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Silurian Chitinozoans and Other Palynomorphs from Quartz Phyllites of the Steinach Nappe (Tyrol, Austria)

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7 Text-Figures, 6 Plates

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Tirol
Steinacher Decke
Silur
Quarzphyllit
Chitinozoen
Palynomorpha

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Silurische Chitinozoen und andere Palynomorpha aus Quarzphylliten der Steinacher Decke (Tirol, Österreich)

Zusammenfassung

Die Quarzphyllite der Steinacher Decke, welche über dem Brenner Mesozoikum und dem Stubaier Kristallin Komplex im westlichen Tirol liegt, enthalten graphitische Phyllite und Schiefer bislang unbekannten Alters. Aus einer Probe konnten Reste von Chitinozoen, trileten Sporen, Skolekodonten und Sphaeromorpha, sowie einige Incertae-sedis-Gruppen gewonnen werden.

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Eine grobe Alterseinstufung ist möglich: das Auftreten von Chitinozoen schließt ein Alter jünger als Devon aus, jenes von Sporen weist darauf hin, daß die Schichten nicht älter als Ashgill sind. Die Zusammensetzung der Chitinozoengesellschaft läßt auf oberes Silur schließen.

Durch die Chitinozoen ist ein vollmarines Ablagerungsgebiet nachgewiesen, das Auftreten von trileten Sporen belegt, daß dieses in relativer Küstennähe gelegen war.

Abstract

The quartz phyllites of the Steinach Nappe, which overlies the Brenner Mesozoic units and the Stubai Crystalline Complex in the western part of Tyrol, contain graphitic phyllites and shales of so far unknown age. However, one sample has yielded remains of chitinozoans, trilete spores, scolecodonts, sphaeromorphs and several incertae sedis groups.

The fossils recovered have allowed an approximate age to be established: the chitinozoans indicate an age no younger than the Devonian whilst the occurrence of trilete spores precludes an age older than the Ashgill. The general aspect of the chitinozoan assemblage suggests an upper Silurian age.

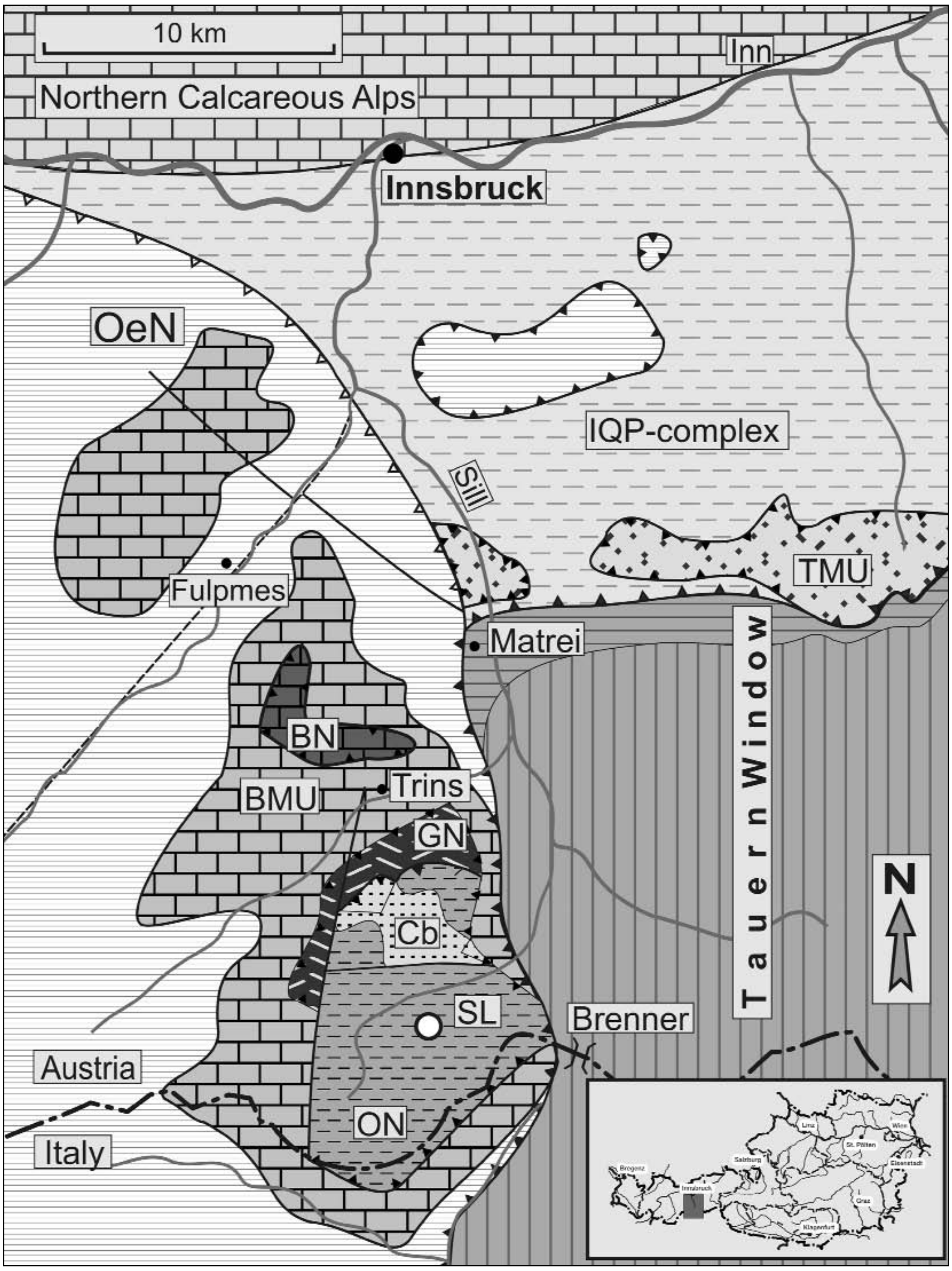
The chitinozoans demonstrate a fully marine environment, that was located not too far from the shore, indicated by the presence of trilete spores.

1. Introduction

The fossils documented here were collected from the Stainach Nappe, which lies on top of the Stubai Crystalline Complex and its Permo-mesozoic cover in the western part of the Eastern Alps (Text-Fig. 1). Before the Neogene exhumation of the Tauern Window, this nappe was part of the Gurktal Nappe, which lies to the east of the Tauern Window.

The nappe consists of two subunits: the Gschnitz Valley Subnappe unit at the base, overlain by the Obernberg Valley Subnappe unit, from which the examined sample was collected. The lithology of the latter unit consists of quartz phyllites, graphitic phyllites and shales, greenschists and carbonates of currently unknown age. These are transgressively overlain by Carboniferous sandstones, conglomerates, siltstones, shales and anthracite.

In the course of the field mapping of the 1 : 50 000 map-sheets Brenner (ÖK 148) and Sterzing (ÖK 175), it was unclear whether the graphitic metasediments of the Obernberg Valley Subnappe are of Carboniferous, or Lower Palaeozoic age; previous attempts to obtain fossils from these rocks had failed. Thus one sample of the dark grey phyllites was treated with standard palynological extraction methods for chitinozoans, to see if this stratigraphically very useful fossil group, which is restricted to the Lower Palaeozoic, occurred in these strata.



Text-Fig. 1.
Geological sketch map of the Brenner region.
SL = sample location; Cb = Carboniferous sediments; ON = Obernberg Valley Nappe; GN = Gschnitz Valley Nappe; BMU = Brenner Mesozoic unit; BN = Blaser Nappe; OeN = Oetz Valley Nappe; IQP-Complex = Innsbruck Quartzphyllite Complex.

After the presence of chitinozoan-remains had been confirmed by a preliminary check with the light microscope, it was decided to examine the palynological residue as thoroughly as possible. The intention was to get a comprehensive record of the composition of the chitinozoan-bearing fraction (>50μ) in this lithology, since these metasediments are quite common in the Eastern Alps and the concept of fossils being preserved in metamorphic rocks is rather controversial in both the geological as well as in palaeontological community.

To this end, extensive and detailed SEM investigations were made, not only on the hundreds of poorly preserved chitinozoans and chitinozoan-like remains recovered, but also on the other palynomorphs that were recovered during sorting out the residue. The aim was to find reliable criteria (e.g. relics of an ornamentation) for distinguishing fragmented fossils from fossil-like fragments. However, it turned out that differentiation was rather difficult or even impossible in many cases, due to the poor state of preservation. Furthermore, an exhaustive investigation should lead to the recognition of the limits to which stratigraphical, palaeoecological and palaeogeographical methods can be applied using metamorphic fossils.

2. Geology of the Area under Investigation

(Manfred ROCKENSCHAUB)

2.1. Sampling Location

The investigated sample was collected from a locality on ÖK50, sheet Brenner (BMN coordinates M28: R 234412, H 208494). The sample location is in the Obernberg Valley Subnappe of the Steinach Nappe, south of the Obernberg Valley. The locality lies at 1900 m, approximately 700 m southwest of the Karalm, on the crest between Frader Bach and Grießbach.

2.2. Geological Setting

The Steinach Nappe overlies Permo-mesozoic metasediments (the Brenner Permo-mesozoic) of the Stubai Crystalline Complex. Tectonically, the nappe correlates with the Gurktal Nappe in the Eastern Alps, east of the Tauern Window. Before the exhumation of the Tauern Window (from the Miocene onwards) the two nappes were part of a single continuous thrust sheet.

The Steinach Nappe consists of two tectonic subunits. The Gschnitz Valley Subnappe at the base consists of predominantly retrograde metamorphic micaschists, whilst the metamorphically prograde Obernberg Valley Subnappe unit comprises phyllites, with transgressive Carboniferous sediments on top.

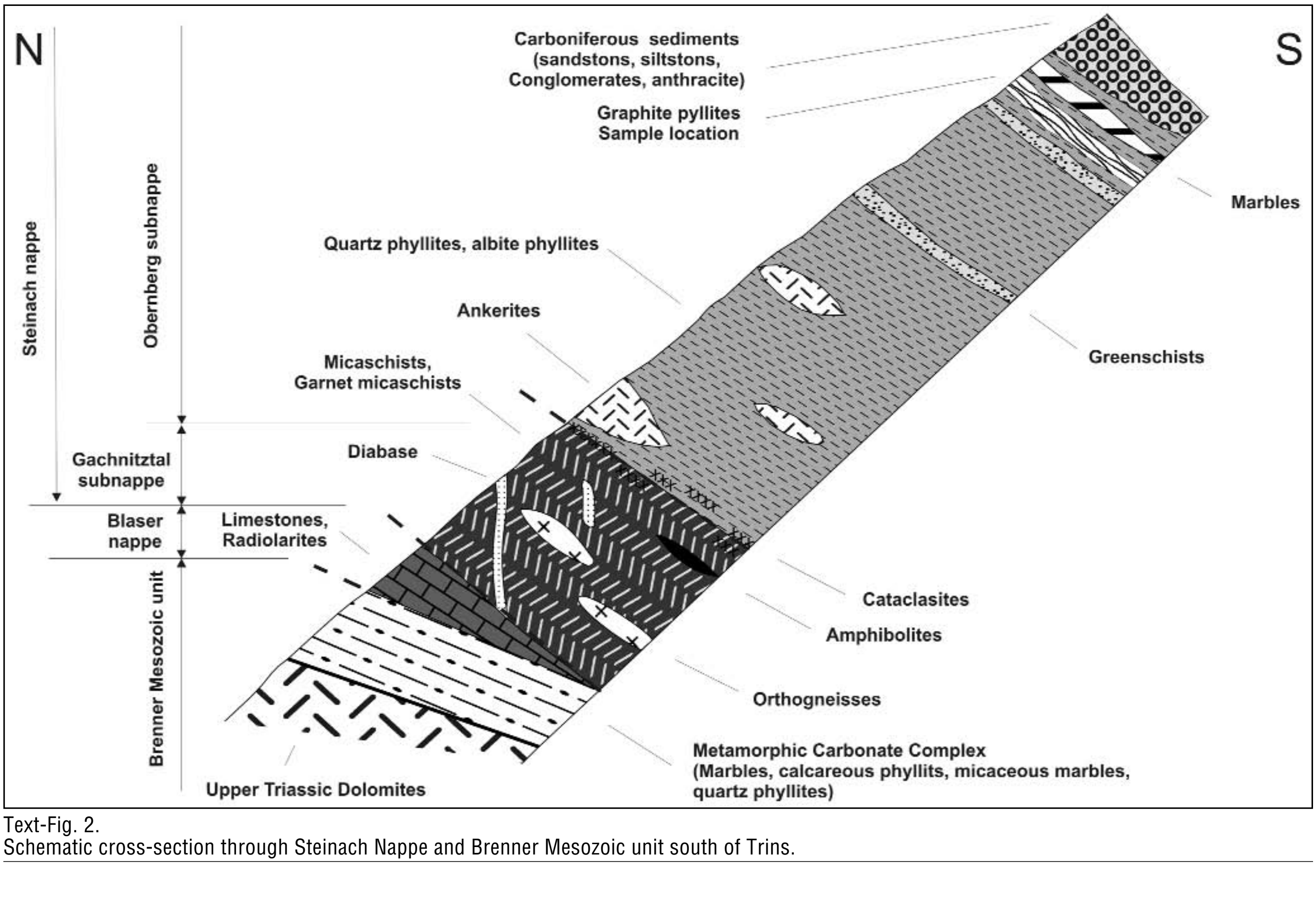
2.3. Lithologies of the Gschnitz Valley Subnappe Unit

Garnet mica schists and mica schists, locally with diabase (lamprophyres), amphibolite and mylonitic para- and orthogneisses are the main lithologies in the Gschnitz Valley Subnappe.

The Variscan metamorphism was within the garnet stability range, with white mica Ar/Ar ages of ±320 Ma interpreted as formation ages (ROCKENSCHAUB et al., 2003). Some garnets contain inclusions of chloritoid. These rocks show an Alpine retrograde overprint. Biotite was chloritised and garnet partly altered into chlorite and sericite. Quartz shows indications of deformation at ~300°C.

2.4. Lithologies of the Obernberg Valley Subnappe Unit

Quartz-, albite- and graphite phyllites, greenschists, carbonates and the overlying transgressive Carboniferous sandstones, conglomerates, siltstones, shales and anthracite are the typical lithologies of the Obernberg Val-



Text-Fig. 2.
Schematic cross-section through Steinach Nappe and Brenner Mesozoic unit south of Trins.

ley Subnappe unit. South of the Obernberg Valley intercalations of quartzites, micaceous quartzites, graphictic phyllites and shales occur. A Carboniferous age could not be excluded for the graphitic metasediments, which were object of the investigation documented here.

The Obernberg Valley Subnappe shows no sign of retrograde metamorphism. The occurrence of chloritoid and the presence of biotite constrain the metamorphic conditions to between 300 and 400°C. Based on Ar/Ar ages of ~320 Ma (ROCKENSCHAUB et al., 2003), this metamorphic paragenesis is Variscan. An Alpine overprint is barely identifiable.

The phyllites contain numerous lenses of Fe-dolomite (ankerite). SCHMIDEGG (1949) described sporadic occurrences of magnesite. Grey coarsely crystalline Palaeozoic limestone marbles occur in combination with the Fe-dolomite.

Mesozoic micaceous marbles (Brennerpermomesozoic) and Palaeozoic micaceous marbles occur next to each other. This is shown by Alpine Ar/Ar ages (88±1Ma) and pre-Alpine metamorphic white mica (Rb/Sr ages of 264±3 Ma). The Rb/Sr age is interpreted as a rejuvenated Variscan metamorphic age. Unambiguous Variscan Ar/Ar ages (~320 Ma) were obtained from white mica from phyllites of the Obernberg Valley Subnappe unit north of the Obernberg Valley.

The Carboniferous sediments of the Steinach Nappe consist of quartz-rich conglomerates, sandstones, siltstones, graphitic shales and anthracite seams, which have been mined. The fine-grained sediments yielded numerous determinable plant fossils; these indicate a Westphalian D age (KERNER, 1897). According to sedimentological investigations (KRAINER, 1990) these are fluviatile sediments, consisting of channels, levee-, and overbank-deposits. The largest occurrences were found around Nößlachjoch. Some smaller occurrences of Carboniferous sediments occur north of the Gschnitz Valley, at the base of the Blaser Nappe, and in the Obernberg Valley.

2.4.1. Macroscopic Description of the Obernberg Valley Subnappe Unit

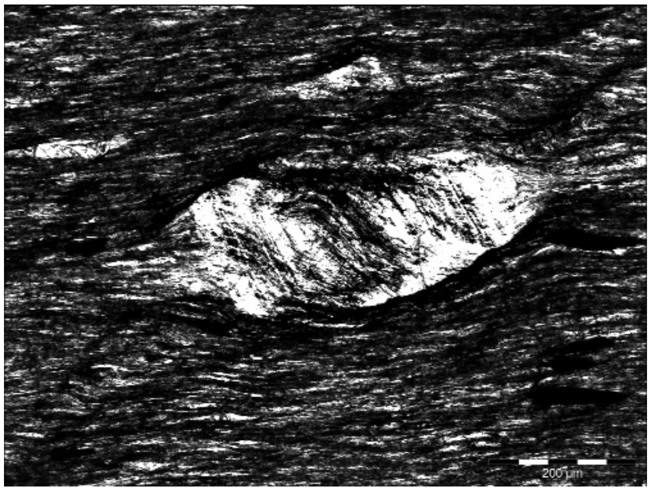
The investigated rocks are dark-grey to black, partly platy shales and phyllites, with patchy rusty-brown weathering colours and an extremely variable graphite content. The pressure solution foliation, which is very well developed, has been locally overprinted by a fine crenulation.

2.4.2. Microscopic Description of the Obernberg Valley Subnappe Unit

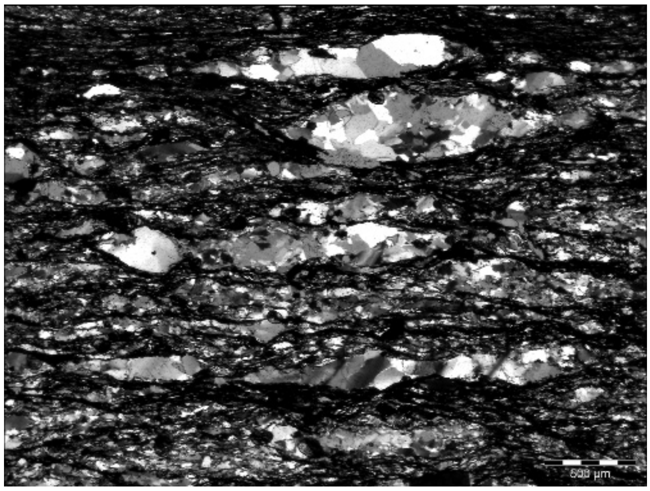
Microscopically, the fine-grained rocks are well foliated and have a variable mineralogical composition. The lithologies range from quartzwackes to mudstones, all of low metamorphic grade. The occurrence of chloritoid in nearby rocks and the absence of biotite indicates that temperatures of 300–400°C must have been reached. Graphite is concentrated in the foliation planes.

In thin-section, graphitic phyllites have been identified, consisting of chlorite, white mica, graphite and a few quartz- and lithoclasts. Some mm-sized albite- and chlorite porphyroblasts are also present. In contrast, shales rich in quartz and feldspar are also present. Chlorite-mica-graphite layers may alternate with quartz- and feldspar-rich layers. In these lithologies, quarzitic and gneissic microconglomerate pebbles as well as detrital white micas occur.

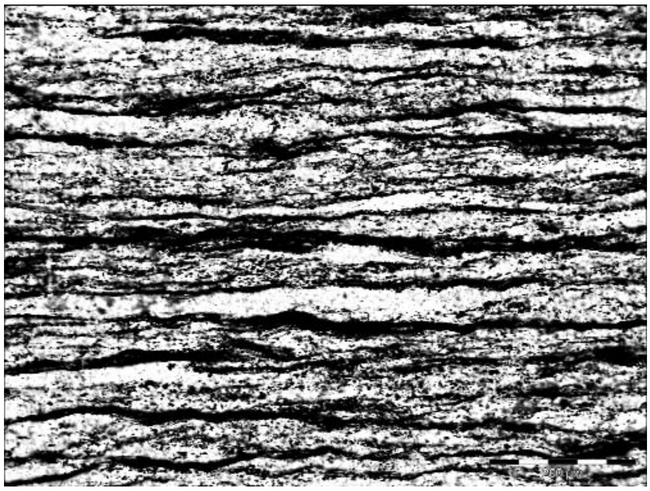
The mineral content is limited to graphite, white mica, albite, chlorite, tourmaline, ore and Fe-carbonate in variable proportions. Quarzitic- and gneissic microconglomerate pebbles as well as detrital micas locally make up a significant proportion.



Text-Fig. 3.
Albite porphyroblast in a fine grained graphite phyllite.
The matrix consists of fine grained quartz, albite, chlorite and sericite.
PPL.



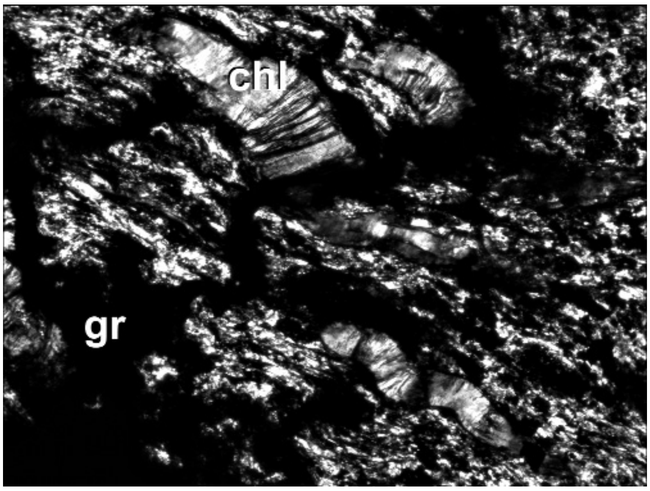
Text-Fig. 4:
Metamorphic graphitic quartzwacke with lithoclasts (quartzites).
PPL.



Text-Fig. 5:
Graphitic quartzite.
PPL.

2.4.3. Microscopic Description of the Investigated Sample

The investigated sample is a fine-grained sericite-quartz-chlorite-graphite-phyllite. Relatively graphite-poor, lighter coloured quartz-and albite-rich layers occur in alternation



Text-Fig. 6.
Graphite phyllite (x25).
The matrix consists of fine grained quartz, albite, chlorite and sericite.
Thin section subparallel to the foliation.
Gr = graphite; Chl = chlorite.

with phyllosilicate- and graphite-richer layers on a mm- to cm-scale thickness. Graphite is concentrated along the foliation planes. Albite-prophyroblasts occur predominantly in the phyllosilicate-layers. Subordinate mm-thick quarzitic layers, small lithoclasts (quartzites) and detrital white mica are also present.

3. The Fossil Content of the Studied Sample

3.1. Preparation of the Sample

About 40 g of dark-grey graphitic quartz phyllite were dissolved by applying the standard palynological extraction method for chitinozoans (PARIS, 1981; p. 65). Subsequently, the residue was gently sieved through a 50 μ-mesh sieve, and then the entire organic matter larger than 50 μ was sorted at low magnification under a binocular microscope. Every object with broadly biogenic appearance was collected. Overall, the 466 most suitable specimens were selected for SEM investigation. The preparation of the specimens for SEM analysis was carried out according to the method of PARIS (1978; fig. 55).

3.2. Treatment of the Selected Objects.

The selected objects were studied in detail under the SEM (CamScan CS24 compact). About 4,000 photos were taken for digital image analysis (analySIS FIVE / Scandium Soft Imaging Systems). Beside a view normal to each specimen, a number of oblique views at angles of about 60° were made, as well as details at higher magnifications. 155 stereopairs were also produced and 60 EDX-analyses (Link ISIS 200/300) on 30 objects were carried out.

Subsequently, the 22 cover slides, on which the fossils and fossil-like objects had been mounted for the SEM, were converted into permanent slides (PARIS, 1981; fig. 55). Afterwards, material identified as having an organic origin was examined and photographed under the transmitting light microscope using digital image analysis (Cell 2.5 Soft Imaging Systems).

The slides with the permanently mounted SEM-preparations are stored in the collections of the Geological Survey of Austria, Vienna, under the numbers 2007/153/1-22; and the thin-sections parallel to the foliation planes under the numbers 2007/153/23-25.

3.3. Description of the Fossils

3.3.1. Preliminary Notes

As the preparation of the sample was primary aimed at obtaining chitinozoans, after the dissolution of the rock material the residue was sieved through a 50 μ-mesh sieve and then the fossils were picked under the binocular microscope at low magnification in order to prepare them for SEM investigations. Thus specimens smaller than ~80 μ were lost, either during sieving or because they were overlooked due to their smallness.

Since all the organic remains are badly preserved (see below), the only morphologic characteristics available are the outlines and the dimensions of the studied objects. The measurements given do not reflect their real dimensions but are just thought to give a general idea of the relative sizes within the fossil association.

As the fossil-remains are too poorly preserved for an assignment to species or even genera level, they have been combined into morphological groups and then compared with taxa that have similar outlines and sizes.

Of the 466 examined organic particles, only 48 (~10 %) were unambiguous fossils. These belong to the following groups: chitinozoans, scolecodonts, sphaeromorphs, sporomorphs and incertae sedis.

Representatives of the incertae sedis group have been compared with acritarchs, melanosclerites, organic walled foraminifers and organic linings of agglutinated foraminifers, teeth of arthropod cuticles and juvenile brachiopods. Note that papers dealing with these fossil groups are generally rare, except for the acritarchs and this is especially true for more recent papers about Silurian members of the above groups.

Four of the examined objects were illustrated in fig. 4 of ROCKENSCHAUB et al. (2003; p. 87). The two upper individuals belong to chitinozoan groups 2 and 4, respectively, discussed below. The third one might be the organic lining of a foraminifera and the lowermost is simply a graphitic fragment.

3.3.2. Preservation of the Fossils

Under the binocular and ordinary light microscopes, the fossil remains from the Steinach Nappe appear black and opaque (s. Pl. 6), sometimes having a silky or flaked surface and are usually completely flattened, and often wrinkled, distorted and broken.

However, when examined in the SEM, a special mode of preservation is apparent: the fossil walls have been altered to stacks of fine layers [less than $^1/_2 \mu$ (s. Pl. 3, Figs. 1c, 4d, 6c, 7b)], with the outermost layers removed, since no ornamentation has ever been observed. Only very rarely are relics of morphologic features like operculi (s. Pl. 2, Figs. 4b-c, 5a, b) or apical structures (s. Pl. 1, Figs. 5a–c) present.

Some of the objects seemed to be somewhat inflated (e.g. Pl. 4, Figs. 1a–c, 2 a, b; Pl. 5, Figs. 3 a–d) which might result from an internal mould of organic matter, as described by RIEGRAF & NIEMEYER (1996; p. 25) for Ordovician agglutinated foraminifers. These authors stated that most of their specimens had a filling of black, strongly graphitized organic matter and clay minerals. In the Steinach fossils, also the internal moulds were split into stacks of layers such that it was no longer possible to distinguish between the outer layers of the moulds and the original fossil walls.

At present, the post-diagenetic processes that caused this exceptional mode of preservation are unknown.

Since many of the studied fossils initially looked entirely or partly like mica grains, numerous EDX-analyses were carried out. The majority of these demonstrated the organic nature of the objects. In only two cases were mineral grains found beside the organic wall: in the central cavity of one chitinozoan, an albite grain has grown (Pl. 1, Fig. 5a) whilst a second chitinozoan had an internal mould of rutile (Pl. 2, Fig. 1a).

3.3.3. Chitinozoans

Six different groups of chitinozoans were identified.

Group 1

Pl. 1, Figs. 1a–d; Pl. 6, Fig. 7

Description (2 specimens): Slender, conical outline of the vesicles with straight flanks tapering in apertural direction, flat base and rounded margins. Apertural part destroyed. No ornamentation preserved.

Maximum length (2 specimens measured): ~150–160 μ.

Discussion: EDX-analyses at two different points on the vesicle (Pl. 1, Figs. 1a–d) proved the graphitic nature of the fossil.

The distinctive outline of the specimens suggests an affinity to *Eisenackitina intermedia* (EISENACK, 1955), although the outer layer, forming the ornamentation of granulae or small spines, is completely removed; see EISENACK (1955; Pl. 3, Fig. 8), EISENACK (1968b; Pl. 25, Figs. 26, 27); EISENACK (1972; Pl. 34, Figs. 11, 14); KRIZ (1992; Pl. 3, Fig. 5); KRIZ et al. (1986 ; Pl. 5, Fig. 6a; Pl. 6, Fig. 4a); LAUFELD (1974; Fig. 26); PRIEWALDER (2000; Pl. 2, Fig. 6); SUTHERLAND (1994; Pl. 2, Fig. 2, 5). The vesicle's length lies within the variation described by EISENACK (1955) in his original description [(p. 161) L = 119–173 μ] or, for example, by SUTHERLAND (1994, p. 30) L = 93–173 μ].

According to VERNIERS et al. (1995; Text.-Fig. 3) *Eisenackitina intermedia* ranges from the base of the *elongata* into the *elegans* chitinozoan biozone (upper Gorstian – lower Pridoli).

Group 2

Pl. 1, Figs. 2, 4a–b, 5a–c; Pl. 6, Figs. 1, 2, 5

Description (4 specimens): Ovoid outline of the vesicles with slightly convex flanks tapering toward the aperture, more or less convex bases and broadly rounded margins. Maximum width varying in position from close to the base to about the lower third of the vesicle length. Apertural part destroyed. No ornamentation preserved.

Maximum length (4 specimens measured): ~120–~220 μ.

Discussion: EDX-analyses at two different points on the vesicle on Pl. 1, Fig. 4a proved the graphitic nature of the fossil. In Pl. 1, Fig. 5a, however, one analysis showed a clear carbon peak, while the other proved the presence of albite, which obviously grew in the central cavity.

In outline, the representatives of the chitinozoan-group 2 resemble the urn- or egg-shaped, partly inflated, thick-walled Desmochitinidae that are very common in upper Silurian rocks. One of them even seems to reveal traces of an apical structure (Pl. 1, Figs. 5a–c).

As no ornamentation is preserved, from their mere shape the specimens could originally have belonged to either the Urnochitina or Eisenackitina genera. They also show the wide variety in outline and size that is typical for these upper Silurian taxa.

Therefore, they might possibly be compared with *Eisenackitina granulata* (CRAMER, 1964) [in PRIEWALDER, 2000; Pl. 2, Fig. 7; SCHWEINEBERG, 1987; Pl. 8, Figs. 9–12], *Eisenackitina* sp. 1 and *Eisenackitina* sp. 2 in DE BOCK (1982; Pl. 1, Figs. 12–22), *Kalochitina lorensis* SCHWEINEBERG, 1987 [in SCHWEINEBERG, 1987; Pl. 8, Figs. 5–8] or *Urnochitina* gr. *urna* (EISENACK, 1934) [in DE BOCK, 1982; Pl. 2, Figs. 5–19; EISENACK, 1934; Pl. 5, Figs. 7–12; PARIS, LAUFELD & CHLUPAC 1981; Pl. 1, Figs. 1–11, 16; PRIEWALDER, 2000; Pl. 2, Fig. 8, in addition to numerous unpublished SEM-photos from representatives of this species from the Cellon-section].

All the above taxa originate from Ludfordian and Pridolian rocks respectively.

Group 3

Pl. 1, Figs. 6a–b; Pl. 6, Fig. 9

Description (1 specimen): Broad conical outline of the vesicle; flanks straight, slightly tapering in apertural direction; base slightly convex; margins broadly rounded. Greatest diameter close to the base; apertural part broken. The upper left part of the vesicle surface has a spotted aspect that might be the relic of a former verrucate or spiny ornamentation.

Maximum length (1 specimen measured): 176 μ.

Discussion: No EDX-analysis was carried out on this vesicle.

As no unambiguous morphologic features are present, it can only be stated that this specimen is a Desmochitinidae indet.

Group 4

Pl. 1, Figs. 3a–c; Pl. 2, Figs. 1a–d; Pl. 6, Figs. 3, 4

Description (2 specimens): Ovoid chambers with the greatest diameter in the middle of their length; flanks and bases convex. Towards the aperture, the flanks gradually pass into the neck.

Length of the chambers [1 specimen measured (Pl. 1, Fig. 3a)]: 94 μ.

Discussion: The two specimens reveal different modes of preservation. One (Pl. 1, Figs. 3a–c) is flattened as usual; EDX-analyses at two points on the vesicle confirmed its graphitic nature.

The other (Pl. 2, Figs. 1a–d) seems to be an internal mould of a chitinozoan vesicle. EDX-analyses at 3 points all showed that the whole body comprises rutile. However, at one point there was also a small, and at a second point there was a prominent carbon-peak in the diagram (s. Pl. 2, Fig. 1a). That indicates that organic material is also present, most probably the remnant of the original vesicle-wall. As is seen in Pl. 2, Fig. 1d, the organic material is decomposed to thin fragments of various sizes.

Furthermore, it seems that the antiapertural and, to a lesser degree, also the right part of the chamber, as well as the neck, were hollow spaces where crystals could grow without hindrance, while on the left side and on the side facing the pad, small crystals in a dense arrangement seem together to have the form of the inside of the former chamber-wall (Pl. 2, Figs. 1b,c).

Since no ornamentation and only the cylindro-ovoid outline are present as diagnostic features, these chitinozoans can only be classified as Lagenochitinidae indet.

Group 5

Pl. 2, Figs. 4a–c, 5a–b; Pl.6 , Figs. 10, 11

Description (2 specimens): Broken and twisted vesicles of more or less elliptical outline, flattened perpendicular or oblique to the axis. Poorly preserved eroded operculi present.

Diameter (2 specimens measured): ~130 μ.

Discussion: No EDX-analyses were carried out on these vesicles.

The two specimens are poorly preserved, but, from their undulating shape with broad fissures, it can be concluded that they were originally sub-spherical or lenticular.

Also, the operculi are badly preserved, having been heavily abraded. They appear to be elliptical, but this is most probably only a secondary feature, since they seem to be broken and/or folded. All other structures around the apertures have been destroyed.
The overall shape of the vesicles and the presence of operculi suggest that they represent the genus *Calpichitina* WILSON & HEDLUND, 1964.

Group 6

Pl. 2, Figs. 2a–b; Pl. 6, Fig. 6

Description (1 specimen): Almost rectangular outline of the vesicle with straight flanks slightly tapering in apertural direction, flat base and rather sharp margins. Apertural part broken. Greatest diameter at the base.

Maximum length: 126 μ.

Discussion: No EDX-analyses were carried out on this vesicle.
The shape of the vesicle and the sharp basal margin are reminiscent of some representatives of the genus *Cingulochitina* PARIS, 1981. However, as no carina is visible, this specimen is assigned to the Desmochitinidae indet.

3.3.4. Scolecodonts

Pl. 2, Figs. 3, 6a–b; Pl. 3, Figs. 6a–c; Pl. 6, Figs. 8, 12, 17

Description: Four corroded and broken scolecodonts were identified by their overall form and the few denticles which are still present on their inner margins. The lengths of two almost complete specimens vary from 127 μ to 367 μ.

Discussion: On the specimen in Pl. 2, Fig. 3, EDX-analyses at two points proved its graphitic nature.
The specimen in Pl. 3, Fig. 6 is a good example of the mode of preservation in this sample, as it demonstrates clearly the splitting of the fossil wall into a stack of thin sheets.

3.3.5. Sphaeromorphs

Pl. 3, Figs. 4a–d, 5; Pl. 4, Figs. 1a–c, 2a–c, 5, 7a-b;
Pl. 6, Figs. 15, 16, 20, 21, 22, 27

Description: A total of 13 broad-elliptical or circular objects were found, some slightly inflated and with more or less thick, rounded margins. The walls seem to be of different thicknesses. The diameters range from 77–215 μ.

Discussion: EDX-analyses on the vesicles in Pl. 3, Fig. 4 and 5 and Pl. 4, Fig. 2 were made at two different points on each. Without exception these proved the material is graphitic.
From the wide range of sizes and the different appearances of these simple vesicles, where no diagnostic morphologic features survived, if they were present, it can be presumed that they originally belonged to more than one fossil group.
Some of them (for example Pl. 3, Fig. 4) might represent the genus Tasmanites, with thick, perforated vesicle-walls and a size range of 30–600 μ, according to TAPPAN (1980; p. 814). Yet, no pores were observed, although this could be a result of the strong alteration of these organic particles.
The vesicles with thinner walls could have belonged to the Leiosphaeres (as Pl. 4, Fig. 5) or (as Pl. 3, Fig. 5) even to large, corroded, circular spores like *Retusotriletes sanpetri* CRAMER, 1967 (stratigraphical range: Ludlovian–Gedinnian according to CRAMER, 1983) with diameters up to 95 μ; see CRAMER (1967; Pl. 2, Fig. 33), CRAMER (1969; Pl. 2, Fig. 7) and in CRAMER (1983; unpubl. Lower Paleozoic miospore catalogue).

The fourth group related to the present sphaeromorphs could be the organic linings of agglutinated foraminifera. Representatives of more or less smooth, spherical or hemispherical foraminiferal genera with a sub-circular to circular outline such as *Psammosphaera* SCHULTZE, 1875, *Hemisphaerammina* LOEBLICH & TAPPAN, 1957 and *Webbinelloidea* STUART & LAMPE, 1947 (in BELL & WINCHESTER-SEETO, 1999; HOLCOVÁ, 2002; WINCHESTER-SEETO & BELL, 1994; WINCHESTER-SEETO & BELL, 1999) and *Archaeochitina* EISENACK 1954 (in EISENACK, 1954, 1966a) are similar to the here described objects.
Another comparable foraminiferal taxon, especially resembling specimens like Pl. 4, Figs. 1, 2, 7 is *Thurammina sphaeroidalis* (PLUMMER, 1945) in RIEGRAF & NIEMEYER (1996; p. 26; stratigraphical occurrences: ?middle Cambrian, late Ordovician, Silurian, late Carboniferous, Permian). In the above paper, the originally spherical bodies with thin walls were secondarily deformed to thick, circular or sub-circular, thrombozyte-like platelets with diameters of 100–1500 μ. In most cases, their typical small rounded protuberances had been corroded and therefore the surfaces now have a smooth appearance. Although the species is said to have very thin walls, the tests now are present as comparatively thick, compact disks. The reason for this is that most of those foraminifers have a solid internal mould consisting of a mixture of black, strongly graphitized organic matter and clay minerals (RIEGRAF & NIEMEYER, 1996, p. 25). Therefore, it is possible that some of the here described sphaeromorphs are also made up of an internal mould of graphitic matter, with the organic lining, or parts of it, on top.

3.3.6. Sporomorphs

Pl. 3, Figs. 1a–c, 2a-b, 3, 7a–b; Pl. 6, Figs. 13, 14, 18, 19

Description: Six sub-triangular badly preserved broken spores, with maximum diameters ranging from 89 μ to 110 μ.

Discussion: Two EDX-analyses of the spore in Pl. 3, Fig. 1 and at one point on the spore in Pl. 3, Fig. 3 all proved the graphitic nature of the fossils.
On two specimens (Pl. 3, Figs. 1 and 7), two thirds of the proximal surface have been broken away along the triradiate scar; a similar feature is shown in GRAY & BOUCOT (1971; Fig. 1d), as well as in PLUG & REITZ (1987; Fig. 1d). The others either show the distal surfaces, or their proximal walls are completely removed and the interior sides of the distal walls are visible.
The illustrations in Pl. 3, Figs. 1c and 7b clearly demonstrate the alteration of the walls into stacks of numerous fine layers. The poor state of preservation of the spores does not allow any taxonomic assignment.
The presence of only large spores is most probably due to the special method of preparation for gathering chitinozoans (which was the primary purpose of these studies – see p. 552, 555). DEUNFF et al. (1971; p. 10) mention that after the sieving of the palynological residue of upper Silurian samples, the fraction larger than 37 μ contained beside chitinozoans and other organic microfossils also large spores, some of which exceeded 500 μ in diameter. A large spore (diameter >90 μ), belonging to a badly preserved Pridolian assemblage of chitinozoans and spores, is also illustrated in BLAISE et al. (1991; Pl. 2, Fig. 4).
The occurrence of trilete spores in the examined sample is of great stratigraphical value: as the spores make their first appearance in the Ashgill of Turkey (STEEMANS, LE HÉRISSÉ & BOZDOGAN, 1996; STEEMANS, 1999), an age older than the Ashgill for the present fossil assemblage can be excluded.

3.3.7. Incertae Sedis

Eight different incertae sedis groups were identified.

Group 1

Pl. 4, Figs. 4a–b; Pl. 6, Fig. 34

Description: One badly preserved specimen was found with 4 broad, relatively short, slightly tapering processes with broadly rounded terminations in a tetrahedral arrangement, connected at their bases by slightly concave transitions, which bound the central cavity. The dimensions of the specimen in Pl. 4, Fig. 4a are 168 x 163 μ.

Discussion: No EDX-analyses were carried out on this vesicle.

In several aspects, the specimen resembles the acritarch species *Pulvinosphaeridium pulvinellum* EISENACK, 1954: the number, form and arrangement of the processes are similar, as is the size of the vesicle; see CRAMER (1970; Fig. 34a); EISENACK (1968a; Pl. 24, Fig. 4) and MULLINS (2004; Pl. 14, Fig. 8).

According to LE HÉRISSÉ (1989, p. 185) the stratigraphical range of *P. pulvinellum* is Llandovery–Ludlow.

Group 2

Pl. 4, Figs. 6a–c; Pl. 6, Fig. 32

Description: One object, large (length 267 μ) and club-shaped. One end is wider and rounded; from here the slightly convex flanks taper to form a blunt tip at the opposite end.

Discussion: The one EDX-analysis carried out on the specimen in Pl. 4, Fig. 6a proved the graphitic nature of the fossil.

This object may be referred to the melanosclerites. However, as there are few papers concerning melanosclerites, especially from the Silurian, making comparisons is difficult. Its shape is in accordance with the definition of the genus *Melanoclava* EISENACK (1942; p. 167), although the short stalk on the wider end is missing here.

Group 3

Pl. 4, Fig. 3; Pl. 6, Fig. 33

Description: One relatively large and broad, subcylidrical specimen, of which the upper end and the right side are destroyed. The opposite end is rounded and in its centre drawn out to form a small conical projection. The flanks are almost straight and widen slightly toward the damaged end.

Length of the object: 206 μ.

Discussion: No EDX-analyses were carried out on this specimen.

Although this object is badly preserved, its shape resembles one genus of the melanosclerites: *Melanocyathus* EISENACK, 1942. The type species of this genus, *M. dentatus* EISENACK, 1942 (EISENACK, 1942; p. 165) from the Upper Ordovician, is characterized by its bell-shaped form, with one end rounded and furnished with a short and more or less thick stalk. The opposite end is widened and provided with several short broad bifurcating teeth.

Group 4

Pl. 5, Figs. 1a–b, 2a–b; Pl. 6, Figs. 28, 29

Description: Three triangular objects. The flanks are straight or slightly concave and taper at an acute angle. The tips are destroyed. The bases are concave.

Length of the only almost completely preserved specimen (Pl. 5, Fig. 1a): 164 μ.

Discussion: The one EDX-analysis on the "tooth" in Pl. 5, Fig. 1a confirmed the graphitic nature of the fossil.

It is possible that these teeth-like objects originated from a polychaete jaw. However, they could also have grown on arthropod cuticles such as those figured in EISENACK (1956a; Pl. 10, Fig. 2a, 3a) or in TAUGOURDEAU (1967; Pl. 2, Fig. 19; and, very similar, but much smaller, in Pl. 1, Fig. 12 and Pl. 2, Fig. 24).

Group 5

Pl. 5, Figs. 3a–d; Pl. 6, Fig. 24

Description: One specimen, with at least 4 broad, almost semicircular lobe-like extensions of different sizes that are connected at their bases at high angles.

Dimensions of the specimen: 162 x 104 μ.

Discussion: EDX-analyses at two points on the vesicle proved the graphitic nature of the fossil.

This object might be the organic lining of an agglutinated foraminifera. Its morphology roughly corresponds to the definition of the genus *Pseudastrorhiza* EISENACK, 1932, and its lobe-like extensions are similar to one specimen of the Upper Ordovician *P. silurica* EISENACK, 1932 (EISENACK, 1932, Pl. 12, Fig. 6), which differs from the typical representatives of this species by its short and almost semicircular arms. As the genus *Pseudastrorhiza* ranges at least into the Carboniferous, it might very well be that, in the Silurian, taxa with short stout arms existed.

A further, similar fossil is the specimen in Pl. 9, Fig. 4 *Archaeochitosa clausa* EISENACK, 1959; stratigraphical range: Ordovician–Ludlow (p. 92)] in EISENACK (1959) with 3 lobe-like extensions, though in the original description of this species no extensions were mentioned.

Group 6

Pl. 5, Figs. 4, 5a–b; Pl. 6, Figs. 25, 26

Description: Three specimens, each consisting of pairs of joined circular vesicles. The vesicles in one pair are of slightly different size.

Length of the pairs: 125–142 μ.

Discussion: Two EDX-analyses were made on the vesicle in Pl. 5, Fig. 4. Both proved the graphitic nature of the fossil.

These objects may be compared with organic linings of agglutinated foraminifera, such as the representatives of the genus *Sorosphaera* BRADY, 1879, which tend to form aggregates of two or more (sub-) globular chambers; see BELL & WINCHESTER-SEETO (1999; Pl. 1, Fig. 9), DUNN (1942; Pl. 42), EISENACK (1954a; Pl. 5, Fig. 4) and KRISTAN-TOLLMANN (1971; Tab. 1).

Webbinelloidea similis STEWART & LAMPE, 1947 (Lower Lochkovian–Lower Carboniferous) is another similar taxon; see CONKIN & CONKIN (1970; Pls. 1–4) and BELL & WINCHESTER-SEETO (1999; Pl. 4, Fig. 13).

Group 7

Pl. 5, Figs. 7a–c; Pl. 6, Fig. 23

Description: Test of the single specimen sub-spherical, tapering toward the two poles to form a blunt tip on one side and a short slender cylindrical projection on the other.

Total length: 222 μ.

Discussion: No EDX-analyses were carried out on this object.

Pl. 5, Fig. 7c shows an interesting detail: on the left side of the test the crushed thin original wall seems to have peeled off from a solid internal mould, which is also split up into a stack of thin layers.

This fossil, which could be the organic lining of an agglutinated foraminifera, resembles representatives of the genus *Amphitremoida* EISENACK, 1967, emend. NESTELL &

TOLMACHEVA, 2004, especially the Upper Ordovician *A. fusiforma* EISENACK, 1967 and its synonym *A. minuta* EISENACK 1967 (in EISENACK, 1967; p. 253, 254; Pl. 25, Figs. 3–8), as well as the Lower Silurian *A. parvituba* (DUNN, 1942) (in DUNN, 1942; p. 333, Pl. 43, Figs. 28, 29). However, it has to be noted that, until now, no organic linings of this genus have been reported. However, in Pl. 10 of NESTELL & TOLMACHEVA (2004), thin sections of several *Amphitremoida* species show dark inner layers of various thickness that might represent such organic linings.

Stratigraphical range of the genus according to NESTELL & TOLMACHEVA (2004; p. 262): Lower Ordovician–Lower Carboniferous.

Group 8

Pl. 5, Figs. 6a–b, 8; Pl. 6, Figs. 30, 31

Description: Two tiny brachiopod-like objects were found. The height of the shell in Pl. 5, Fig. 8 is 118 μ and in Pl. 5, Fig. 6a is 83 μ.

Discussion: No EDX-analyses were carried out on these two specimens.

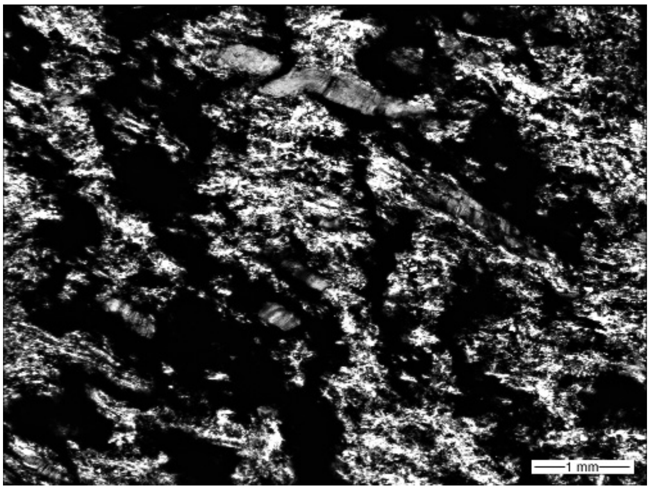
According to WILLIAMS et al. (1997; p. 183), juvenile lingulids, to which these objects may be referred, are already miniature adults when they start to settle after their larval stage. The shells of the inarticulate brachiopods are of organophosphatic composition and contain high levels of organic matter, including chitin (CUSACK et al., 1997, p. 243; WILLIAMS, 1997, Fig. 236). This could be the reason why they survived the post-diagenetic alteration of the rocks, as well as the aggressive palynological preparation method.

3.4. Fossils in Thin-Sections

Three thin-sections of about 1mm thickness subparallel to the foliation planes were examined under a transmitting light microscope. No unequivocal palynomorphs were found, but numerous large brown to black (depending on the thickness) cuticle fragments were present (Text-Fig. 7).

These cuticles are strongly altered and often have holes of different sizes and forms that are distributed randomly or in rows.

Different authors, among others GENSEL et al. (1990, p. 524) and JOHNSON (1985; p. 348), already stated that cuticles occur quite frequently in palynological residues but they have also pointed out that in many cases it is impossible to decide whether they originated from plants or animals (most likely arthopods).



Text-Fig. 7.
Thin-section of the studied sample subparallel to the foliation: black cuticle fragments with holes.
Thin-section number 2007/153/24.

Similar cuticles with holes are also figured in EISENACK (1955, Pl. 5, Fig. 2; Text-Figs. 6–9); EISENACK (1956; Pl. 9, Fig. 6; Pl. 10, Fig. 6), GENSEL et al. (1990, Fig. 9B) and MILLER (1996, Pl. 1, Figs. 1, 2); excepting the plant cuticles in GENSEL et al. (1990, Fig. 4C, 4D), these all are fragments of Eurypterid cuticles.

4. Discussion

4.1. Preservation

At first sight some of the poorly preserved fossils above described could be taken as mica grains. However, under the binocular microscope they are deep black, and often show a silky or flaked surface. Moreover, numerous EDX-analyses demonstrated that they are made up of carbon and hence have a biogenic origin.

The state of preservation of these fossils is unique: the walls, as well as the sometimes occurring internal moulds of graphitized organic matter have been altered to stacks of very fine layers, of which the outermost ones seem to have been removed, as no ornamentation was observed. The current outer layers of the stacks are often crushed into thin fragments of various sizes, giving the surfaces an uneven or rough aspect, while the inner layers and the layers of the internal moulds have a glossy, mica-like appearance (s. Pl. 1, Figs. 4a,b; Pl. 5, Figs. 3b,c).

The post-sedimentary conditions, with increased temperature and pressure (see p. 554), were clearly responsible for these features, but at present it is not possible to explain the particular processes which affected the fossils in this unique way, as well as the factors which finally prevented some of them from complete destruction.

A comparison of the SEM-photos presented in this work with other papers dealing with metamorphosed palynomorphs shows that the state of preservation described above has not been reported previously. Such previously documented vesicles were also more or less strongly coalified and flattened, but, despite this, they had retained their original appearance and were at the most partly broken. Furthermore, the walls were never conspicuously split into layers and still exhibited some ornamentation; see BLAISE et al. (1991; Pl. 2, Figs. 1–7), CHALET et al. (1983; Pl. 1, Figs. 1–4), MONTENARI & SERVAIS (2000; Pl. 1, Fig. 2) and MONTENARI, SERVAIS & PARIS (2000; Figs. 3, 4). This suggests that the Steinach Nappe fossils underwent more severe metamorphic and/or tectonic conditions than did the palynomorphs in the above mentioned papers.

PRIEWALDER & SCHUMACHER (1976) documented Silurian chitinozoans from phyllites in the Niedere Tauern (Styria/Austria). These are also poorly preserved and opaque, and were studied only under a transmission light microscope. As the appearance of the objects often differs considerably in the SEM from that under the light microscope, it is not possible to compare the chitinozoans from the two localities.

4.2. Age Determination

Despite the poor preservation of the fossils, it has been possible to determine a rough age of the studied sample.

The primary aim when the examinations were initiated was to establish whether the sample was of Lower or Upper Palaeozoic age. The presence of chitinozoans, which range from the base of the Ordovician to the top of the Devonian (s. PARIS,1996; Text.-Figs. 2, 6, 8), answers this question unequivocally. However, this gross age classification can be further restricted by the characteristic composition of the studied fossil assemblage.

The occurrence of trilete spores (Pl. 3, Figs. 1–3, 7), which make their first appearance within the Ashgill (s. STEEMANS, LE HÉRISSÉ & BOZDOGAN, 1996, p. 40; STEE-

MANS, 1999, p. 342), precludes an age older than the uppermost Ordovician.

An Upper Ashgillian age is not probable because, during this period, members of the chitinozoan-families Conochitinidae EISENACK, 1931, emend. PARIS, 1981 and Lagenochitinidae EISENACK, 1931, emend. PARIS, 1981 were dominant (s. PARIS; 1996, Fig. 2) and the former is entirely missing in the studied assemblage.

Similarly, no representatives of the thick-walled chitinozoan-genera *Conochitina* EISENACK, 1931, emend. PARIS et al., 1999 and *Belonechitina* JANSONIUS, 1964 are present, both of which were very common in lower to middle Silurian times. Subsequently, they rapidly diminished in importance until they disappeared in the Pridoli (e.g. NESTOR, 1994; Tabs. 1, 3: Llandovery: 19 species, Wenlock: 21 species; SUTHERLAND, 1994; Fig. 36: Gorstian: 9 species, Ludfordian: 1 species). VERNIERS (1982) examined the late Ordovician to early or middle Ludlovian chitinozoans of the Mehaigne area of Belgium, which were transported by turbidites and underwent a very-low grade metamorphism (p. 56, 57, 68, 69). This showed that, in these badly preserved assemblages, *Conochitina* was one of the three dominant genera. Hence, if this genus and/or the similar *Belonechitina* had originally been present in the examined sample, they should also appear in the fossil record. Their absence, therefore, points to a younger age.

Of particular interest for a more precise age determination are the chitinozoan groups 1 and 2 (Pl. 1, Figs. 1, 2, 4, 5). Even though no ornamentation has been preserved, the chitinozoan group 1 (Pl. 1, Fig. 1a-d) resembles *Eisenackitina intermedia* (EISENACK, 1955), which ranges from the base of the *elongata* into the *elegans* chitinozoan biozone (upper Gorstian–lower Pridoli; s. VERNIERS et al., 1995; Text.-Fig. 3). The Chitinozoan group 2 (Pl. 1, Figs. 2, 4a–b, 5a–c) is similar to the thick-walled, urn- or egg-shaped, slightly inflated, spinous or smooth Desmochitinidae, which are known from many localities and are typical for the Ludfordian and the Pridoli (DE BOCK, 1982; DUFKA & GNOLLI, 1995; KRIZ et al., 1986; PARIS & KRIZ, 1981; PRIEWALDER, 2000; SCHWEINEBERG, 1987).

Like in the studied sample, the interval from the uppermost Ludfordian to the uppermost Pridoli in the Cellon-section of the Carnic Alps (PRIEWALDER, 2000; p. 23) is, beside the presence of *E. intermedia* in the lower part and several Lagenochitinidae taxa, dominated by the above mentioned thick-walled, urn- or egg-shaped *Urnochitina* gr. *urna* (EISENACK 1934), *U. urna* and *Eisenackitina* spp.. From the upper Pridoli to the top of the section in the lower Lochkovian, the fauna changes fundamentally as numerous Lagenochitinidae species rapidly replace the Desmochitinidae taxa. The latter finally disappear in the basal Lochkovian. The same phenomenon was reported by CHLUPAC, LAUFFELD & PARIS (1978) and PARIS, LAUFFELD & CHLUPAC (1981) from the Silurian/Devonian boundary stratotypes in Bohemia.

Apart from the great number of Lagenochitinidae, there are also numerous representatives of the Desmochitinidae in the lower Devonian. The latter, however, differ distinctly from those in the upper Silurian. In the Middle and Upper Devonian they diminish strongly in number in favour of the Lagenochitinidae (s. PARIS et al., 2000; Fig. 4). The examined chitinozoan assemblage does not resemble those from the Devonian.

Hence, on the basis of all the above-cited reasons, the chitinozoans from the Steinach Nappe indicate an upper Silurian age. The remaining fossils of the studied association seem to agree with this diagnosis.

4.3. Environment

Although the fossil assemblage is strongly reduced by selective preservation, some statements concerning the environment are still possible. As chitinozoans are exclusively marine, the sedimentation took place in a fully marine environment. However, the trilete spores, which are derived from land plants, indicate that they were deposited in more or less shallow water, not too far from the shore.

This is supported by the considerable number of the studied fossils that show similarities to the organic linings of agglutinated foraminfera, which are common in shallow marine environments during Ordovician to late Devonian times (BELL & WINCHESTER-SEETO, 1999; p. 27).

Furthermore it seems that the environmental conditions were optimal because of the large number of fossil groups that inhabited this part of the sea.

4.4. Palaeobiogeography

Due to the strongly depleted assemblage and the poor preservation of the remaining fossils, it is not possible to make any comments on the palaeobiogeographical relationships of the depositional area.

5. Conclusions

- This is the first report of fossils in the quartz phyllites of the Steinach Nappe. At first sight many of the fossils may look like mica-grains, but numerous EDX-analyses proved their organic nature. However, only 48 (~10%) of the 466 examined specimens turned out to be unambiguous fossils.
- As the samples were prepared for examining chitinozoans, sieving through a 50 μ-mesh sieve followed by picking under the binocular microscope at low magnification, led to a fossil association in which the specimens are no smaller than 80 μ.
- SEM-examination of such poorly preserved fossils is of supreme importance, because only in this way is it possible to distinguish them from often quite similar fragments. The investigations under the binocular light microscope before, and the transmission light microscope after, the SEM studies are also important for obtaining an impression of the original aspect of the biogenous remains, as well as for the evaluation of dubious objects.
- The preservation of the examined fossils is unique: the already thin walls of all the completely flattened and frequently wrinkled, distorted and broken specimens are altered to stacks of numerous fine layers (<$^1/_2 \mu$ thick), with the outermost layers obviously removed, as no ornamentation has been observed. At present, it is not clear what post-sedimentary conditions caused this special feature.
- As no ornamentation and only very rarely morphological features (such as operculi or apical structures with the chitinozoans) have been preserved, the only criteria for the identification of the above described fossils were their shapes and sizes.
- Several fossil-groups have been identified: chitinozoans, scolecodonts, sphaeromorphs, sporomorphs, as well as diverse incertae sedis groups. Members of the latter are similar to acritarchs, melanosclerites, organic linings of arenaceous foraminifera, juvenile brachiopods and the teeth of arthropod cuticles.
- A rough age has been determined: the presence of chitinozoans and trilete spores indicates a Lower Palaeozoic age no older than the Ashgill. The absence of representatives of the chitinozoan-family Conochitinidae and the overall appearance of the chitinozoan assemblage suggest an upper Silurian age for the examined sample.

- The chitinozoans point to a fully-marine environment whilst the trilete spores suggest near-shore sedimentation. Moreover the environmental conditions were optimal, as numerous fossil groups inhabited this part of the sea.
- The poorly preserved fossil assemblage does not permit any conclusion concerning the palaeobiogeographical relationships of the deposition area.

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Plate 1

Fig. 1: **Chitinozoan group 1.**
a) Lateral view.
The left flank of the vesicle is slightly shortened by a distinct wrinkle (s. Fig. 1c); the upper part of the right flank is covered by delicate wall layers with a tight fold (s. Fig. 1d).
× 300; slide 2007/153/8, England Finder (EF): M.23.3.
b) Oblique lateral view*).
× 370.
c) Oblique lateral view.
× 365.
d) Detail of Fig. 1b.
The lower margin of the vesicle shows a tight fold of the stack of fine wall layers.
× 515.

Fig. 2: **Chitinozoan group 2.**
Lateral view.
Outermost layers of the vesicle wall removed; the present surface has a glossy mica-like aspect. The triangular crack in the basal part of the specimen suggests that it was originally more or less inflated.
× 250; slide 2007/153/2, EF: P.15.1.

Fig. 3: **Chitinozoan group 4.**
a) Lateral view.
× 400; slide 2007/153/16, EF: P.17.
b) Oblique lateral view.
× 540.
c) Detail of Fig. 3a in oblique lateral view.
Outer layers of the vesicle wall crushed into thin fragments; inner layers have a glossy, mica-like appearance. A remnant of the former central cavity of the now completely flattened specimen is still visible in the lower left part of the photo.
× 1475.

Fig. 4: **Chitinozoan group 2.**
a) Lateral view.
Outer part of the vesicle wall crushed into thin fragments of various sizes giving the surfaces an uneven rough aspect; inner layers have a glossy, mica-like appearance.
× 300; slide 2007/153/13, EF: O.18.
b) Oblique lateral view.
× 385.

Fig. 5: **Chitinozoan group 2.**
a) Lateral view.
Arrows indicate the EDX analysis points. Point 1: albite grain that grew in the central cavity; point 2: pure carbon.
× 350; slide 2007/153/5, EF: K.13.
b) Oblique anti-apertural view.
Remnant of an apical structure.
× 490.
c) Detail of Fig. 5a in oblique lateral view.
Relic of an apical structure.
× 1515.

Fig. 6: **Chitinozoan group 3.**
a) Lateral view.
On the upper left part, the vesicle surface has a spotted appearance that might represent a former verrucate or spiny ornamentation.
× 300; slide 2007/153/4, EF: M.13.
b) Oblique anti-apertural view.
× 395.

Tilt angle for all the oblique views: 60°.

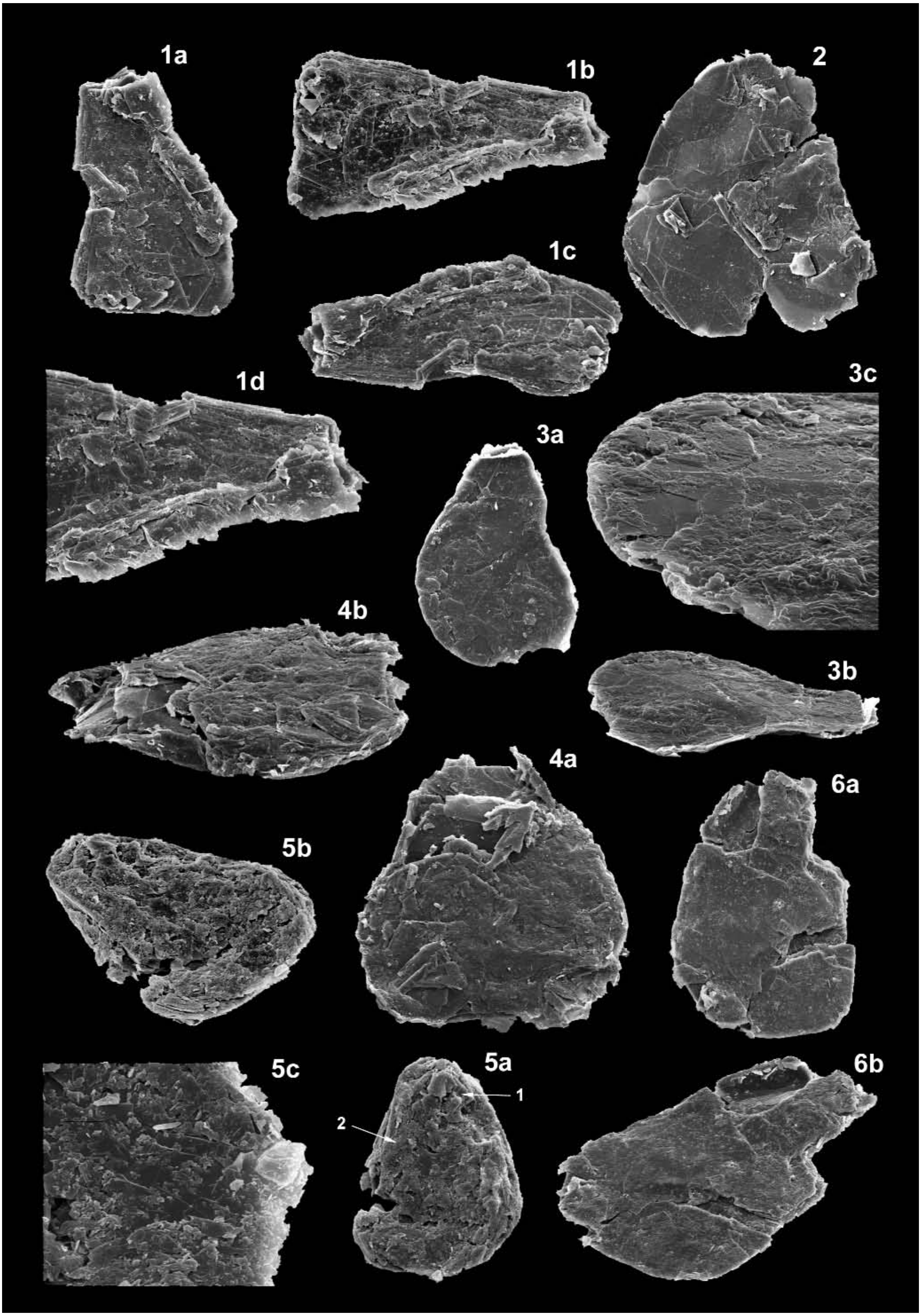
1a
1b
2
1c
1d
3c
3a
4b
3b
4a
6a
5b
5c
5a
1
2
6b

Plate 2

Fig. 1: **Chitinozoan group 4.**
a) Lateral view.
Arrows indicate the EDX analysis points. Point 1: rutile plus a small carbon-peak in the diagram; point 2: rutile plus a prominent carbon-peak; point 3: pure rutile.
× 350; slide 2007/153/5, EF: K.14.1.
b) Oblique anti-apertural view*).
× 545.
c) Detail of Fig. 1a in oblique apertural view.
Rutile crystals covered by relics of an organic wall.
× 855.
d) Detail of Fig. 1c.
Vesicle wall corroded to thin fragments of various sizes.
× 1325.

Fig. 2: **Chitinozoan group 6.**
a) Lateral view.
× 350; slide 2007/153/8, EF: L.21.
b) Oblique apertural view.
The margin on the left side of the vesicle shows an tight fold of the wall, which has been broken up into several layers.
× 440.

Fig. 3: **Scolecodont.**
Normal view.
× 250; slide 2007/153/21, EF: P.16.

Fig. 4: **Chitinozoan group 5.**
a) Lateral view.
× 350; slide 2007/153/22, EF: O.19.4.
b) Oblique lateral view.
The small cavity immediately to the right of the operculum indicates that the specimen was originally hollow.
× 415.
c) Detail of Fig. 4b.
Relic of an operculum.
× 915.

Fig. 5: **Chitinozoan group 5.**
a) Lateral view.
× 350; slide 2007/153/20, EF: N. 15.
b) Detail of Fig. 5a.
Relic of an operculum.
× 630.

Fig. 6: **Scolecodont.**
a) Normal view.
The arrow points to the only completely preserved denticle of the specimen.
× 200; slide 2007/153/19, EF: P.17.
b) Detail of Fig. 6a in oblique view; arrow as in Fig. 6a.
× 555.

*) Tilt angle for all the oblique views: 60°.

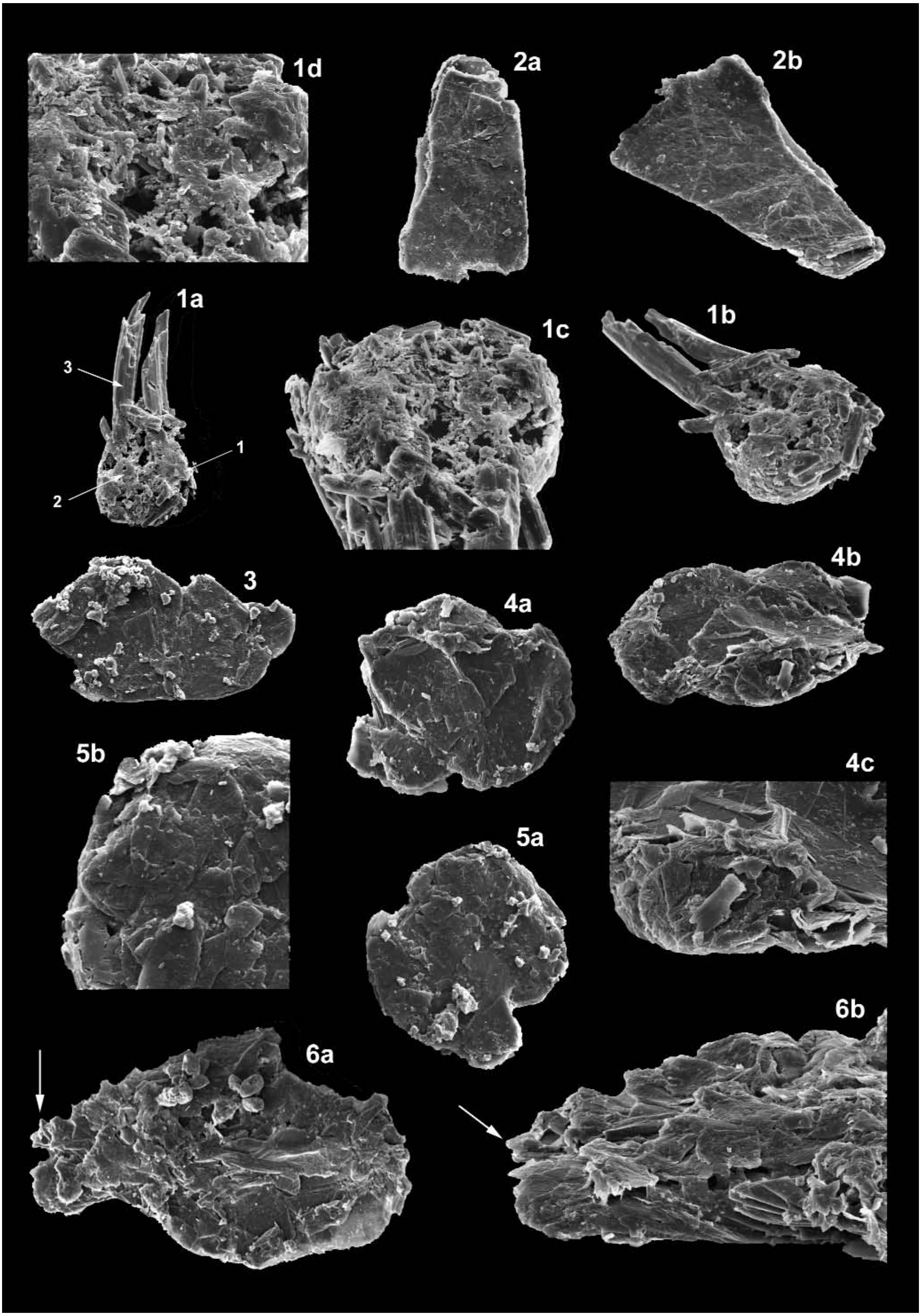
1d
2a
2b
1a
3
1
2
1c
1b
3
4b
4a
5b
4c
5a
6b
6a

Plate 3

Fig. 1: **Sporomorph.**
a) Polar view.
Subtriangular specimen with two thirds of the proximal surface broken away along the tetrade mark.
× 400; slide 2007/153/19, EF: N.17.1.
b) Oblique equatorial view*).
× 480.
c) Detail of Fig. 1b.
The wall of the spore is altered to a stack of delicate layers.
× 825.

Fig. 2: **Sporomorph.**
a) Polar view.
The subtriangular outline of the specimen suggests a sporomorph origin.
× 400; slide 2007/153/16, EF: O.15.
b) Oblique equatorial view.
The slight thickening of the front margin might be caused by an internal mould.
× 490.

Fig. 3: **Sporomorph.**
Polar view.
Proximal surface removed.
× 400; slide 2007/153/21, EF: Q.18.2.

Fig. 4: **Sphaeromorph.**
a) Normal view.
Very large specimen (for comparison, see Pl. 6, Fig. 20).
× 250; slide 2007/153/10, EF: N.14.2.
b) Oblique view.
× 290.
c) Detail of Fig. 4b.
Outer layers of the vesicle wall crushed into thin fragments of various sizes; inner layers with a mica-like appearance..
× 440.
d) Detail of Fig. 4b.
The vesicle wall is altered to a stack of delicate layers.
× 875.

Fig. 5: **Sphaeromorph.**
Normal view.
Comparatively minute specimen (for comparison, see Pl. 6, Fig. 21) on which the outer layers of the vesicle seem to have been removed.
× 400; slide 2007/153/2, EF: P.16.2.

Fig. 6: **Scolecodont.**
a) Normal view.
The arrow points to the only completely preserved denticle of the specimen.
× 350; slide 2007/153/4, EF: R.14.4.
b) Oblique view.
× 405.
c) Detail of Fig. 6a in oblique view.
The wall of the scolecodont is altered to a stack of delicate layers. Arrow as in Fig.6a.
× 920.

Fig. 7: **Sporomorph.**
a) Polar view.
Two thirds of the proximal surface of this originally most likely subtriangular specimen has broken away along the tetrade mark.
× 400; slide 2007/153/13, EF: P.18.
b) Detail of Fig. 7a in equatorial view.
The wall of the spore is divided into numerous thin layers.
× 825.

*) Tilt angle for all the oblique views: 60°.

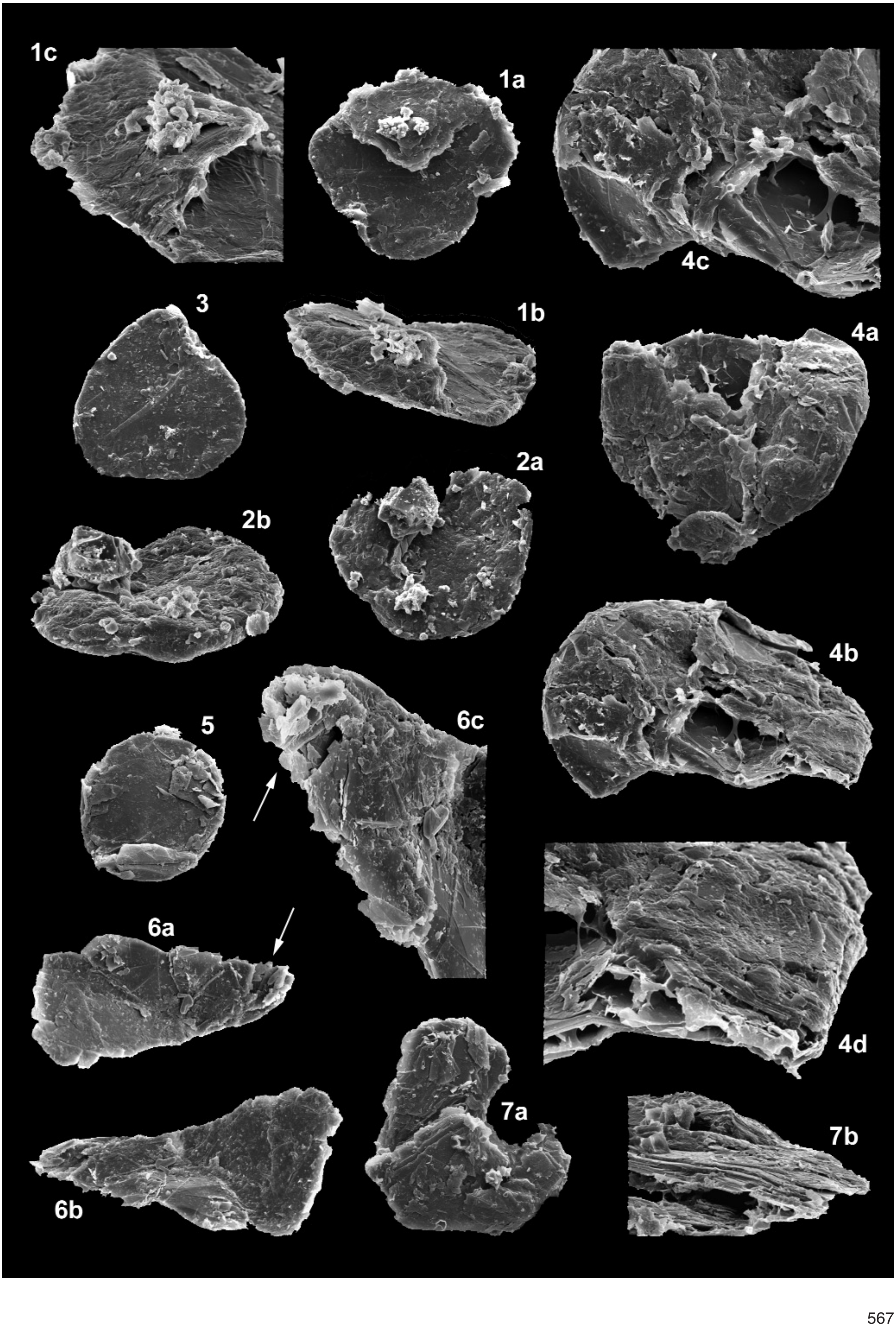
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Plate 4

Fig. 1: **Sphaeromorph.**
a) Normal view.
Specimen slightly inflated, probably due to an internal mould.
× 350; slide 2007/153/5, EF: H.18.
b) Detail of Fig.1a in oblique view*).
Outer part of the wall, which is now present as a stack of delicate layers, has been crushed into fragments of different sizes.
× 1835.
c) Detail of Fig. 1a in oblique view.
× 600.

Fig. 2: **Sphaeromorph.**
a) Normal view.
× 350; slide 2007/153/6, EF: P.20.2.
b) Oblique view.
Slightly inflated; probably internal mould present (with a mica-like aspect of the central part of the specimen).
× 415.
c) Detail of Fig. 2a in oblique view.
Outer part of the wall crushed into thin layered fragments..
× 875.

Fig. 3: **Incertae sedis – group 3.**
Lateral view.
The specimen has been crushed to layered fragments of various size and thickness.
× 250; slide 2007/153/9, EF: J.20.3.

Fig. 4: **Incertae sedis – group 1.**
a) Normal view.
At least four short blunt conical protuberances have a tetrahedral arrangement.
× 300; slide 2007/153/13, EF: P.18.4.
b) Oblique view.
× 395.

Fig. 5: **Sphaeromorph.**
Normal view.
× 350; slide 2007/153/16, EF: P.18.

Fig. 6: **Incertae sedis – group 2.**
a) Lateral view.
× 250; slide 2007/153/10, EF: O.16.4.
b) Oblique lateral view.
The central part of the specimen has been abraded and shows a mica-like appearance.
× 275.
c) Detail of Fig. 6a in oblique lateral view.
× 450.

Fig. 7: **Sphaeromorph.**
a) Normal view.
Central and marginal part of the specimen show different structures.
× 300; slide 2007/153/4, EF: M.13.4.
b) Oblique view.
× 340.

*) Tilt angle for all the oblique views: 60°.

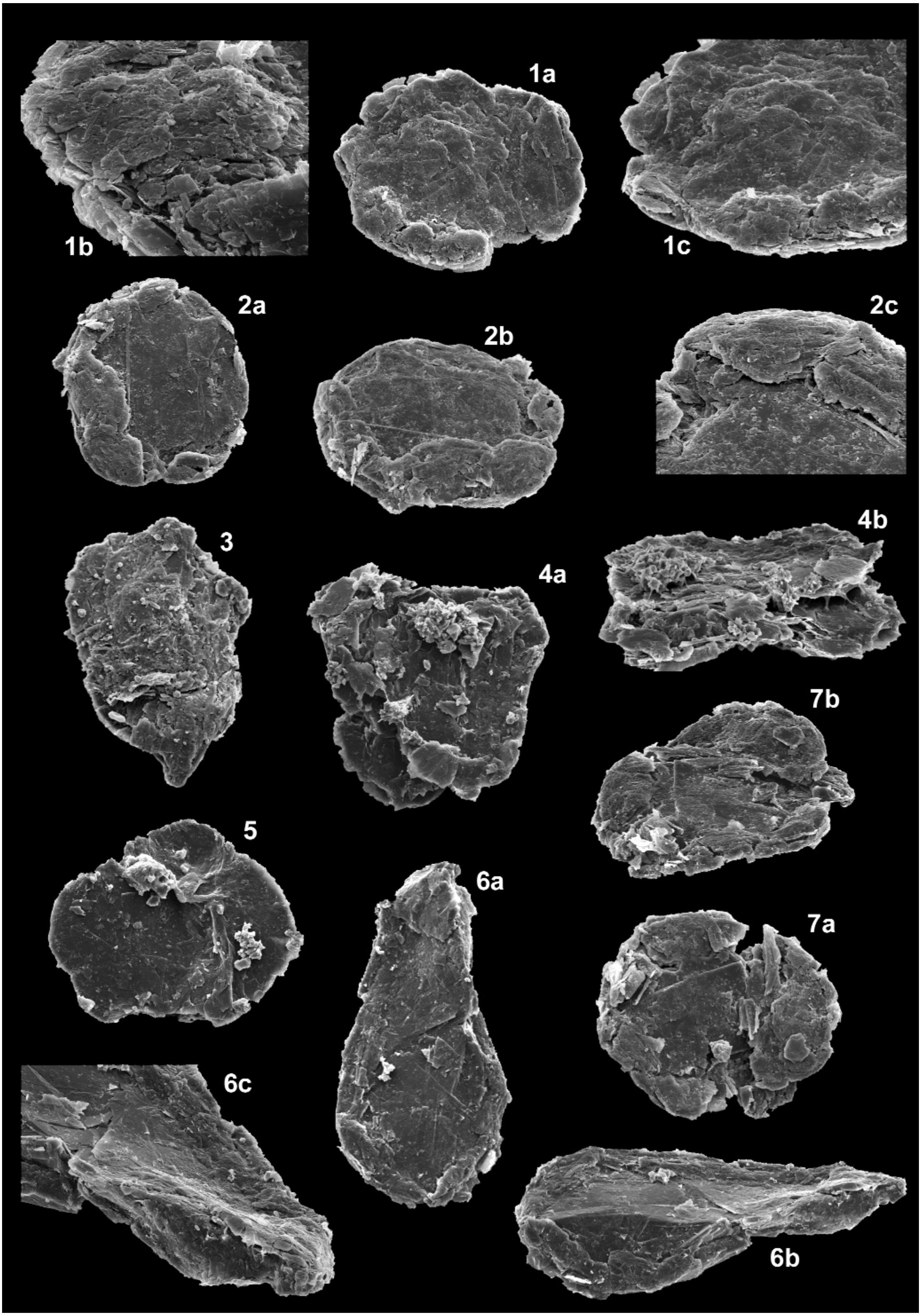
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Plate 5

Fig. 1: **Incertae sedis – group 4.**
a) Lateral view.
× 300; slide 2007/153/9, EF: L.19.1.
b) Oblique lateral view*).
Only in the specimen's thickened lower left area, the front part of the "tooth" seems to be present.
× 375.

Fig. 2: **Incertae sedis – group 4.**
a) Lateral view.
Tip of the originally conical specimen broken away.
× 350; slide 2007/153/10, EF: O.15.2.
b) Oblique lateral view.
× 390.

Fig. 3: **Incertae sedis – group 5.**
a) Normal view.
× 300; slide 2007/153/2, EF: P.16.
b) Oblique view.
Specimen slightly inflated, probably due to an internal mould.
× 490.
c) Detail of Fig. 3b.
Outer layers of the vesicle wall crushed into thin fragments of various sizes, giving the surfaces an uneven, rough aspect; layers of the internal mould have a glossy, mica-like appearance.
× 690.
d) Detail of Fig. 3a in oblique view.
× 645.

Fig. 4: **Incertae sedis – group 6.**
Normal view.
The right part of the specimen is more strongly flattened and deformed than the left.
× 350; slide 2007/153/12, EF: K.14.2.

Fig. 5: **Incertae sedis – group 6.**
a) Normal view.
× 350; slide 2007/153/4, EF: M.13.3.
b) Oblique view.
In the left area of the specimen, the lower part of the stack of layers, to which the wall has been altered, was slightly shifted to the left. This surface has a glossy, mica-like aspect.
× 455.

Fig. 6: **Incertae sedis – group 8.**
a) Normal view.
Obviously an upper and a lower valve present.
× 400; slide 2007/153/20, EF: N.15.
b) Oblique view.
× 470.

Fig. 7: **Incertae sedis – group 7.**
a) Normal view.
× 250; slide 2007/153/8, EF: K.20.
b) Oblique view.
× 305.
c) Detail of Fig. 7a in oblique view.
On the left side of the test, the crushed thin original wall seems to peel off from a solid internal mould, which is also divided into a stack of thin layers.
× 515.

Fig. 8: **Incertae sedis – group 8.**
Normal view.
The structure at the left side of the specimen suggests that an upper and a lower valve are present.
× 350; slide 2007/153/16, EF: O.16.4.

*) Tilt angle for all the oblique views: 60°.

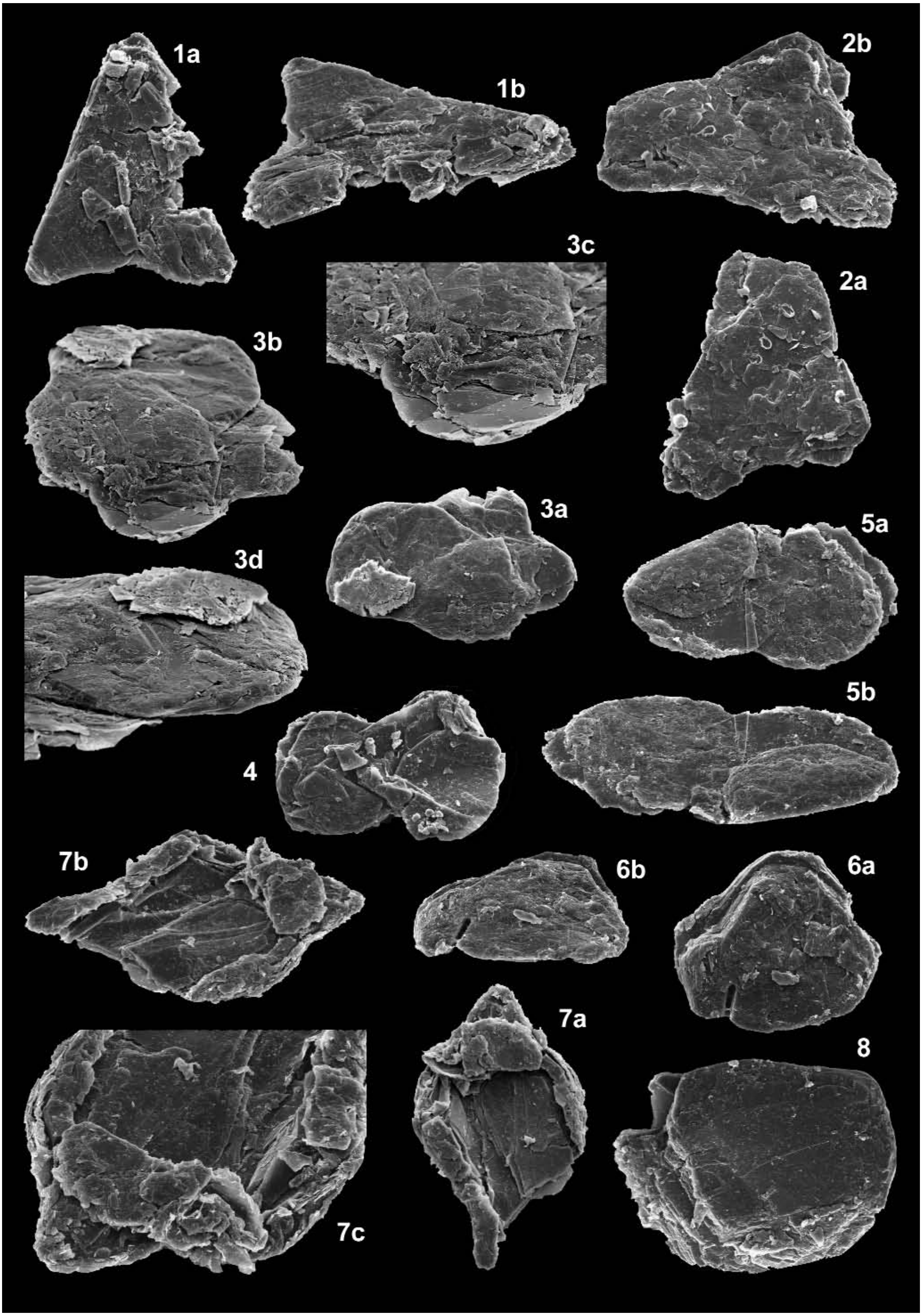
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Plate 6

Chitinozoan – group 1 (P. 556)
Fig. 7: Photo of the specimen in Pl. 1, Fig. 1a.

Chitinozoan – group 2 (P. 556)
Fig. 1: Photo of the specimen in Pl. 1, Fig. 4a.
Fig. 2: Photo of the specimen in Pl. 1, Fig. 5a.
Fig. 5: Photo of the specimen in Pl. 1, Fig. 2.

Chitinozoan – group 3 (P. 556)
Fig. 9: Photo of the specimen in Pl. 1, Fig. 6a.

Chitinozoan – group 4 (P. 556)
Fig. 3: Photo of the specimen in Pl. 2, Fig. 1a.
Fig. 4: Photo of the specimen in Pl. 1, Fig. 3a.

Chitinozoan – group 5 (P. 556)
Fig. 10: Photo of the specimen in Pl. 2, Fig. 5a.
Fig. 11: Photo of the specimen in Pl. 2, Fig. 4a.

Chitinozoan – group 6 (P. 557)
Fig. 6: Photo of the specimen in Pl. 2, Fig. 2a.

Scolecodonts (P. 557)
Fig. 8: Photo of the specimen in Pl. 2, Fig. 6a.
Fig. 12: Photo of the specimen in Pl. 2, Fig. 3.
Fig. 17: Photo of the specimen in Pl. 3, Fig. 6a.

Sphaeromorphs (P. 557)
Fig. 15: Photo of the specimen in Pl. 4, Fig. 5.
Fig. 16: Photo of the specimen in Pl. 4, Fig. 2a.
Fig. 20: Photo of the specimen in Pl. 3, Fig. 4a.
Fig. 21: Photo of the specimen in Pl. 3, Fig. 5.
Fig. 22: Photo of the specimen in Pl. 4, Fig. 7a.
Fig. 27: Photo of the specimen in Pl. 4, Fig. 1a.

Sporomorphs (P. 557)
Fig. 13: Photo of the specimen in Pl. 3, Fig. 1a.
Fig. 14: Photo of the specimen in Pl. 3, Fig. 7a.
Fig. 18: Photo of the specimen in Pl. 3, Fig. 3.
Fig. 19: Photo of the specimen in Pl. 3, Fig. 2a.

Incertae sedis – group 1 (P. 558)
Fig. 34: Photo of the specimen in Pl. 4, Fig. 4a.

Incertae sedis – group 2 (P. 558)
Fig. 32: Photo of the specimen in Pl. 4, Fig. 6a.

Incertae sedis – group 3 (P. 558)
Fig. 33: Photo of the specimen in Pl. 4, Fig. 3.

Incertae sedis – group 4 (P. 558)
Fig. 28: Photo of the specimen in Pl. 5, Fig. 1a.
Fig. 29: Photo of the specimen in Pl. 5, Fig. 2a.

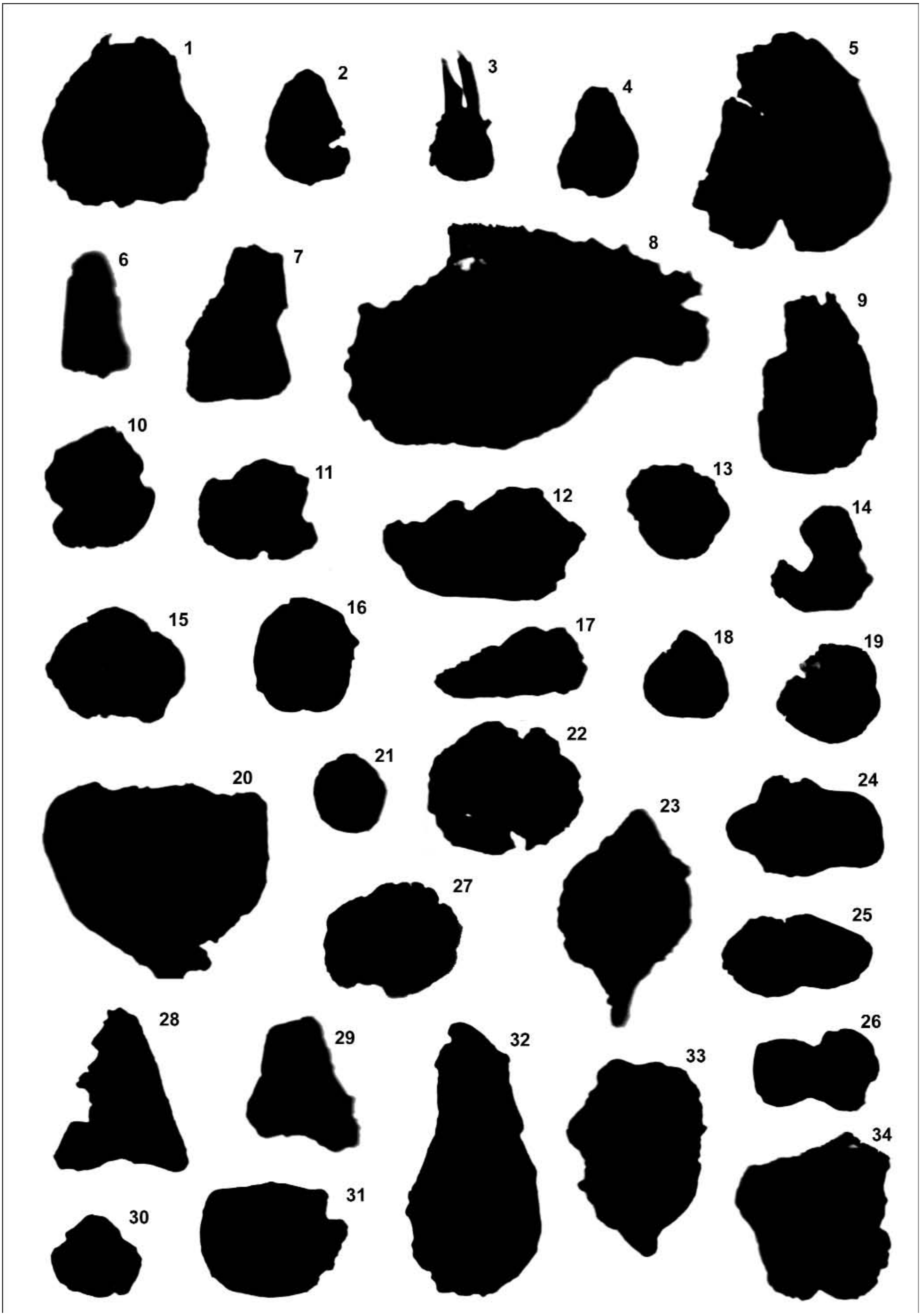
Incertae sedis – group 5 (P. 558)
Fig. 24: Photo of the specimen in Pl. 5, Fig. 3a.

Incertae sedis – group 6 (P. 558)
Fig. 25: Photo of the specimen in Pl. 5, Fig. 5a.
Fig. 26: Photo of the specimen in Pl. 5, Fig. 4.

Incertae sedis – group 7 (P. 558)
Fig. 23: Photo of the specimen in Pl. 5, Fig. 7a.

Incertae sedis – group 8 (P. 559)
Fig. 30: Photo of the specimen in Pl. 5, Fig. 6a.
Fig. 31: Photo of the specimen in Pl. 5, Fig. 8.

Magnification: x 190.
All Figures were made using the transmitted light microscope; SEM photographs of the fossils are shown on plate 1–5.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