Pseudoamorphous organic material in palynological and palynofacies preparations from Mesozoic & Cenozoic sediments in the North Sea, Norwegian Sea and Barents Sea

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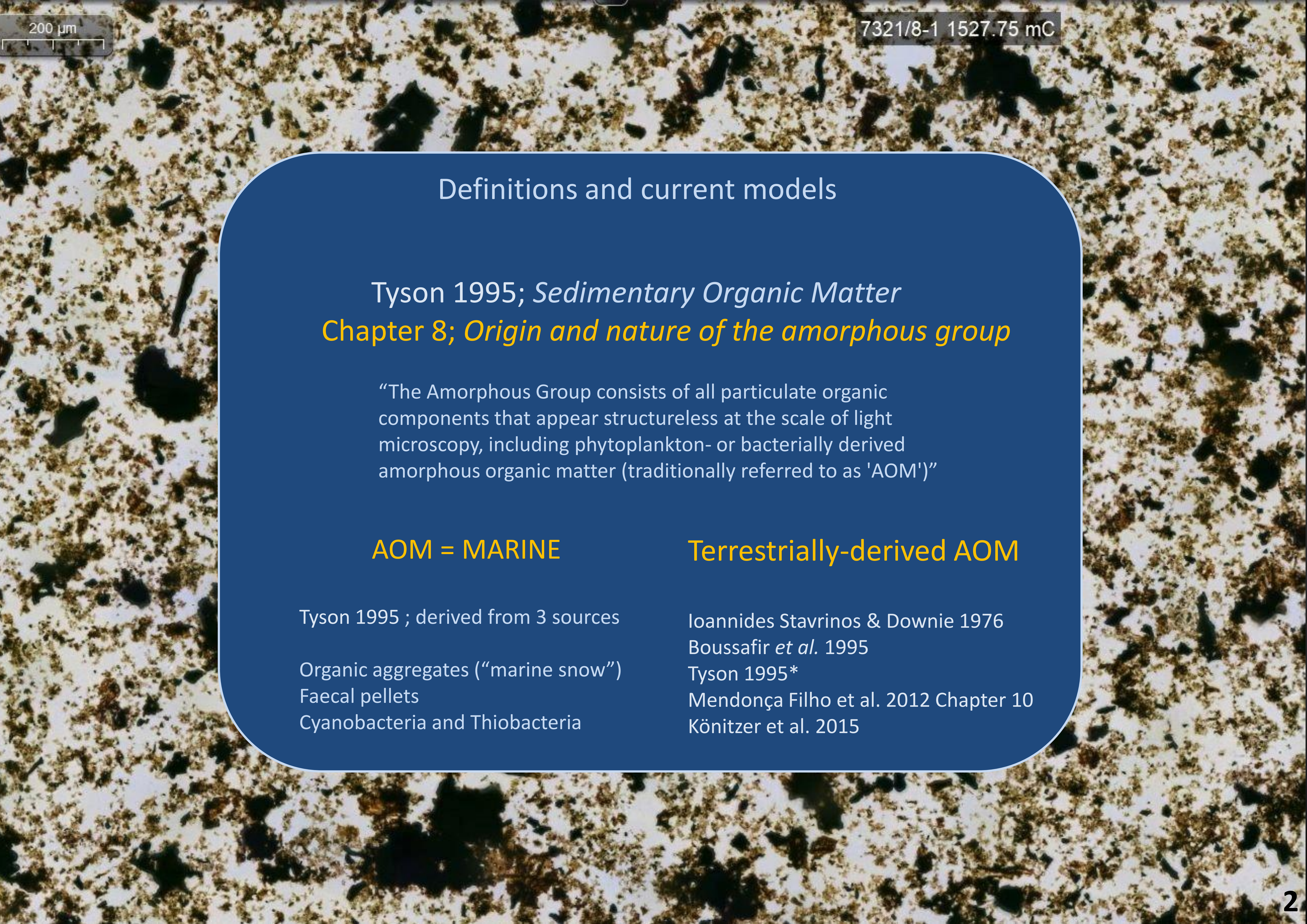
FORCE Webinar presentation
26th October 2021



Definitions and current models

Tyson 1995; *Sedimentary Organic Matter*

Chapter 8; *Origin and nature of the amorphous group*

"The Amorphous Group consists of all particulate organic components that appear structureless at the scale of light microscopy, including phytoplankton- or bacterially derived amorphous organic matter (traditionally referred to as 'AOM')"

AOM = MARINE

Tyson 1995 ; derived from 3 sources

Organic aggregates ("marine snow")
Faecal pellets
Cyanobacteria and Thiobacteria

Terrestrially-derived AOM

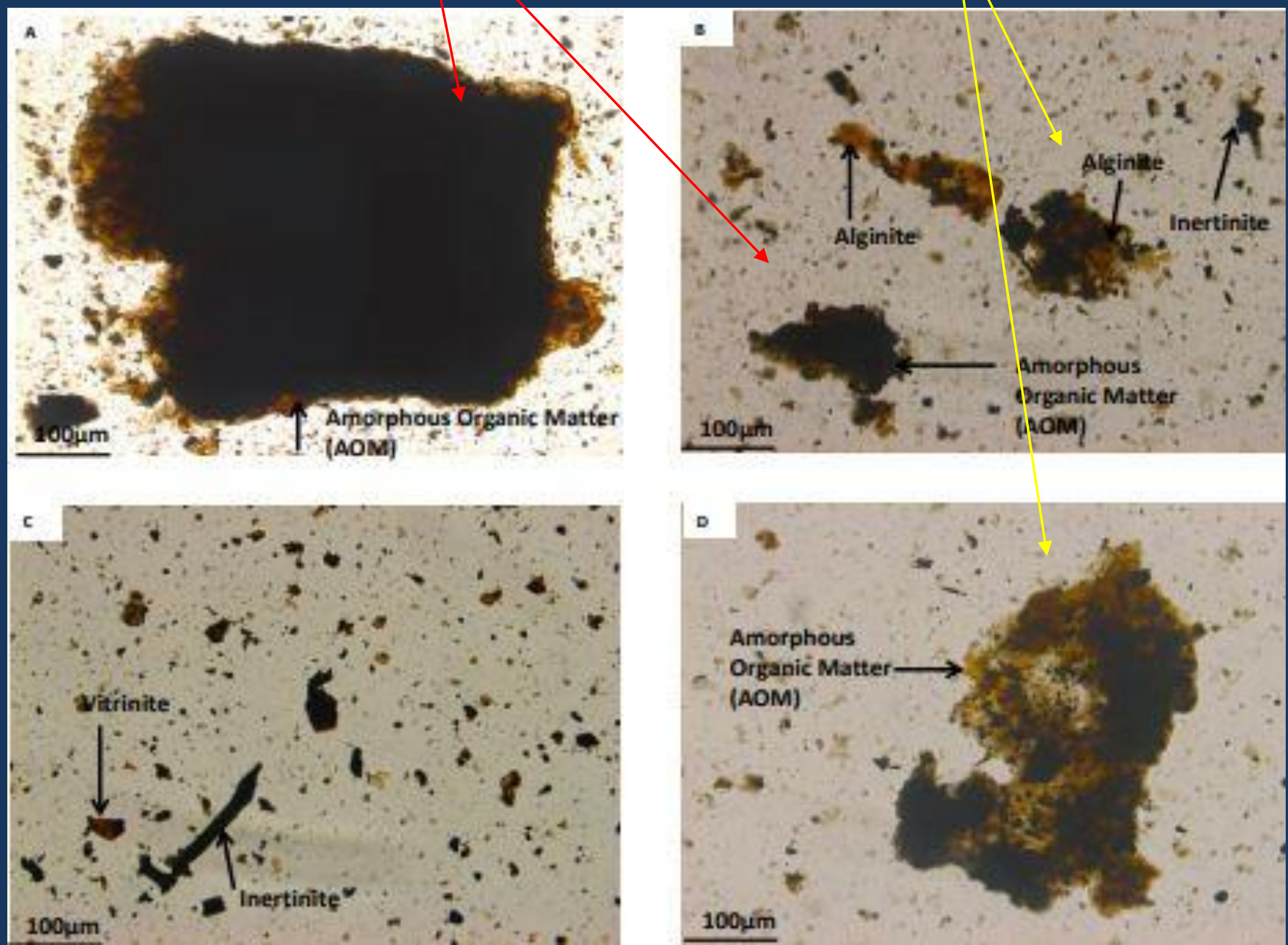
Ioannides Stavrinos & Downie 1976
Boussafir *et al.* 1995
Tyson 1995*
Mendonça Filho et al. 2012 Chapter 10
Könitzer et al. 2015

AOM in palynofacies articles

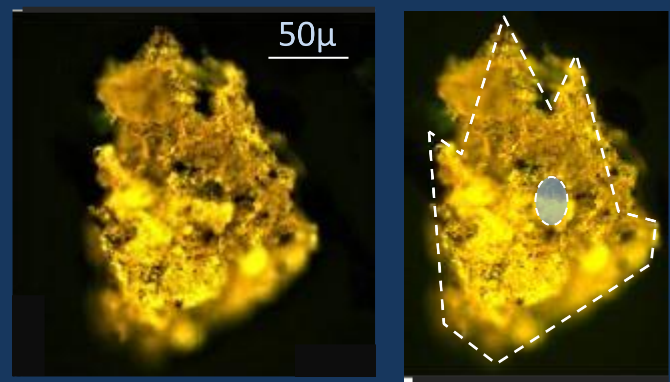
Kerogen from the Kimmeridge Clay Fm, North Sea Raji 2018

Opaque inner zone surrounded by translucent tissue

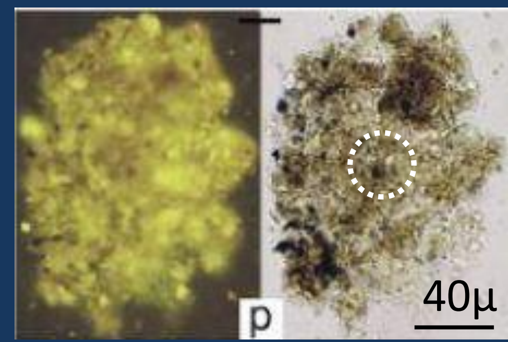
Translucent tissues enclosing several smaller opaque bodies



Faint structures in AOM particles?

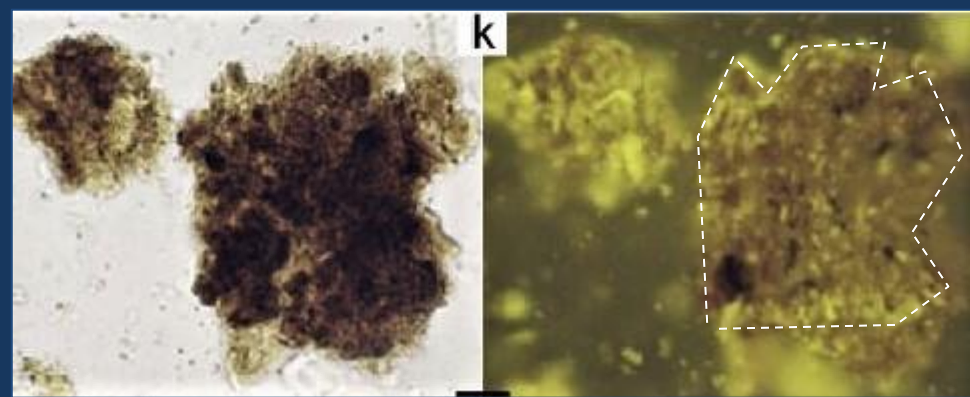


Gonçalves et al 2013 Fig6D (reoriented)



Koch et al. 2017 Fig 5d (reoriented)

Above & below; faint maple leaf shape and central rounded feature highlighted. Upper left; radiating lobes on margin an mamilate boss at centre



"Marine AOM of cyanobacterial origin"; Koch et al 2017 Fig 4k.

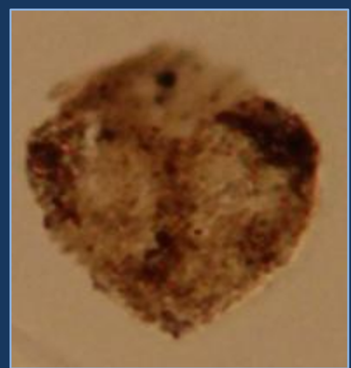
Diaspores: “spores and other propagules that function in dispersal” Glime 2017

Gemma of extant liverwort *Marchantia*

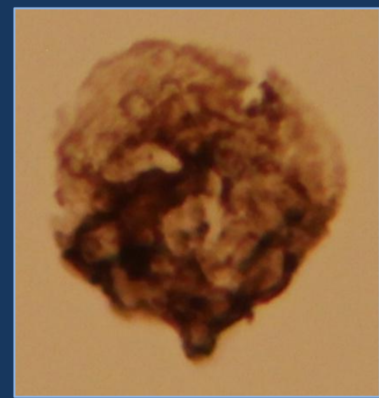
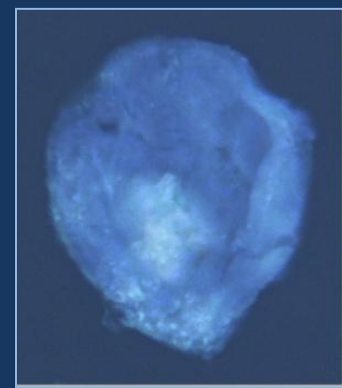
“Sangarelladinium gudrunae”
Mid Jurassic, NNS

Modified from Bailey 2015 (FORCE presentation)



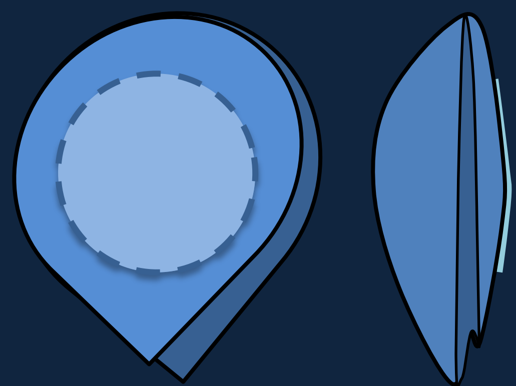



www.flickr.com

20µ approx

FORCE Meeting 2015



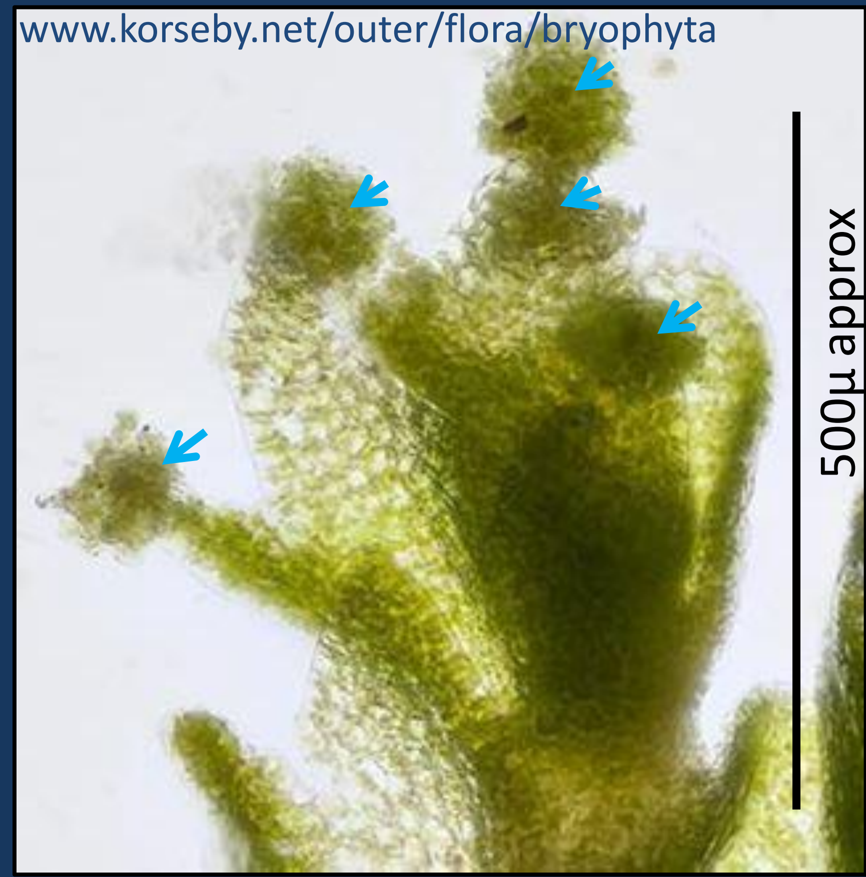
Marchantia gemmae

Discoid
Lenticular transverse X section
Cuneiform longitudinal X section

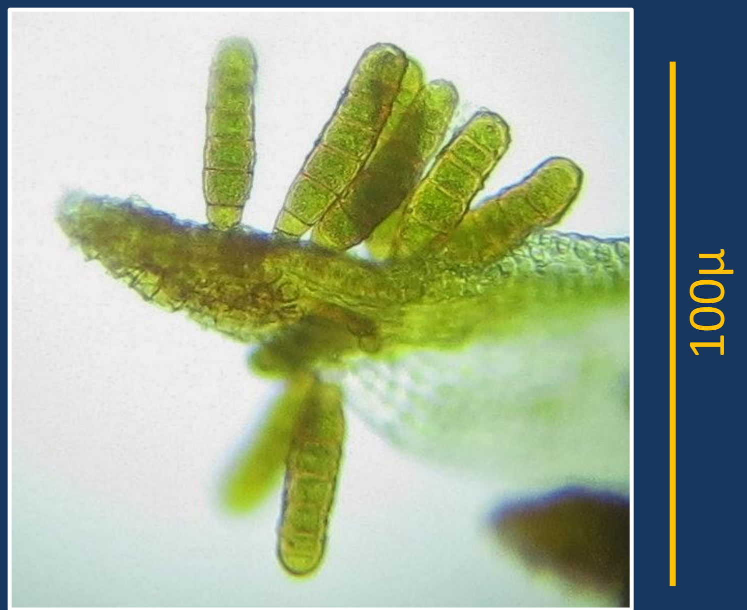
Examples of gemmae in modern bryophytes

Branch of the leafy liverwort *Radula australis*, with discoid, multicellular gemmae along leaf margins. www.una.edu

Gemmae clustered on propaguliferous leaf of extant moss *Grimmea*
Porley & Pressel 2012 Fig. 8b



Branch tip with gemmae of extant liverwort *Lophozia ventricosa*

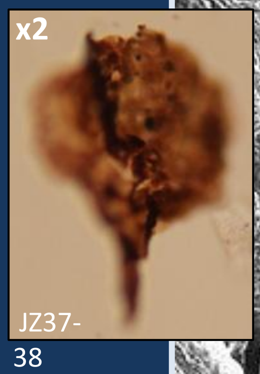


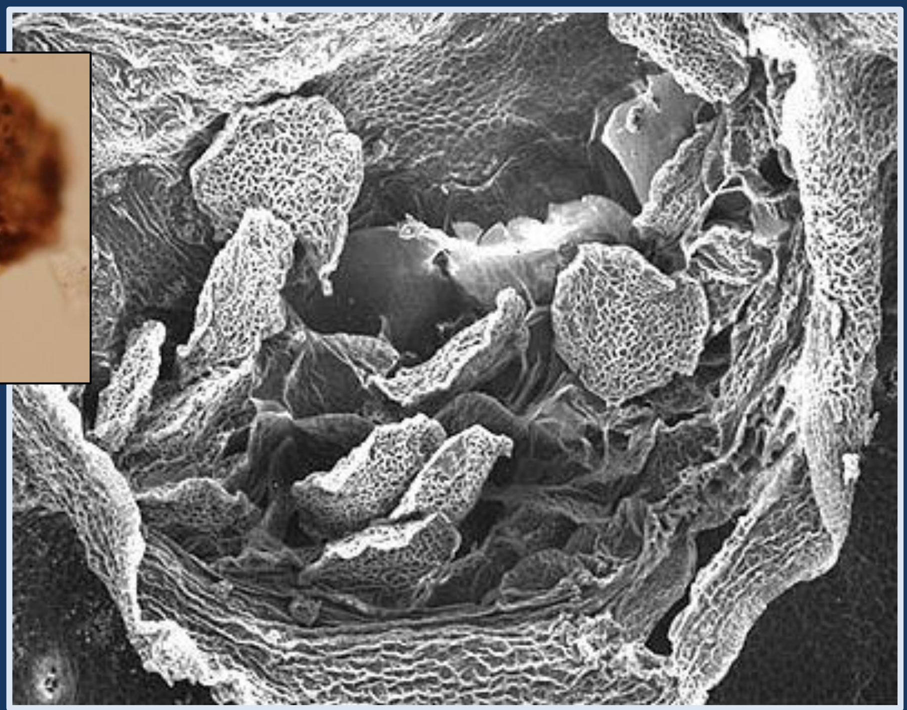
Gemmae of extant liverwort *Ulota phyllantha:* cluster at leaf tip. www.facstaff.cbu.edu

Gemmae of liverwort *Blasia*. www.facstaff.cbu.edu

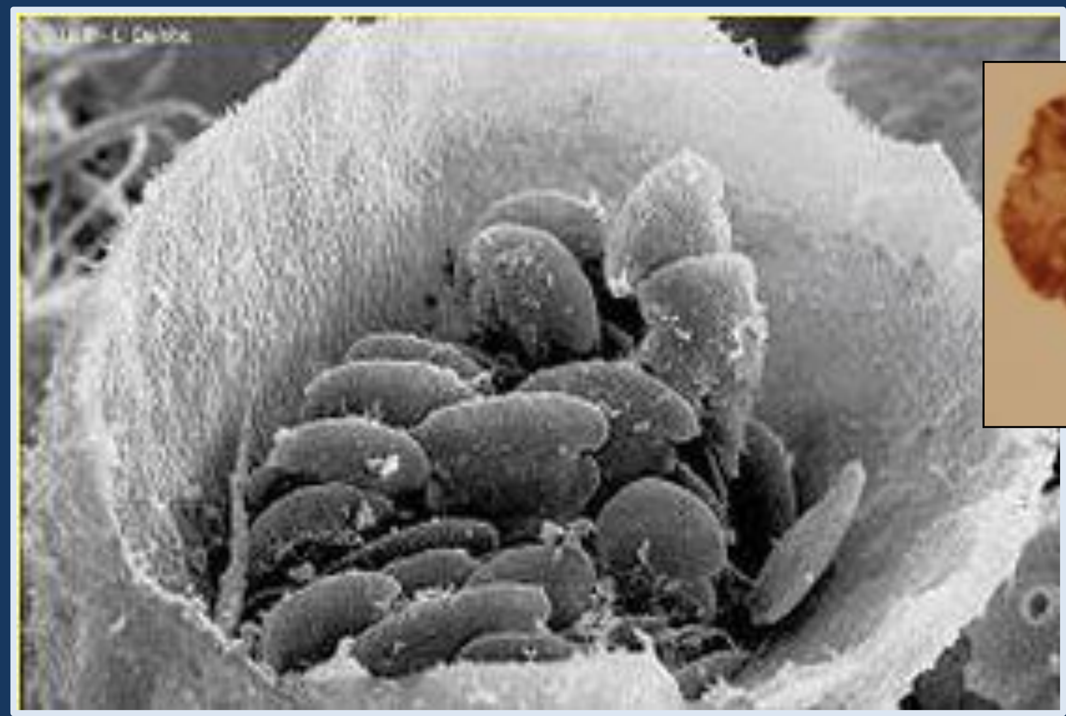
Tritomaria execta
shoot tip with gemmae

Gemmae cups (Thalloid liverworts)





50µ



Gemmae cup of *Lunularia cruciata*, an extant liverwort. www.botany.ubc.ca

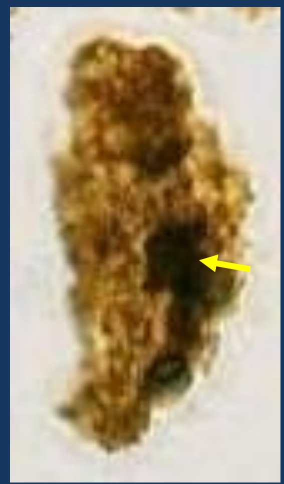
Liverwort gemmae in gemmae cup. www.ou.edu

Modern and fossil gemmae

Modern

Extant Barbula crocea gemma, Chavoutier 2017 , Pl. 9 Bar 30µ approx

Jurassic , NNS



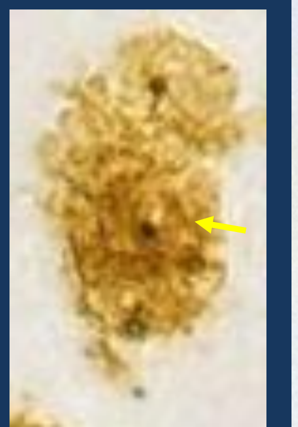
20µ approx

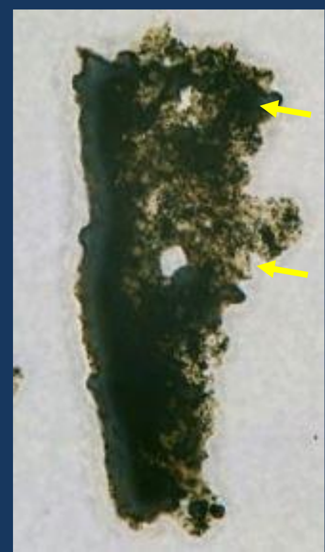
Rosette shape around a darker central feature (yellow arrows) , which commonly has an embedded opaque body. Carotiform shape, sometimes with “stalk” at narrow pole (black arrows), or a constriction (red arrows). In addition there is often a short “upward” pointing spine on one side near the narrow pole (blue arrows).

Koch et al. 2017, Fig. 5 f (as AOM). Late Jurassic of Croatia

Other examples from the Triassic & Jurassic

100µ

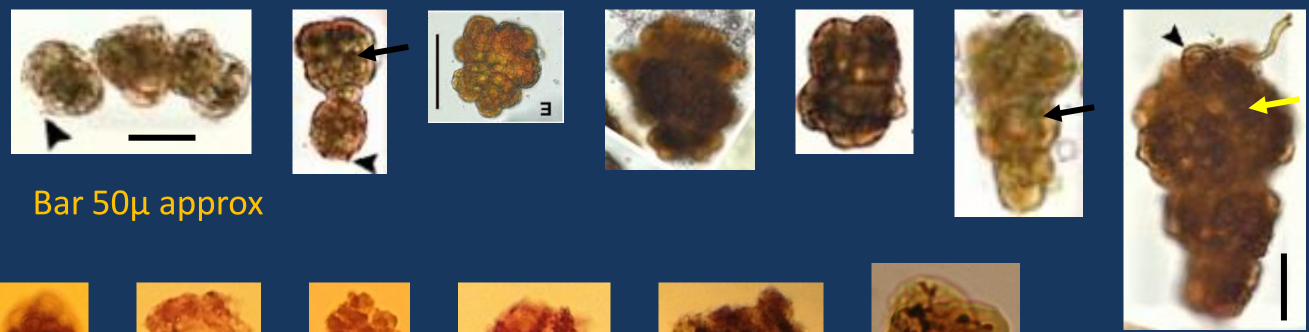




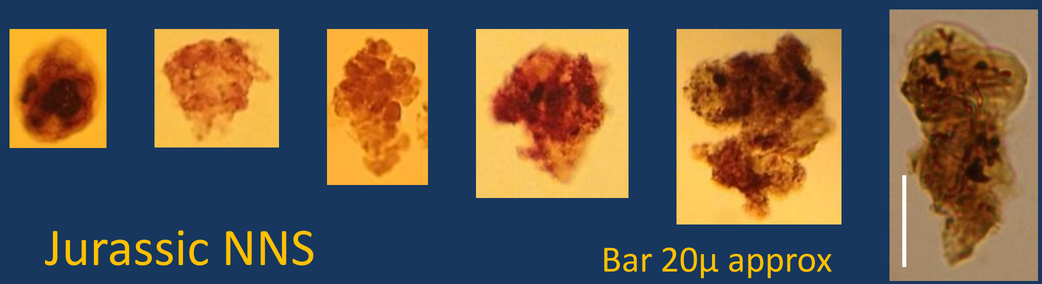
Modern and fossil gemmae

Change of shape during growth

Botryoidal gemmae of extant moss *Grimmea* Porley & Pressel 2012



Bar 50µ approx



Jurassic NNS

Bar 20µ approx

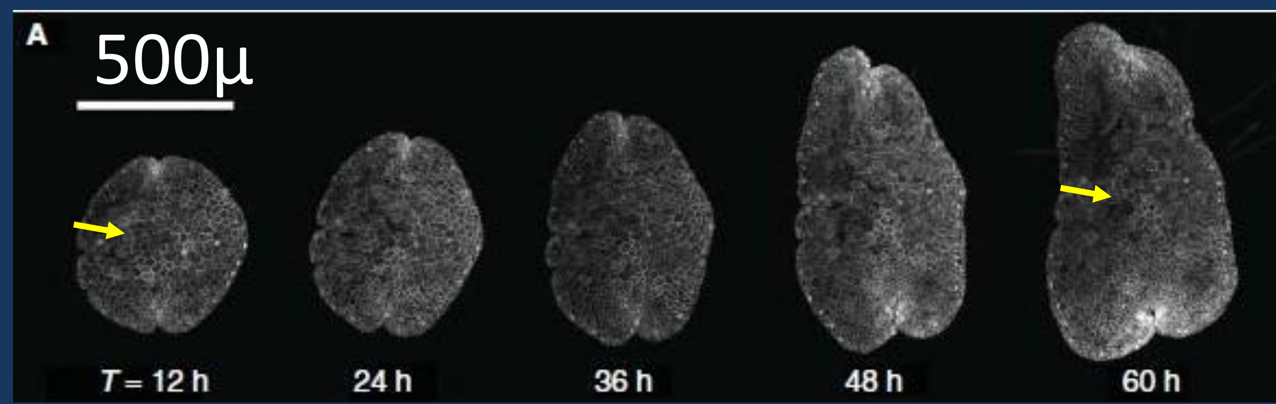
Gemmae on leaf margin of extant leafy liverwort

Jurassic, NNS

Change of shape during growth

Two-day old gemmalings of *Marchantia polymorpha* ,
from Fig. 1A in Honkanen *et al.* 2016. Bar = 100µ

Growth of *Marchantia polymorpha* gemmae.
Boehm *et al.* 2017, Fig. 5A



Silva-E-Costa et al 2017

showing germination and early growth of extant *Frullania ericoides* spores (liverwort)

week 1 | week 2 | week 3 | week 3

Figure 1C

Rupture of wall

Figure 2D

Figure 2 E

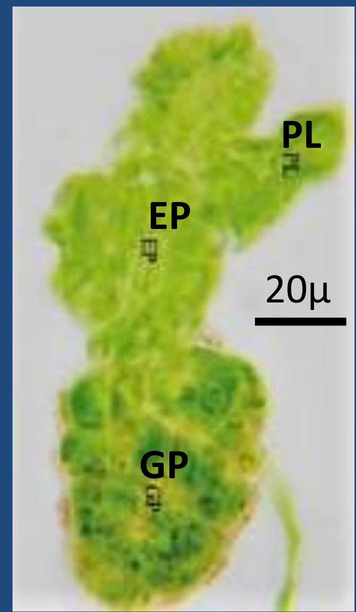


Figure 2F

Silva-E-Costa et al 2017 compiled and reoriented from figs 1 & 2

GP: globular protonema

EP: external protonema

PL: primary leaf

Protonema of *Marchantia* polymorpha Shimamura 2016 Fig 3E & F

10µ

Hornwort spores

https://www2.palomar.edu/users/warmstrong/idyllwild2.htm

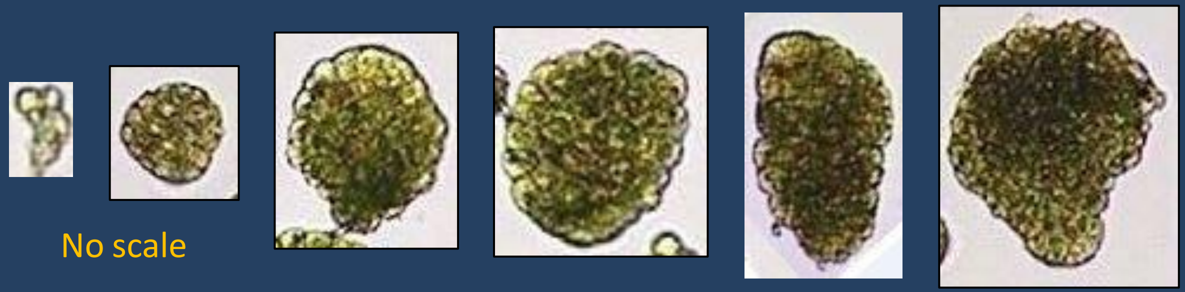
Spores & pseudoelaters of extant hornwort *Anthoceros*

50µ approx

Very similar forms from the Hugin Fm

Sub-rounded, ovoid & “Boxing glove” – shaped diaspores

Gemmae & gemmalings of extant liverwort ***Radula*** www.una.edu



No scale

Jurassic, NNS

Bar = 20µ

“boxing gloves”

Jurassic, NNS

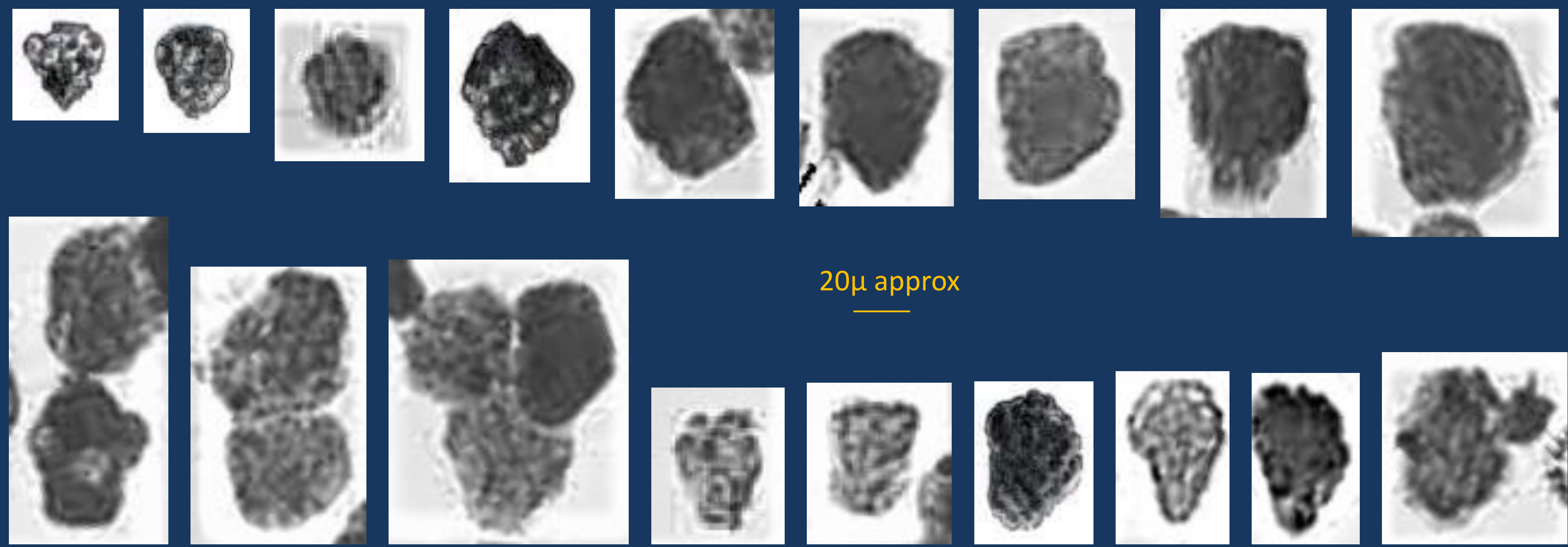
Aposporous outgrowth of *Pteridium*. Bar = 20µ

https://www.chineseherbshealing.com/ferns/apospory.html

Globose spore of *Cyrtogonellum fraxinellum* (fern). Guo & Luo 2013 fig 2

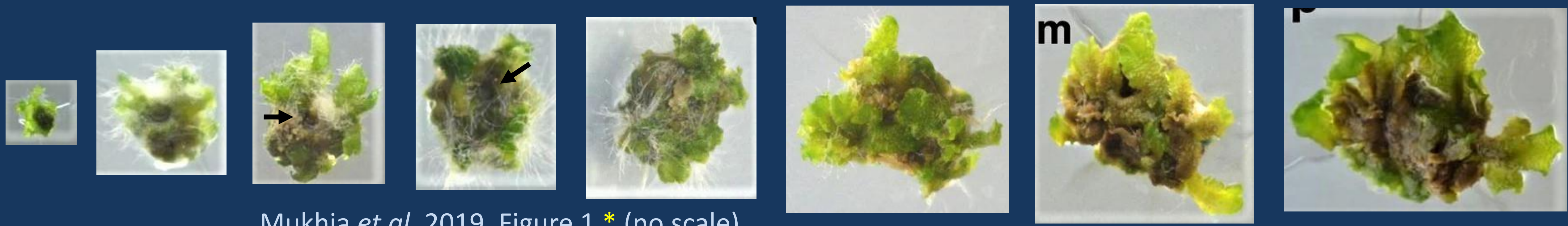
30µ

Batten et al 1994 Pl. 2.10



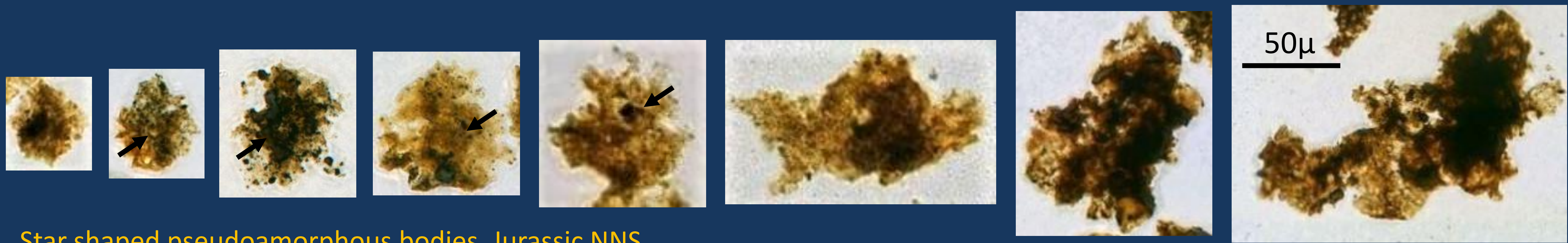
20µ approx

Star-shaped thalloid protonemas of liverworts

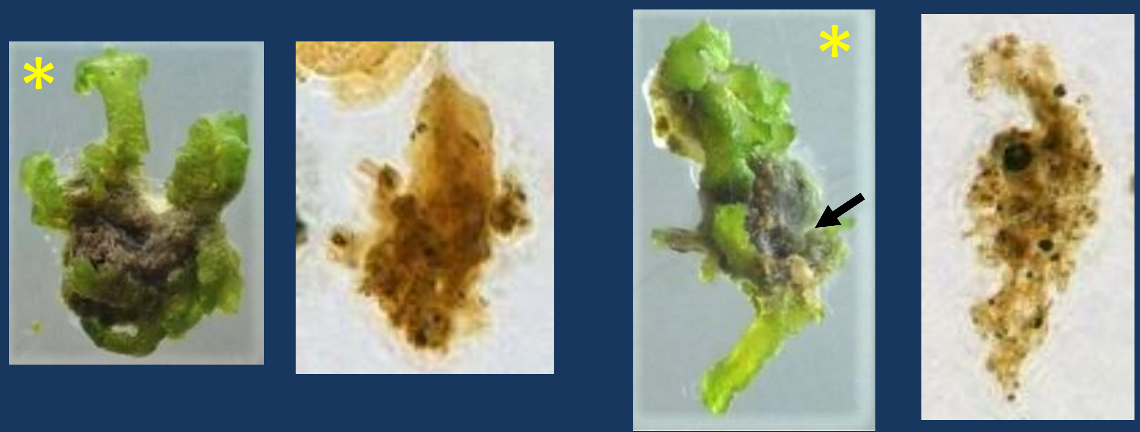


Mukhia *et al.* 2019, Figure 1 * (no scale)

Early *in vitro* growth of thalloid protonema in extant liverwort *Lunularia cruciata*

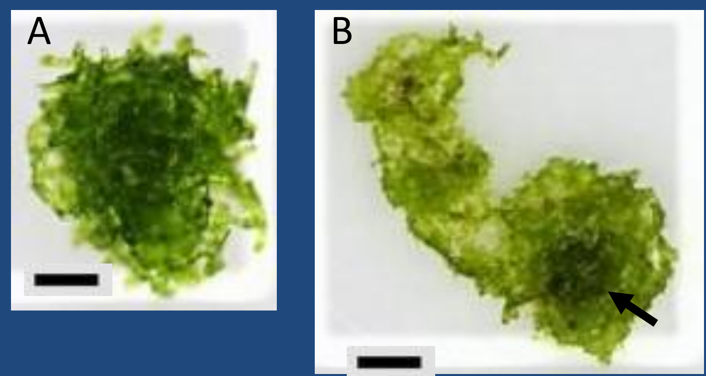


Star shaped pseudoamorphous bodies, Jurassic NNS



* non-stellate protonemas from same batch

Gametophytes of *Pteridium* (bracken)
Bar = 1mm Jang *et al.* 2021, Fig. 4A-B

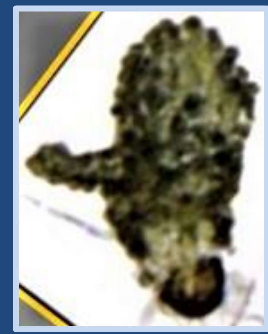


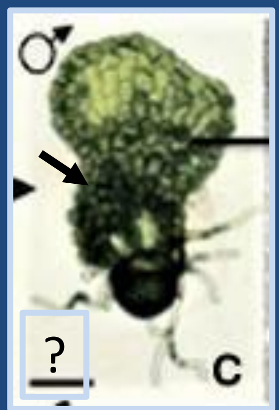
From Eklund et al 2018 Fig 2

3mm

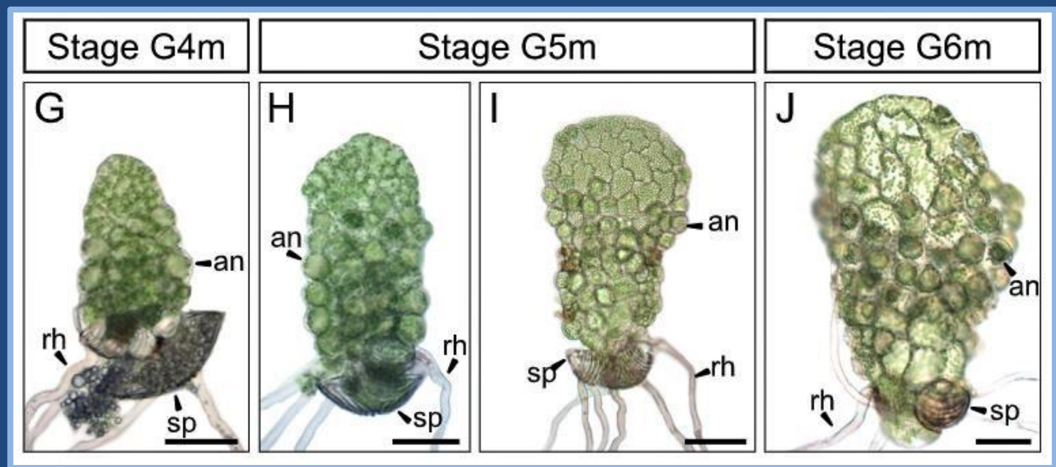
Young fern gametophytes may have similar morphologies, including rosette +/- opaque body

http://www1.biologie.uni-hamburg.de





Male gametophyte of *Ceratopteris richardii*
Atallah & Banks 2015 Fig 2c

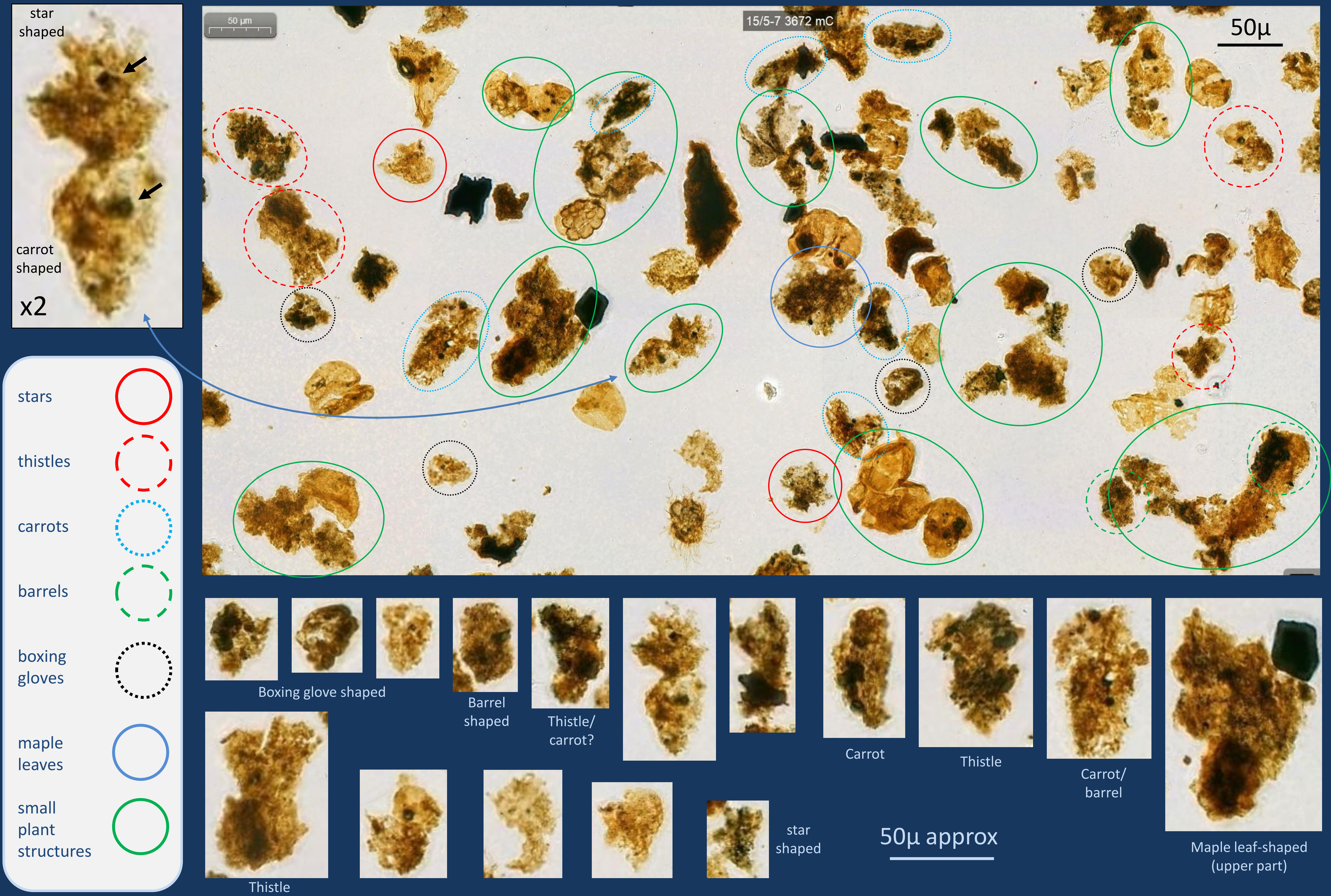


Young gametophytes of the fern *Ceratopteris richardsii* in Conway & Stilio 2020, Fig. 2 G-J
bar = 100µ. an = antheridia

Spatulate gametophyte of *Lygodium venustum*
Bejar et al2019, fig 3C

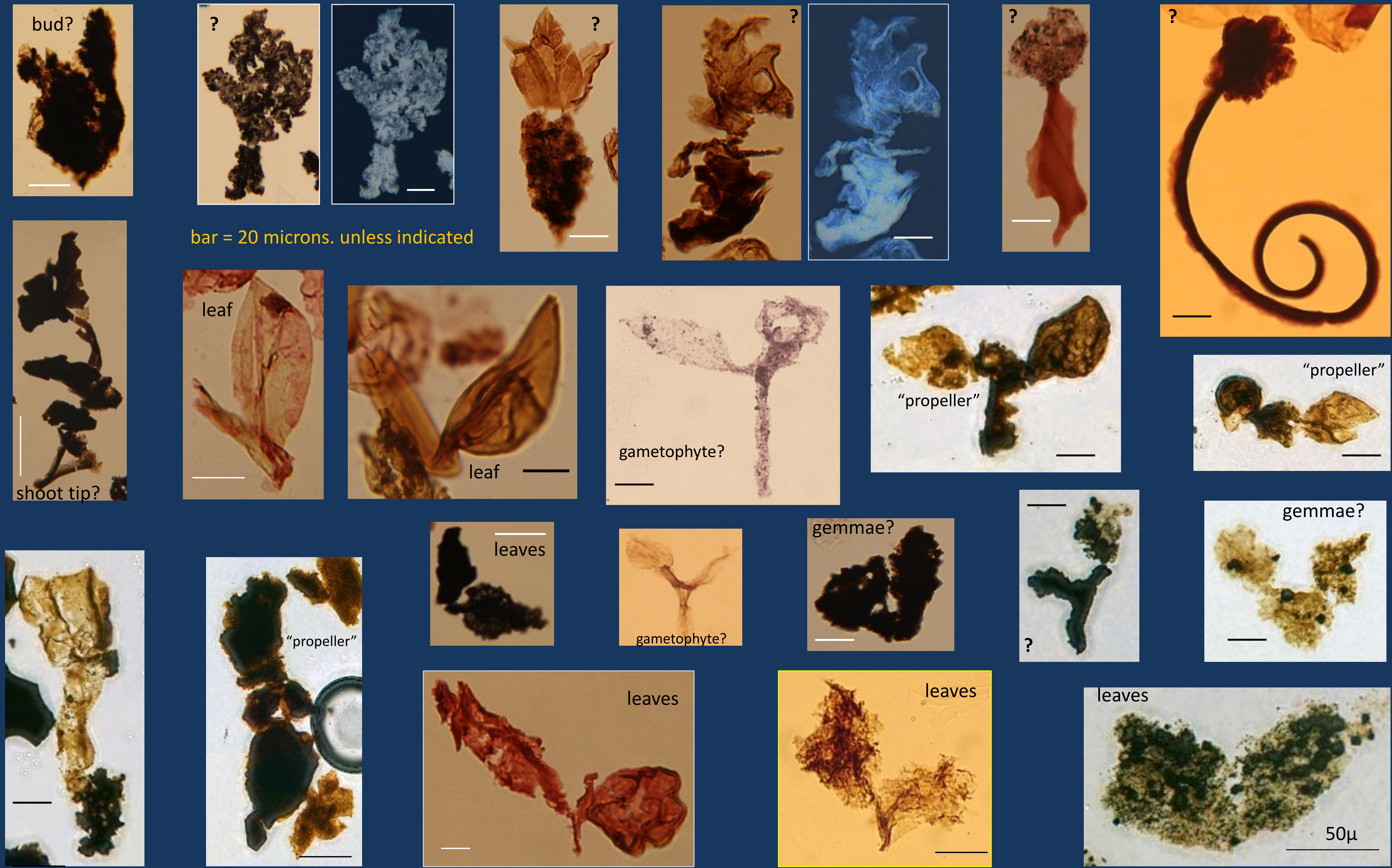
15/5-7 3672m Draupne Fm, Berriasian

Oxidised sample of Draupne Fm, North Sea. Some of the particles normally interpreted as AOM are circled.



"Plant structure" - two or more plant bodies linked together in life position

Plant structures? Are the parts joined together?



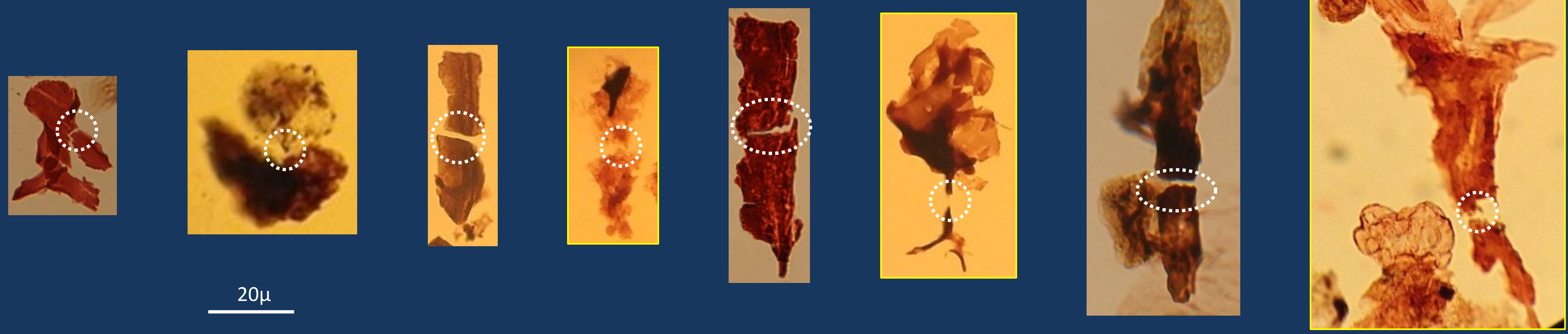
spatulate gametophyte?

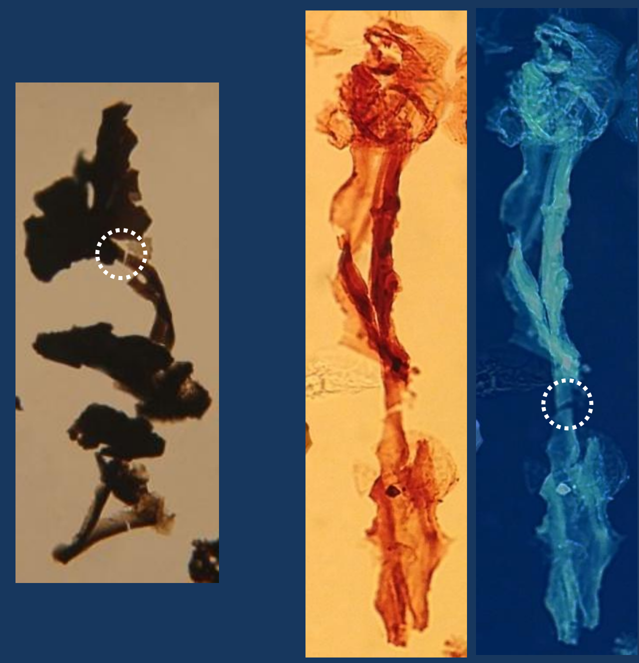
YES!

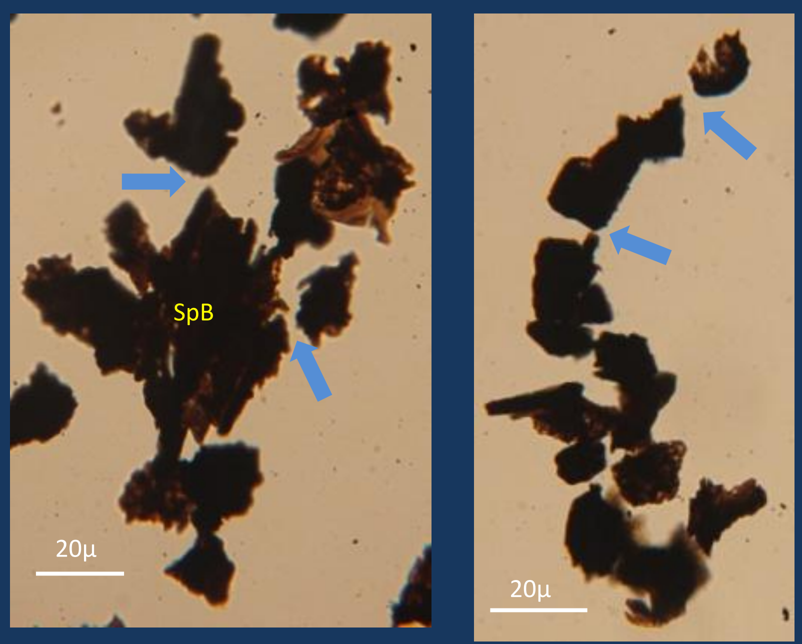
Plant structure - defined as two or more plant bodies linked together in life position

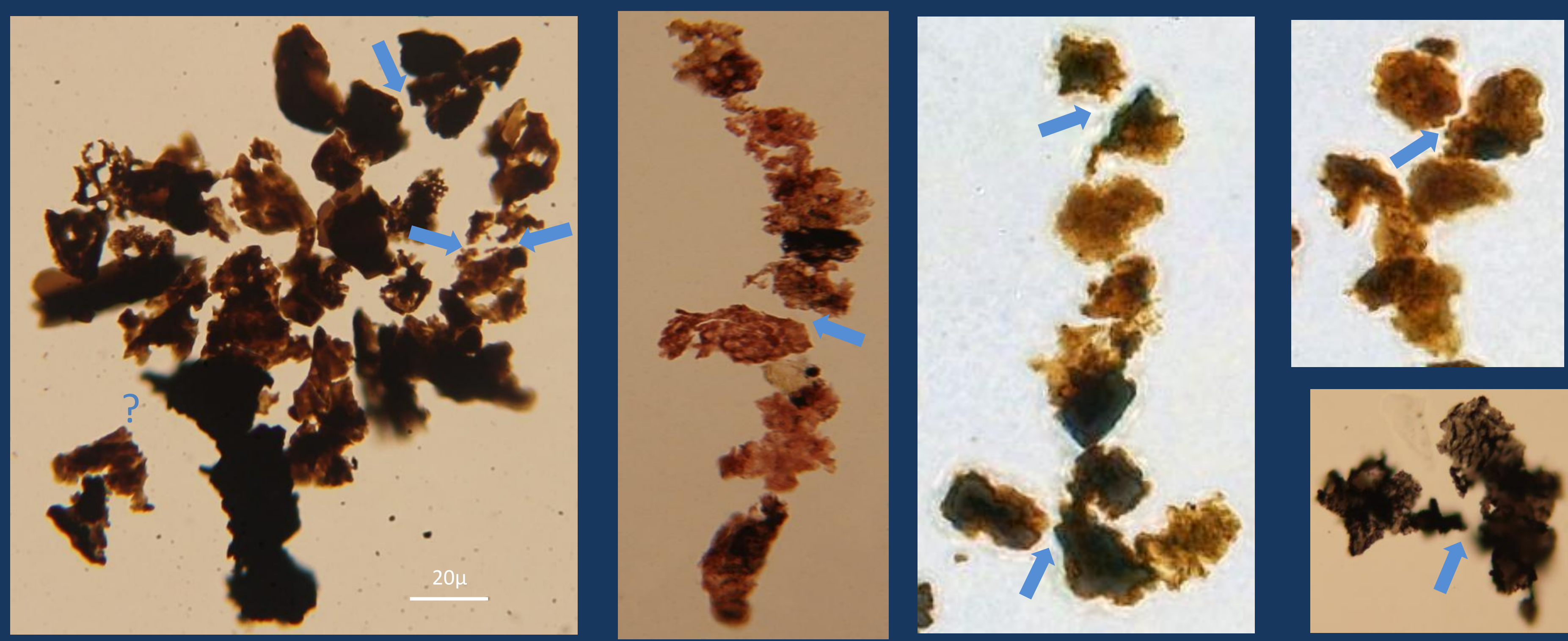
“Coverslip contraction”

The cracks/breakages (circled) must have occurred
after the residues were mounted on the cover slip.







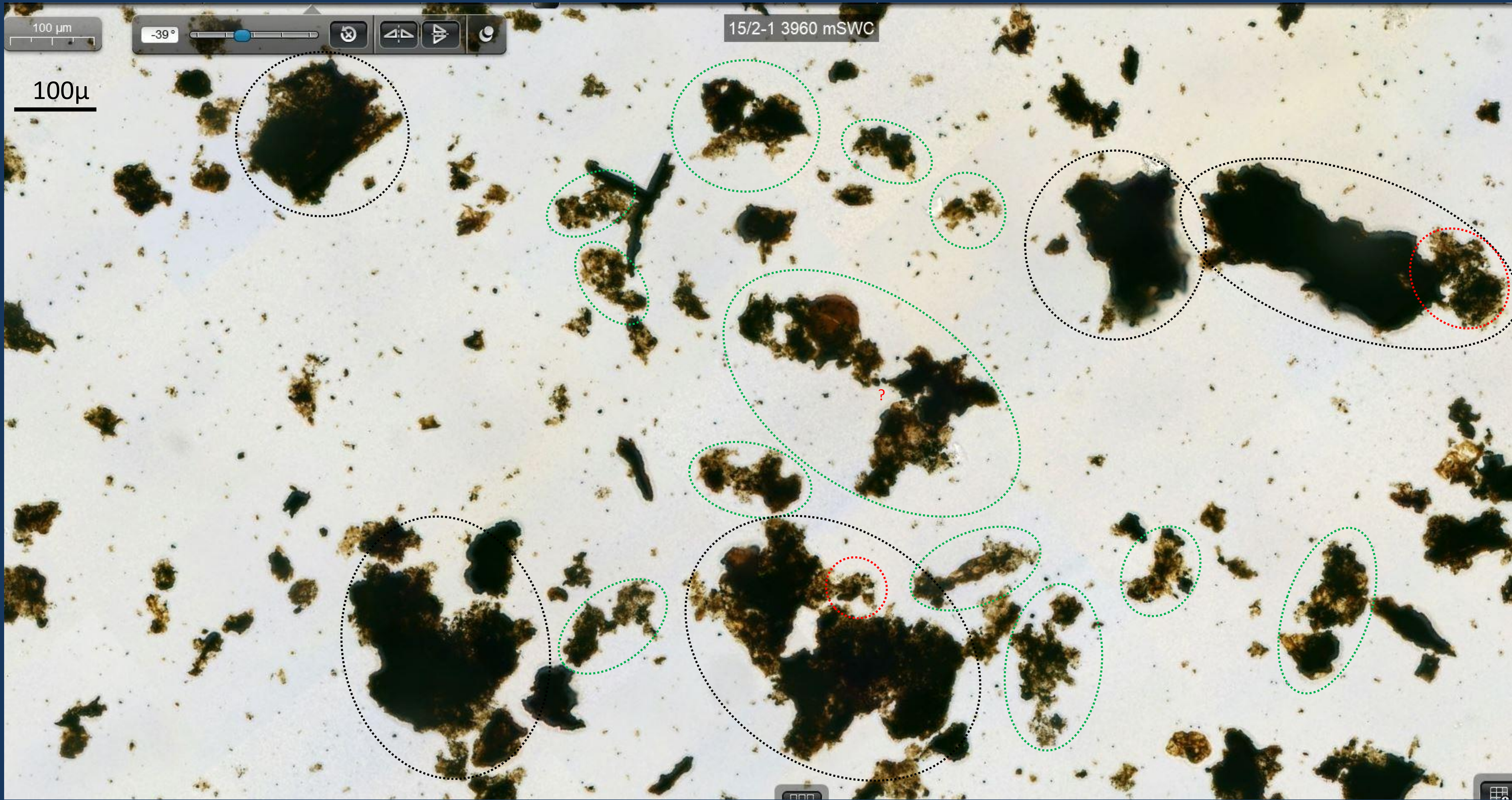


The same thing has happened here.
A common phenomenon

15/2-1 3960.0m Draupne Fm, Tithonian

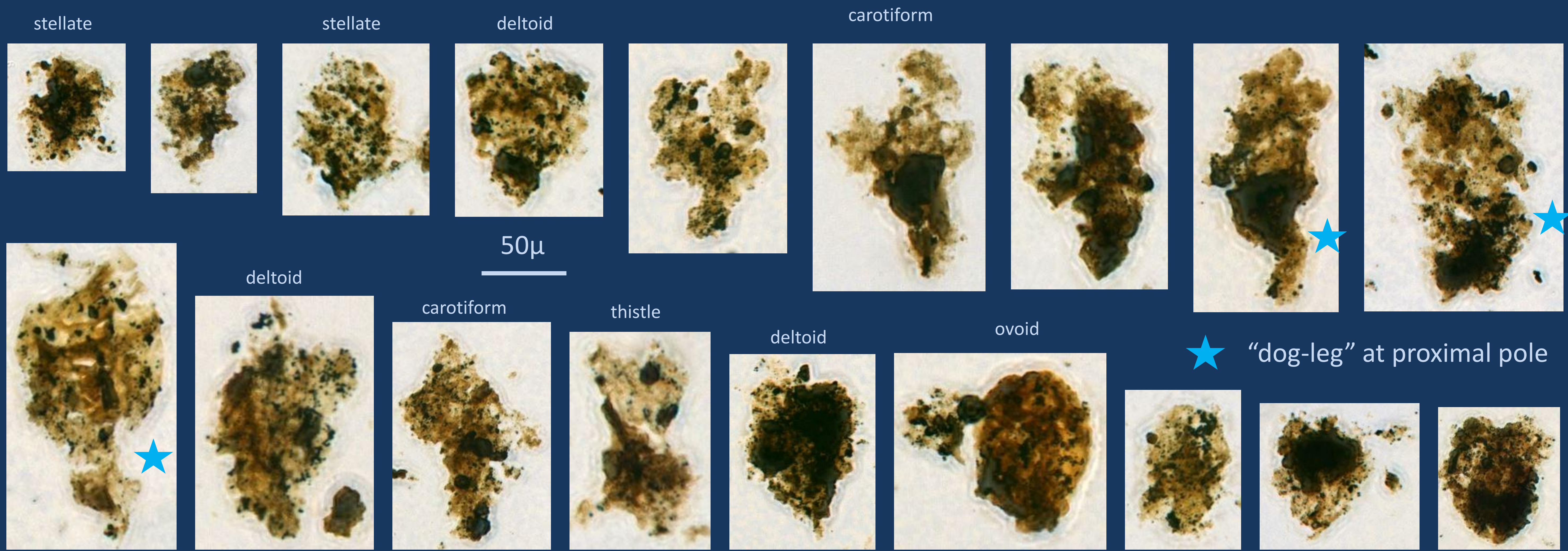
15/2-1 3960.0m Draupne Fm, Tithonian

Opaque and translucent tissues linked in life position

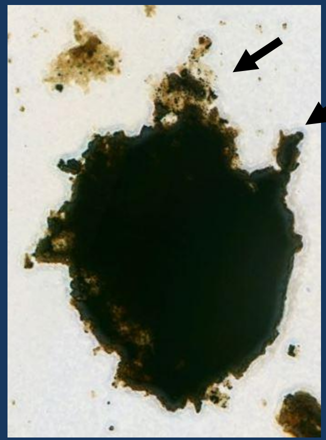


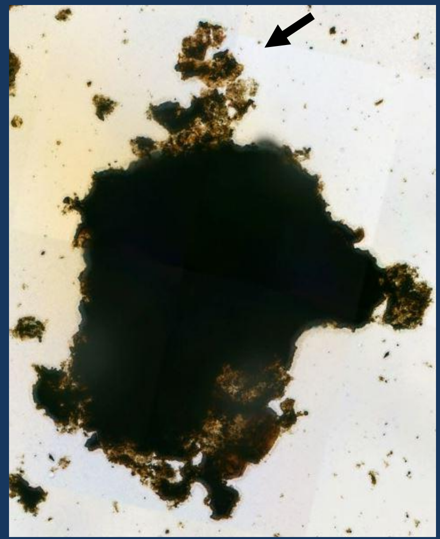
The sample is dominated by large, blocky pseudoamorphous bodies (black circles) and smaller pseudoamorphic bodies, commonly linked together forming small plant structures (green circles), or attached to the large bodies (red circles)

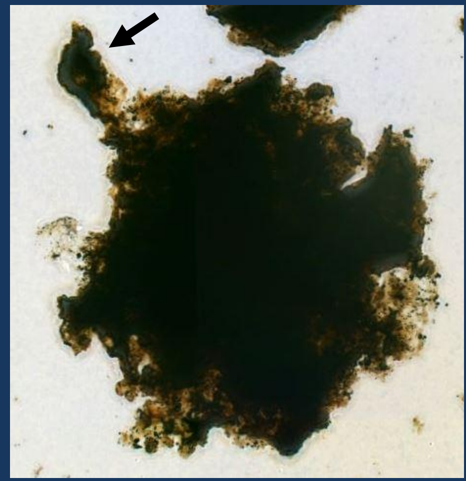
15/2-1 3960.0m Draupne Fm, Tithonian

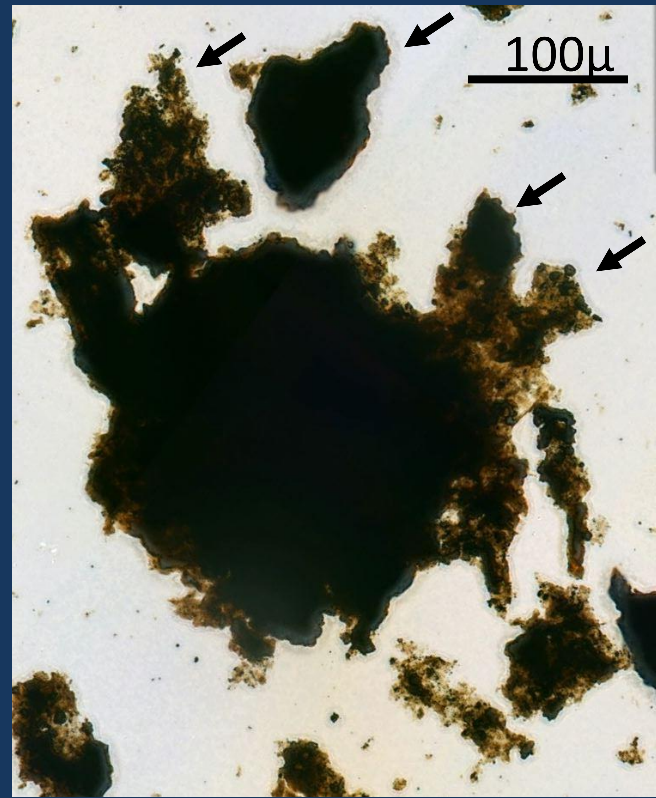


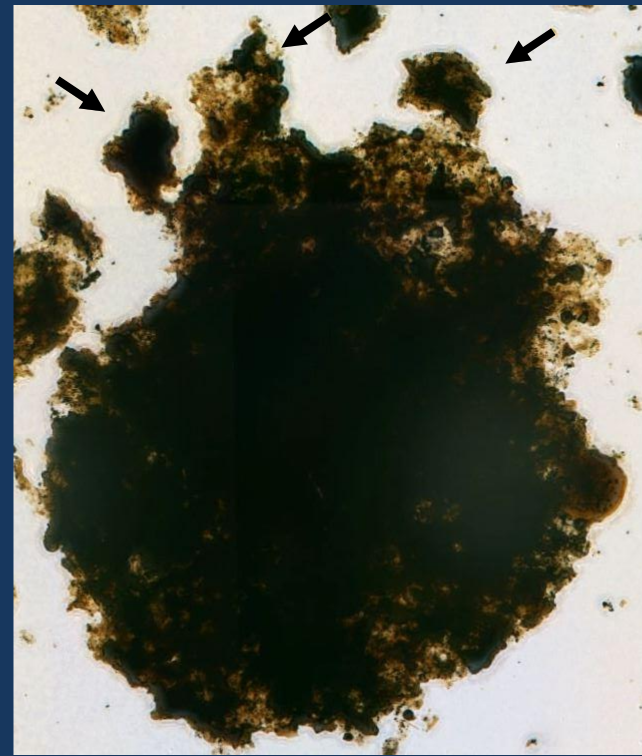
Selection of isolated pseudoamorphous bodies. Similar shapes to previous sample plus common triangular/deltoid types. Many exhibit vegetative growth of new tissues at the wider (?distal) pole. Apart from being more degraded, this material is similar to the sample in 15/5-7 (page 15)



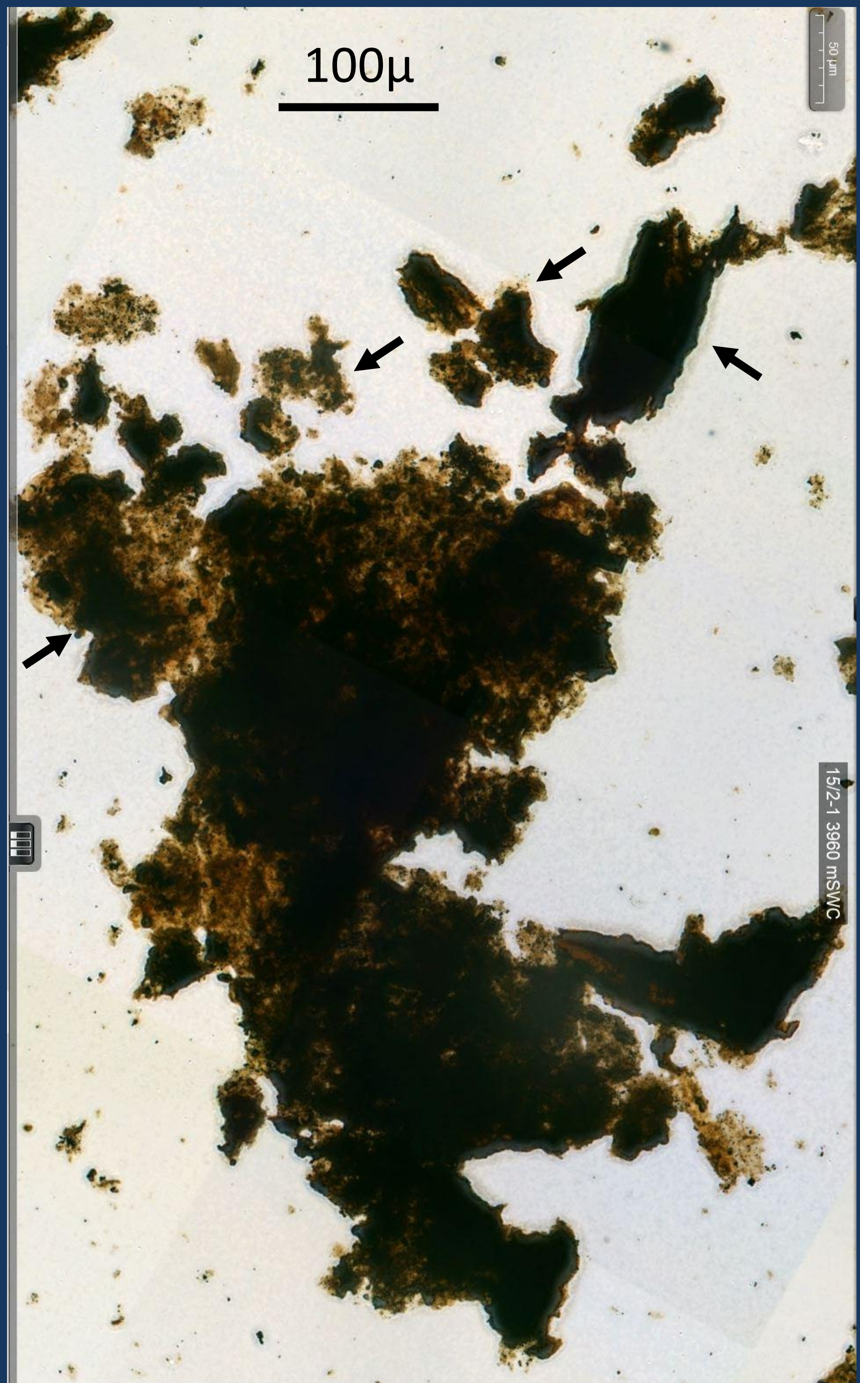


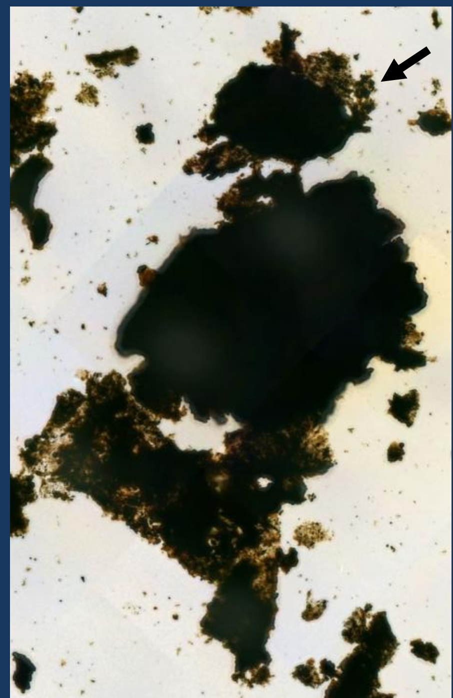


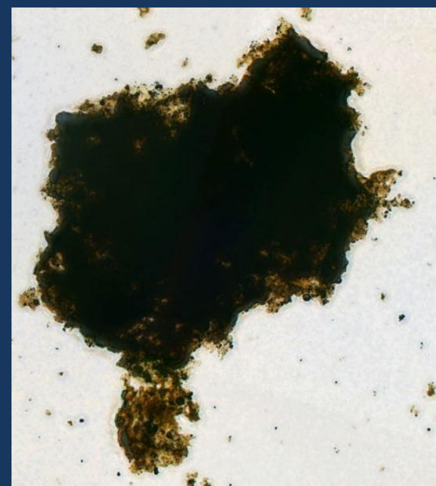




15/2-1 3960.0m
Draupne Fm, Tithonian



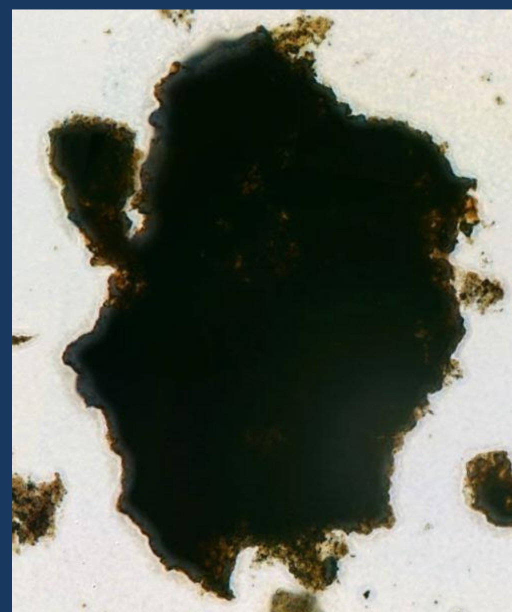


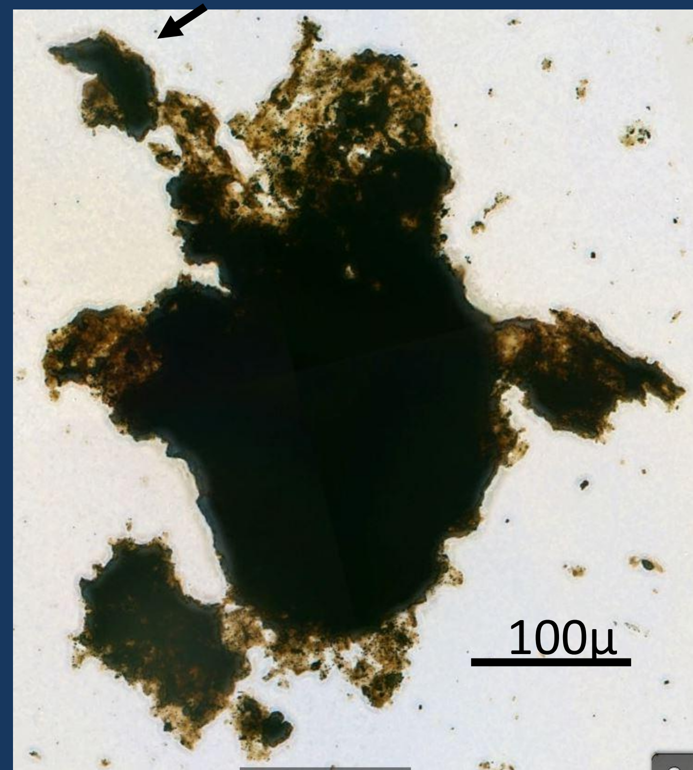


Subpentagonal bodies : SpB's

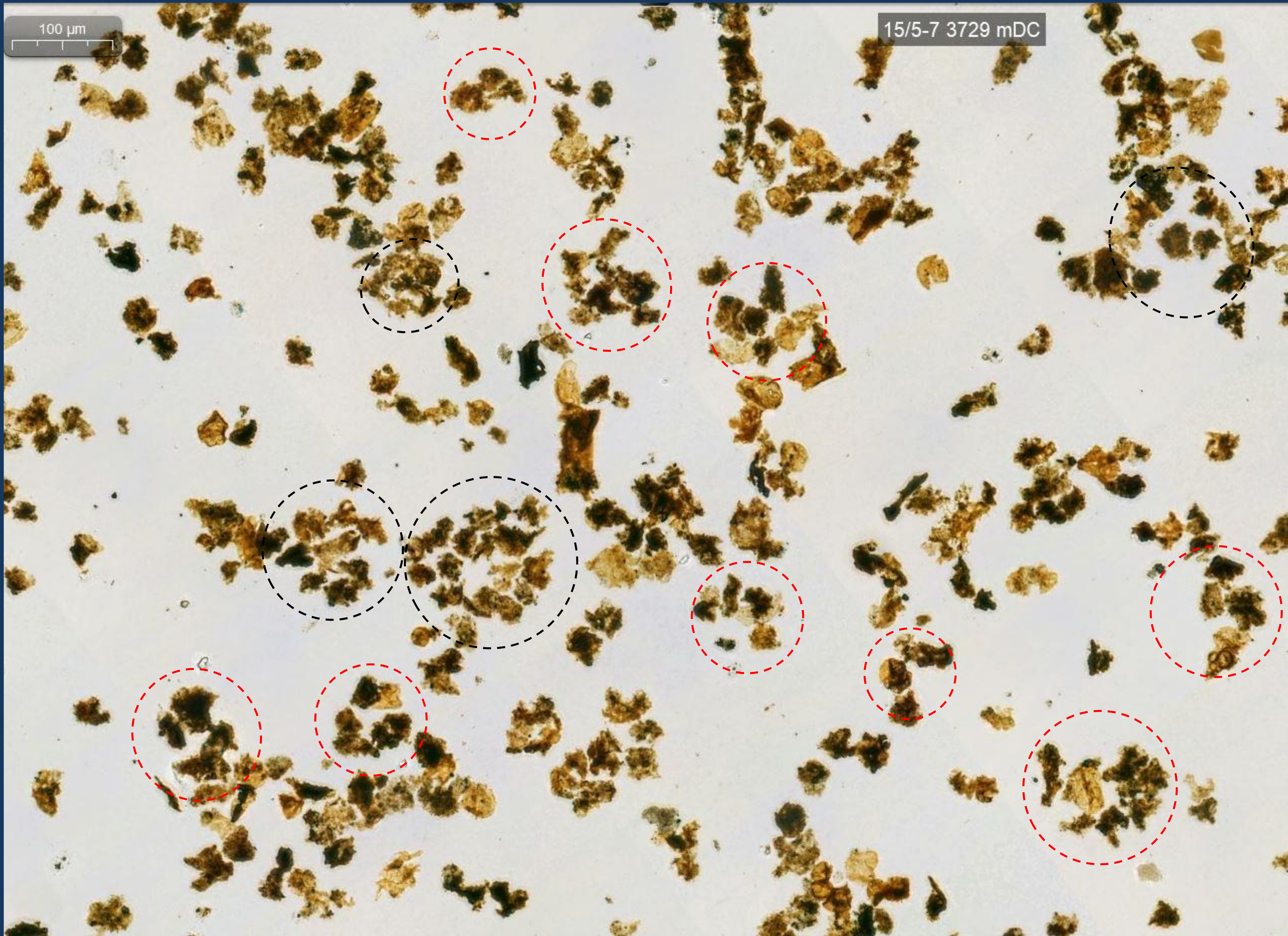
Translucent tissues enveloping opaque inner body(s), which (when visible)often have a vaguely maple-leaf shape. Distally attached bodies (arrows) are common in some samples and this is presumably related to energy conditions in the environment and/or ultrasonic treatment in the lab.

Thallose body



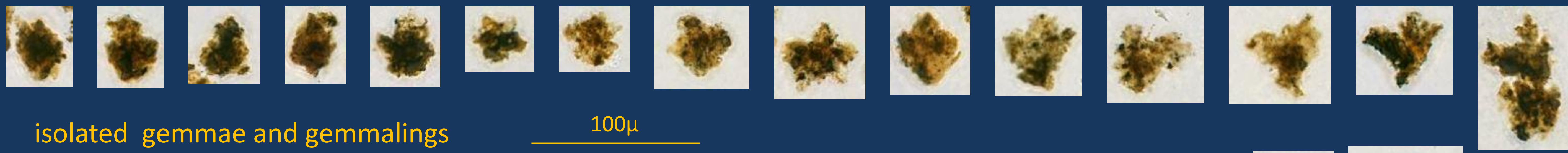


15/5-7 3729m Draupne Fm x100



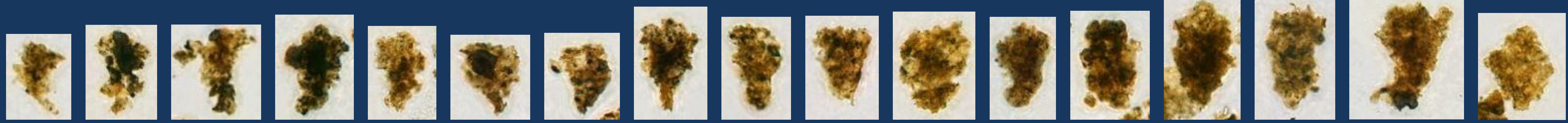
Abundant small plant structures, including many rings formed by pseudoamorphous bodies of similar size. Some of the more complete examples are highlighted (black circles) and a few remnant structures (red circles).

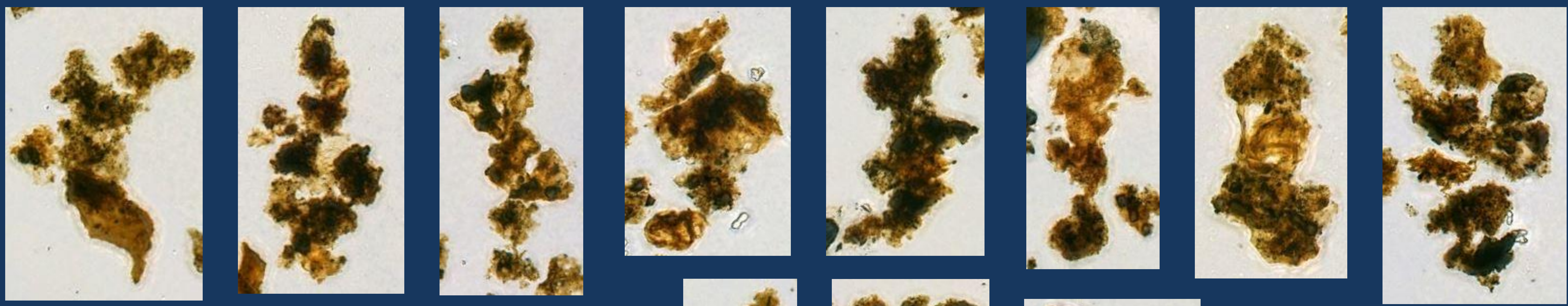
15/5-7 3729m Draupne Fm x200

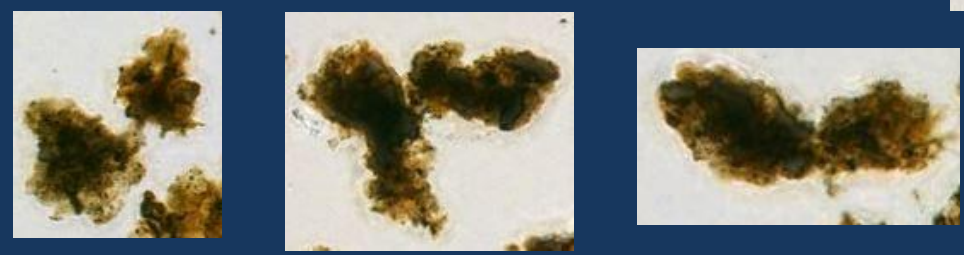


isolated gemmae and gemmalings

100µ

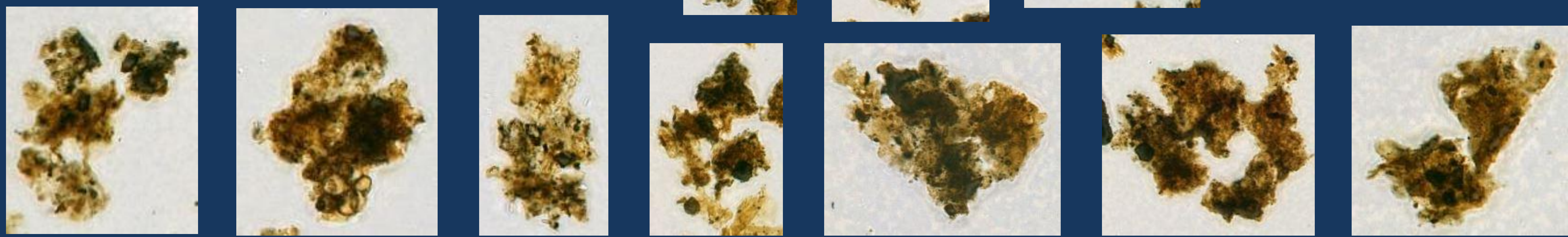




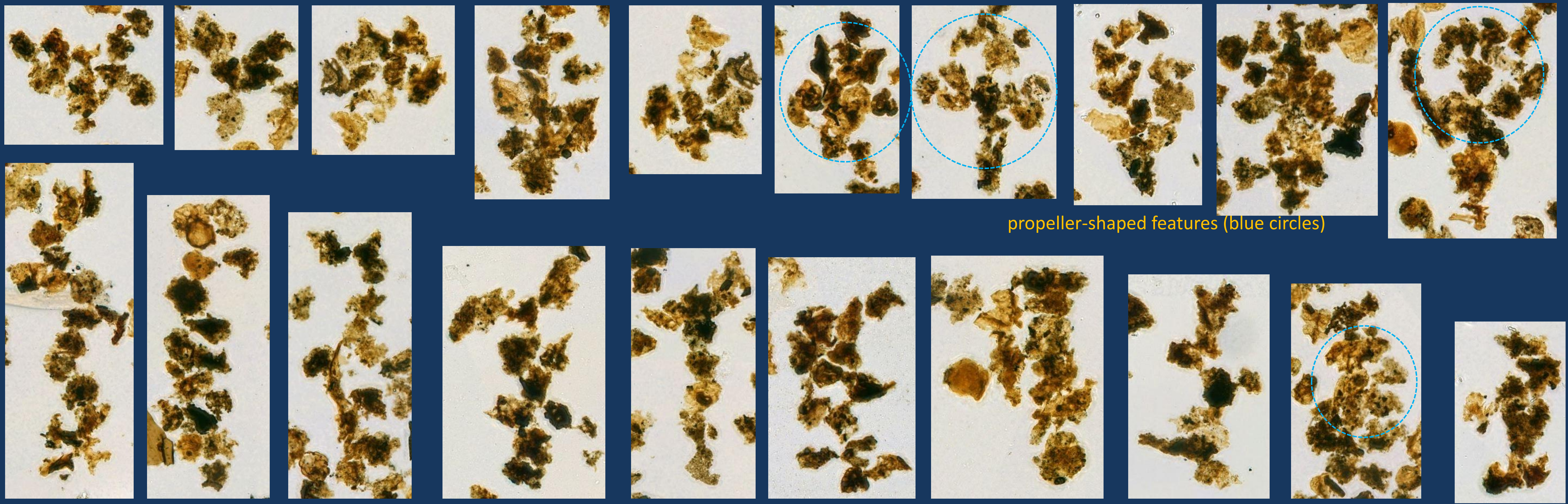


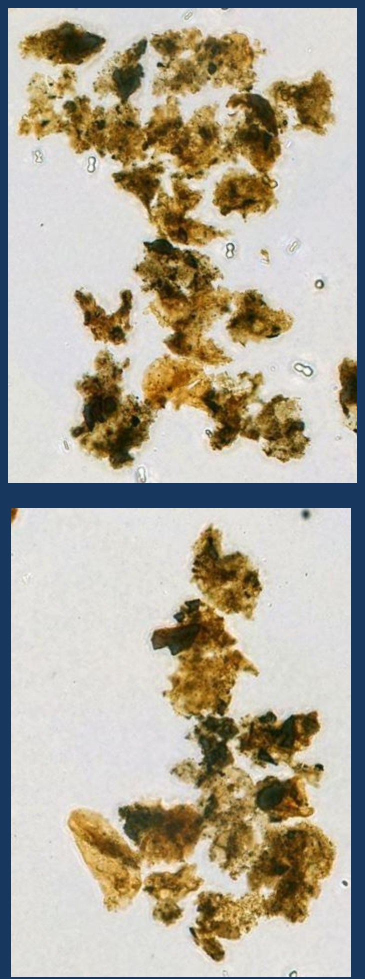
leaf-like

Small plant structures with similar habit



15/5-7 3729m Draupne Fm x100



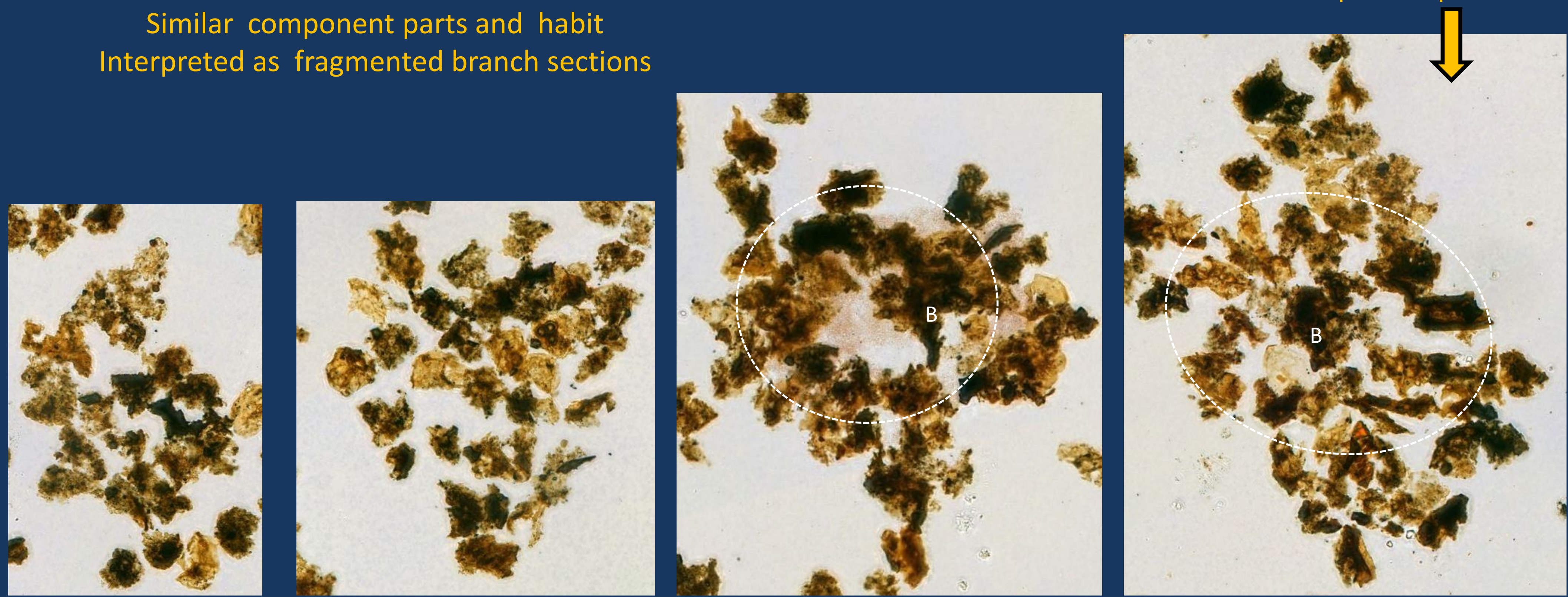


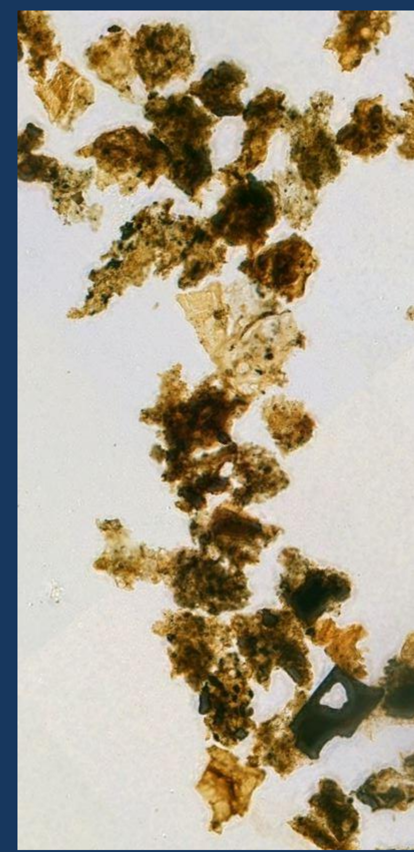
Medium to large plant structures

Similar component parts and habit
Interpreted as fragmented branch sections

200µ

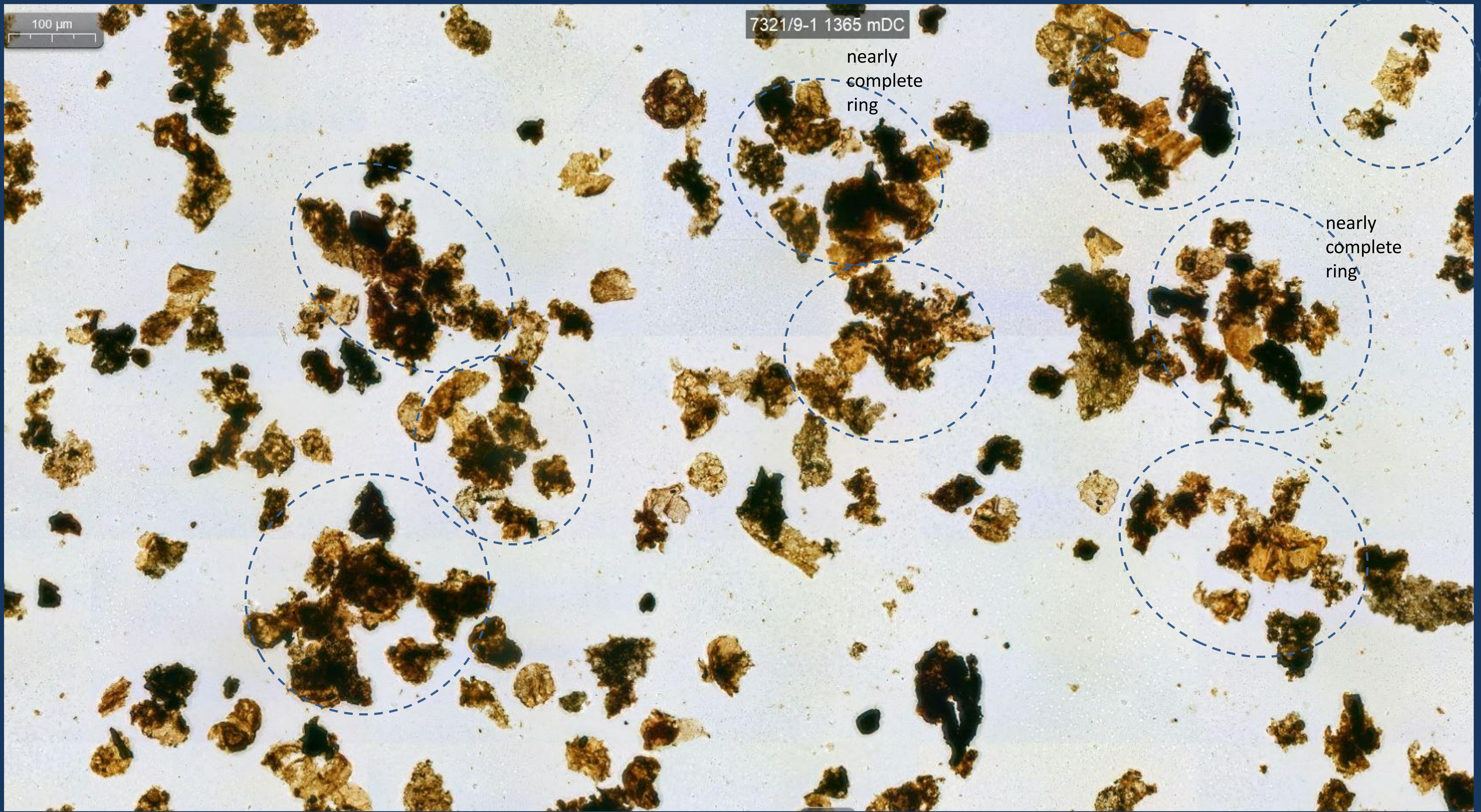
Subpentagonal structure composed of numerous smaller component particles





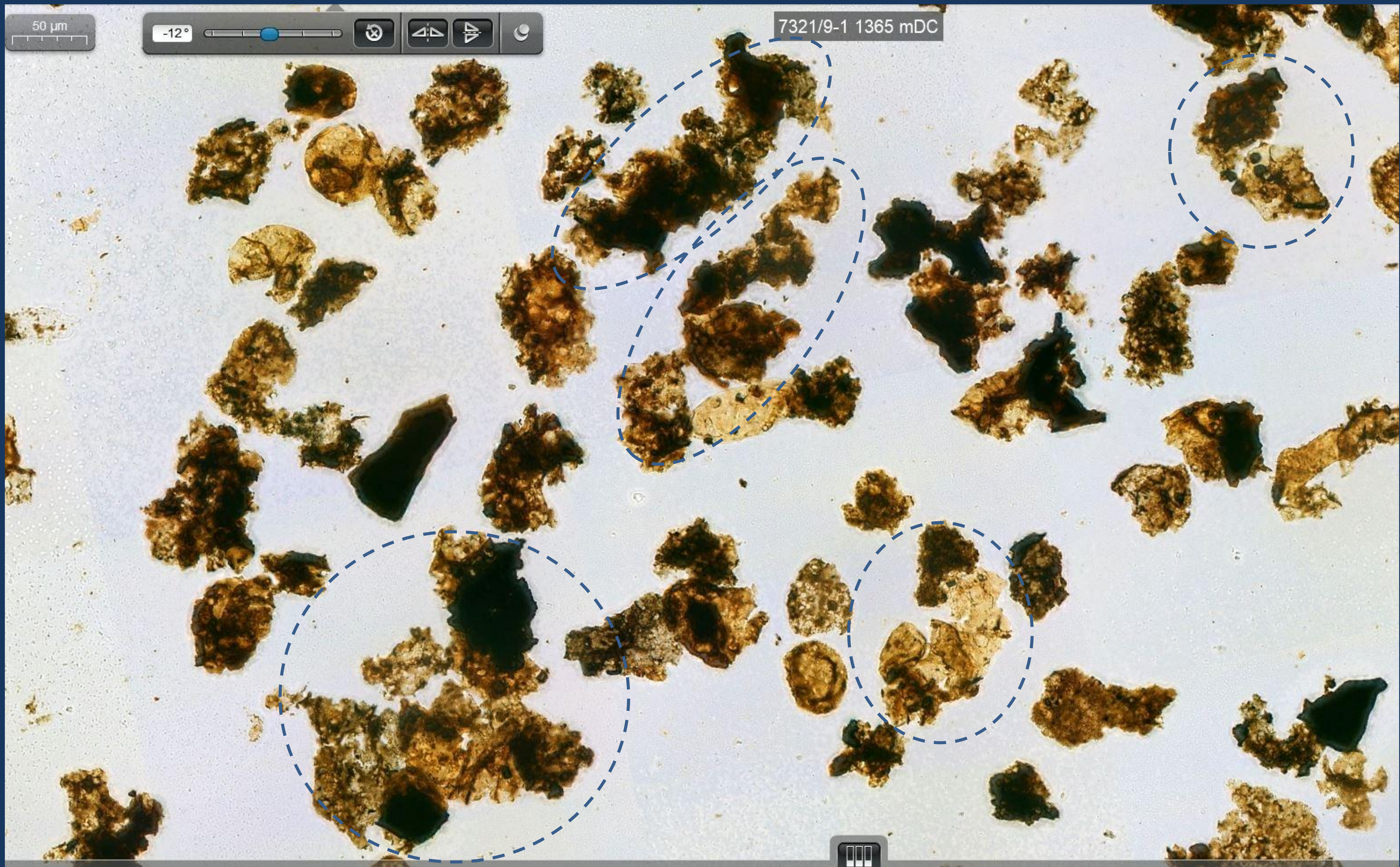
Ring shaped feature (circled) with a large lobed body B at centre
Also visible in other specimens, though less well preserved

7321/9-1 1365m Hekkingen Fm x100



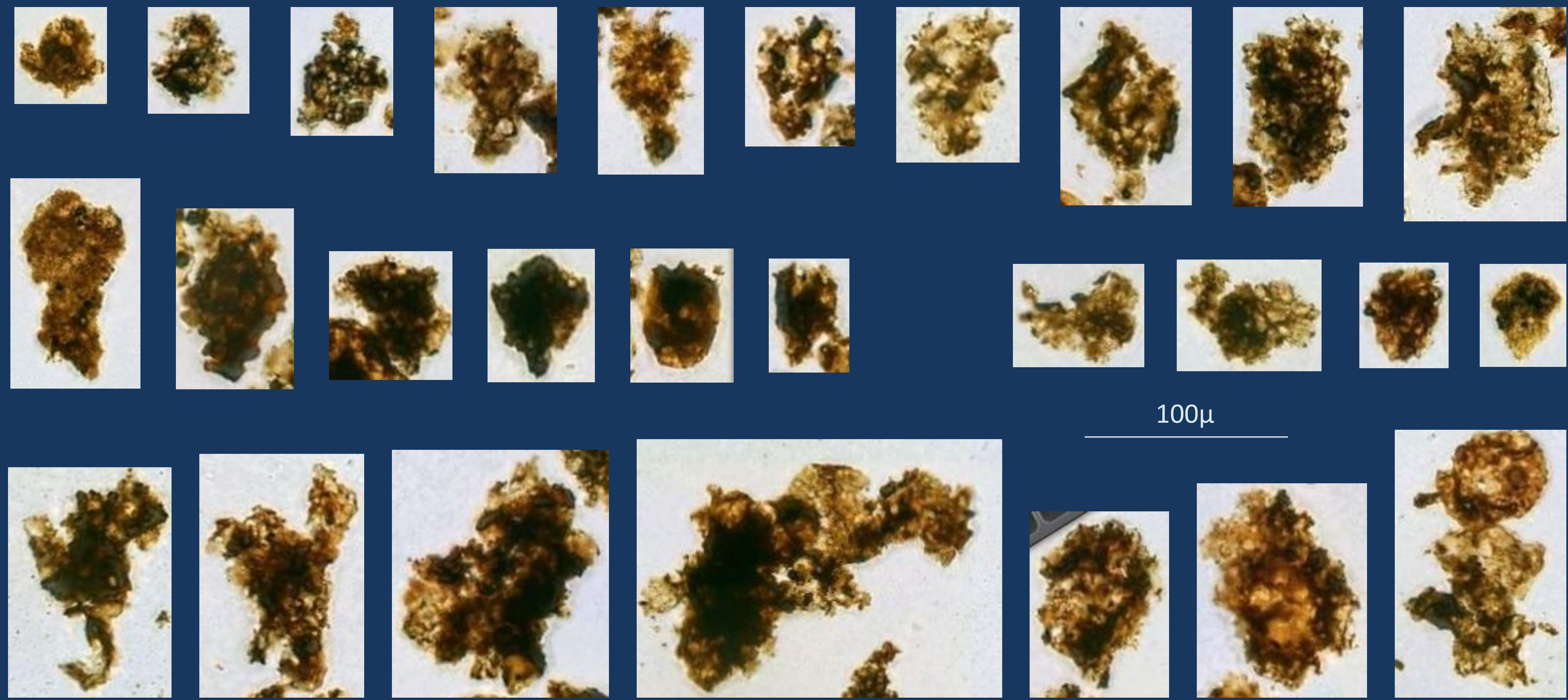
Abundant small to medium sized pseudoamorphous plant structures. At the centre of each is an irregular flattened body of structured vitrinitic material which bears a prominent maple leaf-like feature. Each is surrounded by a variably incomplete ring of fused pseudoamorphous bodies, the most complete of which are indicated.

7321/9-1   1365m Hekkingen Fm

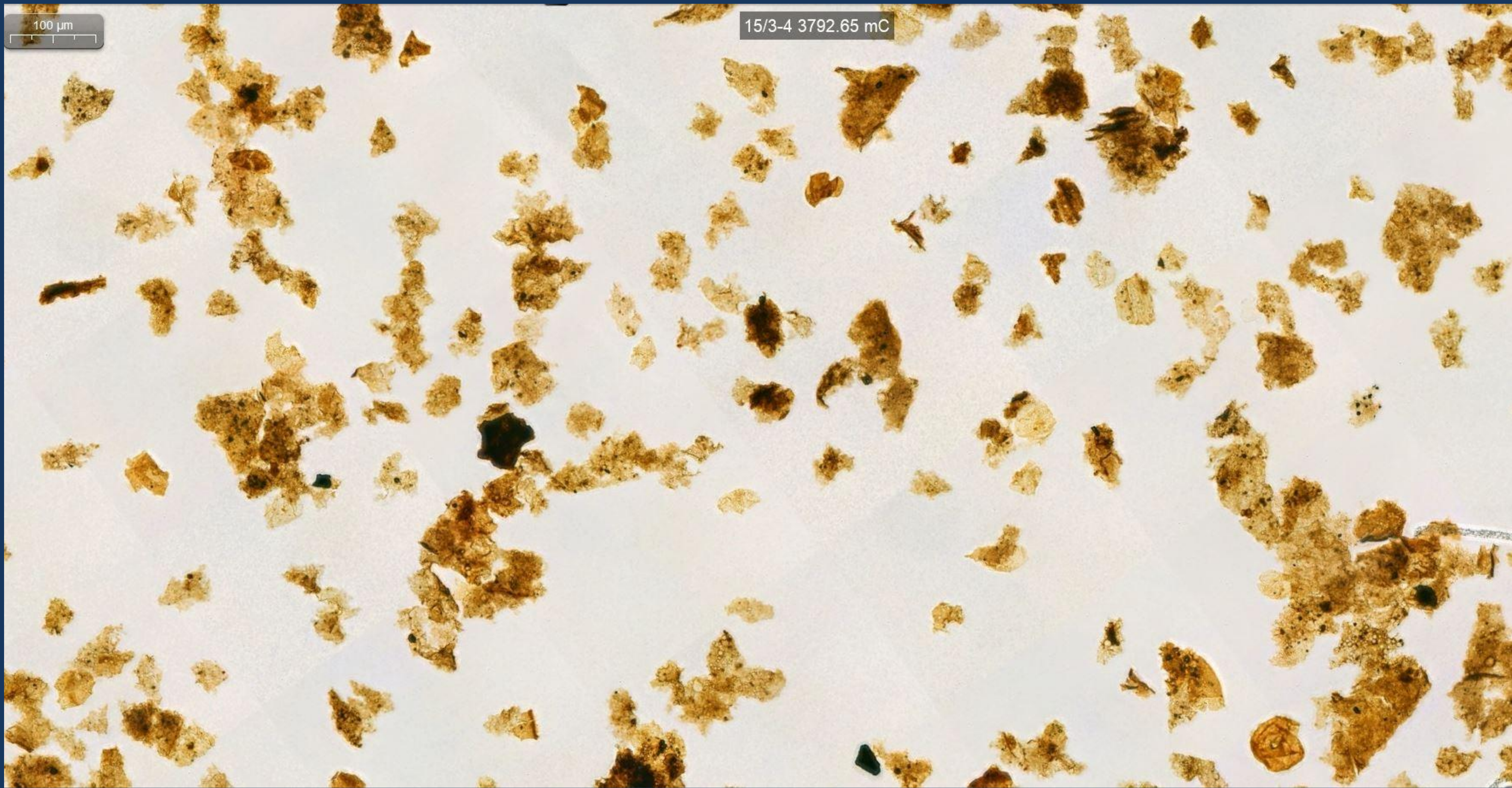


Small plant structures

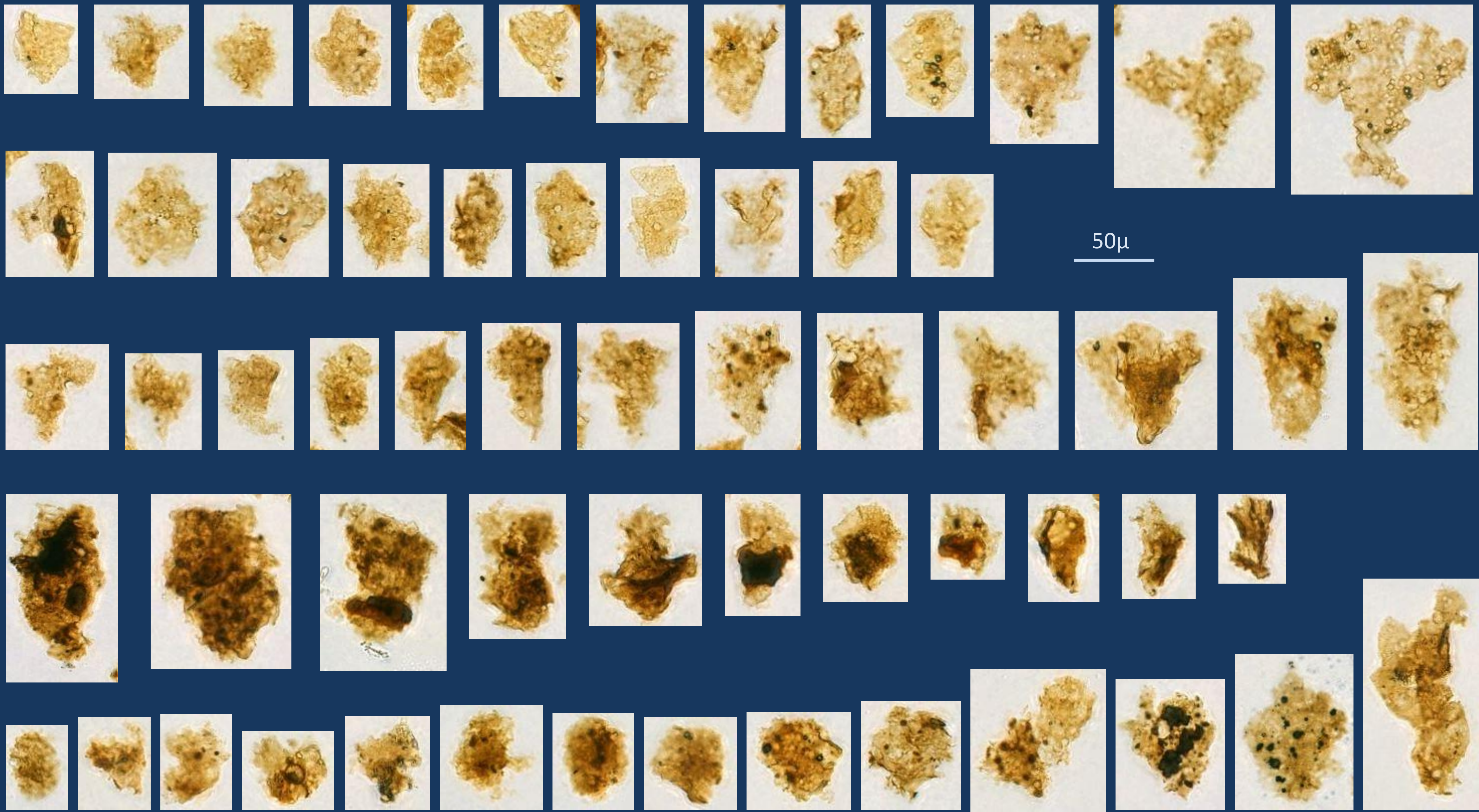
7321/9-1   1365m Hekkingen Fm



15/3-4 3792.65m Hugin Fm (shallow marine)



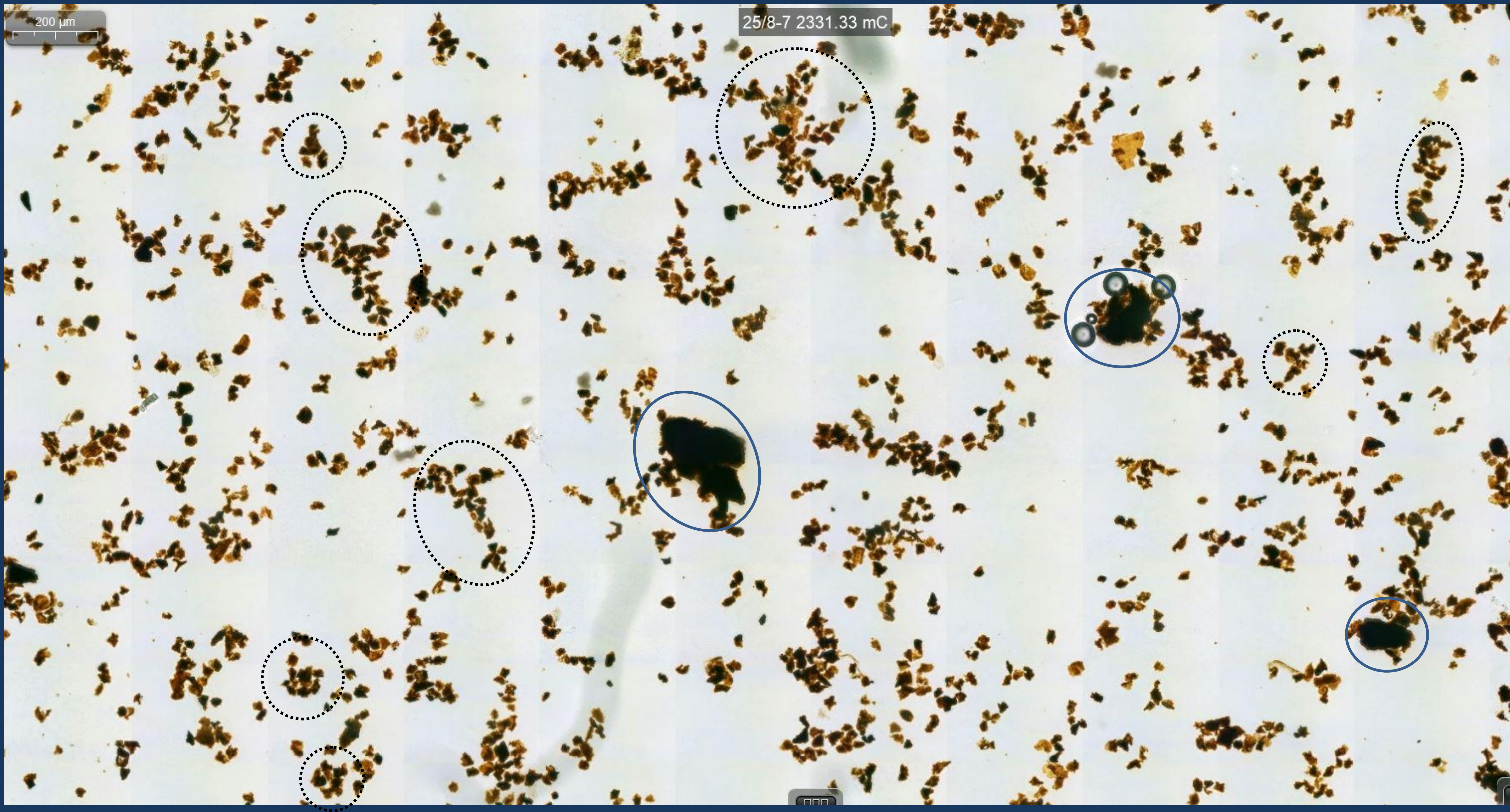
15/3-4 3792.65m Hugin Fm (shallow marine)



small opaque bodies are primary

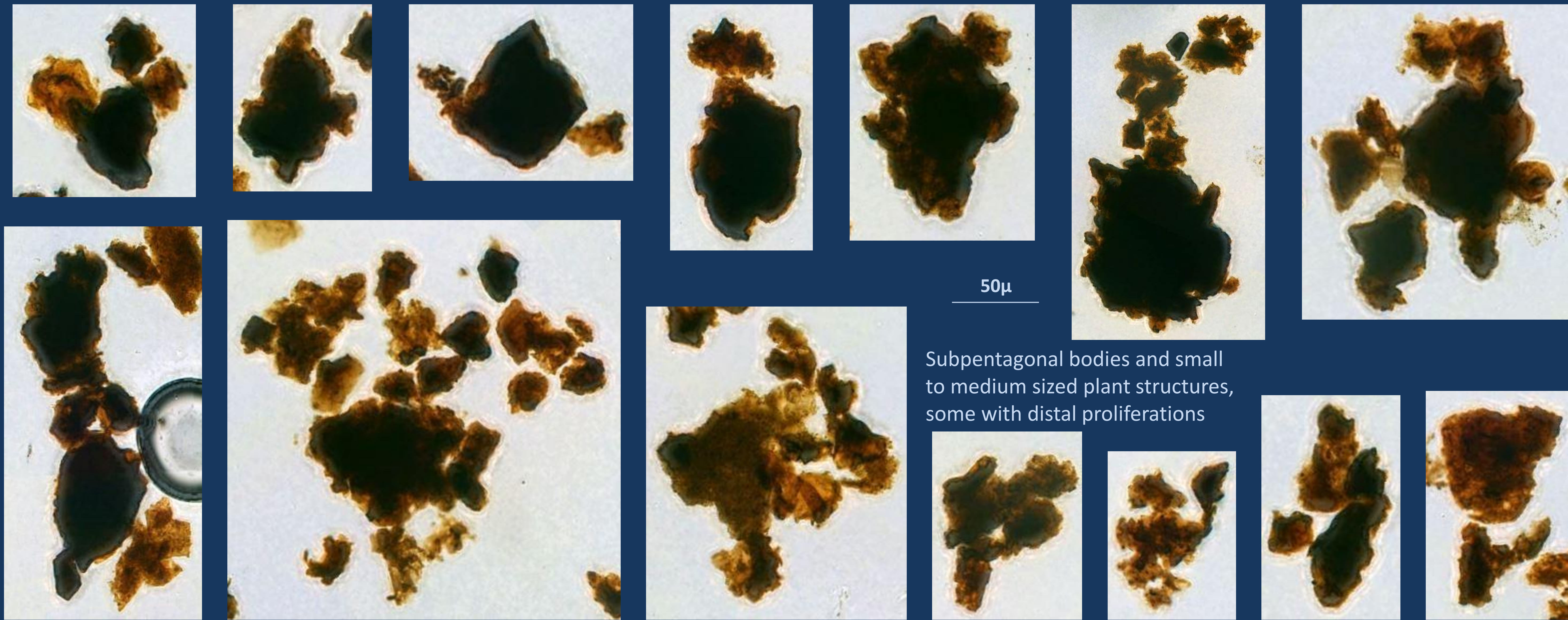
See also page 78

25/8-7 2331.33m Sleipner Fm (non-marine)



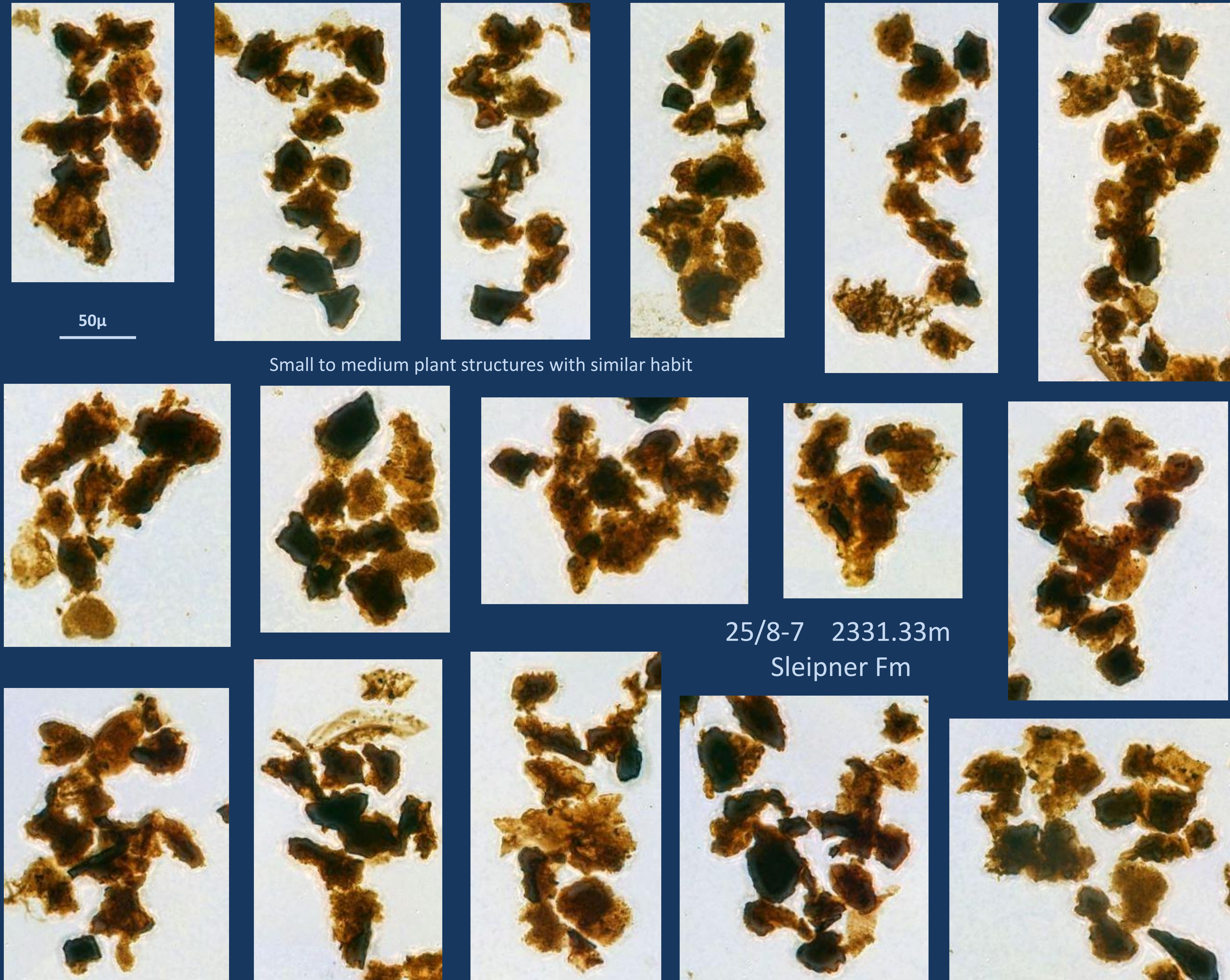
Abundant small – medium sized plant structures with similar habit (selection in dotted circles), with a few SpBs (circles)

25/8-7 2331.33m Sleipner Fm



Subpentagonal bodies and small to medium sized plant structures, some with distal proliferations

25/8-7 2331.33m Sleipner Fm



50µ

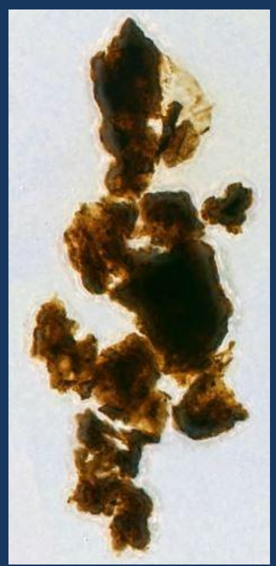
Small to medium plant structures with similar habit

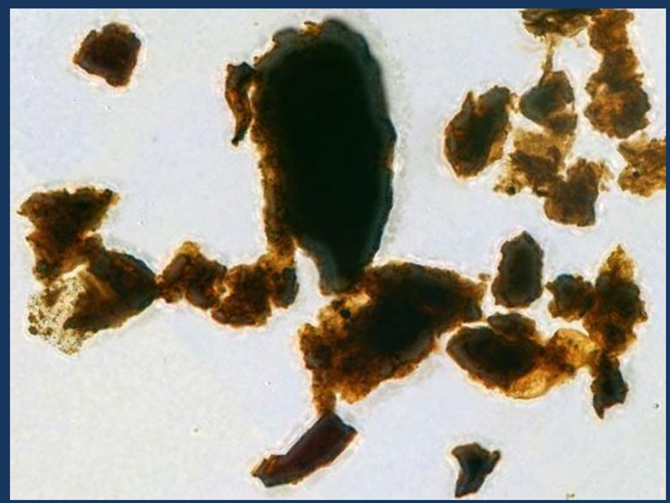
25/8-7 2331.33m
Sleipner Fm

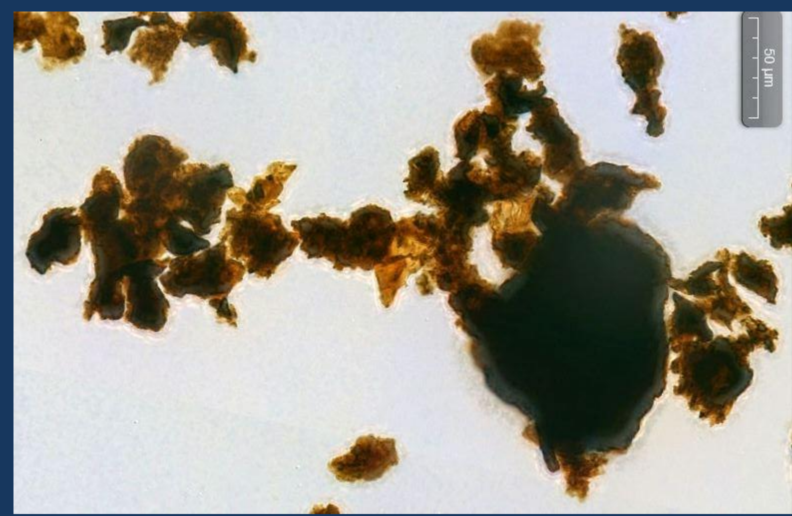
25/8-7 2331.33m Sleipner Fm x100

Medium to large plant structures

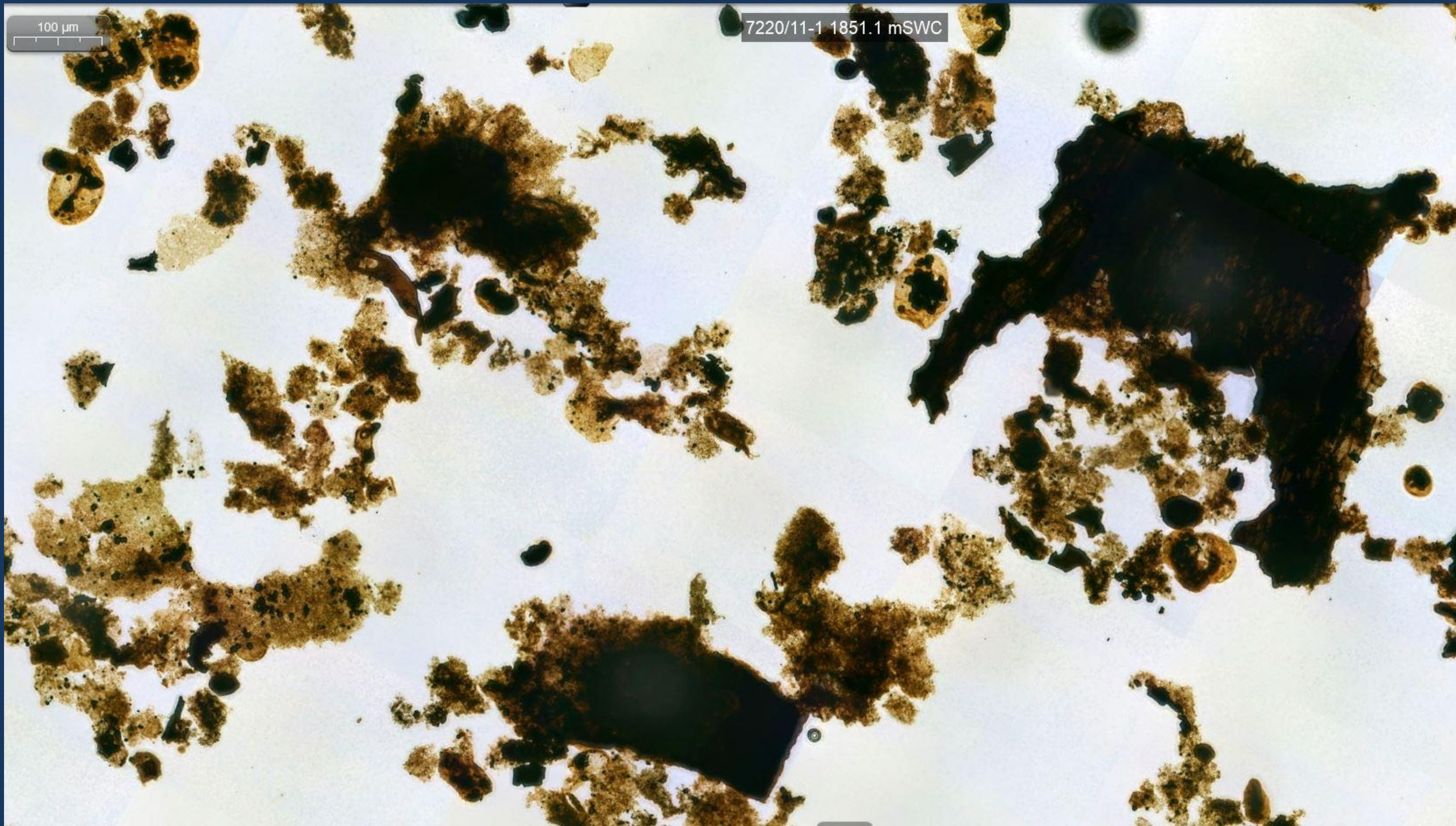
100µ

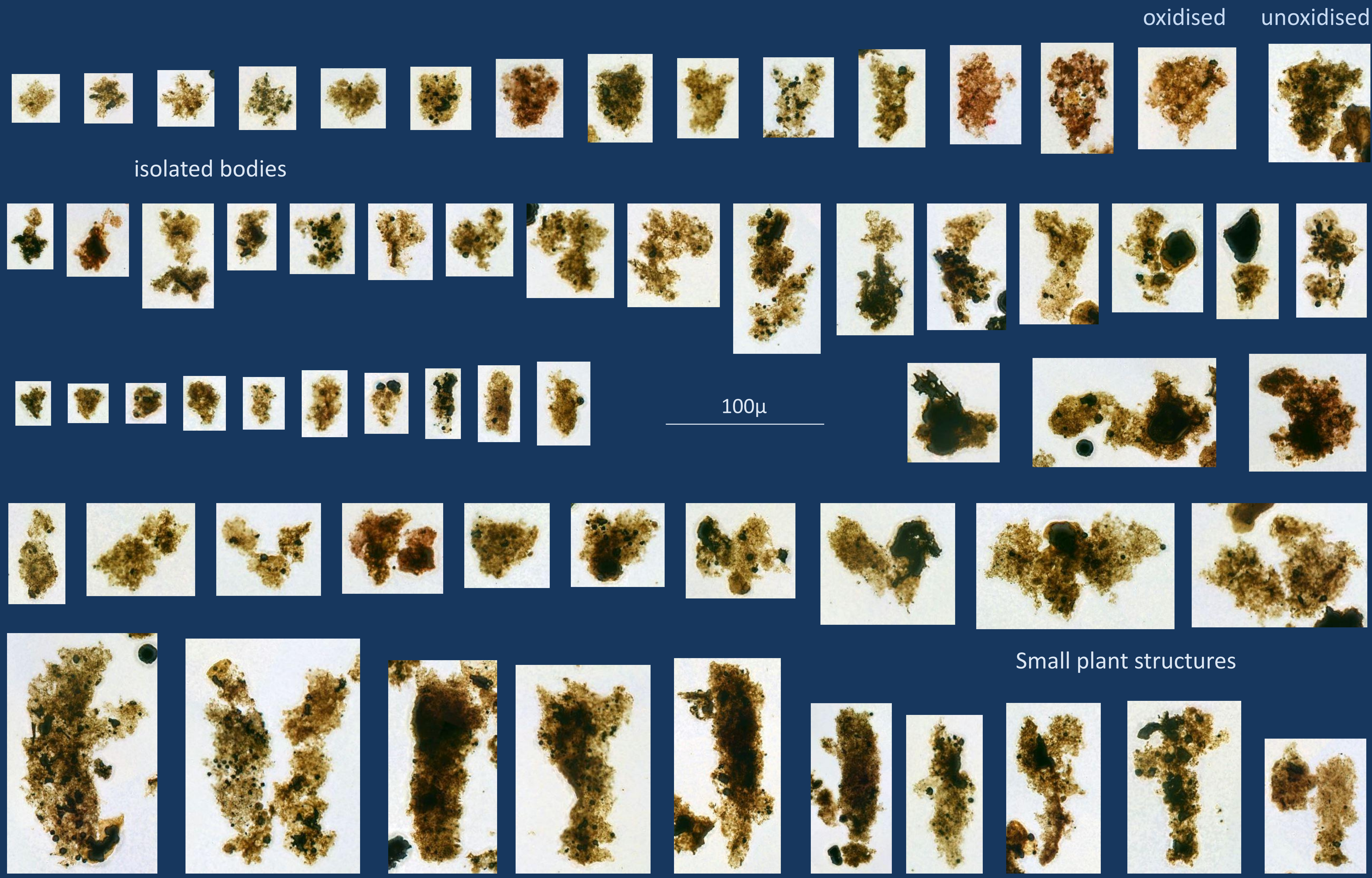




7220/11-1 1851.0m, Snadd Fm, Mid-Late Triassic



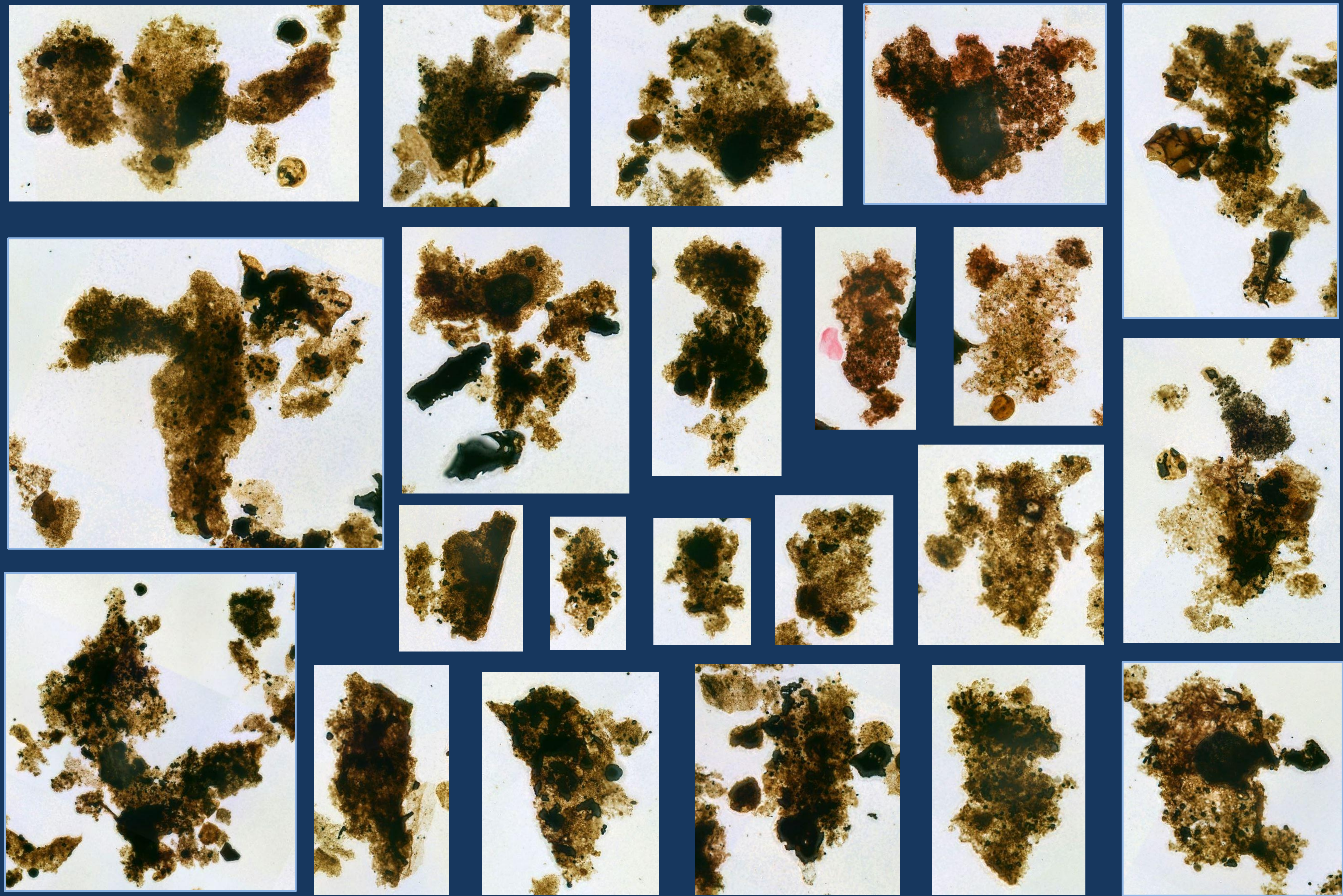
7220/11-1 1851.0m Snadd Fm, Mid-Late Triassic



7220/11-1 1851.0m Snadd Fm

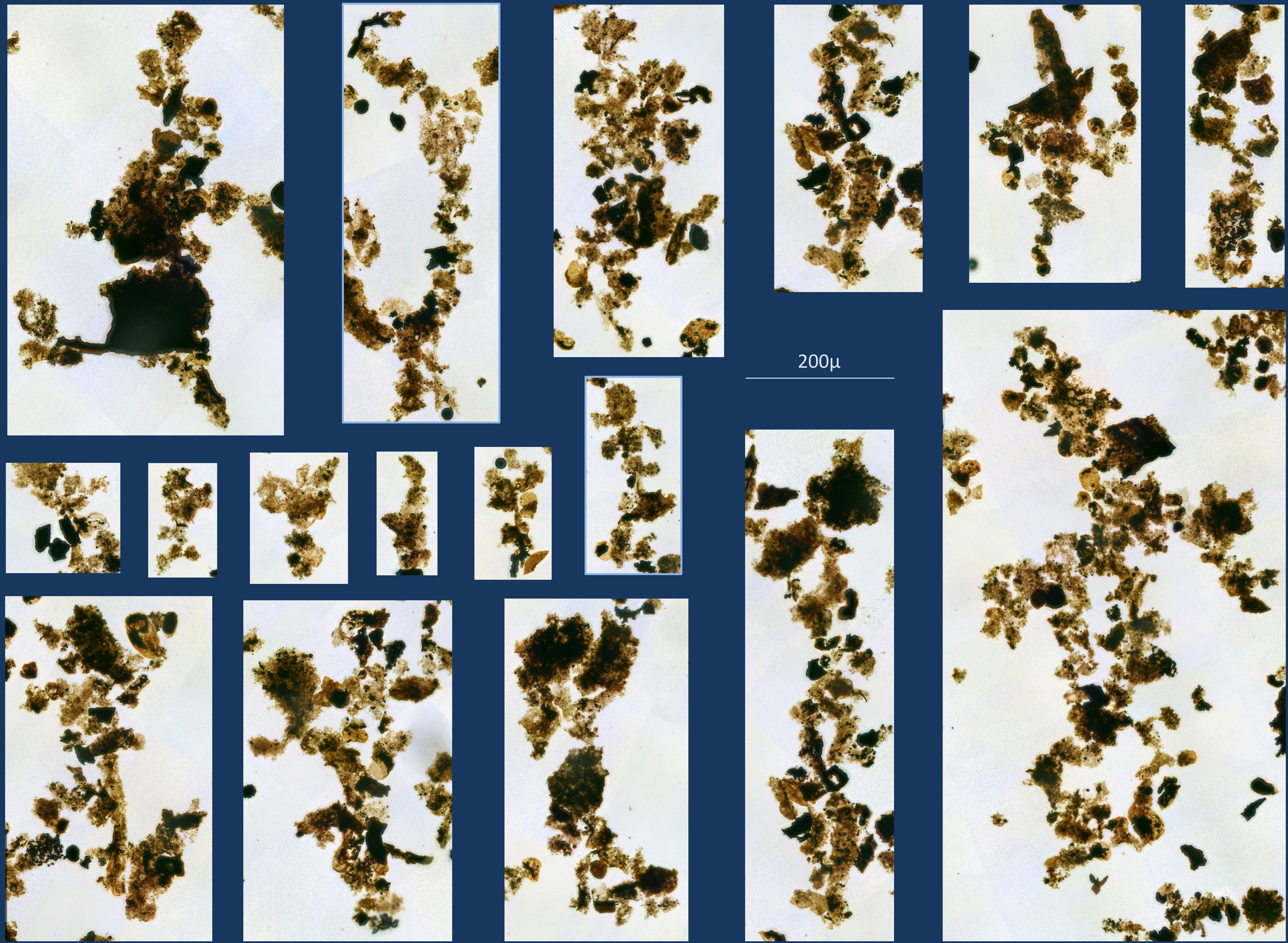
small plant structures and large isolated bodies

100µ

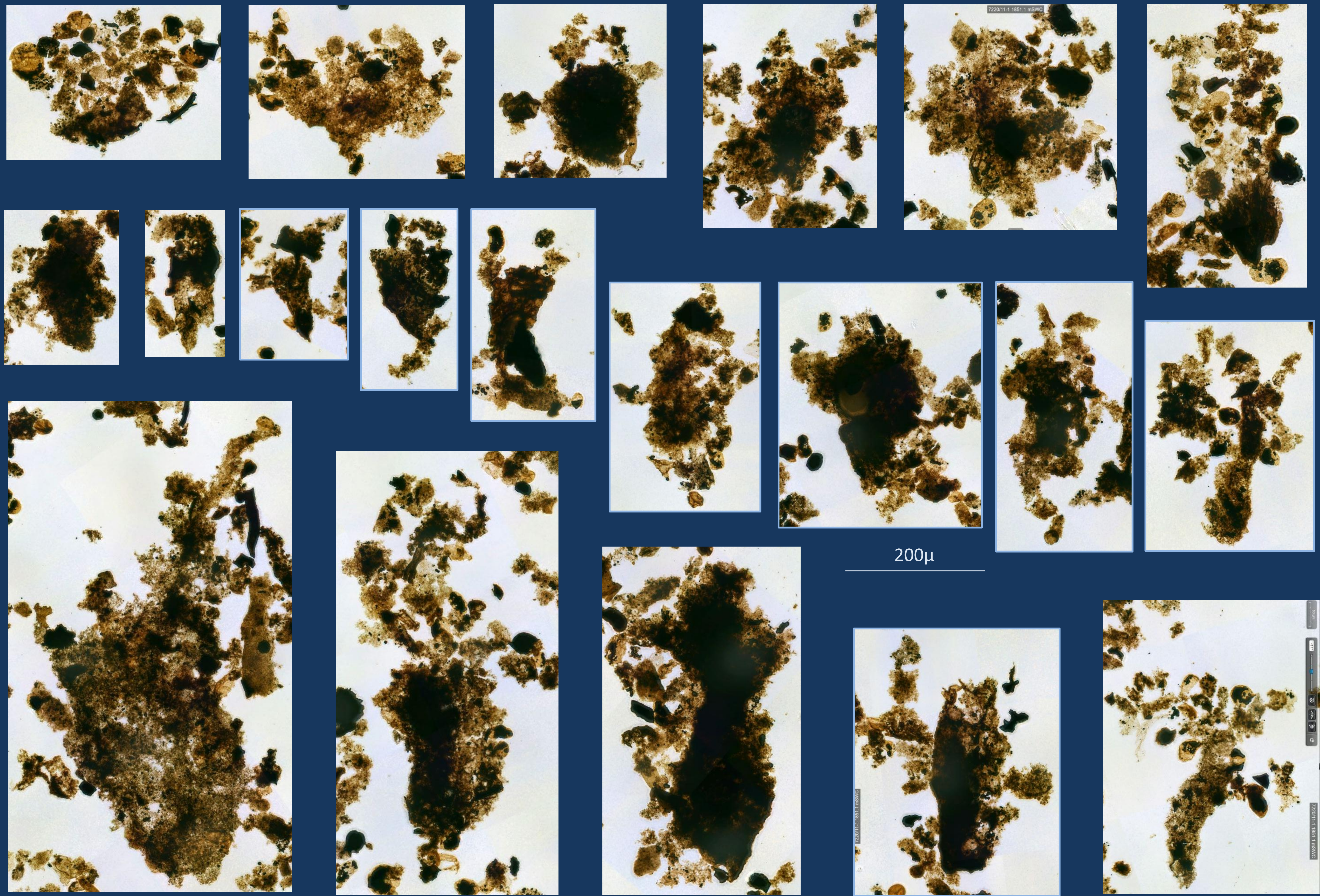


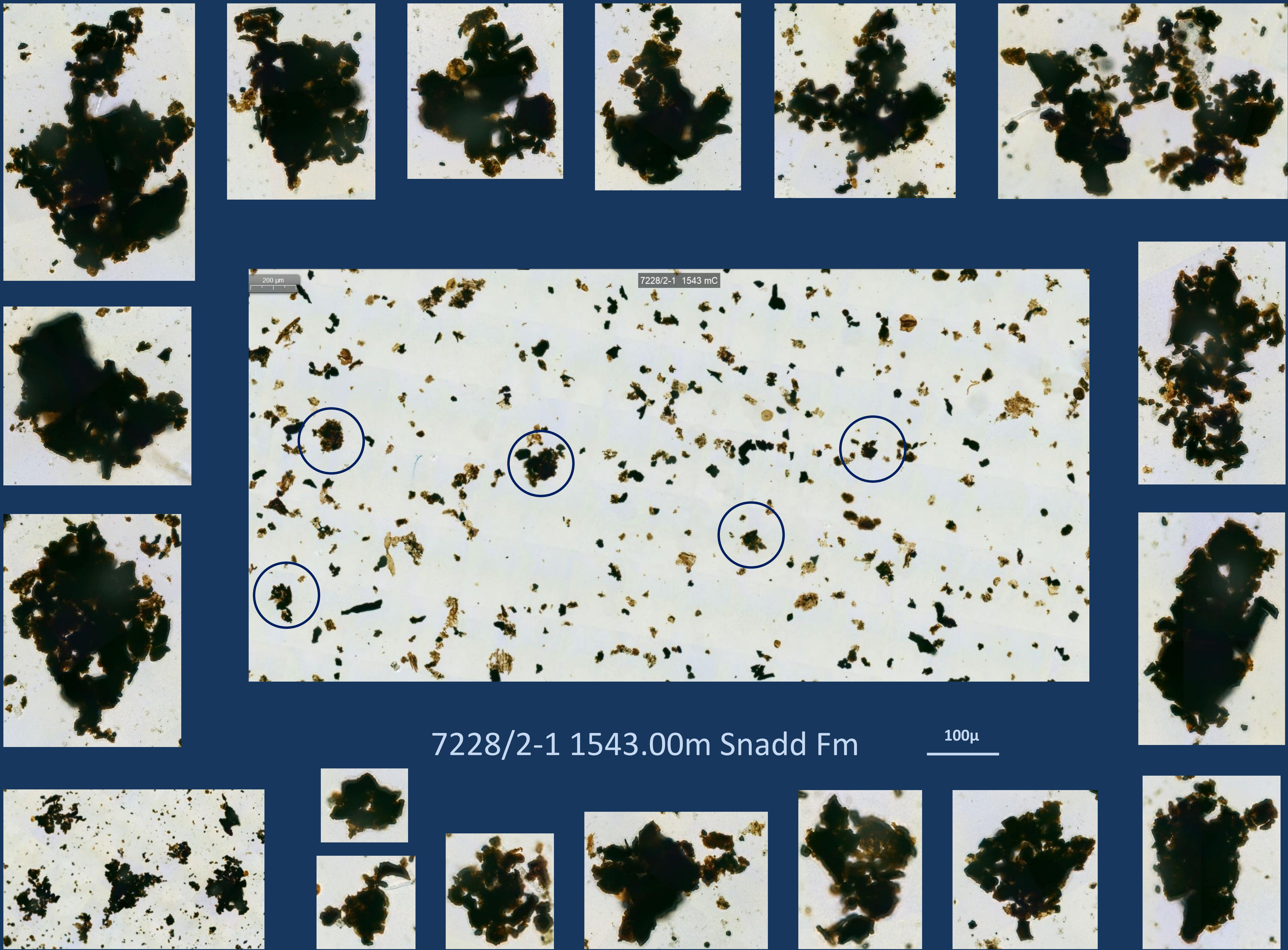
7220/11-1 1851.0m Snadd Fm, Mid-Late Triassic

Small to large branch-like plant structures, many incorporating one or more big SpB's, some with distally attached bodies.



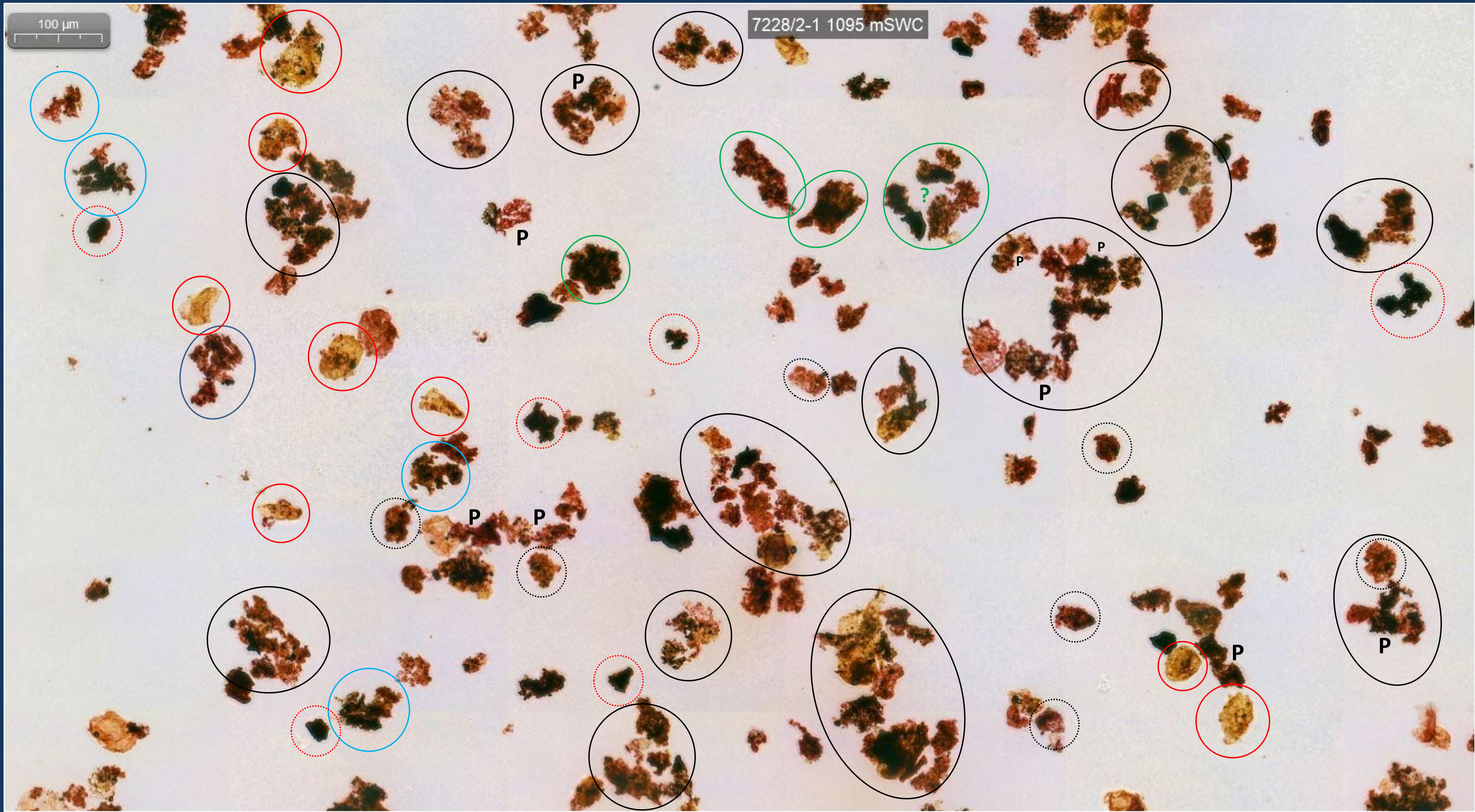
7220/11-1 1851.0m Snadd Fm, Mid-Late Triassic





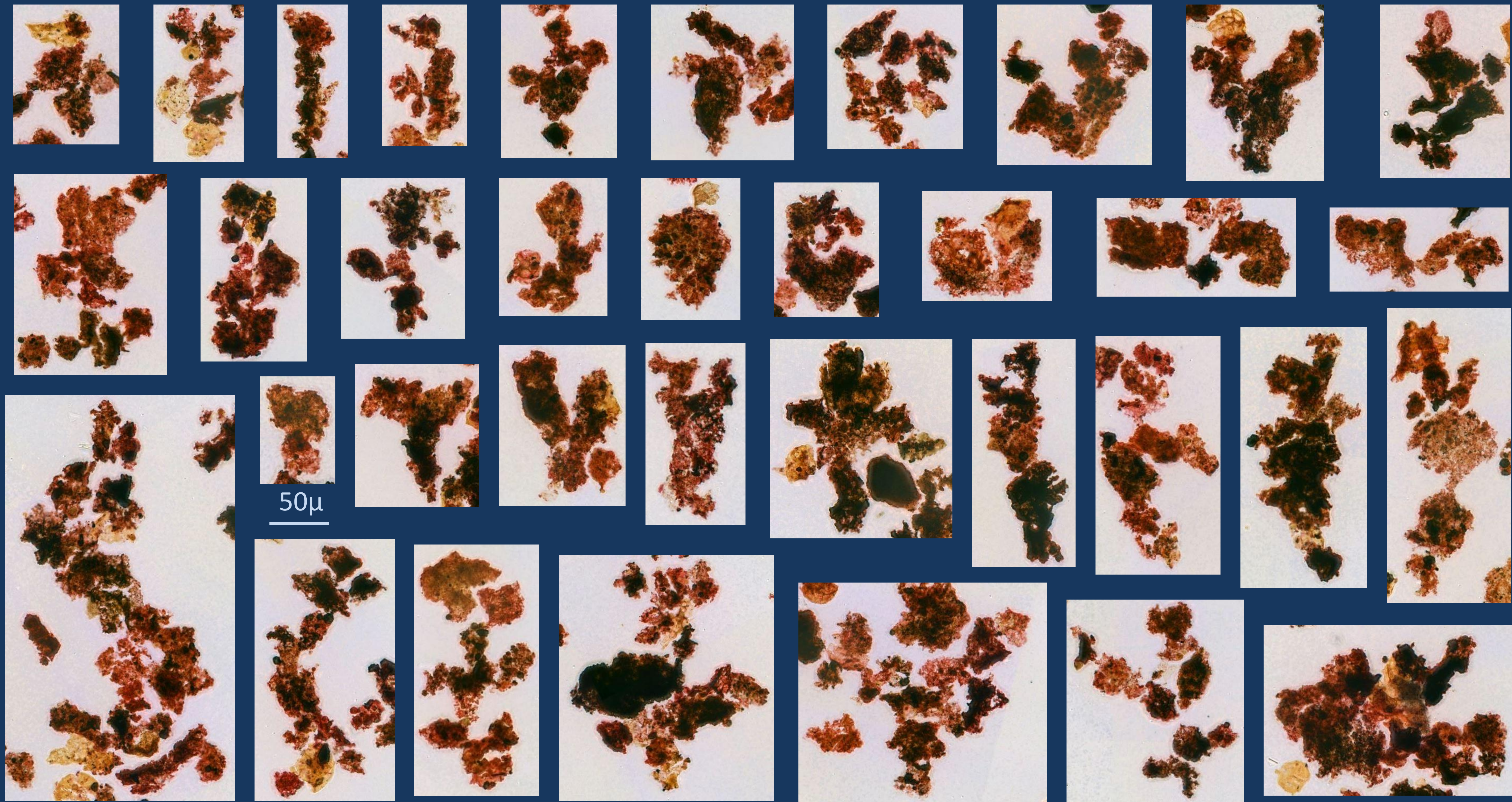
7228/2-1 1543.00m Snadd Fm

7228/2-1 1095.0m Kolmule Fm, Aptian-Cenomanian



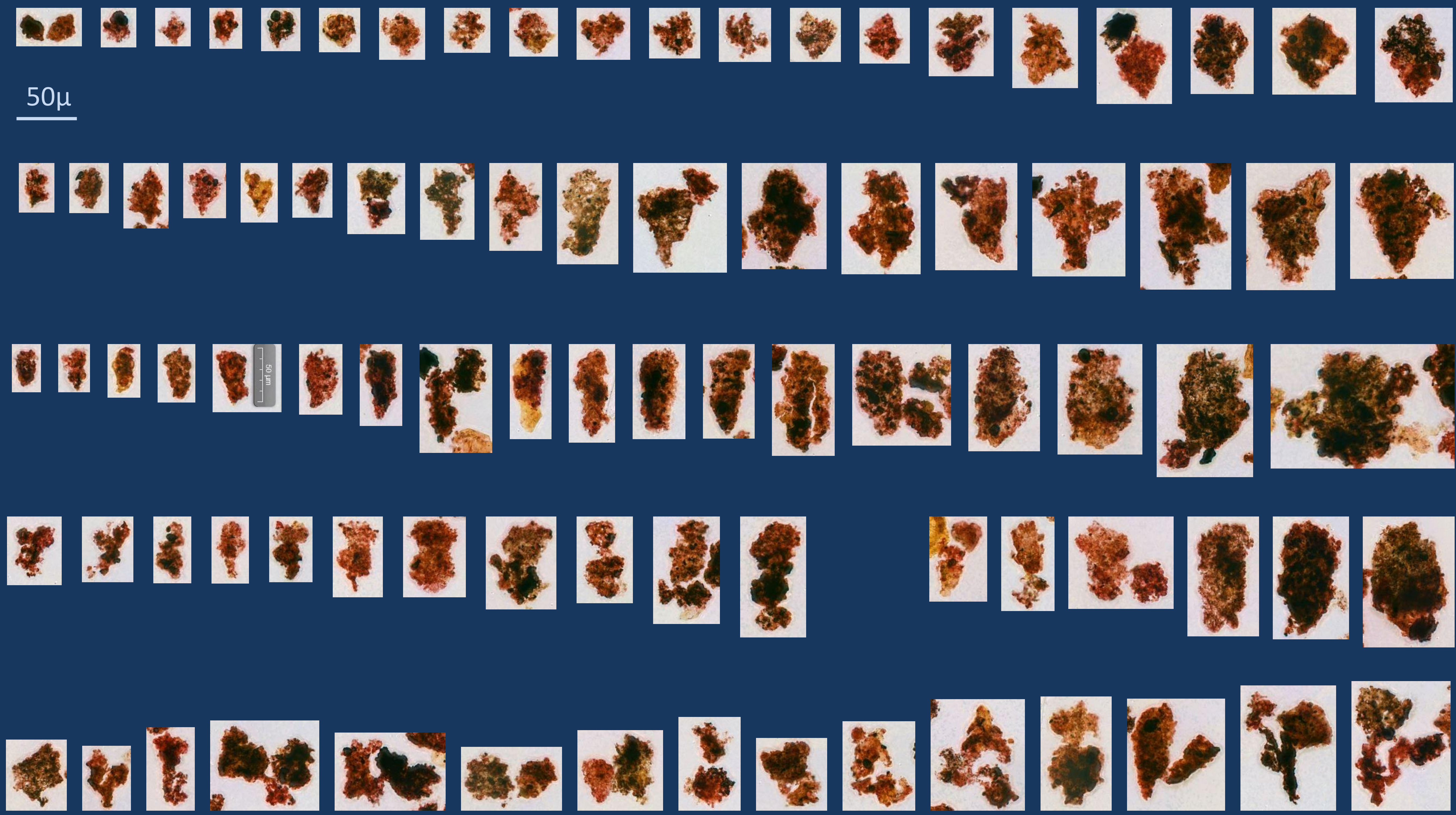
Small plant structures with similar habit (black circles), a few with propeller-shaped elements (P). Some of the larger isolated parts from the same plant (green circles). Foliose bodies of similar appearance and different maturity (blue circles). Small doliform (barrel-shaped) bodies, possibly gemmae (black dotted circles). Yellowish doliform & carotiform bodies; possibly gemmae/gemmalings (blue circles). Disaggregated opaque bodies (red dotted circles) can be seen attached to some of the small plant structures (black circle upper left). Not all examples of each are indicated.

7228/2-1 1095.0m Kolmule Fm, Aptian-Cenomanian

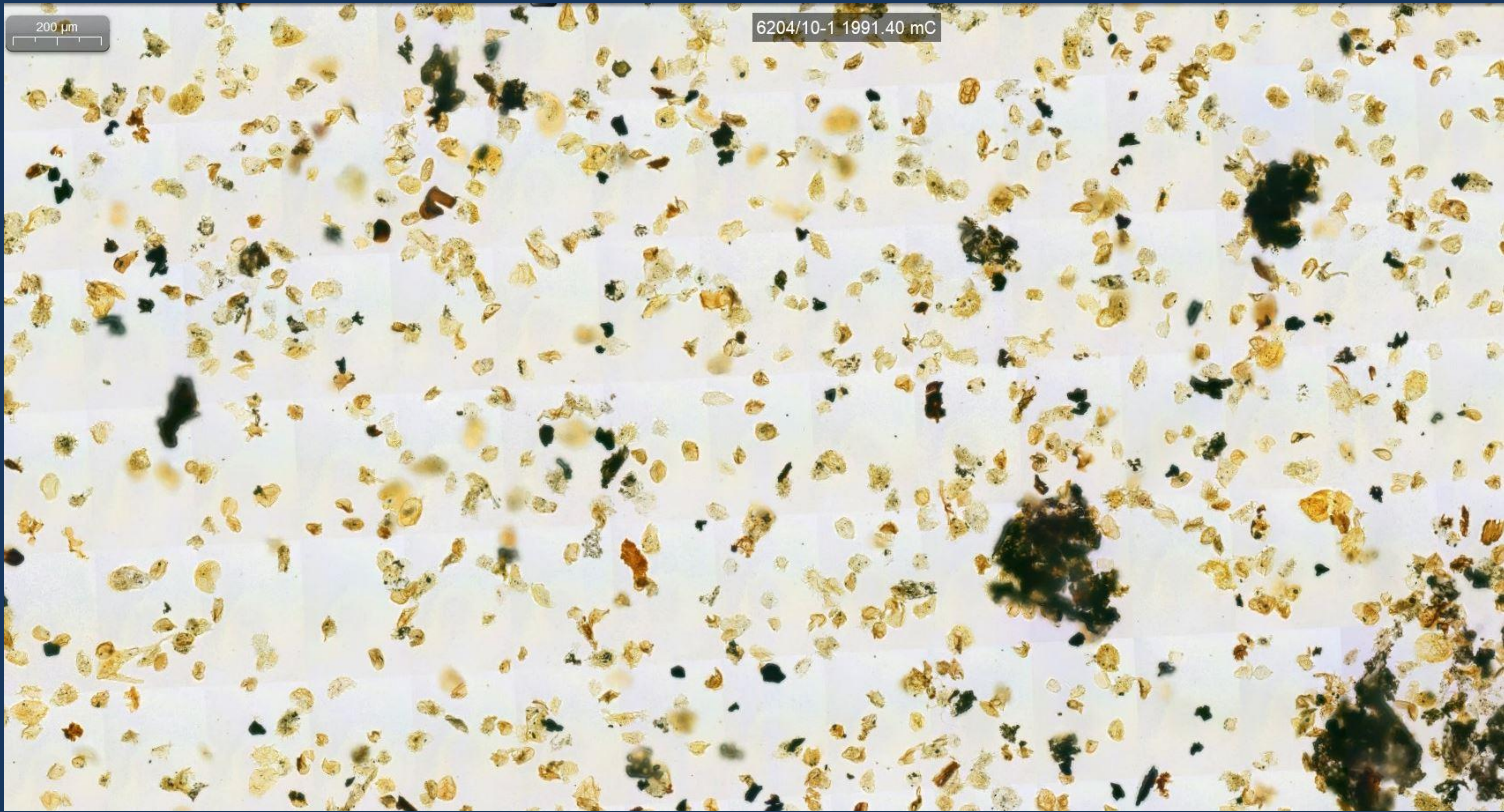


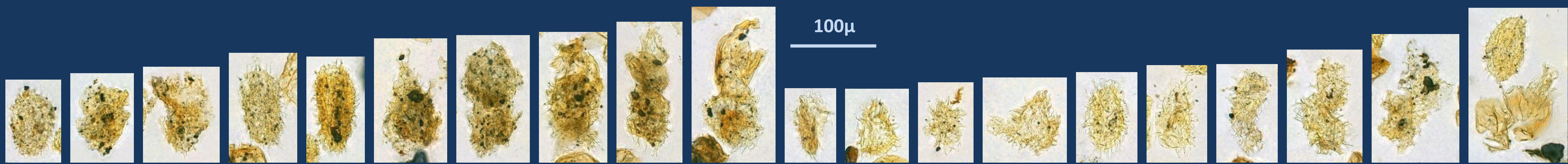
Small branch sections and fragments composed of both pseudoamorphous and more structured parts. Opaque bodies are uncommon, but some can be seen attached to, or embedded within other parts.

7228/2-1 1095.0m , Kolmule Fm, Aptian-Cenomanian

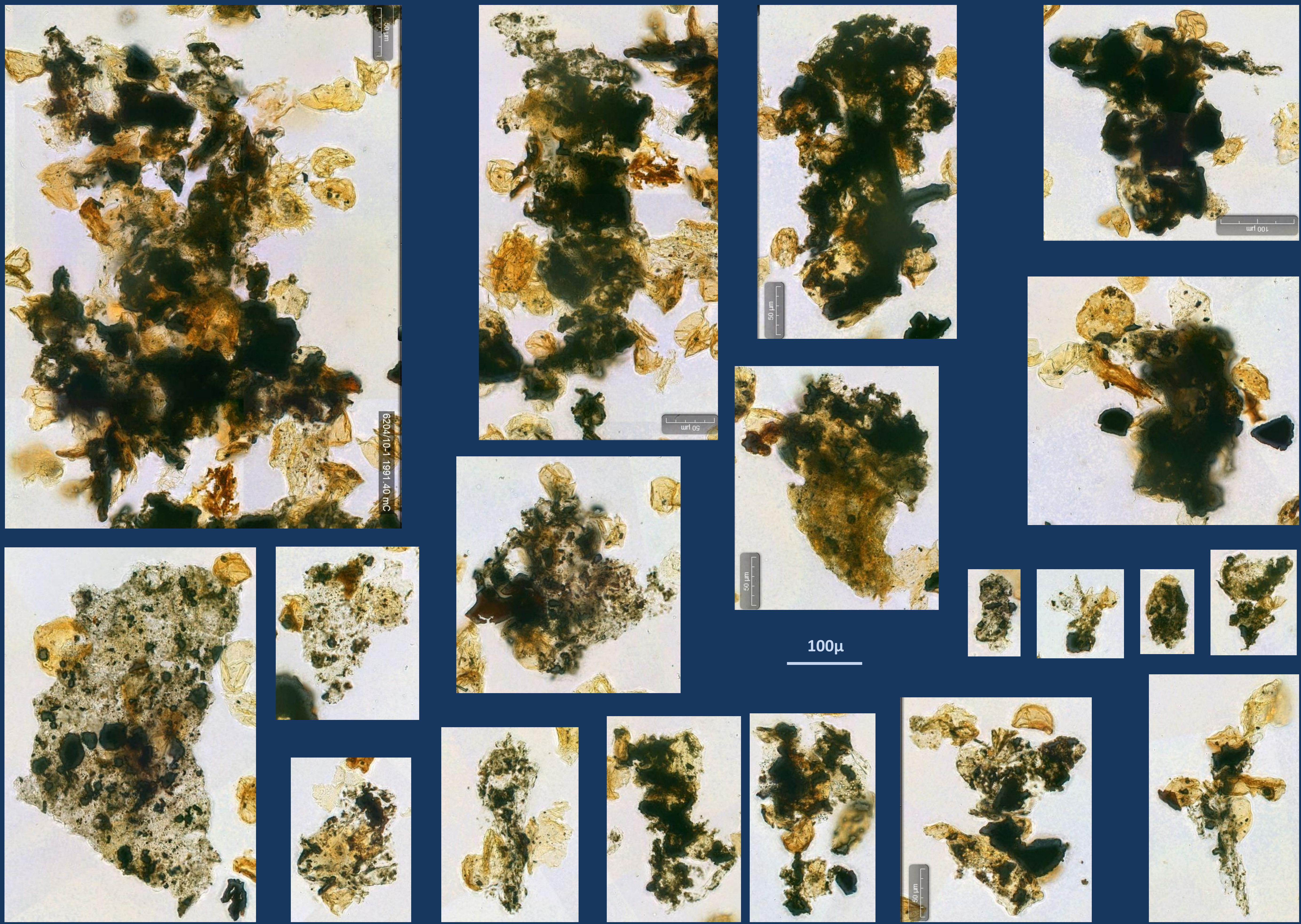


6204/10-1   1991.40m , unnamed unit of Kyrre Fm (Late Turonian – Campanian)



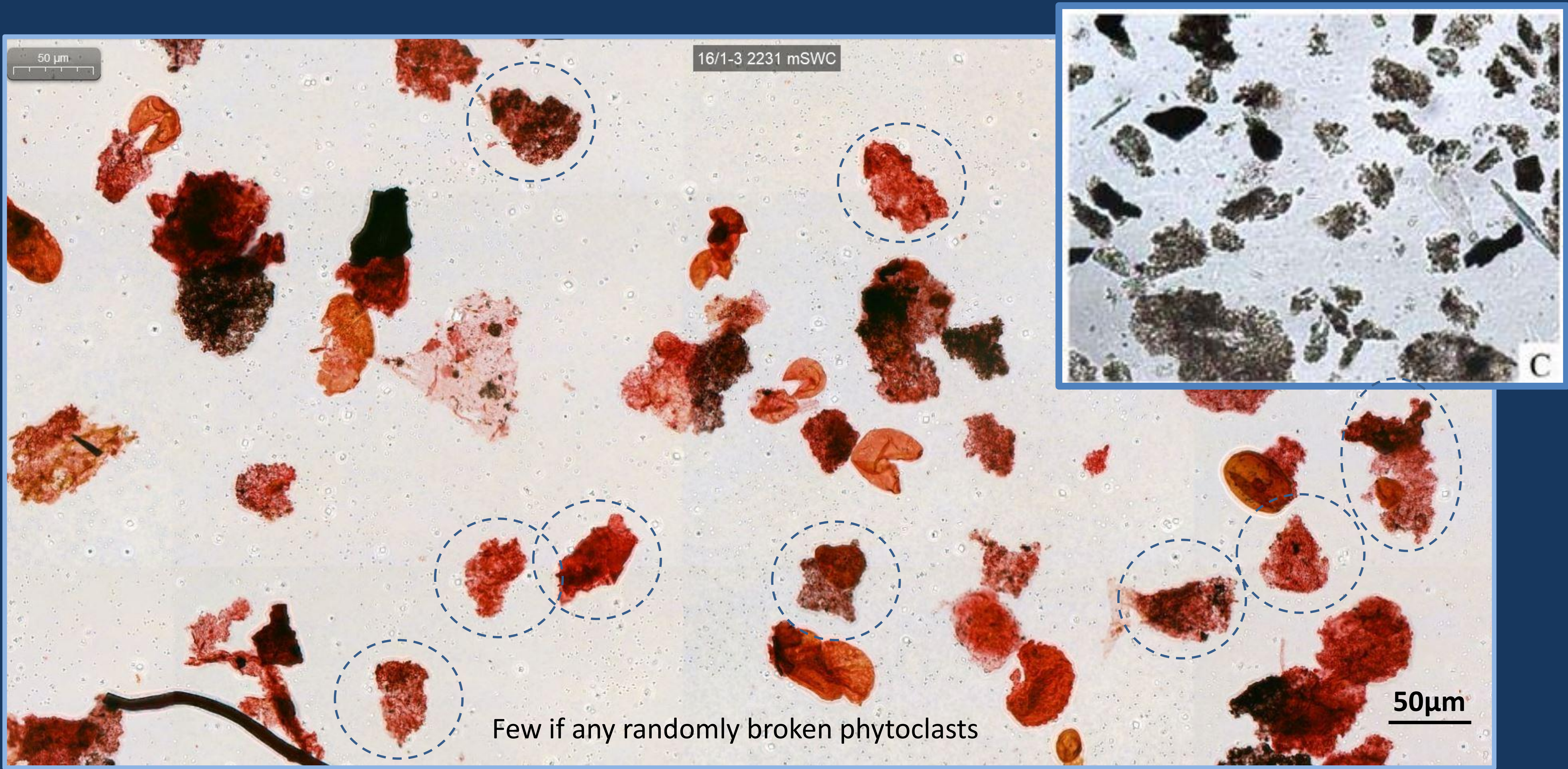


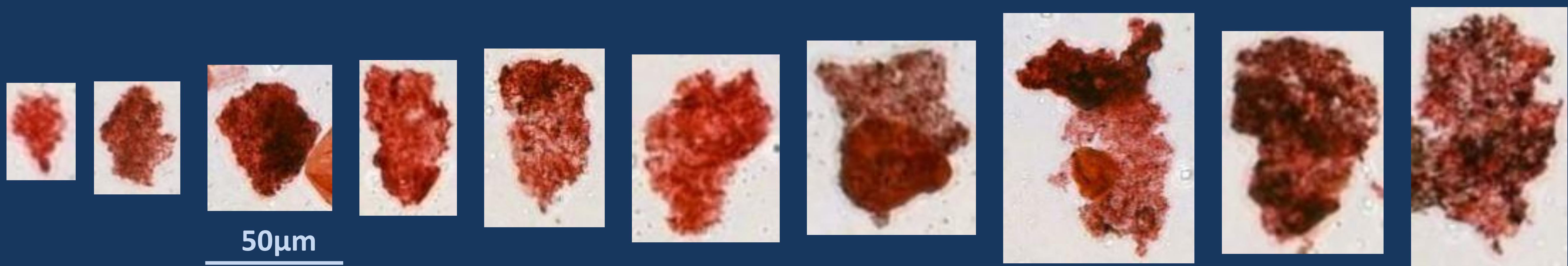
6204/10-1   1991.40m , unnamed unit of Kyrre Fm (Late Turonian - Campanian



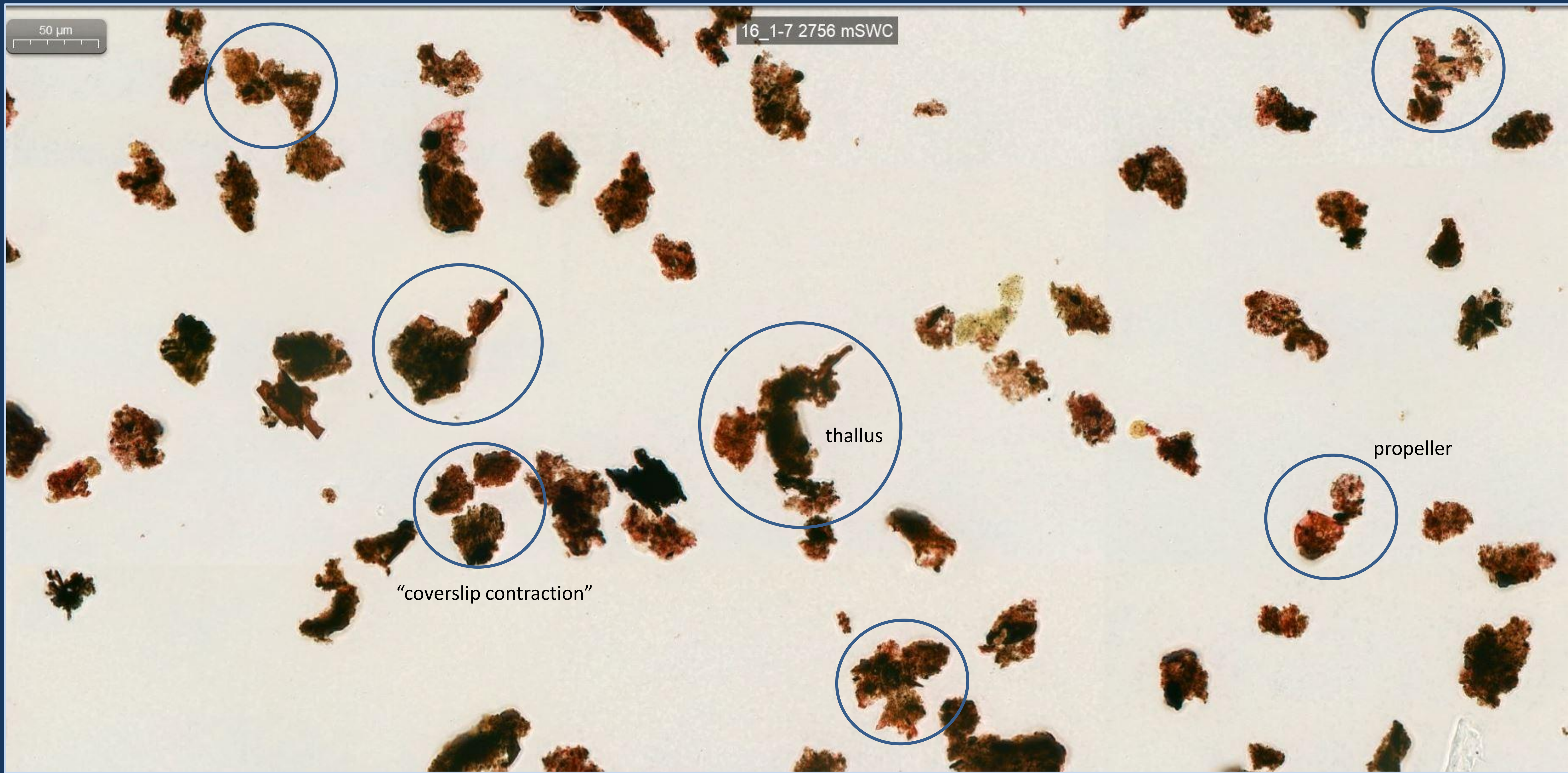
16/1-3 2231.0m Lista Fm, Late Paleocene

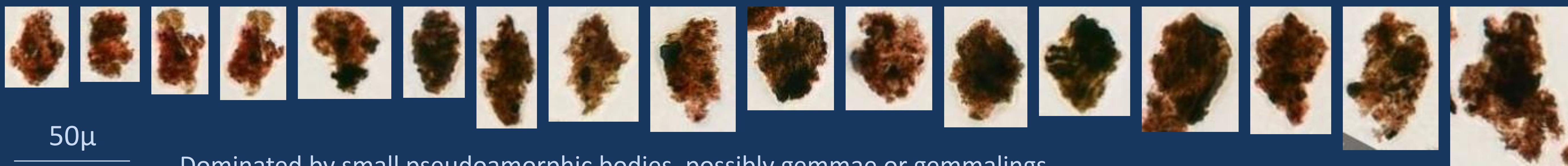
Jianguo & Zhenyu 2007 Pl 1 C; “massive granular” AOM





16/1-7 2756.0m Cromer Knoll Group undiff.

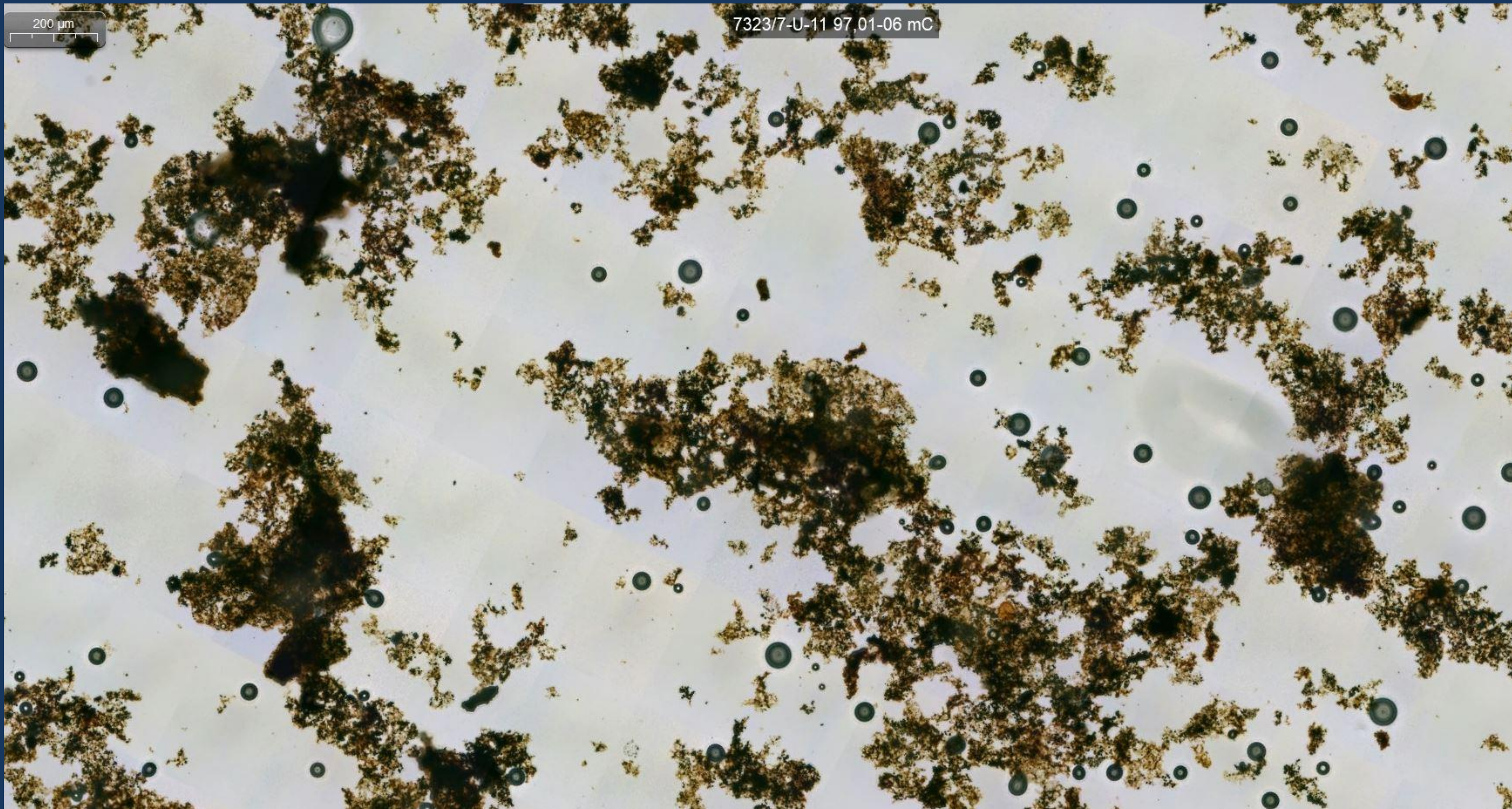




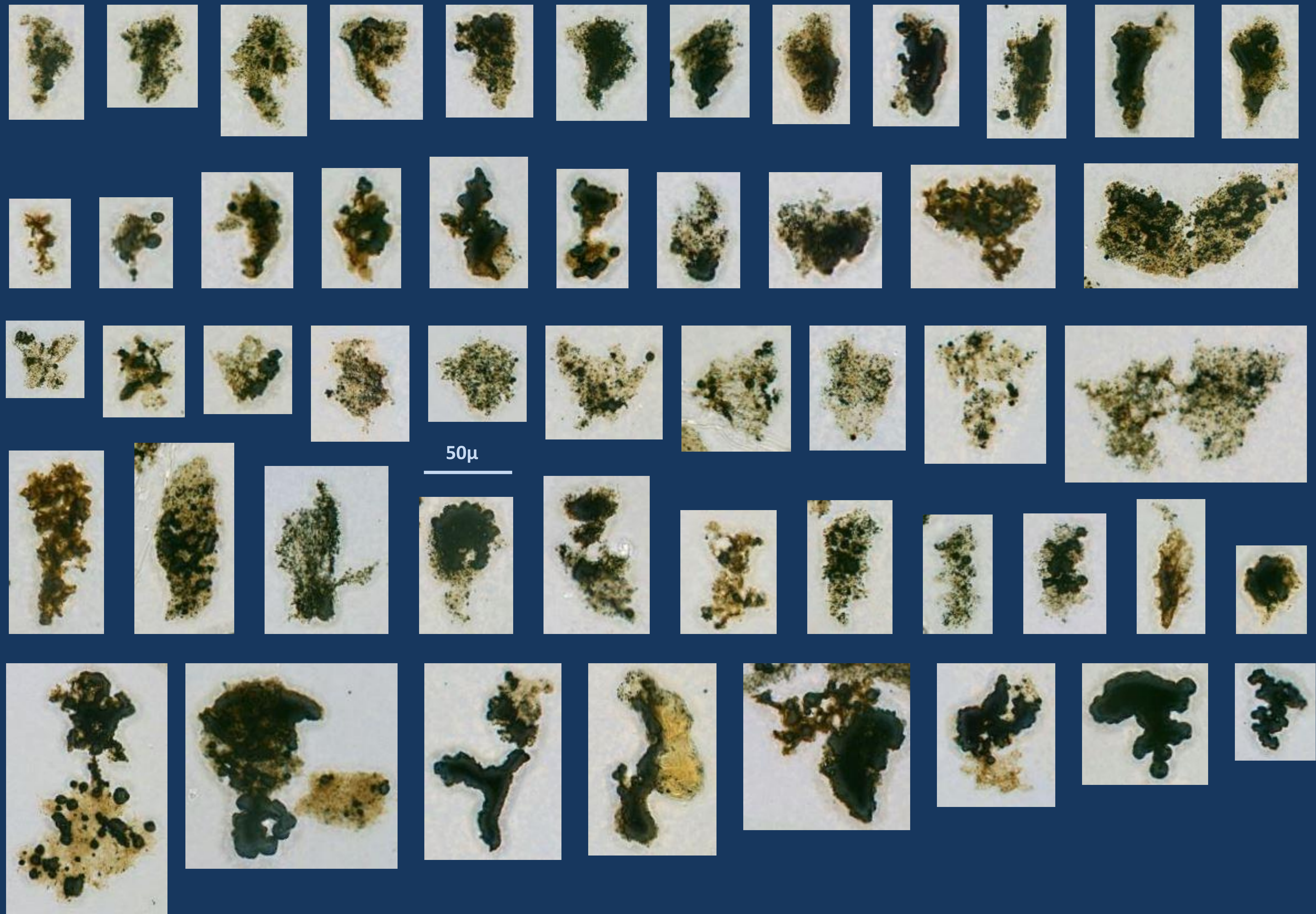
50µ

Dominated by small pseudoamorphic bodies, possibly gemmae or gemmalings and mainly thistle, carrot- and star-shaped. Only a few small plant structures

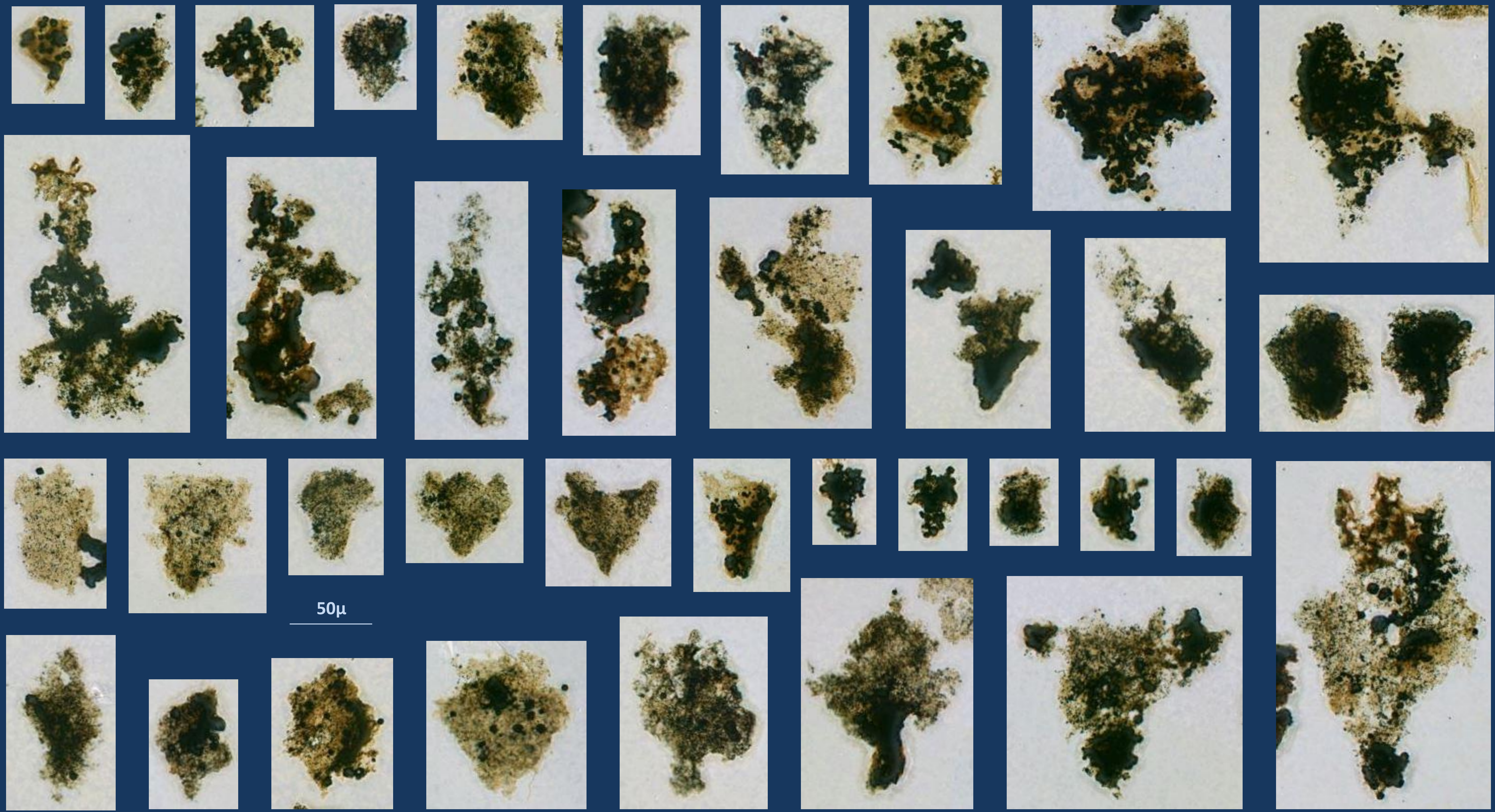
7323/7-U-11 97.06m Permian



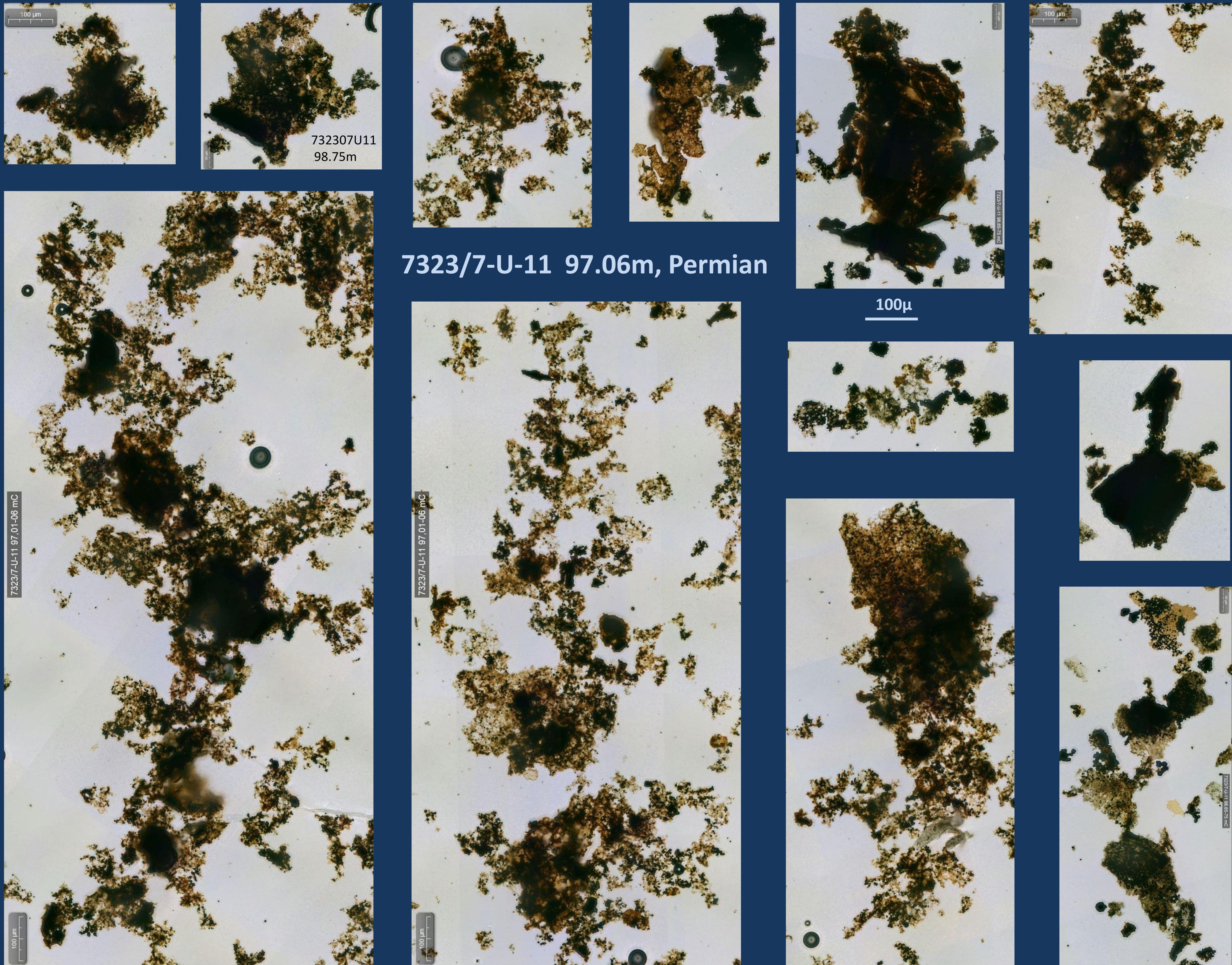
7323/7-U-11 98.75m Permian



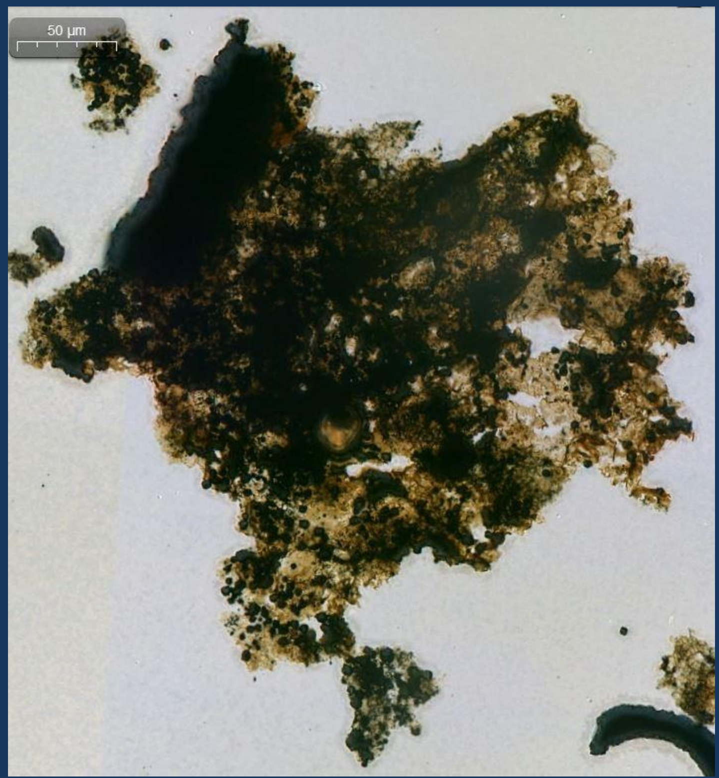
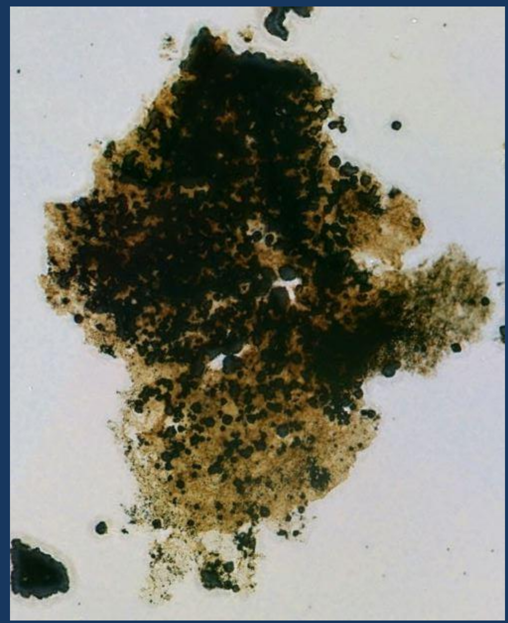
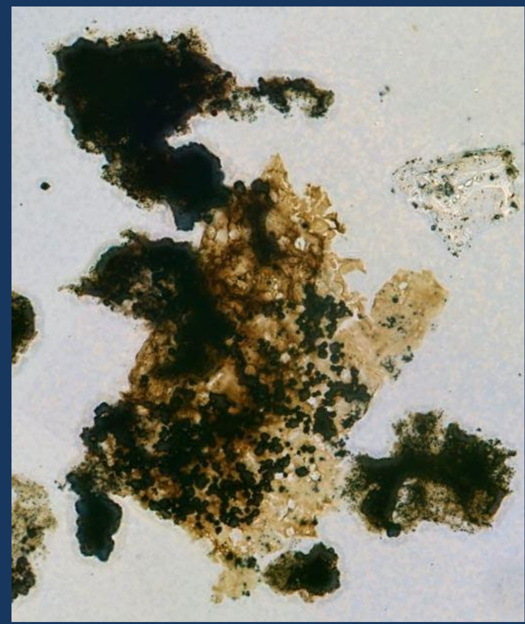
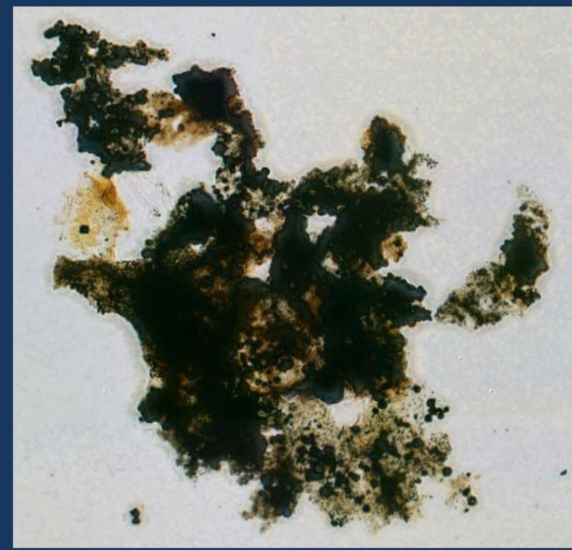
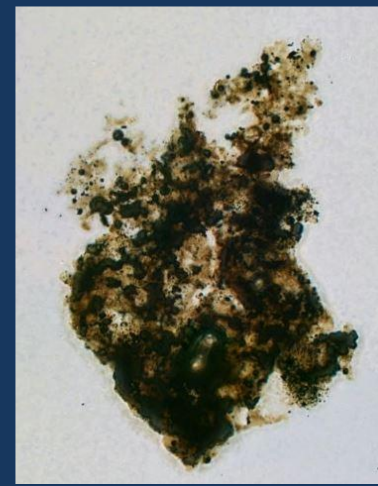
7323/7-U-11 98.75m Permian



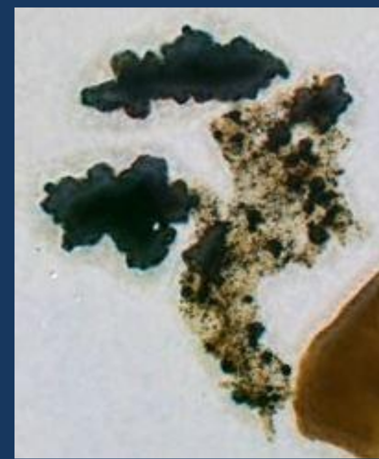
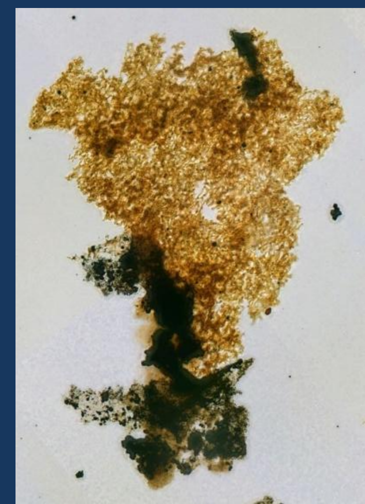
7323/7-U-11 97.06m, Permian



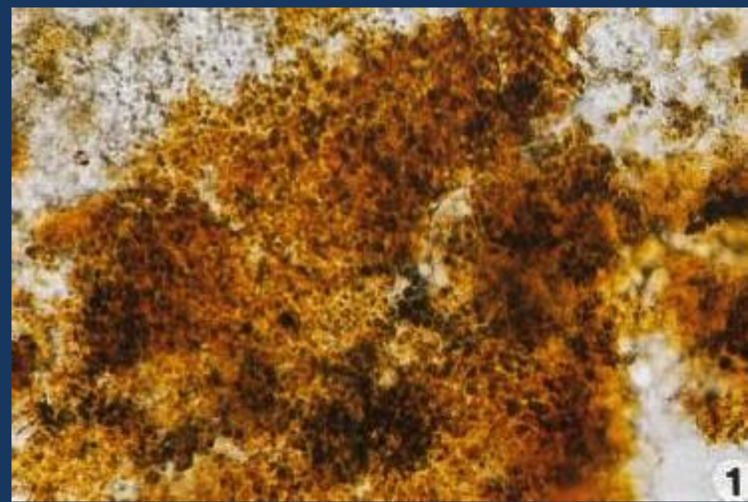
7323/7-U-11 98.75m Permian x200-1

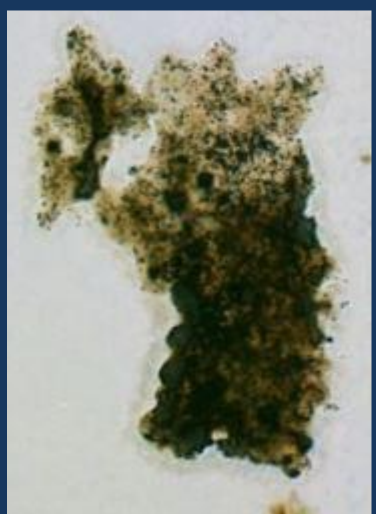
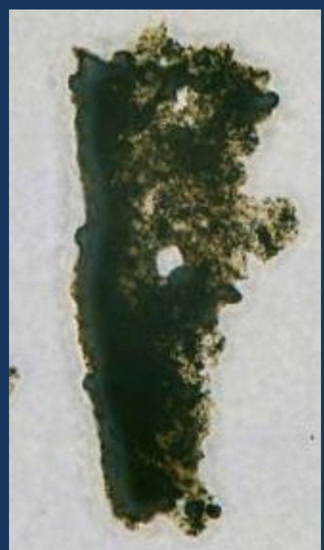
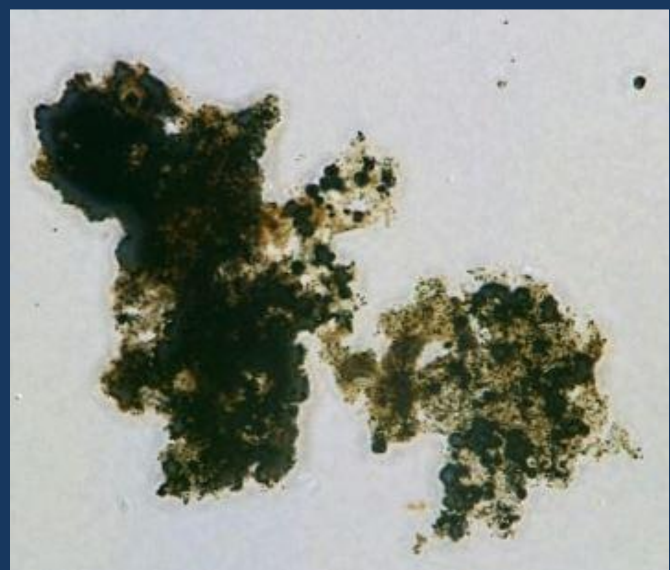
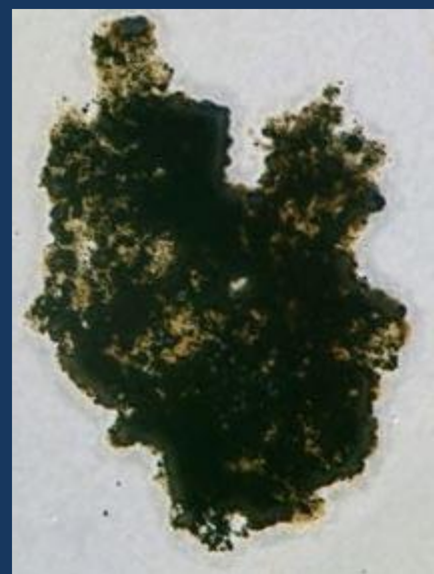
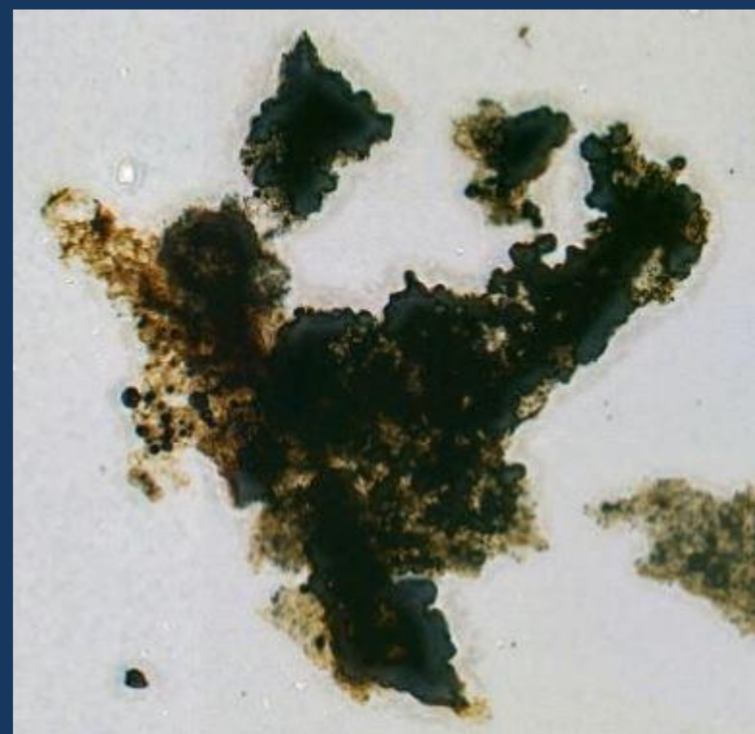






200µ


Batten 1996 Pl.3 Fig 1
cyanobacterial mat from
Sharks Bay, Australia x120

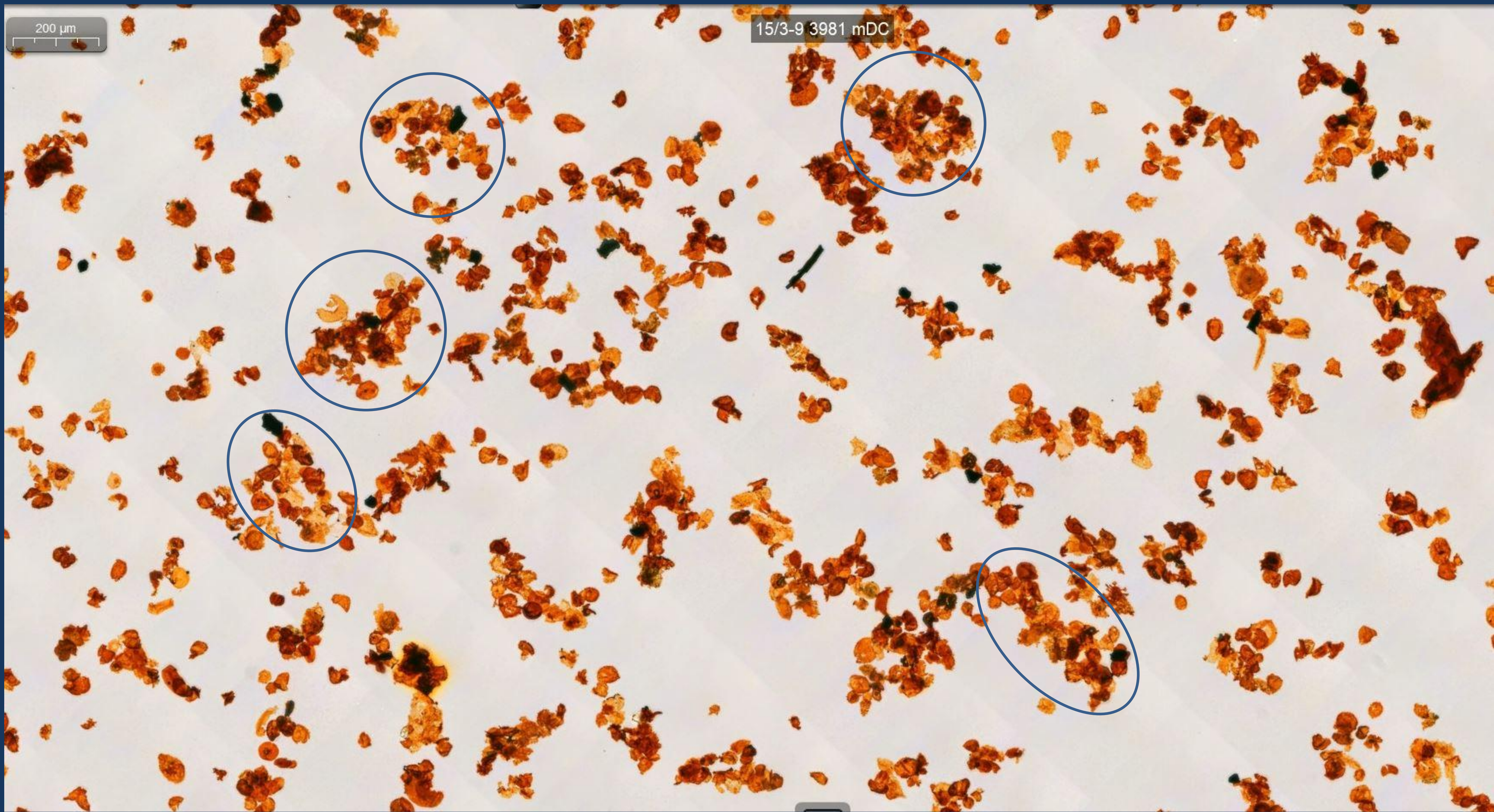


Plant structures are not restricted to pseudoamorphous kerogen

Comparable branch sections and other plant parts also occur in more structured kerogen . Several examples are included here for comparison. The sample on this page is from the Sleipner Fm and has been subjected to minimal transport so that the material is dominated by very large, well preserved plant structures. There are remarkably few isolated particles present, with virtually everything still attached to the parent plant. The attached bodies occur in huge amounts and many are similar in appearance to bisaccate pollen and other miospores. Most of the remaining parts are treated as randomly fragmented “palynodebris”, of which there is almost none.

15/3-9 3981m Draupne Fm, Berriasian.

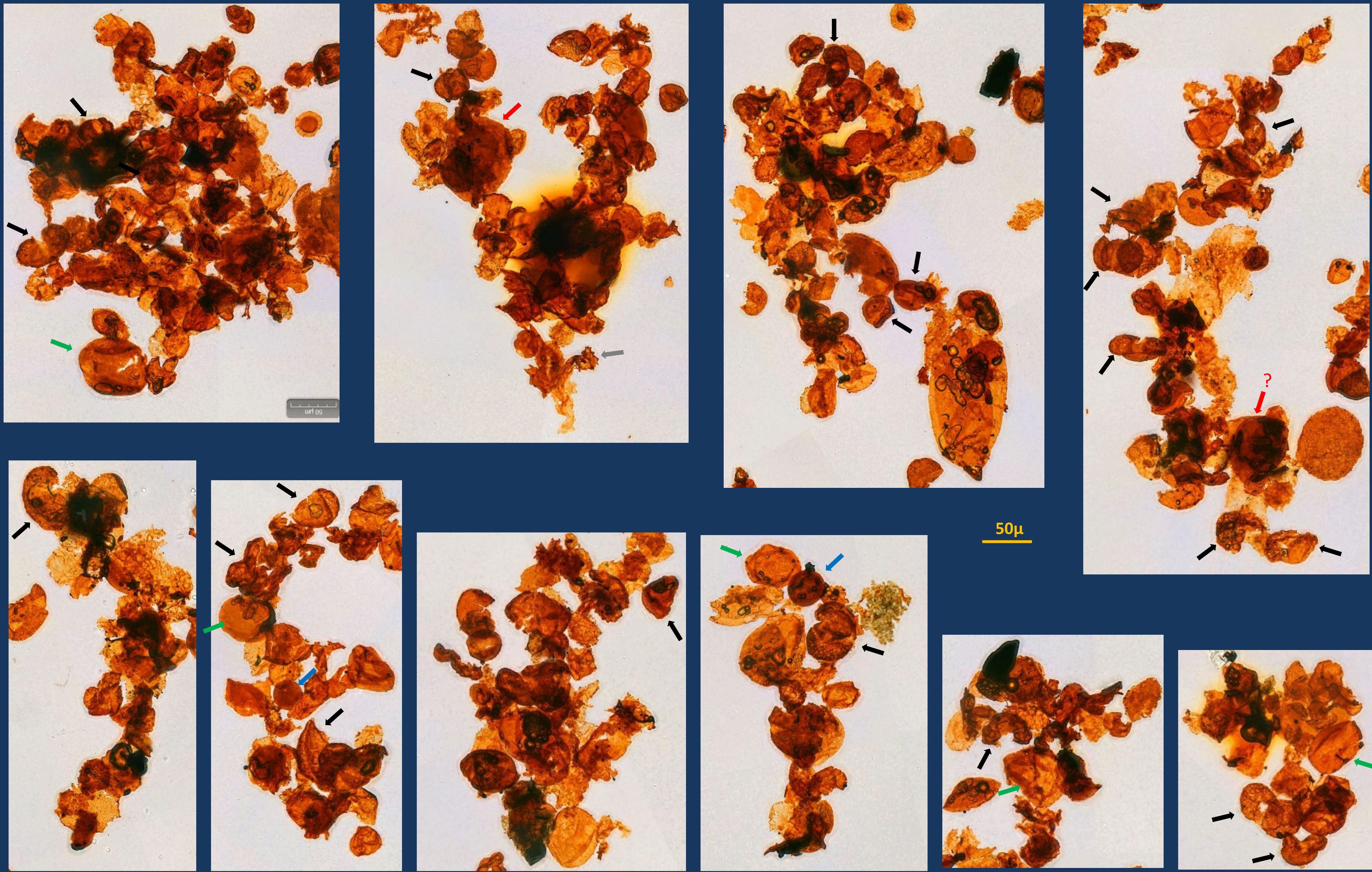


A few medium sized plant structures highlighted

15/3-9 3981m Draupne Fm, Berriasian

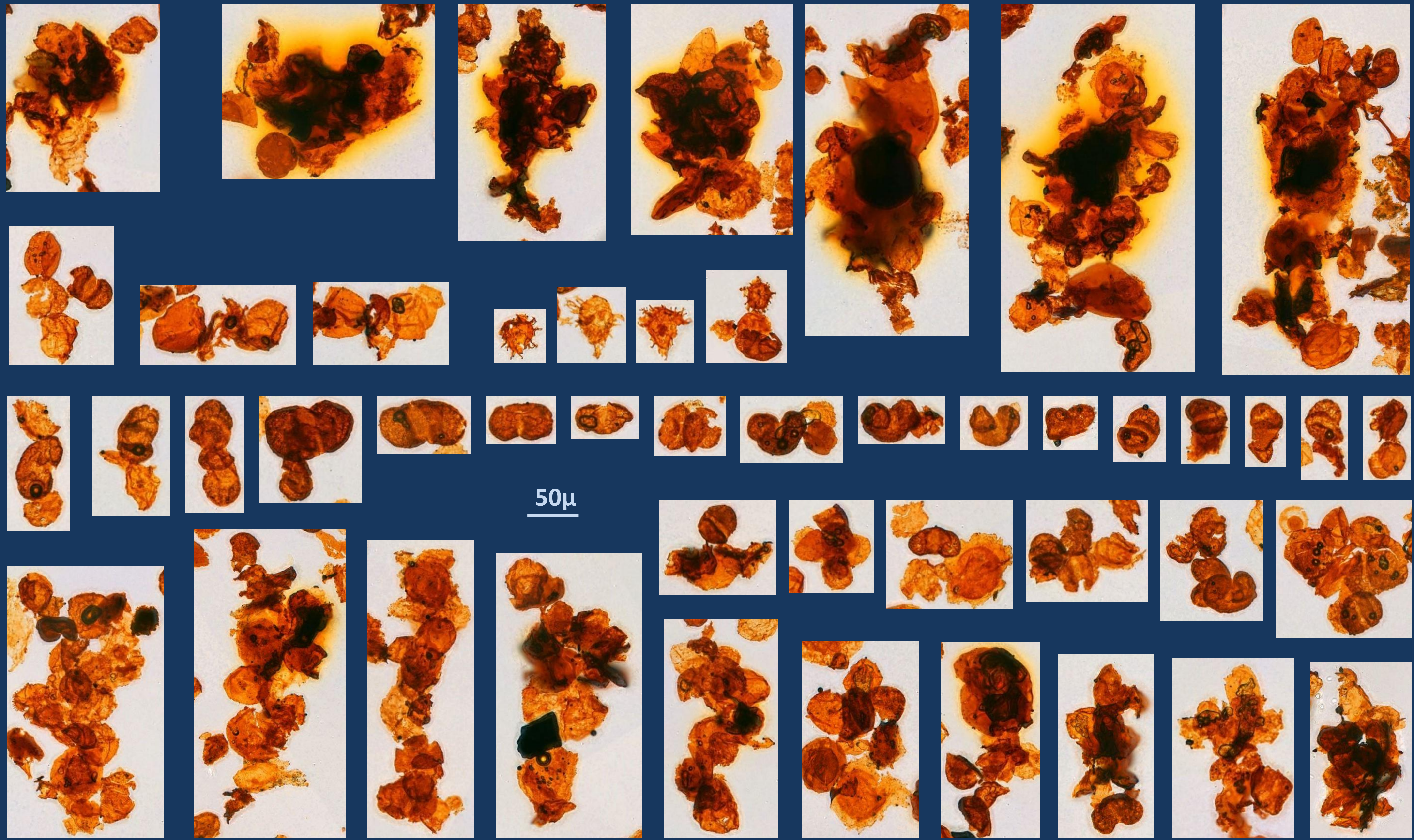
Numerous small structures, most including variably incomplete "propellers", (green circles), together with many individual propellers and propeller fragments (red circles). Attached bisaccate-like bodies (black arrows). Another type of attached cell has a spiny fringe, which is seen *in situ* and disaggregated (blue circles). Virtually everything in the field of view is a component part of the same plant; even the small equidimensional opaque bodies (black circles), though these are relatively uncommon here.

15/3-9 3981m Draupne Fm; large plant structures



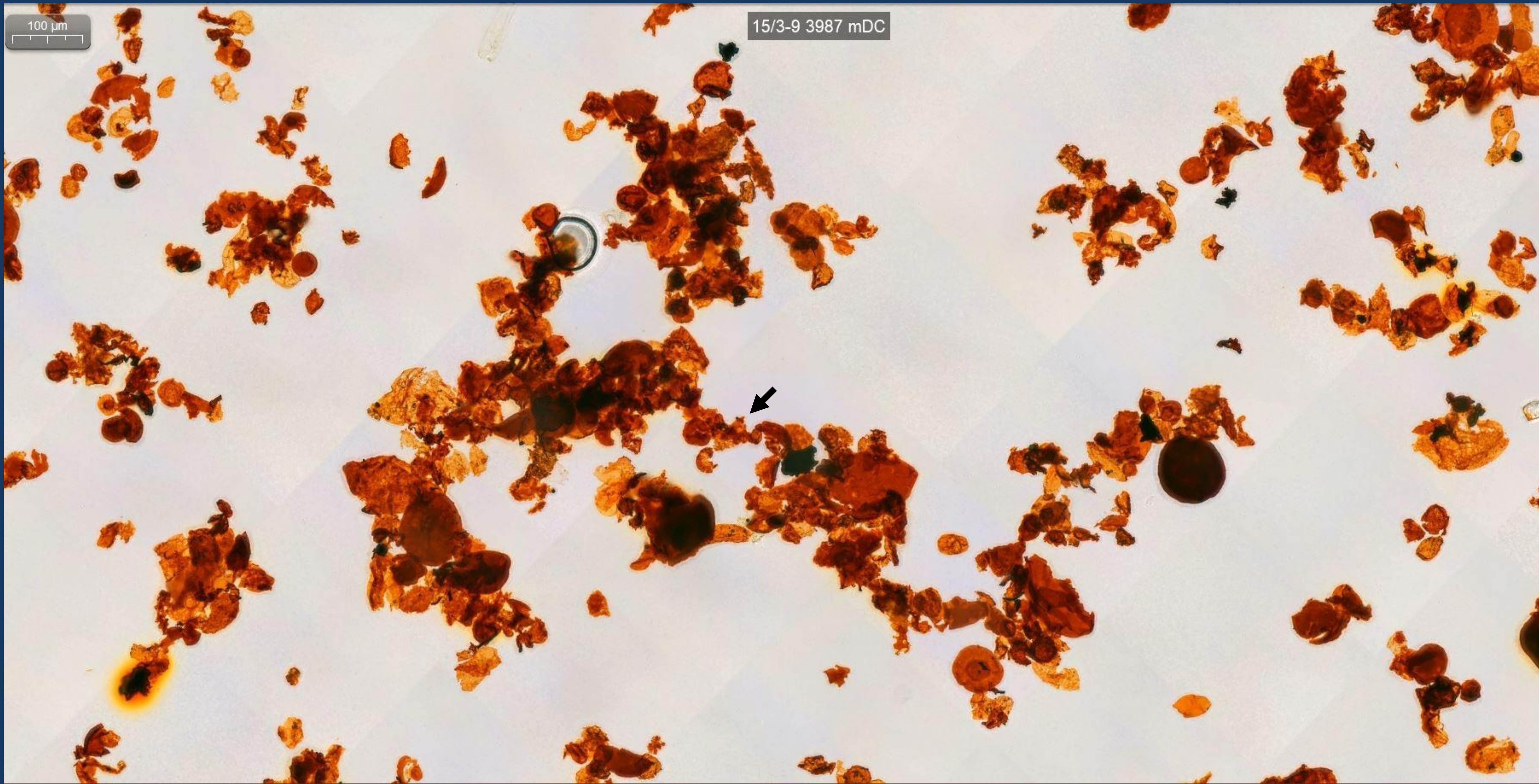
Attached bodies include common bisaccate-like grains (black arrows), *Araucariacidites* –like grains (green arrows), Pterospermella-like bodies (red arrows) and "smooth *Tasmanites*" type cells (*Pterospermella "simplex" sensu* BioStrat; blue arrows). There are many more vaguely pollen-like grains and occasional small spinose bodies (grey arrow).

15/3-9 3981m Draupne Fm



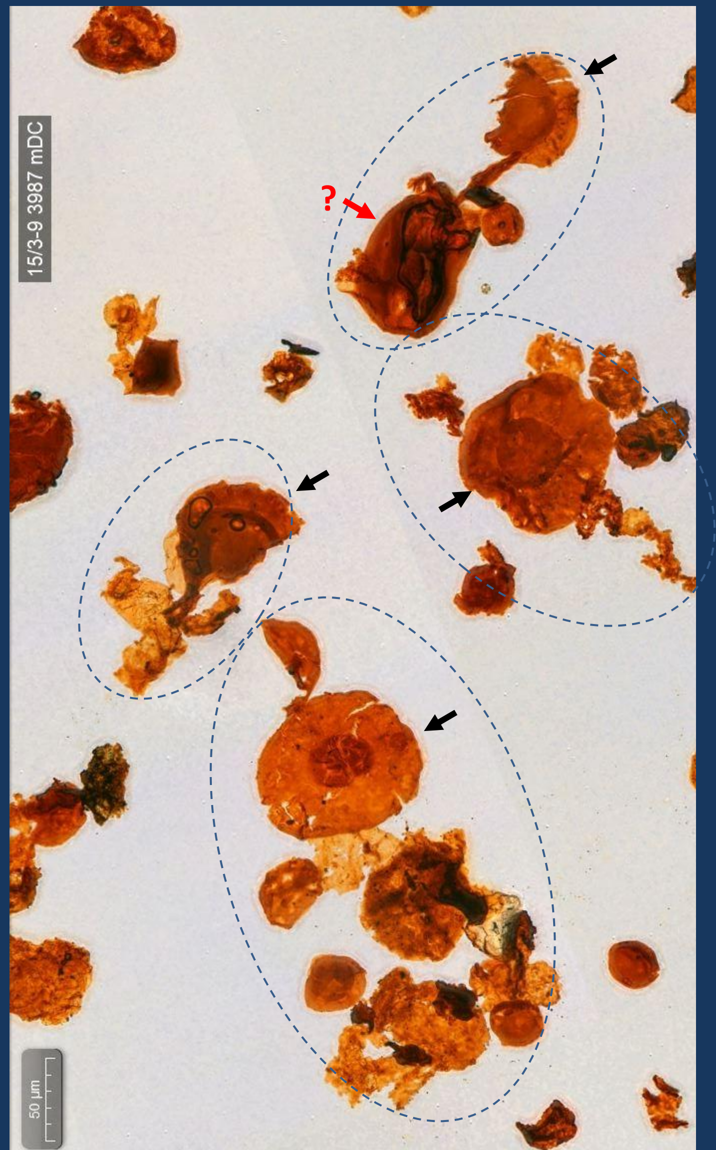
Top row; possible reproductive structures, with centrally located opaque SpB. Second row: “propellers” and small spiny cells. Third row; attached and isolated bisaccate-like cells from the same sample, some with stipules. Fourth row; small incomplete Structures with numerous attached bisaccate-like grains. Bottom row; short branch fragments and small structures.

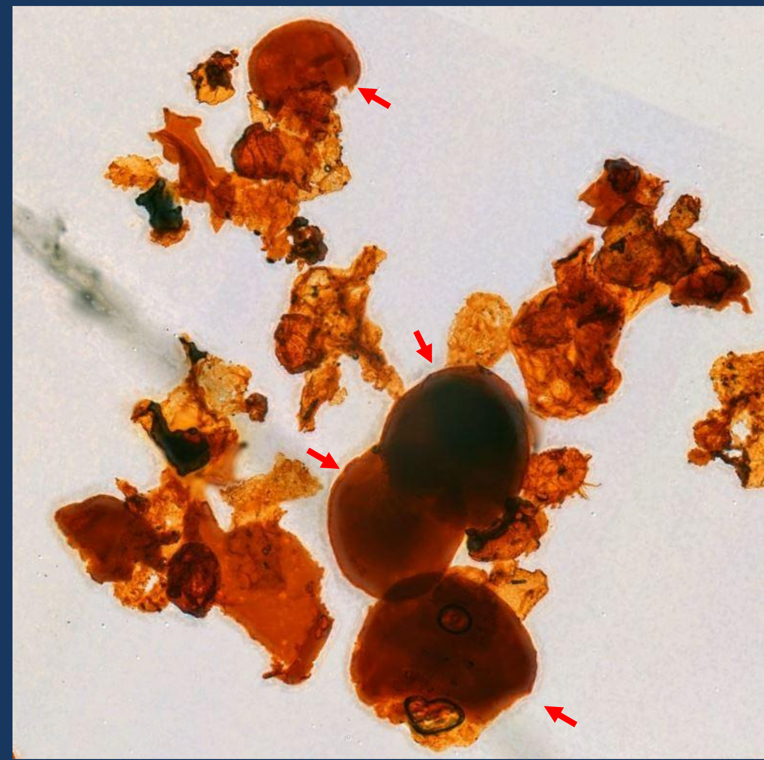
15/3-9 3987m Draupne Fm, “hot shale facies” with abundant *prasinophycaeans*

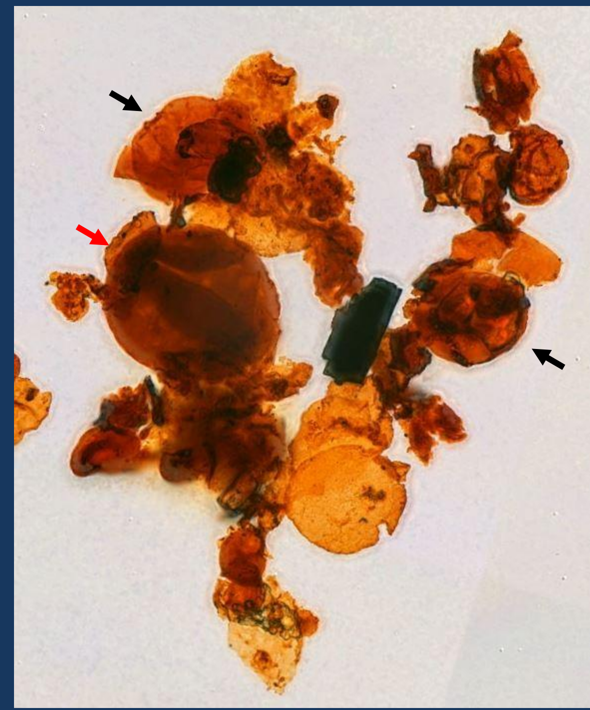


Near the centre of the image a single propeller-like part still connects the two larger structures (black arrow). The propellers are joined in irregular chains, or fused into larger more substantial plant bodies and account for a significant part of the sections. All the large sections around the centre Were possibly in one piece before separating during drying & hardening of the mounting medium. All the smaller structures and isolated bodies are disaggregated from larger parts.

15/3-9 3987m hot Draupne Fm

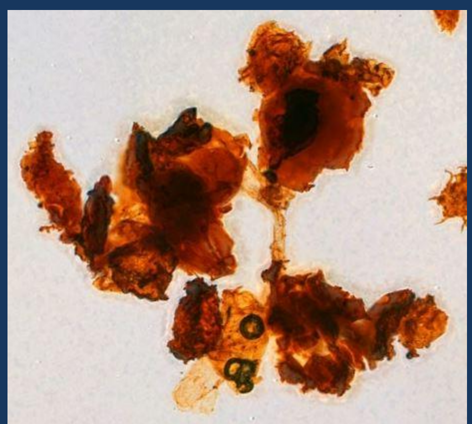


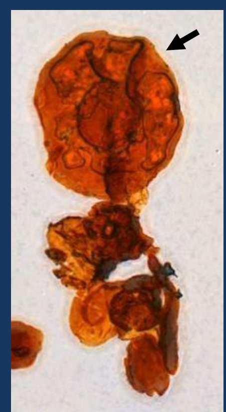


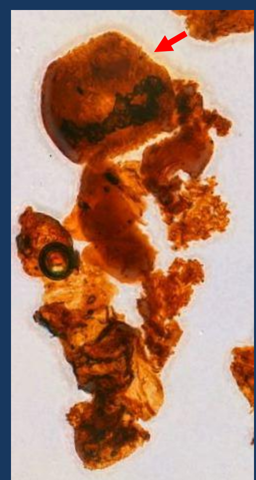


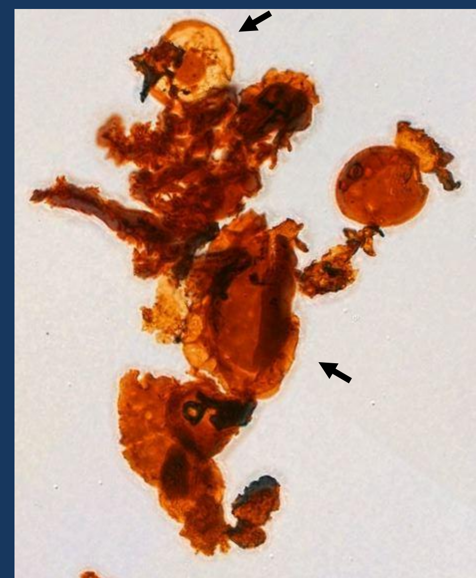
Plant structures with attached prasinophycaean –like bodies, including some referable to *Pterospermella* (black arrows) and others similar to “smooth *Tasmanites*” (red arrows).

50µ

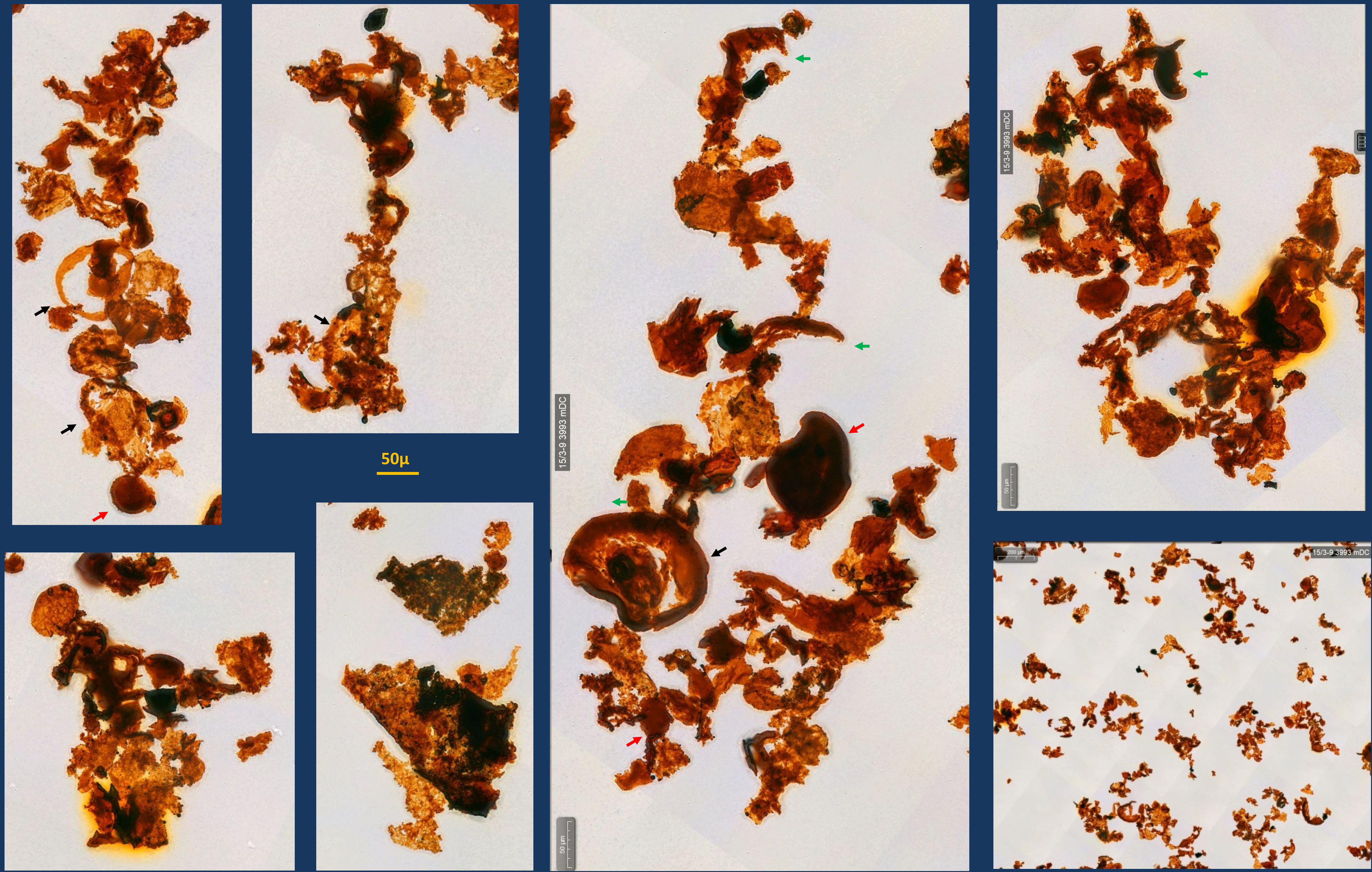






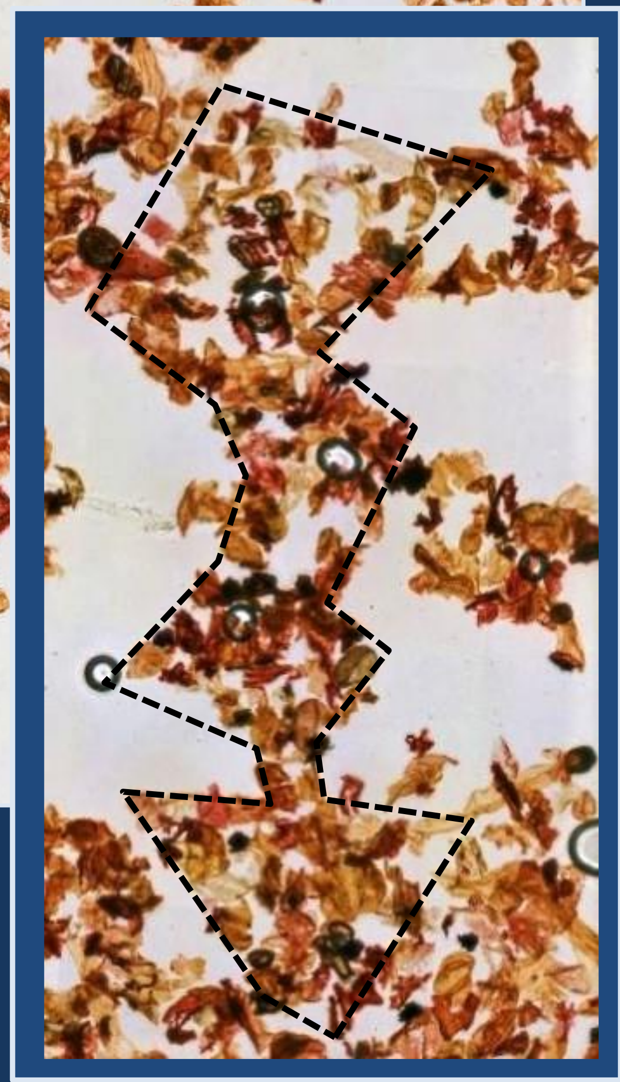


15/3-9 3993m hot Draupne Fm



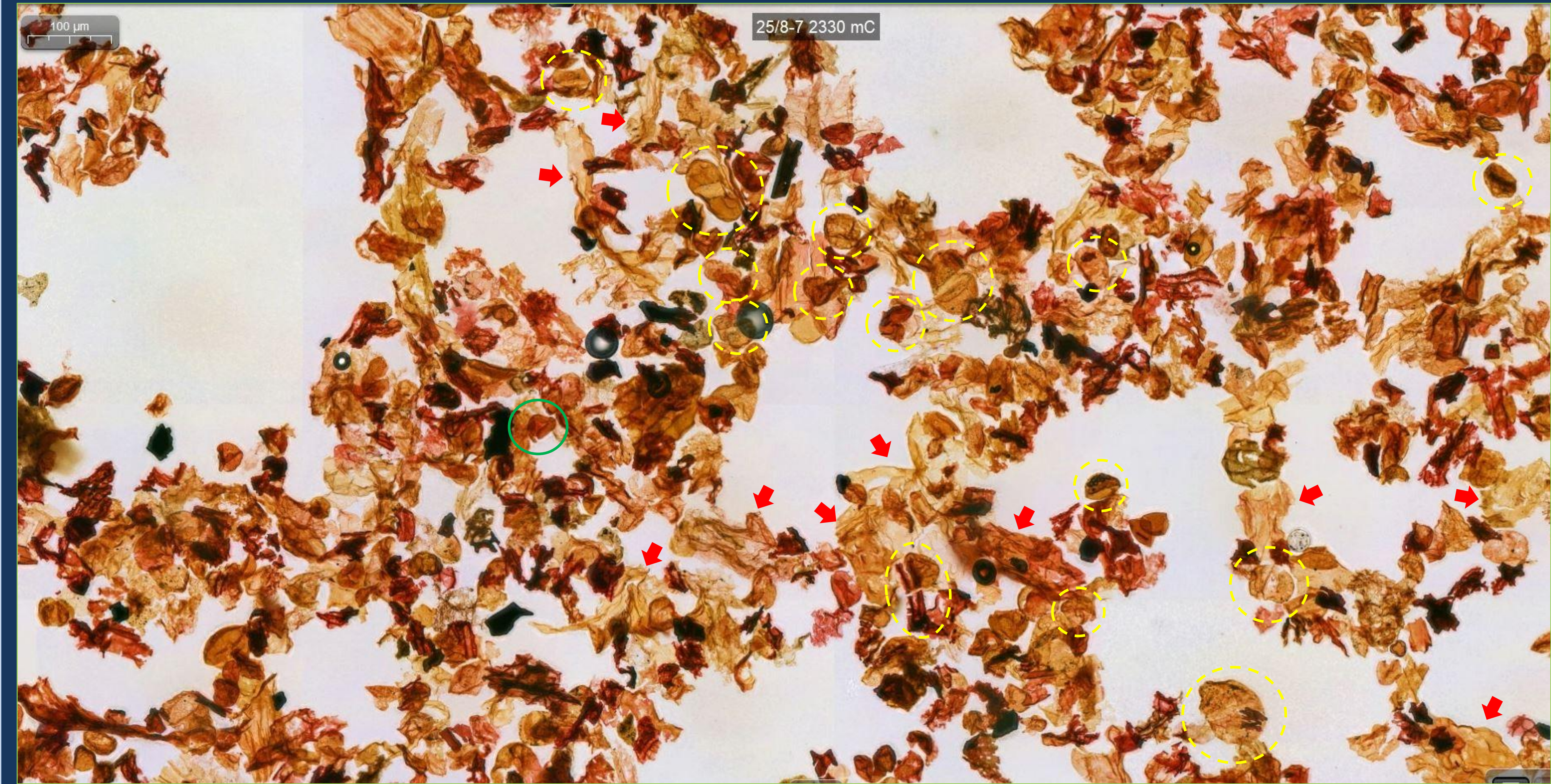
From 6m below the sample on the previous page , the assemblage yielded further examples of attached *Pterospermella*-like bodies (black arrows) and smooth *Tasmanites* (red arrows). There are very few opaque bodies, which may be another characteristic of this particular plant. The irregular interlocking parts of the thallus are clearly visible , especially in the main and upper right images. Some of the “propeller blades” are modified into sickle-shaped elements that are barbed along the concave margin (green arrows)

25/8-7 2330.00m, Sleipner Fm



Main picture; Exceptionally well-preserved large structures are interpreted as sections of a branching plant, possibly a leafy liverwort. The presence of so many intact parts indicates deposition was +/- at source, in a very low energy setting. The various types of attached bodies nearly all remain *in situ* and the sample is remarkable due to the rarity of isolated palynomorphs . The branch sections overlap and cross, producing a confusing array overall and interpreting the edges of discreet sections is not normally possible at this scale. Small opaque bodies are common, the vast majority remaining *in situ.* Inset right; An interpretation of the area highlighted above traces a series of triangular and rhombic shapes aligned along a common axis. Similar features are visible elsewhere in the image. Upper left: Interpreted as thallose bodies which link together, forming the underlying structure of the branch and on which the multitude of miospore-like bodies are attached. Upper right; Closer view of a thallose body bearing numerous attached miospore-like and phytoclast-like parts.

25/8-7 2330.00m Hugin Fm

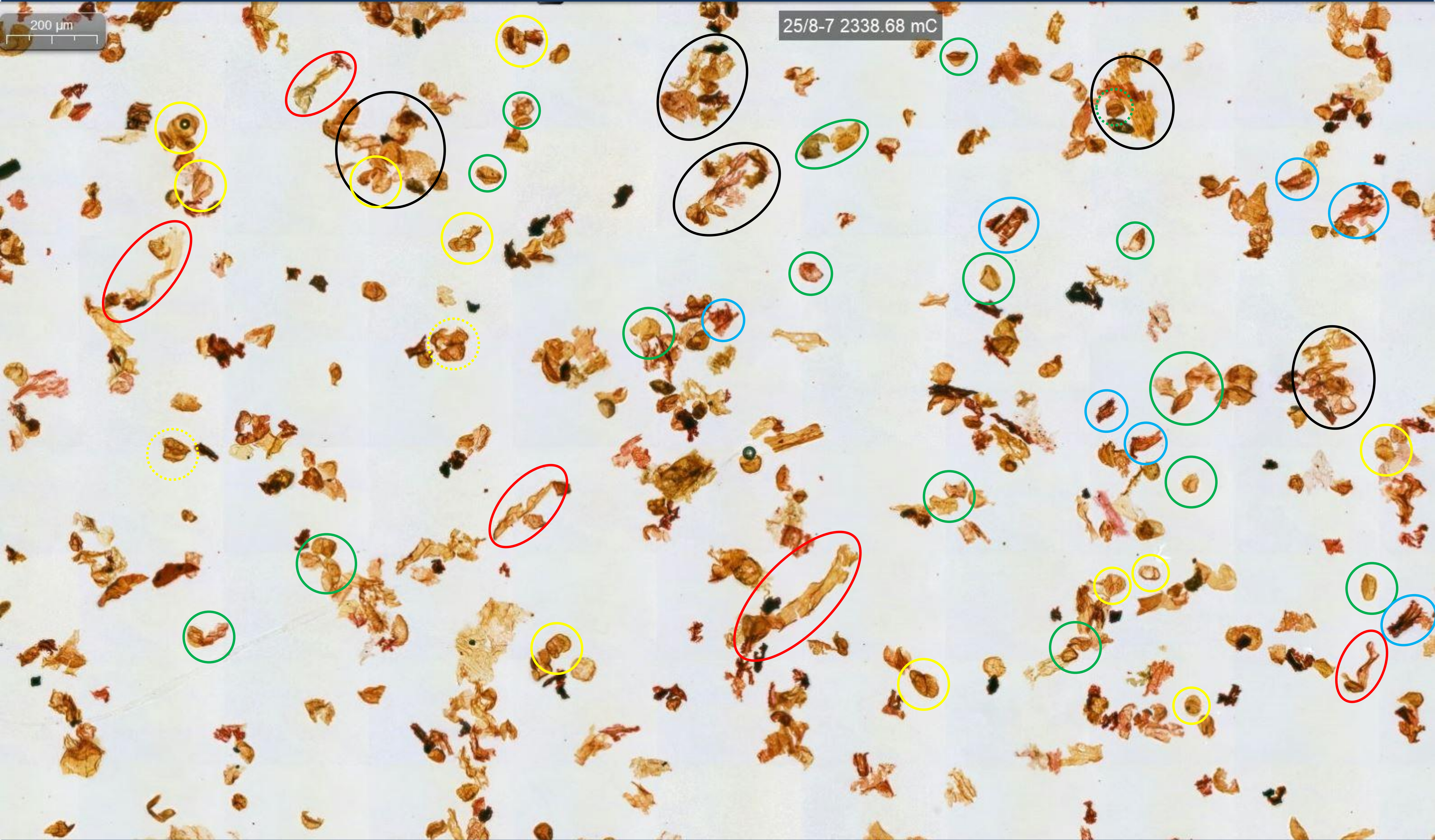


Closer view; interpreted as a lattice of pale thallose bodies (red arrows) with abundant attached parts, including bisaccate-like (yellow circles) and a spore-like body (green circle). Isolated palynomorphs are virtually absent.

25/8-7 2330.00m Hugin Fm

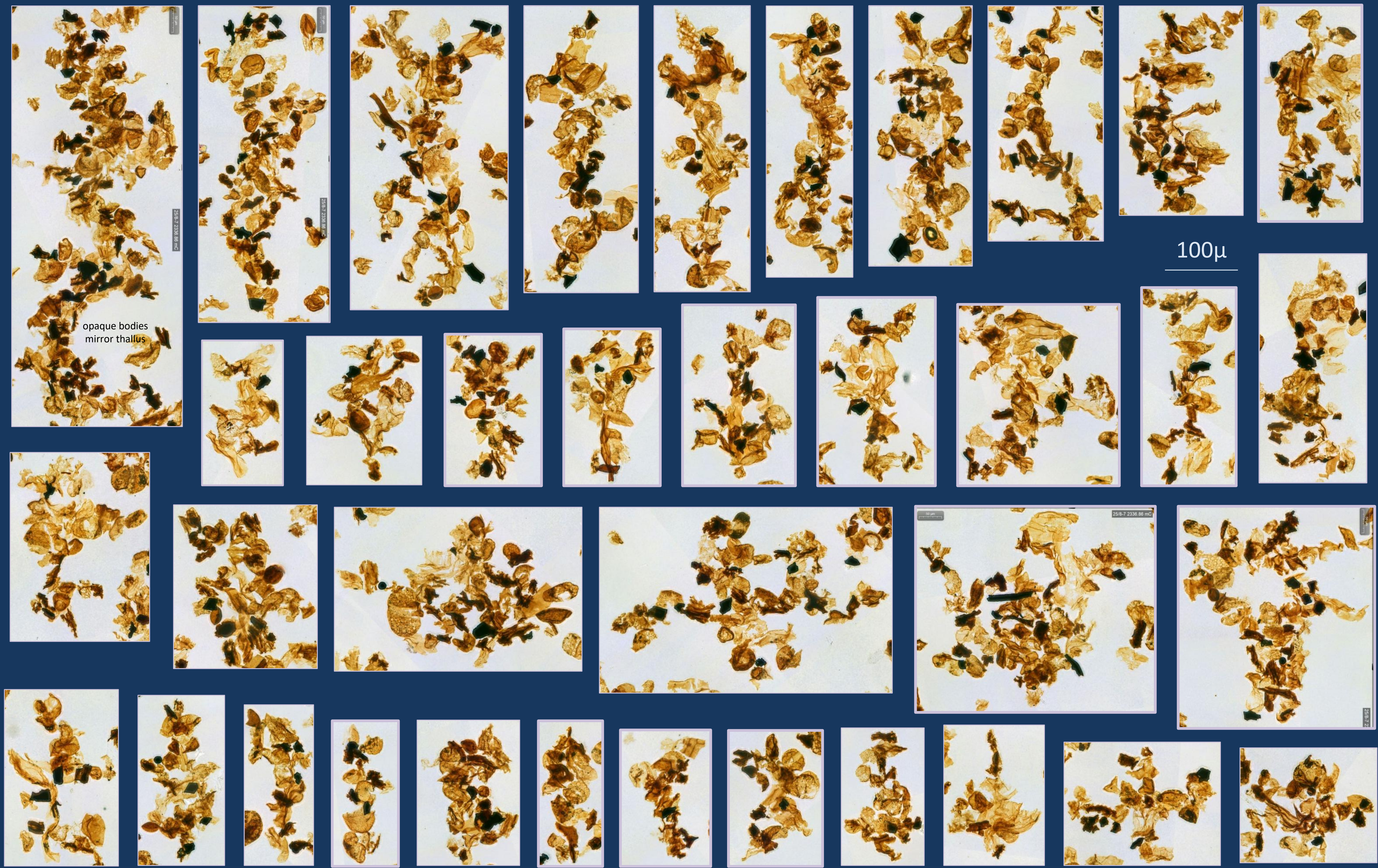
Well preserved fragments of the same plant

25/8-7 2336.86m Sleipner x100



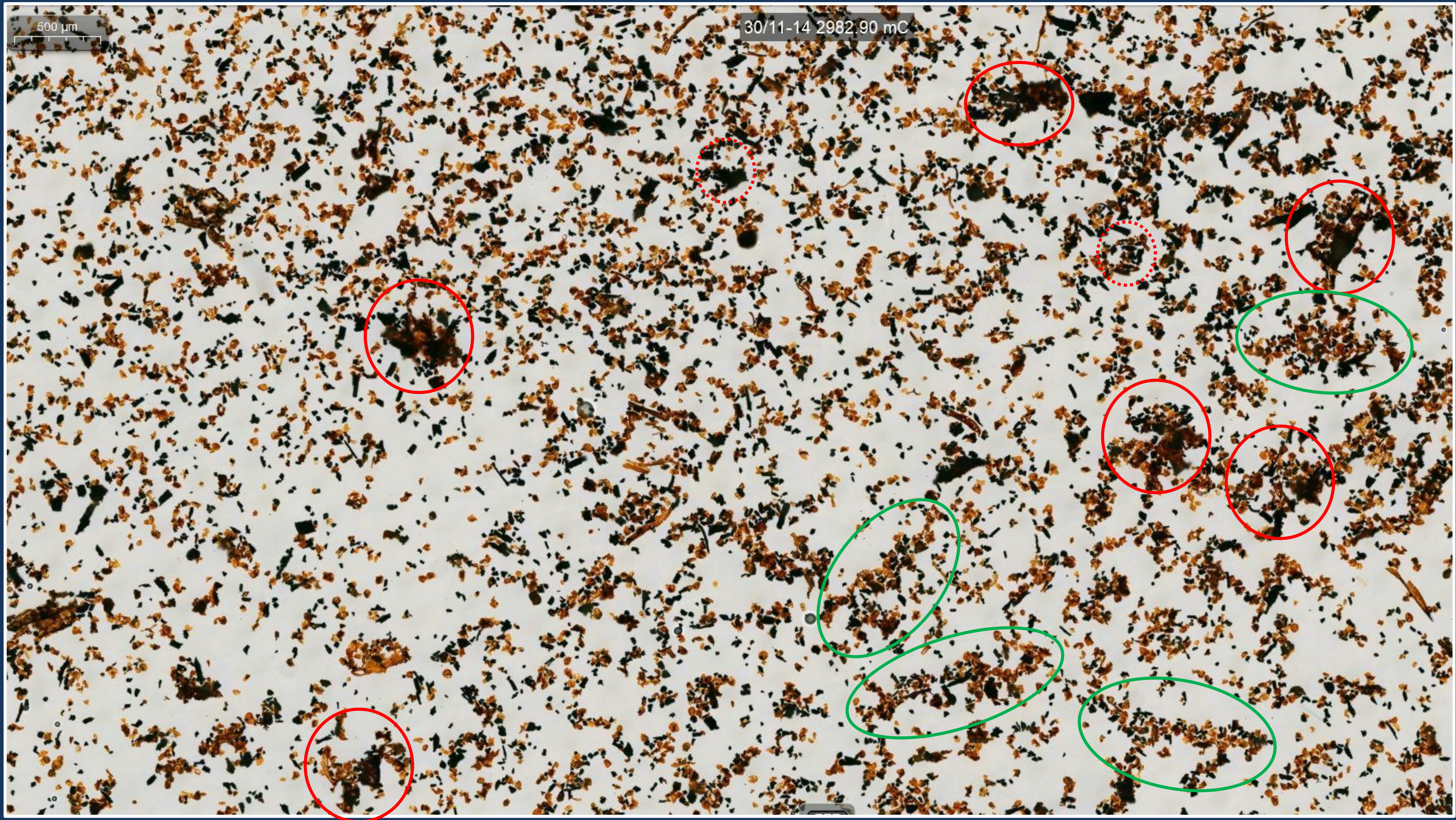
Thought to be the same or similar plant to the previous sample. Small plant structures (black circles); elongate thallose bodies (red circles), "propellers" and "propeller blades" (green circles); bisaccate-like bodies, both attached and isolated (yellow circles).

25/8-7 2336.86m Sleipner x100



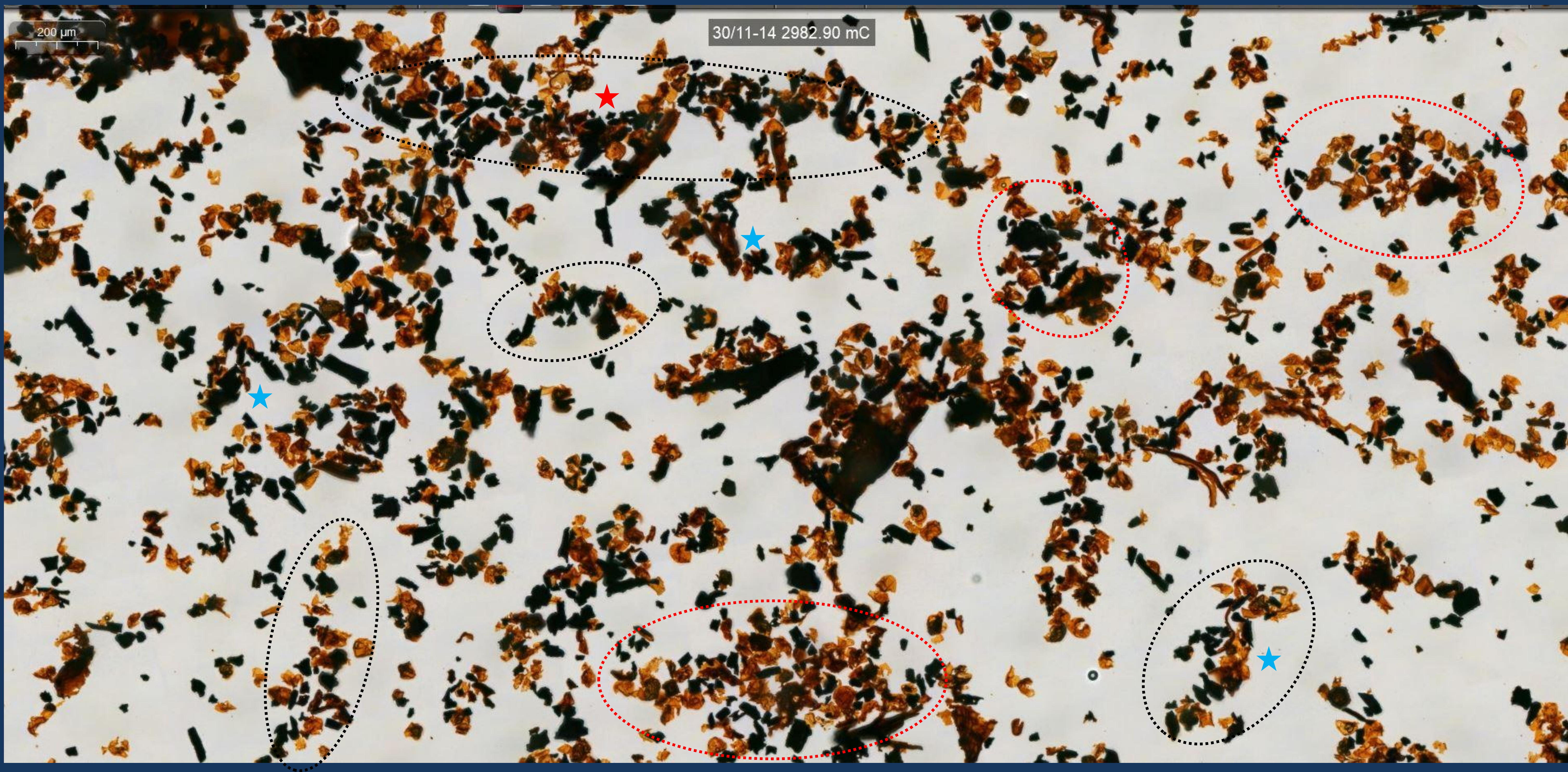
Only a few metres below the previous sample, the same or very similar plant structures occur, only smaller overall and much less abundant. Similar individual component parts are present in approximately the same proportions. Opaque bodies sometimes mirror parts of some specimens (best preserved in first two of top row).

30/11-14 2973.95m Hugin Fm x20



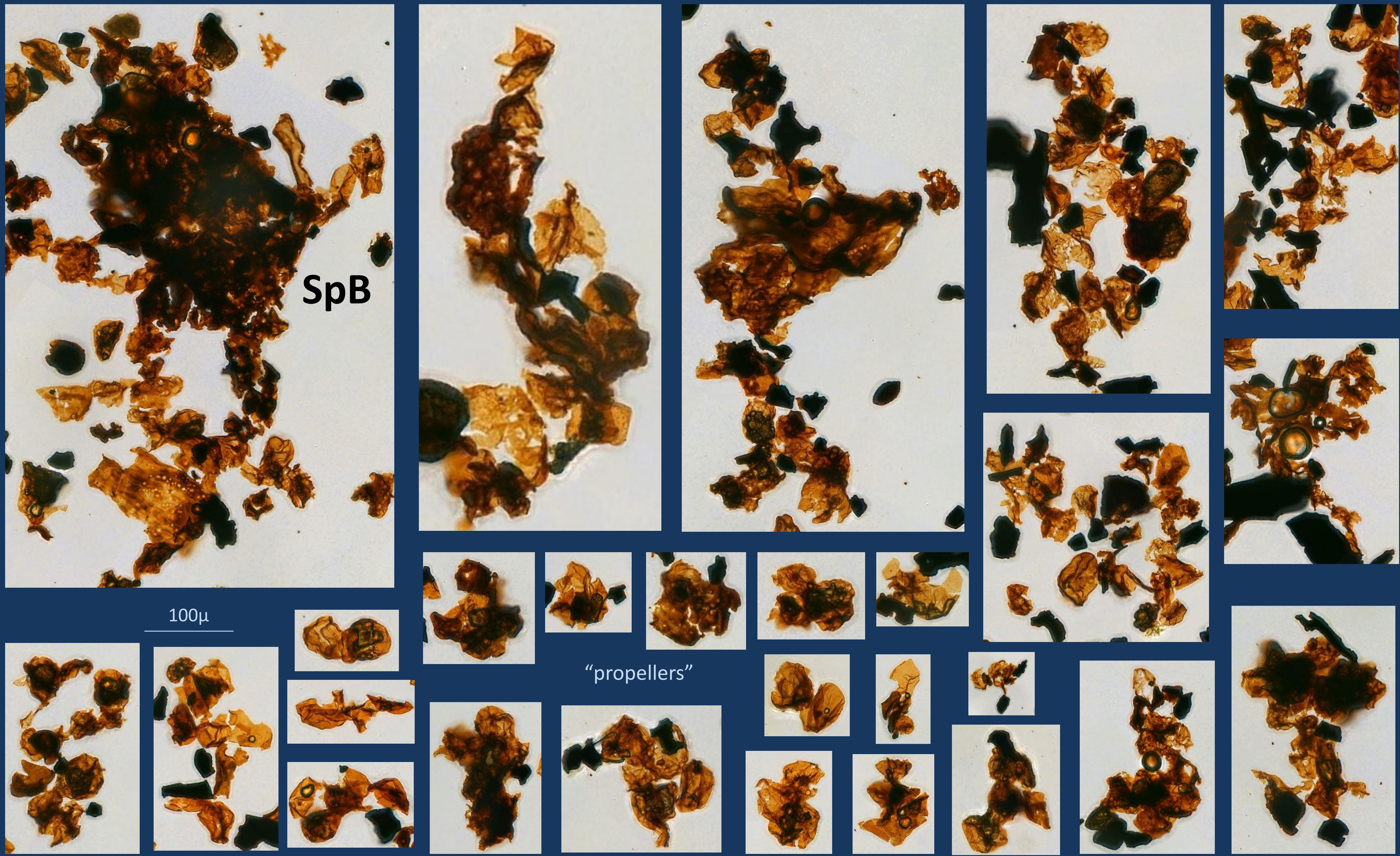
Several larger parts are conspicuous (red circles), in various states of preservation, together with common long branch sections (green ovals), many of which show signs of lateral branching. Medium and small sized parts of the same plant are very abundant and individual component parts are also extremely numerous. Many of these isolated parts resemble miospores,

30/11-14 2973.95m Hugin Fm



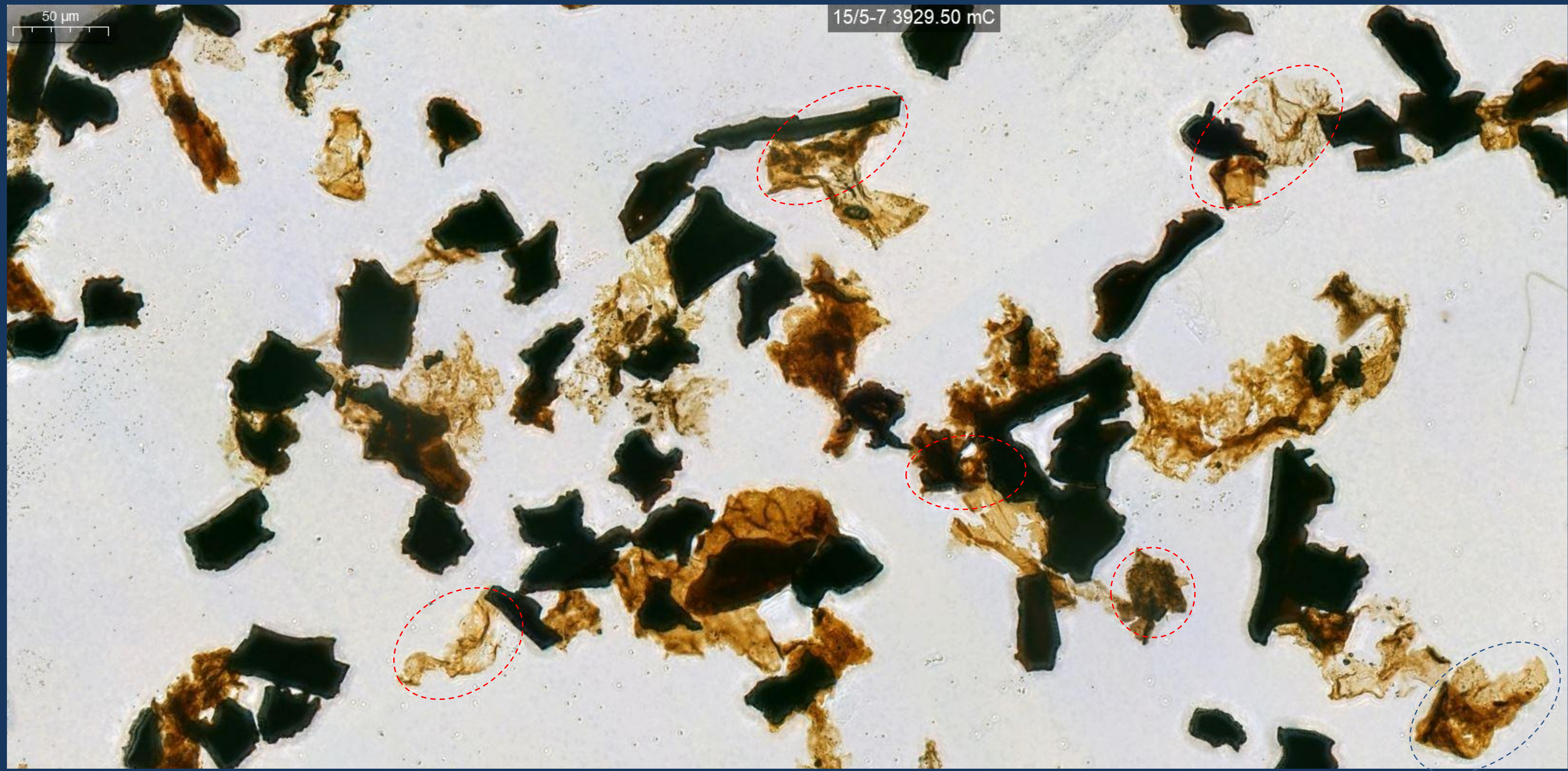
Many large plant structures , mainly branch-like sections (black circles) and large subpentagonal structures composed of numerous small parts (red circles). Very abundant opaque bodies both *in situ* and disaggregated; note how they often mirror the translucent tissues of the same branch section, the best example of this is the large branch running parallel to the upper edge of the image, where numerous tiny opaques are aligned along the main branch axis (red star). On the left side, they even appear to diverge and follow some of the lateral branchlets. Other good examples (blue stars)

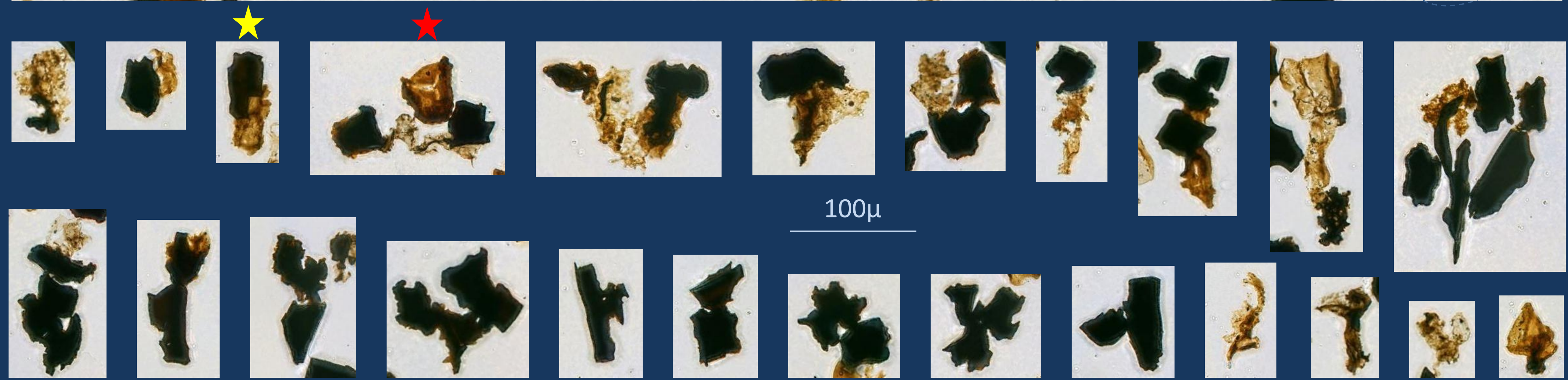
30/11-14 2973.95m Hugin Fm



Selection of large and small plant structures

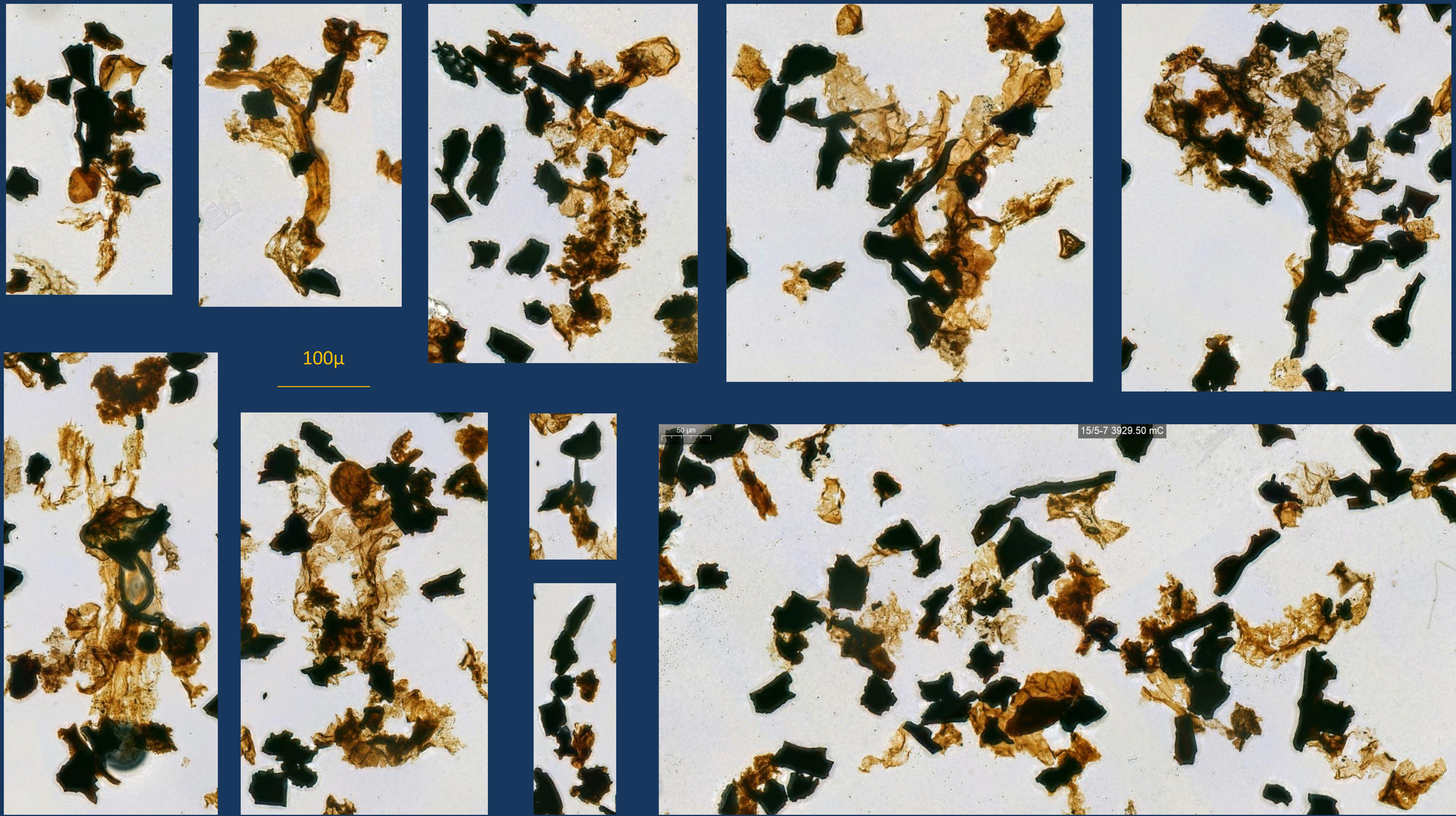
15/5-7 3929.90m Hugin Fm





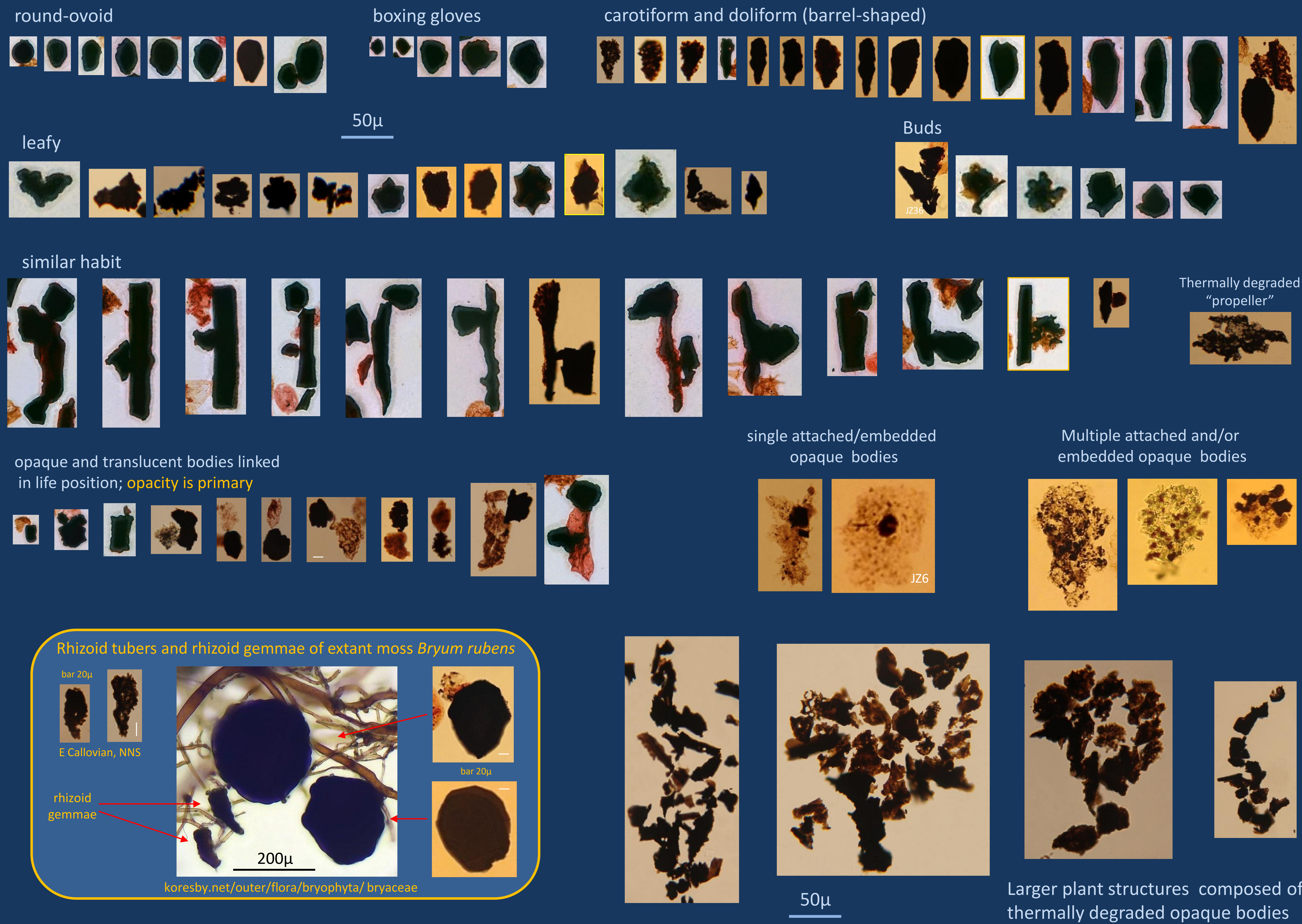
Main picture; phytoclasts include abundant opaque bodies and abundant structured/semistructured vitrinite. First row; opaque and translucent tissues linked together in life position. Sometimes both types appear to be included together in a single body (yellow star). Note also attached spore-like cell (red star). Bottom row; further opaque and translucent. There are no randomly fragmented phytoclasts; everything is a component part and retains the original shape. Very few plant structures with more than 3-4 parts (environment or ultrasonic?). Poorly preserved propeller fragments highlighted in red circles

15/5-7 3929.90m Hugin Fm

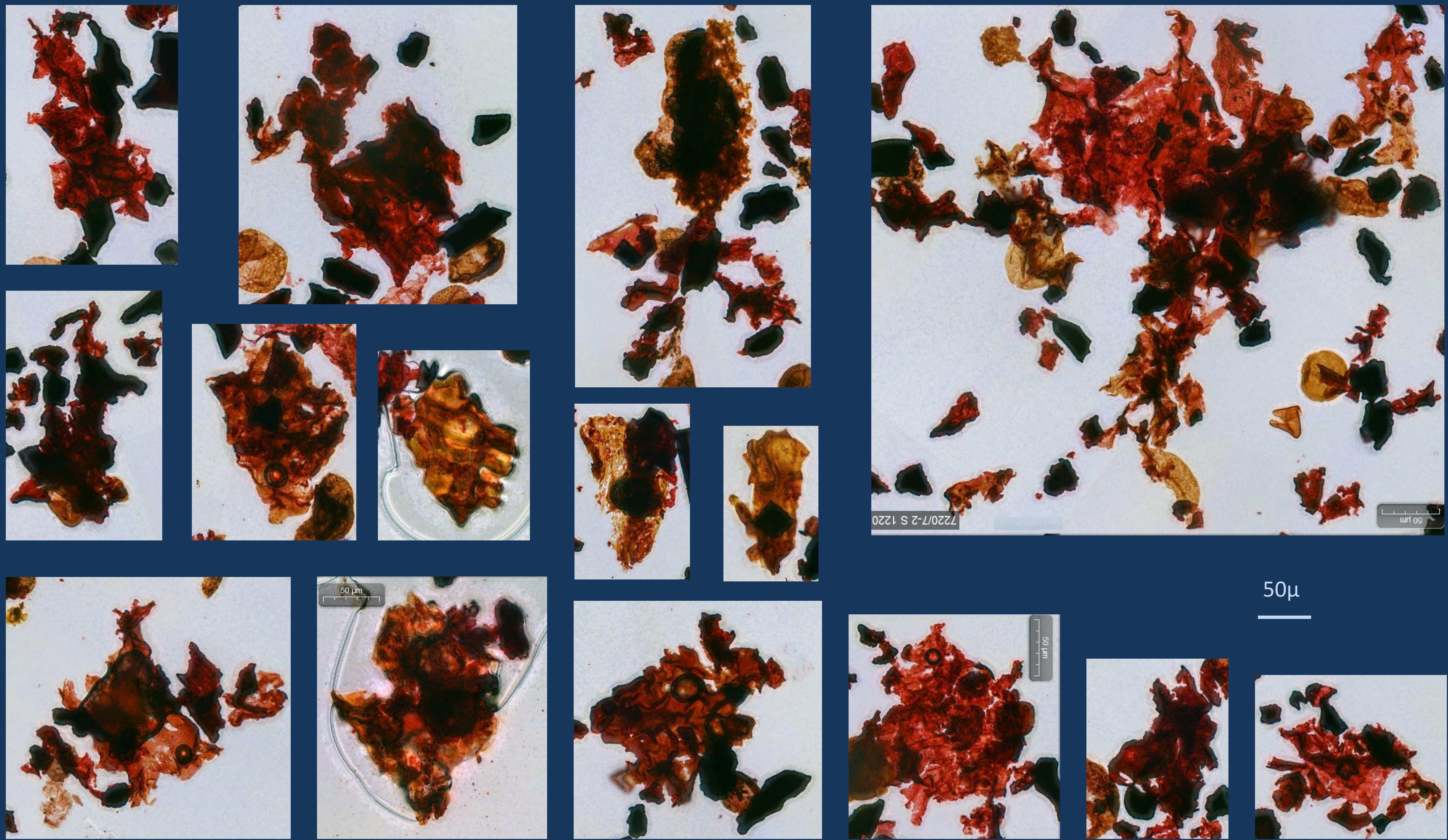


Small and medium sized plant structures are also present, but poorly preserved and few in number. Many of the opaque bodies appear to form a separate “layer” from the translucent tissues and to some extent mirror each other (best seen in 1st, 4th & 5th image of upper row and second image of the bottom row). Using current models for palynofacies analysis, the opaques are considered to be multi-sourced and randomly fragmented .The proportions of lath-shaped and equidimensional opaques is normally included in the count and used to interpret transport history/distance from source. However, here it seems that virtually all the opaques are derived from this plant,

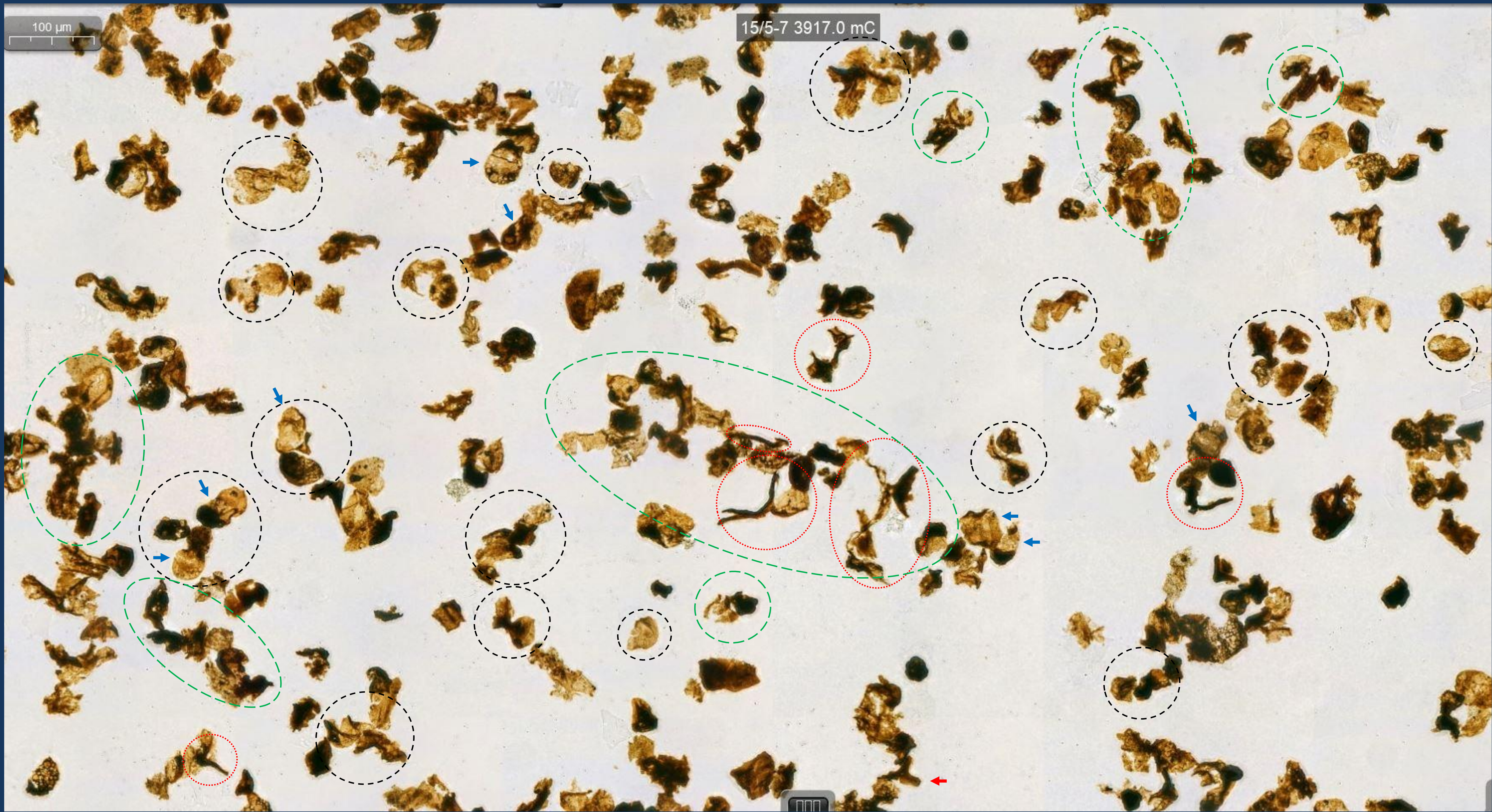
Opaque bodies



7220/7-2 S 1220.50m Tubåen Fm, Rhaetian - Hettangian



15/5-7 3917.00m Hugin Fm



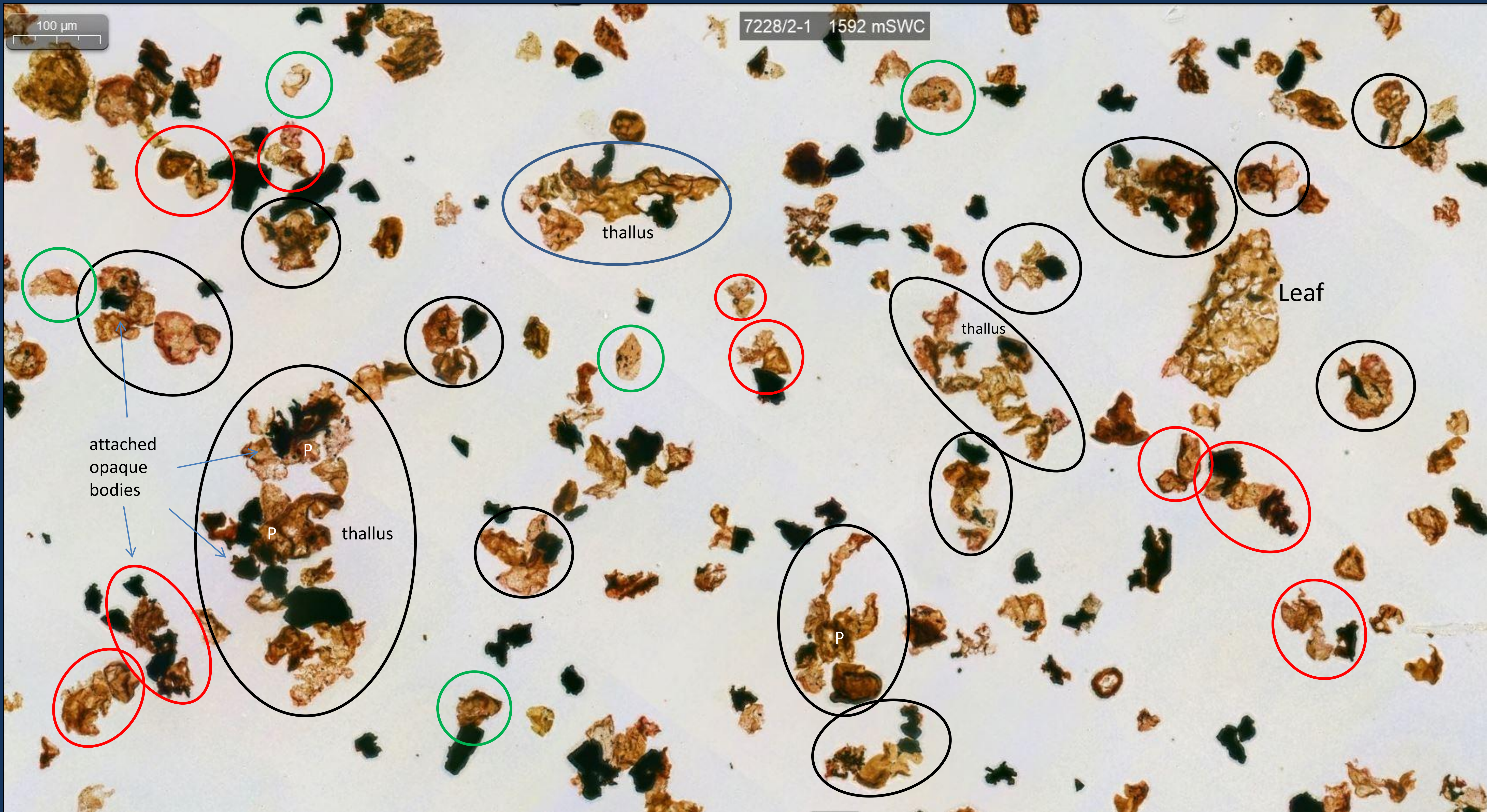
Plant structures composed of structured, pseudoamorphous and opaque bodies

The sample comprises almost exclusively of disaggregated branch parts, mainly “propellers” (some highlighted in black circles) . Most of the parts are thought to be derived from a single plant species and this particular type is characterised by numerous irregular filamentous elements (red circles) . Moderately common small plant structures are preserved (a few shown in green circles). Also note the attached bisaccate-like bodies (blue arrows).

15/5-7 3917.0m base Hugin Fm

Filamentous elements (red arrowheads), "propellers "(black arrowhead at "hub");similar rounded-lacrymose reticulate bodies (green arrowheads), the larger ones of which may resemble bisaccate pollen (blue arrowheads); woody leaflets (black arrows); bat shaped body (grey double arrowhead) and possible immature bat shaped body (grey arrowhead).

7228/2-1 1592.0m Snadd Fm



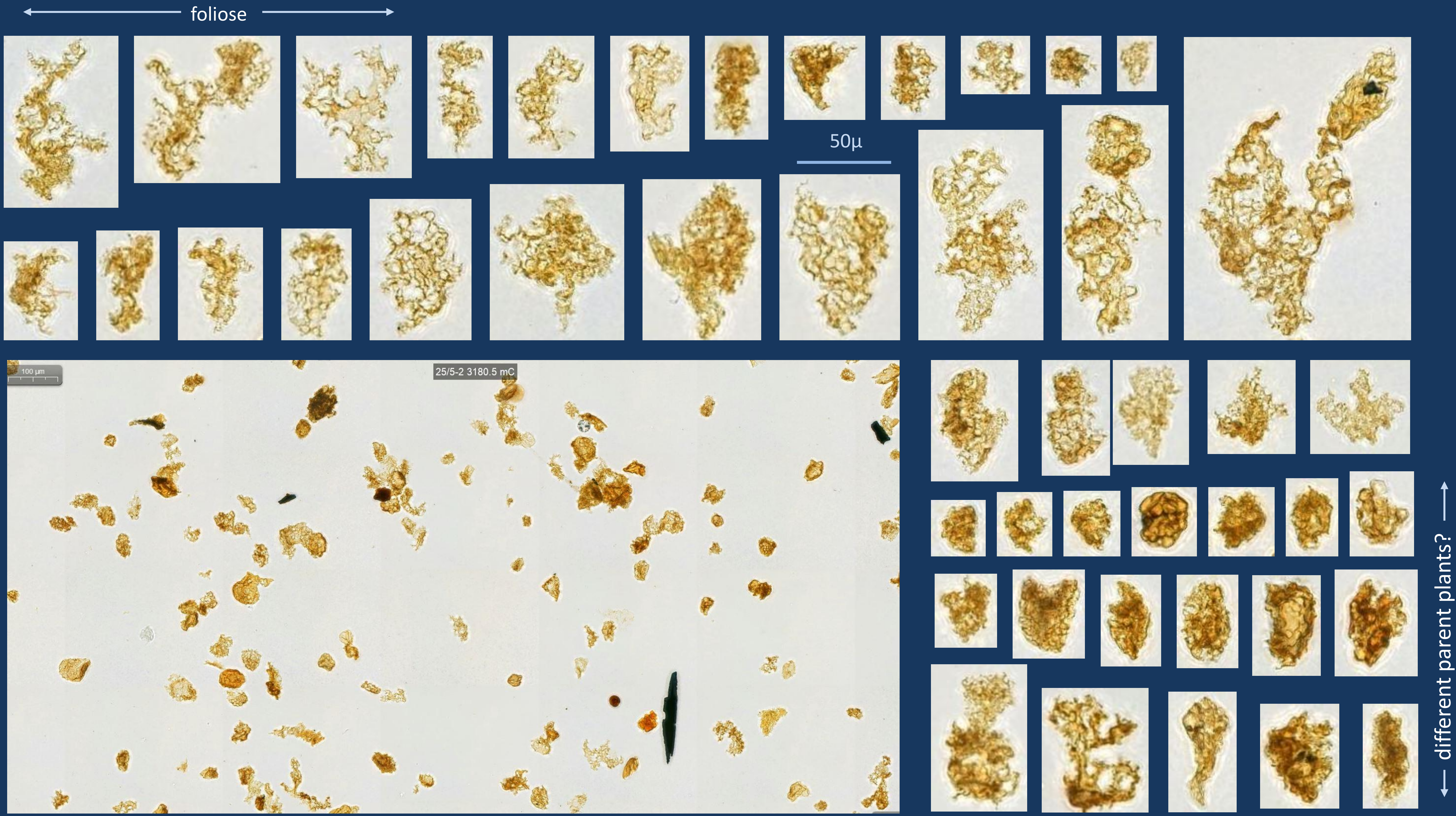
Small to medium sized plant structures (black circles), isolated propellers (red circles), isolated propeller blades (green circles).
Common to abundant opaque bodies, mainly disaggregated, with some preserved in situ (indicated lower left)

7228/2-1 1592.0m Snadd Fm

25/8-9 2401m Heather Fm

Numerous pseudoamorphous plant structures (circled) showing similar habit and bearing many attached bodies, many of which resemble miospores . The vast majority of the isolated grains are disaggregated from the same organism. The size and number of plant structures in a sample is thought to be related to transport history. During processing, such structures have been interpreted as electro-static "clumping" , normally prompting ultrasonic treatment.

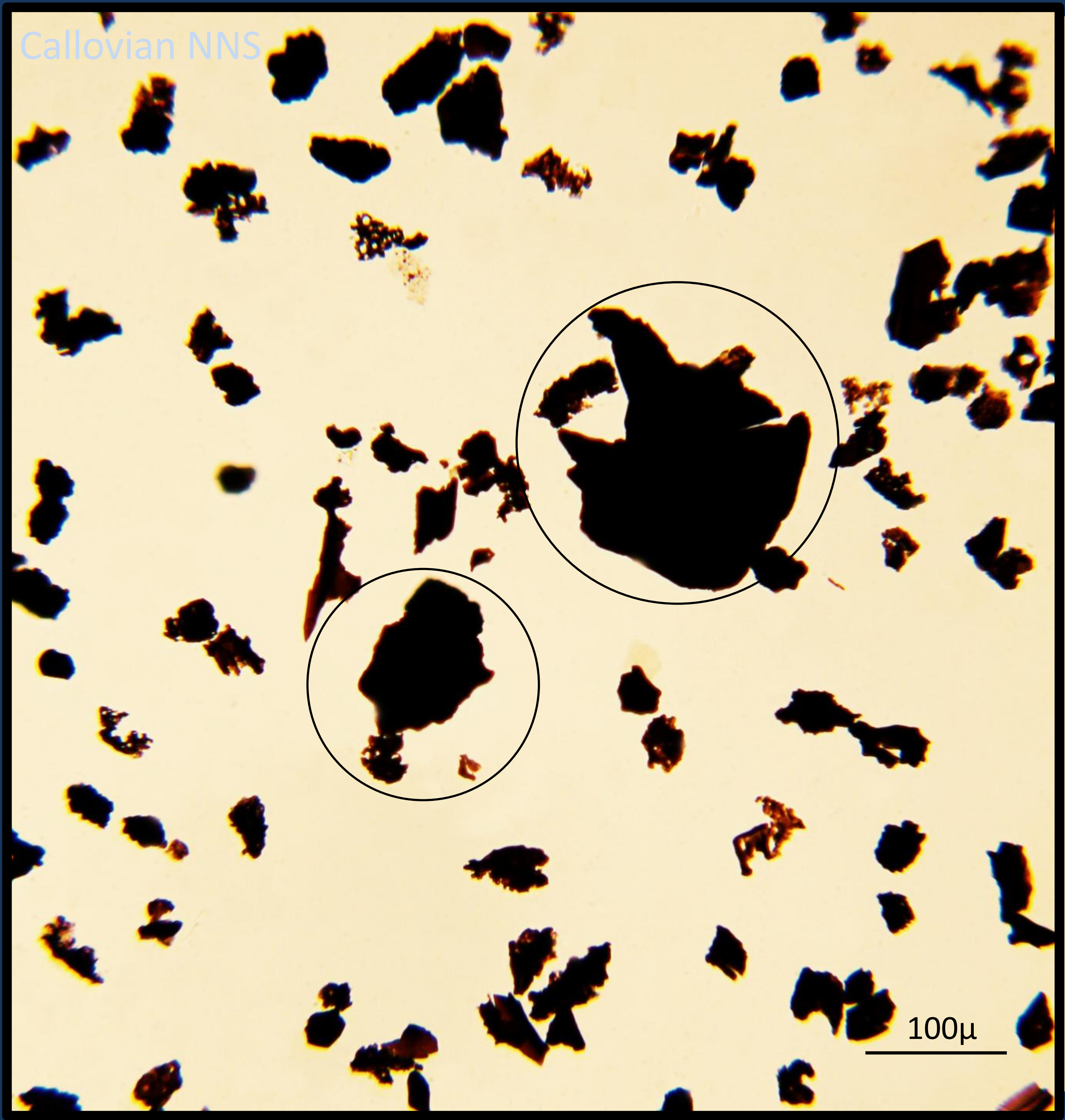
25/5-2 3180.50m Heather Fm x200

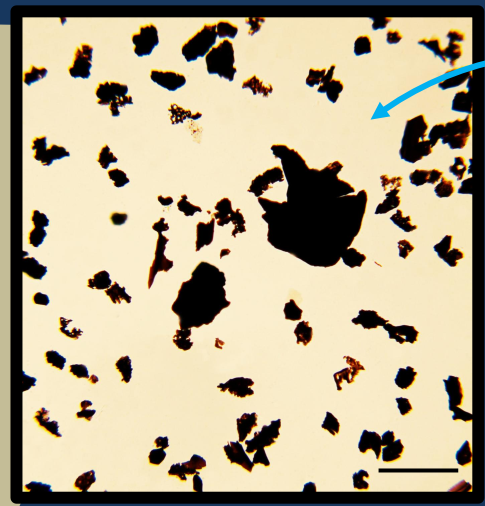


Similar types of thistle, star, carrot & boxing-glove shaped bodies, but with a more delicate structure and an irregularly reticulate sculpture. Some of the parts have a foliose outline and develop short spines around the margin. These are similar to those shown on page 44

Opaque subpentagonal bodies

Opaque subpentagonal bodies without translucent tissues are also common



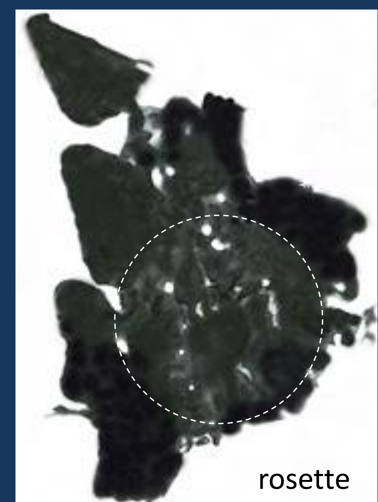


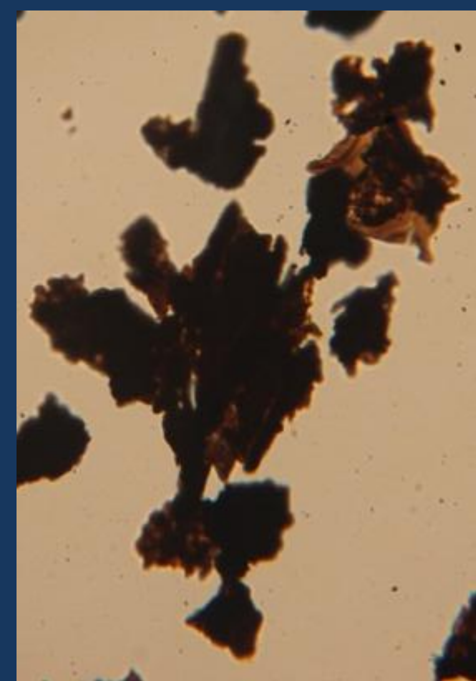
Chavoutier 2017 Pl. 3 (reoriented)
Sauteria alpina a modern thallose liverwort. Opaque sporophyte with "maple leaf" outline

Batten 1983, Fig 27

100µ approx

Batten 1981, Pl. II fig 3

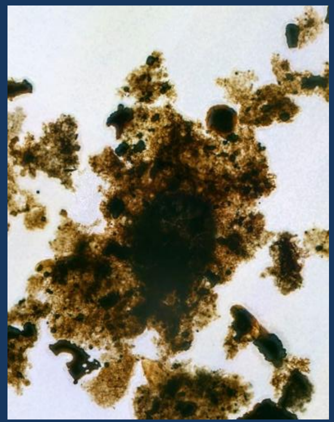


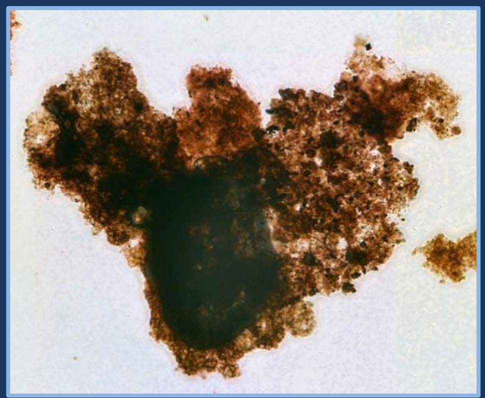


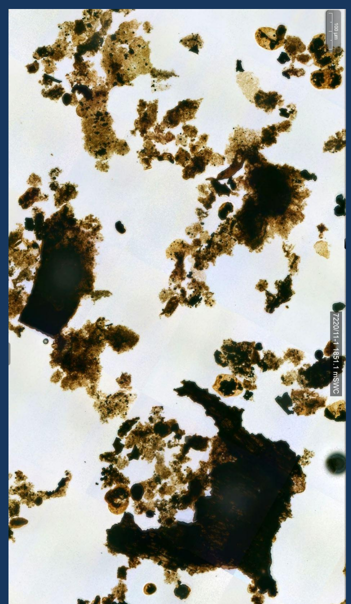
Note proliferation of attached cells distally

Degradation of outer translucent tissues of subpentagonal bodies

translucent tissues
+/- undegraded

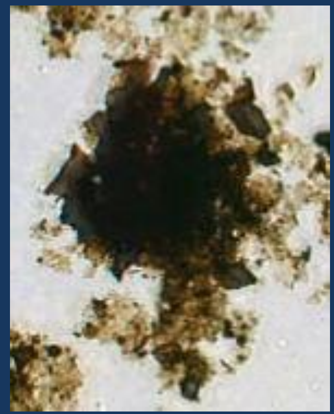


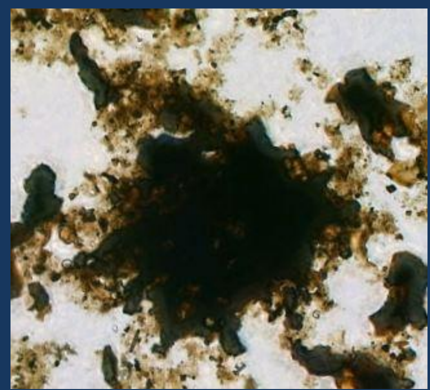


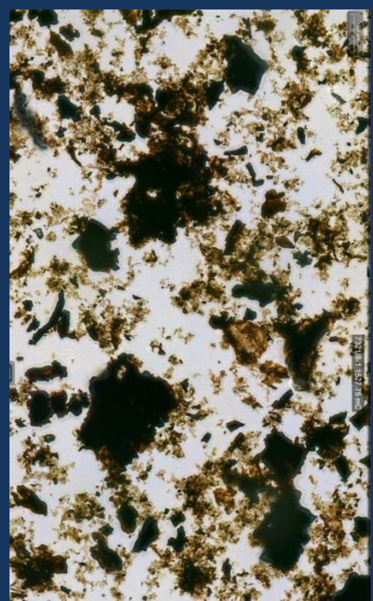


Snadd Fm

translucent tissues
slightly degraded

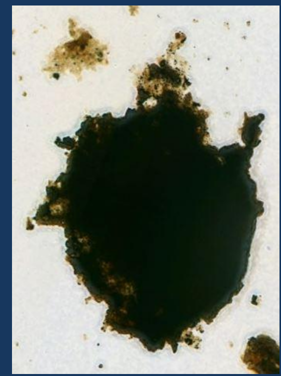


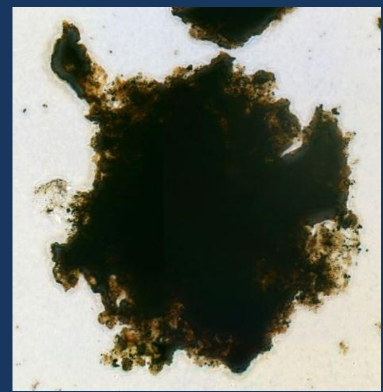


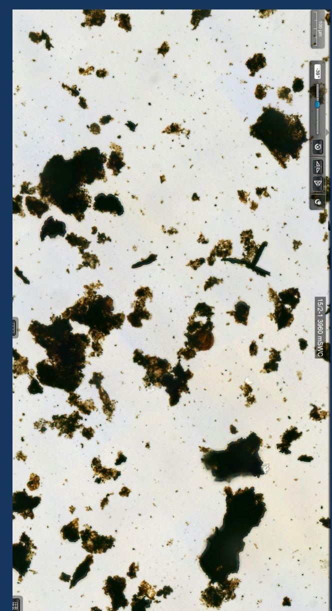


Fruholmen Fm

translucent tissues
significantly degraded

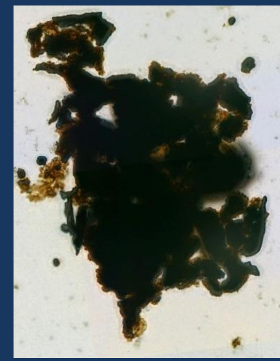


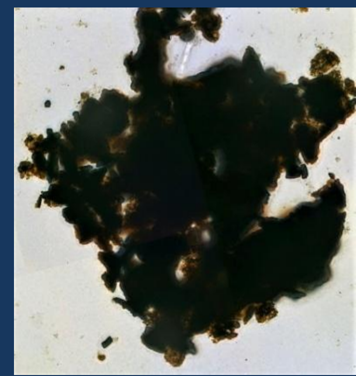




Draupne Fm

translucent tissues
nearly all degraded

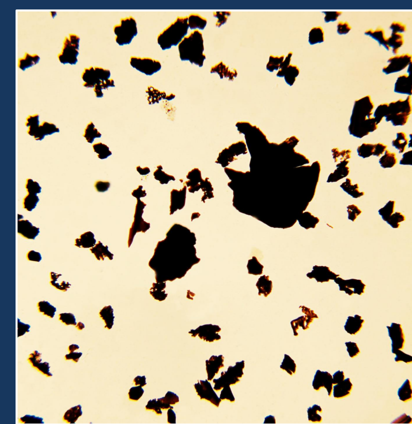




Snadd Fm

no translucent
tissues preserved

Batten 1983, Fig 27



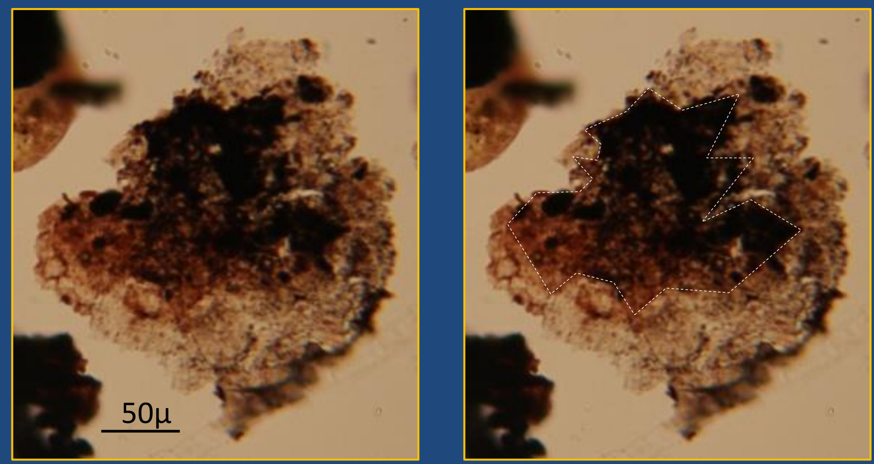
Heather Fm

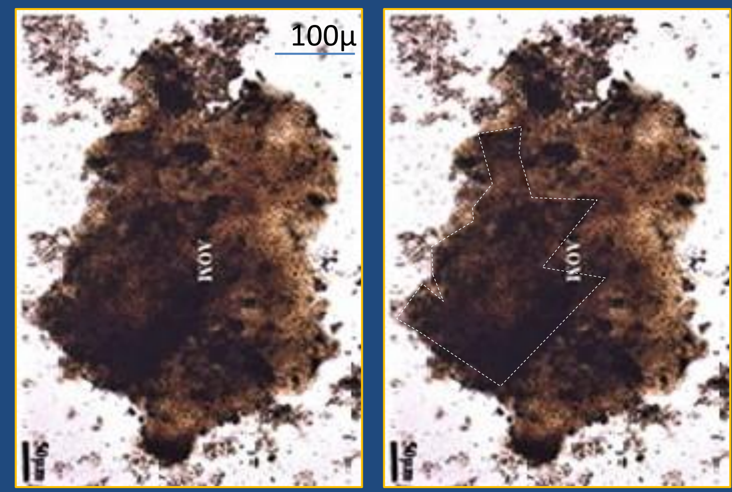
Not all SpB's have internal opaque bodies. Others have multiple small opaque bodies dispersed throughout the translucent tissues, which are probably dispersed into the wider assemblage as degradation progresses.

★ The opacity is primary, not a secondary effect of thermal alteration, as observed in extant species and fossil specimens in amber

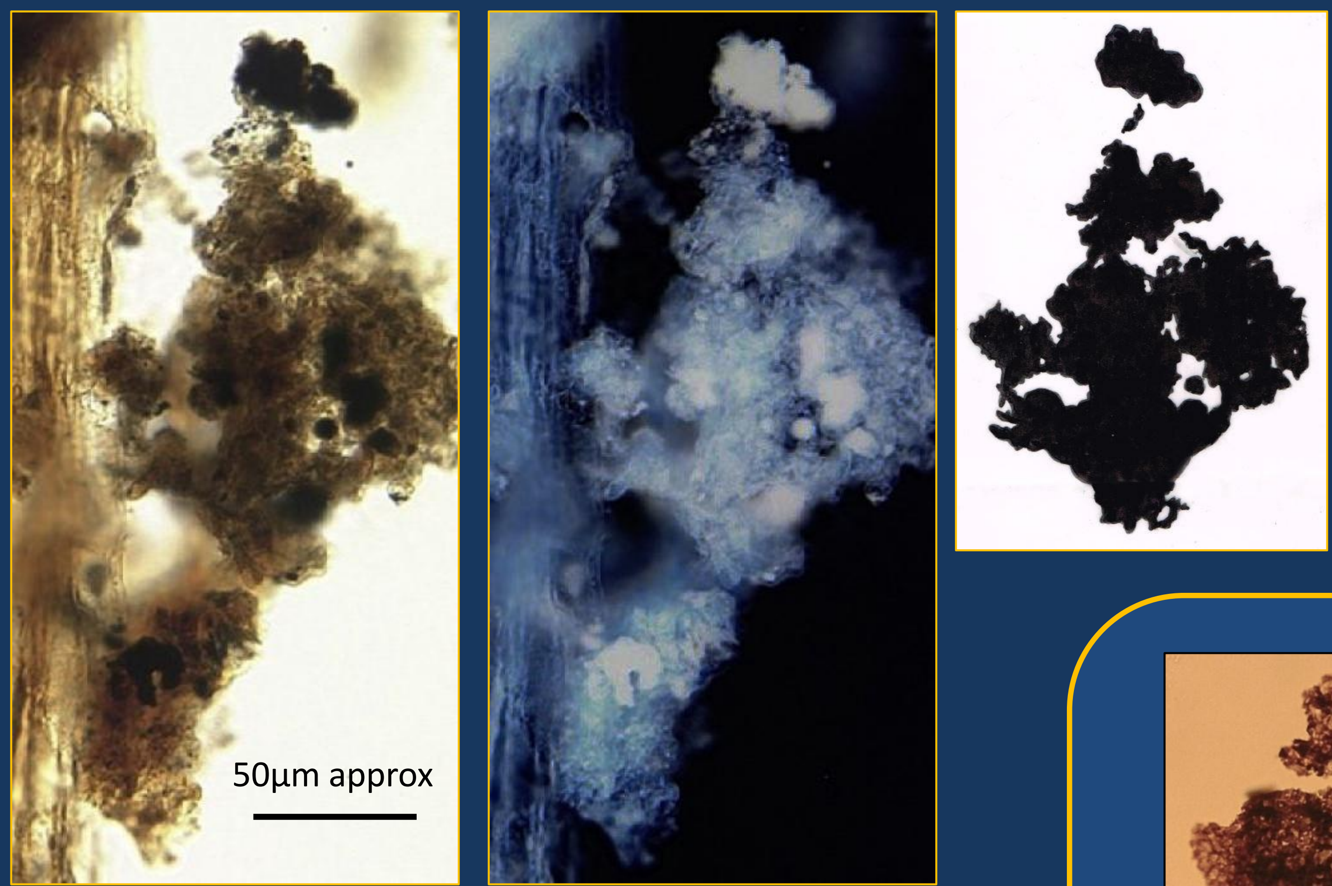
Pseudoamorphous subpentagonal bodies

Pseudoamorphous SpBs with darker/opaque “maple leaf” embedded in (or just below?) the surface on one side

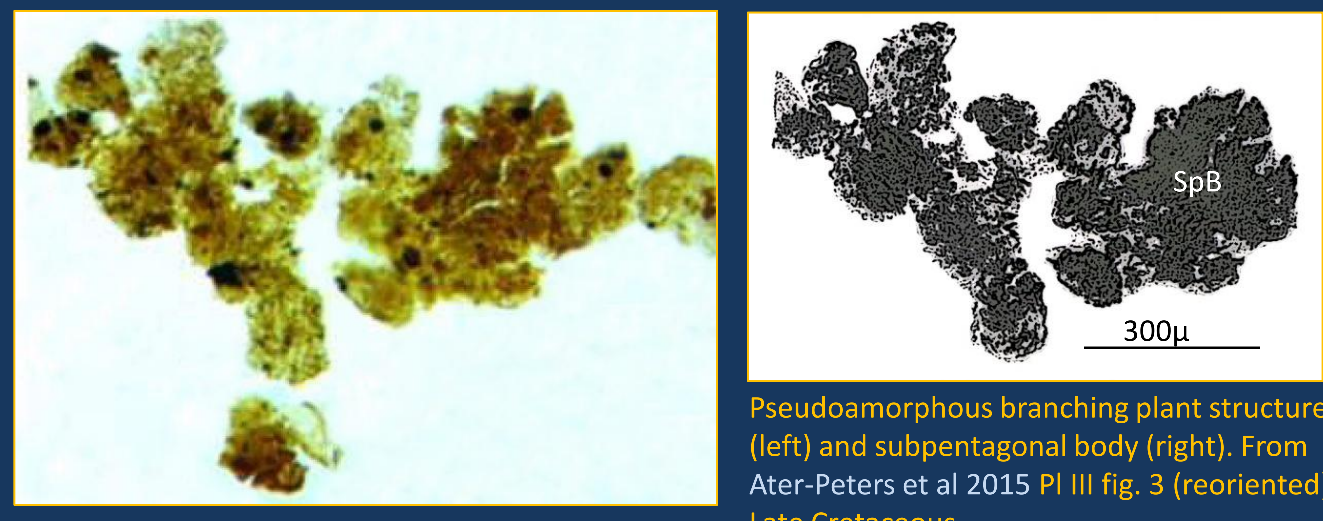




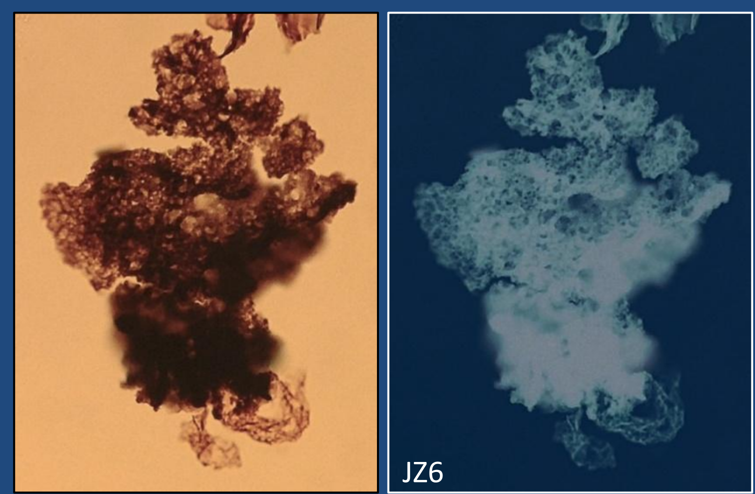
Adegoke et al 2015 Fig 5K, Late Cretaceous

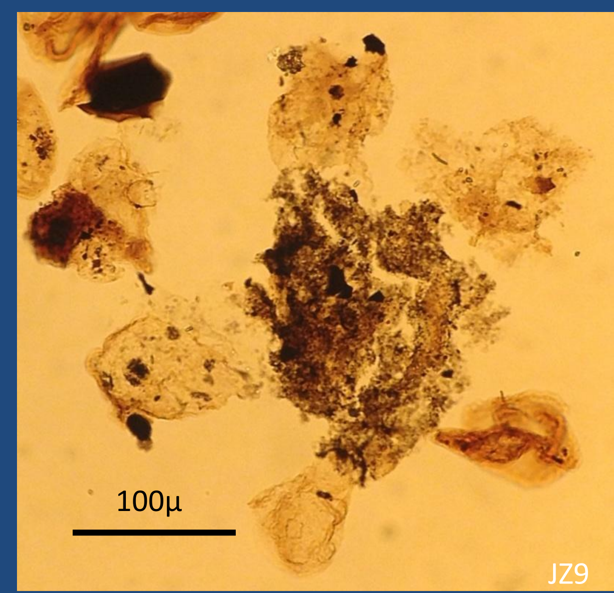


El Diasty et al 2014 , cut from pl 2 fig 7 and reoriented. Upper Cretaceous



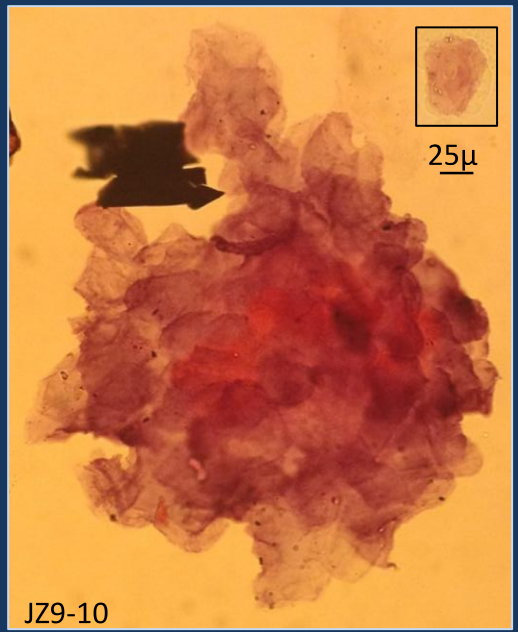
Pseudoamorphous branching plant structure (left) and subpentagonal body (right). From Ater-Peters et al 2015 Pl III fig. 3 (reoriented). Late Cretaceous



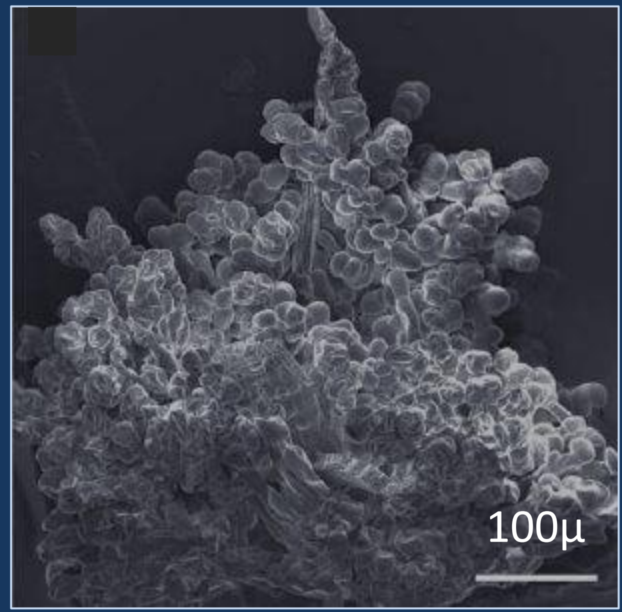


Pseudoamorphous SpB’s from the Early Jurassic, NNS

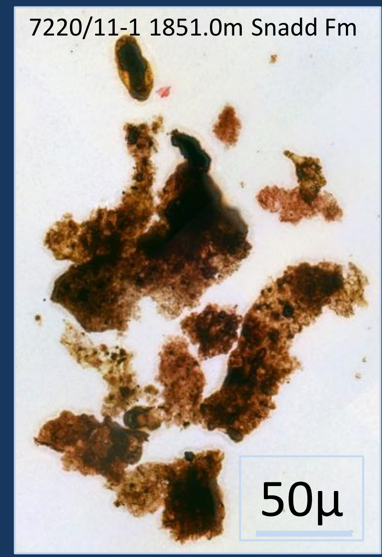
Further examples of modern and fossil subpentagonal bodies



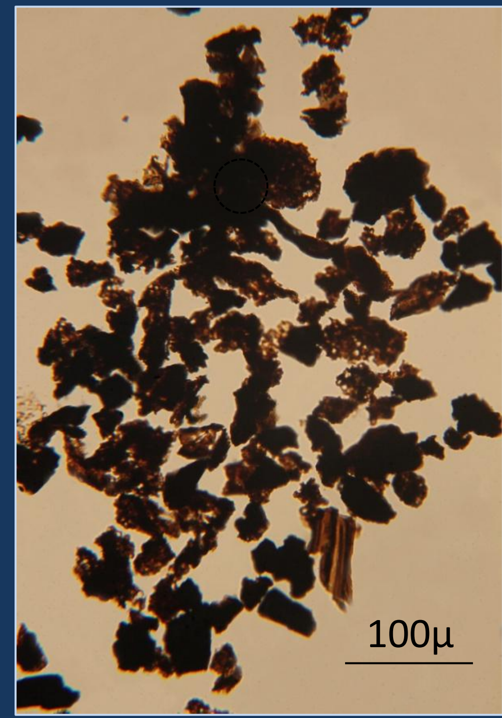
Pseudoamorphous SpB composed entirely of small diaspores, with disaggregated specimens (inset) also present in the sample. Big rosette with darker central boss occupies much of the right hand side.



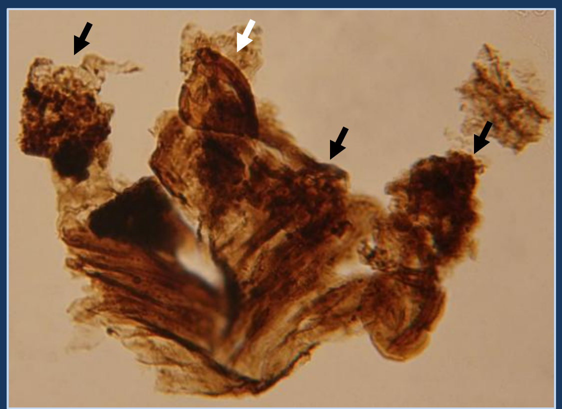
Highly propaguliferous shoot with gemmae. Extant moss *Grimmia fuscolutea*. Porley and Pressel 2012, Fig 5D.



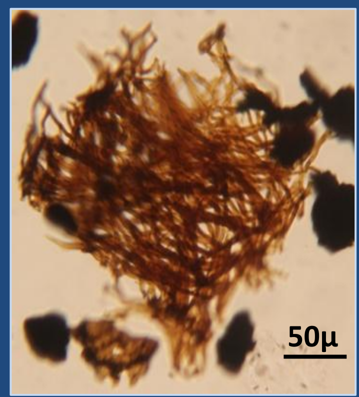
Pseudoamorphous SpB formed by several parts. Snadd Fm.



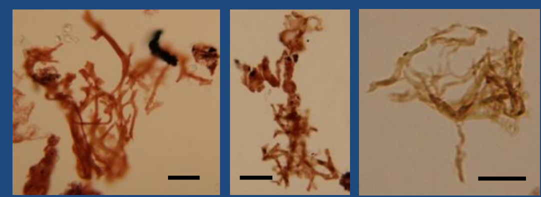
Subpentagonal structure composed of many smaller component particles (see also page 24, bottom row). Thermally altered specimen from over 4000m, NNS



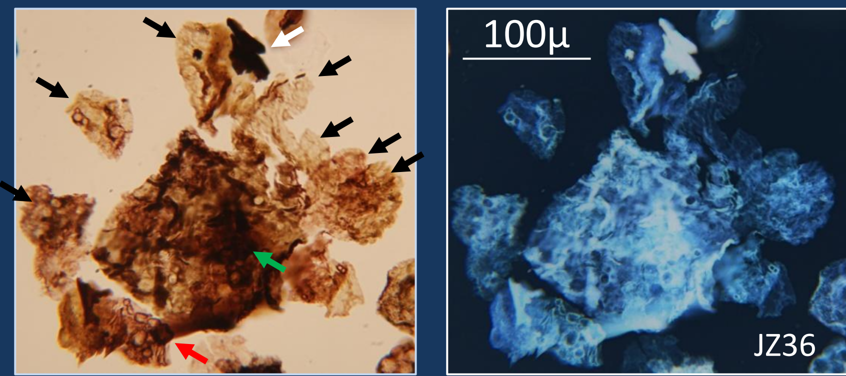
Callovian SpB with ?gemmae (black arrows) and *Striatella* –like body(white arrow)



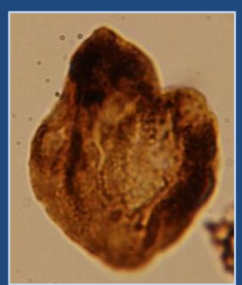
bars 20µ

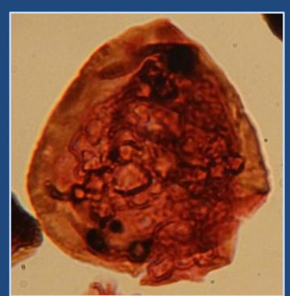


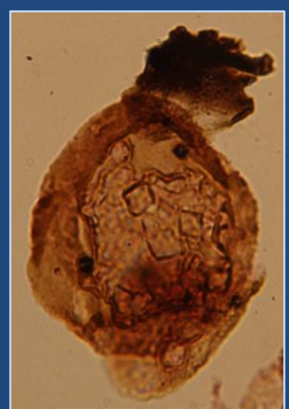
SpB composed entirely of filamentous elements. Normally found as fragments (above). Callovian, NNS. Algae type T sensu BioStrat



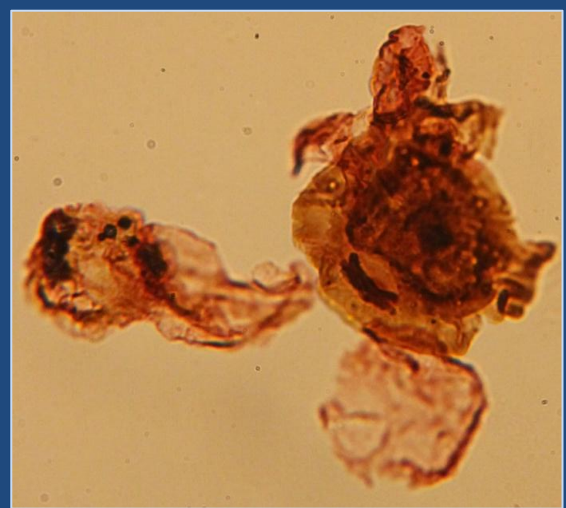
Late Oxfordian SpB with ?gemmae (black arrows); attached opaque body (white); embedded opaque body (green); proximal stipule from thallose body (red arrow).

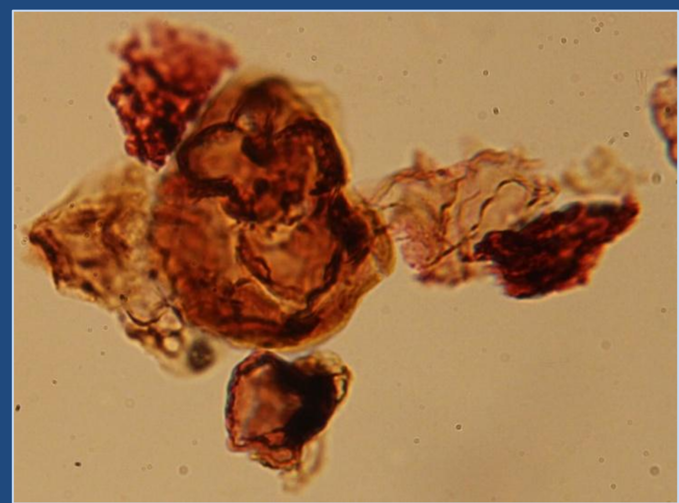


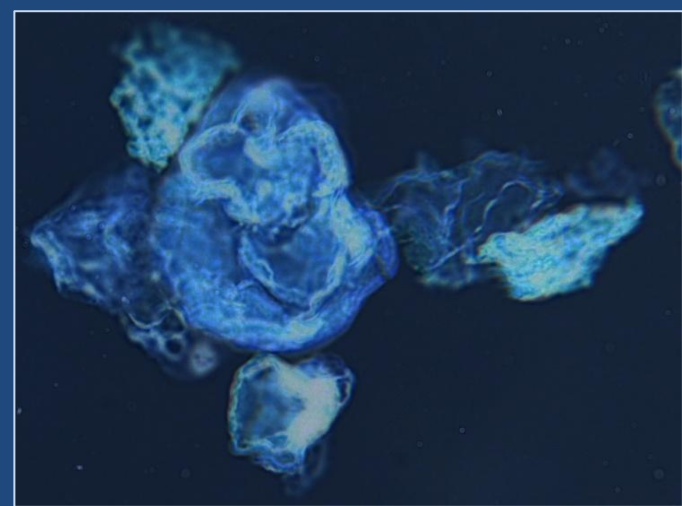




50µ

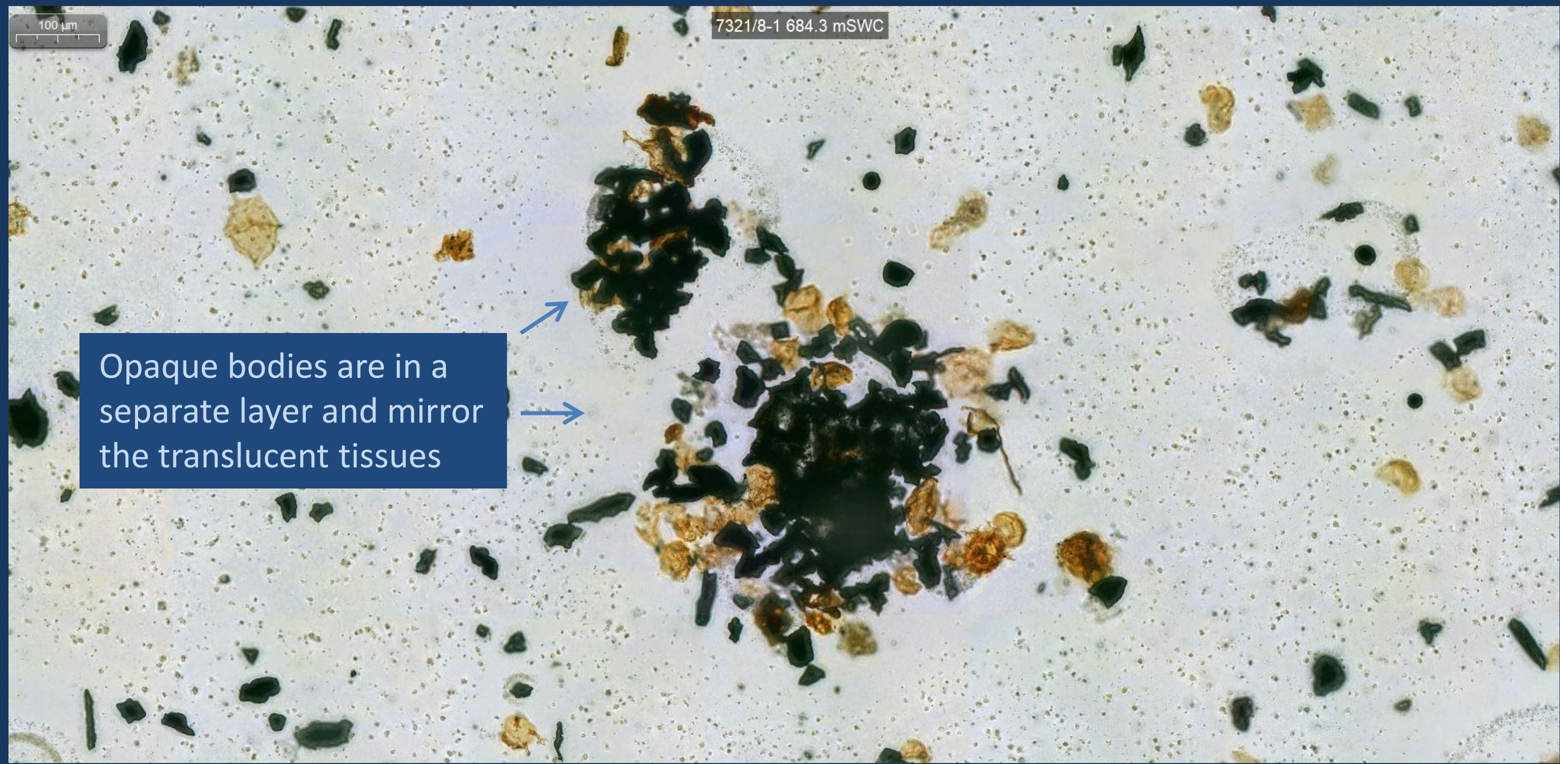


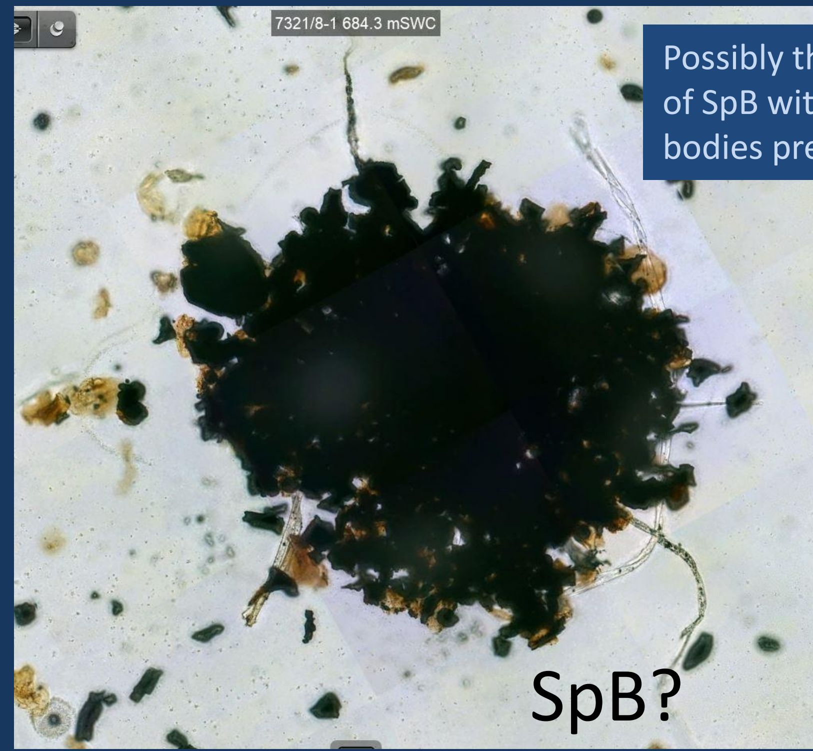




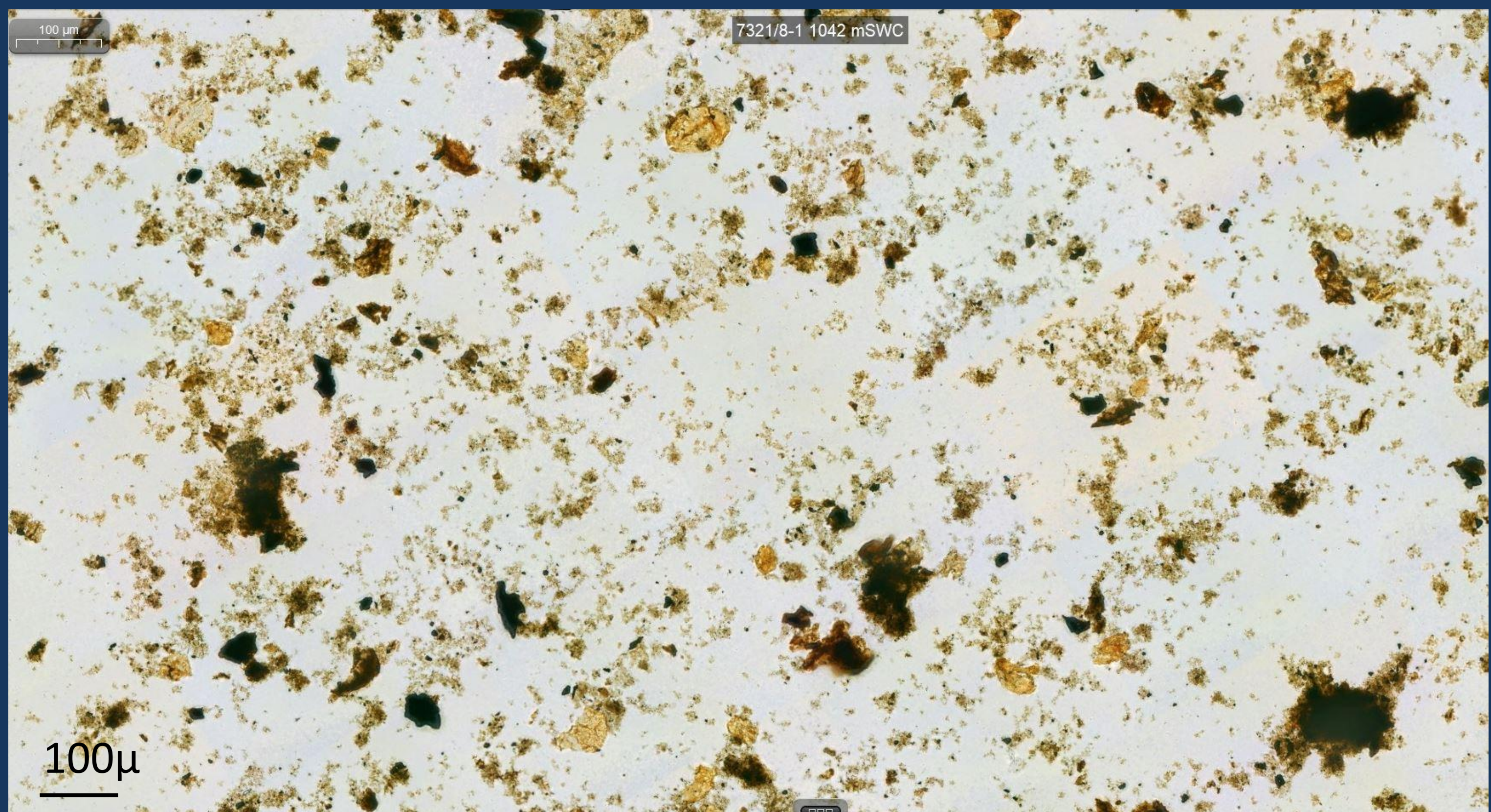
Progressive growth and proliferation of a Callovian SpB from the North Sea

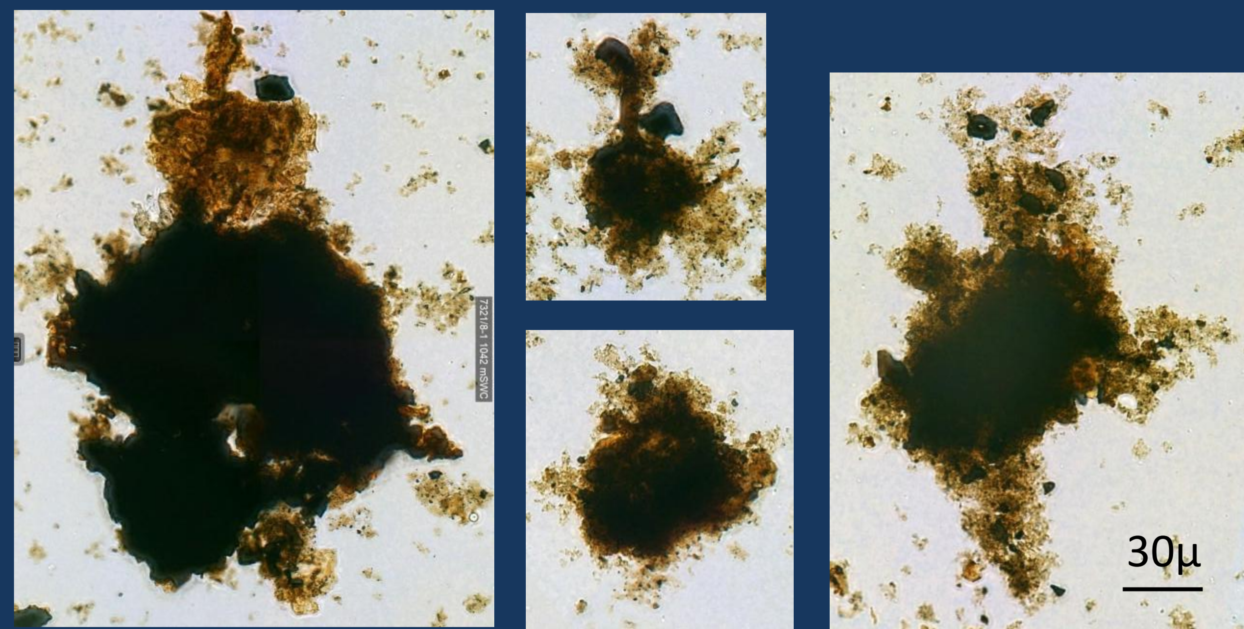
7321/8-1 684.3m Kolmule Fm, Aptian – Cenomanian SpB's





7321/8-1 1042.0m Kolje Fm, Barremian SpB's

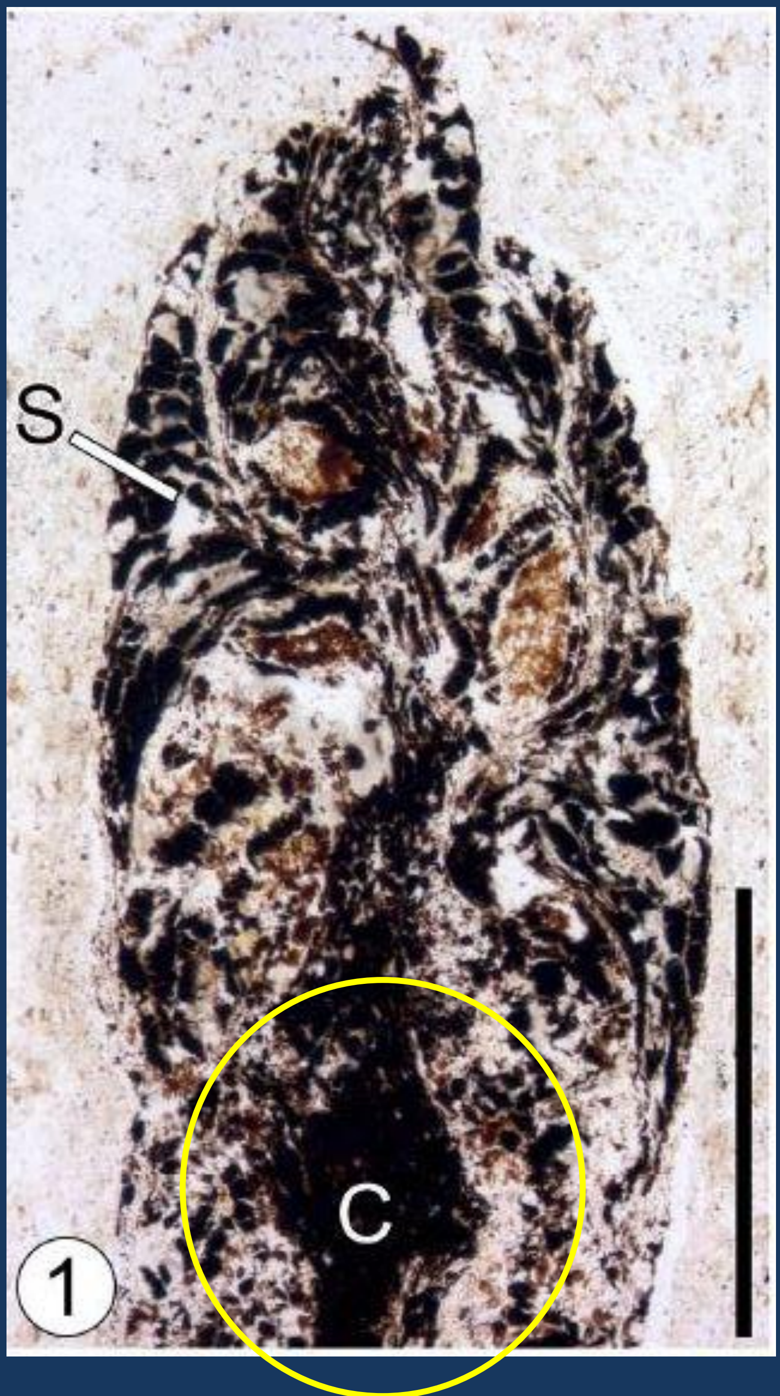




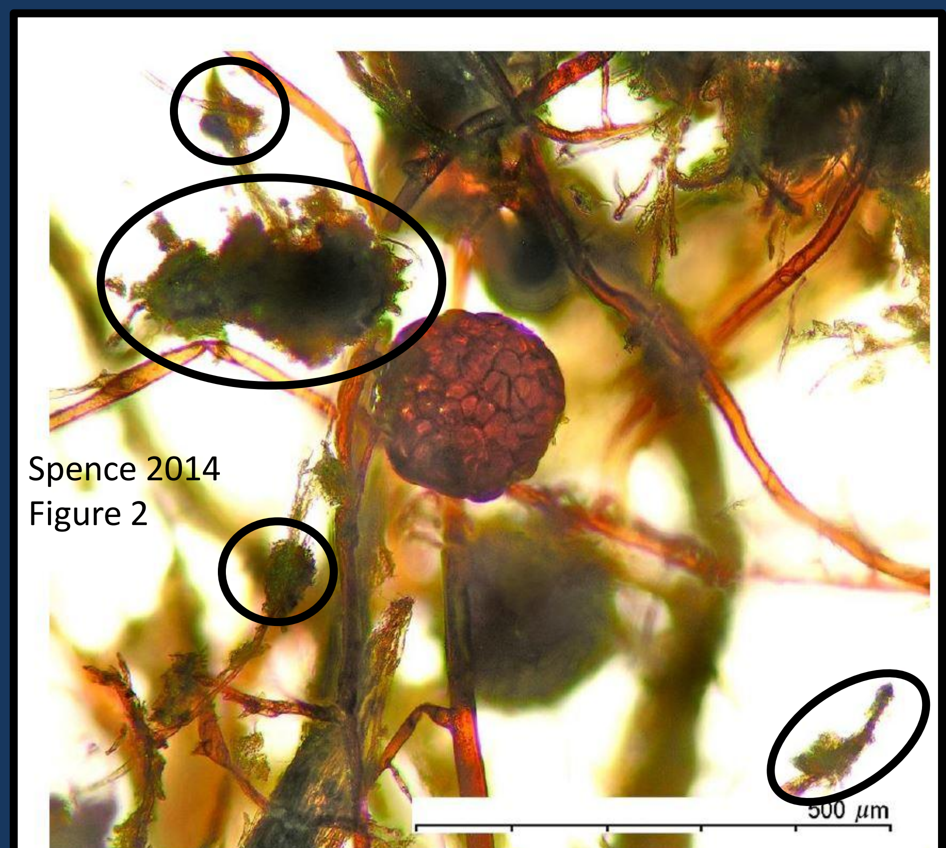
Pseudoamorphous SpB's with translucent tissues enveloping inner opaque body or bodies. Proliferation of attached cells distally

Mesofossils with *in situ* opaque subpentagonal bodies

Moss sporophyte



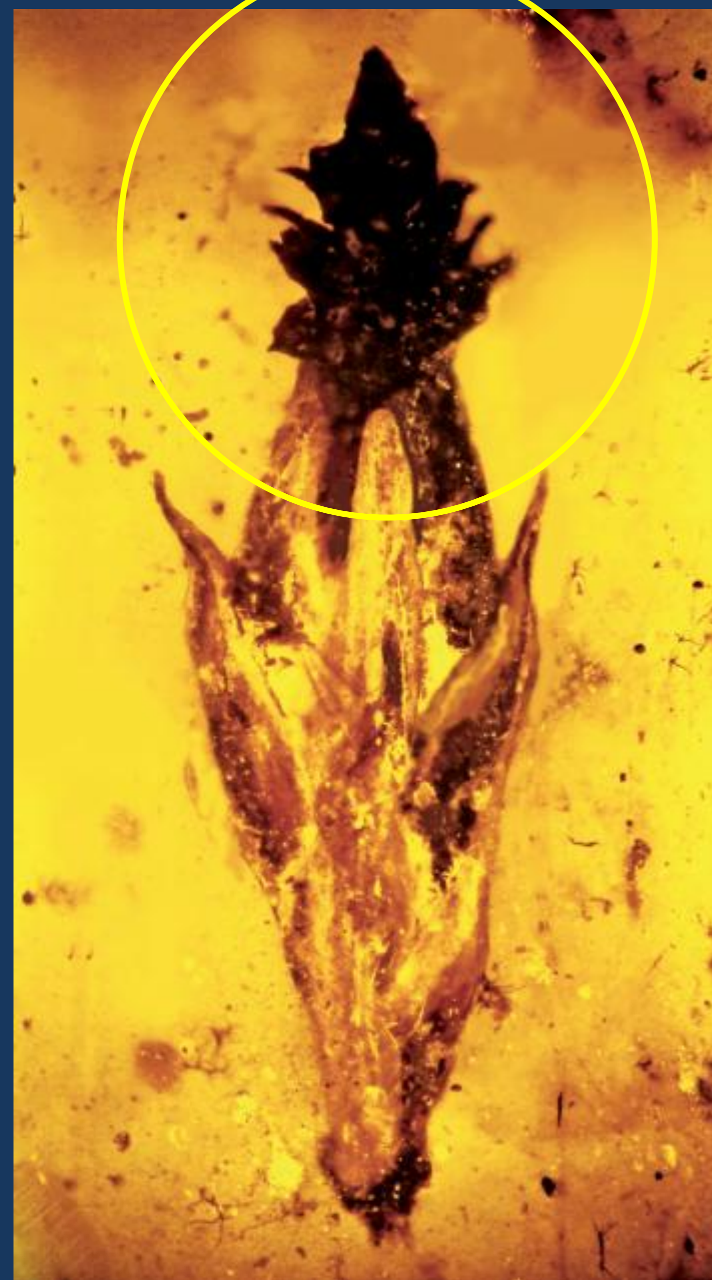
Hieger et al 2015 pl 1.1



The red coloured rhizoid tuber of an extant moss is the subject of this image in Spence 2014 and the SpB's (black rings) are not discussed

Fungal sporophyte

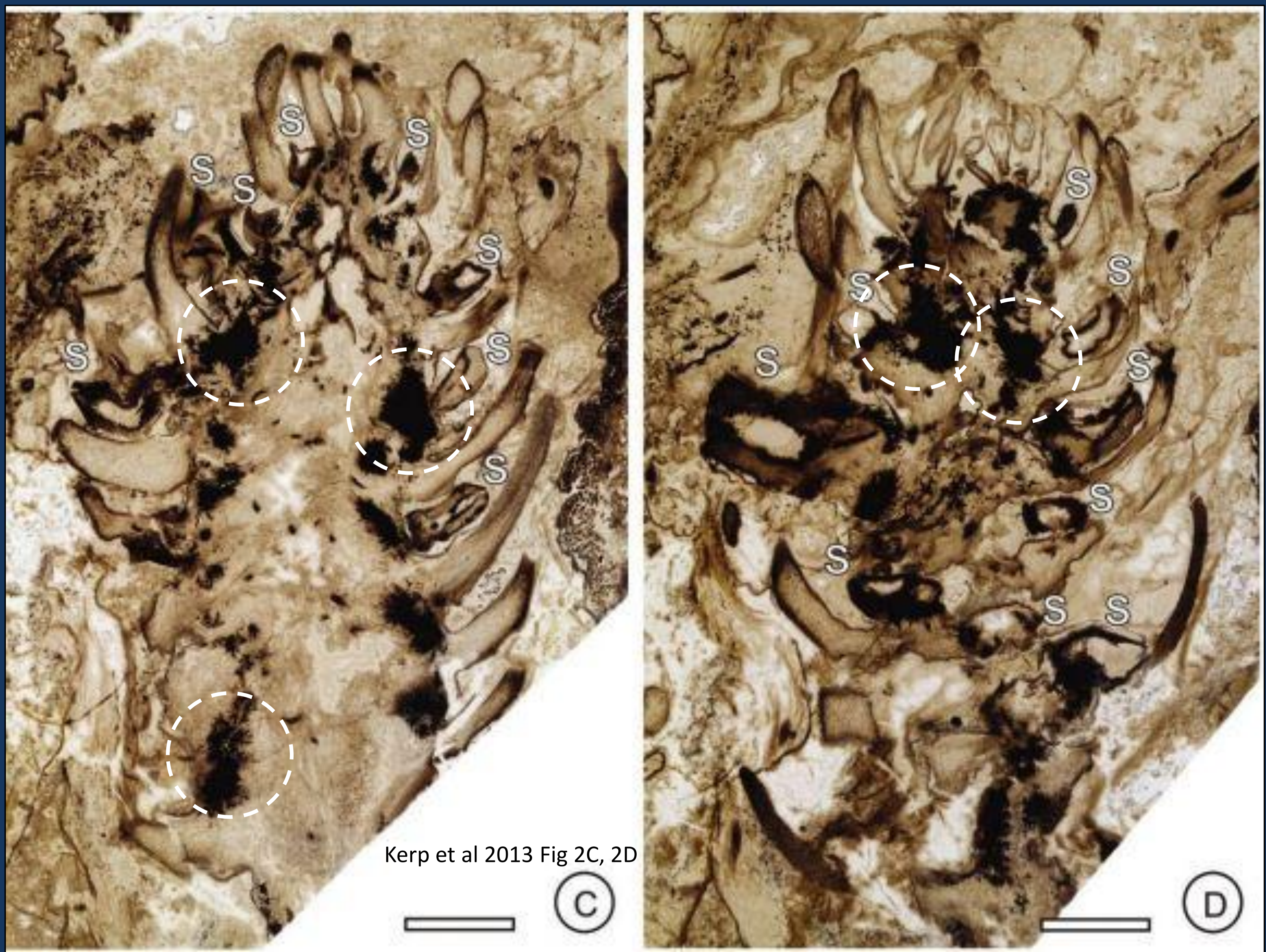
This 100-million-year-old amber-encased specimen contains what could be the oldest grass fossil known, and the only fossilized specimen of the fungus ergot (dark material at top) ever found. Credit: Oregon State University.



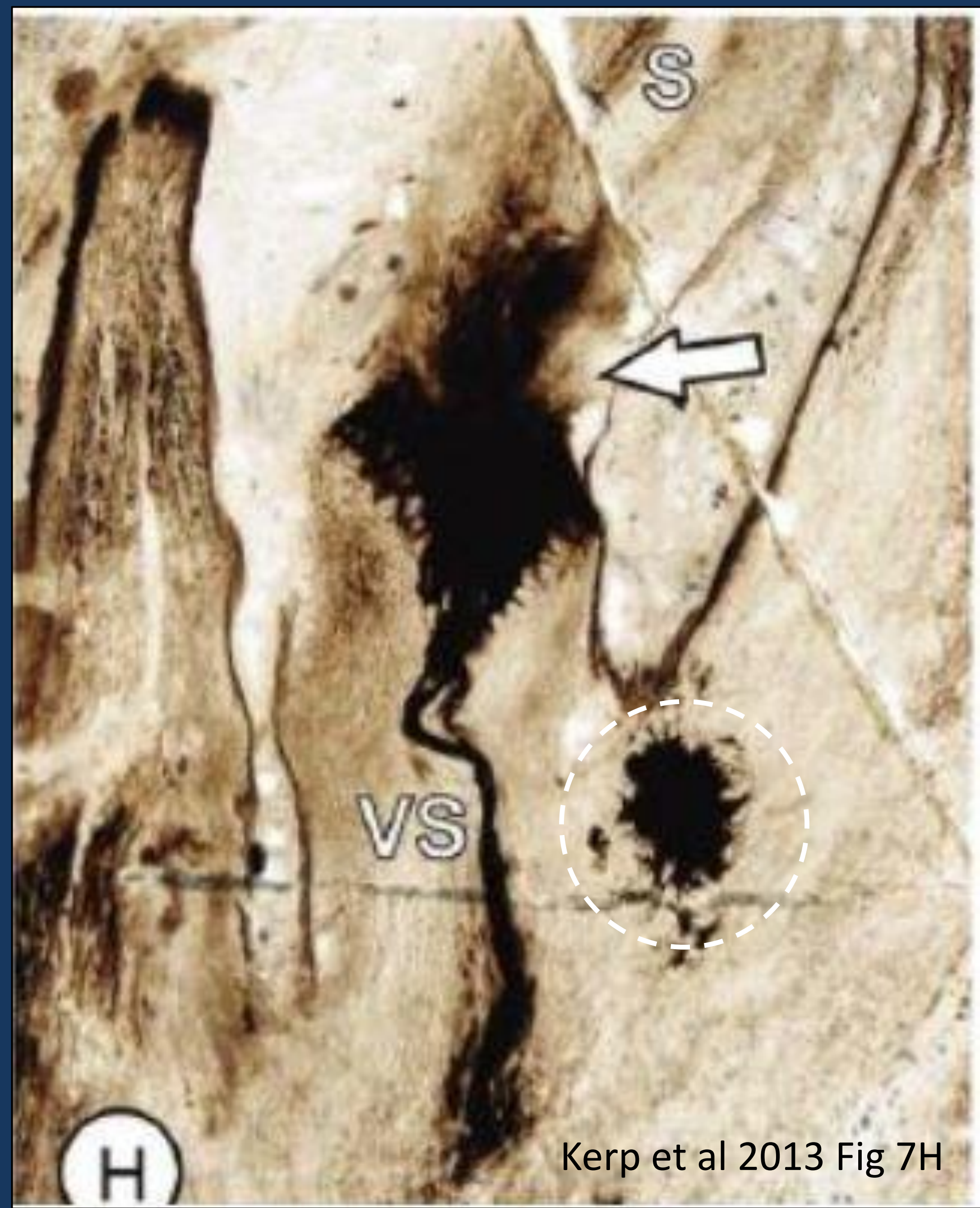
https://www.earthmagazine.org/article/amber-encased-plant-could-be-oldest-known-grass-specimen-may-also-preserve-cretaceous-aged

Kerp et al 2013 Rhynie Chert

Sporangia of extinct Early Devonian plant, annotated S in original article and white arrow in right hand photograph.
Best examples with most similarity to SpB's have been circled here.



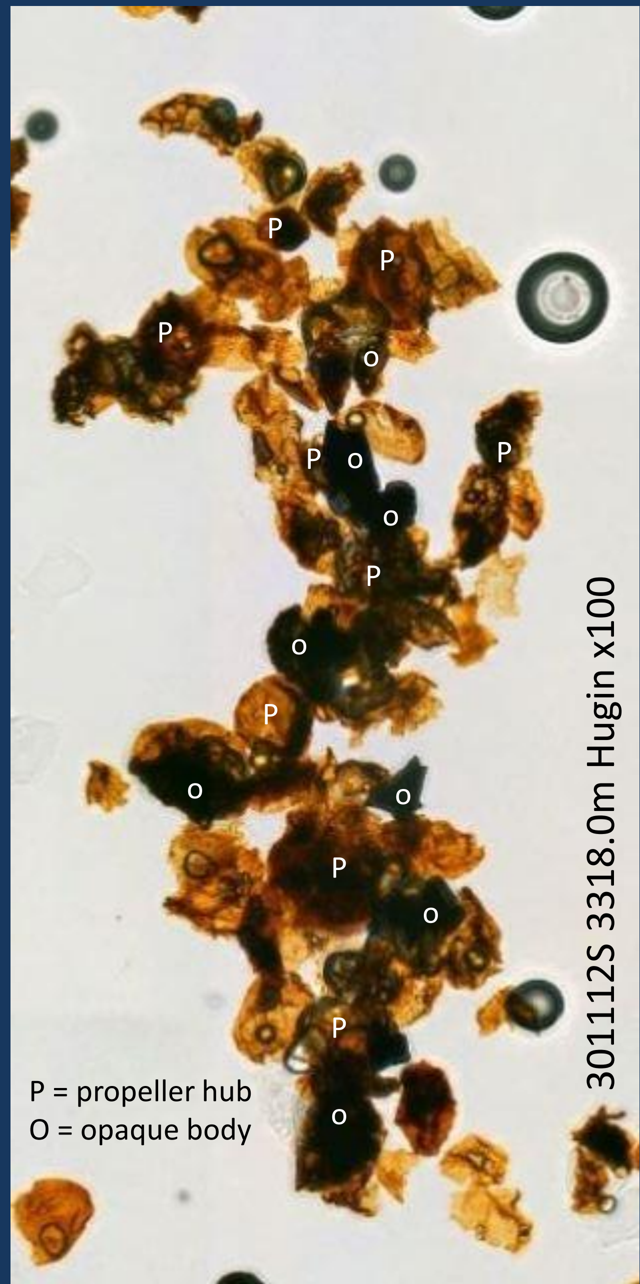
Kerp et al 2013 Fig 2C, 2D



Kerp et al 2013 Fig 7H

Branch morphology

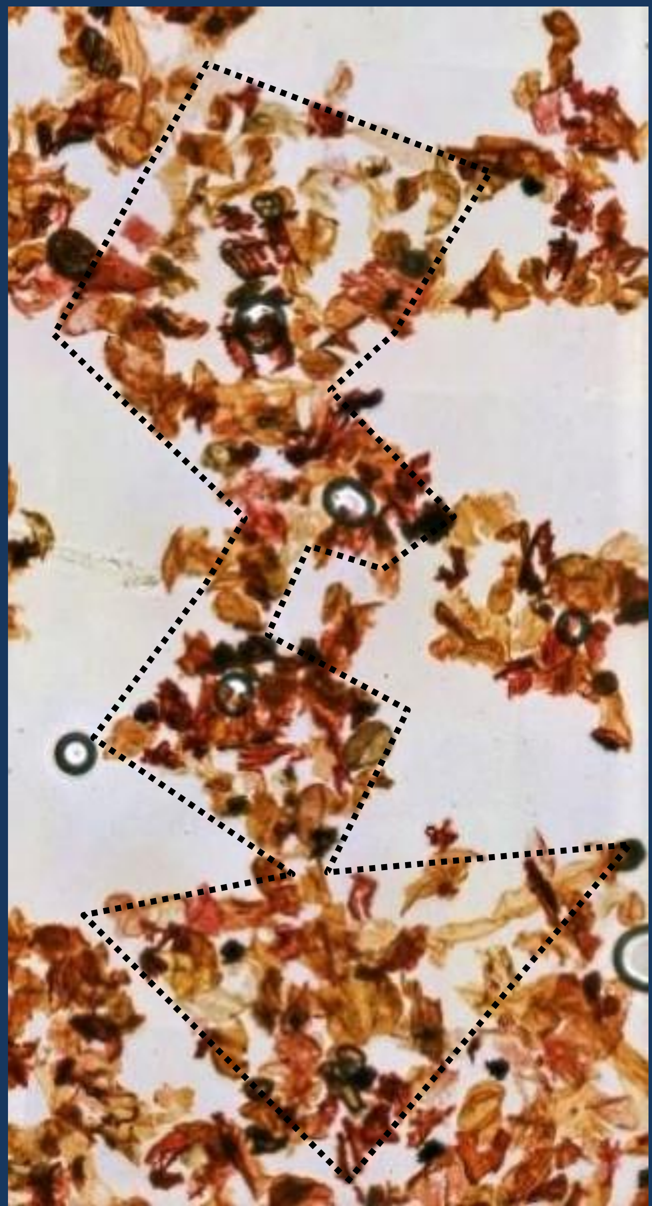
Wide view	Zoom	Annotated	Propeller-like structures Top tow; four bladed. Second row; two blades



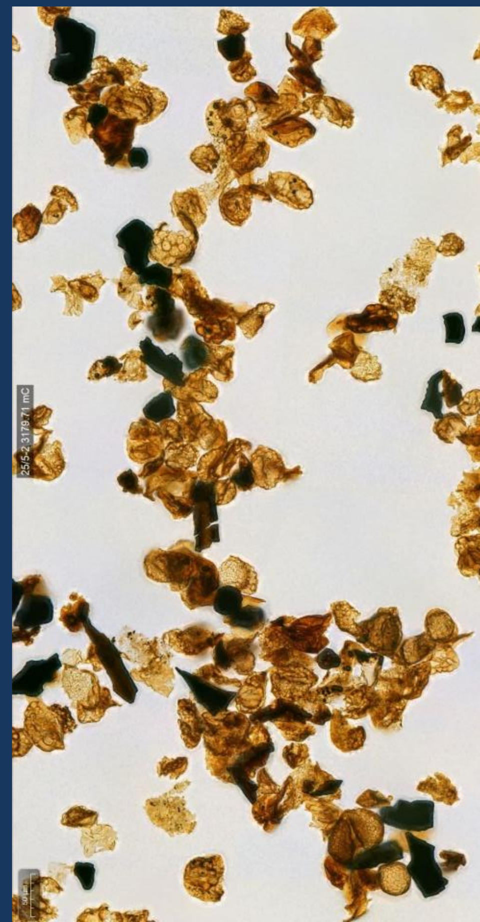
Branches appear to be formed of interconnecting propeller-like bodies. The propeller blades are commonly shared between two adjacent hubs, so it is often difficult to work out which are hubs and which are blades. There is a distinct zigzag along the branch axis, which is a typical feature in modern leafy liverwort. The opaque bodies seem to mirror the zigzags

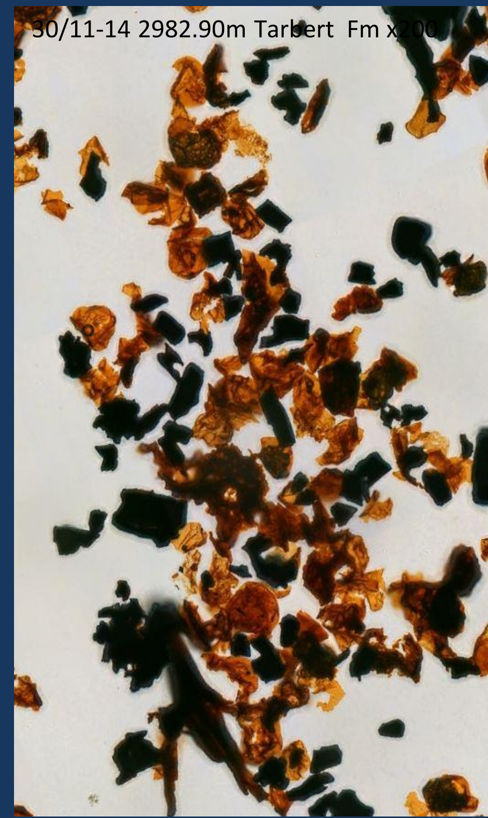
Branch morphology

The preservation in the first specimen is excellent, with most attached bodies still *in situ* , though they obscure detail of the thallose bodies underneath (interpretation highlighted). It is easier to observe the underlying "skeleton" after many/most of the attached parts have been disaggregated , as in the 2nd and 3rd specimens. All three show a series of rhomboid and triangular structures aligned along the axes . The right hand specimen possibly a larger version of these features.



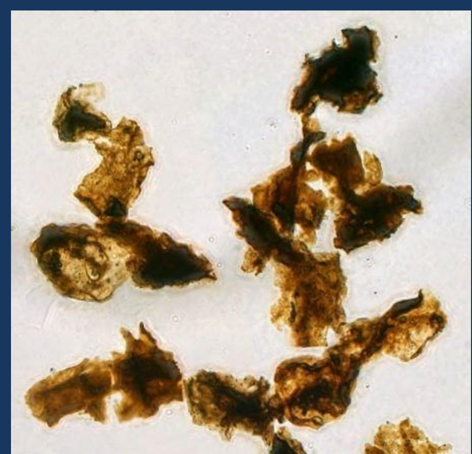
100µ

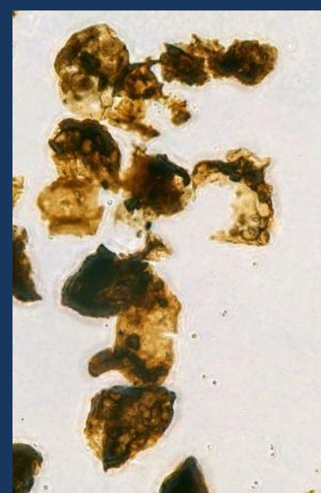


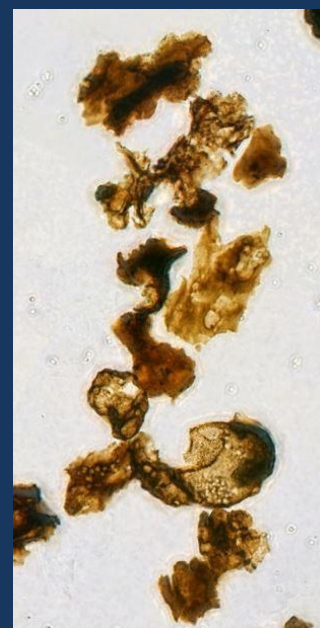


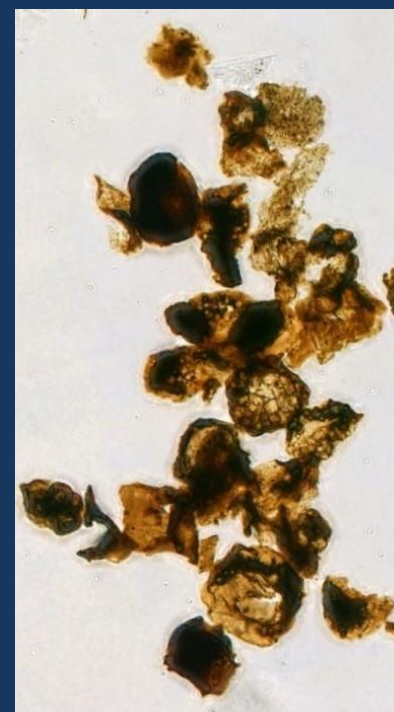
Specimens on the bottom row have lost almost all of the attached bodies and detail can be seen of the smaller scale structure of interlocking propeller -like elements.

50µ



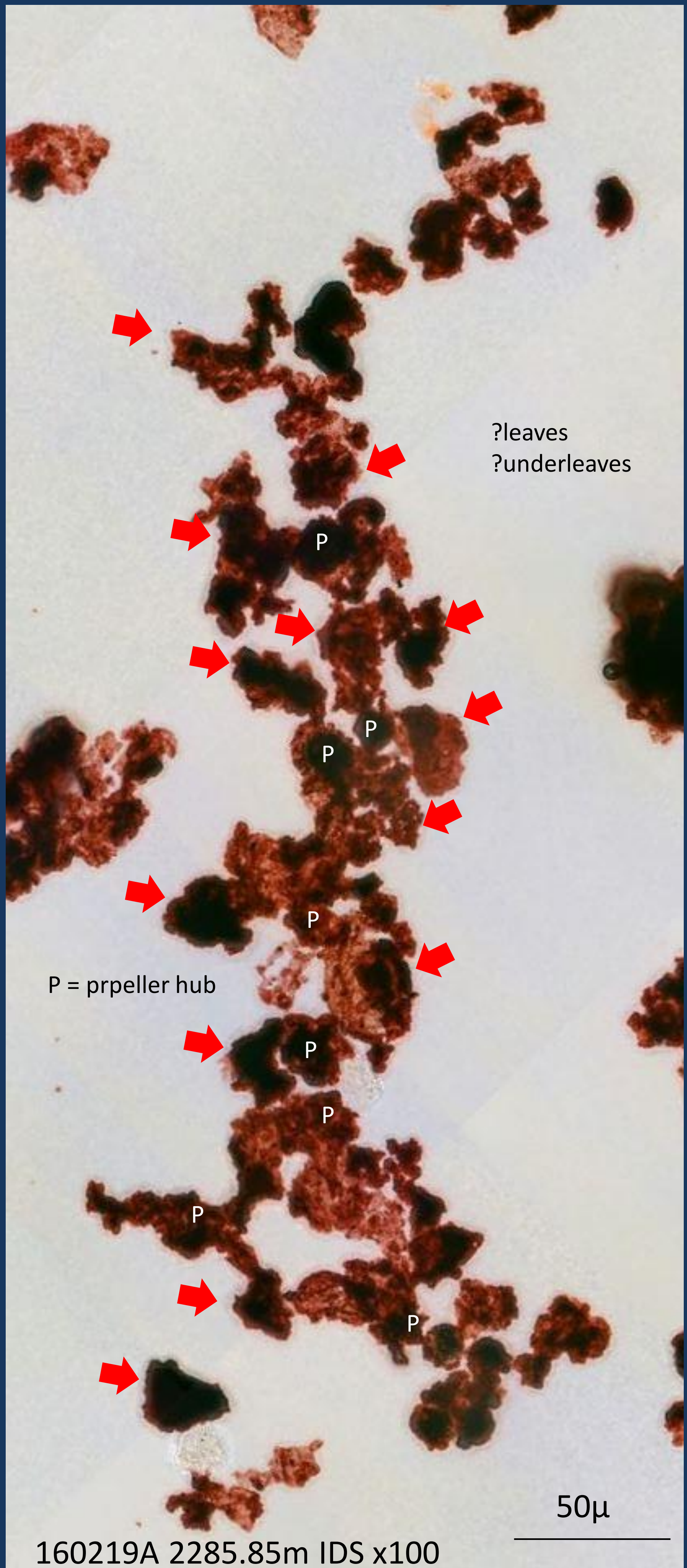


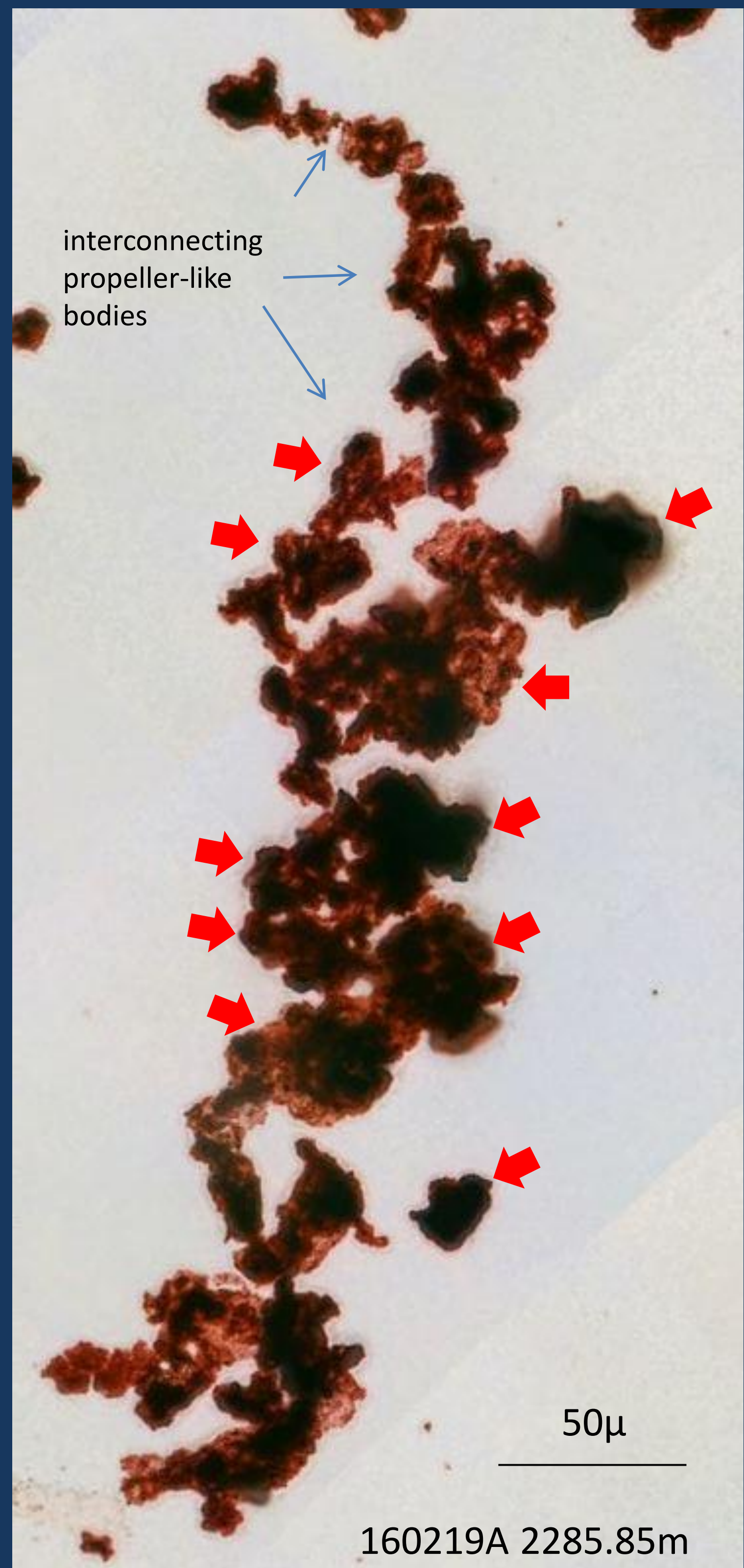




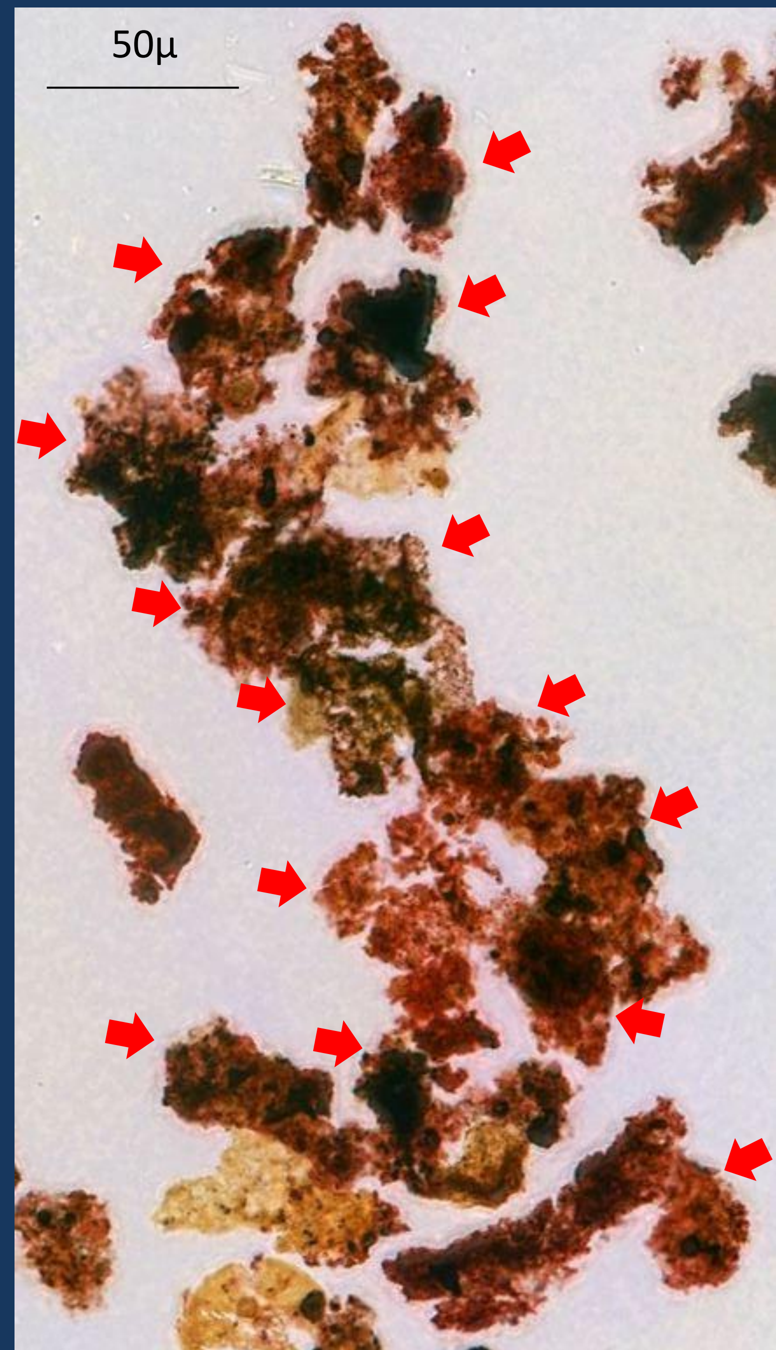
Leafy liverworts?

Three degraded yet relatively intact branch sections from the Intra-Draupne Sandstone (Kimm-Tithonian) are similar in general appearance (though smaller) to the leafy shoot of a Late Cretaceous liverwort preserved in amber (right). The branches are built of irregular interconnecting propeller-like elements (P on hub, left hand specimen only). All have leaf-like bodies (red arrows) attached along both sides of the gently zigzagging axis

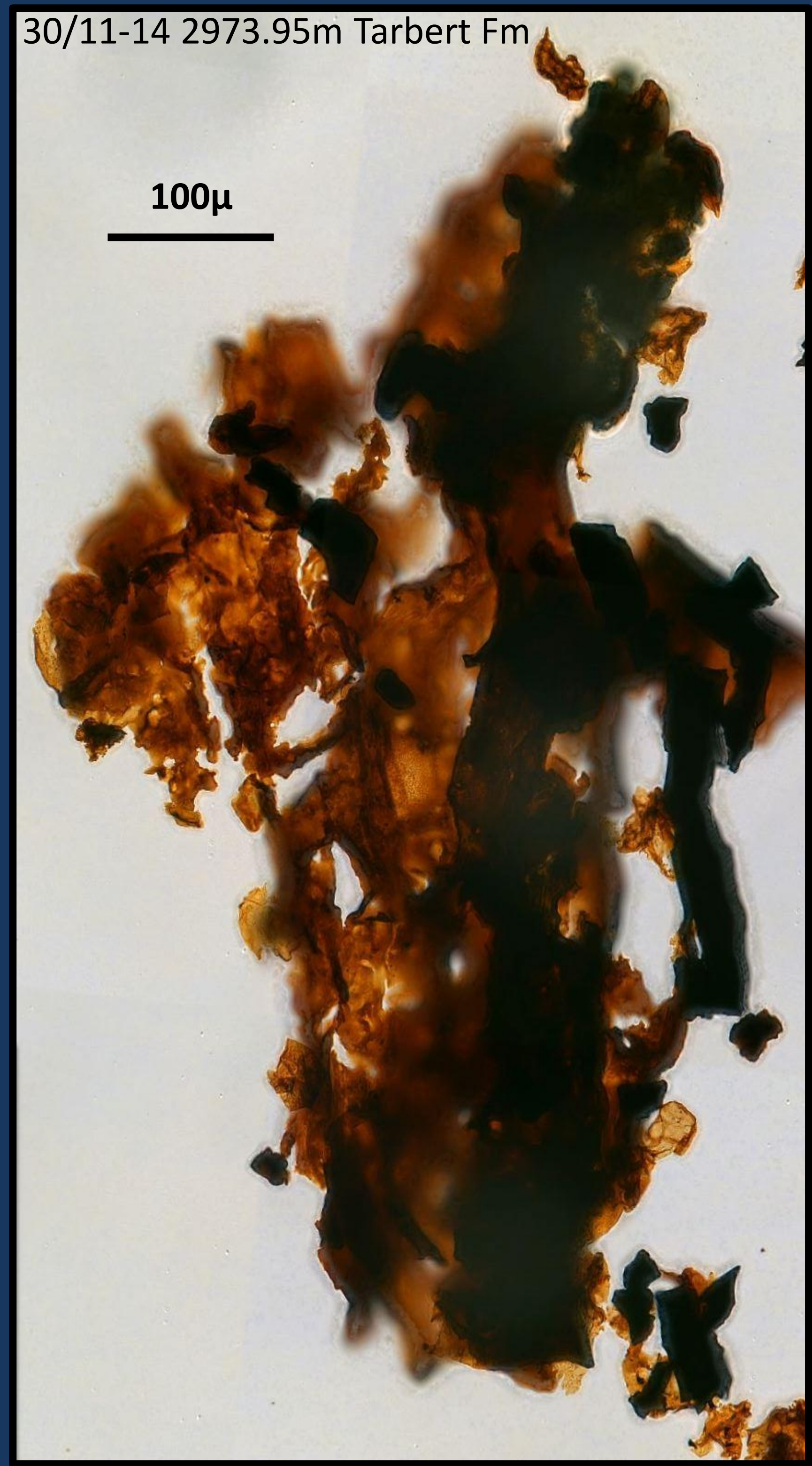


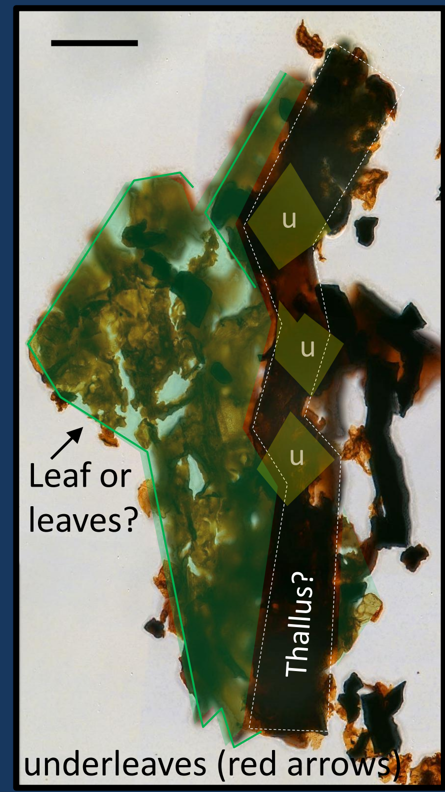


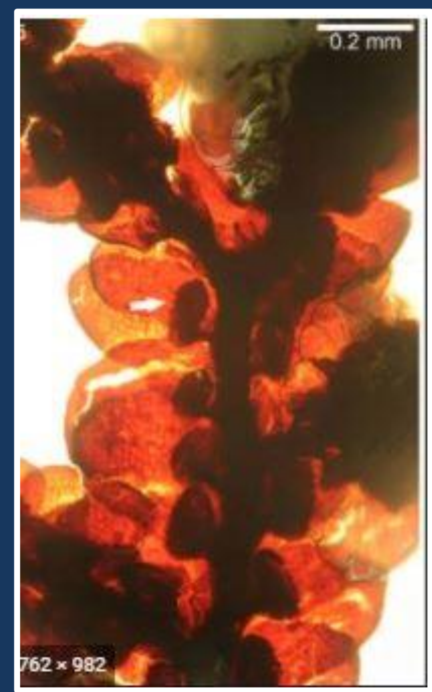
Hentschel *et al.* 2009 Fig 7.4. Leafy shoot of *Frullania cretacea*



30/11-14 2973.95m Tarbert Fm x200



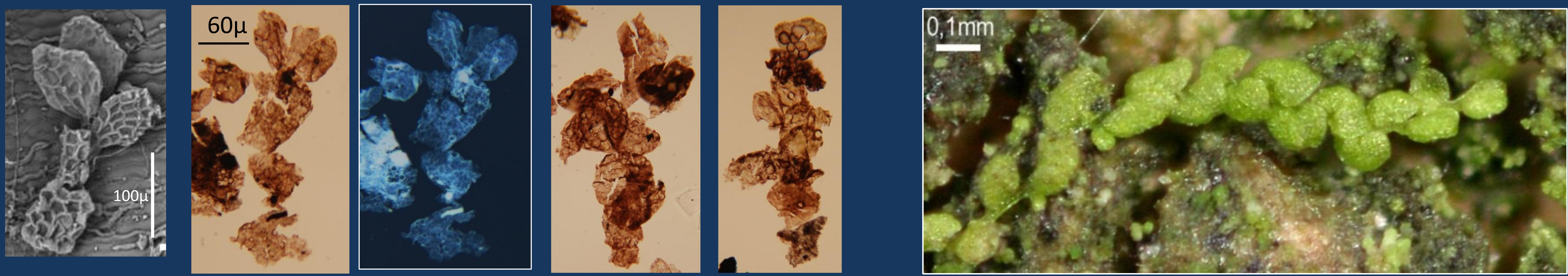




Two very large (c.1mm) structures are tentatively interpreted as sections of thallus from a leafy liverwort. The specimen above is annotated (upper right) with gently zigzagging thallus, main leaf or leaves and underleaves . The general appearance of both specimens has a resemblance to the underside of a fossil liverwort preserved in amber (Heinrichs *et al* 2016, Figure 7G)

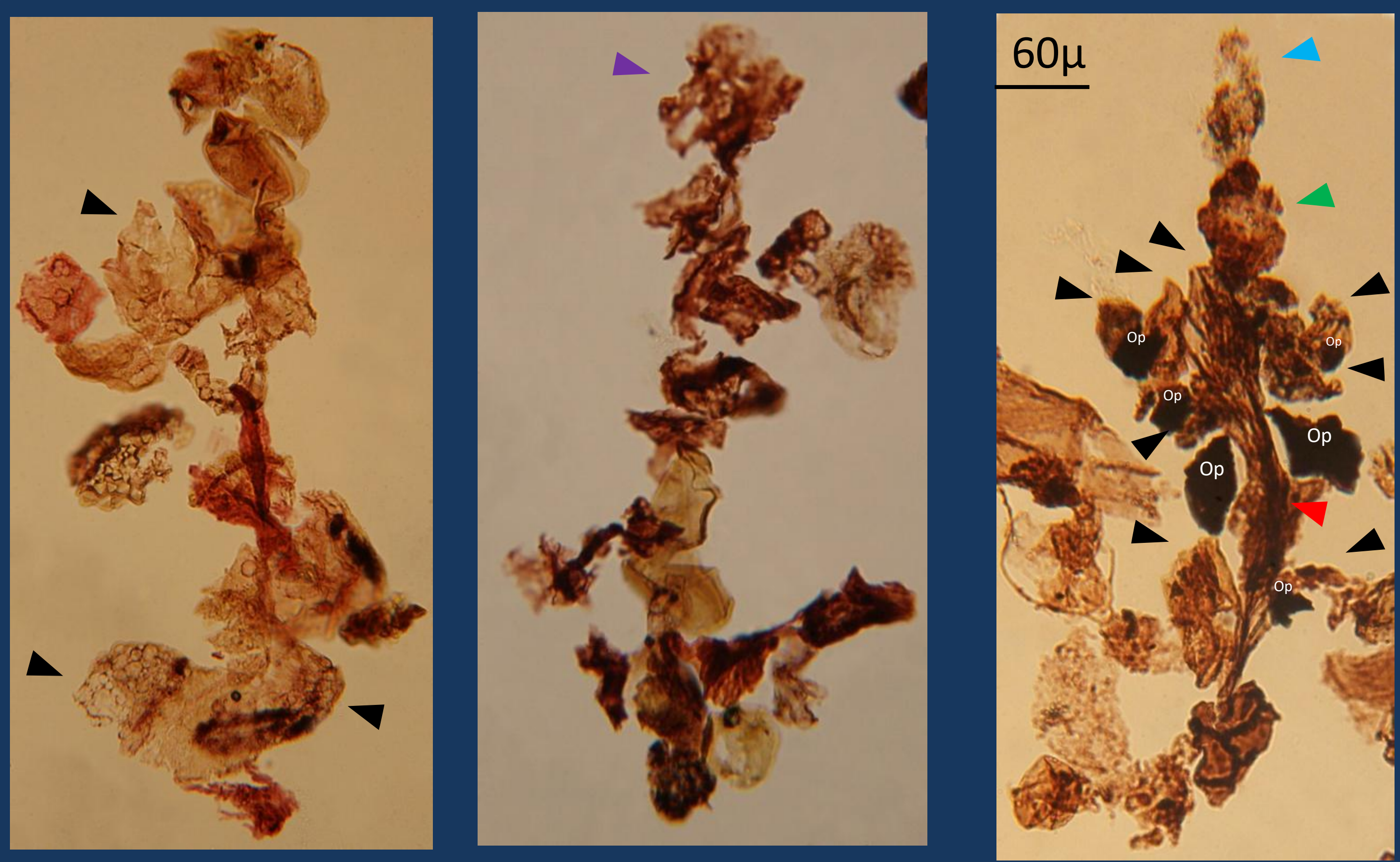
Other plants

Late Oxfordian-Kimmeridgian NNS

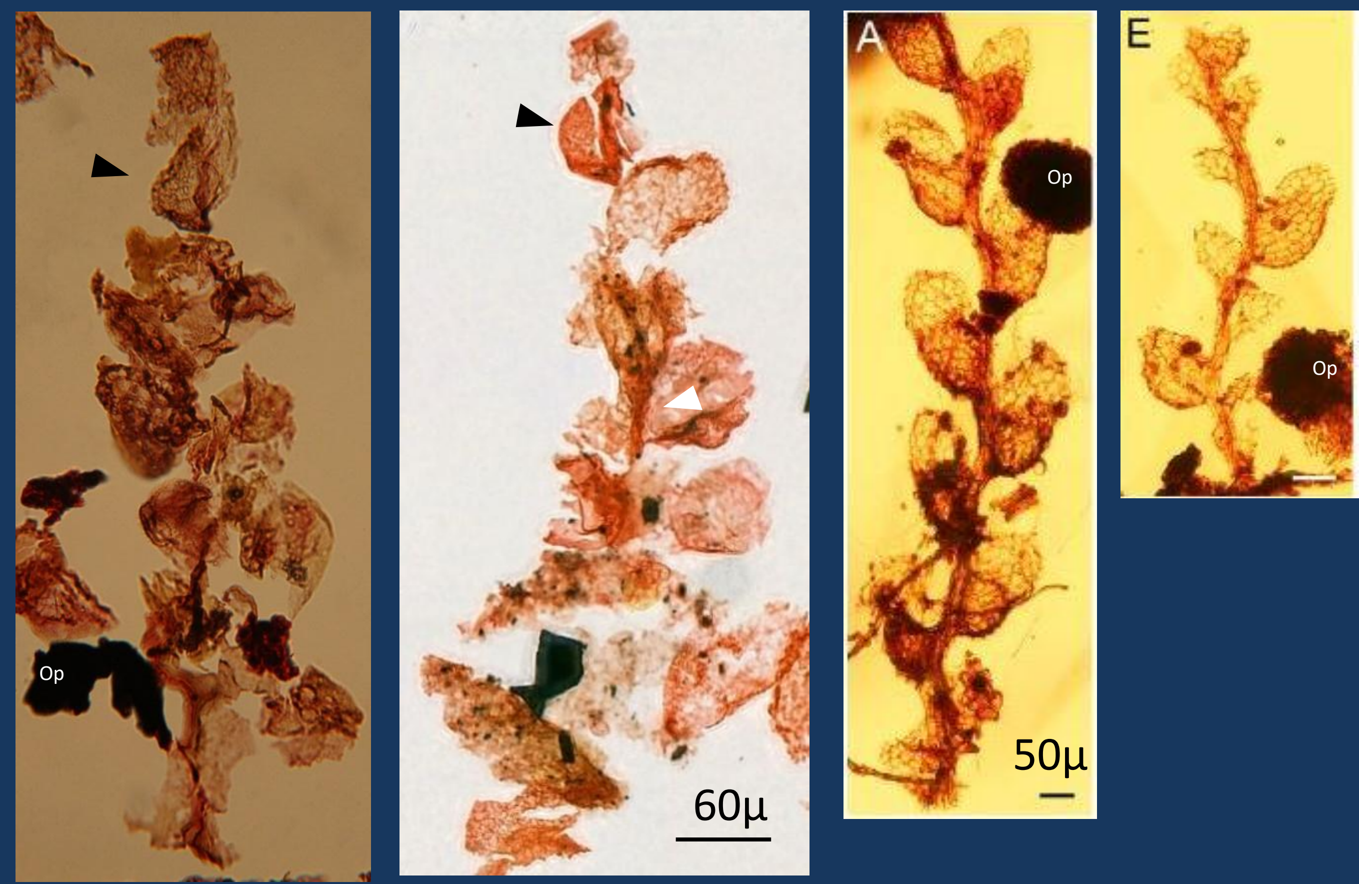


Jurassic plant structures from the North Sea are compared to modern epiphyllous leafy liverworts, including the SEM of a *Leptolejeunea* gametophyte illustrated in Beardmore-Herd *et al.* 2018 (left) and a fully-grown shoot of *Microlejeunea ulicina* illustrated *at* www.bbsfieldguide.org.uk (right).

Callovian NNS



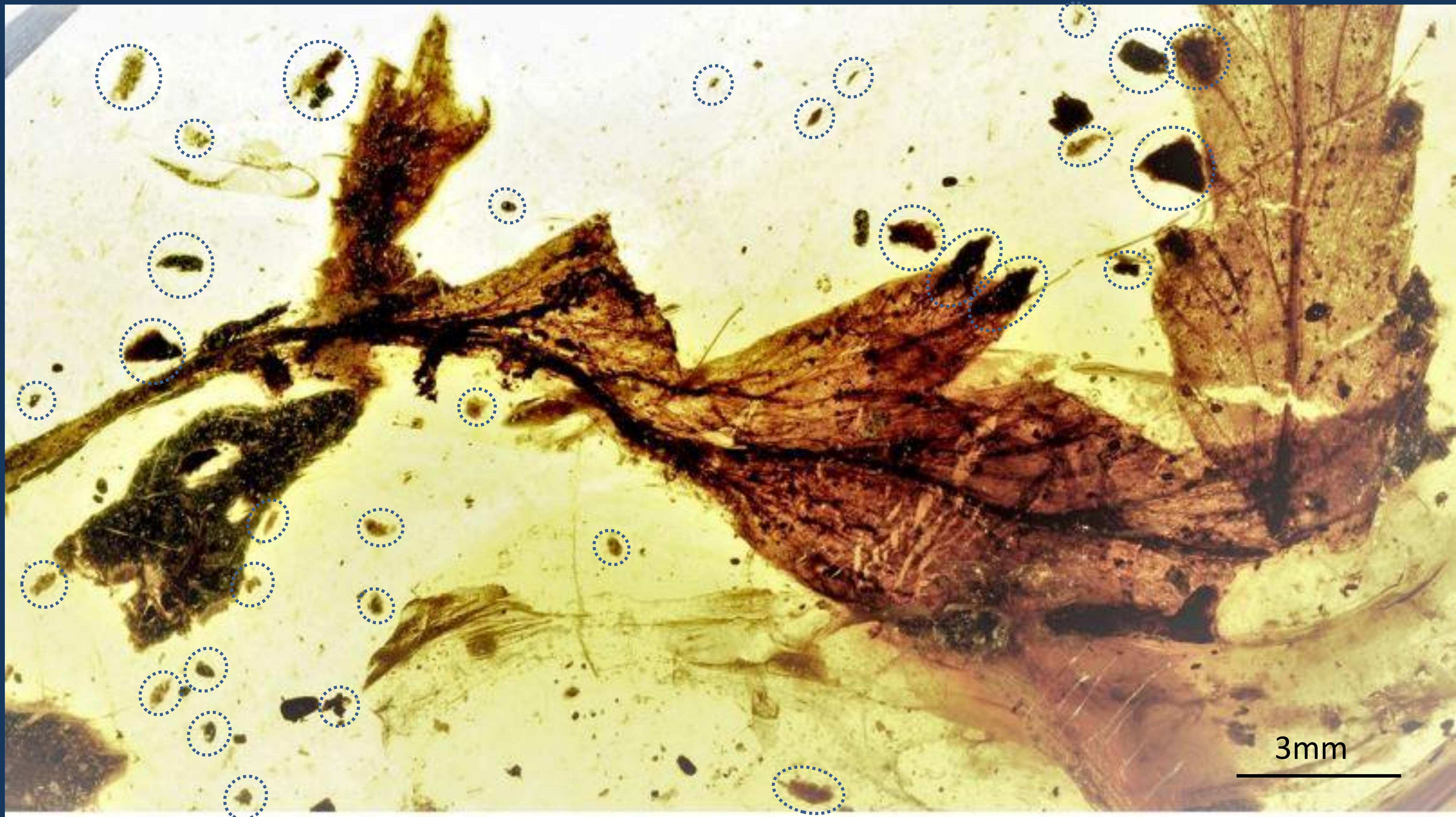
Left; unknown plant structure incorporating bisaccate-like bodies (arrowheads)
Middle; shoot tip? with diamond-shaped body attached distally. (arrowhead).
Right; leafy shoot? Elongate stem with diverging elements (red arrowhead), prominent lobate body (green) and "sprouting" cell (blue). Several attached opaque (Op) and leafy bodies (black arrowheads).



The two specimens on the right from the Jurassic of the North Sea are comparable to the gametophytes of an Eocene leafy liverwort illustrated in Heinrichs *et al* 2016, Figures 2A and 2D

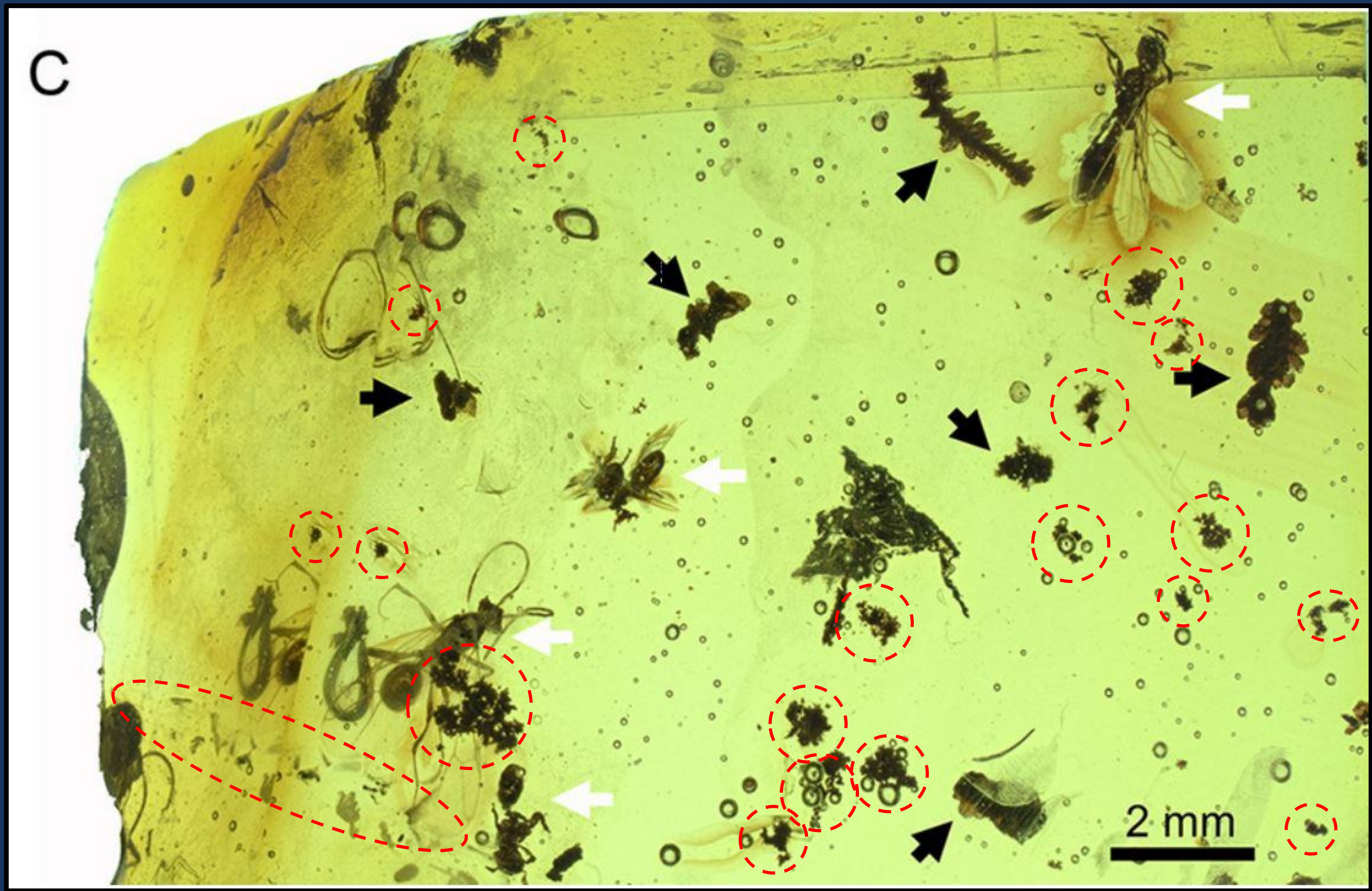
“Background debris” of amber samples containing fossil organisms include the same particles!

An independent line of evidence for the idea of “component bodies” vs. randomly fragmented phytoclasts is the background debris in illustrations of fossil organisms in amber. Rarely the subject matter in the articles, this material is a mirror of the phyto--debris in palynology and palynofacies preparations! Many of the small isolated bodies are virtually identical to those shown in the presentation, including specimens formed of pseudoamorphous, structured and opaque tissues.



Regalado et al 2017 Fig 1a. Fern in Cretaceous amber from Myanmar

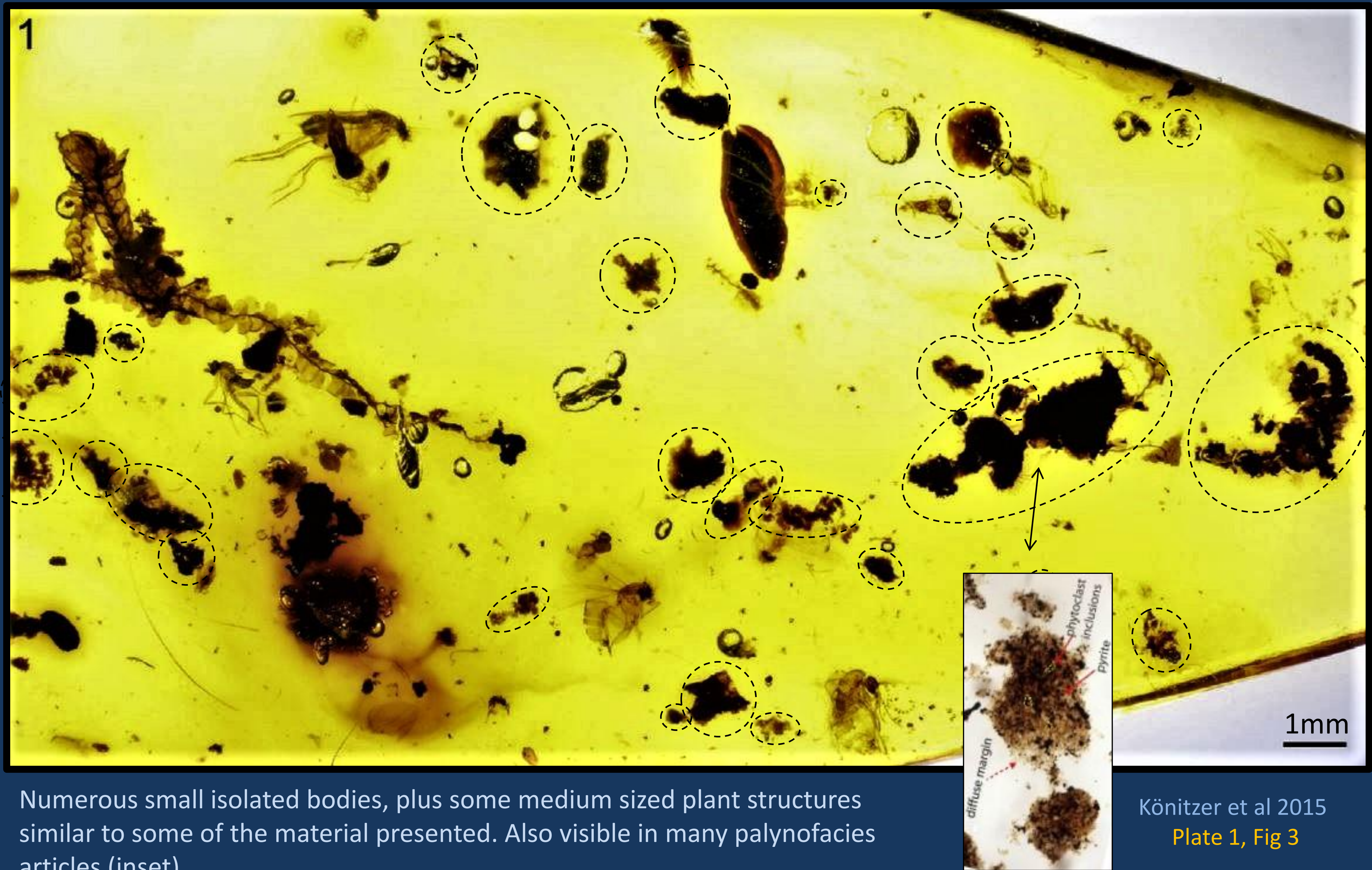
Illustration of ants in Miocene amber from Ethiopia in Bouju & Perrichot 2020 (fig. 3c) includes annotated liverwort specimens



In original publication;
Ants - white arrows,
Liverworts (Marchantiophyta) black arrows

Additional bryophytic parts circled, mainly young gemmalings?

Heinrichs *et al.* 2015, Fig. 1.1. Miocene Mexican amber with holotype of liverwort *Mastigolejeunea extincta*

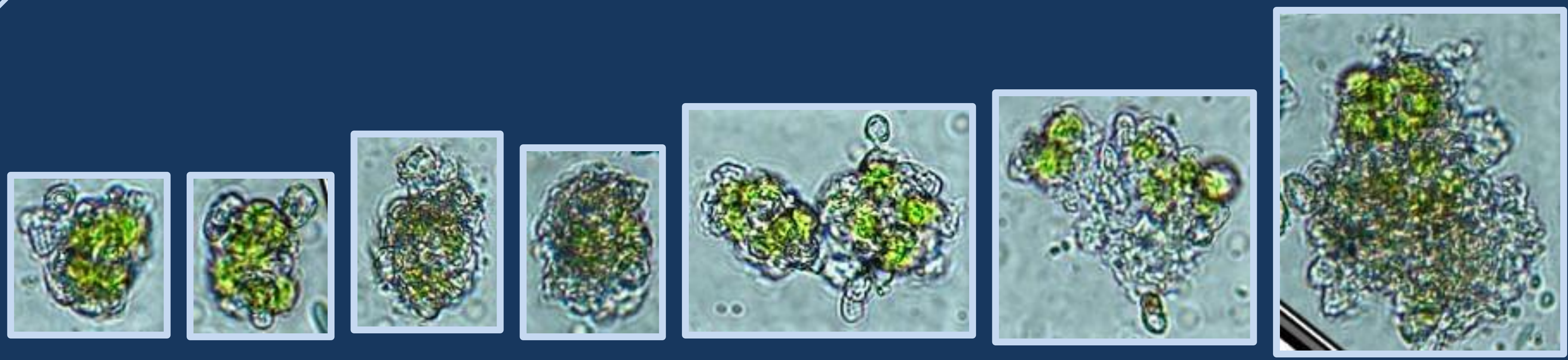


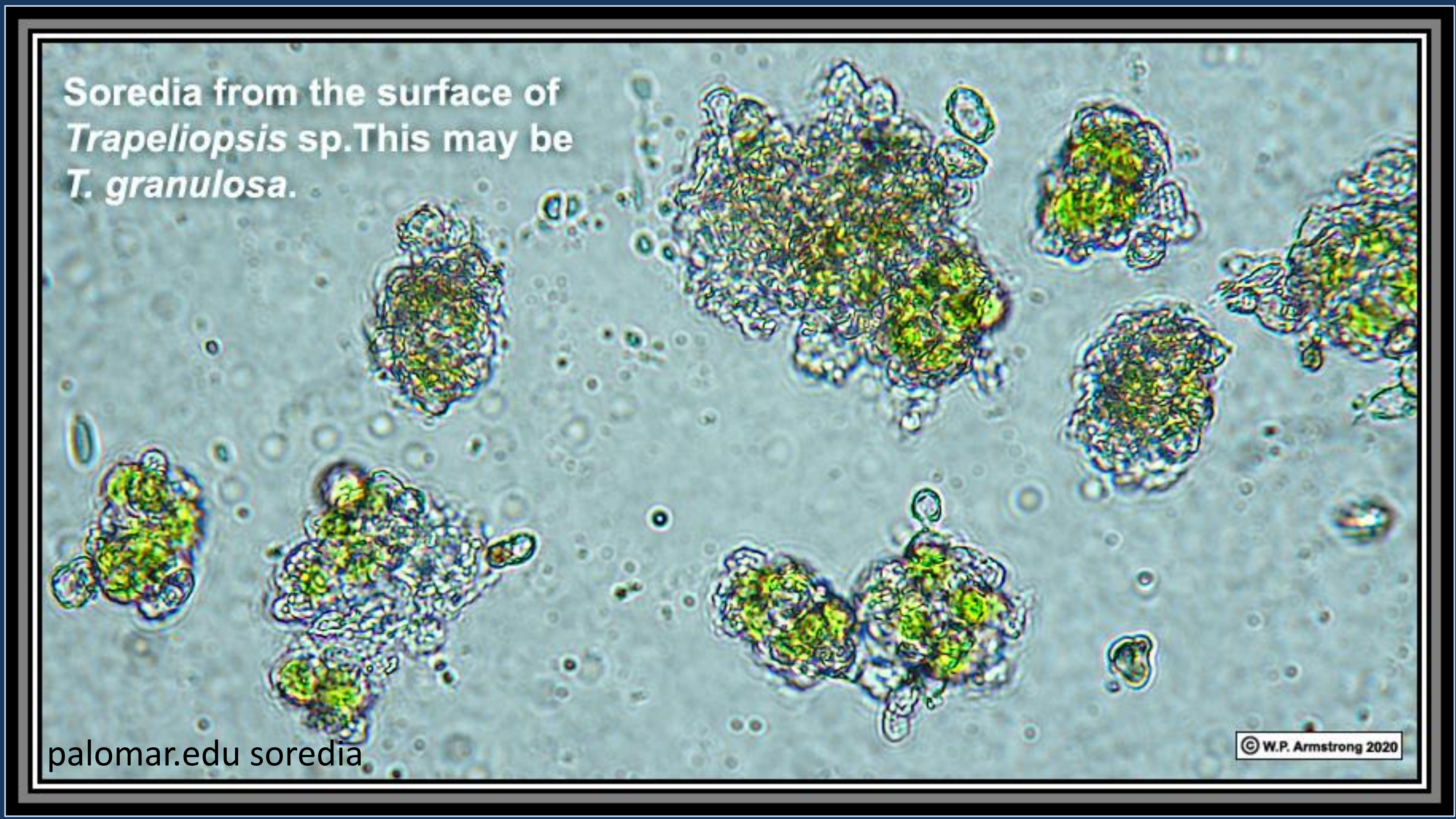
Numerous small isolated bodies, plus some medium sized plant structures similar to some of the material presented. Also visible in many palynofacies articles (inset)

Könitzer et al 2015
Plate 1, Fig 3

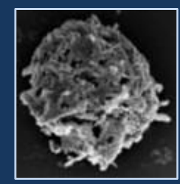
Barden *et al*. 2017. A New Genus of Hell Ant from the Cretaceous (Hymenoptera: Formicidae: Haidomyrmecini) with A Novel Head Structure. *Systematic Entomology* 42 (4): 837-846; doi: 10.1111/syen.12253

Other possible candidates for pseudoamorphic bodies; soridia of lichen

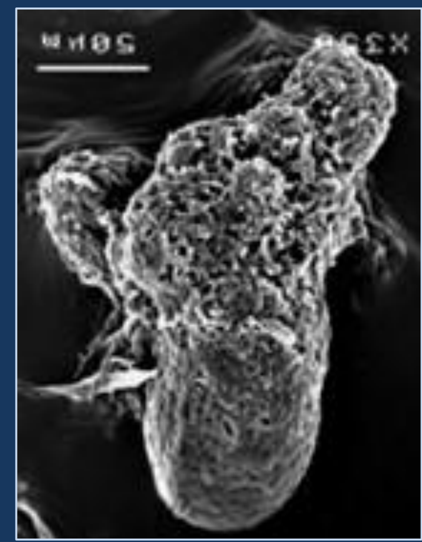




soridium

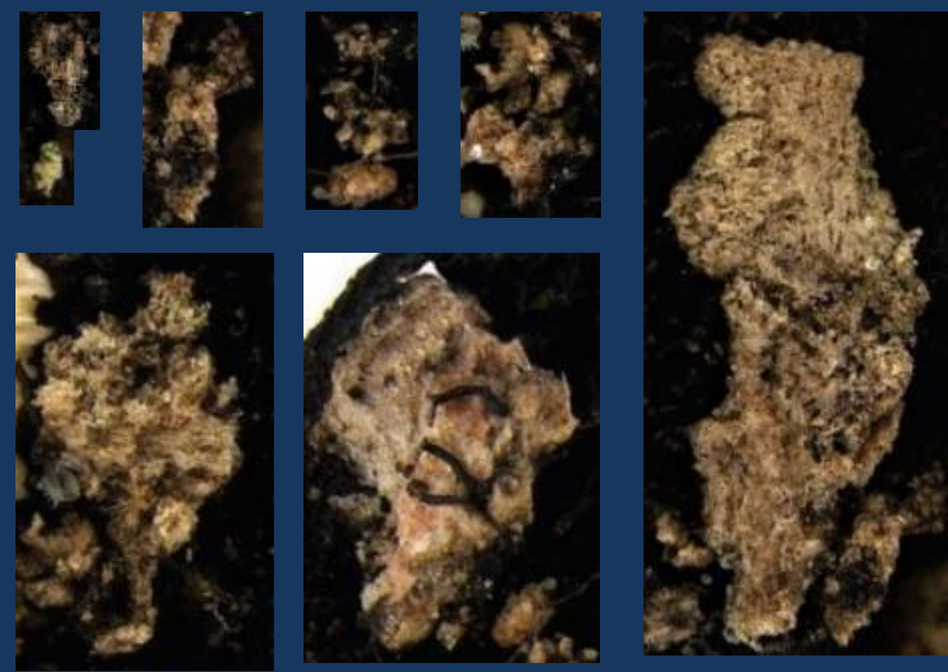


9 months >



Kon &Ohmura 2010 Fig 1B, 1C

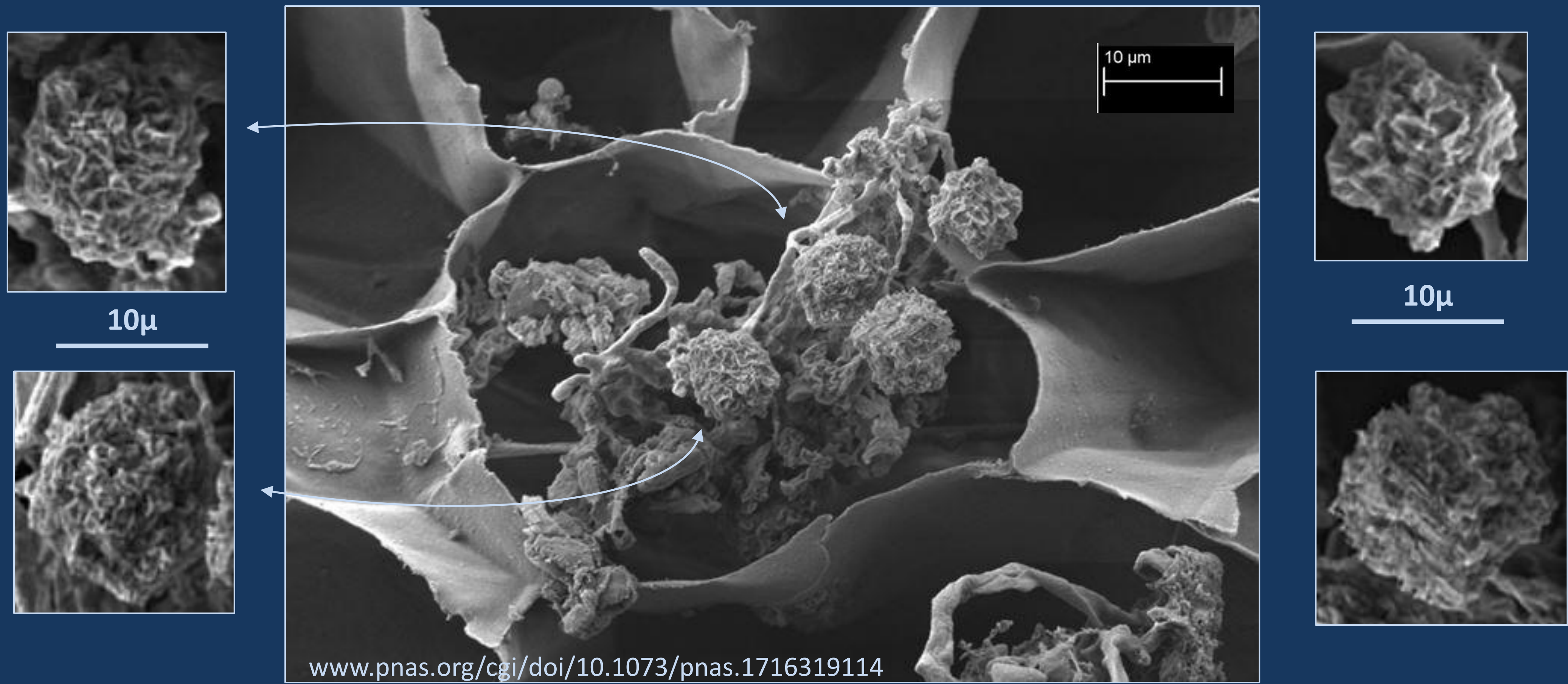
1mm



Aloquio & Lopes-Andrade 2016

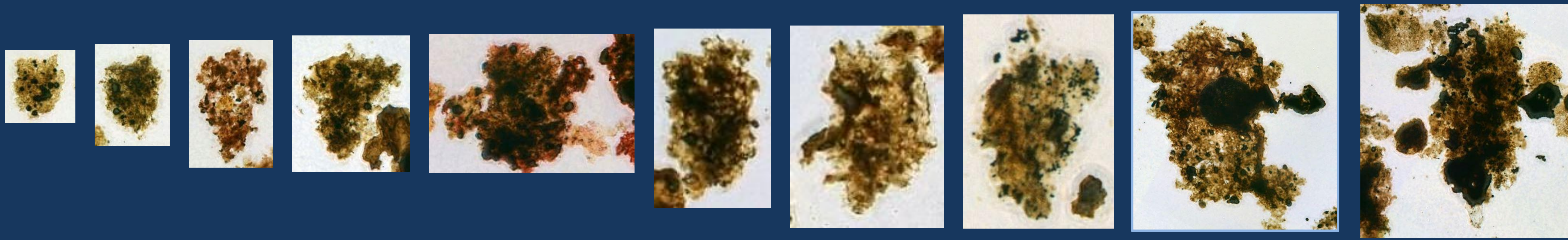
“More than 80% of land plants partner with fungi to help those plants extract nutrients” Amber Dance (PNAS) 2017

Other possible candidates; fungi



Thallus of *Treubia lacunosa* (extant liverwort).
infected with intracellular coils of fungus

Discussion

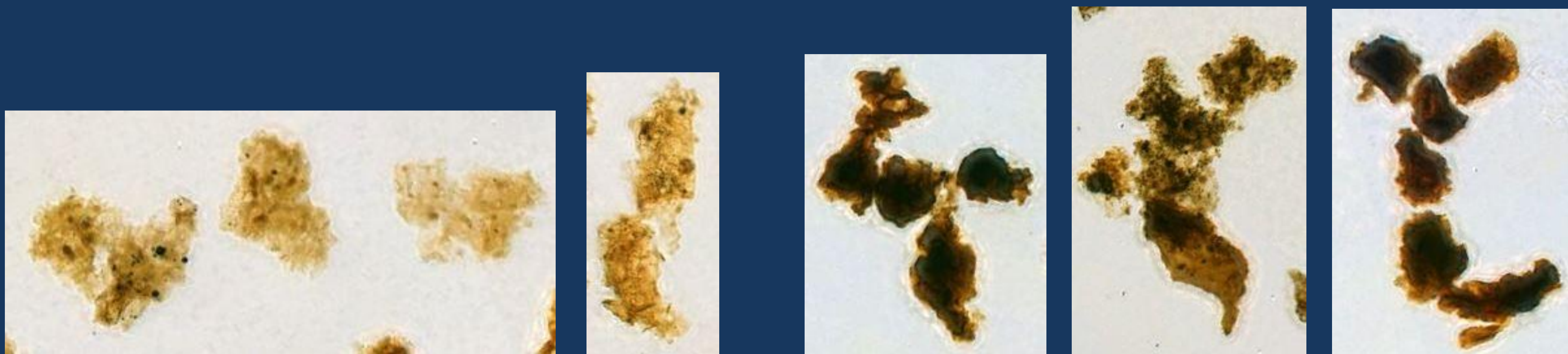


Uncertain of exact affinities; numerous candidates; Input of botanical expertise required

Evidence of bryophytes, ferns, fungi & lichen all suggest a terrestrial source. Cyanobacterial mats are oligotrophic organisms found in marine, non-marine and transitional environments. Often associated with intertidal ecosystems.

For now, the primary aim is to demonstrate how they do not correspond with current definitions and models by exhibiting consistency in outline and morphology.

Many questions remaining; e.g. why do some grow (above) and others build (below)?



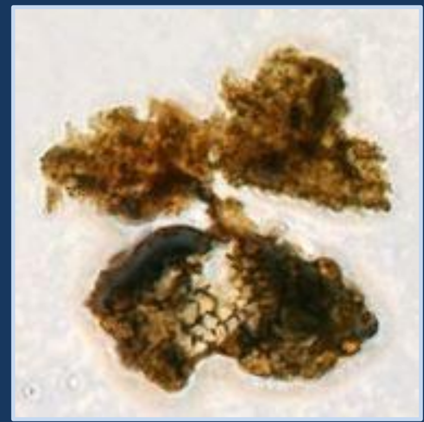
Conclusions

Amorphous/pseudoamorphous

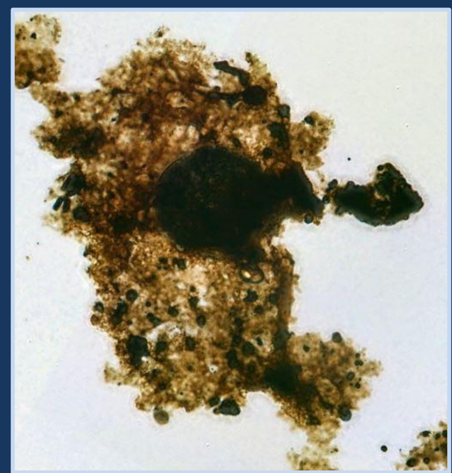
- Much of the material published as AOM is inconsistent with the currently accepted definition.
- Many of the pseudoamorphous particles bear a strong resemblance to diaspores, thalloid protonemas and young gametophytes of extant lower plants , especially bryophytes.
- Similar bodies are also produced by lichen, fungi and some cyanobacteria. Input of botanical expertise is required to accurately interpret affinities .

All kerogen

- Substantial amounts of palynodebris previously overlooked as randomly broken plant fragments are discreet organisms or constituent parts of larger organisms, normally retaining their original shape.
- These parts are commonly preserved linked together in life position, forming plant structures of variable size
- Implications are very significant for palynofacies, requiring a re-evaluation of procedures and applications.
- Much of the debris is derived from bryophytic plants, which are uncommon as macrofossils.
- Study and interpretation of this material requires greater integration of palynology with palaeobotany and a modified approach to palynofacies.
- Great potential for more detailed and accurate palaeoenvironmental interpretations.



Thank you



Special thanks to NPD for access to *Avatara*

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