Acritarchs and prasinophytes of the Silurian-Devonian GSSP (Klonk, Barrandian area, Czech Republic)

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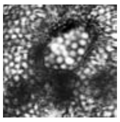

At the GSSP for the Silurian-Devonian boundary at Klonk, Czech Republic, a comparatively poorly diversified palynomorph assemblage has been documented. The boundary interval is characterized by the predominance of thick- and/or thin-walled prasinophytes (*Leiosphaeridia* spp., ?*Pleurozonaria* spp.), while the other organic-walled microfossil groups are relatively rare (chitinozoans, acritarchs, scolecodonts, certain prasinophytes, mazuelloids). The highest taxonomic diversity of palynomorphs has been documented in the uppermost Přídolí and in the lower part of the Lochkovian. Such a pattern of distribution could be connected with transgressive and regressive pulses occurring at the boundary interval. • Key words: Silurian-Devonian boundary, acritarchs, prasinophytes, mazuelloids.

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The section at Klonk near Suchomasty (Barrandian area, Central Bohemia, Czech Republic) was approved by the Silurian-Devonian Boundary Committee in 1971 and accepted by the International Commission on Stratigraphy and IUGS at the 24th International Geological Congress in Montreal in 1972 as the global stratotype section and point (GSSP) for the Silurian-Devonian boundary. The stratigraphy, palaeontology, and lithology of the section have been described and discussed in detail in papers by Chlupáč (1971, 1977), Chlupáč *et al*. (1972), Chlupáč & Kukal (1977, 1988), Hladil (1991, 1992), Chlupáč & Hladil (2000), and references therein. Magnetostratigraphy and strontium, carbon, and oxygen isotope data from the boundary interval have been recently studied by Hladíková *et al*. (1997), Crick *et al*. (2001), and Frýda *et al*. (2002).

Geology

The GSSP is characterized by a comparatively uniform succession without distinct facies changes. The upper Přídolí (Požáry Formation) and the lower Lochkovian (Lochkov Formation) are composed of greyish-black, platy, fine-grained, bituminous limestones alternating with calcareous shale (mudstone) interbeds. Rhythmic alternation of carbonates and mudstones show coarsening and thickening upwards. Sedimentological analyses have suggested rapid deposition (supposed accumulation rates of the order of 20m/Ma) and the presence of "reworked distal turbidites" for some limestone beds (Hladil 1991, 1992, Crick *et al*. 2001). The Přídolí-Lochkovian boundary has been placed in the upper part of the limestone bed 20 (Fig. 1).

The Silurian-Devonian boundary at Klonk near Suchomasty has been revisited by drilling new, shallow, and fully cored borehole adjacent to the stratotype section. Both the stratotype section and the core were studied palynologically with respect to the exact position of the boundary within the framework of a multidisciplinary approach, including geochemistry and sedimentology (Mann *et al*. 2004). The subject of the present paper is a detailed evaluation of prasinophytes and acritarchs of the GSSP and the Klonk-1 borehole (Fig. 1).

Previous research of OWM at the GSSP (Klonk)

Organic-walled microfossils (OWM) of the GSSP have been studied and/or discussed by several authors. Chitinozoans have proved to be the most indicative OWM for stratigraphic purposes (Paris *et al*. 1981). At the GSSP, the Silurian-Devonian boundary can be fixed by the FAD (First Appearance Datum) of *Angochitina chlupaci*

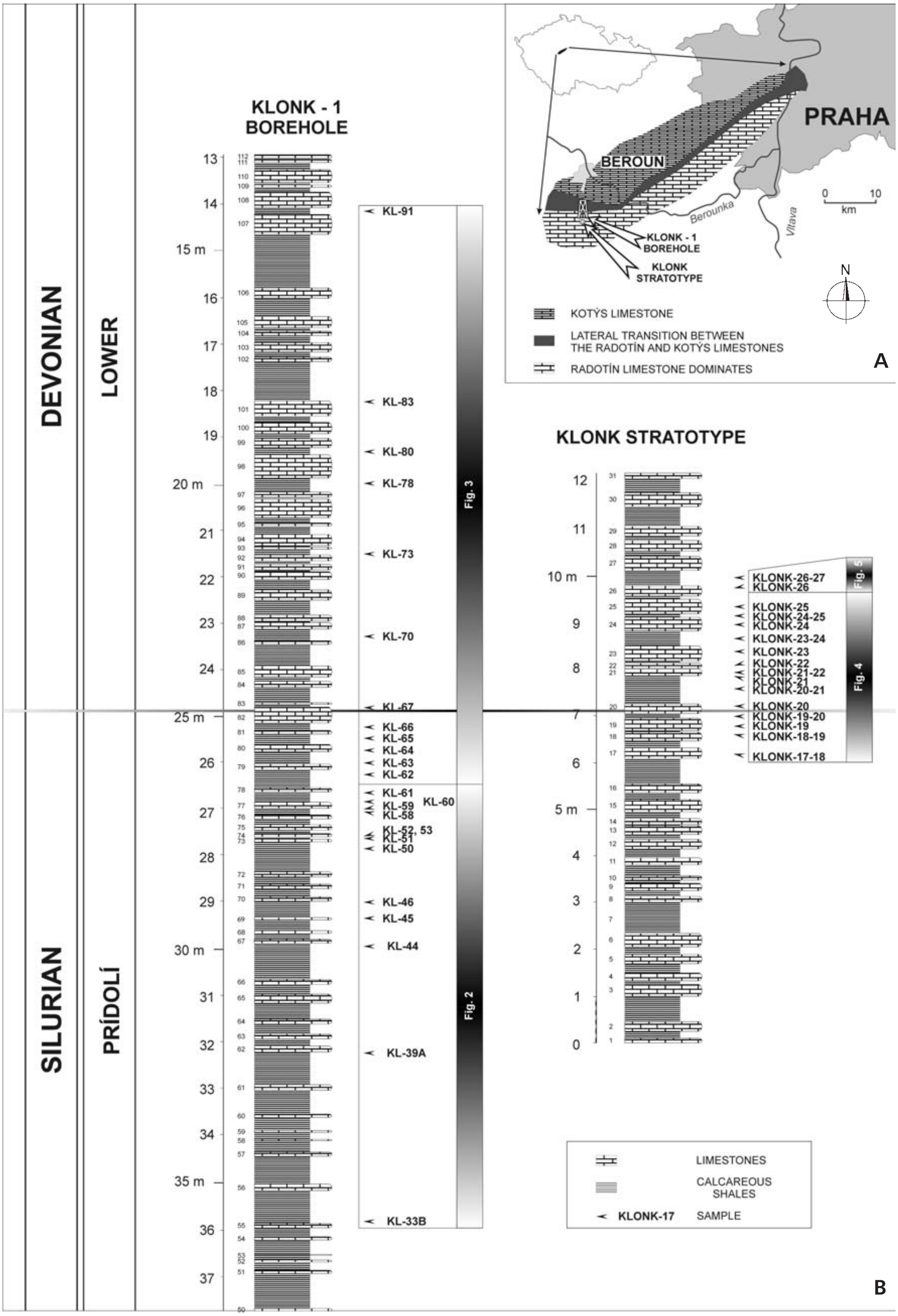


Figure 1. • A – facies distribution in the lower part of the Lower Devonian Lochkov Formation (modified after Chlupáč 1977). • B – the Silurian-Devonian boundary interval in the GSSP at Klonk near Suchomasty, with distribution of analyzed samples.

Paris & Laufeld, 1981 and the LAD (Last Appearance Datum) of *Linochitina klonkensis* Paris & Laufeld, 1981 and *Urnochitina urna* (Eisenack, 1934) Paris, 1981. The basal Lochkovian is characterized by the FAD of *Eisenackitina bohemica* (Eisenack, 1934) (after Paris *et al*. 1981). A distinct accumulation ("acme-zone") of *Calpichitina annulata* Paris, 1981 within the boundary interval (Fig. 1) was ascertained at the GSSP and at several other sections.

Deunff (1980, p. 490–494) briefly discussed the stratigraphic distribution of 10 taxa of OWM (8 acritarch species and two prasinophytes) in six samples from the GSSP. Paris (1981, p. 61) reports a predominance of *Leiosphaeridia* and chitinozoans, while acritarchs and spores were very rare or absent. Acritarchs were also mentioned by Richardson *et al*. (1981, p. 217), who reported the occurrence of "long-ranging palynomorphs such as Leiospheres and Micrhystridia". Le Hérissé (2002, p. 363) discussed the presence of the genus *Cymbosphaeridium* in the stratotype section of Klonk within the oceanic "Bohemian Magnafacies" of Richardson (1984). Some results of the recent study were preliminarily discussed by Brocke *et al*. (2002) and Fatka *et al*. (2003).

Material and methods

For the present study of OWM, 25 samples were taken from the Klonk-1 borehole (Fig. 1: KL-33B to KL-91) and 16 samples from the stratotype section (Fig. 1: KLONK-17 and 18 to KLONK-26 and 27). All samples were processed by standard methods (HCl, HF treatment without oxidation). The remaining organic residue was separated into three fractions of > 63 μm, > 40 μm, and > 10 μm.

Reference slides are stored in the collections of the Research Institute Senckenberg, Palaeobotany, Frankfurt am Main, Germany. The locations of illustrated specimens in slides are based on England-Finder coordinates.

Systematic palaeontology

Green Algae – Prasinophytes

Most of the observed OWM are sphaeromorphs without processes and are usually assigned to prasinophytes. However, distinct genera are represented in very different proportions. *Leiosphaeridia* predominates in all of the studied samples, whereas ?*Pleurozonaria* occurs only in some levels, and *Pterospermella* is present in a few samples only. True *Tasmanites* has not been found.

Genus *Leiosphaeridia* Eisenack 1958, emend. Downie & Sarjeant 1963

Type. – *Leiosphaeridia baltica* Eisenack 1958

Description. – Simple sphaerical phycomata without any ornamentation are assigned to *Leiosphaeridia*. Most of the individual specimens are comparatively thin-walled.

***Leiosphaeridia* spp.**
Figures 2, 3, 5A–K, M, N, 6, 7

Description. – Several thousand observed specimens show very wide morphologic variations. The spectrum ranges from small (10 μm) to very large specimens (about 700 μm in diameter), and from thin-walled and subtle (Figs 5D, E) to thick-walled and very robust forms (e.g. Figs 5B, I, M, N). No relation between the thickness of the wall and the diameter of the central body has been established.

The complete spectrum of small to very large morphotypes is present in some of the samples (e.g. KLONK-19, KLONK-21-22). 90 % of the observed specimens are smaller than 250 μm in all samples. However, in three samples (KL-63, KL-65 and KLONK-20) two distinct populations can be recognized.

Genus *Pleurozonaria* Wetzel 1933

Type. – *Pleurozonaria globula* Wetzel 1933

Diagnosis. – Palaeozoic prasinophytes with canals or pores are usually classified within the genus *Tasmanites*. However, the family Tasmanacea Sommer 1956 emend. Mädler 1963 is characterized by pore canals and incorporates several other genera. Our material from the GSSP shows a morphology similar to the specimens described by Mädler (1963) from the Jurassic Posidonia Shales and assigned to *Pleurozonaria* Wetzel 1933. The opinion on validity of the genus *Pleurozonaria* has been summarized by Fensome *et al*. (1990, p. 395) and is followed here. The original diagnosis by O. Wetzel emphasized the presence of a polar opening ("Polöffnung"), which was also mentioned by Mädler (1963, p. 332). In some of the specimens of both of our morphotypes, a circular opening has been observed (compare Figs 11C, K, L). The diameter of the opening ranges between 1/5 and 1/3 of the phycoma diameter.

Due to the state of preservation, a direct comparison to the material figured and described by Mädler (1963) is impossible, and thus the generic assignment of our material must remain uncertain.

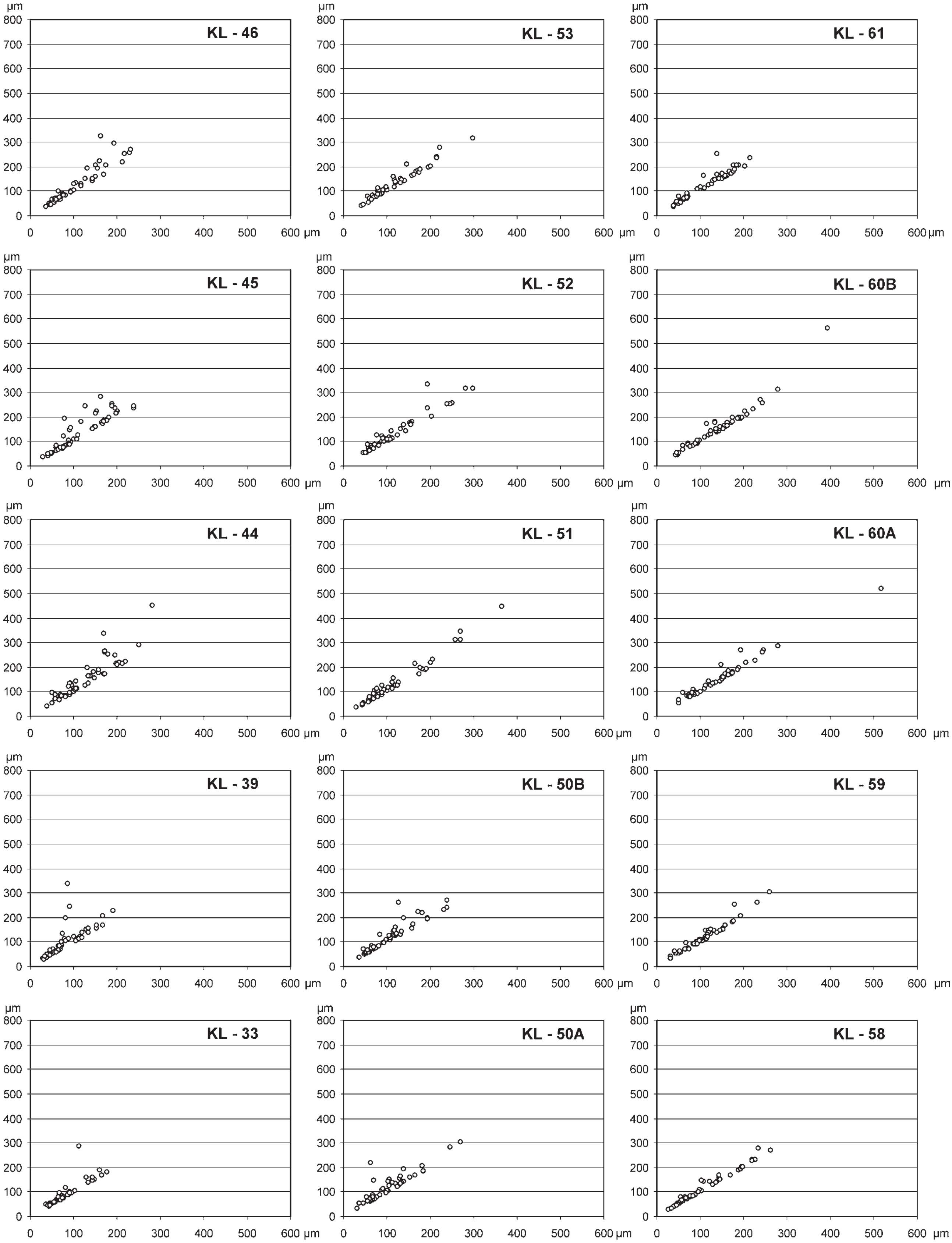


Figure 2. Variation of the diameters (maximum versus minimum) of the central body for *Leiosphaeridia* spp. in samples KL-33 to KL-61 of the Klonk-1 borehole.

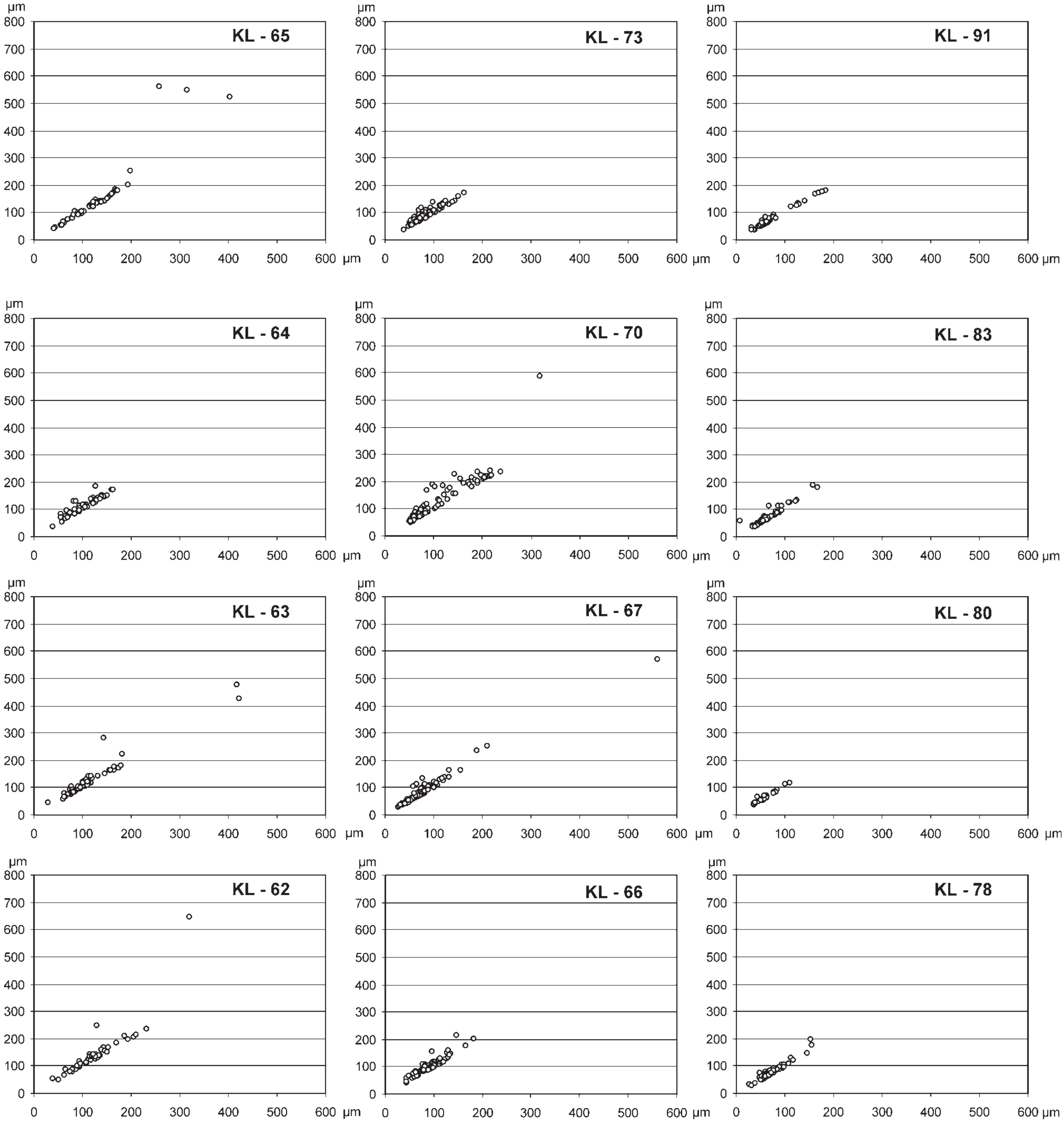


Figure 3. Variation of the diameters (maximum versus minimum) of the central body for *Leiosphaeridia* spp. in samples KL-62 to KL-91 of the Klonk-1 borehole.

?*Pleurozonaria* morphotype 1
Figures 11A, B, D, E

Description. – This morphotype is characterized by a regular and comparatively foveolate to fine reticulate surface. The diameter of the vesicle ranges from 70 to 91 µm. Single canals are sometimes visible in the centre of each depression. The diameter of individual canals does not exceed 1.5 µm.

?*Pleurozonaria* morphotype 2
Figures 11C, F–L

Description. – This morphotype shows a regular but always fine reticulate surface like that observed in morphotype 1, but the ridges of the reticulum are narrower and the individual canals are larger, ranging between 1.8 and 3 µm in diameter. The diameter of the vesicle ranges from 73 to 105 µm.

Genus *Pterospermella* Eisenack 1972

Type. – *Pterospermella aureolata* (Cookson & Eisenack 1958) Eisenack 1972

Diagnosis. – The genus *Pterospermella* is mainly characterized by an ovoidal to subsphaerical central body surrounded by a conspicuous velum displaying radial folds or ribs.

***Pterospermella* sp.**
Figures 5K, L

Description. – Four specimens of this genus have been found in samples KLONK-20 and KL-51. The central body diameter ranges from 65 to 85 μm, while the diameter of the velum is between 125 and 208 μm.

Acritarcha

Genus *Buedingisphaeridium* Schaarschmidt 1963 emend. Staplin *et al*. 1965 emend. Lister 1970

Type. – *Buedingisphaeridium permicum* Schaarschmidt 1963

Diagnosis. – This genus is characterized by sphaerical central body covered by numerous short conical and hollow processes.

cf. *Buedingisphaeridium* sp.
Figure 9H

Description. – The observed specimen bears short hollow, distally solid conical processes. The central body measures 34 μm in diameter. Due to the poor state of preservation a final determination is not possible.

Genus *Cymbosphaeridium* Lister 1970

Type. – *Cymbosphaeridium bikidium* Lister 1970

Remarks. – *Cymbosphaeridium* is characterized by a double-walled central body, distally branched processes, and the presence of a large opening covered by a process bearing an operculum.

The genus includes about 10 species ranging from the Silurian (Llandovery) to the early Devonian (Le Hérissé, personal communication). From the GSSP at Klonk, Deunff (1980, fig. 6) reported *Cymbosphaeridium pilar* (Cramer 1964) Lister 1970 in bed number 5, and *C. cariniosum* (Cramer 1964) Jardiné *et al*. 1972 in beds 5, 10, and 20. The recently studied specimens show important differences in diameter of the central body and length of the processes. Therefore, they could not be assigned to any of the previously described species. But, two distinct morphotypes may be distinguished (Fig. 8).

***Cymbosphaeridium* morphotype 1**
Figure 4

Description. – In the four specimens the central body diameter ranges between 17–21 μm, and the length of processes ranges between 7–11 μm.

***Cymbosphaeridium* morphotype 2**
Figures 4, 9A–E, G, J, K, N

Description. – 42 specimens, central body diameter ranges between 24 and 39 μm (mean 31,4 μm), the length of processes ranges between 7–20 μm.

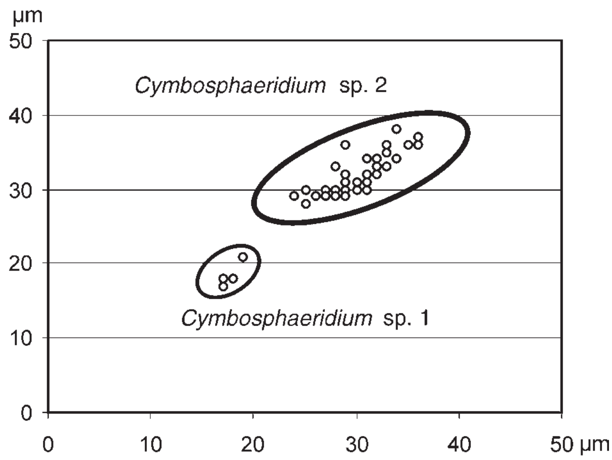
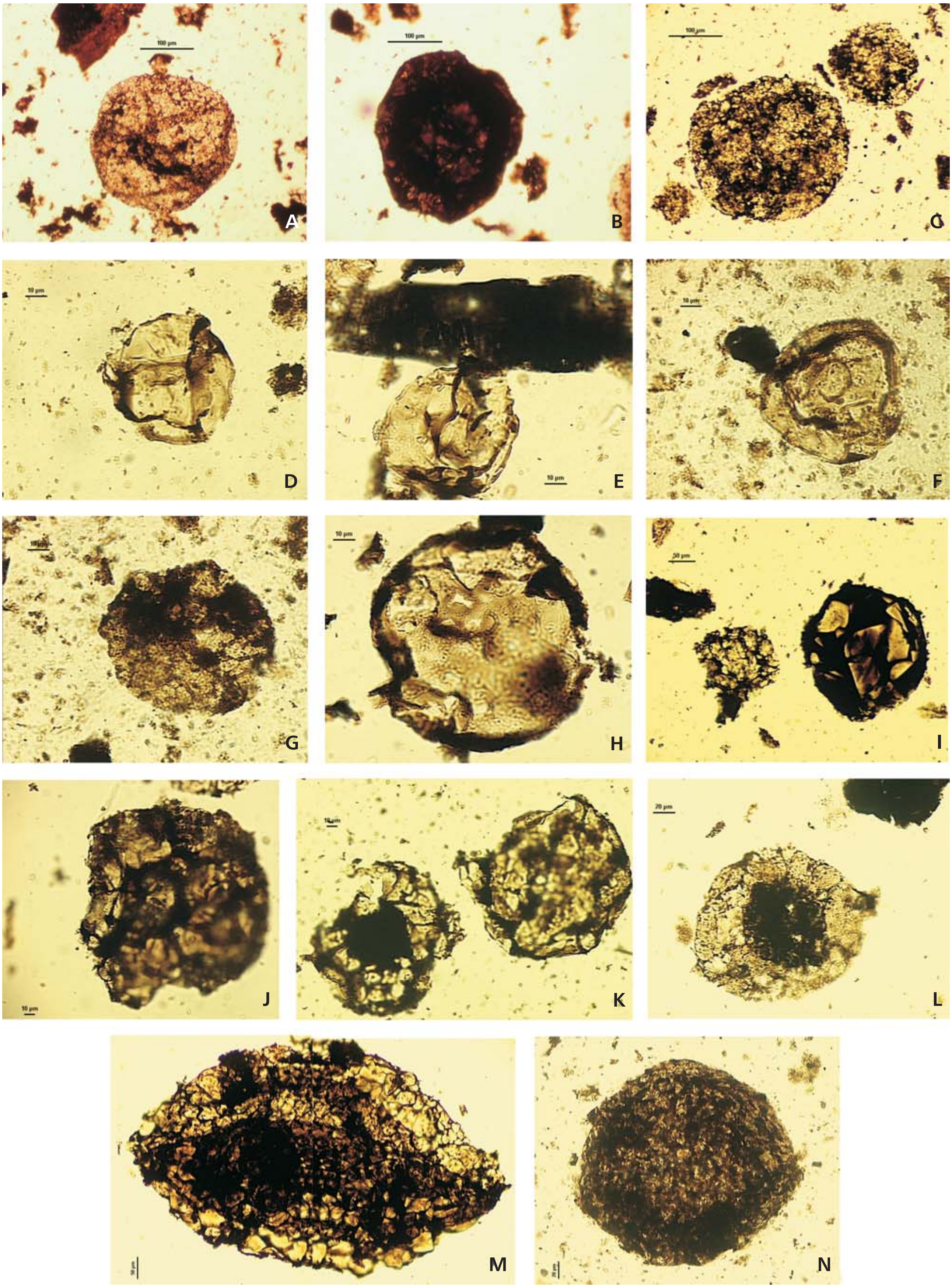


Figure 4. Variations of the diameters (maximum versus minimum) of the central body for *Cymbosphaeridium*.

Figure 5. Leiospheres and other prasinophytes of the Silurian-Devonian boundary beds at Klonk near Suchomasty. • A – *Leiosphaeridia* sp., sample KL-53 (H48.1). • B – *Leiosphaeridia* sp., sample KL-53 (K38). • C – *Leiosphaeridia* sp., sample KLONK-45 (M40.2). • D – *Leiosphaeridia* sp., sample KLONK-20 (S56). • E – *Leiosphaeridia* sp., sample KLONK-21 (M66). • F – *Leiosphaeridia* sp., sample KLONK-20 (J54). • G – *Leiosphaeridia* sp., sample KLONK-20 (R51.1). • H – *Leiosphaeridia* sp., sample KLONK-21 (N64). • I – *Leiosphaeridia* sp., sample KLONK-20 (O48.2). • J – *Leiosphaeridia* sp., sample KLONK-20 (O40.4). • K – *Leiosphaeridia* sp. and *Pterospermella* sp., sample KLONK-20 (P52). • L – *Pterospermella* sp., sample KL-51 (N39.3). • M – *Leiosphaeridia* sp., sample KLONK-20 (N33.3). • N – *Leiosphaeridia* sp., sample KLONK-45 (S47).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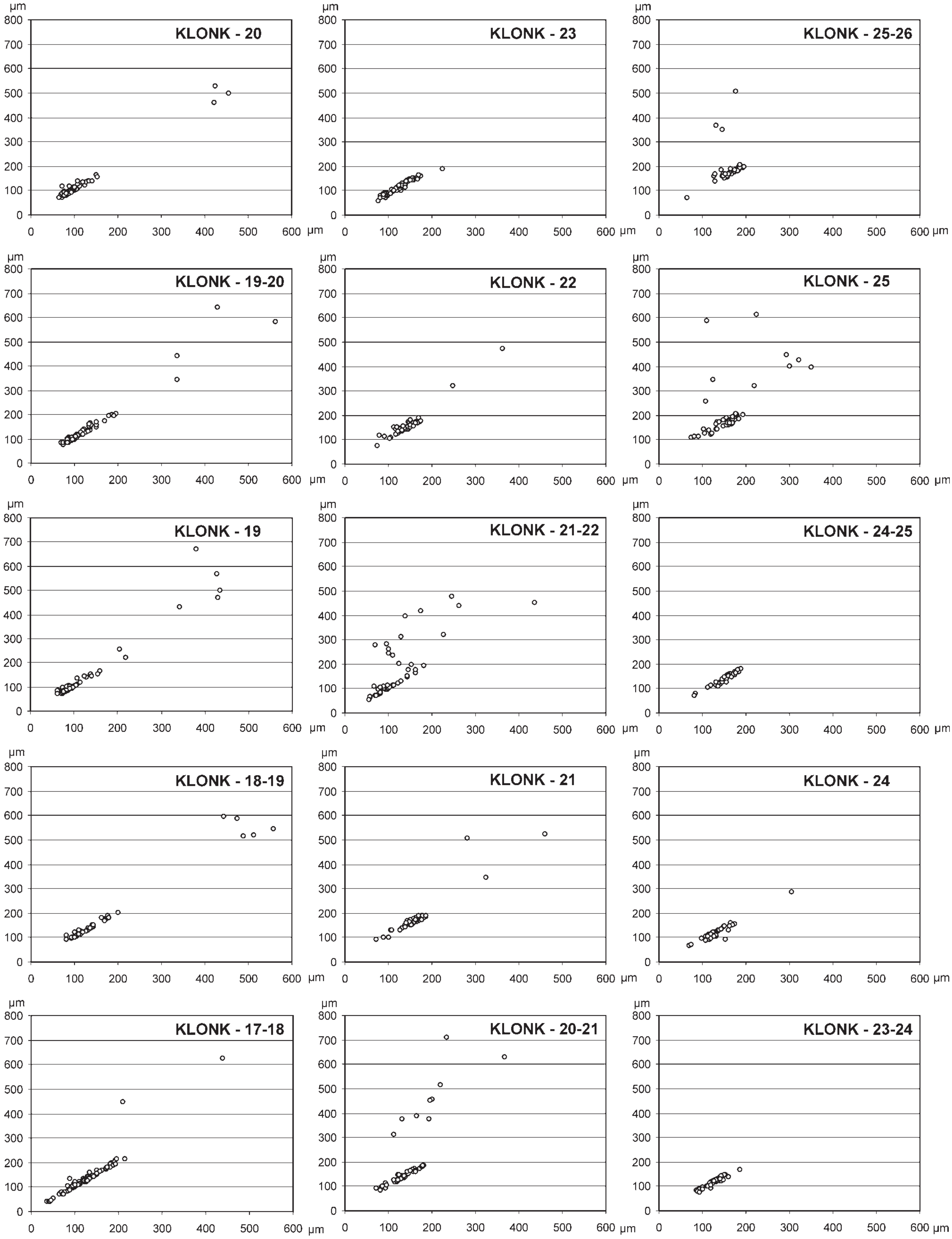


Figure 6. Variation of the diameters (maximum versus minimum) of the central body for *Leiosphaeridia* spp. in samples KLONK-17-18 to KLONK-25-26 of the Klonk stratotype section.

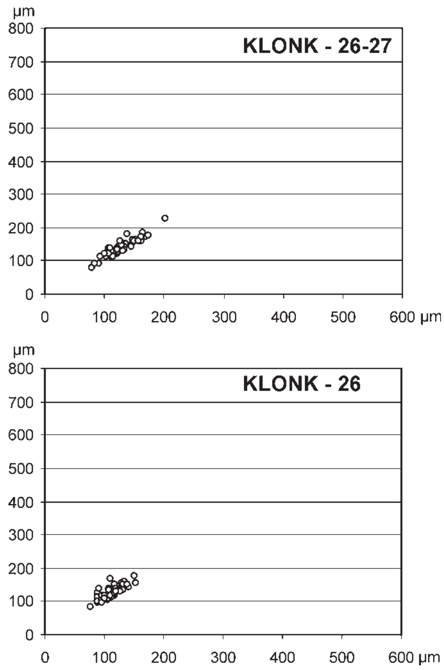


Figure 7. Variation of the diameters (maximum versus minimum) of the central body for *Leiosphaeridia* spp. in samples KLONK-26 to KLONK-26-27 of the Klonk stratotype section.

Genus *Diexallophasis* Loeblich 1970

Type. – *Diexallophasis denticulata* (Stockmans & Willière 1963) Loeblich 1970

Diagnosis. – Vesicle sphaerical to subsphaerical, bearing a few to numerous bifurcate to multifurcate processes. Process cavity freely communicates with the vesicle interior. Along the processes, spinous to denticulate ornamentation is developed.

Remarks. – Deunff (1980, fig. 6) mentioned the occurrence of *Diexallophasis denticulata* (Stockmans & Willière 1963) Loeblich 1970 in beds 5, 10, and 20 of the GSSP. This cosmopolitan species ranges from the Upper Ordovician (Le Hérissé *in* Molyneux *et al*. 1996) to the late Middle Devonian (Wicander *in* Molyneux *et al*. 1996).

cf. *Diexallophasis* sp.
Figures 9P, Pa

Description. – The two poorly preserved specimens lack the distal parts of processes and can be only provisionally assigned to the genus *Diexallophasis*.

Genus *Multiplicisphaeridium* Staplin 1961, restrict. Staplin, Jansonius & Pocock 1965, emend. Lister 1970

Type. – *Multiplicisphaeridium ramispinosum* Staplin 1961

Remarks. – *Multiplicisphaeridium* represents subsphaerical to almost polygonal central bodies with numerous homomorph to heteromorph, distally polyfurcate processes. It differs from *Diexallophasis* in the lack of wall ornamentation.

***Multiplicisphaeridium* sp.**
Figure 9I

Description. – The central body of the single specimen is sphaerical with 12 heteromorphic processes. The hollow processes freely communicate with the central cavity; distally they are irregularly branched. Central body diameter 27 µm, the length of processes ranges from 12 to 15 µm.

Genus *Onondagaella* (Cramer 1966) Playford 1977

Type. – *Veryhachium asymetricum* Deunff 1954

Diagnosis. – Triangular vesicle with three heteromorphic processes, two of which are tapering and spine-like, while the third has a prominent distal circular opening, if closed, designated as epibystra by Playford (1977, p. 30).

Remarks. – Two species of the genus *Onondagaella* are documented to cross the Silurian-Devonian boundary: *O. deunffii* Cramer 1966 has been reported to range from the base of the Ludlow (Le Hérissé in Molyneux *et al*. 1996) to the end of the Lochkovian (Le Hérissé *et al*. 2000); *O. assymetrica* (Deunff 1954 *ex* Deunff 1961) Cramer, 1966 ranges from pre-Přídolí levels (Le Hérissé *et al*. 2000) to the end of the Emsian (Wicander *in* Molyneux *et al*. 1996).

***Onondagaella* aff. *assymetrica* (Deunff 1954 *ex* Deunff 1961) Cramer 1966**
Figures 10B, C

Description. – The two discovered specimens are similar to *O. assymetrica* in terms of dimensions (38 × 43 µm and 52 × 60 µm) and general morphology.

***Onondagaella* sp.**
Figure 10A

Description. – The central body of the single observed specimen measures 51 × 66 µm.

Genus *Oppilatala* Loeblich & Wicander 1976

Type. – *Oppilatala vulgaris* Loeblich & Wicander 1976

Remarks. – The genus *Oppilatala* is characterized by a circular central body with a variable number of distally multifurcate processes. It differs from *Multiplicisphaeridium* by its proximally plugged processes, and from *Cymbosphaeridium* by the absence of a large circular opening and process bearing operculum.

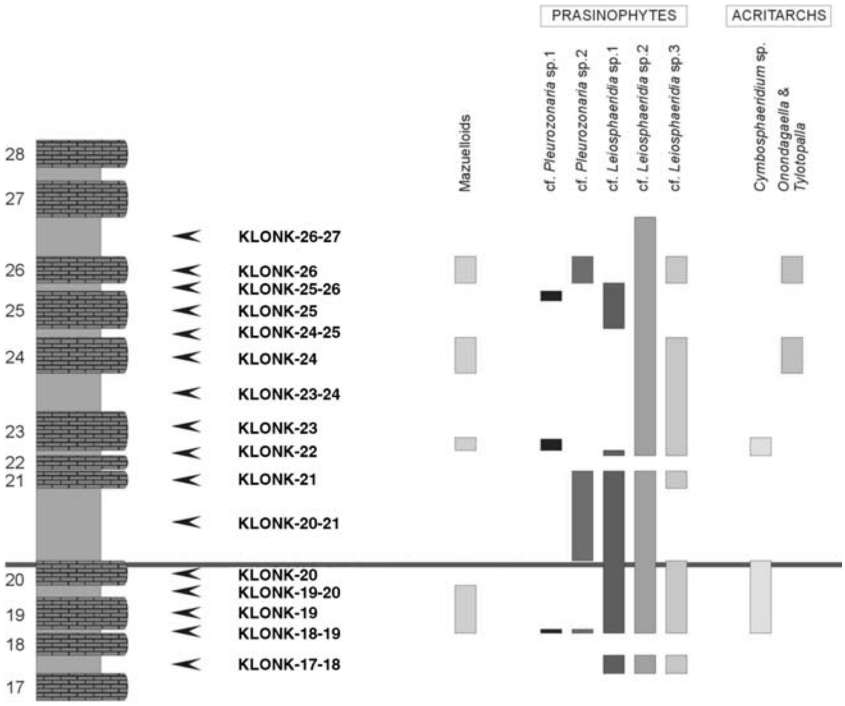


Figure 8. Distribution of microfossils within the GSSP at Klonk near Suchomasty.

***Oppilatala* sp.**
Figure 9O

Description. – The figured specimen (Fig. 9O) is comparatively well preserved. The diameter of the central body is between 22 and 27 µm; there are at least five processes between 18 and 30 µm in length. Two other specimens (Figs 9L, M) show comparable dimensions, but because of poor preservation they are only tentatively assigned to the genus *Oppilatala*.

Mazuelloids

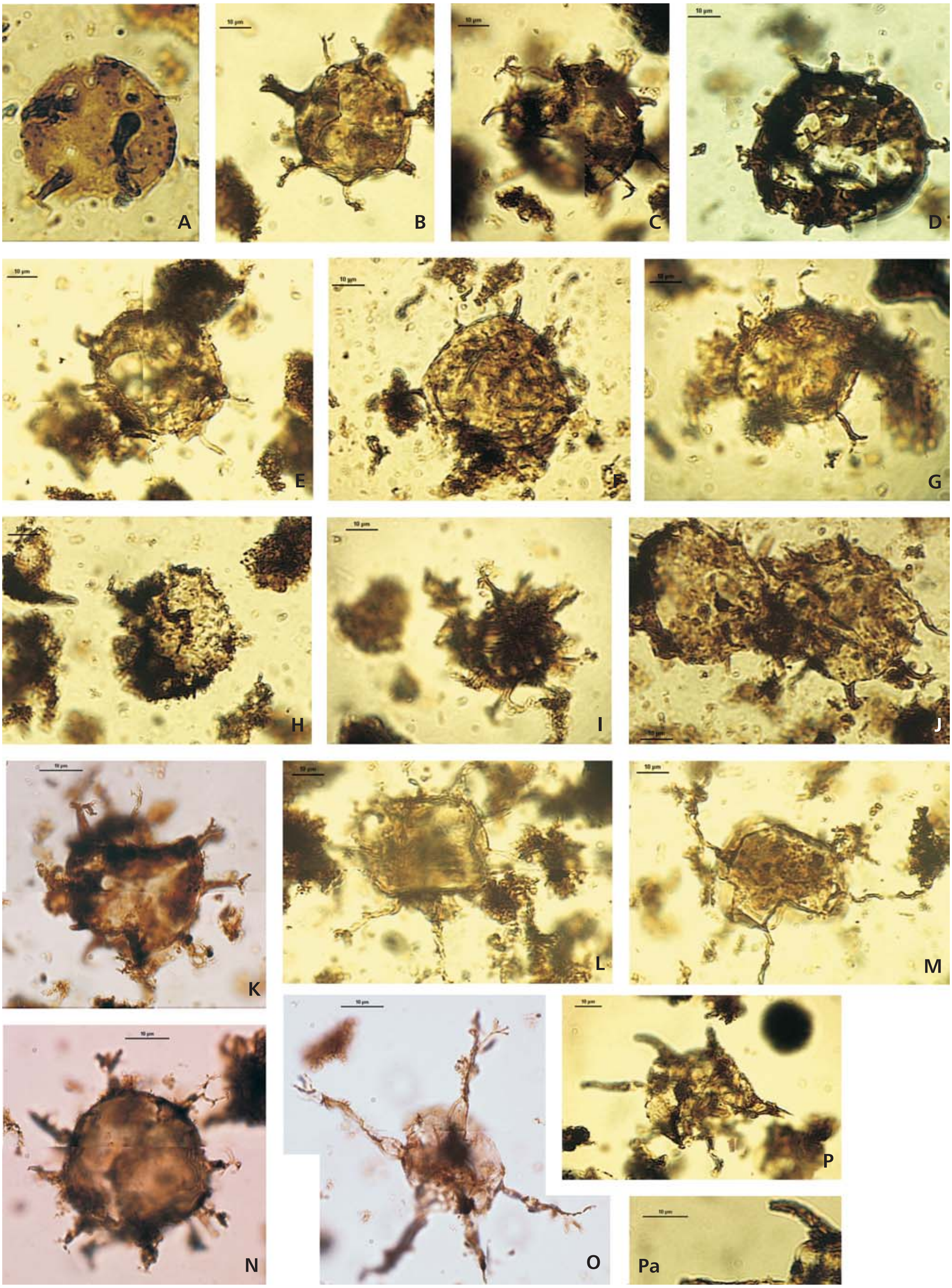
In addition to acritarchs and prasinophytes, mazuelloids have been found in four levels. In samples KLONK-19 and KLONK-20, broken pieces and/or complete long processes are quite common in comparison to much more rarely observed complete specimens. In samples KLONK-23-24, KLONK-24, and KLONK-26, only a few complete specimens of varieties with short processes have been noted.

Conclusions

Acritarchs and prasinophytes have systematically been evaluated from the Silurian-Devonian GSSP at Klonk and the Klonk-1 borehole (both near Suchomasty, Fig. 1) for the first time.

Acritarchs. – Knowledge on late Silurian to early Devonian acritarchs is generally very limited. This is especially true for deep-water deposits on the margins of the Rheic Ocean (Richardson 1984, Le Hérissé 2002), which have been called the "Bohemian Magnafacies" by Richardson (1984). The extensive reinvestigation of the stratotype section, and the adjacent borehole also confirmed the presence of poorly preserved and less diversified acritarch assemblages. The new data could not improve the poor stratigraphic potential of acritarchs across the Silurian-Devonian boundary within the "Bohemian Magnafacies".

Figure 9. Acritarchs of the Silurian-Devonian boundary beds at Klonk near Suchomasty. • A – operculum of *Cymbosphaeridium* morphotype 2, sample KLONK-18-19 (F33). • B – *Cymbosphaeridium* morphotype 2, sample KLONK-24 (H34). • C – *Cymbosphaeridium* morphotype 2, sample KLONK-19-20 (T44.4). • D – *Cymbosphaeridium* morphotype 2, sample KLONK-18-19 (W42.3). • E – *Cymbosphaeridium* morphotype 2, sample KLONK-19-20 (W34.3). • F – gen. et sp. indet., sample KLONK-20 (P52.3). • G – *Cymbosphaeridium* morphotype 2, sample KLONK-19-20 (V48.3). • H – cf. *Buedingisphaeridium* sp., sample KLONK-19-20 (Q33). • I – *Multiplicisphaeridium* sp., sample KLONK-18-19 (W38.3). • J – ?*Cymbosphaeridium* morphotype 2, sample KLONK-20 (C52.3). • K – *Cymbosphaeridium* morphotype 2, sample CZ-KL-53 (V48.2). • L – cf. *Oppilatala* sp., sample KLONK-19 (S32.1). • M – cf. *Oppilatala* sp., sample KLONK-19 (Q46). • N – *Cymbosphaeridium* morphotype 2, sample KL-53 (T38.2). • O – *Oppilatala* sp., sample KL-53 (R42.3). • P, Pa – cf. *Diexallophasis* sp., sample KLONK-23A II (Y50.3).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Prasinophytes. – In contrast to acritarchs, prasinophytes are widely distributed in all studied samples, particularly within the boundary interval. They have been assigned to the following taxa: *Leiosphaeridia* spp., ?*Pleurozonaria* morphotype 1, ?*Pleurozonaria* morphotype 2 and *Pterospermella* sp.

Our measurements of more than 2 000 specimens of *Leiosphaeridia* spp. (Figs 2, 3, 6, 7) from the stratotype and the borehole show a general trend regarding changes in size.

Leiospheres from the upper Přídolí generally measure less than 300 μm in diameter (KL-33 to KL-62). In the uppermost part of the Přídolí and the lowermost Lochkovian (KL-63 to KL-70) the diameter is generally smaller than 250 μm, and higher up in the sequence it does not exceed 200 μm (KL-73 to KL-91). In some samples (KL-33, KL-44, KL-52, KL-60, KL-62, KL-63, KL-65, KL-67, KL-70) very large specimens occasionally occur. They are absent above sample KL-70. The largest specimens are concentrated around the Silurian-Devonian boundary. A comparable trend is apparent in samples from the stratotype.

Richardson (1984, p. 341) defined the "Bohemian Magnafacies" as follows: "Deeper water deposits, at times oceanic, often consisting of black shales containing only pelagic microfossils (Bohemian Magnafacies), are characterized by prasinophycean 'cysts', frequently in great abundance, in chitinozoa while miospores and acritarchs in this magnafacies are rare." In addition, the frequent occurrence of mazuelloids is to be mentioned as characteristic of this type of facies.

Mazuelloids. – A recently published interpretation of the common occurrence of mazuelloids, as observed in the lower Silurian of the Holy Cross Mountains in Poland (Kremer 2005), seems to fit with the trophic changes driven by uppwellings.

Phytoplankton cysts at the Silurian-Devonian boundary GSSP at Klonk are specifically represented by acritarchs and prasinophytes, and questionably also by mazuelloids – see discussion of the origin of mazuelloid in Kremer (2005). Fluctuation in the frequency of these groups may have been related to transgressive/regressive pulses, which have been repeatedly recorded for the Silurian-Devonian boundary interval (Crick *et al*. 2001). Controversy, however, continues as to whether the boundary itself was characterized by a transgression (Mann *et al*. 2001) or regression (Saltzmann 2002).

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Figure 10. Acritarchs, mazuelloids and problematica of the Silurian-Devonian boundary beds at Klonk near Suchomasty. • A – *Onondagaella* sp., sample KLONK-26-I (Y35.4). • B – *Onondagaella* aff. *assymetrica* (Deunff 1954 *ex* Deunff 1961) Cramer 1966, sample KLONK-19 (B35.4). • C – *Onondagaella* aff. *assymetrica* (Deunff 1954 *ex* Deunff 1961) Cramer 1966, sample KLONK-19 (T47). • D – Mazuelloid sp., sample KL-50-A (F37). • E – Mazuelloid sp., sample KL-59 (U37.2). • F – Mazuelloid sp., sample KL-59 (Q37.3). • G, H – Mazuelloid sp., sample KL-53 (M43.1). • I – Mazuelloid sp., sample KL-50B (Q50). • J – *Tersisphaera* sp., sample KL-53 (H48.1). • K – Mazuelloid sp., sample KL-51 (W51.3). • L – *Tersisphaera* sp., sample KL-53 (H48.1). • M – *Porcatitubulus* sp., sample KLONK-20-21 (P51). • N, O – animal cuticule, sample KL-53 (G46.2).

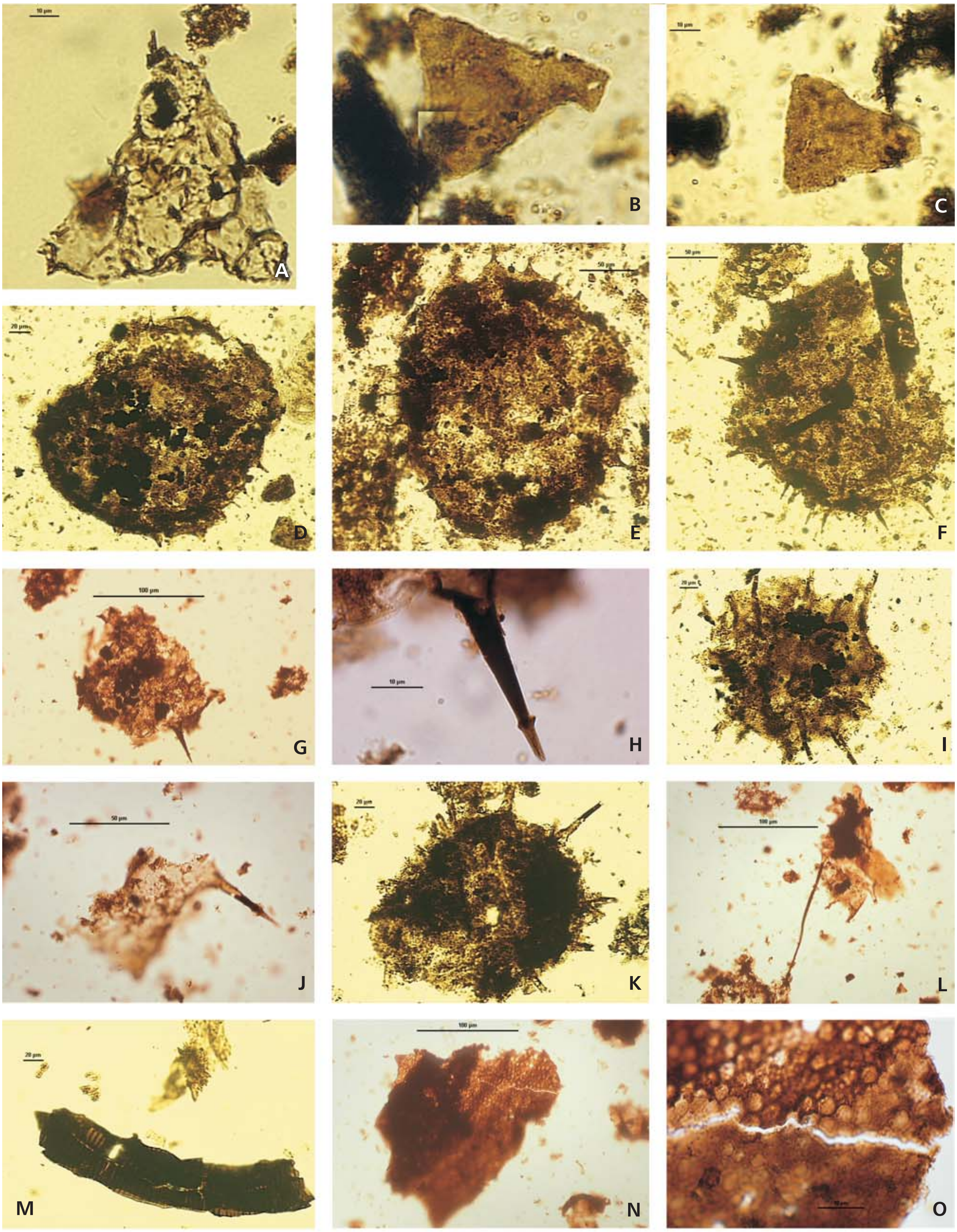
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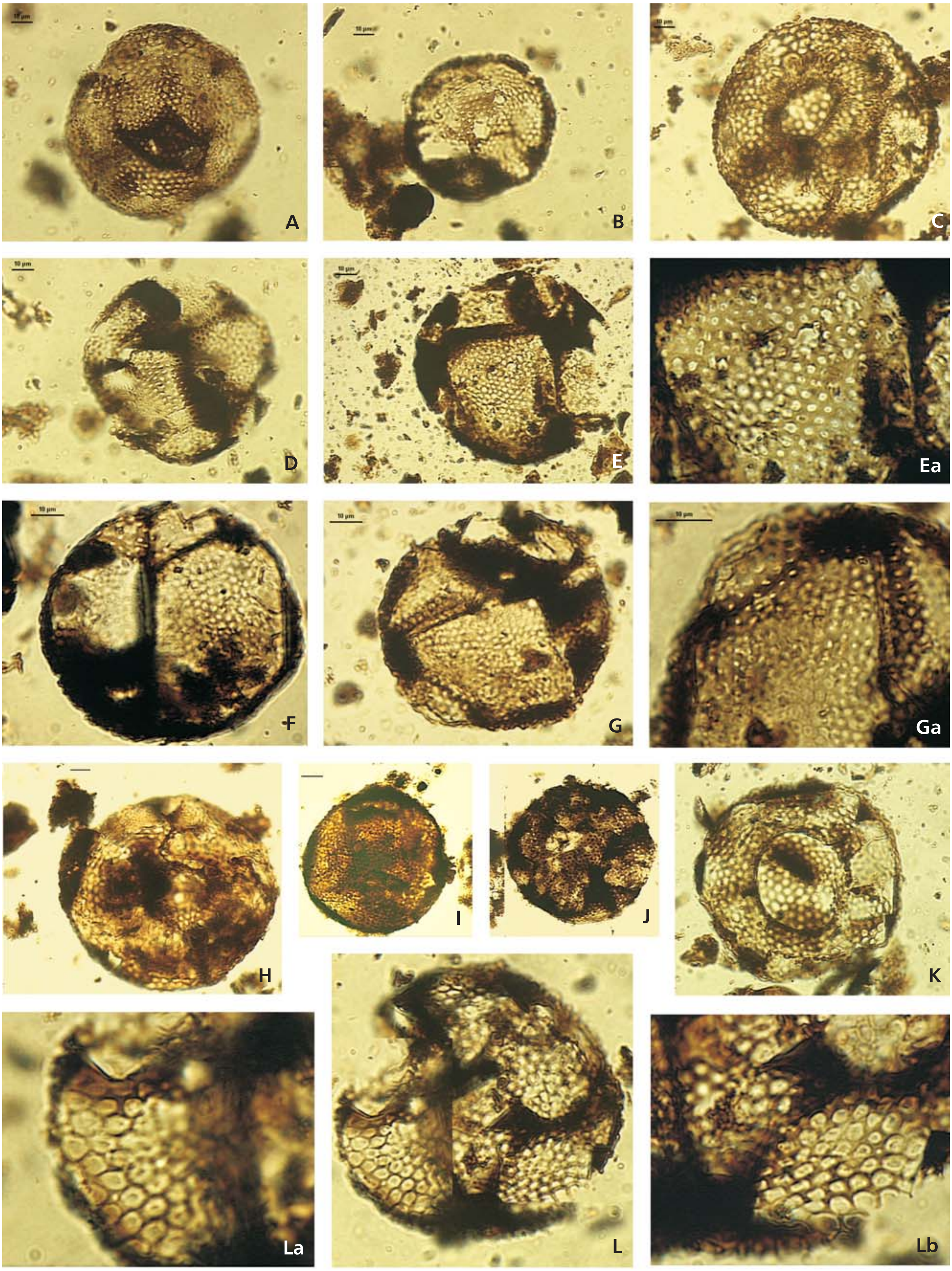
Figure 11. Prasinophytes of the Silurian-Devonian boundary beds at Klonk near Suchomasty. • A – ?*Pleurozonaria* morphotype 1, KLONK-18-19 (Q38.3). • B – ?*Pleurozonaria* morphotype 1, KLONK-18-19 (R34). • C – ?*Pleurozonaria* morphotype 2, KLONK-18-19 (Q40). • D – ?*Pleurozonaria* morphotype 1, KLONK-18-19 (R33). • E, Ea – ?*Pleurozonaria* morphotype 1, KLONK-18-19 (Z49.2). • F – ?*Pleurozonaria* morphotype 2, KLONK-18-19 (X42.1). • G, Ga – ?*Pleurozonaria* morphotype 2, KLONK-18-19 (Y44.4). • H – ?*Pleurozonaria* morphotype 2, KLONK-18-19 (X41.4). • I – ?*Pleurozonaria* morphotype 2, KL-51 (O43.2). • J – *Pleurozonaria* morphotype 2, KL-51 (U56.3). • K – ?*Pleurozonaria* morphotype 2, KLONK-18-19 (X42.1). • L, La, Lb – ?*Pleurozonaria* morphotype 2, KLONK-18-19 (G39).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