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Ordovician–Silurian boundary in the Bardo Syncline, Holy Cross Mountains, Poland — new data on fossil assemblages and sedimentary succession

Monika MASIAK, Teresa PODHALAŃSKA and Marzena STEMPIEŃ-SAŁEK

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A gradual transition from sandy through silty to clayey strata occurs near the Ordovician–Silurian (O/S) boundary in the southern part of Holy Cross Mountains, in the Bardo Syncline. Three graptolite biozones are distinguished for the O/S boundary interval deposits: *?persculptus, ascensus-acuminatus* and *vesiculosus.* The first, rare graptolites appear below "graptolitic shales" in the *?persculptus* Biozone. The diversity of the assemblage increases in the next two biozones. An analysis of acritarch frequency shows a decrease of acritarch frequency at the O/S boundary and then a gradual increase in the lower part of the *ascensus-acuminatus* biozone with a maximum in the *vesiculosus* Biozone**.** The taxonomic diversity of the acritarch assemblage shows a similar trend although the maximum of acritarch frequency observed in the *vesiculosus* Biozone do not coincide the maximum of acritarch taxonomic diversity.

Monika Masiak and Marzena Stempień-Sałek, Polish Academy of Sciences, Institute of Geological Sciences, Twarda 51/55, PL-00-818 Warszawa, Poland; e-mail: mmasiak@twarda.pan.pl, mstempie@twarda.pan.pl; Teresa Podhalańska, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland; e-mail: tpod@pgi.waw.pl *(received: May 25, 2003; accepted: October 2, 2003).*

Key words: Holy Cross Mts., Bardo Syncline, Ordovician/Silurian boundary, lithology, graptolites, acritarchs.

INTRODUCTION

The Ordovician/Silurian transition deposits discussed in this study are exposed in the Bardo Syncline in the southern Holy Cross Mountains (Kielce region). This is a small tectonic unit about 16 km long and 2–3 km wide, elongated NW–SE. This Variscan structure is composed of Ordovician and Silurian strata, truncated and overlain paraconformably by Devonian rocks. The Palaeozoic rocks are largely blanketed by a thick cover of Quaternary deposits. The outline of the Syncline is marked by diabases, which follow the boundary between different Silurian deposits: graptolitic shales and greywackes.

The material used for palaeontological investigation comes from two sections located in the southern limb of the Bardo Syncline: Zalesie Nowe (palynology) and Bardo Stawy (graptolites and palynology) (Fig. 1).

In the Zalesie Nowe section that is located in the eastern part of Bardo Syncline, the Upper Ordovician and Silurian rocks crop out in the left side of stream valley escarpment near the village of Zalesie Nowe. The stratigraphic subdivision we employed here is based on Kremer (1998, 2001), although with modifications noted below.

The Bardo Stawy section is situated in the central part of southern limb of the Bardo Syncline, about 3 km west of the Zalesie Nowe section. The Ordovician and Silurian strata crop out along small unnamed stream valley escarpments.

Our investigations have focused on the graptolite fauna and microphytoplankton (acritarch) assemblages from the Ordovician/Silurian transition beds. We have revised the biostratigraphy of these sections, and investigated diversity and sedimentary facies patterns. Our work builds on previous stratigraphic works in the area. Most of them, especially in the Bardo Stawy outcrop, were conducted during the 1950's and 1960's, and their results were not always unequivocal and they do not match the present state of knowledge.

PREVIOUS GEOLOGICAL INVESTIGATIONS

Geological investigations, particularly stratigraphic studies were conducted at Zalesie Nowe by Czarnocki (1928*a*, *b*), Bednarczyk (1971, 1981) and at Bardo Stawy by Kielan (1956, 1960), Tomczyk (1962*a*, *b*), Temple (1965), Bednarczyk and Tomczyk (1981) and Tomczykowa and Tomczyk (1981). Some palynological investigations of Early Ordovician (Late

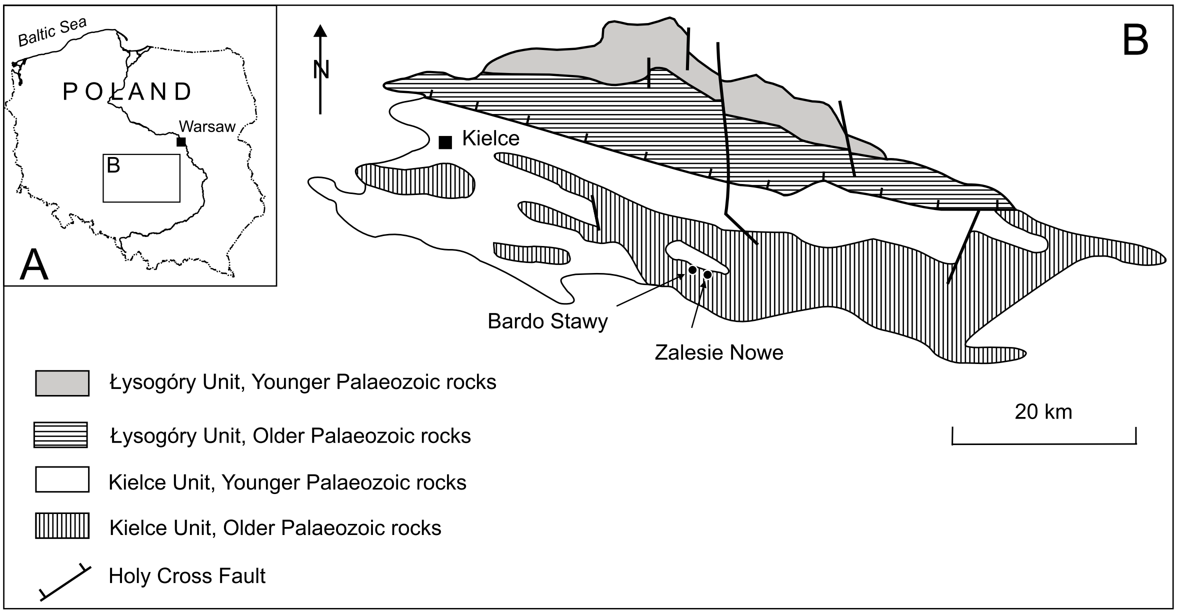

Fig. 1. Location sketch of the Bardo Stawy and Zalesie Nowe outcrops

Tremadocian) acritarchs were conducted by Górka (1969) and those of the latest Ordovician/earliest Silurian acritarchs and prasinophytes by Kremer (2001). A petrographic study was conducted by Chlebowski (1971) and a tectonic study was made by Stupnicka (in Bednarczyk, 1996).

ZALESIE NOWE

The Ordovician succession at Zalesie Nowe is stratigraphically almost complete. It is divided into local formations (Bednarczyk, 1971, 1981).

In the Upper Ordovician, the Zalesie Claystones with Bentonite Formation is distinguished. This formation is lithologically tripartite. Its uppermost part is represented by dolomitic marls and dolomites, sandwiched between bentonites; its topmost part is composed of marls and dark red and grey-greenish marly shales. Czarnocki (1928*a*, *b*) regarded this topmost part is Silurian in age.

The marls pass upward into dark grey shales interbedded with black laminated cherts.

Fossils are scattered in the dolomitic strata but ubiquitous in the shales, so those uppermost part of Zalesie Formation is divided into two informal stratigraphic units.

The lower stratigraphic unit (uppermost Zalesie Formation) is called the *Dalmanitina* Beds (Kielan, 1956) or Zalesie Beds (Tomczyk, 1962*a*). The age of these beds is well documented by the trilobite *Dalmanitina* (=*Mucronaspis*) *mucronata* (Brongniart) as latest Ashgill (Kielan, 1956), also brachiopods (Temple, 1965) point to a Hirnantian age.

The succeeding informal stratigraphic unit conformably overlying the Zalesie Beds is the Bardo Beds. Kielan (1956) regarded these beds as earliest Silurian in age based on the presence of *Climacograptus scalaris normalis* Lapworth (= *Normalograptus normalis*) and, some metres higher, of *Akidograptus* (=*Parakidograptus*) *acuminatus* (Nicholson). The latest investigations of the graptolite fauna (Kremer, 1998, 2001) indicate a Late Ordovician (Ashgill)–Early Silurian age for the Bardo Beds at Zalesie Nowe.

BARDO STAWY

The strata exposed in the Bardo Stawy ravine represents the latest Ordovician to earliest Silurian interval.

The latest Ordovician consists of dark red clayey-marly rocks locally interbedded with mudstones and bentonite layers. This sequence is assigned to the lower Ashgill and may be correlated with equivalent deposits in Scandinavia, Estonia and Latvia (Bednarczyk, 1971). Above these rocks there is a succession of sandy mudstones and marls (Kielan, 1956, 1960) or, according Chlebowski (1971), variegated shales with mudstone and sandstone intercalations and one, relatively thick, bentonite bed.

Above the latter, dark grey shales with graptolites, interbedded with black laminated cherts occur. Kielan (1956, 1960) regarded the succession between the dark red clayey-marly sequence and the dark grey shales as the equivalent of the Zalesie (*Dalmanitina*) Beds of upper Ashgill age, on the evidence of the trilobite fauna.

The brachiopod fauna from this succession is similar to the *Hirnantia* fauna of North Wales (Temple, 1965).

According Kielan (1960), only the *Dalmanitina* (=*Mucronaspis*) *olini* and lower part of *Mucronaspis mucronata* Biozones are developed within the Zalesie Beds. The higher part of the *M. mucronata* Biozone is missing due to faulting.

The presence of the *mucronata* Biozone in the Bardo Stawy section was also ascertained by Bednarczyk (1971).

The succession representing the Zalesie Beds passes upwards into the Bardo Beds with *Normalograptus normalis* (Lapworth) and *N. miserabilis* (Elles and Wood) which is regarded e.g. by Bjerreskov (1975), Rickards (1988), Štorch and Serpagli (1993) as *Normalograptus angustus* (Perner). According to Kielan (1956), these beds correspond to the *Glyptograptus* (=*Normalograptus*) *persculptus* Biozone although no *G. persculptus* (Elles and Wood) was found at Bardo Stawy. Kielan (1956) found the first *Parakidograptus acuminatus* 4 m above the base of the graptolitic shales.

On the other hand, Tomczyk (1962*a*, *b*) stated that a rich graptolite assemblage corresponding to the Silurian *Akidograptus ascensus* regional graptolite biozone of Bohemia and Scania occurs at the base of these shales, which conflicts with the suggestion by Kielan (*op. cit.*) that the basal part of these shales belongs to the *persculptus* Biozone.

METHODS

Optical petrographic studies of thin sections were made. For the Upper Ordovician siliciclastic deposits, average and the maximum grain diameters were measured, and relative proportions of matrix and detrital grains and estimates of grain rounding were made using comparison charts. The rock classification was based on Pettijohn *et al*. (1972), Potter *et al*. (1980) and Jaworowski (1987).

A moderately rich graptolite assemblage was collected from the Bardo Stawy section. Graptolites, preserved mainly as flattened specimens in clayey shales and in weathered sandy and silty shales were examined using a stereo microscope and were drown (using the camera lucida) and photographed by the one of us (TP) (Figs. 4–8). Attempts were made to isolate graptolites, but these were not successful.

37 palynological samples of clayey-siliceous shale and silty to sandy claystone and silty-clayey, very fine-grained sandstones were subjected to standard laboratory treatment (Wood *et al*., 1996). All samples were used for quantitative analysis of assemblage similarity. In this analysis, the following method was used: the organic residues obtained after complete dissolution of 5 grams of rock were supplemented to a volume of 4 ml with methyl alcohol. From each sample, three slides were made; and for each slide, 0.5 ml of well-mixed solution were counted. For each sample level, arithmetic mean was calculated from three slides. All slides are housed in the Department of Stratigraphy and Palaegeography, Institute of Geological Sciences, PAN (INGPAN). Graptolites and petrographic thin sections are stored in the Department of Regional and Petroleum Geology, Polish Geological Institute (PIG).

DEPOSITS OF THE ORDOVICIAN–SILURIAN BOUNDARY INTERVAL IN THE BARDO SECTION

The problem of Ordovician /Silurian transition in the Bardo Stawy remains problematic and this has prompted our studies of these deposits.

LITHOLOGICAL DESCRIPTION

The six samples described below come from the Ordovician/Silurian boundary interval, which is associated with lithological change.

Samples BS. 1 and BS. 2: have a high content of quartz grains, and the rock may be classified as a silty-clayey, very fine-grained, poorly sorted sandstone (Fig. 2a). The main constituents are poorly rounded quartz grains with small amounts of feldspar, muscovite and glauconite as well as a few lithoclasts. In the more sandy parts, about 50% of the grains are above 0.06 mm in diameter. The most frequent grain size is 0.07–0.08 mm. The largest grain recorded 0.37 mm. Some iron oxides are present in the matrix. There is some variability in grain/matrix proportions and grain size and more silty levels occur even in the same thin section.

Sample BS. 3: silty to sandy claystone, beige to yellow-beige in colour (Fig. 2b). The detrital grains are mainly quartz with rare muscovite and glauconite. Fine lamination may be seen at some places. The local presence of coarser quartz grains in the fine laminae suggests slightly higher energy episodes.

Samples BS. 4 and BS. Gr.: silty to sandy, beige and beige-brown claystones and shales with fine lamination marked by an increased content of coarser grains, mostly of quartz, with minor muscovite (Fig. 2c). In the matrix, there are iron oxides with traces of indeterminable organic matter. In the sample BS. 4 the first graptolites appear.

Sample BS. 5 (Figs. 2d–f): dark clayey shales containing up to a few percent of amorphous organic matter, locally with some fine quartz grains (Fig. 2d, e — lower part) and with the first laminae of the black cherts (Fig. 2e — upper part and Fig. 2f). In black silica-rich laminae chalcedonic spherolites occur which frequently contain framboidal grains of pyrite (Fig. 2f).

The lithology seen in sample BS. 5 may be observed in the stratigraphically younger samples (from BS. 6–BS. 22) of section investigated.

SEDIMENTOLOGICAL AND PALAEOENVIRONMENTAL INTERPRETATION

The gradational decrease in detrital quartz and in grain size from very fine-grained sandstones and siltstones to mudstones is characteristic of the latest Ordovician and earliest Silurian strata of the Bardo Stawy section (Fig. 2).

The deposits at the Ordovician/Silurian boundary zone change gradually in texture from non-bedded, very fine-grained sandstones and siltstones to laminated claystones and shales. There is also a change of colour from beige to brown-grey and dark grey. The latter depends on the amount of iron oxides present in the matrix as well as on the increasing content of disseminated organic matter and pyrite, suggesting a growing oxygen deficiency at the local Early Silurian sea floor. Both the decrease in the amount and size of the grains and the change in rock colour from pale to dark may indicate a gradational change from periods of better ventilation and increased circulation to a more sluggish, hypoxic environment. Thus, these features of the uppermost Ordovician–lowermost Silurian sequence indicate a gradual slowdown in sedimentation marked by a progressive restriction of terrigenous sediment supply, related either to the post-glacial eustatic sea level rise or to a decrease in erosion on the adjoining land.

The first graptolites appear in strata preceding the final change from silty and sandy facies into dark clayey facies, with graptolites unequivocally indicating the base of the Silurian.

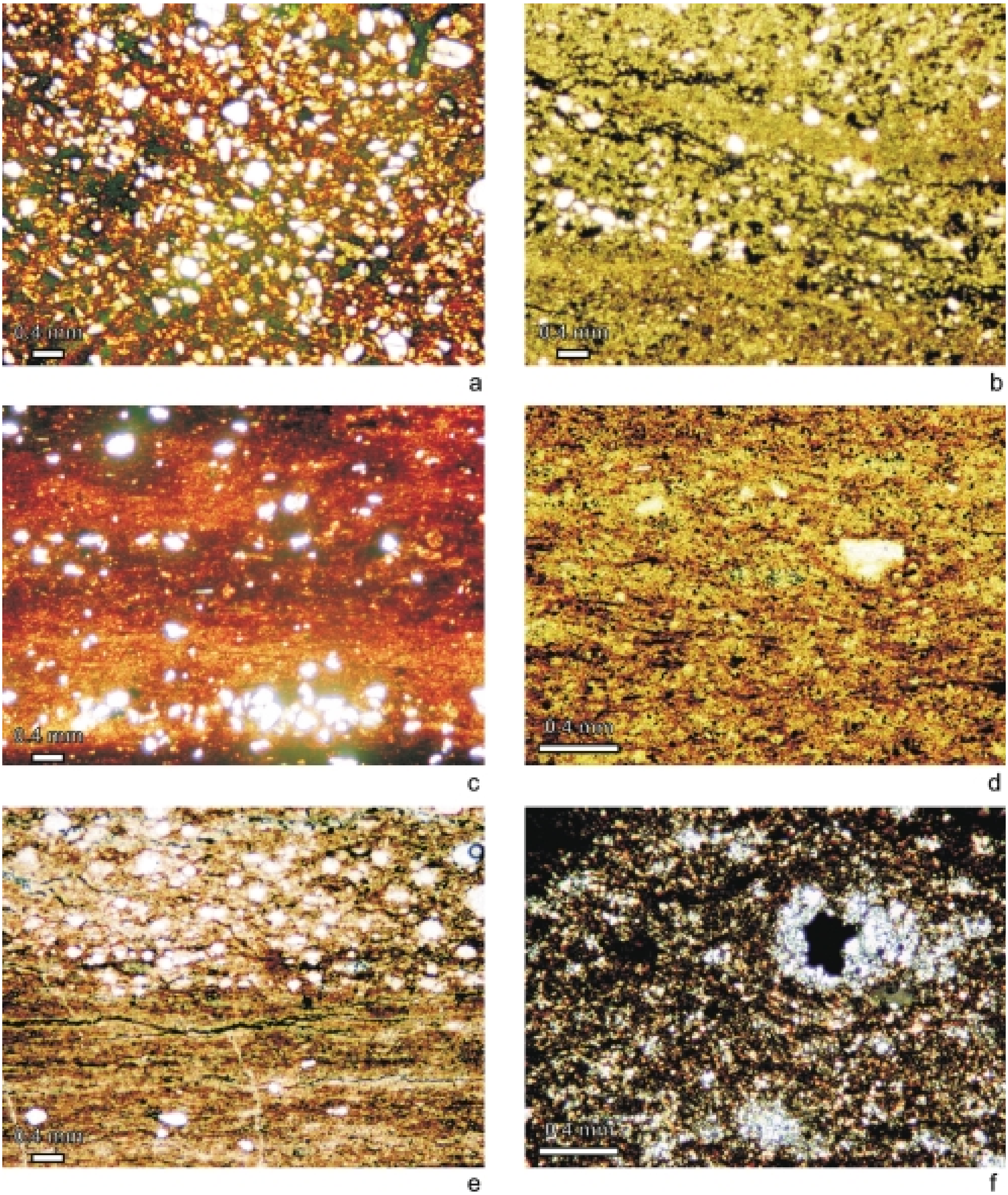

Fig. 2. **a** — silty-clayey very fine-grained and poorly sorted sandstone, sample BS. 2; **b** — silty to sandy claystone of beige and yellow-beige colour, with laminae enriched in coarser quartz grains, sample BS. 3; **c** — silty to sandy microlaminated beige-brown shale with the first graptolites, brown laminae are enriched with iron oxides, sample BS. 4; **d** — clayey shale with very sparse grains of quartz, sample BS. 5; **e** — transition between clayey shale (lower part) and black laminated chert (upper part), in clayey shale a few detrital quartz grains are visible, sample BS. 5; **f** — details of black laminated chert, white is chalcedony, black — framboids of pyrite, sample BS. 5

The oldest graptolites were found in sample BS. 4 in the beige claystones and shales containing quartz silt and sand grains (Fig. 2c), beneath the clayey dark shales of sample BS. 5, which in the lower part are still intercalated with beige sandy shales. It indicates that the first graptolites preceded the final change from light silty and sandy to dark clayey facies and appeared still before the near-cessation of sedimentary activity in oxic or, at most, suboxic conditions in the terrigenous sediment in which little organic matter was preserved.

The typical Lower Silurian deposits are dark but not black, clayey shales with only small amounts of coarser quartz grains and organic matter (Fig. 2d). Within the monotonous Lower Silurian clayey succession there occur silica-rich laminae with chalcedony spherolites, described for the first time by Sujkowski (1937). These deposits comprise mostly cryptocrystalline silica with an admixture of organic matter that encloses, according to Kremer and Kaźmierczak (2002) silicified, benthic, microbial mats composed of colonial coccoid cyanobacteria. The contact of the clayey shales with the chert laminae is distinct and is marked by an increase in silica content (Fig. 2e).

BIOSTRATIGRAPHY

GRAPTOLITE BIOZONES IN BARDO STAWY SECTION

In the Holy Cross Mountains, Tomczyk (1962*a*, *b*) and Tomczykowa and Tomczyk (1981) documented the graptolite biozones which for the lower part of the Silurian agrees with the first generalised Silurian graptolite zonation created by Teller (1969) for the area of Poland.

Our study of the graptolite fauna focuses on the biodiversity of the graptolite assemblages, their occurrence, stratigraphic range and associations (Fig. 3), from around Ordovician/Silurian boundary in the Bardo Stawy section.

First graptolites appear in sample BS. 4 (Fig. 3) 20 cm below the typical dark, clayey “graptolite shales”.

The preservation of the graptolites depends on lithology but they are generally poorly preserved, especially those occurring in the lowermost part of the succession in the silty to sandy claystones and shales. They are mostly flattened and preserved as easily weathering carbonised film and “in many cases only thin impressions of the rhabdosomes are seen on the bedding planes” (Koren’ and Bjerreskov, 1997). Preservation in low relief is rare and concerns only the large normalograptids and neodiplograptids with thick, rigid periderm, found mostly in the upper part of the succession.

Close sampling of the 6 m thick interval of the Bardo Stawy section allowed distinction of the *?persculptus*, *ascensus-acuminatus* and *vesiculosus* Biozones.

Stratigraphical distribution of graptolites in Bardo Stawy section is presented on Figure 3.

? *PERSCULPTUS* BIOZONE

The *persculptus* Biozone was first separated as a biostratigraphical unit underlying the *P. acuminatus* Biozone in central Wales by Jones (1909). In our material the lowest graptolites were found in sample BS. 4

The oldest graptolite fauna contains only biserial graptolites, predominately normalograptids. The following graptolite species are recorded from this level: *Normalograptus parvulus* (H. Lapworth) (Figs. 4g, l, q), *N.* cf. *persculptus* (Elles and Wood) (Figs. 4a–c and 7a) a form very close to those described and illustrated by Štorch and Loydell (1996) from Bohemia, *N. miserabilis* (Elles and Wood) (Figs. 4d, f and 7h), *N. avitus* (Davies) (Figs. 4h and 7g) with its distinctive bifurcated virgella, and the long-ranging *N. normalis* (Lapworth) (Figs. 4e, 5b, c and 7b). The thickness of this zone is 20 cm. *N. normalis* and *N. miserabilis* were earlier recorded from the same section, by Kielan (1956) and Tomczyk (1962*a*, *b*), in beds directly overlying the Zalesie Beds but below the shales with *Parakidograptus acuminatus* which were then regarded by Kielan (1956) as equivalent to the *persculptus* Biozone.

The specimens assigned to *N. parvulus* are close to those described by Loydell *et al*. (2002). This species has been recorded from Wales, (Zalasiewicz and Tunnicliff, 1994), from the Schweizer Member in Illinois (Loydell *et al*., 2002) and Arctic Canada (Melchin and Mitchell, 1991) where it has a short stratigraphic range that is restricted to the uppermost Ordovician *persculptus* Biozone or to “one of the two biozones straddling the Ordovician–Silurian boundary” (Loydell *et al*., 2002). Štorch (1983) cited *Diplograptus* (= *Normalograptus*) aff. *parvulus* as one of the earliest *modestus* group diplograptids from Bohemia.

N. avitus probably ranges above *persculptus* Biozone but it was recorded by Williams (1983) from below the *acuminatus* Biozone in Dob’s Linn, by Chen *et al.* (2000) from the *persculptus* Biozone of the Yangtze region and by Zalasiewicz and Tunnicliff (1994) from the upper part of the *persculptus* Biozone. It is thought to be an evolutionary ancestor of akidograptinae (Melchin, 2001). Its presence thus strongly suggests the presence of the *persculptus* Biozone in the Bardo Syncline. *N. avitus* has also been found below the first appearance of akidograptids in the Łeba Elevation boreholes in northern Poland (Podhalańska, 2002, 2003*a*, *b*).

The presence of these graptolites, and the observed absence of *Akidograptus* and *Parakidograptus* in the lowermost graptolitic samples suggests the presence of the *persculptus* Biozone, and thus of latest Ordovician strata. This is in agreement with Kielan (1956) who postulated the presence of the *persculptus* Biozone in the Bardo Stawy section between the Zalesie Beds and the shales with *P. acuminatus*.

ASCENSUS-ACUMINATUS BIOZONE

According to the recommendation of the Ordovician–Silurian Working Group of the I.U.G.S. Commission on Stratigraphy, the boundary between Ordovician and Silurian is placed at the base of the *P. acuminatus* Biozone, marked by the first appearance of *Akidograptus ascensus* Davies and *Parakidograptus acuminatus s.l.* in Dob’s Linn, Scotland (Cocks, 1985; Williams, 1988) and according to the Generalised Graptolite Zonation (GGZ) the *acuminatus* Biozone is defined as a range zone (Koren’ *et al*., 1996).

In many parts of the world a distinct interval with abundant *A. ascensus* occurs below the first appearance of *P. acuminatus*. This stratigraphic interval is often recognised as a separate but not, at present, formal *ascensus* Biozone or *ascensus-acuminatus* biozone (Štorch, 1986; Koren’ and Rickards, 1996; Štorch and Loydell, 1996; Rong *et al*., 1999; Chen *et al*., 2000; Melchin and Williams, 2000; Melchin, 2001). It should be stressed that this agrees with the graptolite zonation of Teller (1969, 1988) who distinguished two separate

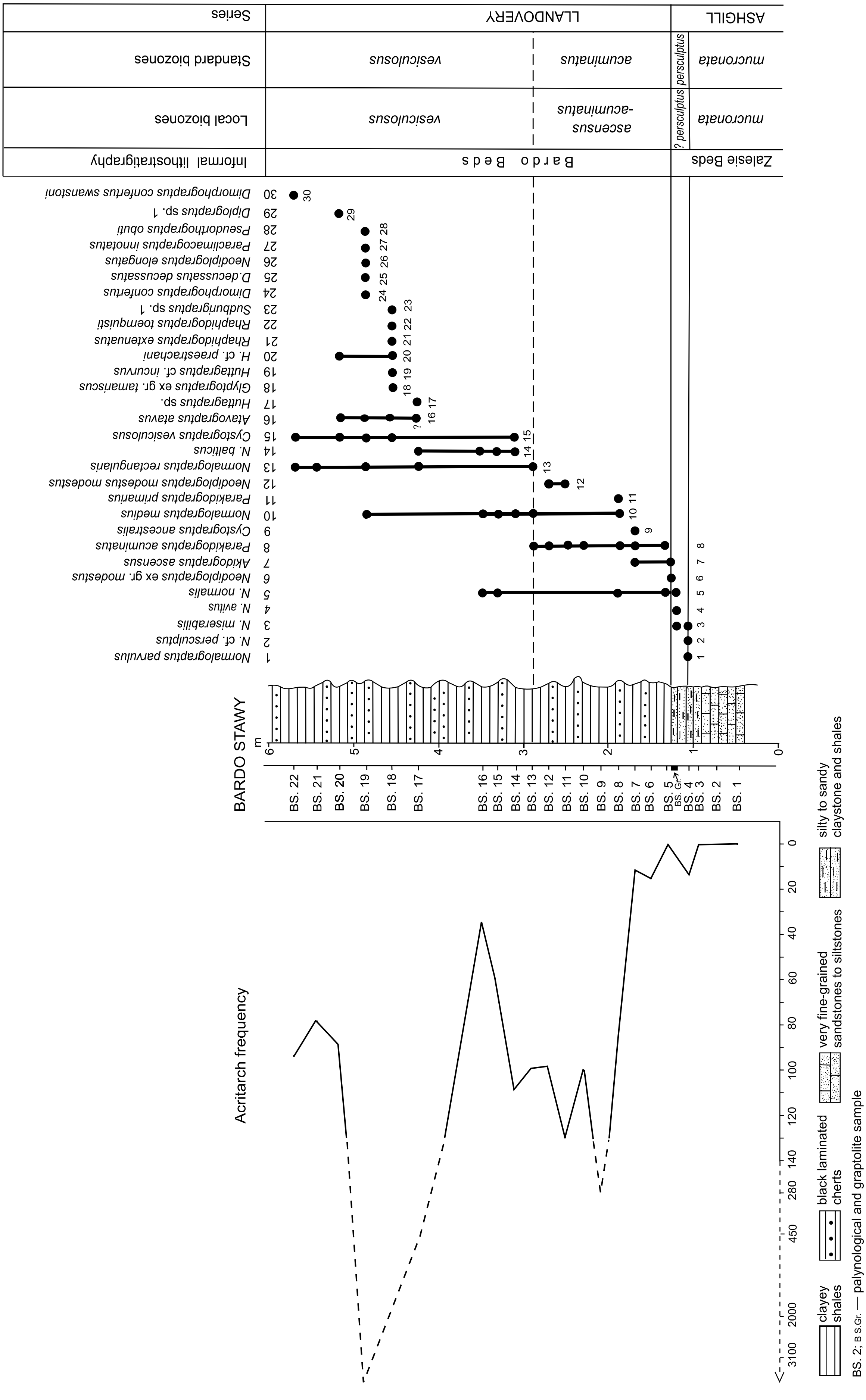

Fig. 3. Lithology and range chart of the graptolites together with acritarch frequency in the Bardo Stawy outcrop

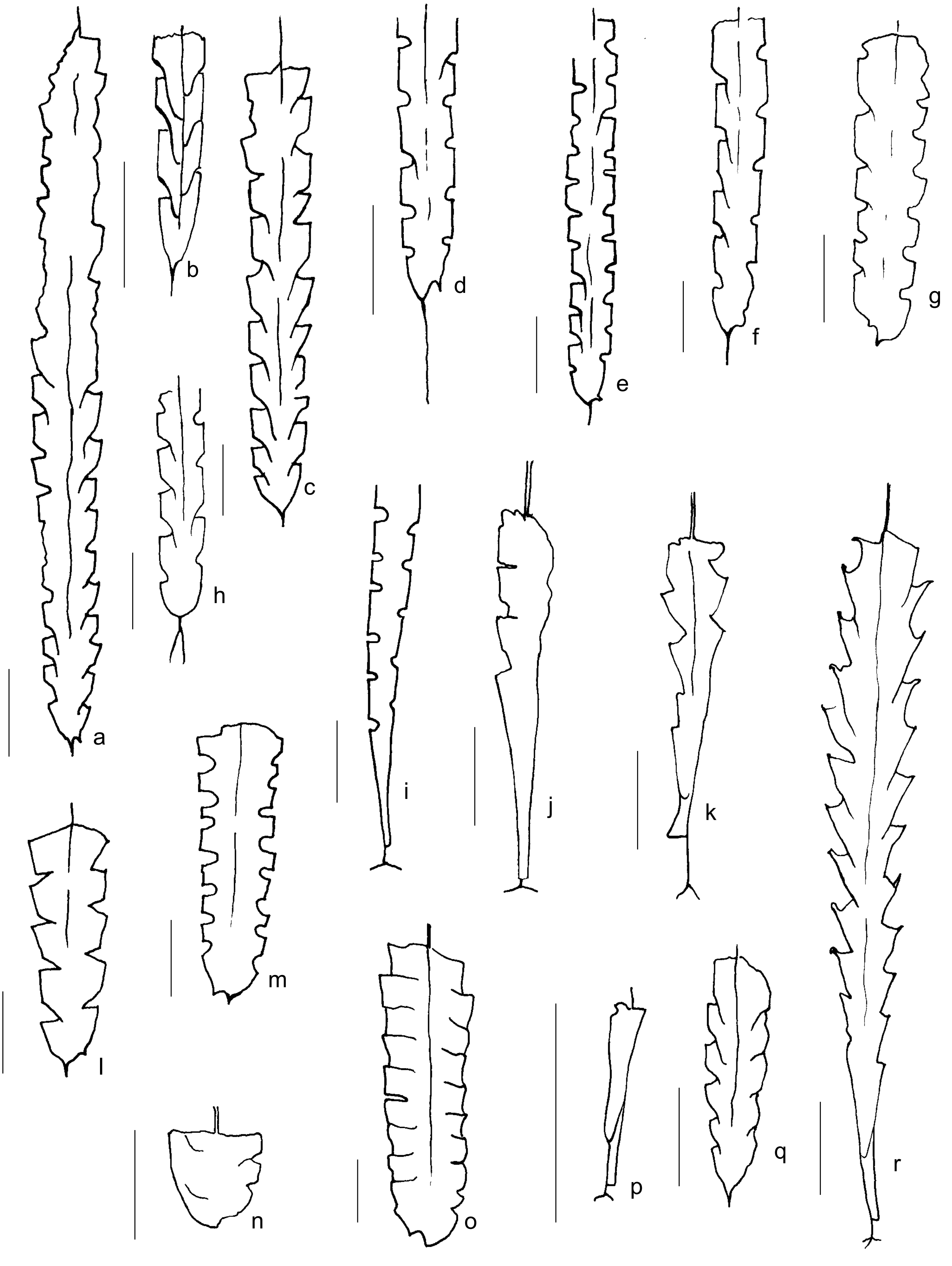

Fig. 4. **a**–**c** — *Normalograptus* cf. *persculptus* (Elles and Wood), sample BS. 4: **a**, **c** — flattened specimens, **b** — specimen in half relief, lateral view; **d**, **f** — *Normalograptus miserabilis* (Elles and Wood), sample BS. Gr.; **e** — *Normalograptus normalis* (Lapworth), sample BS. 5; **g**, **l**, **q** — *Normalograptus parvulus* (H. Lapworth), sample BS. 4, **q** — form in half relief; **h** — *Normalograptus avitus* (Davies), sample BS. Gr.; **i**, **j**, **p** — *Akidograptus ascensus* Davies: **i**, **p** — sample BS. 5, **p** — juvenile form, **j** — sample BS. 7, compressed specimen, lateral view; **k** — *Parakidograptus primarius* Li, sample BS. 8; **m** — *Neodiplograptus modestus modestus* (Lapworth), sample BS. 11; **n**, **o** — *Cystograptus ancestralis* Štorch, sample BS. 7: **n** — juvenile form, **o** — adult form; **r** — *Parakidograptus acuminatus* (Nicholson), sample BS. 5; bar scales for Figures 4–8 are 2 mm

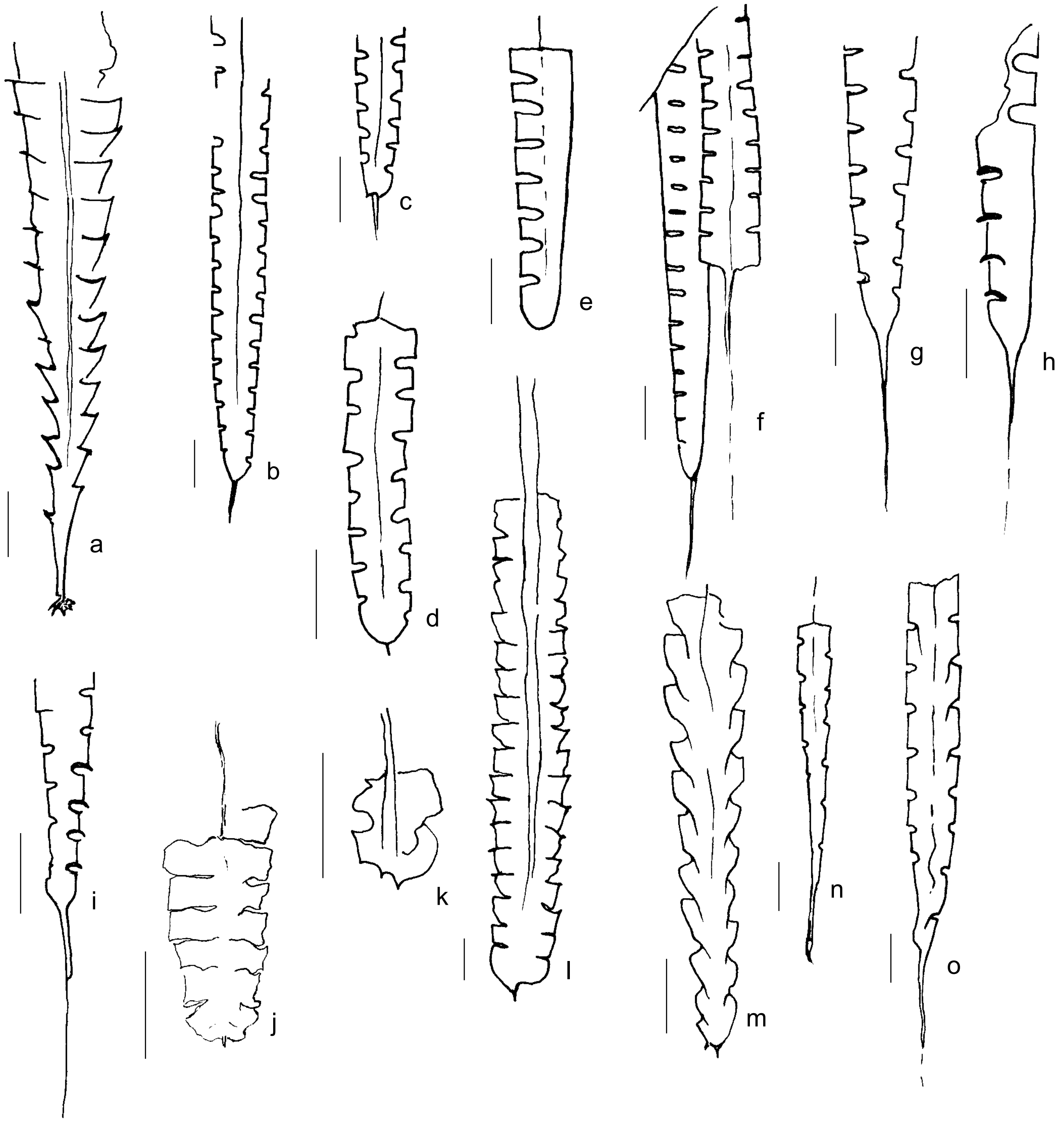

Fig. 5. **a** — *Parakidograptus acuminatus* (Nicholson), sample BS. 8, slightly curved form with root-like virgella; **b**, **c** — *Normalograptus normalis* (Lapworth), sample BS. 15; **d**, **e** — *Normalograptus medius* (Törnquist), sample BS. 16; **f** — *Normalograptus rectangularis* (M'Coy), sample BS. 22; **g**–**i** — *Normalograptus balticus* (Pedersen), sample BS. 17: **g** — flattened specimen, **h**, **i** — forms in half-relief with characteristically thickened aperture rims and very stout virgella; **j**–**l** — *Cystograptus vesiculosus* (Nicholson): **j** — sample BS.18, with only a few pairs of thecae, **k** — sample BS. 20, early astogenic stage, **l** — well preserved adult form with nematularium; **m** — *Glyptograptus* ex gr. *tamariscus,* sample BS. 18; **n** — *Rhaphidograptus extenuatus* (Elles and Wood), sample BS. 18, poorly preserved gracile rhabdosome; **o** — *Rhaphidograptus toernquisti* (Elles and Wood), sample BS. 18, reverse side with slightly undulating median septum; other explanations see Figure 4

biozones: *ascensus* and *acuminatus,* as the lowermost Silurian biozones in Poland.

In the Bardo Stawy section, the abundance and diversity of graptolites clearly increase in this interval. Poorly preserved specimens, seemingly juvenile *A. ascensus* (Fig. 4p), together with other, undetermined juvenile graptolites appear in the lower part of sample BS. 5, in beige intercalations still occurring between the dark shales. This level is slightly below that of the appearance of *Parakidograptus acuminatus*. At the same level, the Early Silurian *Neodiplograptus* ex gr. *modestus* appears. On this evidence it is not reasonable to distinguish a separate *ascensus* Biozone, and thus an *ascensus-acuminatus* biozone has been distinguished in the Bardo Stawy section. It is the equivalent of the entire standard *acuminatus* Biozone deter-

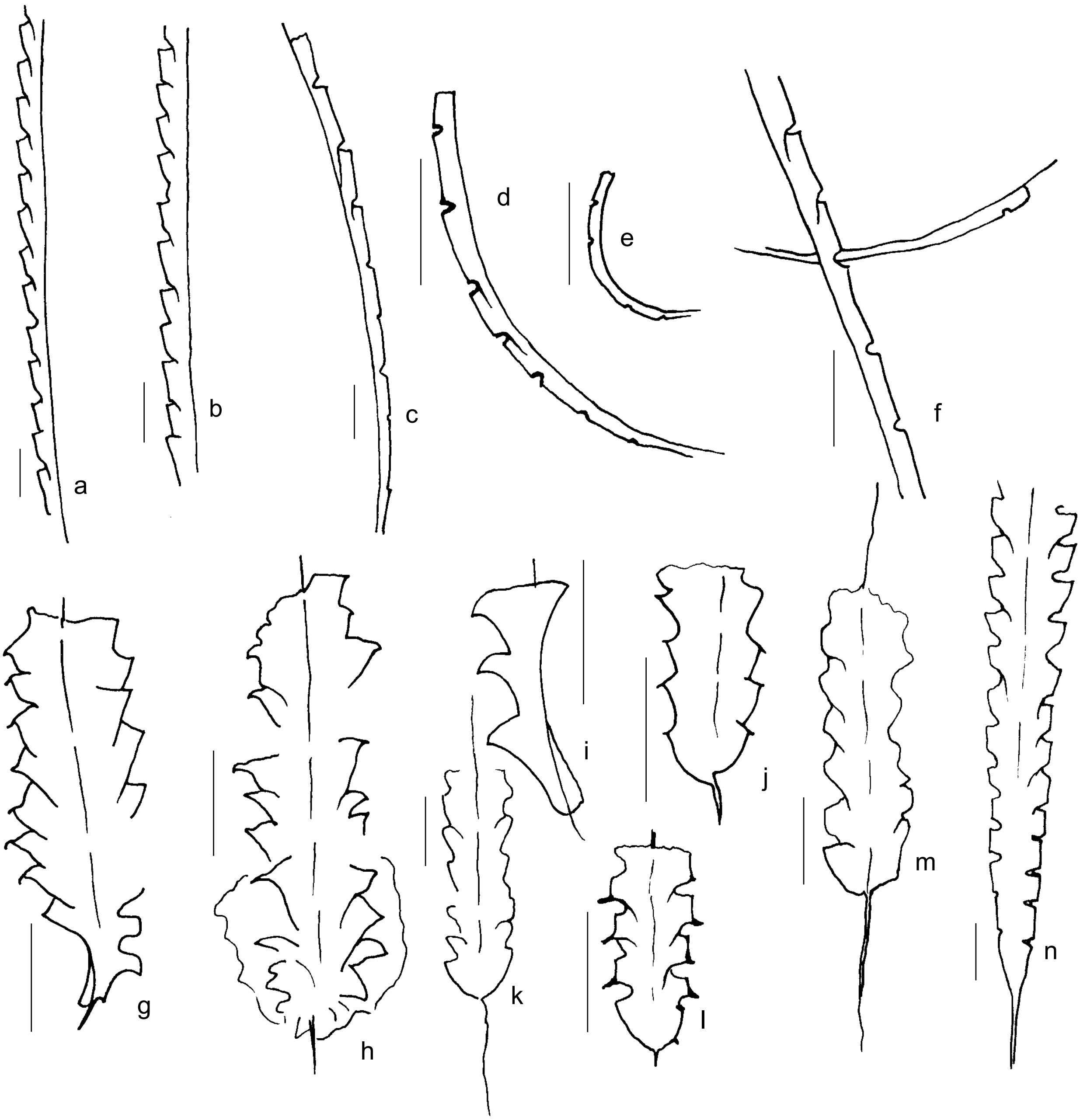

Fig. 6. **a**, **b** — *Atavograptus atavus* (Jones): **a** — sample BS. 18, **b** — sample BS. 19; **c**, **f** — *Huttagraptus* cf. *praestrachani* (Hutt and Rickards), sample BS. 18; **d**, **e** — *Huttagraptus* cf. *incurvus* Koren' and Bjerreskov, sample BS. 18; **g** — *Dimorphograptus decussatus decussatus* (Lapworth), sample BS. 19; **h** — *Pseudorthograptus obuti* (Rickards and Koren'), adult rhabdosome with preserved ?membranous tissue, sample BS. 19; **i** — *Dimorphograptus confertus* (Nicholson), proximal fragment, sample BS. 19; **j** — *Sudburigraptus* sp. 1, sample BS. 18; **k**, **m** — *Diplograptus* sp. 1, sample BS. 20; **l** — *Paraclimacograptus innotatus* (Nicholson), sample BS. 19; **n** — *Neodiplograptus elongatus* Churkin and Carter, sample BS. 19; other explanations see Figure 4

mined in the GGZ as the lowermost Silurian graptolite biozone and its lower boundary here represents the system boundary.

Thus, the lowermost Llandovery is represented here by a graptolite assemblage typical of the standard *acuminatus* Biozone. The base of the zone is defined by the incoming of *Akidograptus ascensus* (Figs. 4i, j and 7i). *Parakidograptus acuminatus* (Figs. 4r, 5a and 7c) appears slightly higher. *A. ascensus* disappears in the sample BS. 7, considerably earlier than does *P. acuminatus* (comp. Fig. 3).

Besides the index forms *Parakidograptus primarius* Li (Figs. 4k and 7d) has been recorded in Poland for the first time.

Other species present are: *Cystograptus ancestralis* Štorch (Figs. 4n, o and 8f), *Normalograptus normalis*, *N. medius* (Törnquist) (Fig. 5d, e) and, in the upper part of the biozone, *Neodiplograptus modestus modestus* Lapworth (Fig. 4m) and *Normalograptus rectangularis* (McCoy) (Figs. 5f and 8d).

The graptolite assemblage found in this biozone in the Bardo Stawy is similar to the assemblage known from Łeba El-

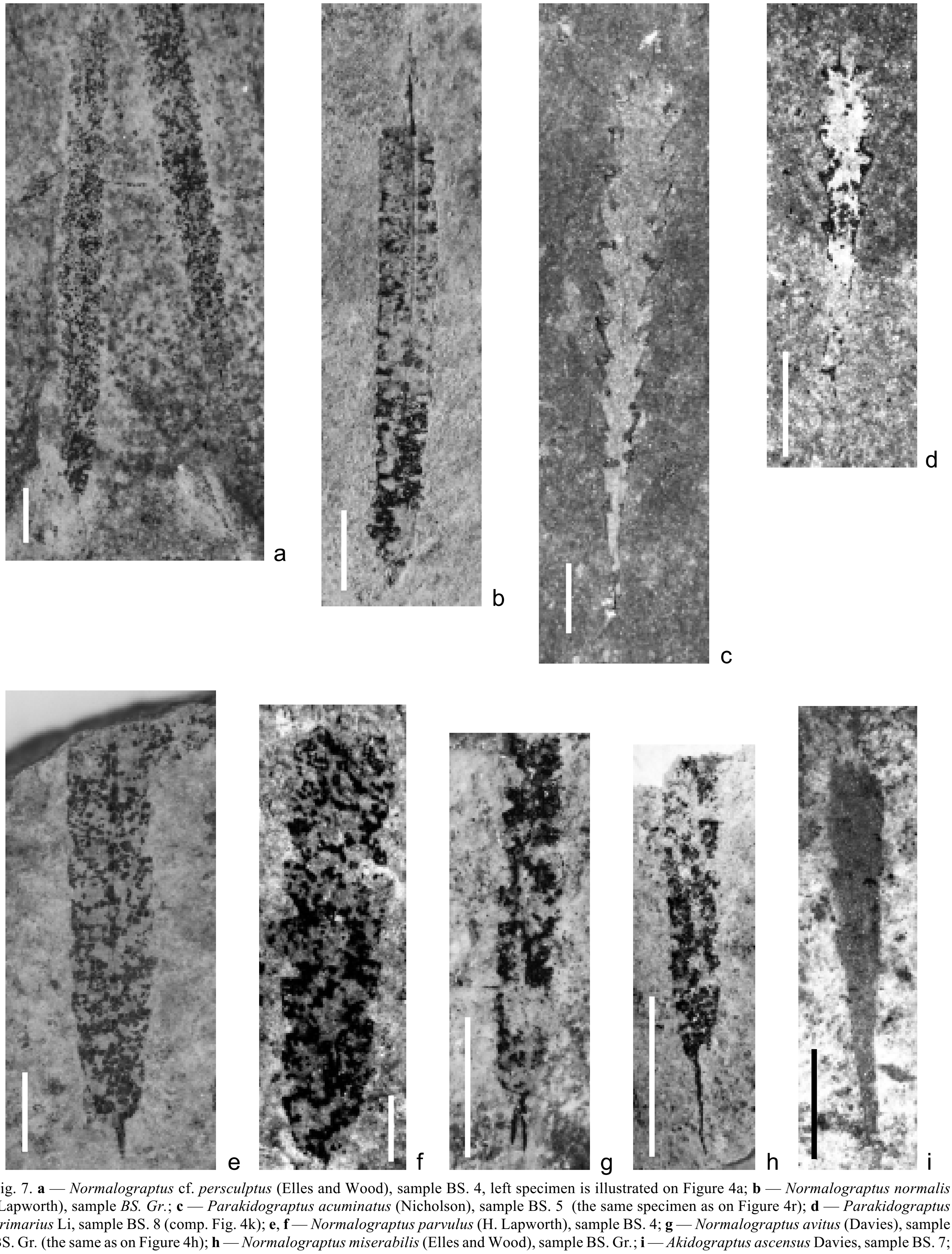

Fig. 7. **a** — *Normalograptus* cf. *persculptus* (Elles and Wood), sample BS. 4, left specimen is illustrated on Figure 4a; **b** — *Normalograptus normalis* (Lapworth), sample *BS. Gr.*; **c** — *Parakidograptus acuminatus* (Nicholson), sample BS. 5 (the same specimen as on Figure 4r); **d** — *Parakidograptus primarius* Li, sample BS. 8 (comp. Fig. 4k); **e**, **f** — *Normalograptus parvulus* (H. Lapworth), sample BS. 4; **g** — *Normalograptus avitus* (Davies), sample BS. Gr. (the same as on Figure 4h); **h** — *Normalograptus miserabilis* (Elles and Wood), sample BS. Gr.; **i** — *Akidograptus ascensus* Davies, sample BS. 7; other explanations see Figure 4

evation, northern Poland (Podhalańska 1980, 1999, 2002, 2003*a*) besides *C. ancestralis* and *P. primarius* which are recorded from Poland for the first time as well as *Normalograptus trifilis* Manck, which is common in the lower Rhuddanian of northern Poland but has not been found in Bardo Syncline.

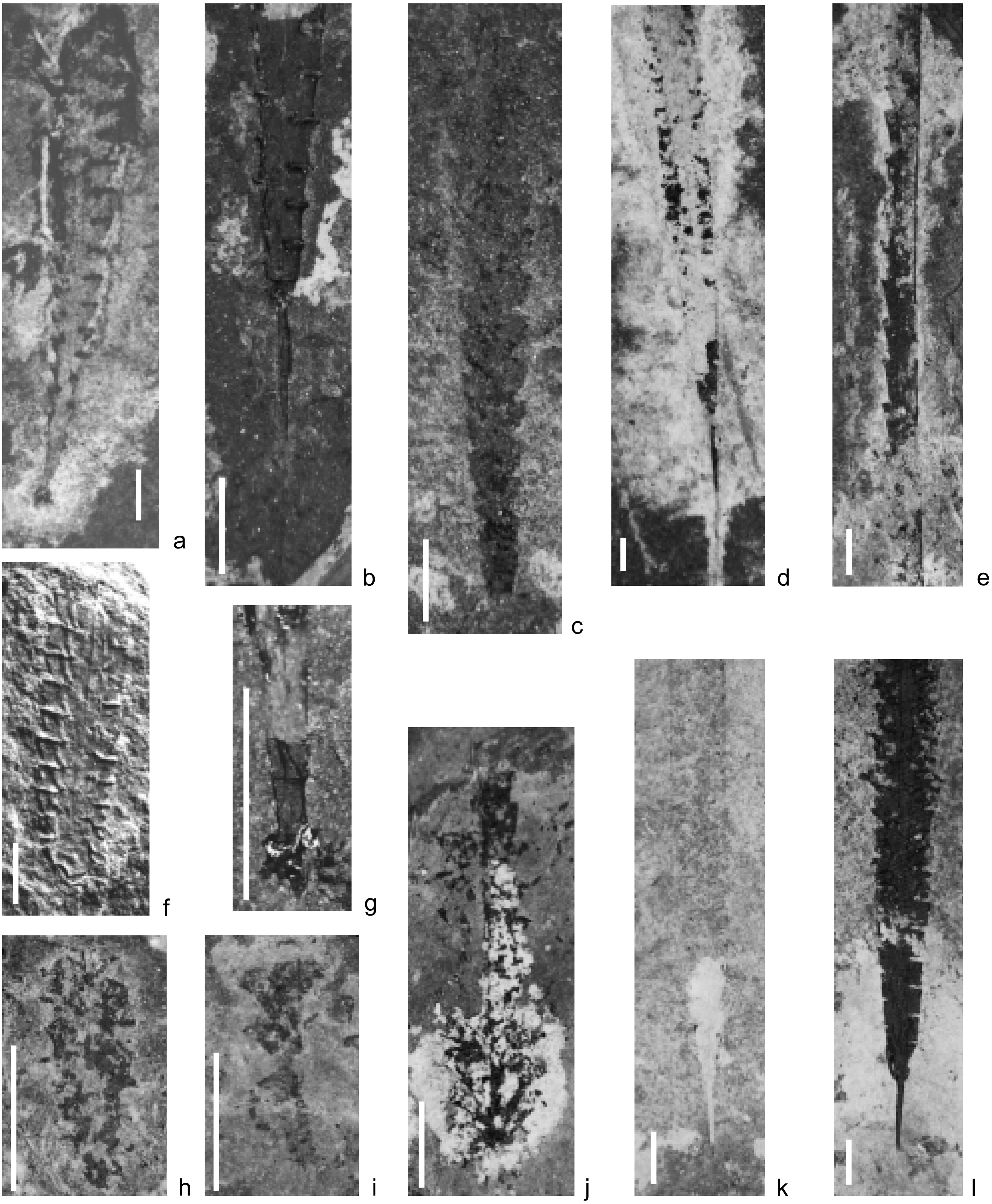

Fig. 8. **a**, **g** — *Parakidograptus acuminatus* (Nicholson), sample BS. 8: **a** — evolutionary younger, adult form with root-like virgellar structure, **g** — virgellar structure in detail; **b** — *Normalograptus balticus* (Pedersen), sample BS. 17, form with a stout virgella and thickened aperture rims; **c** — *Glyptograptus* ex gr. *tamariscus,* sample BS. 18; **d** — *Normalograptus rectangularis* (M'Coy), sample BS. 17; **e** — *Atavograptus atavus* (Jones), sample BS. 18; **f** — *Cystograptus ancestralis* Štorch, adult form, sample BS. 7; **h** — *Paraclimacograptus innotatus* (Nicholson), sample BS. 19; **i** — *Dimorphograptus confertus* (Nicholson), sample BS. 19, proximal part, the same specimen as on Figure 6i; **j** — *Pseudorthograptus obuti* (Rickards and Koren'), adult rhabdosome, sample BS. 19; **k** — *Rhaphidograptus toernquisti* (Elles and Wood), reverse side with slightly undulating median septum, sample BS. 18; **l** — *Neodiplograptus* cf. *elongatus* Churkin and Carter, sample BS. 19; other explanations see Figure 4

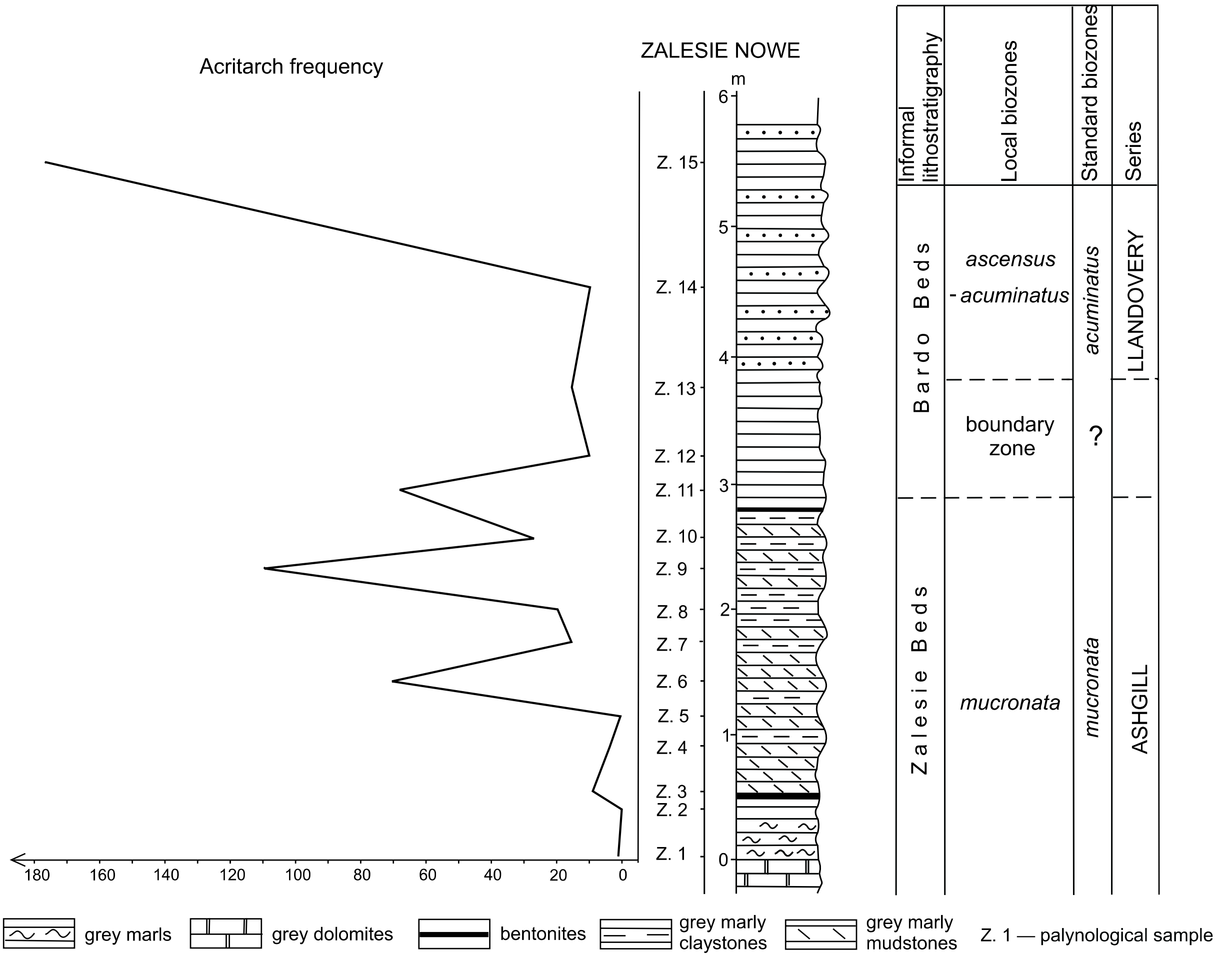

Fig. 9. Lithology and acritarch frequency in the Zalesie Nowe outcrop

For other explanations see Figure 3

VESICULOSUS BIOZONE

According to the General Graptolite Zonation, the *vesiculosus* Biozone is a partial-range zone (Koren' *et al*., 1996). In the Bardo Syncline, the lowest occurrence of *Cystograptus vesiculosus* (Nicholson) is in sample BS. 14, which succeeds sample BS. 13 with the last *P. acuminatus*. The lowermost part of the zone (samples BS. 14, BS. 15 and BS. 16) is characterised mainly by a normalograptid fauna. *C. vesiculosus* is, in most cases, represented by juvenile specimens (Fig. 5j, k) while mature rhabdosomes are rare (Fig. 5l). The dominant elements of the associations are long-ranging, robust normalograptid species: *N. normalis*, *N. medius, N. rectangularis* and *N. balticus* (Pedersen) (Figs. 5g–i and 8b).

From the level BS. 17, the number and diversity of graptolites increase. In sample BS. 17, the monograptids appear for the first time, but they are rare and badly preserved. They may belong to the new genus *Huttagraptus* erected by Koren' and Bjerreskov (1997) on the base of graptolite material from Bornholm and Ural. *Huttagraptus* includes such species as *gracilis* (Hutt), *praestrachani* (Hutt and Rickards), *strachani* (Hutt and Rickards) (formerly *Atavograptus*) as well as *acinaces* (Törnquist) (formerly *Lagarograptus*) and some new species.

The most diverse and numerous monograptid fauna has been found in sample BS. 18. It comprises *Huttagraptus* sp., *Huttagraptus* cf. *incurvus* Koren' and Bjerreskov (Fig. 6d, e), *H.* cf. *praestrachani* (Fig. 6c, f) together with numerous and well preserved *Atavograptus atavus* (Jones) (Figs. 6a, b and 8e).

The succession of graptolites of the *vesiculosus* Biozone including the oldest monograptids in the Bardo Syncline is very similar to the succession known from the stratigraphical interval between the top of the *acuminatus* Biozone and the base of the *cyphus* Biozone in Bornholm, Great Britain and Bohemia (Toghill, 1968; Rickards, 1970, 1976; Bjerreskov, 1975; Hutt, 1975; Štorch, 1988, 1994; Zalasiewicz and Tunnicliff, 1994; Koren' and Bjerreskov, 1997).

The most diverse and abundant graptolite fauna has been found in samples BS. 18 and BS. 19. In addition to long-ranging normalograptids and monograptids, *Dimorphograptus decussatus decussatus* Lapworth (Fig. 6g), *Dimorphograptus confertus* (Nicholson) (Figs. 6i and 8i), *Paraclimacograptus innotatus* (Nicholson) (Figs. 6l and 8h), *Pseudorthograptus obuti* (Rickards and Koren') (Figs. 6h and 8j), *Rhaphidograptus extenuatus* (Elles and Wood) (Fig. 5n), *R. toernquisti* (Elles and Wood) (Figs. 5o and 8k) and *Neodiplograptus elongatus* Churkin and Carter (Fig. 6n) have

Table 1

Acritarchs from the Zalesie Nowe outcrop

List of species in Zalesie Nowe	Sample number														
	Z. 1	Z. 2	Z. 3	Z. 4	Z. 5	Z. 6	Z. 7	Z. 8	Z. 9	Z. 10	Z. 11	Z. 12	Z. 13	Z. 14	Z. 15
Navifusa sp. A			x	x											x
Baltisphaeridium sp.						x	x	x	x	x	x				
Goniosphaeridium sp.						x	x	x	x	x	x				
Diexallophasis remota (Deunff) Playford, 1977						x	x	x	x	x					x
Micrhystridium sp.						x	x	x	x	x	x	x		x	x
Ordovicidium sp.						x									
Veryhachium sp.						x	x	x	x	x	x	x	x		x
Villosacapsula cf. *irrorata* (Loeblich and Tappan) Fensom*et al.*, 1990						x		x							
Polygonium sp.							x	x	x	x					
Multiplicisphaeridum sp.								x	x	x	x	x			x
Gorgonisphaeridium sp.									x	x	x	x	x		
Veryhachium cf. *reductum* (Deunff) Downie and Sarjeant, 1965									x		x				
Diexallophasis sp.										x					x
Acanthodiacrodium sp.											x				
? Acanthodiacrodium sp.											x				
Veryhachium cf. *lairdi* (Deflandre) Deunff, 1954 ex Loeblich, 1970											x				
Veryhachium cf. *hamii* Loeblich, 1970												x			
Multiplicisphaeridum lobeznum (Cramer) Eisenack, Cramer and Diez, 1973														x	
Salopidium wenlockensis (Downie) Dorning, 1981														x	x
Ammonidium sp.															x
Evittia robustospinosa (Downie) Le Hérissé, 1989															x
Tylotopalla caelamenicutis Loeblich, 1970															x
T. deerlijkianum (Martin) Martin, 1978															x
T. guapa (Cramer) Eisenack, Cramer and Diez, 1973															x
Tylotopalla sp.															x

been found. In the upper part of the investigated section a few specimens of *Diplograptus* sp. 1 have been found (Fig. 6k, m).

MICROPHYTOPLANKTON

ZALESIE NOWE

Ten samples (Z. 1–Z. 10) representing the *mucronata* Biozone have been examined (Fig. 9). Seven of them yielded acritarchs. The preservation of the particular taxa is poor, hence many are determined to generic level only or left in open nomenclature. However, several forms can be recognised precisely. In sample Z. 6, *Baltisphaeridium* sp. and *Ordovicidium* sp. with wide and long processes appear, which are characteristic of the Late Ordovician. They are accompanied by long-ranging taxa of simple morphology such as *Micrhystridium* sp., *Veryhachium* sp. Other widespread taxa such as *Goniosphaeridium* sp., *Gorgonisphaeridium* sp., *Diexallophasis* sp., *Multiplicisphaeridium* sp. and *Polygonium* sp. occur in samples Z. 6 to Z. 10.

Specimens of *Veryhachium* cf. *reductum*, *Diexallophasis remota* and *Villosacapsula* cf. *irrorata* were also found at this level. Generally the acritarch frequency is rather low being up to 30 acritarchs per slide. Only in two samples (Z. 6 and Z. 9) is frequency higher: from 70–110 specimens.

Samples from Z. 11 to Z. 13 (Fig. 9) come from the Ordovician–Silurian boundary interval, which was distinguished on the basis of lithology and graptolites (Czarnocki, 1928; Kremer, 2001) and acritarch frequency (this paper). It is not possible to determine exactly the position of this boundary. The acritarch assemblages from this interval are even less diverse than those from the *mucronata* Biozone. Long ranging taxa are dominant, such as: *Micrhystridium* sp., *Multiplicisphaeridium* sp., *Gorgonisphaeridium* sp. and *Veryhachium* cf. *hamii*, *V.* cf. *lairdi*, *Veryhachium* sp. Only two distinctive forms — *Acanthodiacrodium* sp. and *Baltisphaeridium* sp. were found in this zone. Acritarch frequency in the boundary zone varies, but generally falls from 68 (sample Z. 11) to 16 specimens (sample Z. 13) per slide.

The first sample from the Silurian (the lower part of the *ascensus-acuminatus* biozone — sample Z. 14) still yields low-diversity and sparse acritarch assemblages. There are only 10 specimens per slide. They belong to *Ammonidium* sp., *Micrhystridium* sp. and *Multiplicisphaeridium lobeznum*. The acritarchs are thin, pale and small.

The next sample (Z. 15) that comes from the Silurian deposits (about 1.5 m above the upper limit of the O/S boundary zone) yielded a rich and diverse assemblage. There are more than 170 specimens per sample. The first appearance of *Tylotopalla* was observed. All species are listed in the Table 1 some of them are presented on Figure 10.

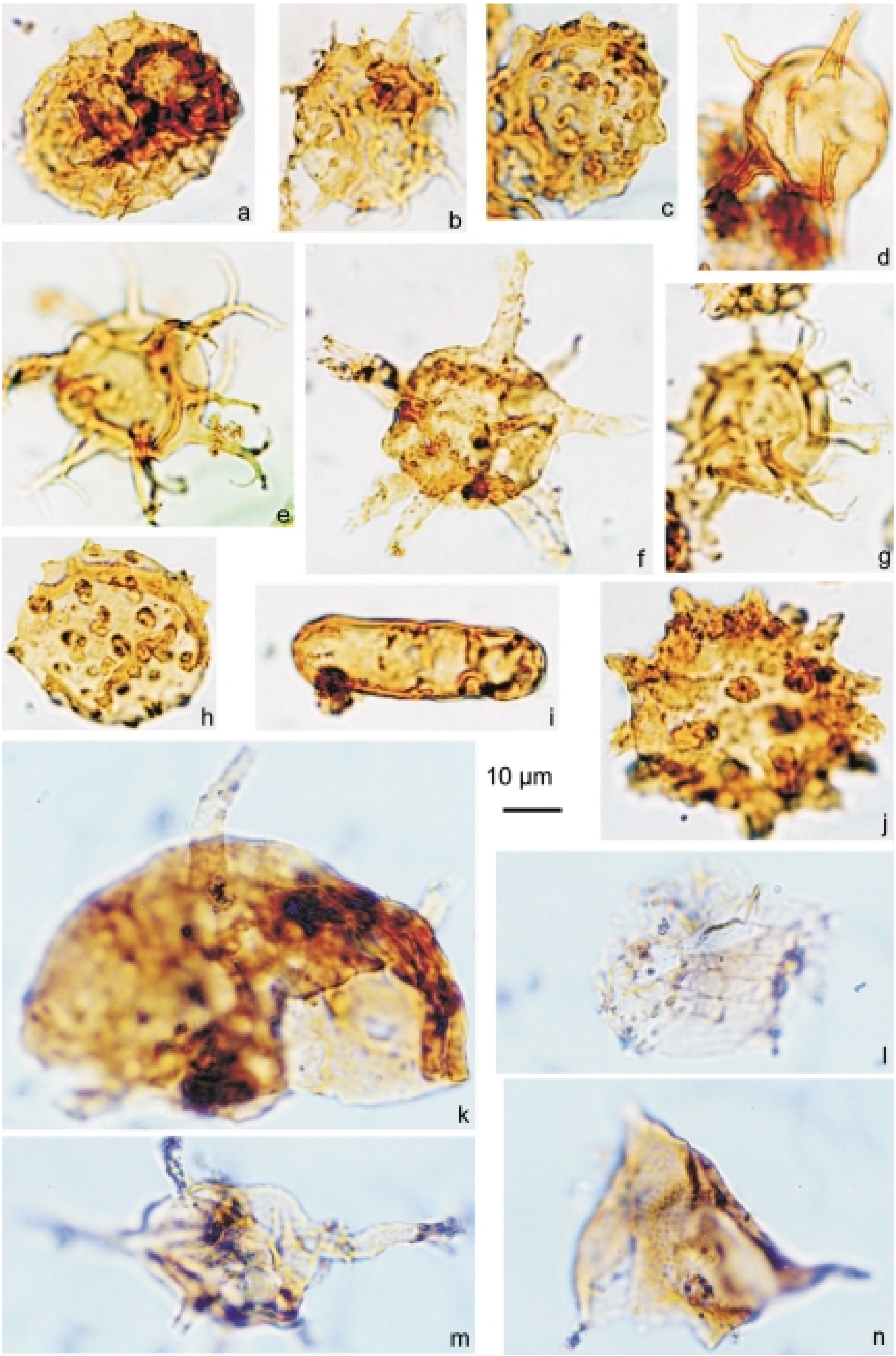

Fig. 10. Acritarchs from the Bardo Syncline

a — *Dictyotidium dictyotum*, sample BS. 11; **b** — *Ammonidium* sp., sample BS. 12; **c** — *Buedingiisphaeridium lunatum*, sample BS. 11; **d** — *Leprotolypa gordonense*, sample BS. 16; **e** — *Multiplicisphaeridium monki*, sample BS. 11; **f** — *Diexallophasis sanpetrensis*, sample BS. 11; **g** — *Multiplicisphaeridium mingusi*, sample BS. 11; **h** — *Tylotopalla deerlijkianum*, sample BS. 11; **i** — *Navifusa* sp. A, sample BS. 11; **j** — *Tylotopalla caelamenicutis*, sample BS. 22; **k** — *Baltisphaeridium* sp., sample Z. 6; **l** — *Acanthodiacrodium* sp., sample Z. 6; **m** — *Diexallophasis* sp., sample Z. 6; **n** — *Villosacapsula* cf. *irrorata*, sample Z. 6; specimens 1–10 are from the Bardo Stawy (Silurian) and 11–14 from the Zalesie Nowe outcrops (Ordovician)

Table 2

Acritarchs and prasinophytes from the Bardo Stawy outcrop

List of species in Bardo Stawy	Sample number																					
	BS. 1	BS. 2	BS. 3	BS. 4	BS. 5	BS. 6	BS. 7	BS. 8	BS. 9	BS. 10	BS. 11	BS. 12	BS. 13	BS. 14	BS. 15	BS. 16	BS. 17	BS. 18	BS. 19	BS. 20	BS. 21	BS. 22
Micrhystridium sp.		x	x	x		x		x	x	x	x		x	x	x		x	x	x	x	x	x
Multiplicisphaeridium sp.		x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Polygonium sp.		x	x																			
Veryhachium sp.		x	x	x				x	x	x		x	x				x	x	x	x		x
Acanthodiacrodium sp.				x																		
Orthosphaeridium sp.				x																		
Ammonidium sp. A						x			x	x	x	x	x	x				x				
Elektoriskos pogonius Loeblich 1970						x		x			x											
Navifusa sp. A						x		x	x	x	x	x	x	x	x		x	x	x	x	x	
Ammonidium microcladum (Downie) Dorning, 1981							x	x	x		x		x	x	x			x	x			x
Diexallophasis tappana (Kiryanov) Wicander, 1986							x	x		x	x	x		x	x		x	x		x		x
Elektoriskos brevispinosum (Lister) Vanguestine, 1979							x		x													x
Elektoriskos sp.							x	x								x	x	x	x	x		
Ammonidium sp.								x				x	x	x	x		x	x				
Micrhystridium inflatum (Downie) Lister 1970								x		x	x											
Multiplicisphaeridium cladum (Downie) Eisenack, 1969								x			x	x		x	x						x	
M.imitatum (Deflandre) Lister, 1970								x	x	x			x	x	x		x	x	x	x	x	x
M. lobeznum (Cramer) Eisenack, Cramer and Diez, 1973								x			x	x	x			x					x	
M. mingusi Le Hérissé, 1989								x	x	x	x	x	x	x	x	x	x	x		x		
Salopidium sp.								x		x					x	x						x
Tylotopalla caelamenicutis Loeblich, 1970								x	x	x	x	x	x	x	x		x	x	x	x	x	x
T. guapa (Cramer) Eisenack, Cramer and Diez, 1973								x	x		x	x										x
Veryhachium valiente Cramer, 1964								x			x	x	x	x	x	x		x	x			
Diexallophasis sanpetrensis (Cramer) Dorning, 1981									x	x	x	x	x	x			x	x				x
Evittia robustospinosa (Downie) Le Hérissé									x								x					
Multiplicisphaeridium monki Le Hérissé, 1989									x	x	x	x				x	x		x			
M. pardaminum Diez and Cramer, 1976									x		x											
M. variabile (Lister) Dorning, 1981									x			x	x	x	x		x	x	x		x	x
Tylotopalla deerlijkianum (Martin) Martin, 1978									x	x	x		x						x			x
Tylotopalla sp.									x	x							x					
Veryhachium trispinosum (Eisenack) Stockmans and Willière, 1962									x		x		x		x							
Buedingiisphaeridium sp.										x												
Diexallophasis sp.										x		x	x	x	x		x	x		x	x	x
Buedingiisphaeridium lunatum Le Hérissé, 1989											x	x										
Gorgonisphaeridium sp.											x					x						
Lophosphaeridium parverarum Stockmans and Willière 1963											x											
Veryhachium trapezionarion Loeblich, 1970											x											
Elektoriskos aurora Loeblich, 1970												x									x	
Glyptosphaera speciosa Kiryanov, 1978												x	x	x								
Gorgonisphaeridium cf. *succinum* Lister, 1970												x					x					
Micrhystridium radians Stockmans and Willière, 1963												x			x	x						
Multplicisphaeridium illinoi (Cramer and Diez) Eisenack, Cramer and Diez, 1973												x										
M. mergaeferum Loeblich, 1970														x							x	
Dictyotidium dictyotum (Eisenack) Eisenack, 1955															x		x	x	x	x		
Domasia limaciforme (Stockmans and Willière) Cramer, 1970																x						
Leprotolypa gordonense (Cramer) Colbah, 1979																x						
*Pterospermella*sp.																	x					
Multiplicisphaeridium paraguaferum Cramer) Lister,1970																	x		x			
M. raspum (Cramer) Eisenack, Cramer and Diez, 1973																	x	x	x			
Cymatiosphaera sp.																		x	x			
Micrhystridium stellatum Deflandre, 1945																				x		
Diexallophasis remota (Deunff) Playford, 1977																						x

BARDO STAWY

Four samples from the Ordovician strata of the Bardo Stawy section have been taken. The distribution of taxa in the samples studied is shown in Table 2.

No acritarchs have been found in the *mucronata* Biozone (samples BS. 1, BS. 2 and BS. 3) but occasionally some *Leiosphaeridia* occur. One sample (BS. 4) belonging to the lowermost part of the ?p*ersculptus* Biozone, has been examined. The acritarch assemblage found in this sample is poorly preserved and of low diversity, and the specimens have been recognised only at genus level. The assemblage includes *Acanthodiacrodium* sp., *Orthospaeridium* sp. and long-ranging taxa such us *Micrhystridium* sp., *Veryhachium* sp., *Multiplicisphaeridium* sp. Acritarch frequency in the *?persculptus* Biozone is generally low (18 acritarchs per slide).

The lowest sample (BS. 5) taken from the basal Silurian, the lowermost part of the *ascensus-acuminatus* biozone, did not contain any organic matter. The next sample, BS. 6 yielded a very poor acritarch assemblage with simple forms (similar to those that occur in the latest Ordovician): *Micrhystridium* sp. and *Multiplicisphaeridium* sp. (small specimens) and some new taxa as *Ammonidium* sp. A, *Navifusa* sp. A and *Elektoriskos pogonius*. The very rare specimens of those genera are thin, pale and poorly preserved so it is not possible to recognise most of them at species level. The first appearance of new taxa is observed in sample BS. 7 — *Ammonidium microcladum*, *Diexallophasis tappana* and *Elektoriskos brevispinosum*. The abundance of acritarchs at this level is still low: 12 specimens per slide. The first change in diversity and frequency of microphytoplankton follows in sample BS. 8, taken 0.65 m above the base of the *ascensus-acuminatus* biozon *Micrhystridium inflatum*, *Multiplicisphaeridium cladum*, *M. imitatum*, *M. lobeznum*, *M. mingusi*, *Salopidium* sp., *Tylotopalla cae. The assemblage is more diverse and several species appear:elamenicutis*, *T. guapa* and *Veryhachium valiente*. The frequency of acritarchs is much higher than at the base of the *ascensus-acuminatus* biozone — BS. 5 contains no acritarchs whereas BS. 8 contains 85 per slide at the base of *ascensus-acuminatus* biozone.

The very significant change in microphytoplankton frequency occurs 0.85 m above the base of the Silurian (sample BS. 9). There are more than 280 specimens per slide (in contrast with 10–15 specimens in samples, taken from the lowermost part of the *ascensus-acuminatus* biozone. The diversity of the assemblage also increases: *Diexallophasis sanpetrensis*, *Evittia robustospinosa, Multiplicisphaeridium monki*, *M. pardaminium*, *M. variabile*, *Tylotopalla deerlijkianum*, *Veryhachium trispinosum* appear.

After the peak of high frequency within the *ascensus-acuminatus* biozone, the abundance of microphytoplankton decreases to the average of 100 specimens per slide. The diversity of assemblages in the uppermost part of *ascensus-acuminatus* biozone slowly increases. The species *Buedingiisphaeridium lunatum*, *Lophosphaeridium parverarum*, *Veryhachium trapezionarion*, *Elektoriskos aurora*, *Glyptosphaera speciosa*, *Gorgonisphaeridium* cf. *succinum*, *Micrhystridium radians*, *Multiplicisphaeridium illinoi* appear in samples BS. 11 and BS. 12.

In the lowermost part (samples BS. 13 to BS. 16) of the *vesiculosus* Biozone, the abundance of acritarchs decreases slightly to the level of 60–35 specimens per slide (samples BS. 15 and BS. 16), although this is a high diversity level with the appearance of new species: *Multiplicisphaeridium mergaeferum*, *Dictyotidium dictyotum*, *Domasia limacifome* and *Leprotolypa gordonense*, *Multiplicisphaeridium paraguaferum* and *M. raspum.*

1.5 m above the base of the *vesiculosus* Biozone there is an interval (0.50 m) where a second peak in acritarch frequency was noted (samples BS. 17–BS. 19). The assemblages are very rich in specimens (reaching 3000 specimens per slide, while there is no significant change in diversity. The upper part of the *vesiculosus* Biozone (samples BS. 20–BS. 22) is characterised by moderate frequency (average of 80 specimens per slide) and diversity more or less the same as in the upper part of the *ascensus-acuminatus* biozone. Only two new species appear: *Diexallophasis remota* and *Micrhystridium stellatum*.

The frequency analysis of acritarch assemblages helped the tectonic analysis that established the thickness of the deposits in the flexure zone, comprising the uppermost part of *Dalmanitina* Beds and the clayey-siliceous shales transition zone (the O/S boundary interval) in the Bardo Stawy section.

Regionally, a narrow Ordovician/Silurian boundary interval of very low acritarch frequency seems to be present, at Zalesie Nowe (herein), and over the East European Platform (unpublished data).

In the Bardo Stawy outcrop, the section where the dip of the layers is reversed (flexure zone) is probably complete because the interval of very low frequency could be noted. The thickness of the *?persculptus* and *ascensus-acuminatus* biozones seems to be normal.

OTHER FOSSILS

In the part of the profile studied, other fauna and ichnofauna accompany graptolites and acritarchs.

In the ?*persculptus* Biozone we have found no fossils other than low diversity graptolite fauna and poor acritarch assemblage.

In the *ascensus-acuminatus* biozone, a low diversity assemblage of Lower Silurian Chitinozoa comprising *Cyathochitina campanulaeformis* (Eisenack) and *Cyathochitina calix* (Eisenack) has been found, most numerous in samples BS. 8–BS.10, with the maximum abundance in sample BS. 9. Within the *ascensus-acuminatus* biozone there is a 2.6 m thick sequence of grey-brown, but not black, clayey-siliceous shales which probably indicates low oxygen (dysoxic) but not necessary anoxic conditions. A benthic fauna has not been found. The deposits are not strongly bioturbated but a few, probably feeding burrows have been found in the lower part of the shale sequence in samples BS. 5 and BS. 6. The presence of bioturbation in the lowermost Llandovery proves a limited metazoan colonization of the sea floor.

Animal fossils and ichnofauna are more abundant in the *vesiculosus* Biozone. Sample BS. 19 is distinctive due to the abundant graptolites and Chitinozoa, which are seen in great numbers on the rock surfaces together with other fauna, such as inarticulate brachiopods and a few gastropods. The Chitinozoa assemblage is represented mainly by *Conochitina praeproboscifera* Nestor with infrequent *Cyathochitina* sp. The benthic fauna is rather poor but feeding or dwelling burrows are reasonably common in this sample and in higher samples of this interval. Apart from graptolites, fauna is abundant also in lower samples, such as sample BS. 16 in which conodonts and coprolites accompany graptolites on the bedding planes. This may indicate not very restricted and relatively shallow sedimentary conditions in this part of the *vesiculosus* Biozone.

The diversity and abundance of fossils and microfossils, both of benthic and planktonic character as well as ichnofauna throughout the interval studied, especially in the *vesiculosus* Biozone, runs counter to the notion of monotonous "black graptolitic Silurian shales" in the Bardo section.

DISCUSSION

We have observed, in the Bardo Stawy outcrop, that the dip of the clayey-siliceous shales cropping out in a stream floor and in valley escarpments is conformable to the general dip noted in the Bardo Syncline (to the north). The same trends are observed in older deposits (very fine-grained sandstones of the *Dalmanitina* Beds). In the contact zone (shales and sandstones) the dip of the strata changes to the South, and this is probably due to flexure (Stupnicka, pers. comm.).

Bednarczyk and Tomczyk (1981; fig. 15, p. 141) illustrated the sedimentary conformity of the *Dalmanitina* Beds and the clayey-siliceous shales but did not mention this change of dip in the contact zone.

Kielan (1956) distinguished an equivalent of the *persculptus* Biozone in the Bardo Stawy section on the basis of correlation with Sweden where *Climacograptus scalaris normalis (=Normalograptus normalis)* and *C. s. miserabilis* (= *N. miserabilis*) are present directly above the *Dalmanitina* Beds. Our studies show that *N. normalis* co-occurs with *Parakidograptus acuminatus* and *Cystograptus vesiculosus*, so the occurrence of *N. normalis* does not prove the presence of the *persculptus* Biozone. The thickness of the ?*persculptus* Biozone in the Bardo Stawy section reaches 0.20 m. The top of this biozone is marked by the appearance of *Akidograptus ascensus* (juvenile forms) and *P. acuminatus.*

According to Kielan (1956) the equivalent of the *persculptus* Biozone comprises the lower part of the clayey-siliceous shales and extends to the first appearance of *P. acuminatus,* 4 m higher. In sample BS. 20, from a level 4 m above the lithological changes we found a graptolite assemblage comprising *C. vesiculosus, Atavograptus atavus, Huttagraptus praestrachani* and *Diplograptus* sp. 1, indicating a level younger than the *acuminatus* Biozone.

A frequency analysis of the latest Ordovician and the earliest Silurian acritarch assemblages from the Zalesie Nowe section was published by Kremer (2001), who, however, analysed the relative proportions between taxa whereas in this paper we are concerned with absolute frequency, so the results of both papers are not comparable.

CONCLUSIONS

In the Ordovician/Silurian boundary interval in the Bardo Stawy section, there is a conformable and gradual transition from sandy through silty to clayey deposits as well as a gradual change of colour of the rock from light to dark.

The uppermost Ordovician–lowermost Silurian succession indicates a gradual stagnation and progressive oxygen deficiency of the depositional environment related to a deepening of the sea during the post-glacial sea level rise.

The complete succession of the ?*persculptus*, *ascensus-acuminatus* and *vesiculosus* Biozones has been established in the interval investigated in the Bardo Syncline.

The first graptolites from near the boundary zone indicate the ?*persculptus* Biozone of the uppermost Ordovician and appear in beige claystones and shales containing silt to sand-sized quartz grains, preceding the facies change to dark "graptolitic shales".

A Silurian graptolite assemblage indicating the lowermost part of the Llandovery *ascensus-acuminatus* biozone appears in the interval of alternating dark and light laminated shale.

A rich Early Llandovery monograptid assemblage has been identified in the *vesiculosus* Biozone.

The latest Ordovician palynological assemblage (Zalesie Nowe section) includes only long ranging acritarchs, mainly of simple morphology. The acritarch frequency is moderate. At the Ordovician/Silurian boundary in the Zalesie Nowe and the Bardo Stawy sections, a considerable decrease of acritarch frequency was observed. The frequency and diversity increase, in both sections, in the lower part of the *ascensus-acuminatus* biozone.

In the Bardo Stawy section, the maximum acritarch frequency is attained in the lower part of the *vesiculosus* Biozone although the diversity does not change.

The change in acritarch assemblages is not related to lithology. The distinct drop in frequency in the ?*persculptus* and lower part of *ascensus-acuminatus* biozones occurs in the Zalesie Nowe section within the interval of clayey shales, and, in the Bardo Stawy section, it occurs in a gradual change in lithology (from a sandy and silty to a clayey succession).

The decrease in acritarch frequency at the O/S interval in both sections allowed distinction of the boundary zone in the Zalesie Nowe section. This boundary zone involves most probably the ?*persculptus* Biozone and the lowermost part of *ascensus-acuminatus* biozone.

The peak in acritarch frequency noted in the lower part of the *ascensus-acuminatus* biozone coincides with a considerable increase in chitinozoa abundance whereas bioturbation was observed slightly below.

The peak in acritarch frequency noted in the lower part of the *vesiculosus* Biozone coincides with a huge increase in chitinozoa abundance, and the occurrence of bioturbation, brachiopods, and conodonts.

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