to produce a robust stratigraphic framework.

Taken all together, with the present state of knowledge, using the base of the *Nowakia elegans* Biozone as a possible level for the definition of an Emsian substage (stage) boundary appears to us to be a choice, which must be considered. This choice has the same significance as all

hitherto suggested boundaries. Nevertheless, additional biostratigraphic studies will have to be performed before a final decision can be made.

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