New information on phytodebris in palynological and palynofacies samples from the Triassic to Early Cretaceous of the North Sea includes evidence of abundant bryophytes.

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BioStrat Ltd

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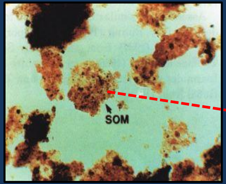
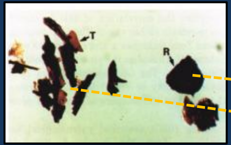
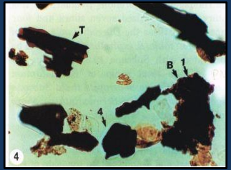
Typical palynofacies scheme (from Van der Zwan 1990)







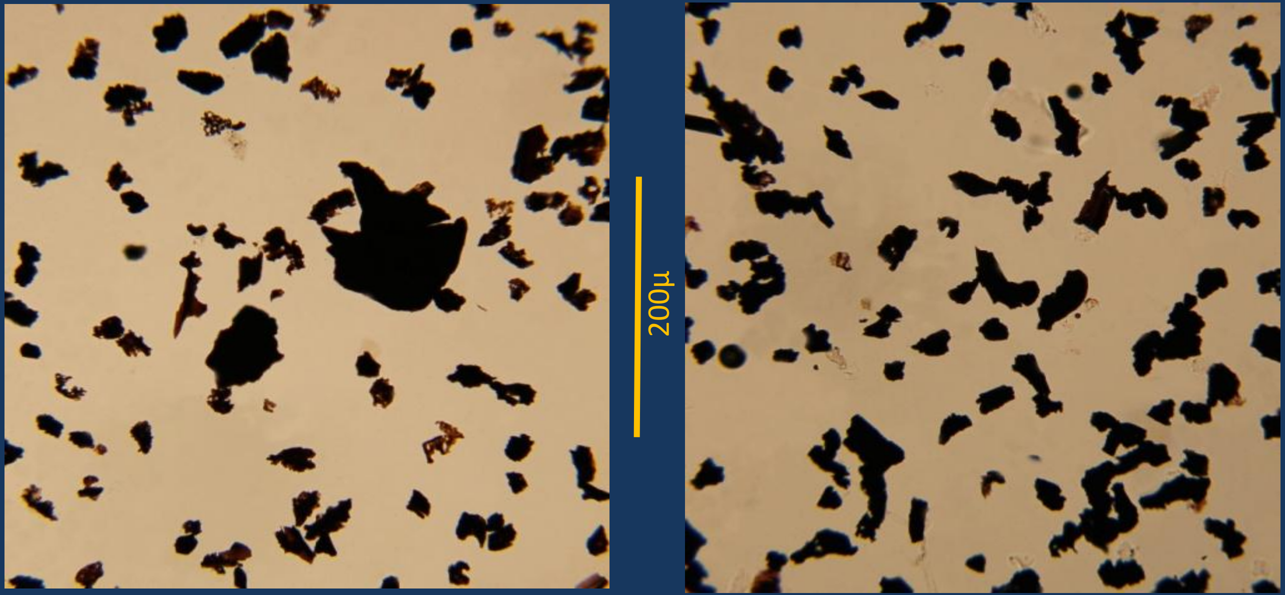
MAIN PALYNODEBRIS CATEGORIES: MODIFIED AFTER WHITAKER, 1984		MAIN PALYNODEBRIS CATEGORIES: BOULTER AND RIDDICK, 1986	APPROX. COAL MACERAL EQUIVALENT
DARK STRUCTURELESS ORGANIC MATTER (SOM)		COMMINUTED DEBRIS DEGRADED DEBRIS BROWN WOOD	
PALYNOMACERAL 1			VITRINITE
PALYNOMACERAL 2		WELL PRESERVED WOOD, PARENCHYMA	
PALYNOMACERAL 3		LEAF CUTICLE, UNSTRUCTURED DEBRIS	CUTINITE
EQUI-DIMENSIONAL	PALYNOMACERAL 4	BLACK DEBRIS	INERTINITE
BLADES	PALYNOMACERAL 4		
SPORES		BISACCATES AND SPORES (PRO PARTE)	SPORINITE
FUNGAL SPORES		FUNGI	
FRESHWATER ALGAE (BOTRYOCOCCUS)		ALGAE (PRO PARTE)	LIPTINITE
Pollen BISACCATES		BISACCATES AND SPORES (PRO PARTE)	
DINOFLAGELLATE CYSTS		DINOFLAGELLATE CYSTS	
ACRITARCHS		ALGAE (PRO PARTE)	LIPTINITE
MARINE ALGAE (TASMANITES)			
STRUCTURELESS ORGANIC MATTER (SOM=SAPROPEL)		AMORPHOUS MATTER, SPECKS	
MICROFORAM TEST LININGS			PECTIN

In palynofacies analysis the phytoclasts are considered to be randomly fragmented organic particles ="woody debris".

Main applications

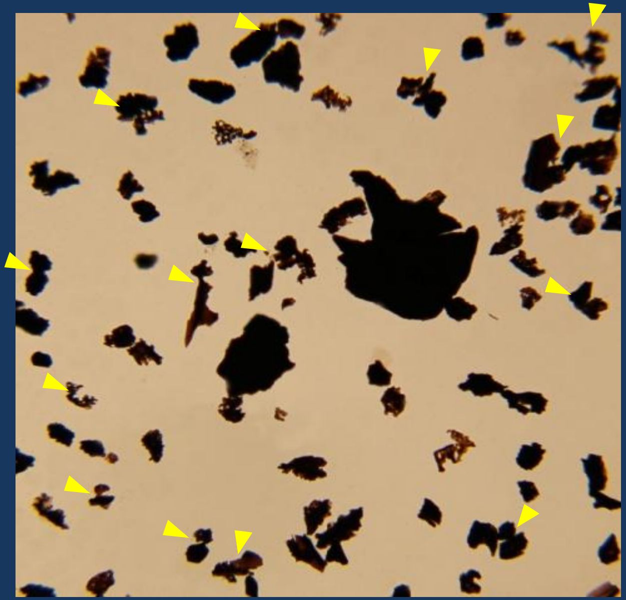
- Palaeoenvironment
- Transport history
- Depositional processes

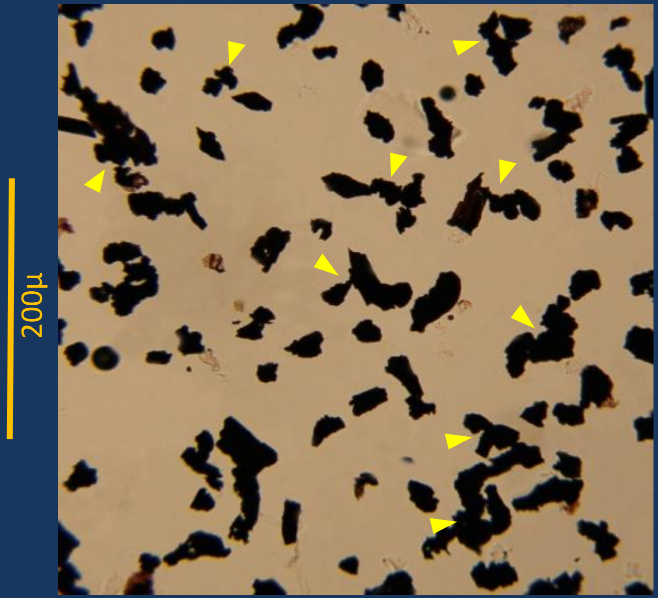
The size and shape of particles are recorded during sample analysis to provide data for interpretation of transport history and depositional processes



Hugin Formation, Early Callovian, NNS. Two samples from over 6000m. No identifiable palynomorphs. Phytodebris dominated by opaque equidimensional particles

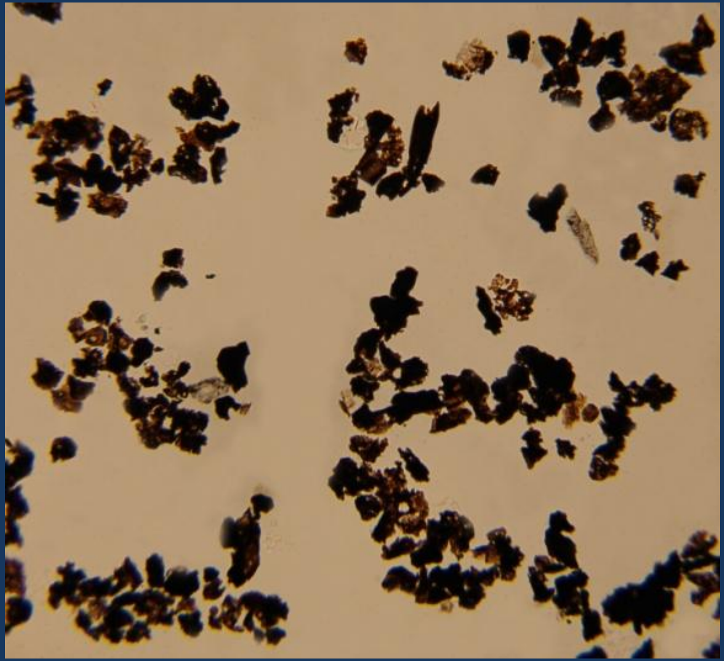
Linked cells





Hugin Formation, Early Callovian, NNS

"Clumping"?



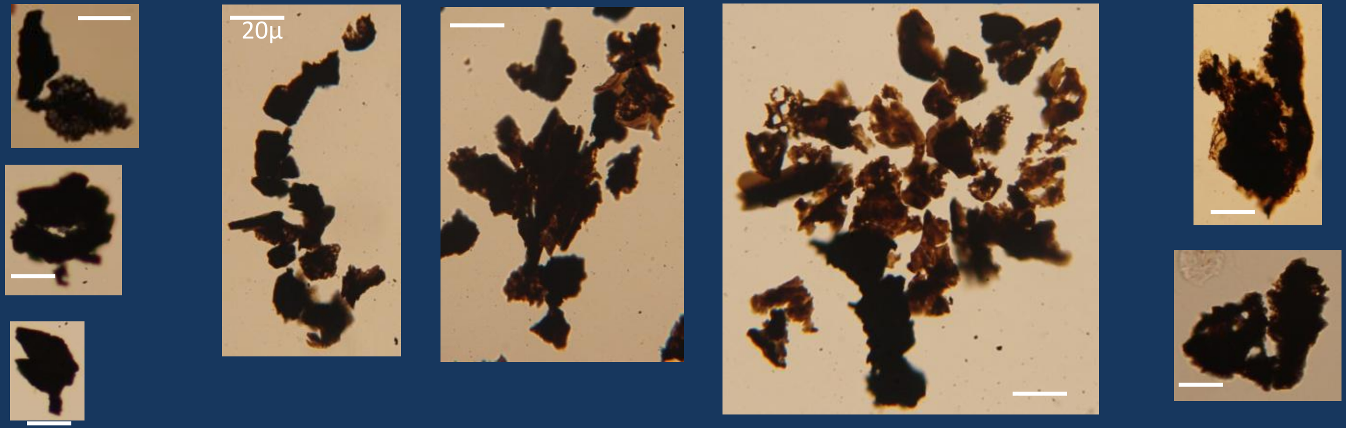
250μ

During sample processing, this "clumping" would be treated with deflocculant and ultrasonic (M. Jones PLS Ltd *pers com*)

but with minimal, or no ultrasonic....

Plant structures

leafy



bud

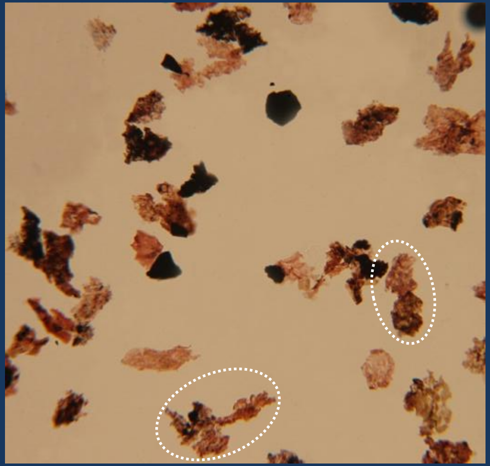
gemmae

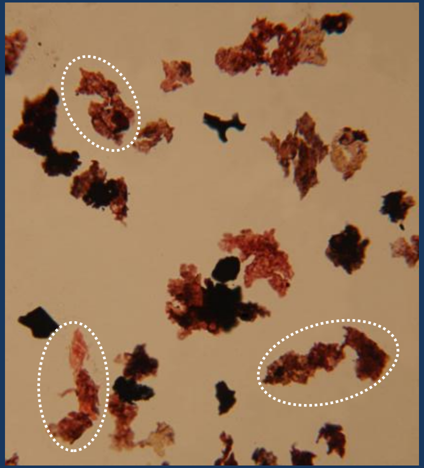
Not randomly broken debris, but component parts of larger plant/algal structures.

Individual phytoclasts retain original shape

Lower Draupne Formation (Kimmeridgian) , SVG

Phytoclasts mainly equidimensional; dominated by unstructured and semi-structured vitrinite, with secondary equidimensional opaques



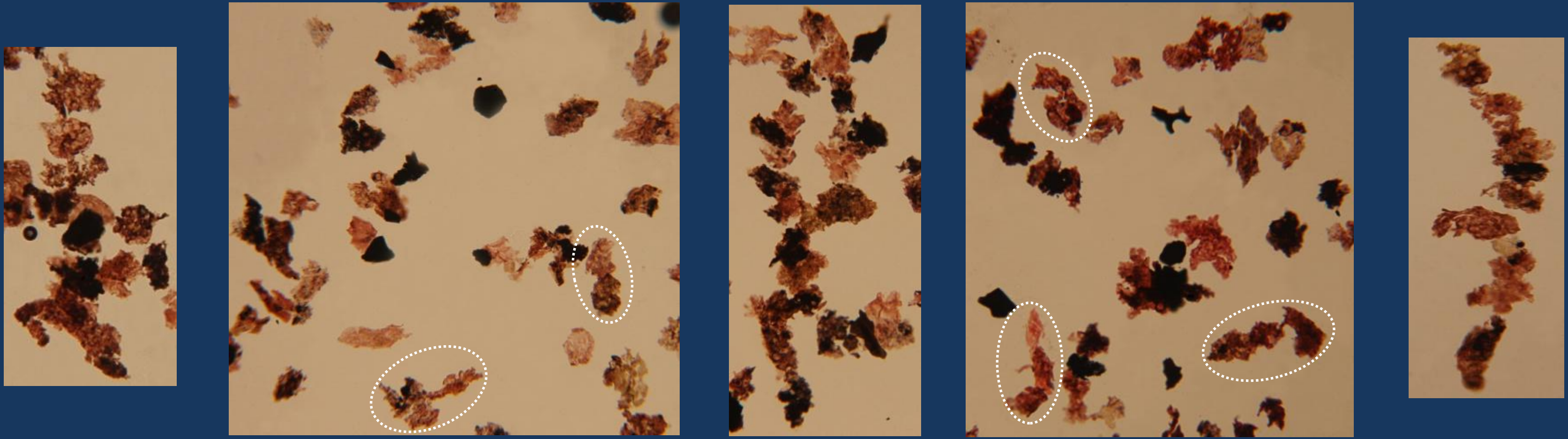


linked cells

500μ

Lower Draupne Formation (Kimmeridgian) , SVG

Phytoclasts mainly equidimensional, dominated by unstructured and semi-structured vitrinite, with secondary equidimensional opaques

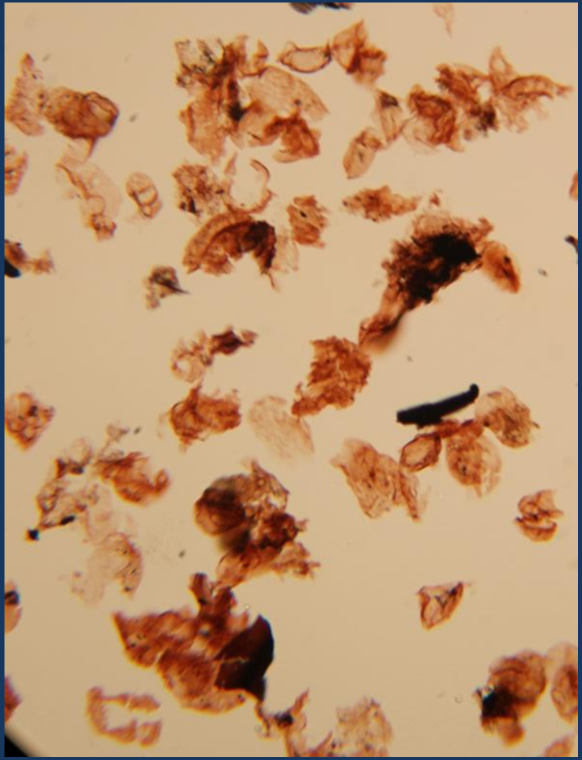


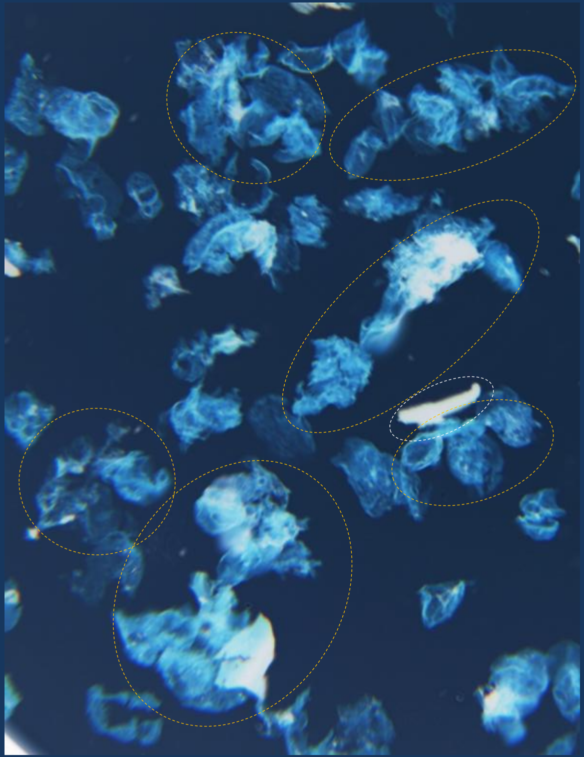
linked cells from branching shoots

500µ

Most are component cells from larger branching structures and retain original shape.
Same proportion of vitrinite & opaques in branches & disaggregated debris
Little or no randomly fragmented phytoclasts

Upper Draupne Formation (Berriasian), South Viking Graben





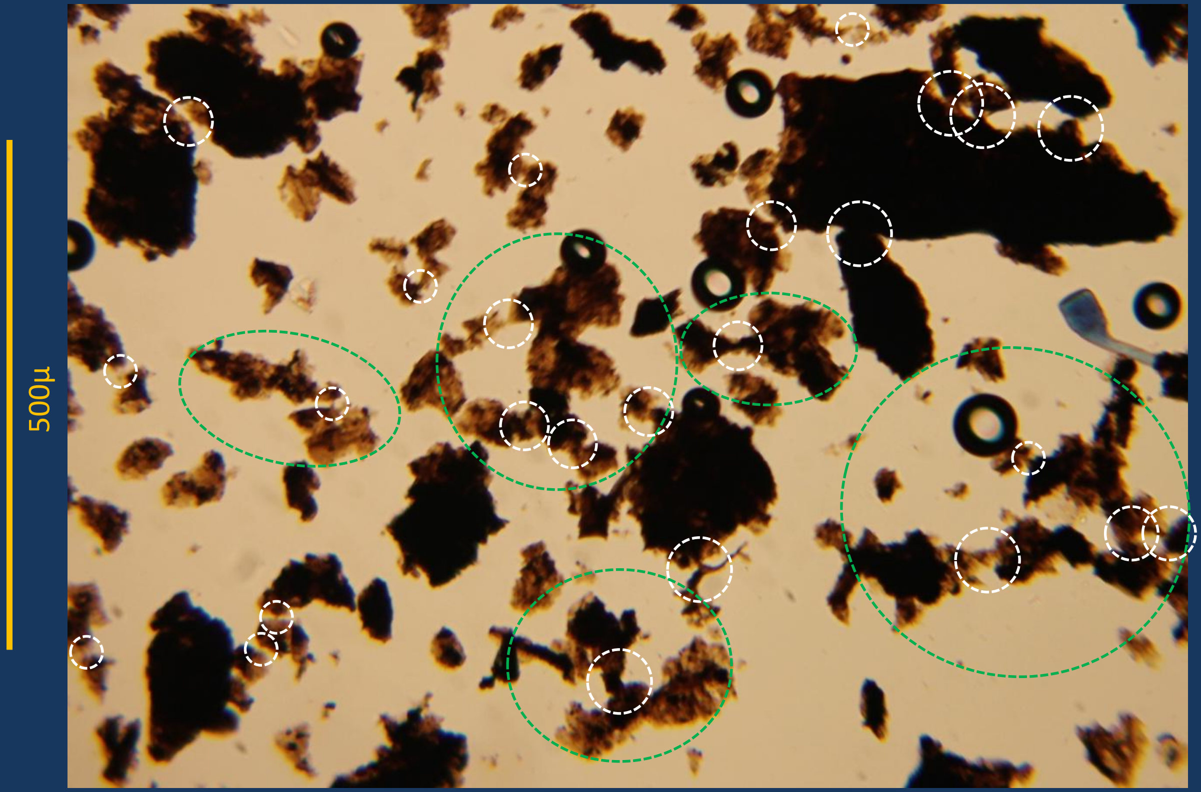
Leafy shoots with similar habit

Virtually everything in the field of view is a constituent piece, or unit of a larger organism.

Almost no randomly fragmented plant debris or AOM (oxidised sample).

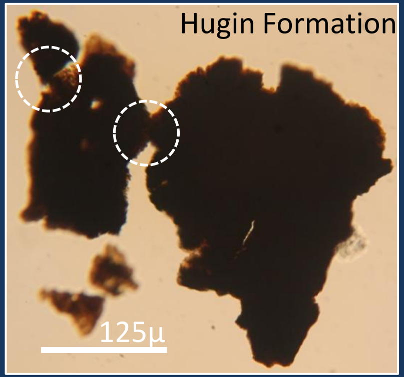
250µ

Heather Formation (Late Oxfordian), Viking Graben



Phytodebris dominated by thalloid structures, often linked in life position. Note similar growth pattern exhibited in linked sections. Many of the smaller isolated phytoclasts are propagules, probably derived from the same organism. Very few randomly fragmented phytoclasts.

see also Garel *et al* 2017, Fig 4B, Batten 1983, Figs. 7, 25, 26



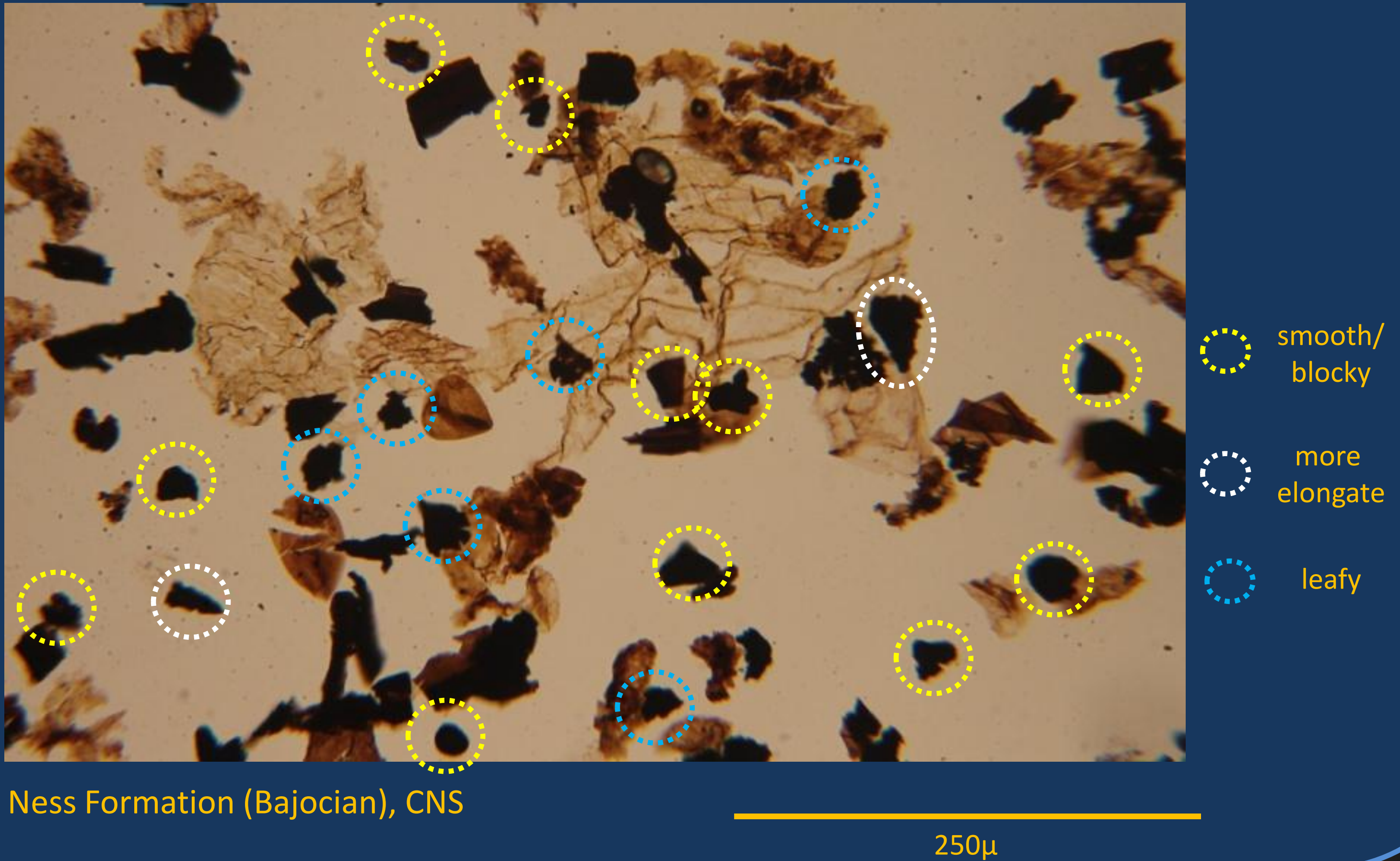
linkage or stalk

similar habit of linked sections

What are these phytoclasts?

- Antheridia/archegonia-like cells of lower plants: “opaques”
- Thalloid gametophytes /prothalli of lower plants
- Leafy shoots, leaves and underleaves of liverworts
- Propagula of liverworts & mosses
- Thalloid phytoclasts & thalloid plant structures
- Other isolated or incomplete plant/algal structures
- Randomly fragmented plant debris , i.e. “normal” palynodebris

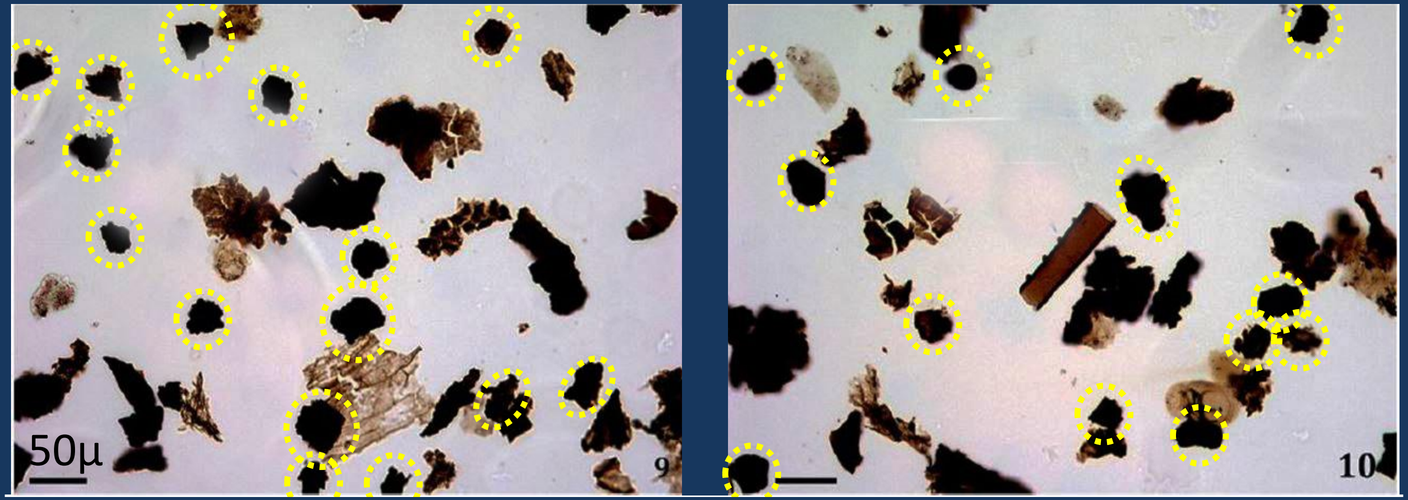
Small equidimensional opaque phytoclasts = antheridia-like cells



Ness Formation (Bajocian), CNS

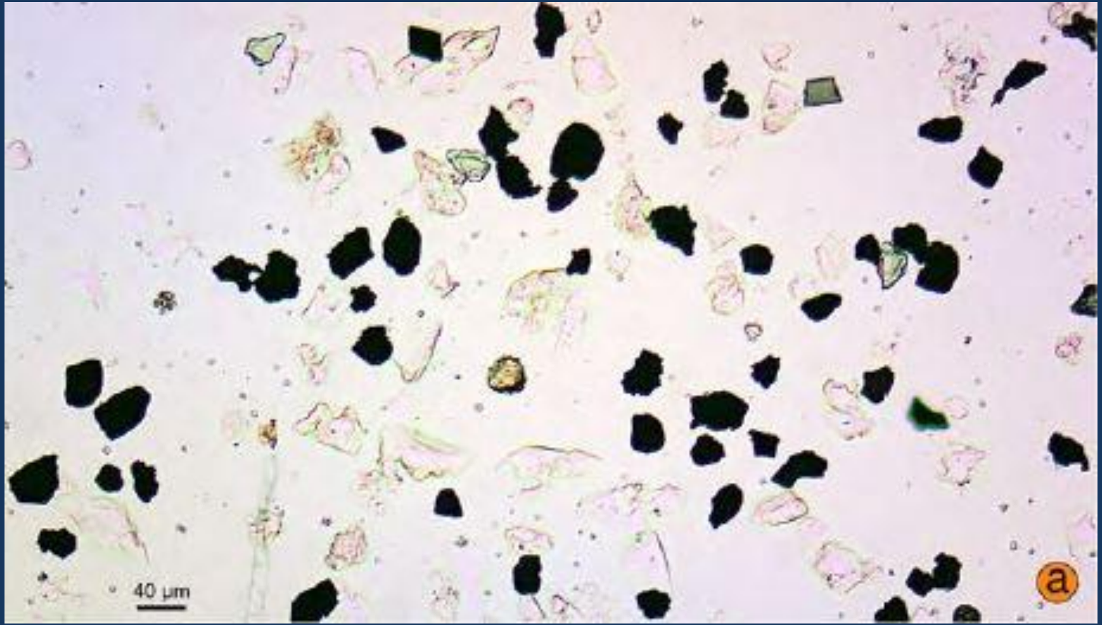
Small equidimensional opaque phytoclasts – ubiquitous!

visible in many illustrations from previous palynofacies publications

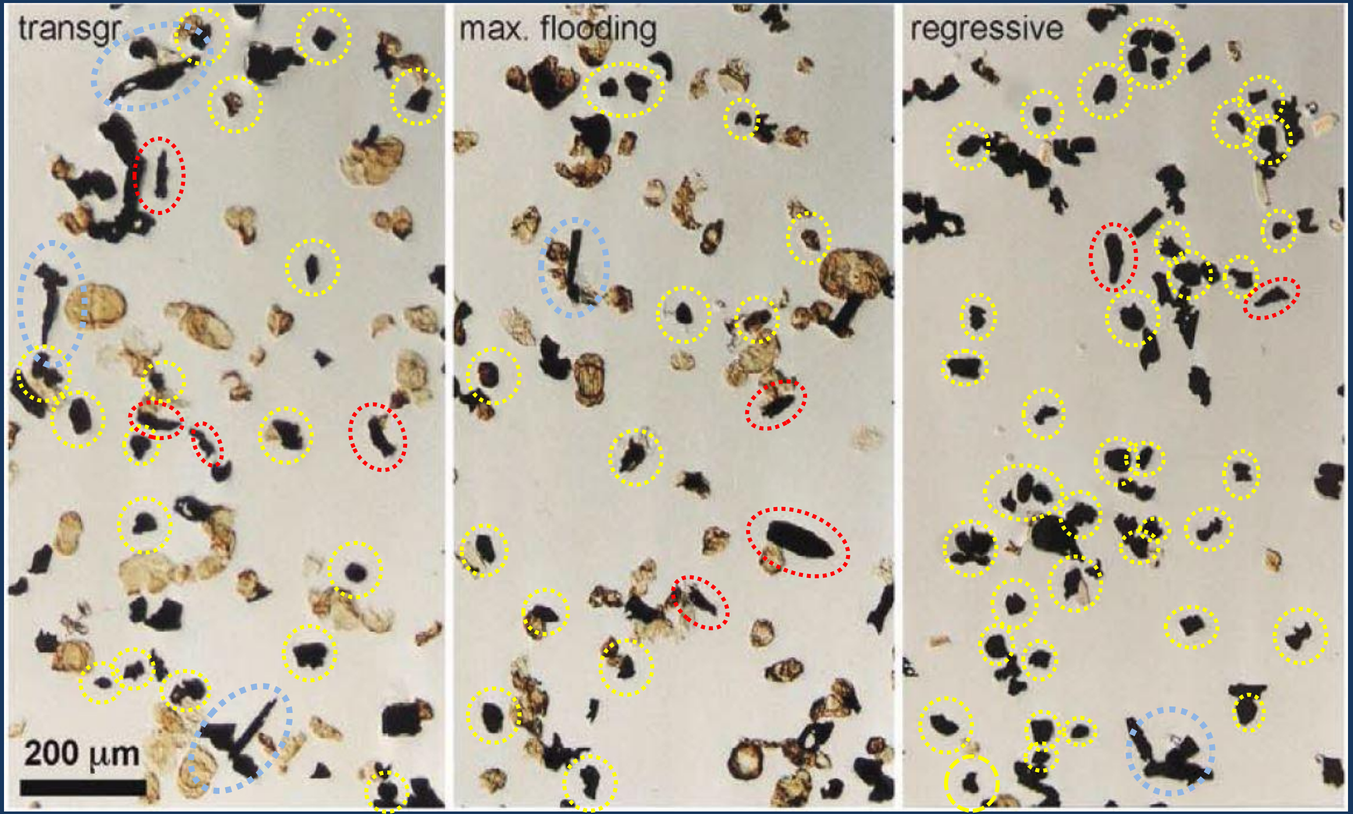


Palaeogene, USA (Zobaa *et al* 2011, Pl. III, figs 9,10)

Small equidimensional opaques are commonly abundant and are often the dominant phytoclast in palynofacies samples



Eocene of Egypt, Wanas *et al* 2015 Fig 9a



Rameil et al 2000 Plate 29b

Not highlighted every example .

Most, possibly all of the other opaque phytoclasts are also constituent cells and retain their original shape.

equidim

elongate

similar habit

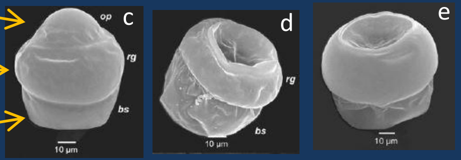
antheridia male reproductive organ in algae, mosses, ferns, fungi & primitive gymnosperms

Martinez *et al* 2013, Figs 4c-e

opercular cell

ring cell

basal cell



extant fern antheridia

operculum

opercular cell

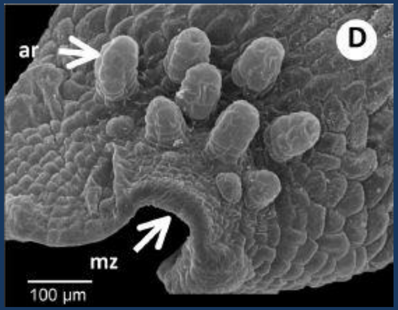
ring cell

basal cell

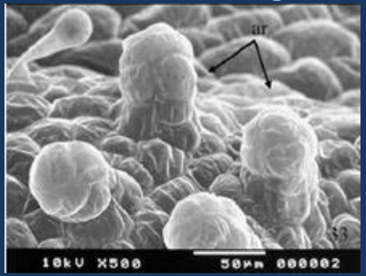
Sleipner Fm

archegonia female reproductive organ in mosses, liverworts, ferns & primitive gymnosperms

Castrejón-Varela *et al* 2018, Fig. 2D

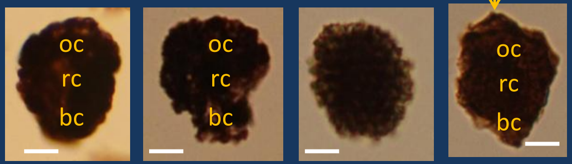


de León *et al* 2008 Fig. 33



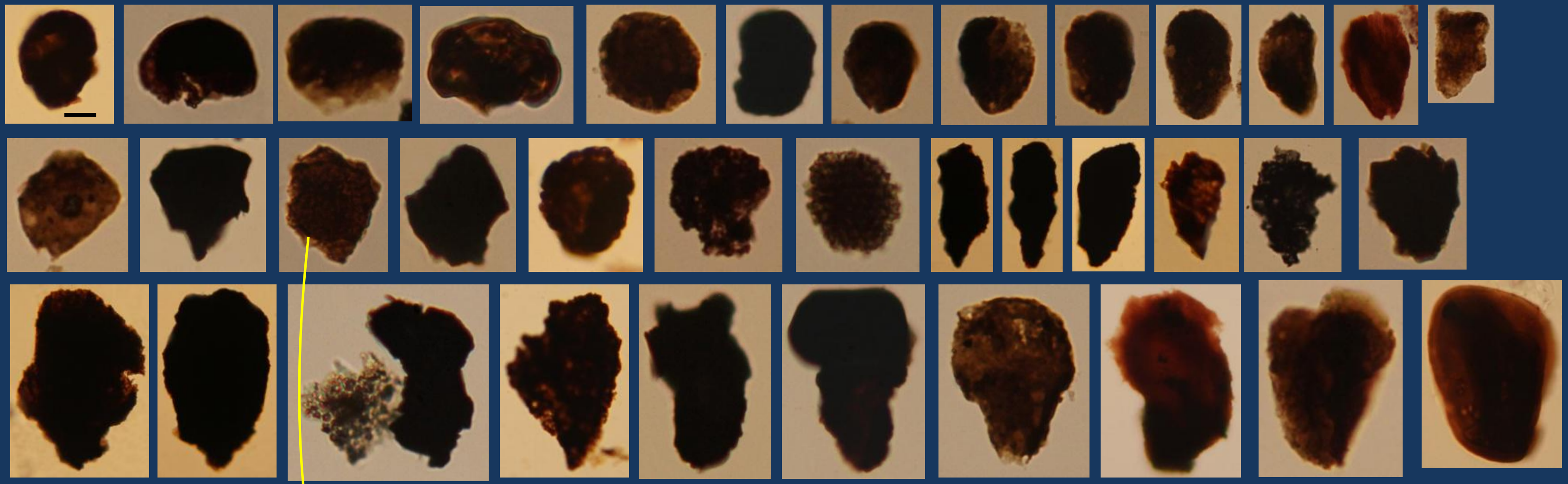
extant fern archegonia

operculum?

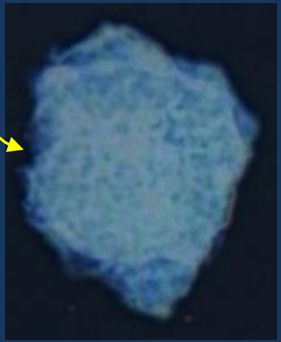


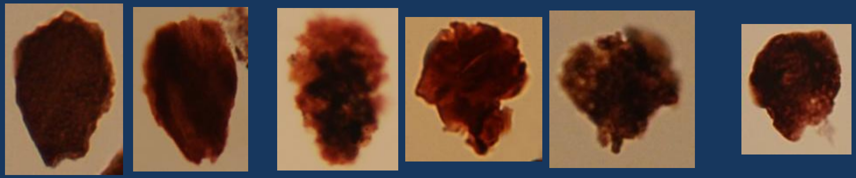
Sleipner Fm

More examples of antheridia-like opaque phytoclasts

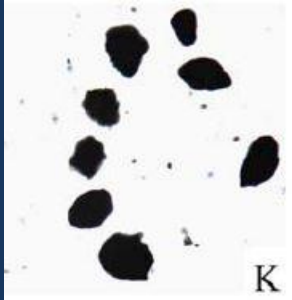


20μ all except



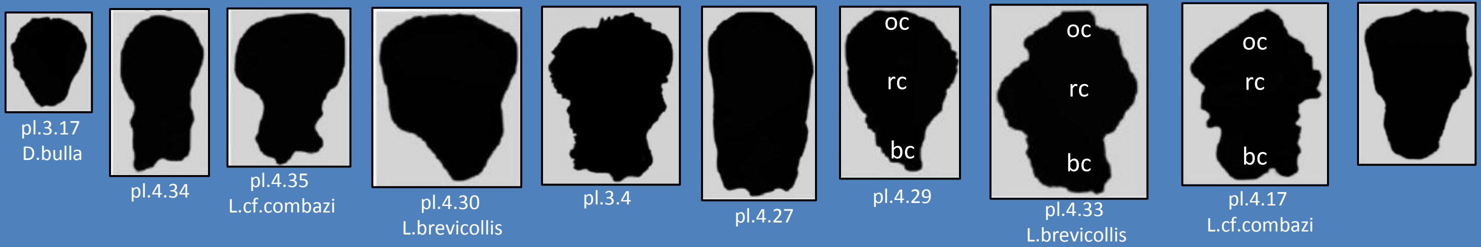


antheridia-like opaque phytoclasts retain their original shape



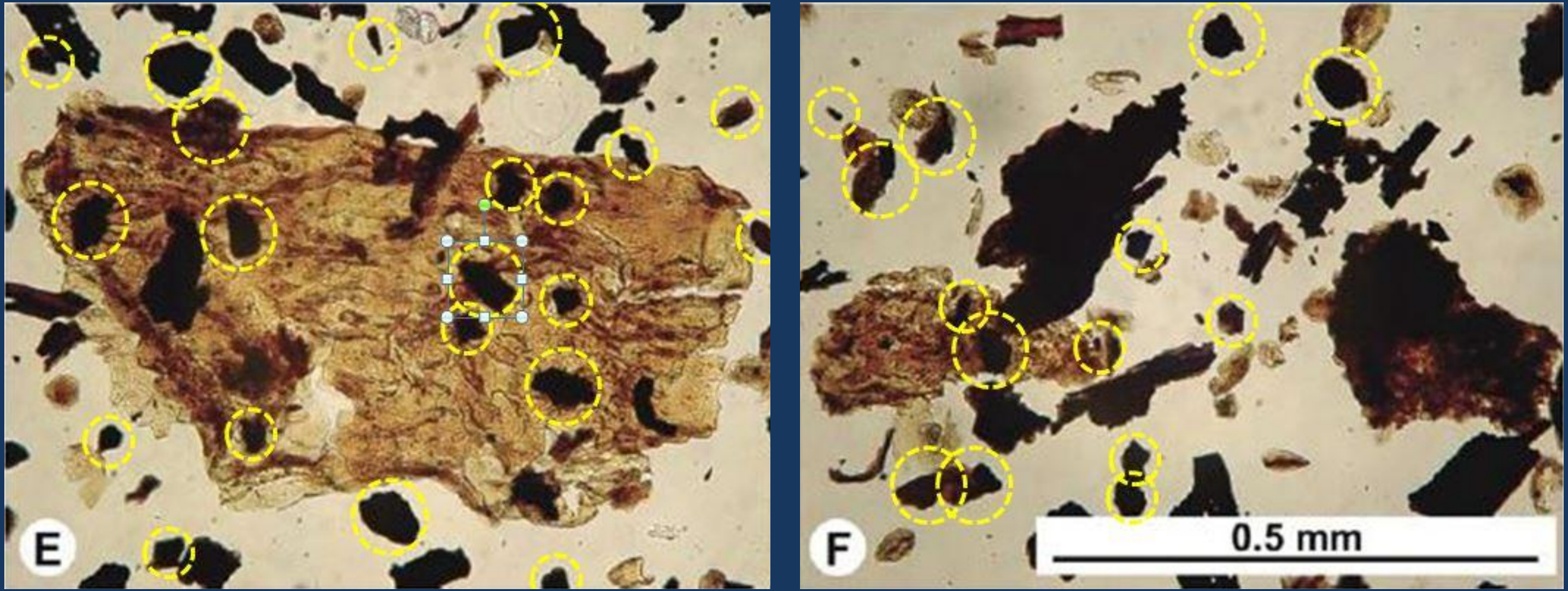
Jianguo & Zhenyu 2007 pl 1 fig K (part): "black phytoclasts with more or less rounded angular, indicating reworking or long distance of transportation"

"The opaque phytoclasts are derived from the oxidation of woody materials either during prolonged transport or post – depositional alteration" Ater-Peters *et al* 2013, p. 41



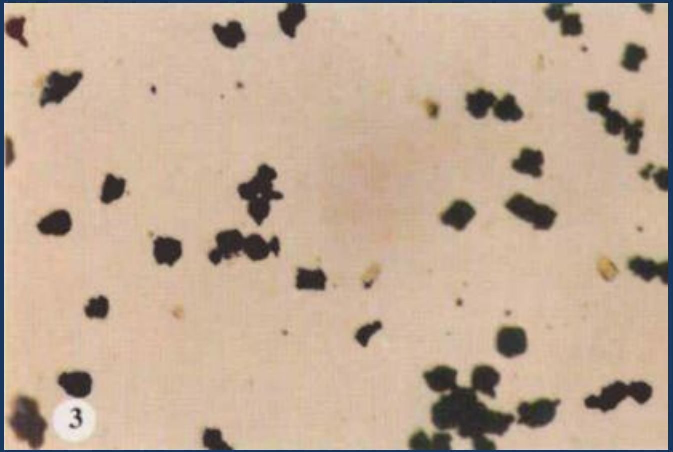
Olaru 2005, Ordovician of Romania (as chitinozoa)

Abundant antheridia-like phytoclasts

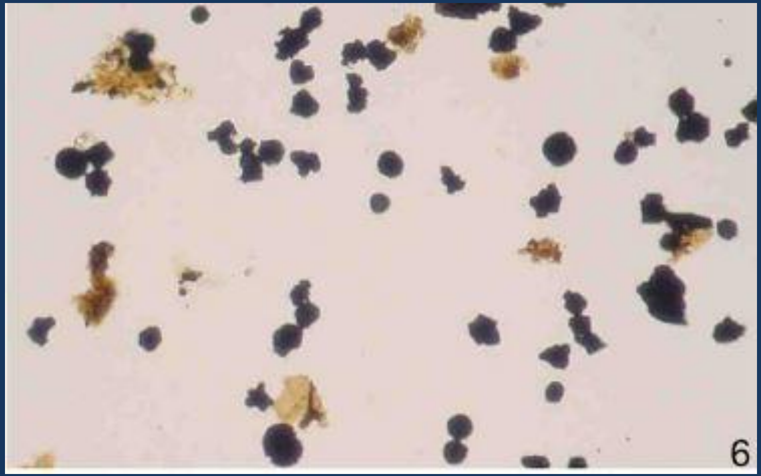


Gedl & Ziaja 2012 Figures 4E, 4F

Abundant antheridia-like phytoclasts



Ibrahim *et al* 1997 Pl 3, fig 3. Jurassic-Lower Cretaceous, Egypt (framboidal pyrite)

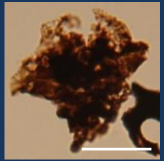


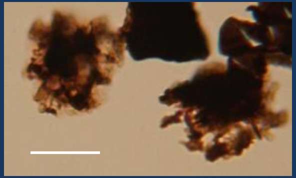
Cirilli *et al* 2015 pl, III fig 6. Upper Triassic, Italy (inertinite)

Also commonly catergorised as charcoal
 e.g. Zhu *et al* 2014, fig 2.17

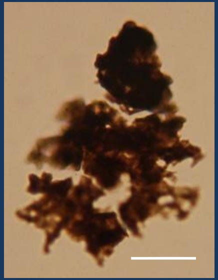
examples of other opaque phytoclasts

gemmae?





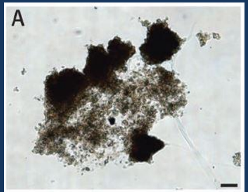
liverwort leaf bud?



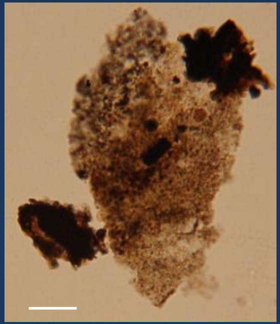
bar = 20µ

all Jurassic, NNS

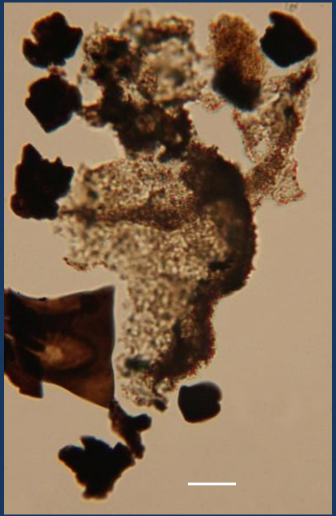
except



Gadens Marcon 2014a, Fig. 5A



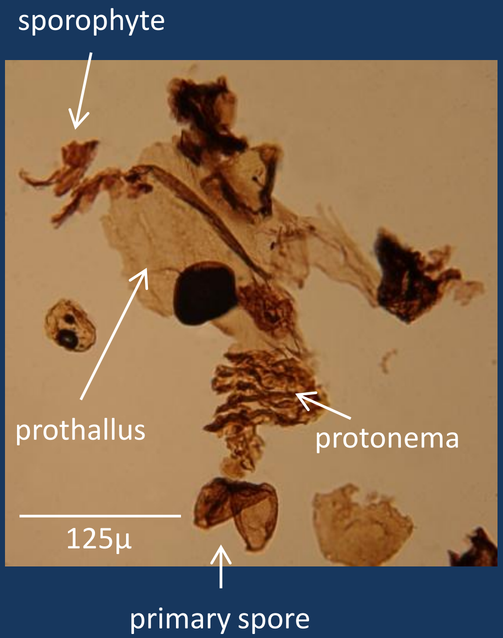
fruiting structures with multiple opaque cells

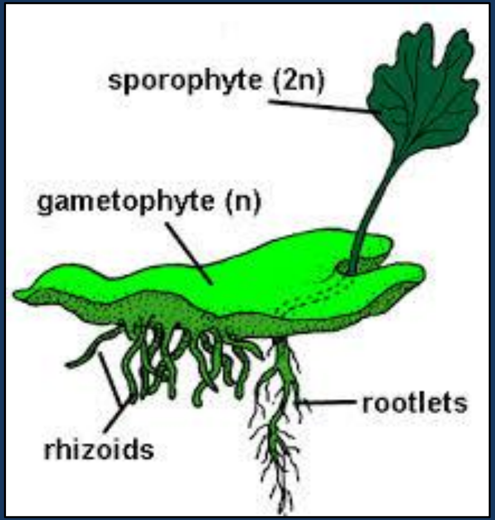


see also page 26

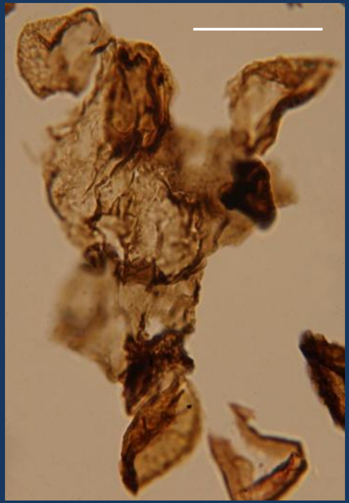
Thalloid gametophytes /prothalli of lower plants

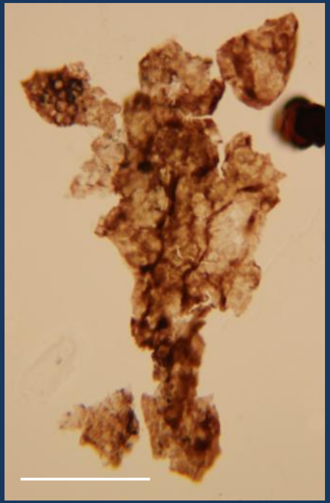
Thalloid gametophytes





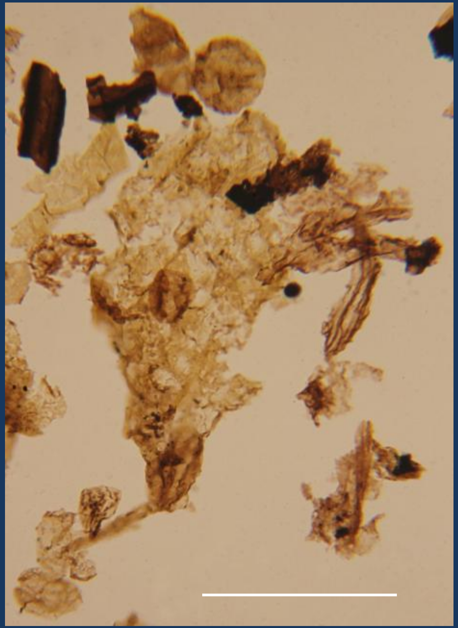
Thalloid gametophytes?

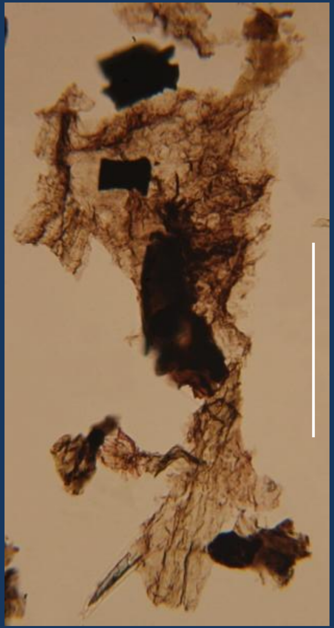




bar = 125µ

Thalloid gametophytes - ?bryophytic

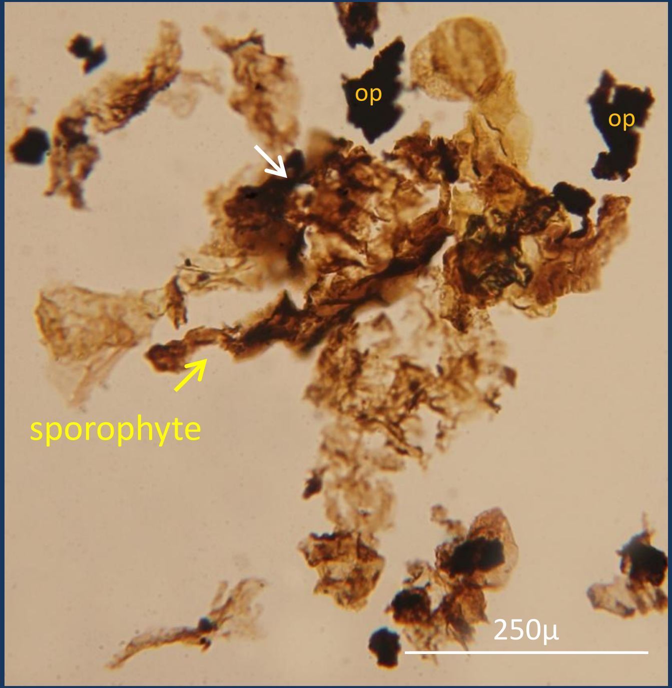


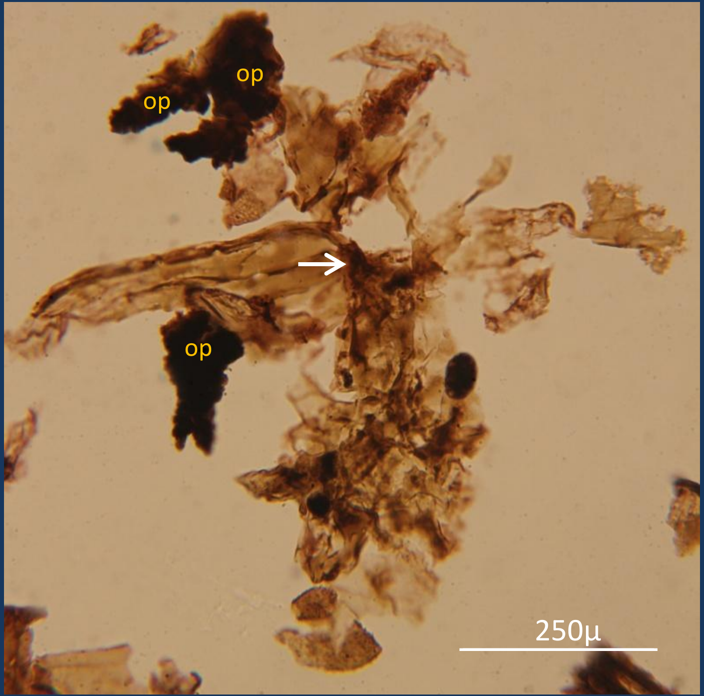


In bryophytes the gametophyte is the dominant generation
and is a self-sustaining, often complex organism

bar = 250µ

Thalloid gametophytes - ?bryophytic



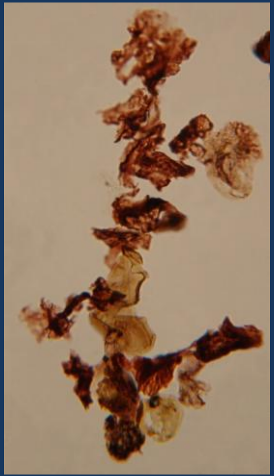


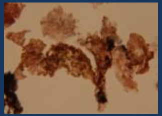
op = large irregular opaque cells → = centre of radiating structure

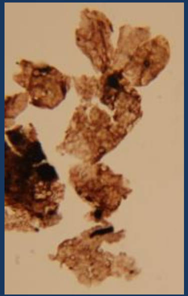
Leafy shoots, leaves and underleaves of leafy liverworts

Shoots of leafy liverworts.

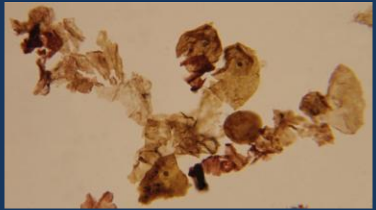
Leafy shoot of extant *Microlejeunea ulicina*.www.bbsfieldguide.org.uk





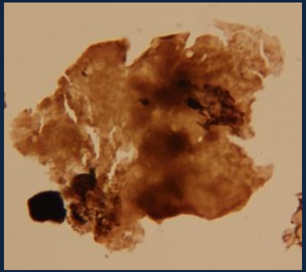


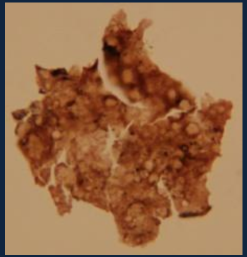
250µ

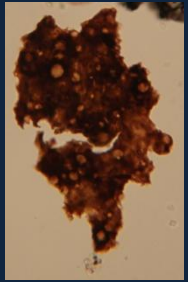


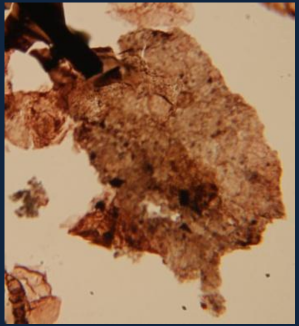
Jurassic, NNS

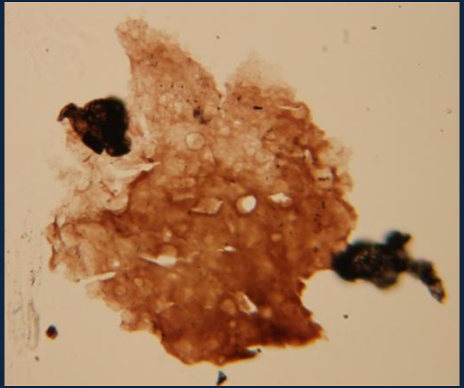
Underleaves of leafy liverworts





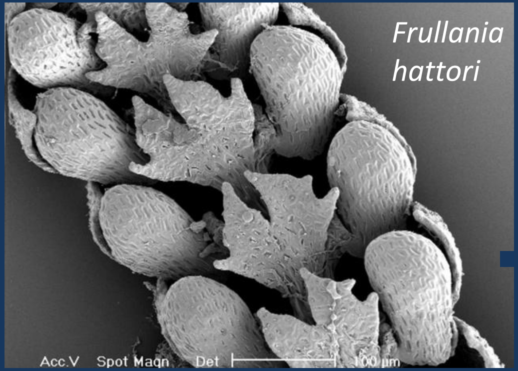




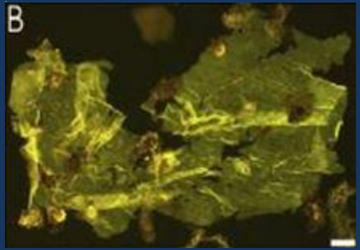


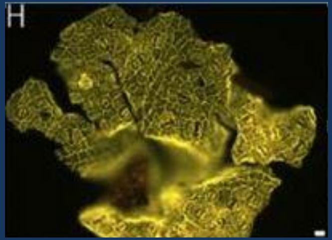
Underleaves of Jurassic Frullaniaceae

250µ

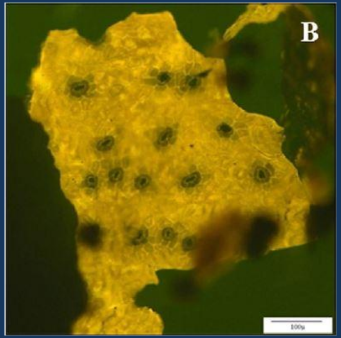


www.discoverlife.org photo: Matt von Konrat





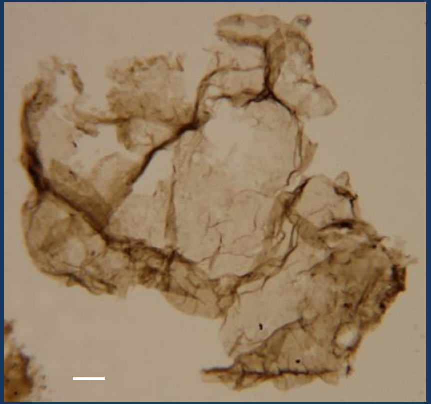
Gadens-Macon *et al* 2014, Figs 7B, 7H
(membrane & cuticle)

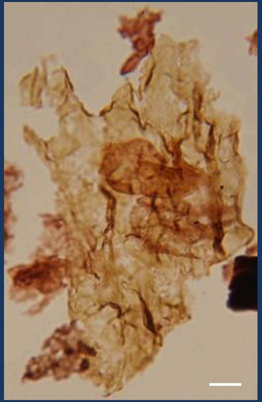


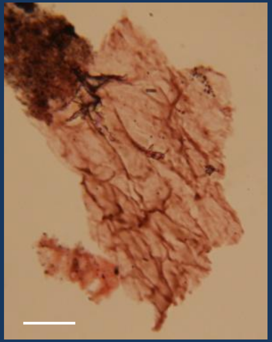
Goncalves et al 2015 Fig 4B
(cuticle)

Underleaves of leafy liverworts

Late Triassic-Early Jurassic



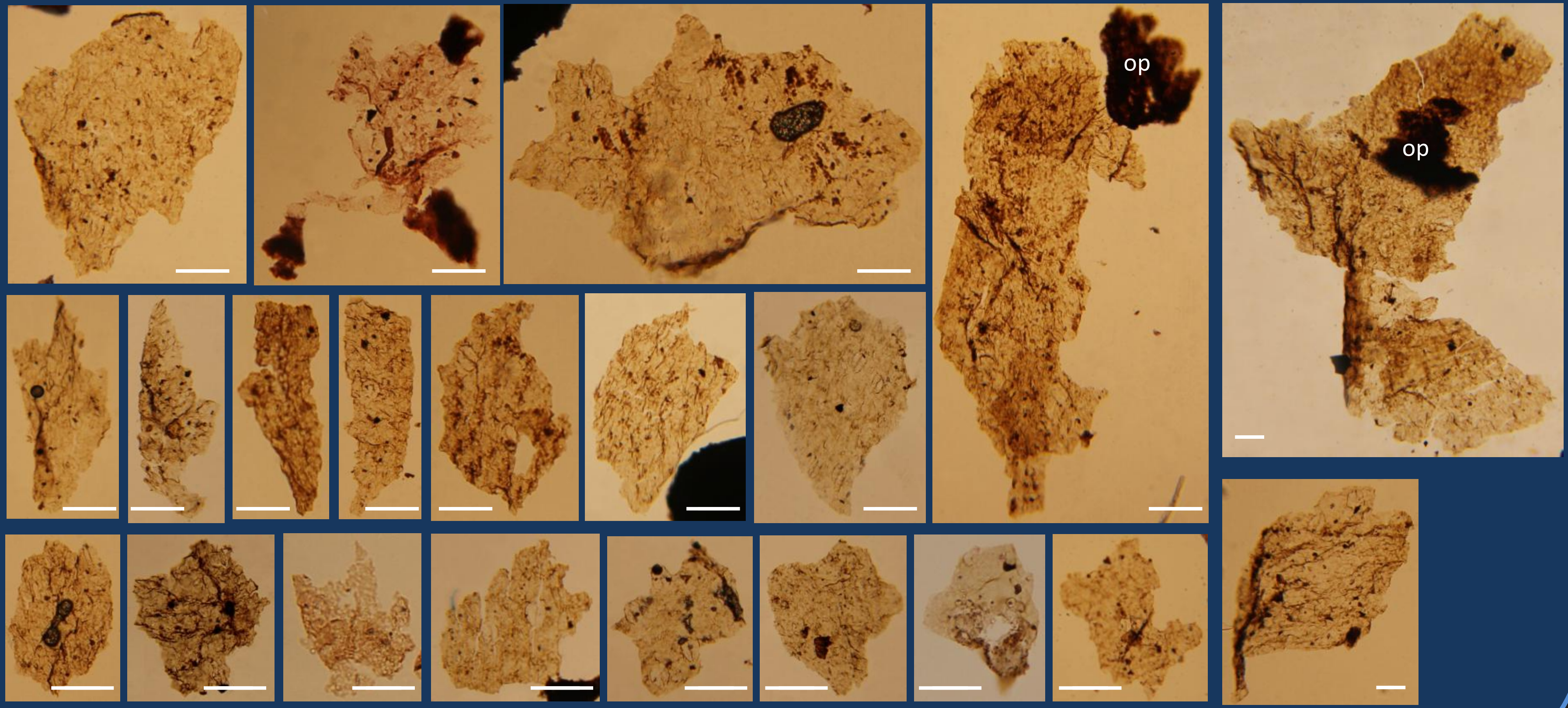




bar = 20µ

★ margin of phytoclast independent of internal structure ★

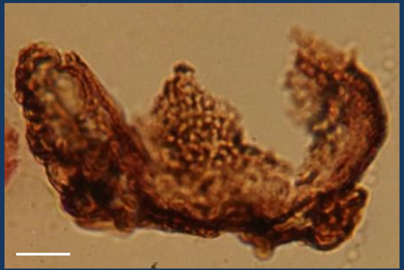
Leaves and underleaves of Middle Jurassic liverwort. Sleipner Fm



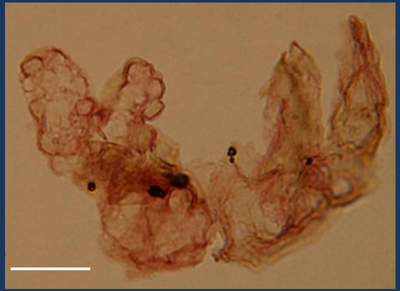
bar = 50µ

specimens from 125µ + slide

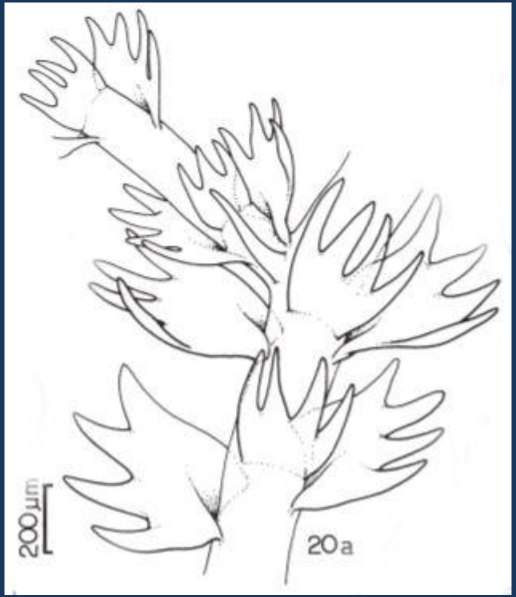
Underleaves of leafy liverworts



bar = 20µ

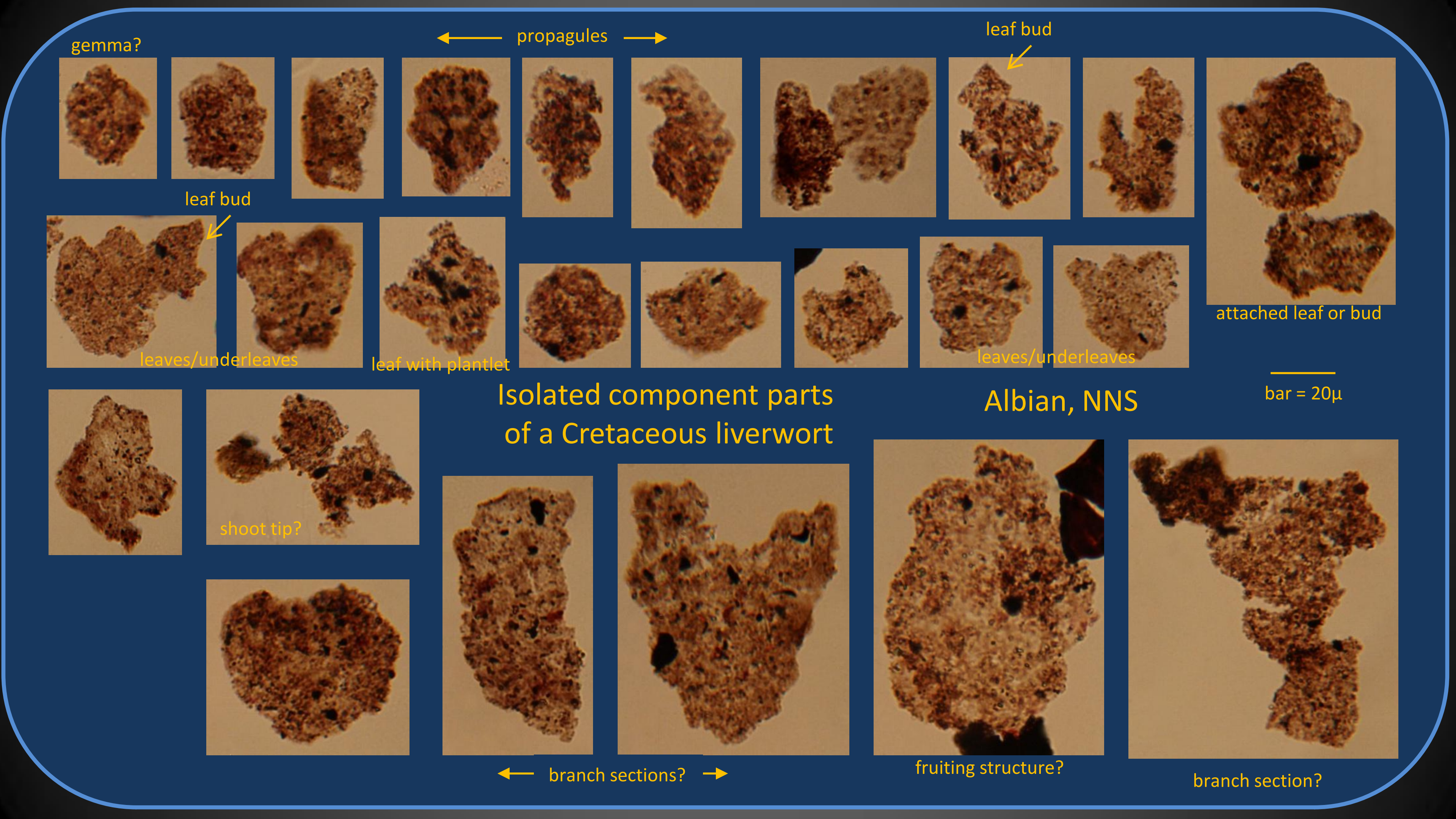


Jurassic *Lepidozia* –type leaves

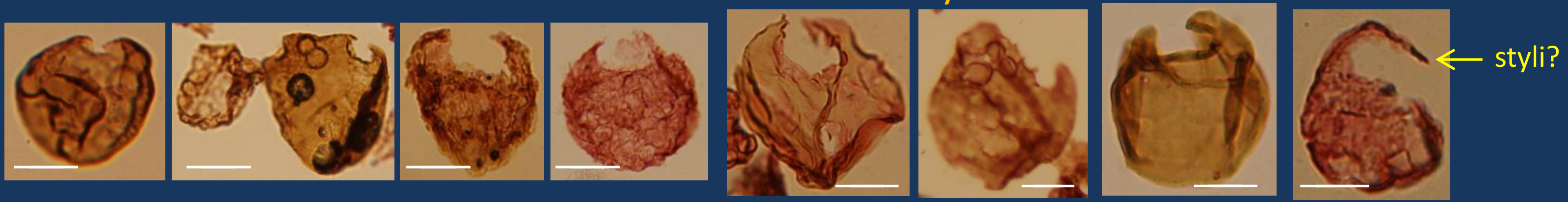


Lepidozia cupressina (extant liverwort)

de Brito Valente & Pôrto 2006, Fig. 20a

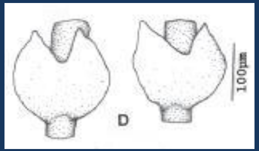

gemma?
propagules
leaf bud
leaf bud
leaves/underleaves
leaf with plantlet
leaves/underleaves
attached leaf or bud
Isolated component parts
of a Cretaceous liverwort
Albian, NNS
bar = 20µ
shoot tip?
branch sections?
fruiting structure?
branch section?

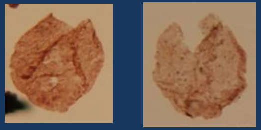
Stem leaves or dorsal lobes from Triassic –Jurassic leafy liverworts

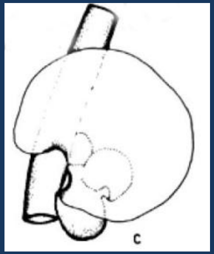


bar = 20µ

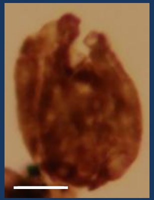
Cheilolejeunea aneogyna
Passos Bastos 2012 Fig.1 D





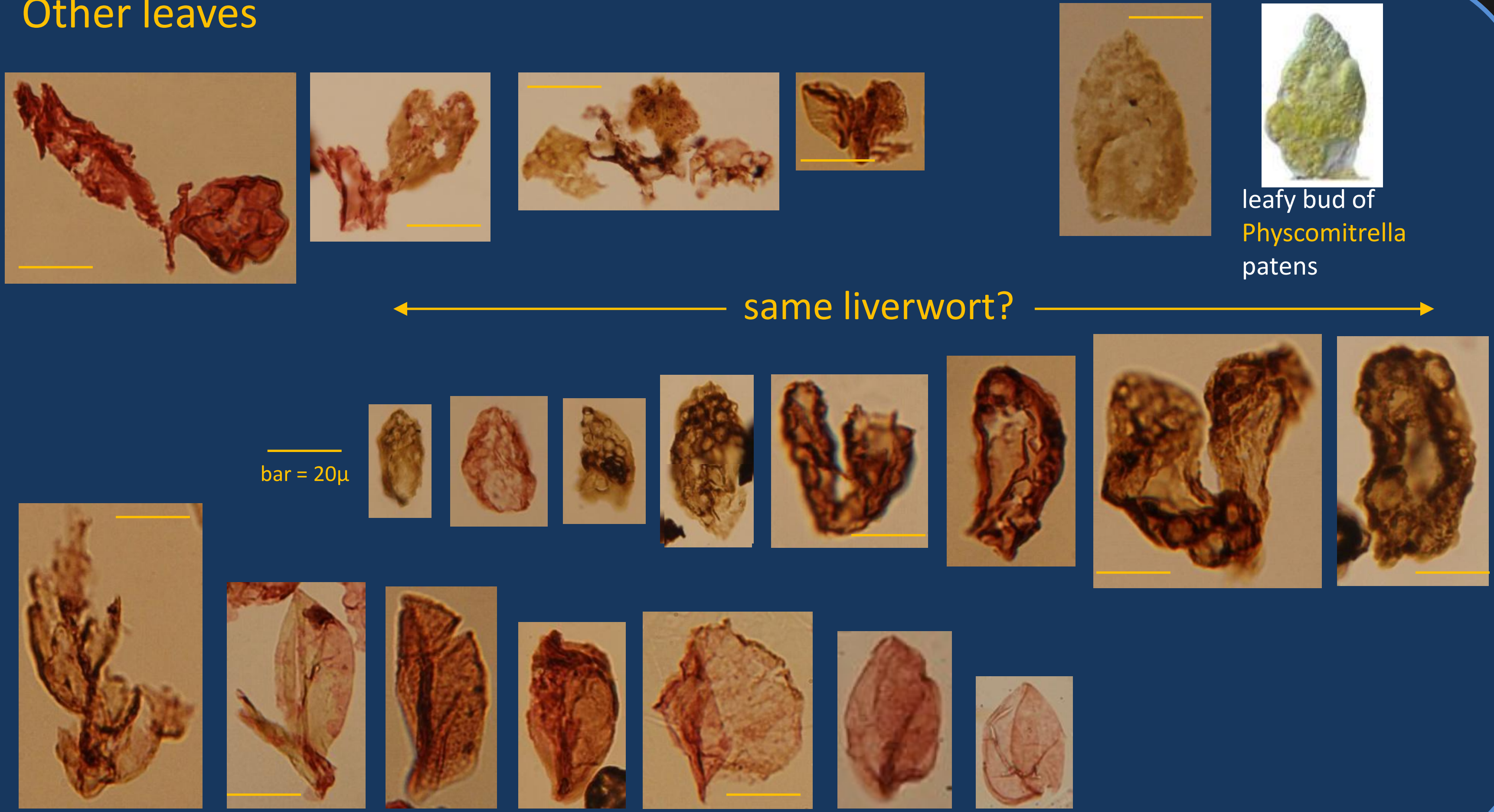


Stem leaf Gradstein & Uribe 2011 Fig 4C *Frullania*



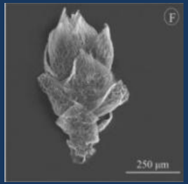
Dorsal lobe of leaf in *Frulliana calcarifera* Borovichev & Vilnet 2015, Fig 1.9

Other leaves



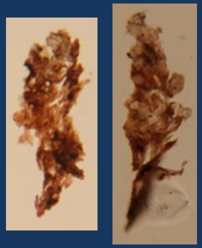
Propagula of liverworts & mosses.

Caducous vegetative propagules

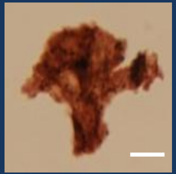


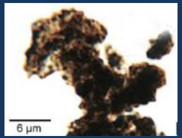
Peñaloza-Bojacá *et al* 2018 Fig 3F

bar = 20µ

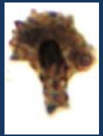


Isolated propagules; Triassic-Jurassic NNS



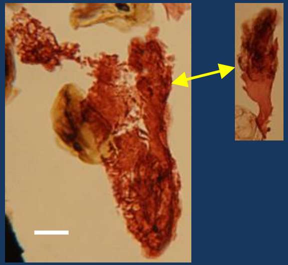


Mushroom-shaped algae Scwab *et al* 2013 Fig 4B



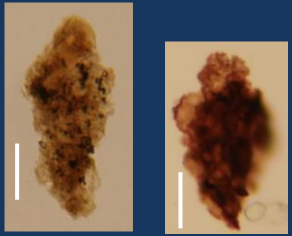
Interpreted as green algae. (Cenomanian), Texas

Broccoli-head algae Scwab *et al* 2013 Fig 4A



Attached propagules

AOM-like propagules

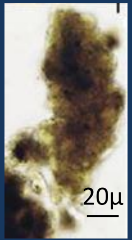


Jurassic, NNS

Singh et al 2015, fig 5e (saplopelic AOM)

Chirila & Tabara 2010, Pl II fig 2a (AOM)

Silva et al 2010 fig 3c (part) as (AOM)

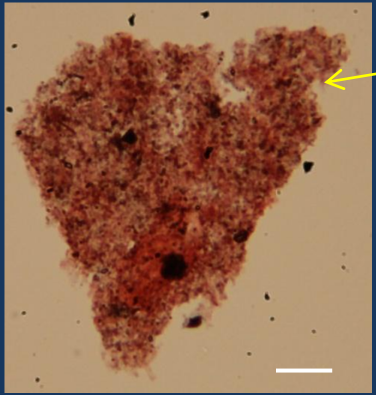


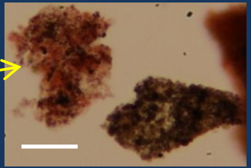
Koch et al 2017 fig 5f (AOM)

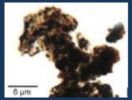
Stetten et al 2015 fig 4c (part, scale approx

AOM-like propagules

normally recorded as AOM
in palynofacies analysis





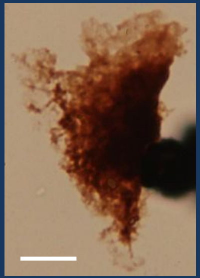


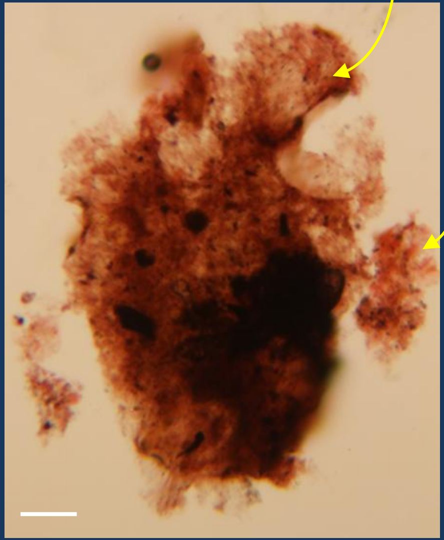
Mushroom-shaped
algae Scwab *et al*
2013 Fig 4B

Ibrahim *et* al 2002
Pl I3fig b (AOM)

see also Batten 1983, Fig. 24

normally recorded as AOM
in palynofacies analysis

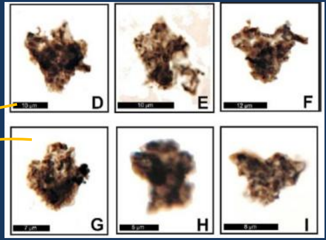




bar = 20µ

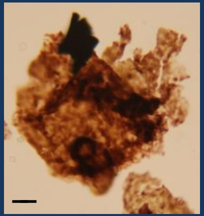
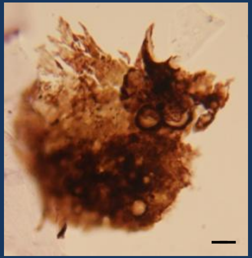
Propagule to fruiting structure?

Schwab *et al.* 2011, Pl 2, figs D-I







bar = 20µ

Draupne Formation (Kimmeridgian), SVG

Brynum dichotomum bulbil from leaf axils. Fig 93 in Glime 2014

Bulbils?

Rhizoid gemmae and rhizoid ?tubers of bryophytes

rhizoid gemmae
E Callovian, NNS

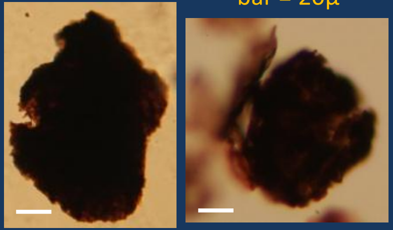
bar = 20µ

Bryum rubens (moss) rhizoidal tubers & rhizoidal gemmae
Koresby online

Ditrichum corbubicum rhizoidal tuber. Fig 105 in Glime 2014 (no scale).

?

bar = 20µ

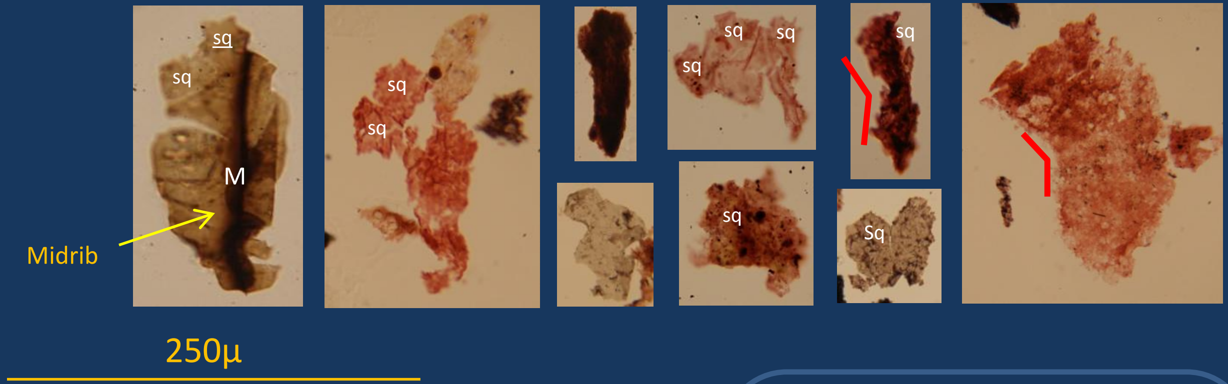


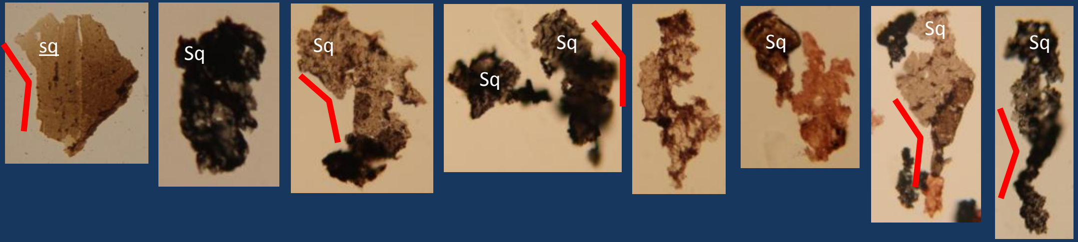
rhizoidal tubers?

Thalloid phytoclasts & thalloid plant structures

Thalloid phytoclasts; square cell & dog-leg

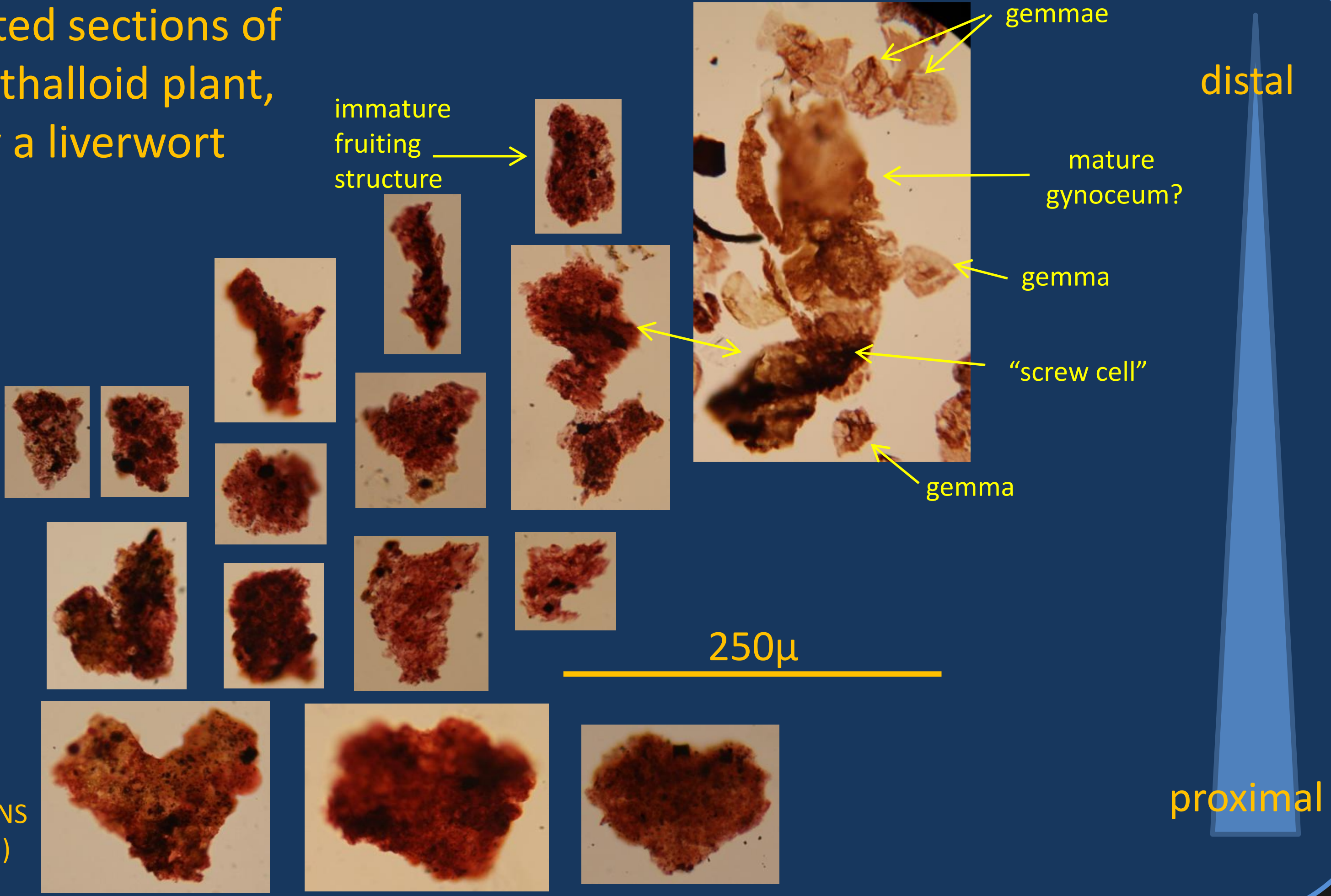
margin independent of internal structure





Olaru 2007, Ordovician of Romania (as Chitinozoa)

Disaggregated sections of branching thalloid plant, possibly a liverwort



Heather Formation, NNS
(Callovian - Oxfordian)

Thallus sections with attached spore-like cells - ?gemmae

bar = 20μ

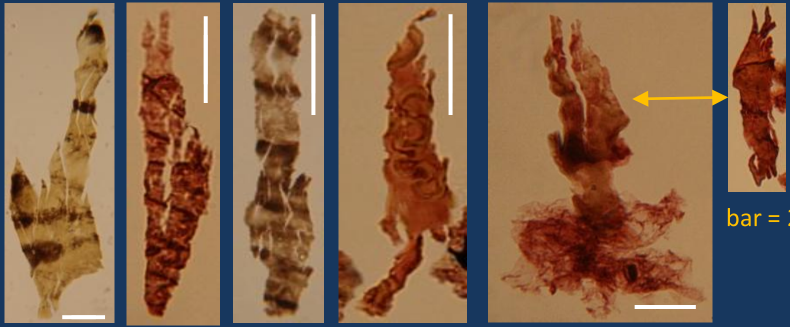
These sections of a thalloid organism would be interpreted as randomly fragmented structured vitrinite during palynofacies analysis.

Other isolated or incomplete plant/algal structures

Peristome teeth of mosses

http://blogs.ubc.ca/biology321

Early and Middle Jurassic

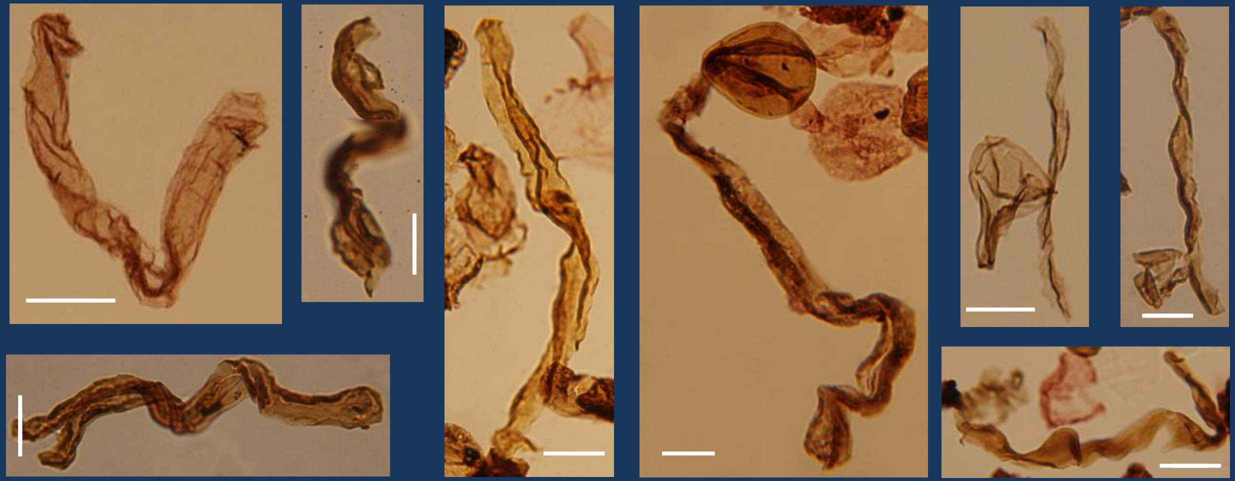


bar = 20μ

Palynofacies = lath-shaped structured vitrinite

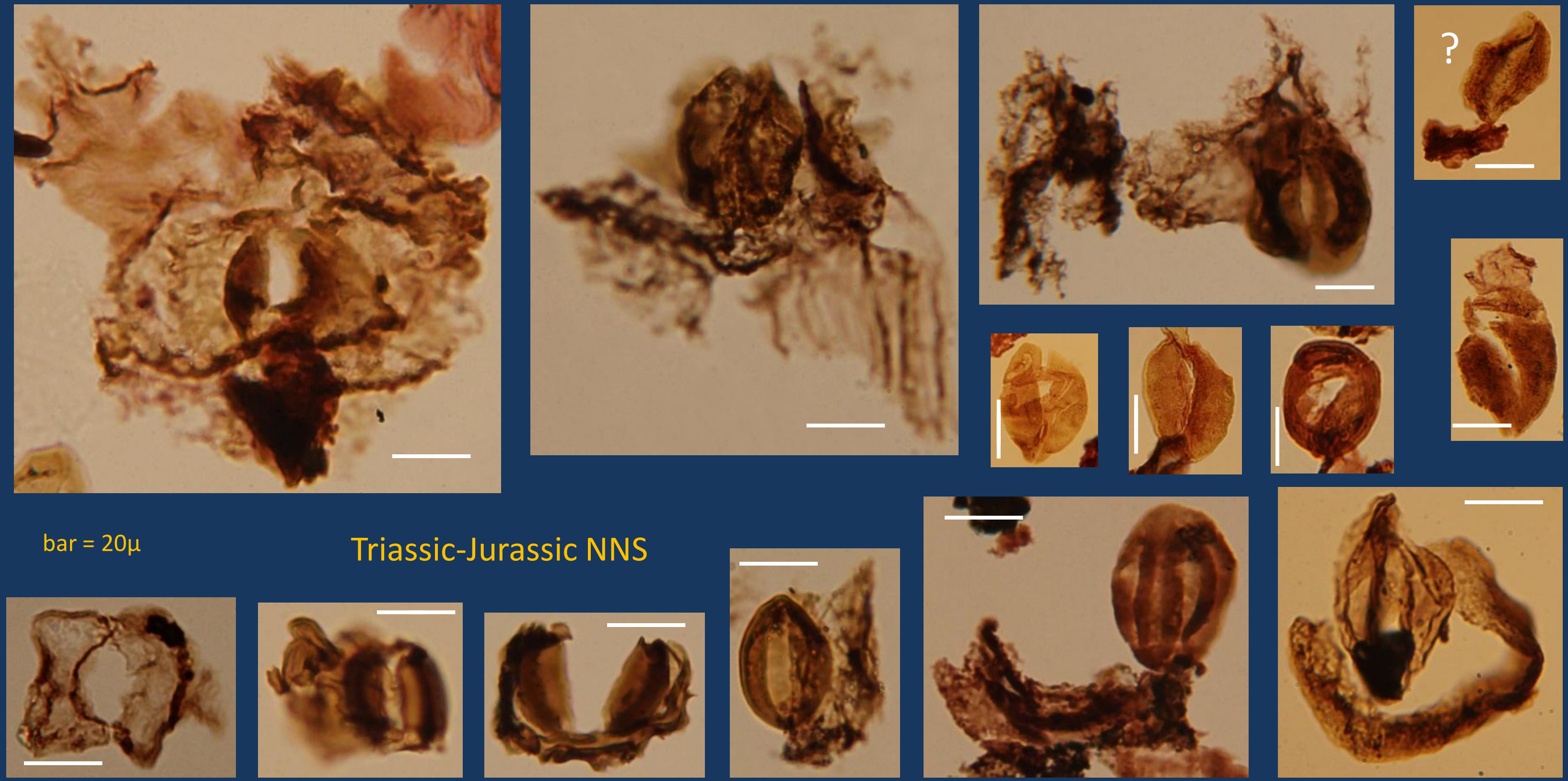
Pseudoelaters of hornworts

bar = 20µ



Occasionally with attached spores

Stomata

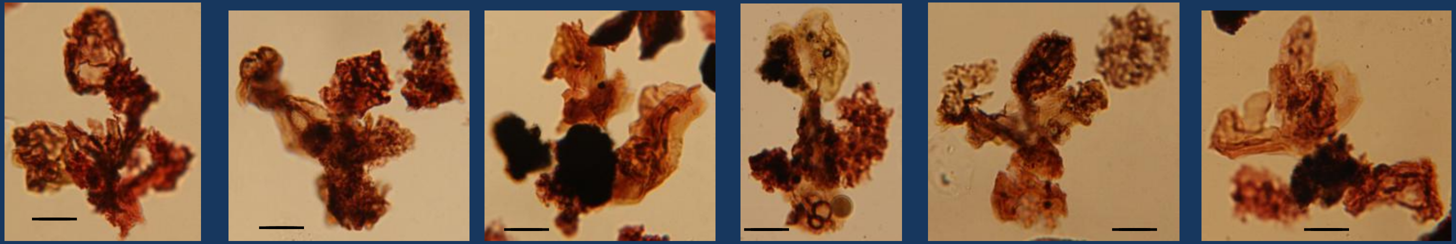


bar = 20µ

Triassic-Jurassic NNS

see also Pocock 1970, Pl 22, fig 2

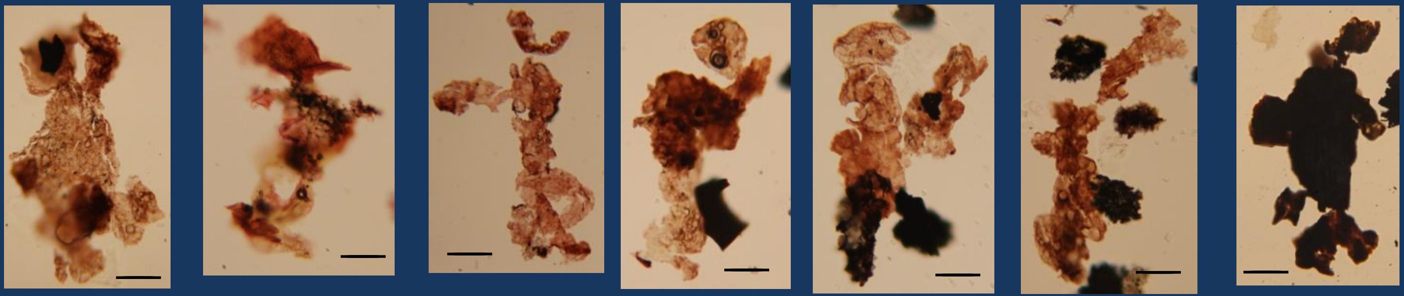
Incomplete structures from same plant-?liverwort



bar = 20µ

Sleipner Formation (Bathonian-Callovian), NNS

Incomplete plant structures from same plant

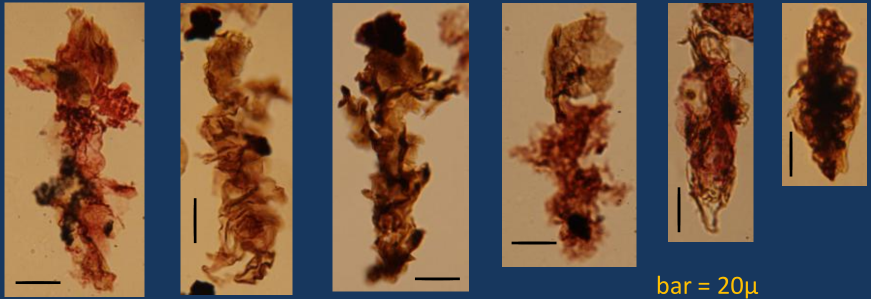


bar = 20µ

Heather Formation (Oxfordian), NNS

specimen recovered from over 6000m (barren of palynomorphs)

Incomplete plant structures from same plant?

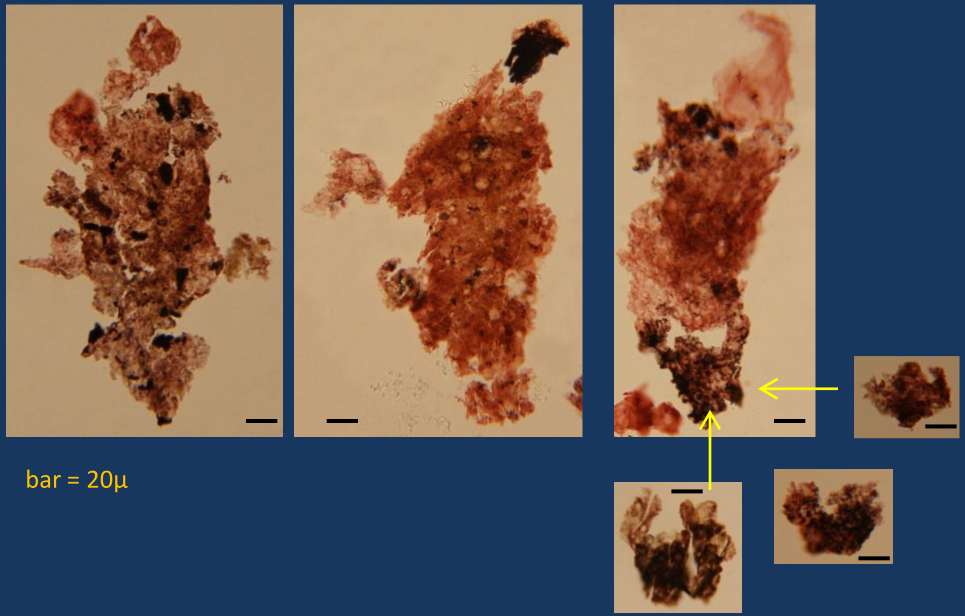


bar = 20µ

Hugin Formation (Callovian), NNS

Incomplete plant structures from same plant

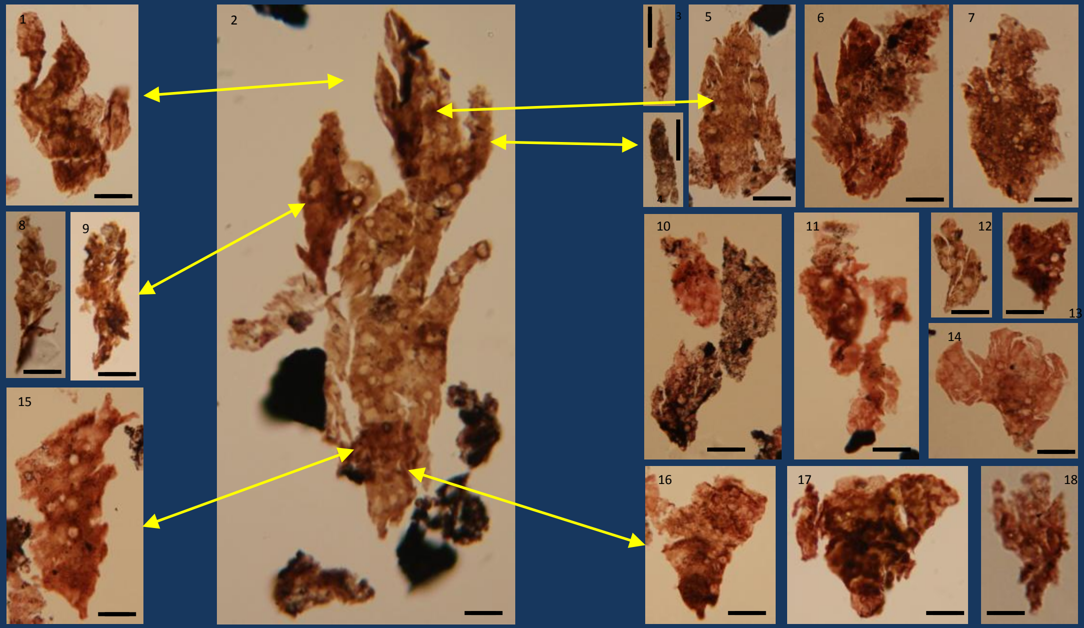
Heather Formation (Oxfordian), NNS



bar = 20µ

Probably same plant/alga as following page

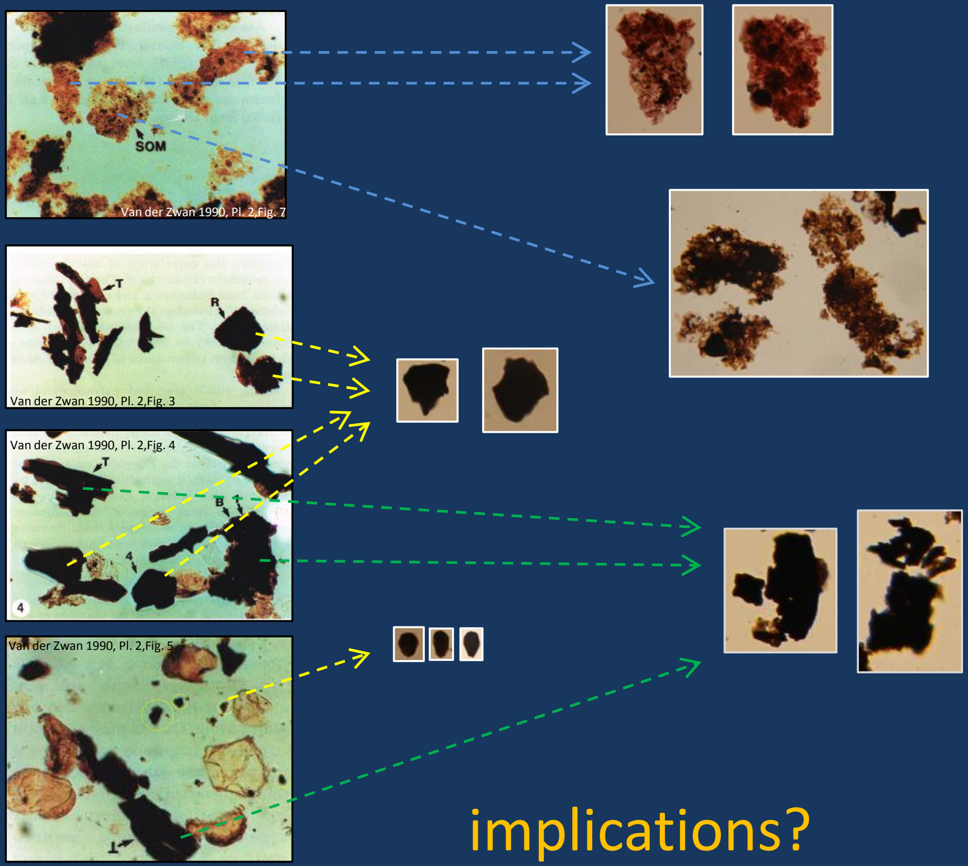
Partial plant reconstruction from fragments



Heather Formation (Oxfordian), NNS

bar = 20µ

Van der Zwan 1990



implications?

Implications for palynofacies analysis

- Palaeoenvironment: much more detailed info on plant affinities available
  need to re-evaluate counting procedures, categories etc.
- Transport history: NO! many phytoclasts retain original shape
- Depositional processes unaffected

Conclusions

- Substantial amounts of palynodebris previously overlooked as randomly broken plant fragments are constituent parts of larger organisms normally retaining original shape.
- 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.

Bailey, D.A. (*in prep*) New information on phytodebris in palynological and palynofacies samples from the Triassic to Cretaceous of the North Sea includes evidence of abundant bryophytes. *in* Cross-Border Petroleum Geology & Exploration: The North Sea. GSL Special Publications