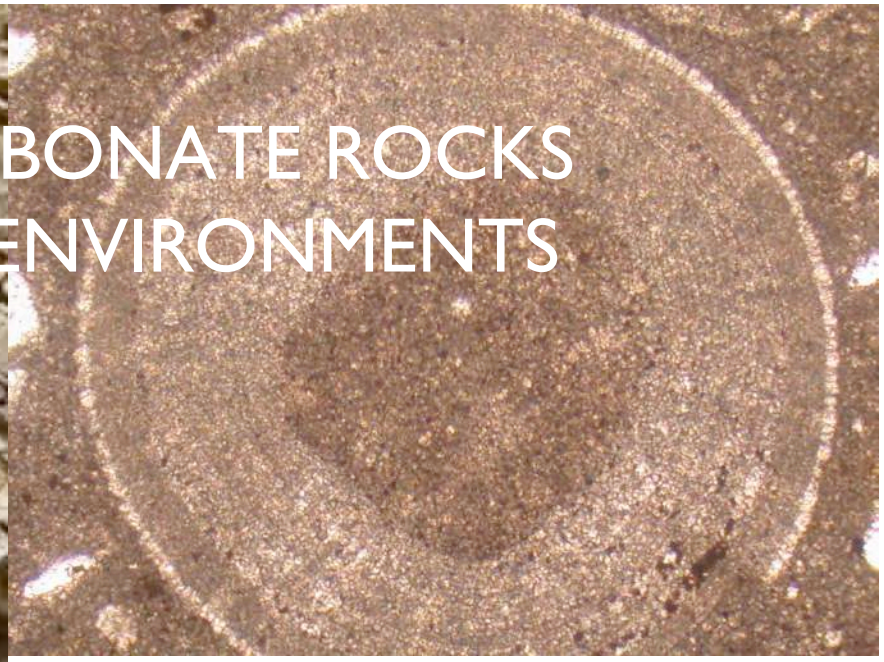
MICROFACIES OF CARBONATE ROCKS AND DEPOSITIONAL ENVIRONMENTS

GEOL.F.304



Prof. Alain Préat
Free University of Brussels

PETROGRAPHY OF CARBONATES

1. MATRIX

2. CEMENT

3. GRAINS

A carbonate grain tells a story ≠ A clastic grain
(‘highly sensitive’ > < ‘inert’)

Erik Flügel

MICROFACIES OF CARBONATE ROCKS

Analysis, Interpretation and Application

2004

Springer

ERIK FLÜGEL was born in Austria and obtained his Ph.D. degree from the University of Graz. After working as a curator at the Natural History Museum in Vienna, he spent ten years at the Technical University of Darmstadt and subsequently held the chair at the Institute of Paleontology at the University of Erlangen-Nürnberg from 1972 to 1999. His research on microfacies and facies analysis of limestone and the investigation of Paleozoic and Mesozoic reefs and reef-building fossils has enabled many ancient environments to be reconstructed. Springer published his textbooks *Microfacies Analysis of Limestones* in 1978 and 1982. He co-edited the SEPM Special Volume *Phanerozoic Reef Patterns* published in 2002 and led a Priority Research Program funded by the German Research Foundation, devoted to *The Evolution of Reefs through Time*. Flügel also held courses and workshops dealing with microfacies and facies models in Europe and Africa. He was an Honorary Member of the GSA and Professor Emeritus at the Erlangen Institute of Paleontology.

Flügel ■ **MICROFACIES OF CARBONATE ROCKS**

with CD-ROM

The book brings together the methods used in microfacies analysis and details the potential of microfacies in evaluating depositional environments and diagenetic history, and, in particular, applying microfacies data to the study of carbonate hydrocarbon reservoirs and the provenance of archaeological materials. The first part of the book introduces microfacies analysis; the second part deals with the interpretation of the microfacies data; and the third part explores the practical use of microfacies. This last part focuses on the facies controls of reservoir and host rocks, the importance of microfacies and diagenesis for understanding the technological properties of carbonate rocks and the destruction and conservation of carbonate objects, and discusses the potential of microfacies for archaeometrical studies. Nearly 400 instructive plates and figures (30 in color) showing thin-section photographs with detailed explanations form a central part of the content.

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springeronline.com

PETROGRAPHY OF CARBONATES
3. CARBONATE GRAINS

✓ various organic and non-organic particles of limestones that are larger than the groundmass = ‘grains’, ‘particles’,’ constituents’, ‘allochems’ (the last term –Folk 1962- for mechanically deposited grains that have undergone transportation => = ‘intraclasts’),

✓ the final useful subdivision is between NON-SKELETAL grains and SKELETAL grains
= > skeletal grains comprise complete or fragments fossils (= ‘bioclasts’)
= > non-skeletal grains are peloids, various ‘coated grains’ (ooids, oncoids, …), grain aggregates and clasts,

✓ **interest** : grain types are palaeoenvironmental proxies both from non-marine and marine carbonates (e.g. water energy levels, sedimentation rates …).
Grain association patterns also allow reconstitution of paleoclimate and paleolatitudinal zones.
Grain type, mineralogy and spatial variations in their distribution are major control on the porosity development of reservoir rocks.

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.1 BIOCLASTS

✓ cf. first part of the course ('invertebrate fossils in rocks and thin sections')
= **skeletal grain** or **bioclast** ('organoclast', 'phytoclast', 'zooclast')

✓ their record is strongly controlled by
- the primary skeleton mineralogy : ±50% = carbonate, other are phosphate and silica
- taphonomic and diagenetic processes : transport (with or without breakdown) and/or dissolution
  = > many skeletal grain types have specific preservation potential…
  = > nb : dolomitization…
- methodological bias : thin sections do not document the total record of skeletal grains
  => some very small grains may be missed, 'non skeletal' grains are definitively lost.

✓ dating : they are the most valuable grain types to determine the age of limestone samples
=> forams, sometimes algae

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.1 BIOCLASTS

Primary skeletal mineralogy of organisms

● *dominant*

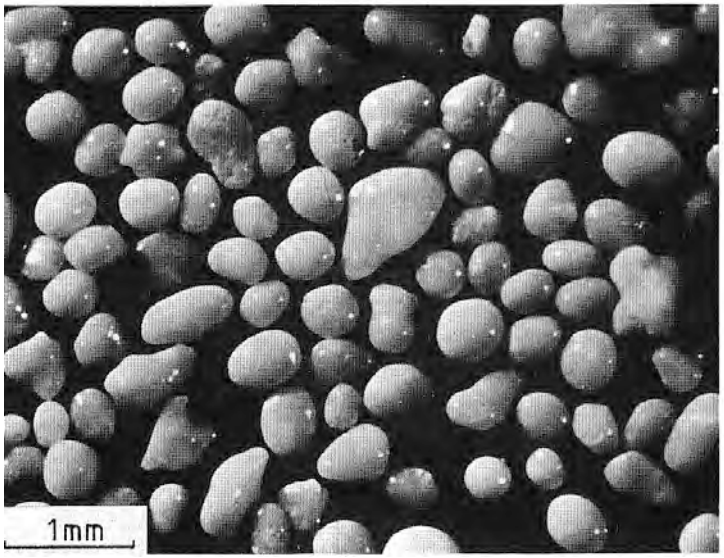
o *less common*

		Aragonite	Low-Mg Calcite	High-Mg Calcite	Aragonite + Calcite	Ca-Phosphates	Silica
Cyanobacteria		o	●	o			
Pyrrhophyta:	Calciodinoflagellata		●				
Chrysophyta:	Diatoms						●
	Coccolithophorida		●				
Chlorophyta:	Dasycladaceae	●					
	Udoteaceae	●					
	Gymnocodiaceae	●					
	Charophyceae		●	●			
Rhodophyta:	Solenoporaceae	●					
	Squamariaceae	●					
	Corallinaceae			●			
Radiolaria							●
Foraminifera		o	●	●			
Ciliata:	Calpionellida		●				
Sponges:	Demospongea		o				●
	Calcarea		●				
	Sphinctozoa	●	●				
	Stromatoporoidea	o	●	●			
	Chaetetida	●	●				
	Archaeocyathida		●				
	Hexactinellida						●
Scyphozoa:	Conulata					●	
Hydrozoa		●	o	o			
Corals:	Octocorallia	o	o	●	o		
	Rugosa		●	o			
	Heterocorallia		●				
	Tabulata	o	●	o			
	Scleractinia	●					
Bryozoa		o	●	o	●	o	
Brachiopoda:	Articulata		●	o			
	Inarticulata					●	
Mollusca:	Monoplacophora	●			●		
	Polyplacophora	●					
	Scaphopoda	●					
	Bivalvia	●	●		●		
	Gastropoda	●	●		o		
	Nautiloidea	●	o		o		
	Ammonoidea	●	● Aptychus				
	Belemnoidea				●		
Tentaculitida		●		●			
Annelida:	Serpulida	●	●	o	o	o	
Arthropoda:	Trilobita		o			●	
	Ostracoda		●	o			
	Cirripedia	o	●	●			
	Decapoda		●	●			
Echinodermata				●			
Tunicata		●					
Vertebrata		o (otoliths)				●	
Conodonts						●	

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.2 OOIDS

OOIDS ARE SPHERICAL PARTICLES WITH CONCENTRIC LAMINAE COATING A NUCLEUS



Dean & Fouch 1983

Bars of oolites, parallel to the shoreline Great Salt Lake

Spill-over lobes, backside of an active ooid shoal (clean, crossbedding, Great Bahama Bank)

Halley et al 1983

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.2 OOIDS

OOIDS ARE SPHERICAL PARTICLES WITH CONCENTRIC LAMINAE COATING A NUCLEUS

Clean sands on an active sand shoal.
Well-sorted, medium sand-size ooids in sligthly dipping laminae.
Thicker laminae with coarse grains (algae, forams, aggregates), loose-packing.
Joulters ooid shoal, Great Bahama Bank
Halley et al 1983.

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.2 OOIDS

OOIDS ARE SPHERICAL PARTICLES WITH CONCENTRIC LAMINAE COATING A NUCLEUS

✓ known since Sorby 1979 and Kalkowsky 1908 => 'intriguing constituent'

✓ for a long time, they were regarded as 'inorganic' grains
=> strong biological controls have been highlighted : cumulative processes by biofilm attachment and subsequent carbonate (mostly aragonite) encrusation
= = > 'microbial'contact (coccoid cyanobacteria and diatoms)
= = > also inorganic ooids = hydrodymanic control (Bahamian ooids/oolites)?

✓ microfabrics, mineralogy, abundance and size reflect physical and chemical conditions of the depositional environments in marine and non-marine settings
=> ooids = proxies for water energy, temperature, salinity, water depths…

✓ present-day marine Bahamian-type ooids formed in turbulent environments,
=> not necessarily analogues of ancient ooids
=> moreover, the transport of ooids from the areas in which they were produced to the depositional areas is often underestimated
=> changes in mineralogy and abundance over time have been correlated to changes in CO_2atm or to the rate of sea-level change => also a relation with climates.

✓ **oolites (carbonate rocks composed of ooids) formed on marine PF and ramps comprise > 50% of the world's carbonate hydrocarbon reservoirs.**

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

DEFINITION : Ooids are spherical and egg-shaped carbonate or non-carbonate (iron-ooids) coated grains exhibiting a **nucleus** surrounded by an external **cortex**, the outer part of which is concentrically smoothly laminated.

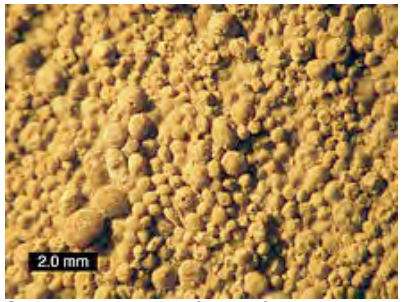
Most ooids <u>are smaller than 2 mm</u> in diameter, many ooids between 0.5-1 mm in size

Modern ooids = ARAG and/or CALCITE.

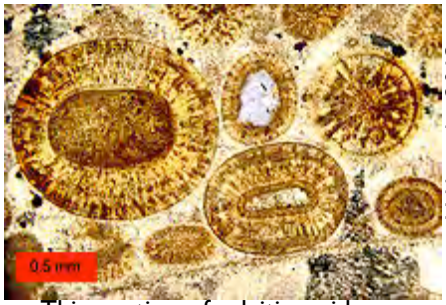
The cortices exhibit a variety of microfabrics caused by different orientations of carbonate crystals in the laminae

- TANGENTIAL or CONCENTRIC OOIDS : tangentially or randomly arranged crystals
- RADIAL or RADIAL-FIBROUS OOIDS : radially arranged HMC and/or ARAG crystals
- MICRITIC OOIDS : spherical grains with a nucleus and micritic cortex
- SPHEROIDS : radially arranged fibrous crystals

Modern ooids from a beach on Joulter's Cay, The Bahamas



Ooids on the surface of a limestone Middle Jurassic, southern Utah



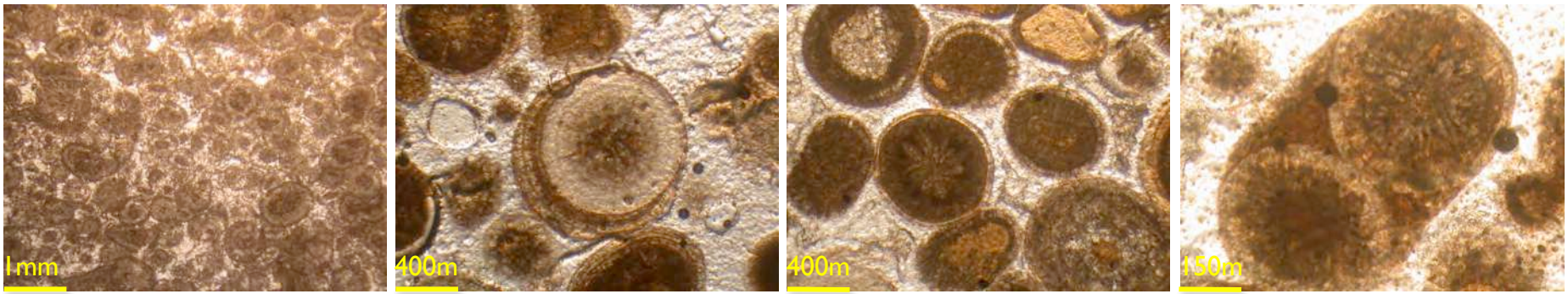
Thin-section of calcitic ooids Jurassic, southern Utah

Wikipedia 2013

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

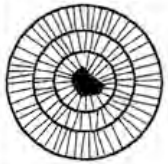
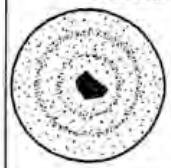
KEY INTERPRETATION

- TANGENTIAL TANGENTIAL or CONCENTRIC OOIDS = **HIGH-ENERGY**
- RADIAL or RADIAL-FIBROUS OOIDS = **MODERATE to LOW-ENERGY**
  if well-preserved in geological series => HMC => LMC
- MICRITIC OOIDS = obliteration/recrystallization of previous ones
- SPHEROIDS : radially arranged fibrous crystals



Neoproterozoic, Bas Congo, Delpomdor, Préat, Van Vliet 2011

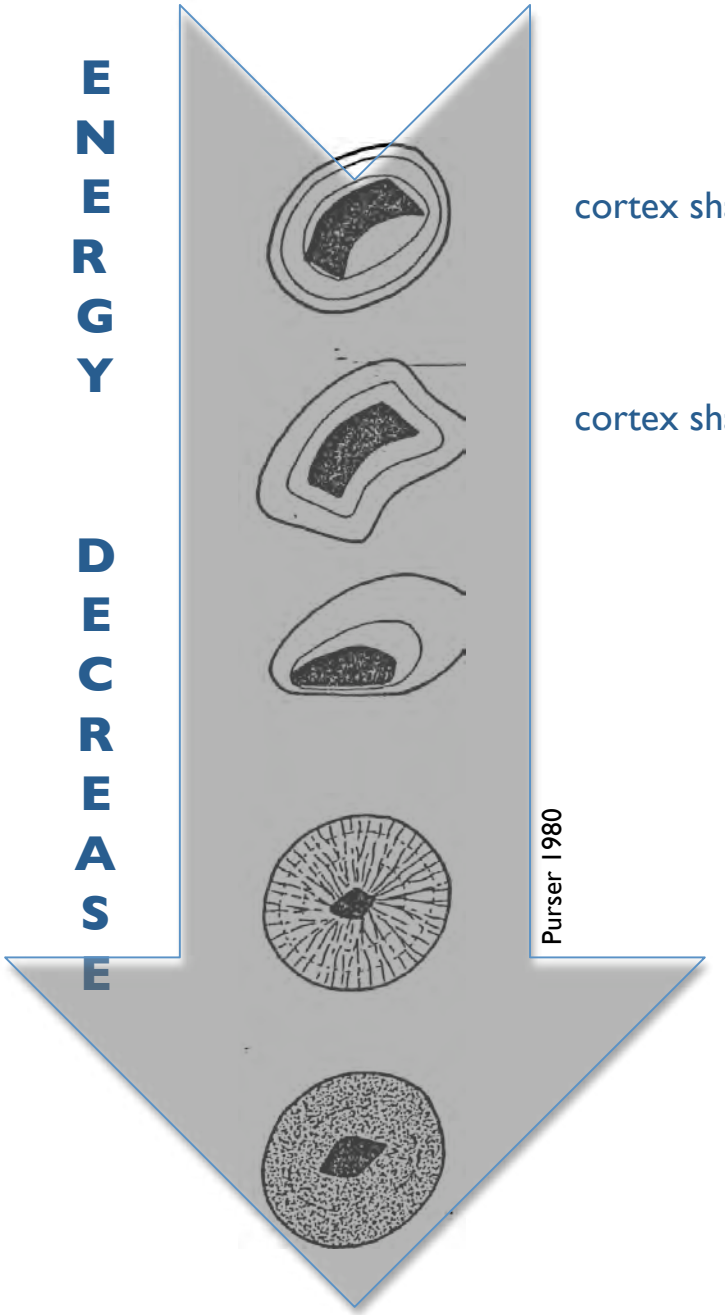
PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

	Microfabric of the cortex	Mineralogy, modern examples		Environment
Concentric (tangential) **ooids** 	Concentric laminae consisting of tangentially arranged crystals whose long axes are aligned to the surface of the laminae. High microporosity	Aragonite:	Bahamas, Yucatan, Abu Dhabi, Persian Gulf	Very shallow, warm low-latitudinal seas; *common in high-energy settings*
			(Great Salt Lake/Utah)	Lacustrine-hypersaline
		Low-Mg calcite: Caliche ooids*		Terrestrial
Radial (radial-fibrous) **ooids** 	Laminae consisting of radially arranged crystals; long crystal axes perpendicular to the laminae surface	Aragonite:	Persian Gulf, Great Barrier Reef, (Yucatan, Shark Bay, Mediterranean)	Shallow marine, *common in low-energy settings*
			Gulf of Aqaba	Sea-marginal hypersaline pool
			Great Salt Lake/Utah	Lacustrine-hypersaline
		Mg-calcite:	(Baffin Bay/Texas)	Marine-hypersaline
		Calcite and Low-Mg calcite:	e.g. Cave pearls*	Non-marine
Micritic (random) **ooids** 	Laminae composed of randomly arranged microcrystalline crystals or Laminae obliterated or absent, due to a pervasive micritization of the cortex	Aragonite:	Bahamas	Shallow-marine

Flügel 2004

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.2 OOIDS

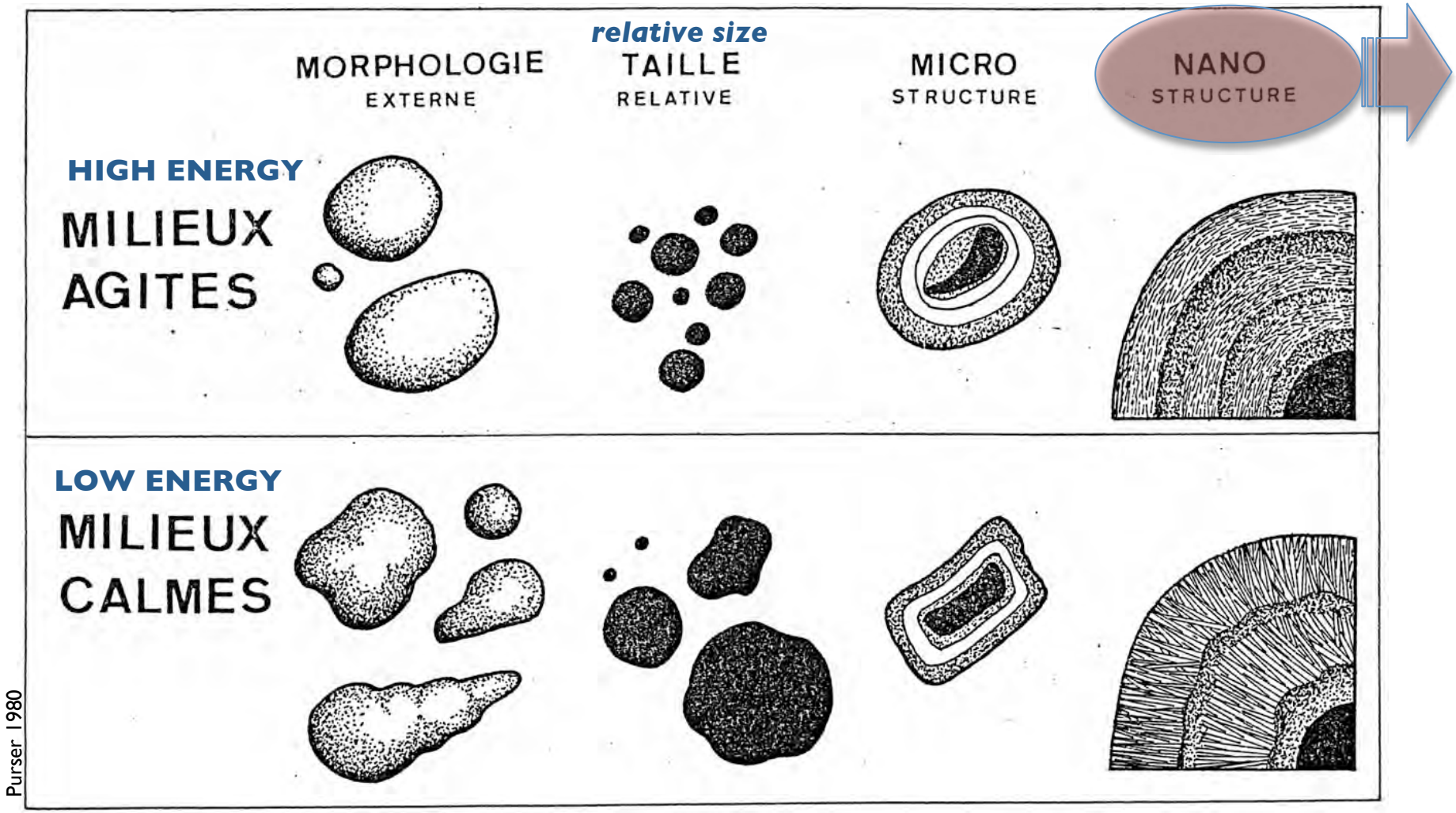


cortex shape independent of nucleus

cortex shape dependent of nucleus

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.2 OOIDS

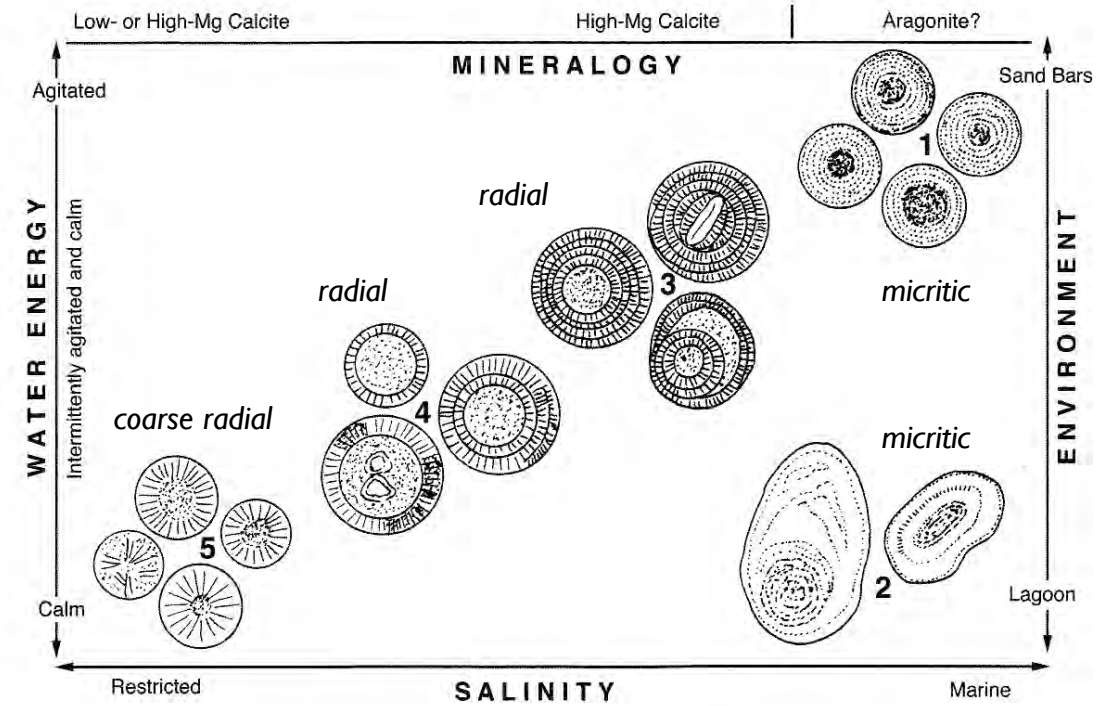


Purser 1980

PETROGRAPHY OF CARBONATES

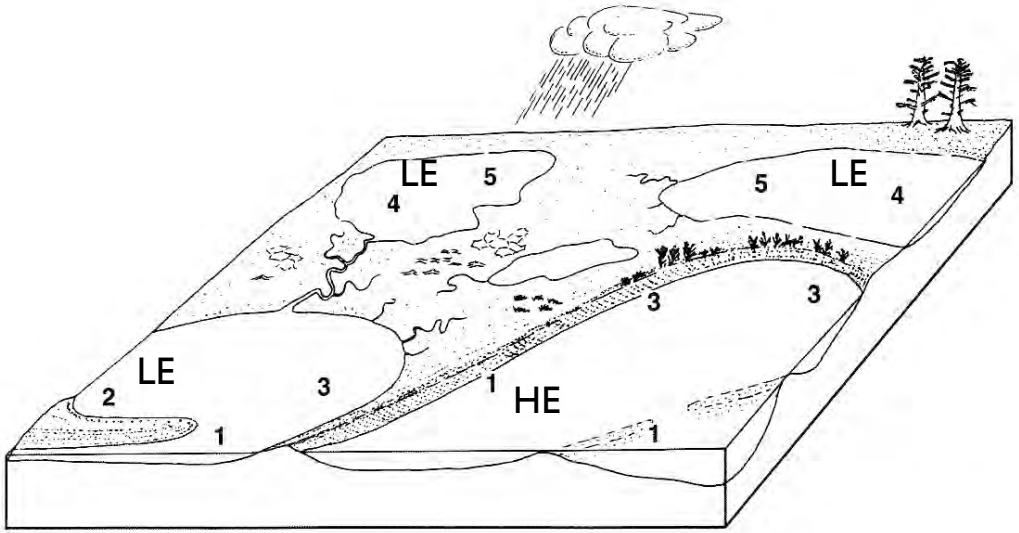
3. GRAINS = 3.2 OOIDS

Depositional sites and environmental controls of ooids. *Purbeck facies, lowermost Cretaceous, Swiss, France Jura mountains (Strasser, 1986).*

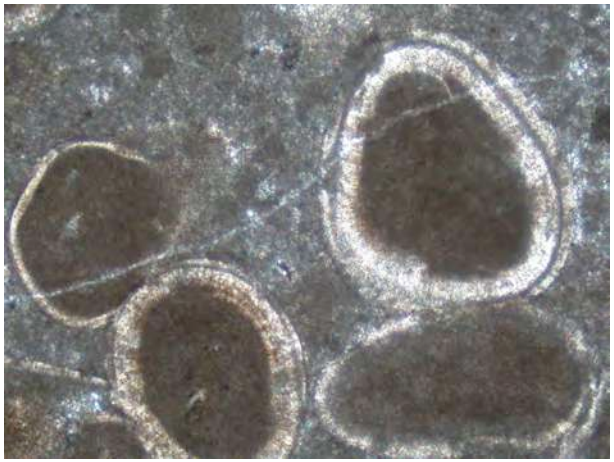


Shallow
sub-
inter-
supratidal

normal marine
bracksih
freshwater
hypersaline



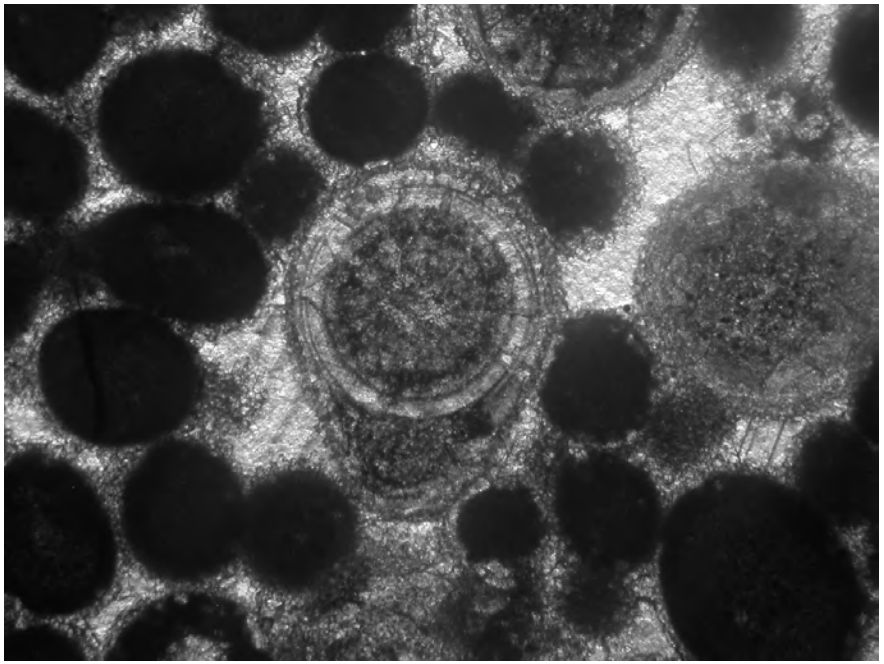
Ooid packstone
Radial ooid partially replaced in a pre-evaporitic supratidal environment.
Middle Devonian (Givetian), France, Préat.
Ooid sizes : 200-300µm

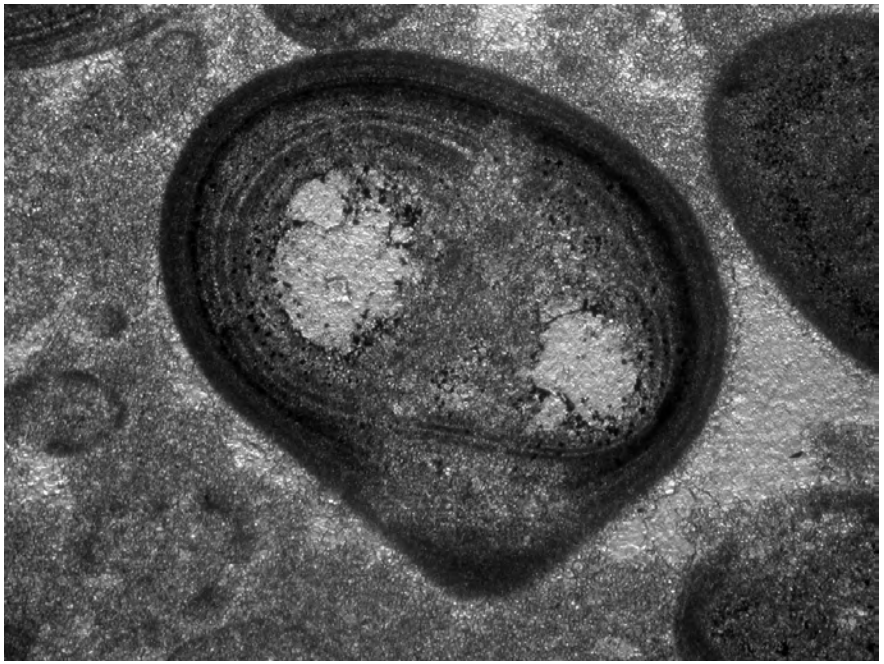


Ooid grainstones in a vadose freswhater-influenced back shoal area. Radial partially micritized ooids, bladed HMC with needle (former aragonite) inclusions, equant clear calcite and meniscus calcite cements. Intertidal setting.
Givetian, Belgium, Préat.
Ooid sizes 100-300µm

OOIDS IN VADOSE EVAPORITIVE ENVIRONMENT NEOPROTEROZOIC, CONGO-BRAZAVILLE, Préat 2012

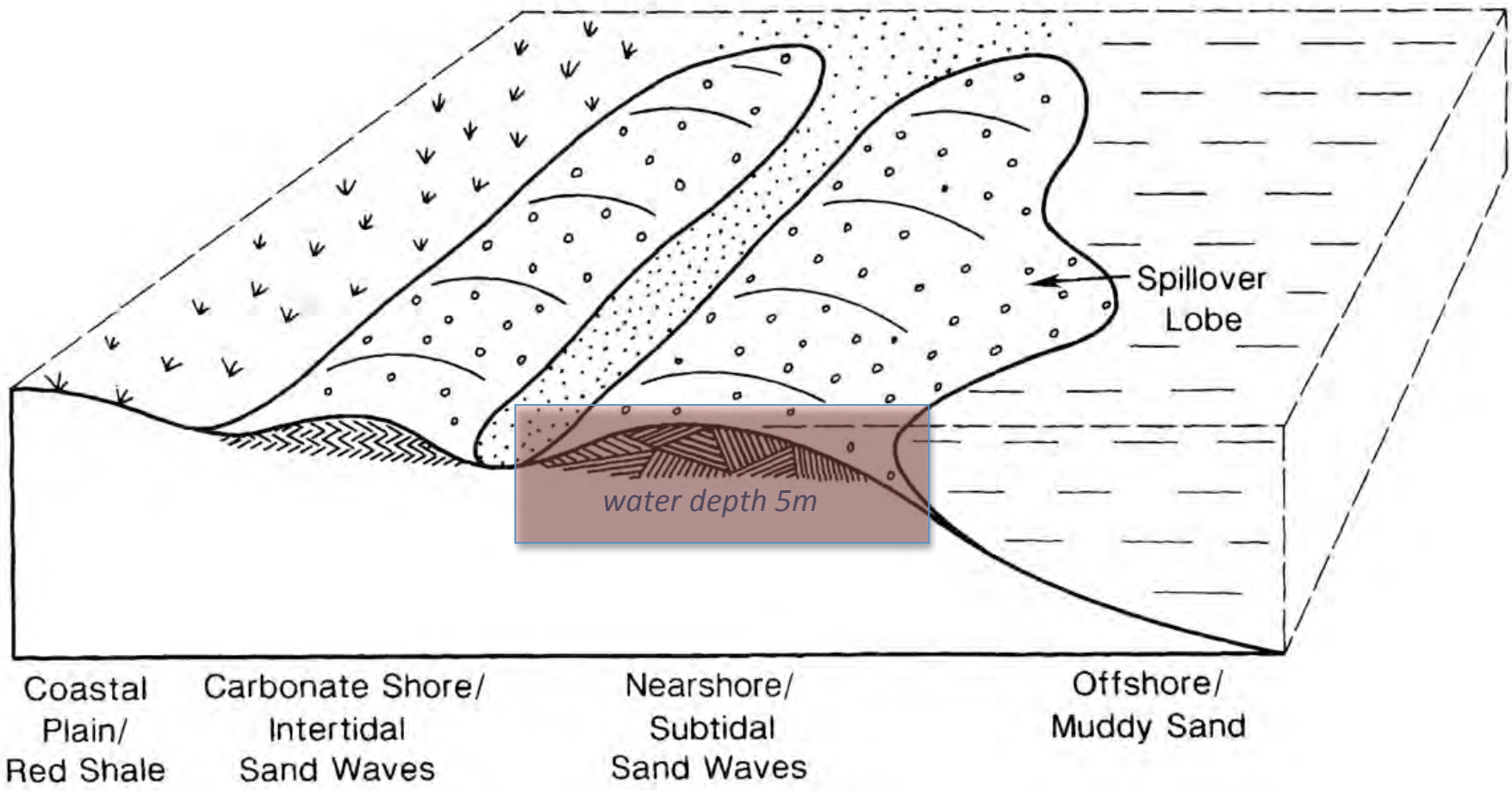
Diameters of ooids
± 0,5 mm





PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

OOLITIC TIDAL-BAR RESERVOIRS, MISSISSIPPIAN, WEST VIRGINIA



Smosna & Koehler 1993

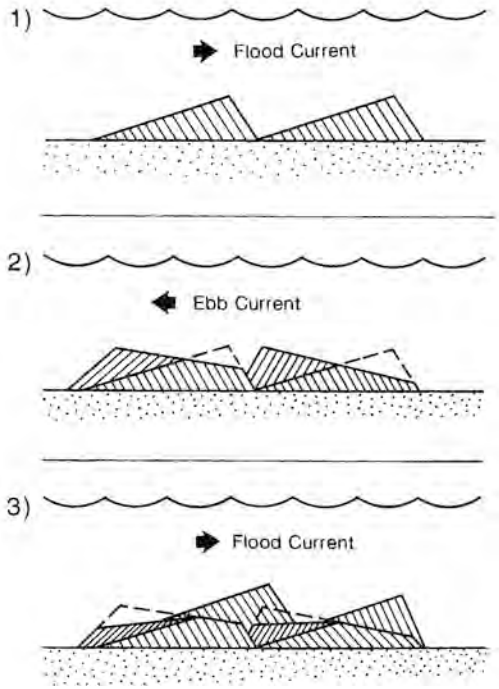
Depositional model of the Pickaway ramp, Mississippian, West Virginia.

Small intertidal sand waves, large subtidal sand waves, offshore spillover, offshore muddy sands.

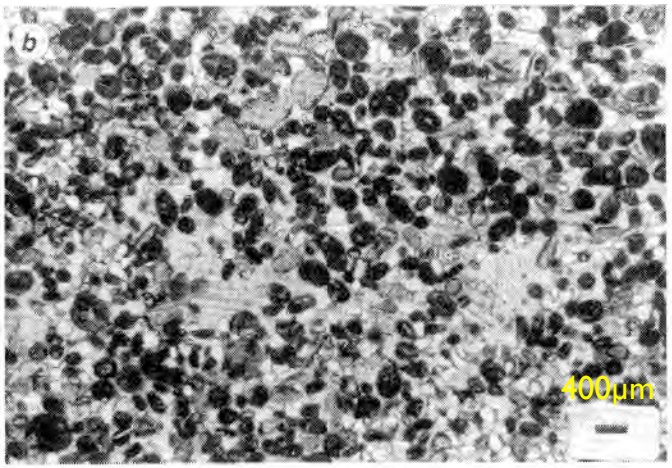
OOLITIC TIDAL-BAR RESERVOIRS, MISSISSIPPIAN, WEST VIRGINIA

Smosna & Koehler 1993

Sets of wedge shaped cross-strata with planar bounding surfaces

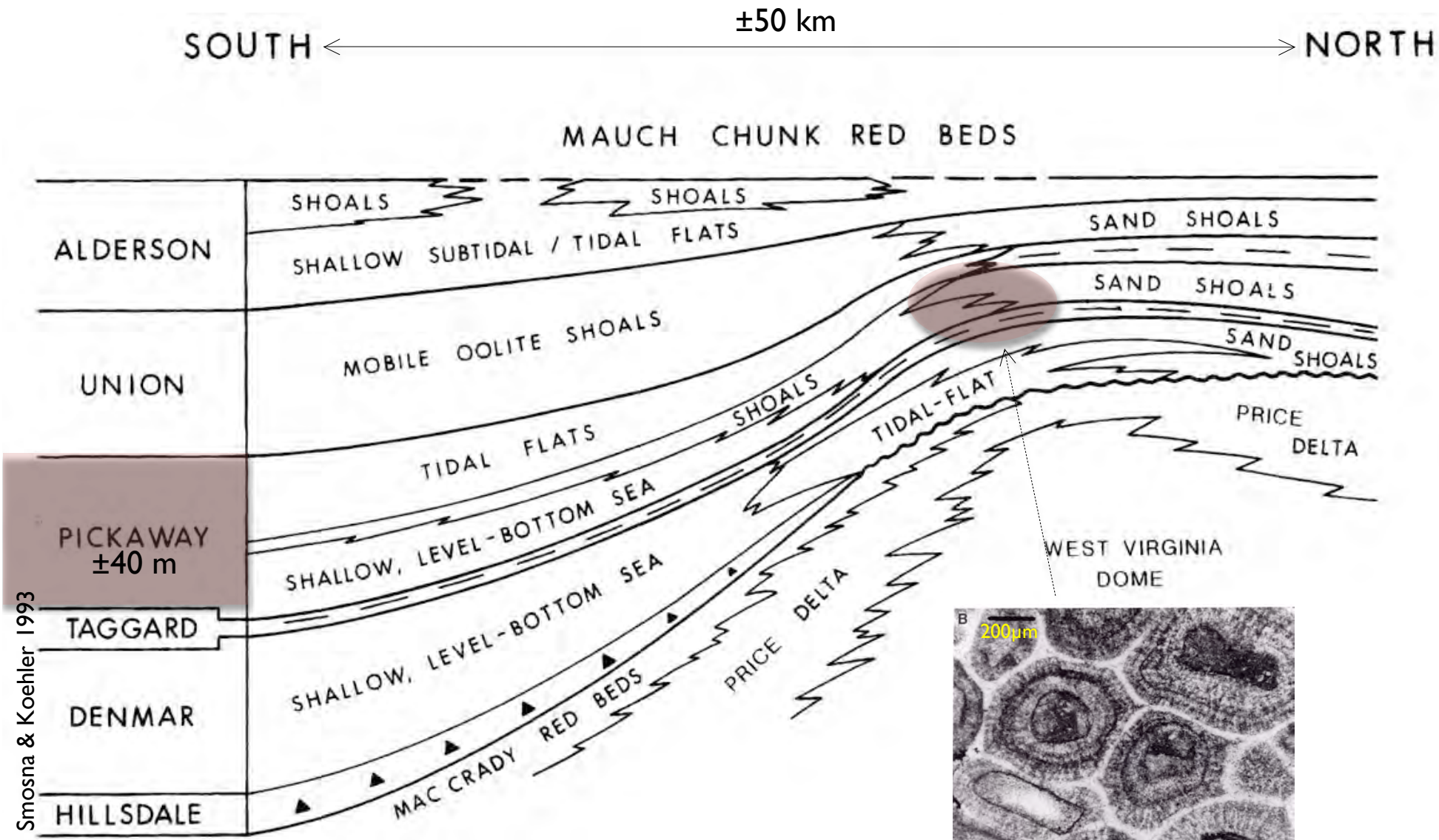


Wedge shaped cross-strata with bidirectional foresets that formed when sand waves migrated under the influence of reversing tidal currents



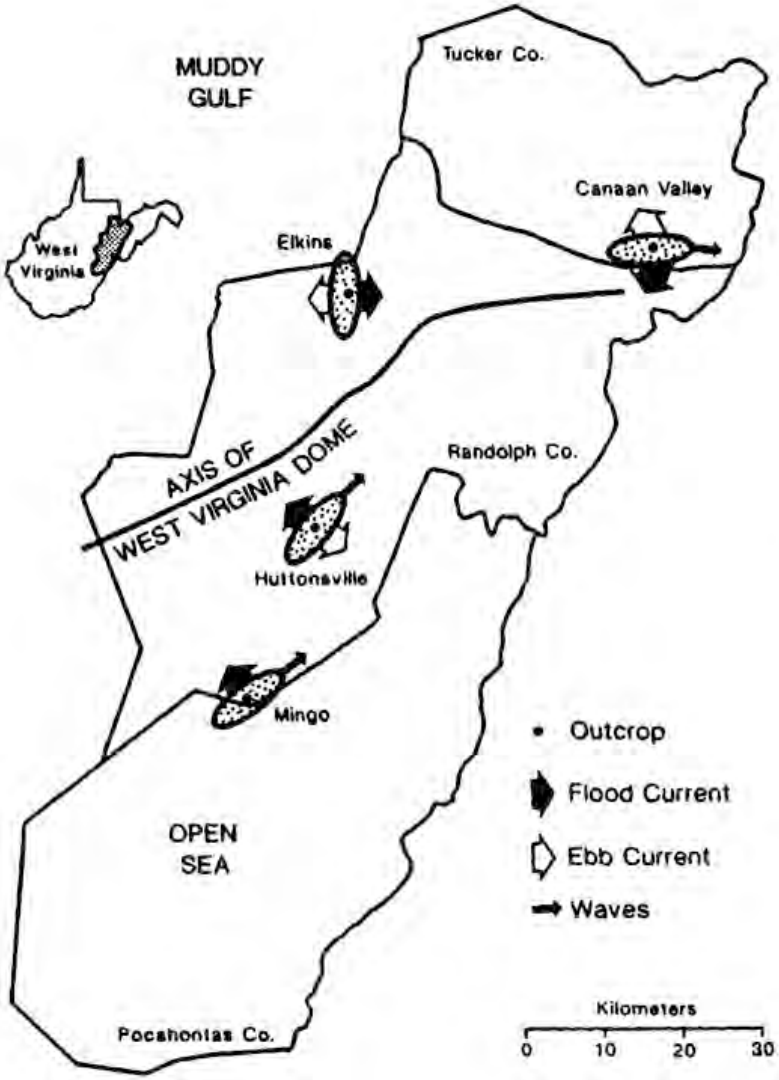
Grainstone with peloids, quartz, OOIDS, bioclasts

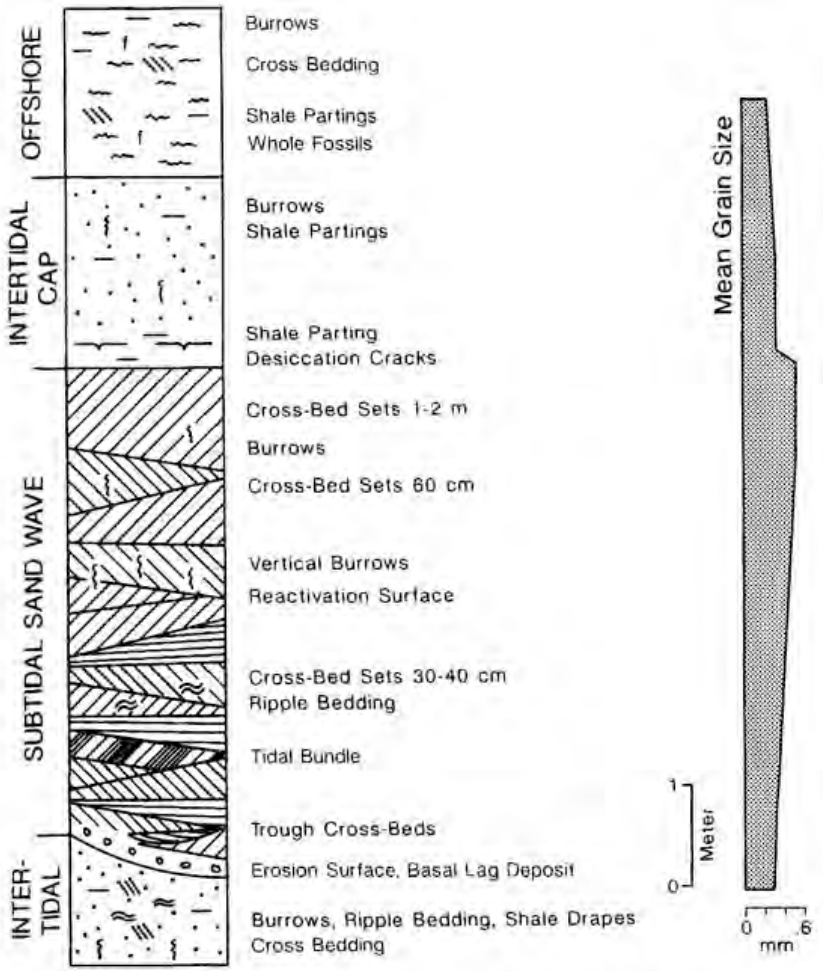
OOLITIC TIDAL-BAR RESERVOIRS, MISSISSIPPIAN, WEST VIRGINIA



Fitted fabric (chemical compaction)
Enhanced permeability by producing ***long*** *contacts between grains*

OOLITIC TIDAL-BAR RESERVOIRS, MISSISSIPPIAN, WEST VIRGINIA



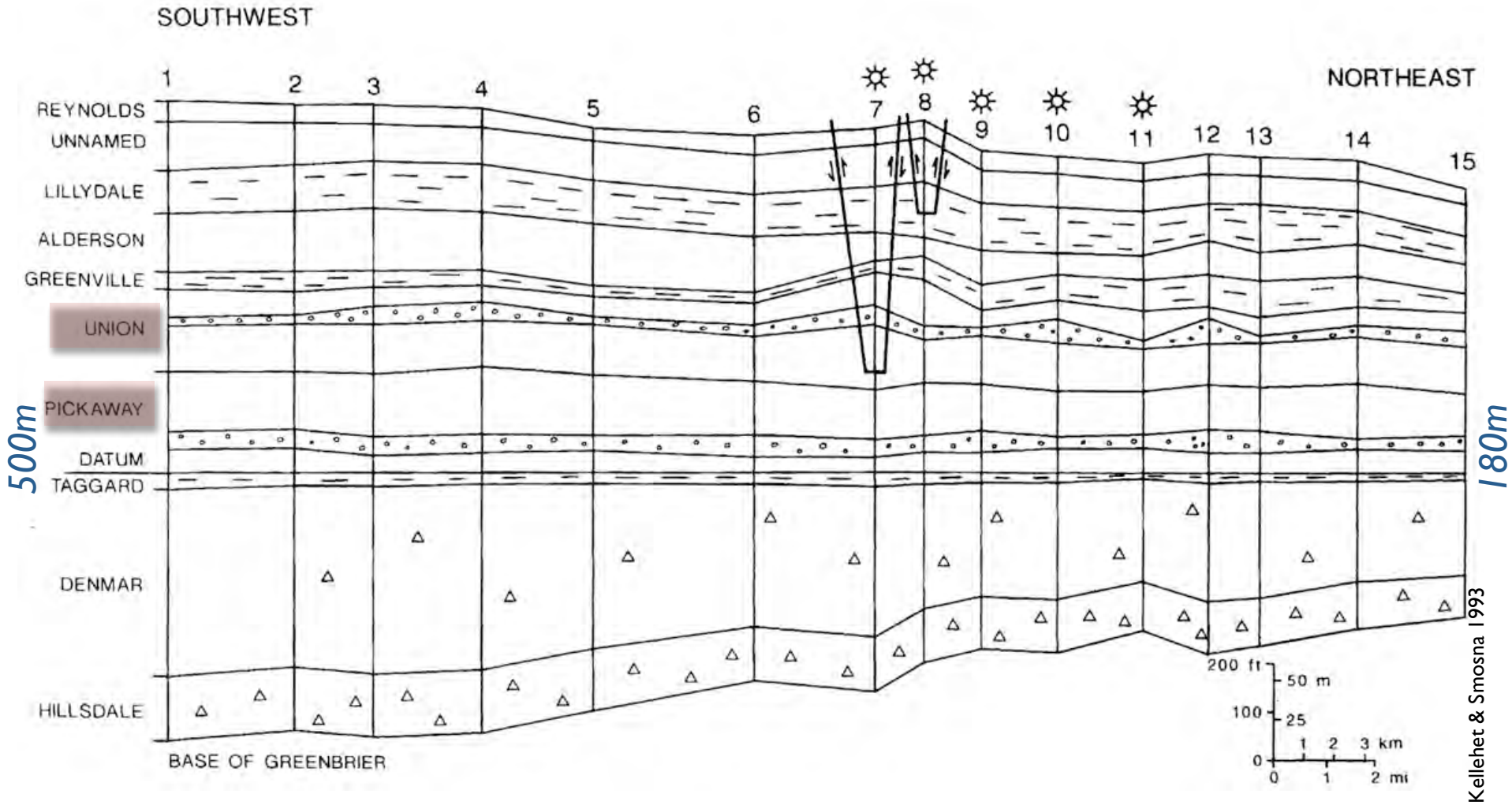


Smosna & Koehler 1993

Stratigraphic succession of facies from Huttonsville. Basal erosion surface and lag deposit.

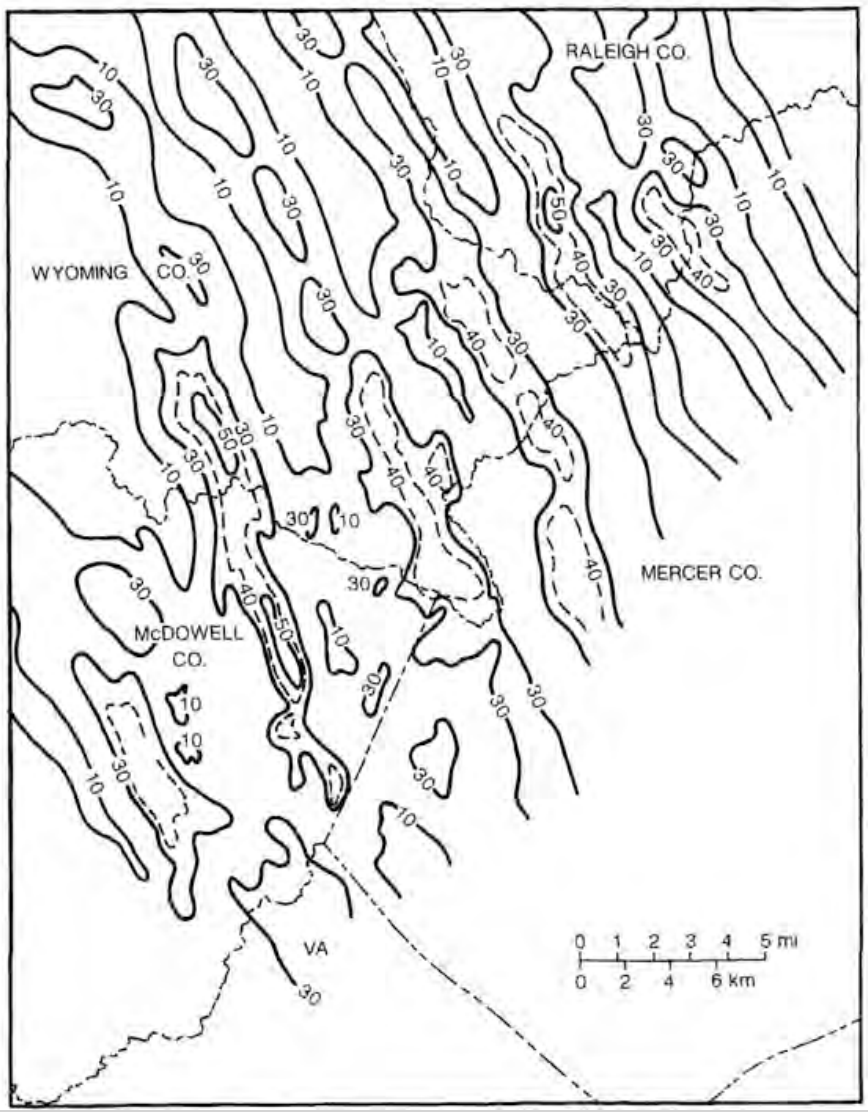
Paleogeography around the axis or crest of the West Virginia dome. Flood and ebb tidal currents flowed perpendicular to the axis and waves came from W-SW.

Individual ooid tidal bars : 4.6-9.1m, porosity >6%

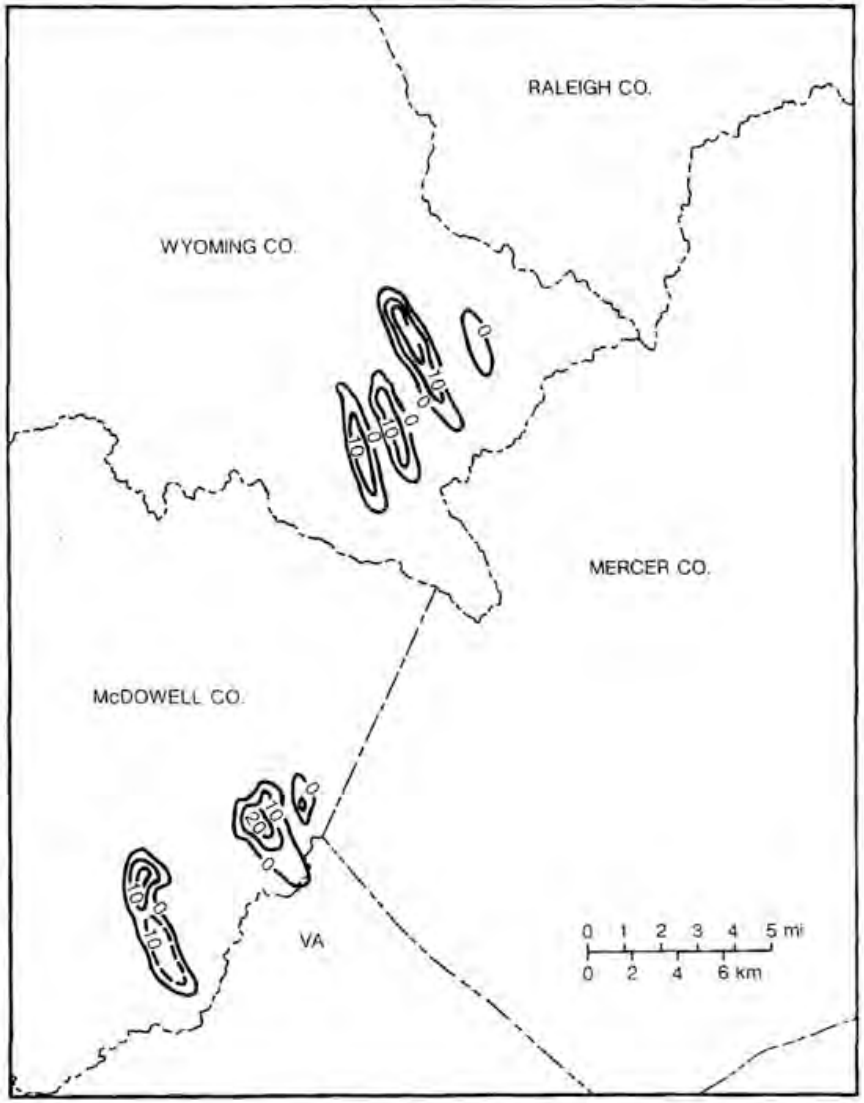


Producing zones in grainstones with porosity 9.5% and K 0.15md
Ooids altered during meteoric diagenesis => high inter/intra-granular microporosity
K enhanced by chemical compaction => long contacts between microporous grains

OOLITIC TIDAL-BAR RESERVOIRS, MISSISSIPPIAN, WEST VIRGINIA



Isopach map, Union Oolite Member.
NW-trending tidal bars, 12m-thick (av.),
1.4km in width and 32km in length



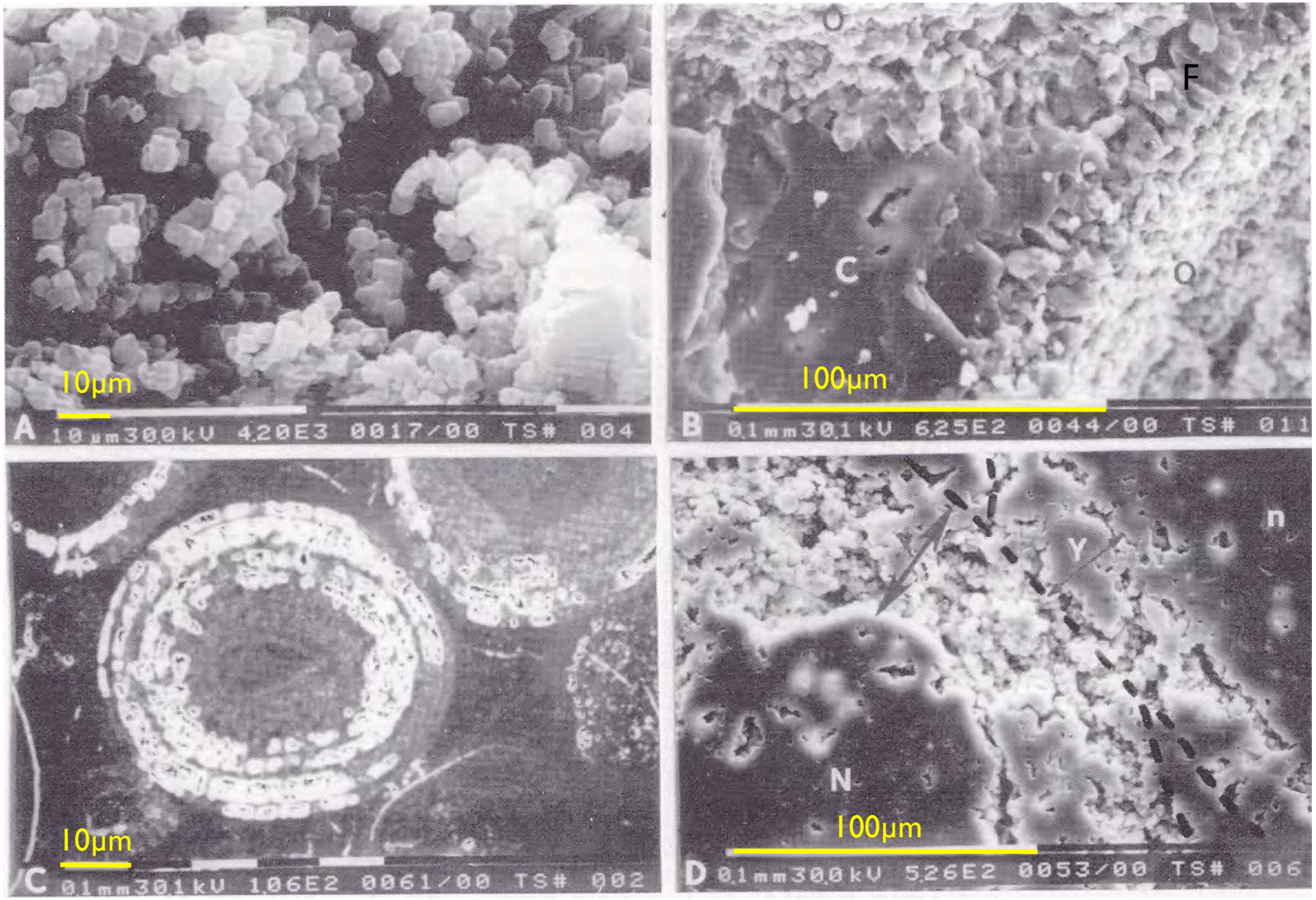
Kellehet & Smosna 1993

Isopach map, Union Pickaway member.
Net pay zone (porosity = ou > 6%

OOLITIC TIDAL-BAR RESERVOIRS, MISSISSIPPIAN, WEST VIRGINIA

microLMC (meteoric diagenesis)
intraooid microporosity (high
pores with large throats and interconnections

parts of two ooids (O)
isopachous fringe cement (F) followed by
coarse void-filling LMC cement (C)

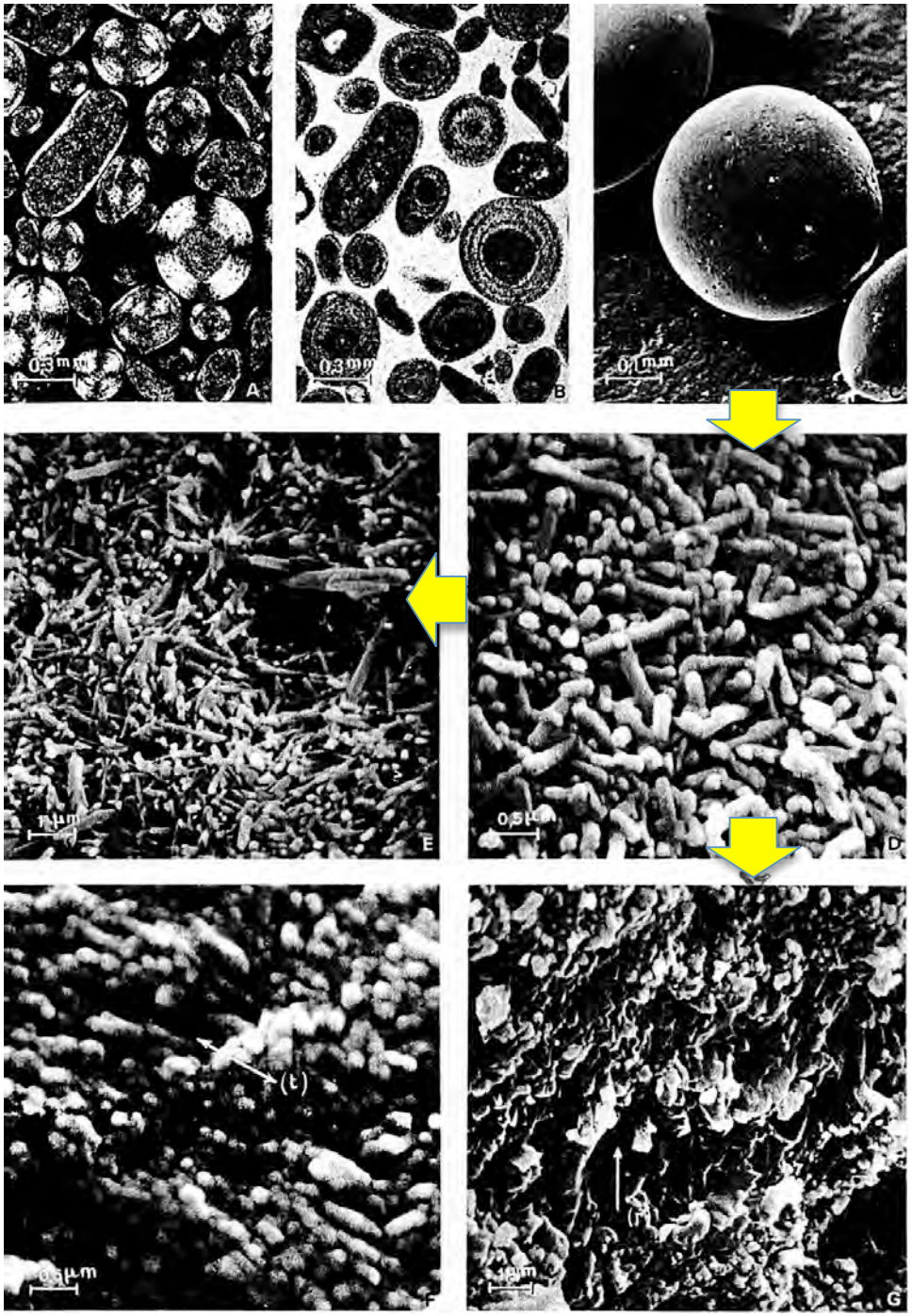


Kellehet & Smosna 1993

microporosity (white areas) along dissolved
laminae of the cortex

polished section, long interconnection (fitted fabric)
between two ooids (N and n = nucleus, Y =porous
cortex, dashed line = boundary between the ooids)

BAHAMAS
Loreau 1982



Agitated environments

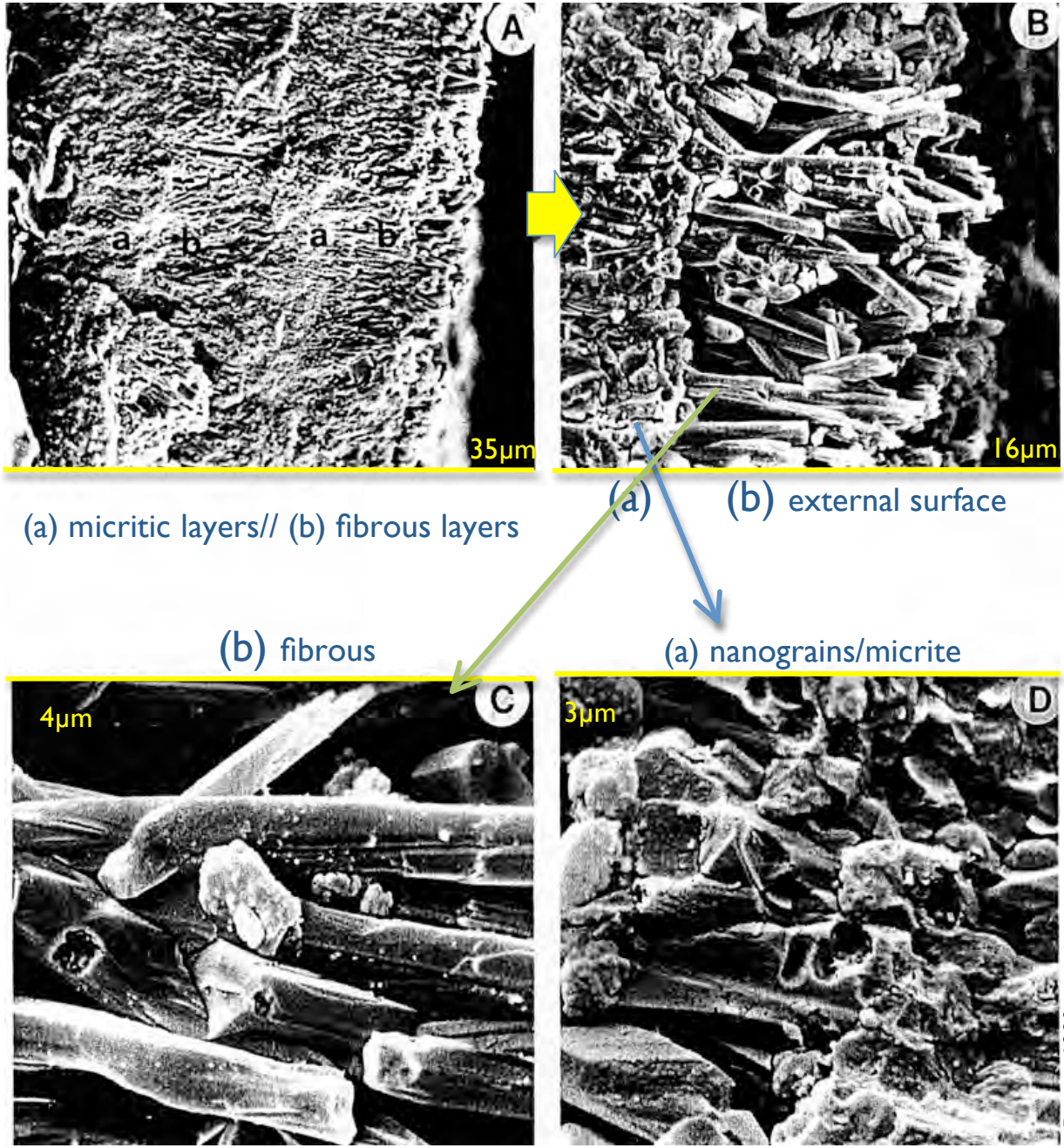
subhedral needles
0.2 x 1 to 2.5µm

elongated and
subrounded
(tangential)
rods
0.13-0.3
x
0.5 x 1 to 1.7µm

TANGENTIAL
STRUCTURE

radial nanocrsytals
< 1µm

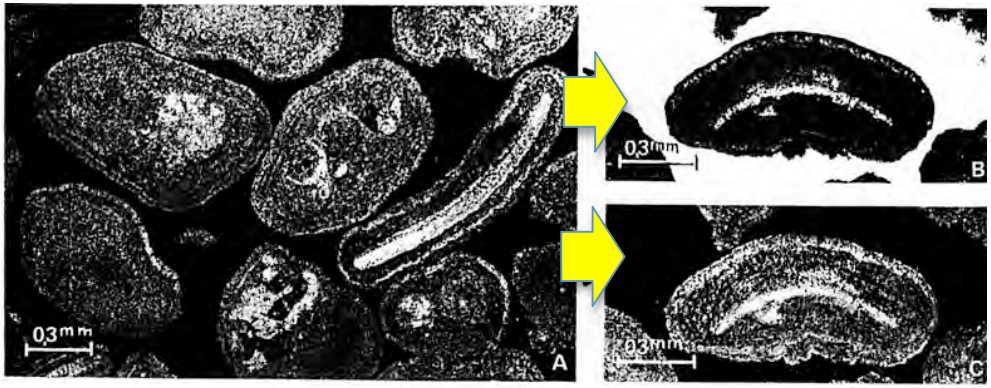
Quiet environments : nanostrucure of the cortex



Purser 1980

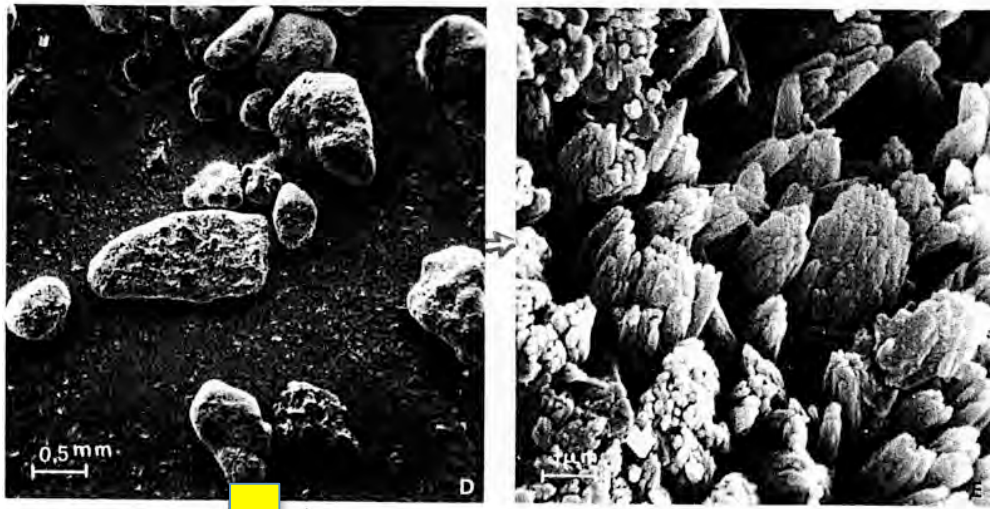
PERSIAN GULF
Loreau 1982

'protected' ooids in intertidal-supratidal lagoon …



…with' microstalactitic ' cement'

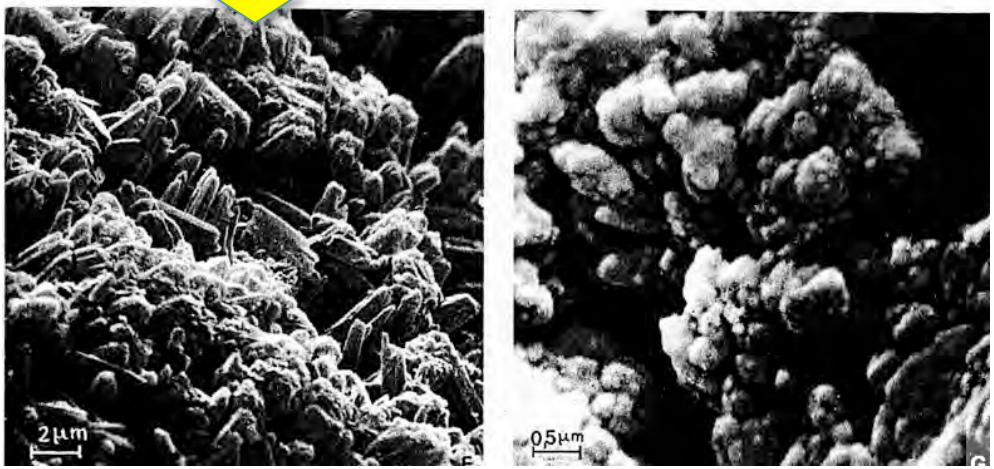
irregular lagoonal ooids



tiny crystals
0.2-0.4
x
2-4µm
forming
2-5µm-thick bundles

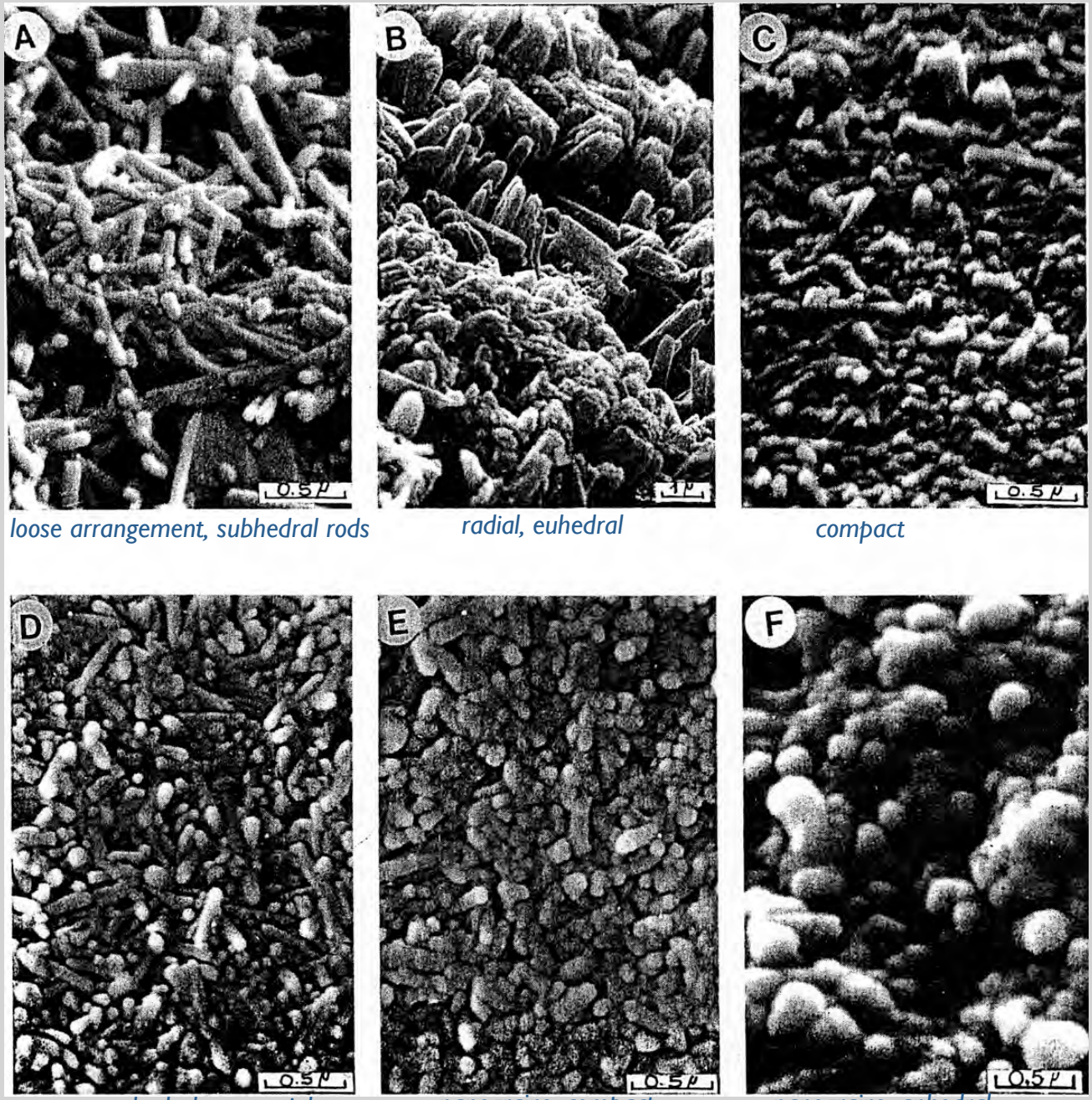
with

thicker 'radial'crystals
2-4µm



ooid with stacked nanograins
0.1-0.6µm

NANOSTRUCTURES OF CORTEX (MARINE OOIDS)



loose arrangement, subhedral rods

radial, euhedral

compact

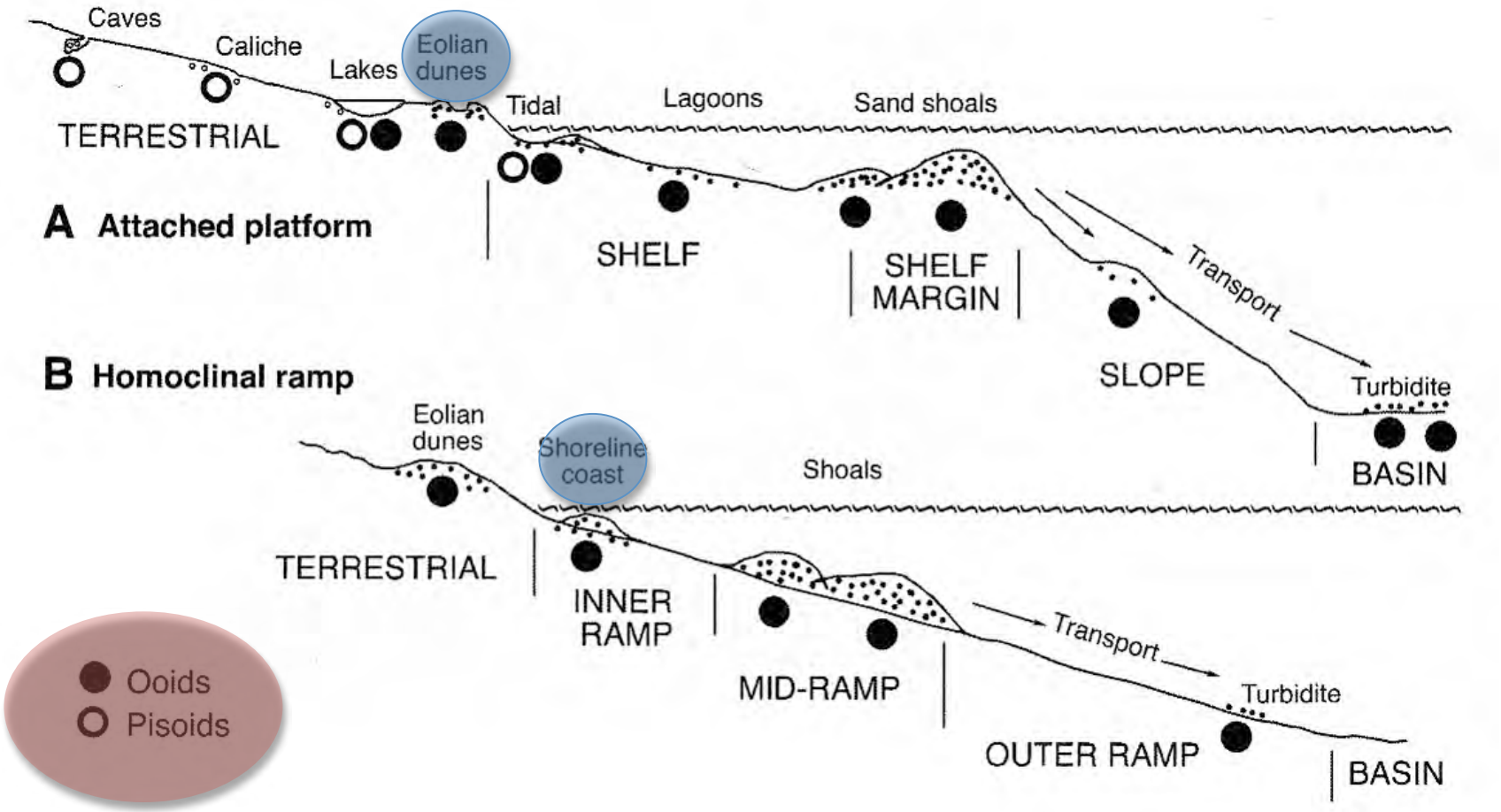
euhedral, tangential

nanograins, compact

nanograins, anhedral

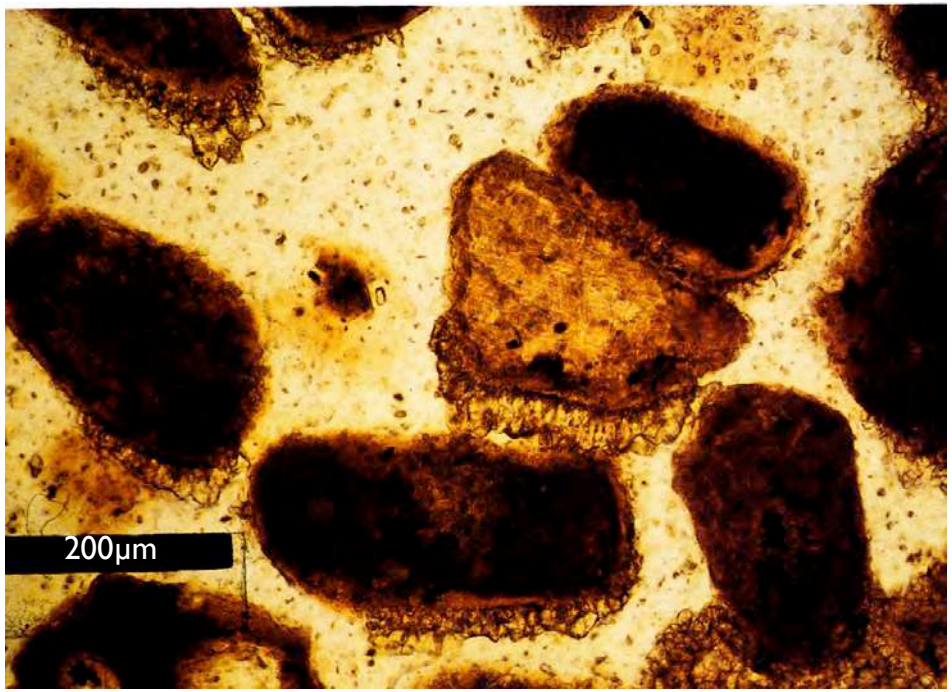
Purser 1980

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

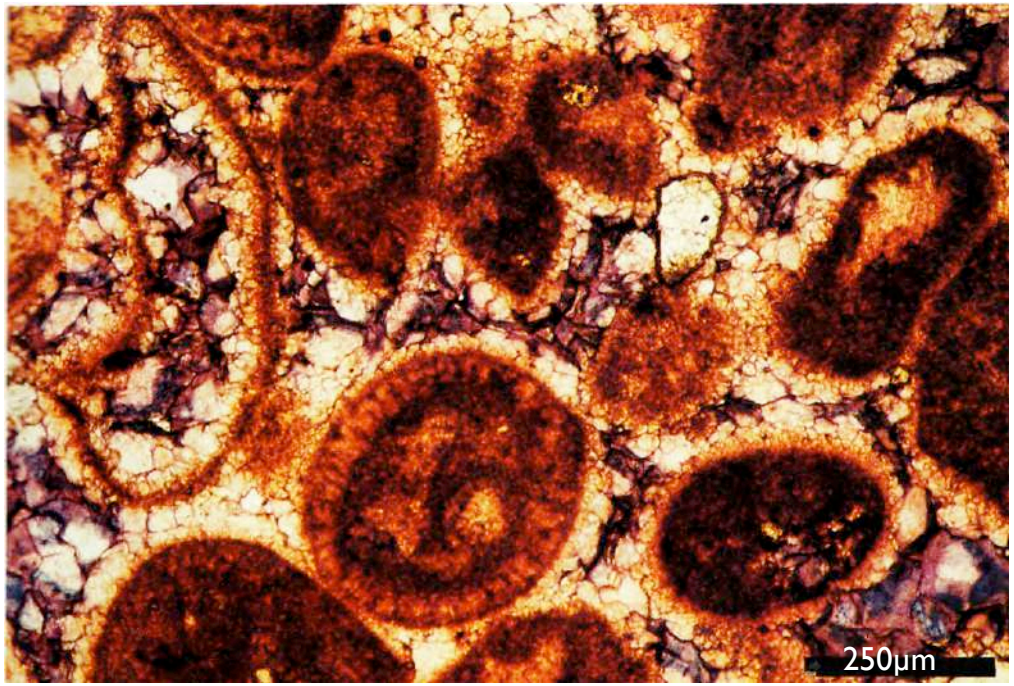


Sites of ooid and pisoid formation : autochthonous = eolian dunes, marine shoals, banks, sheet-like bodies, allochthonous accumulations = turbidites, debris flows on slopes and in basins (from Flügel 2004).

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

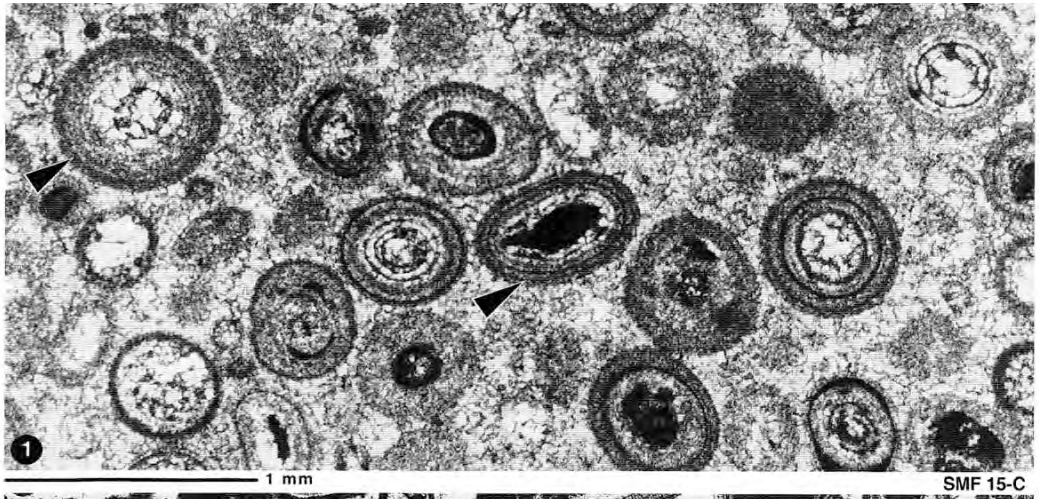


Pendulous cement, Holocene **eolianite**,
Isla Blanca, Yucatan Peninsula
McKee & Ward 1983

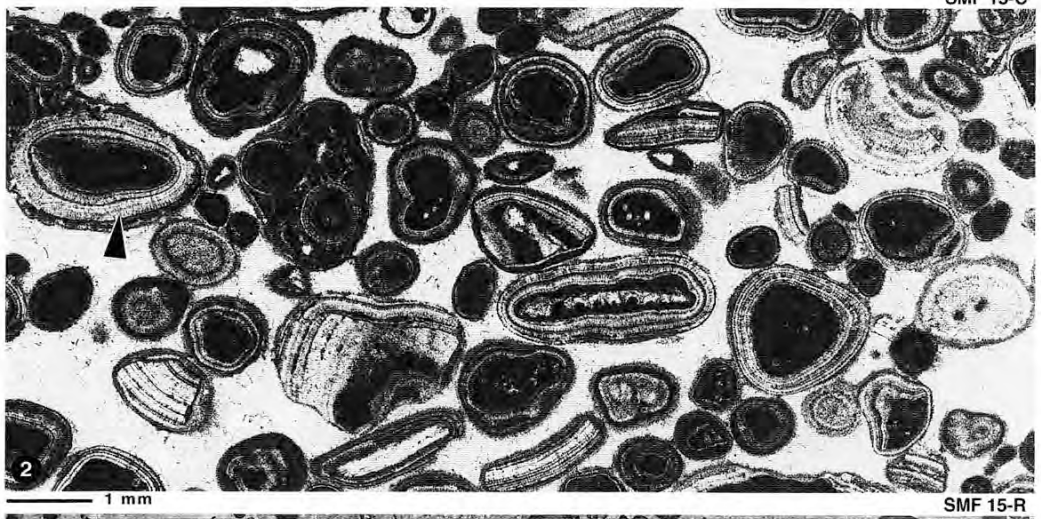


Well sorted oolite-intraclast lime grainstone,
Fe-free bladed and equant spar, later Fe-rich equant spar (purple), **barrier beach**, *Mississippian, Kentucky*
Inden & Moore 1983

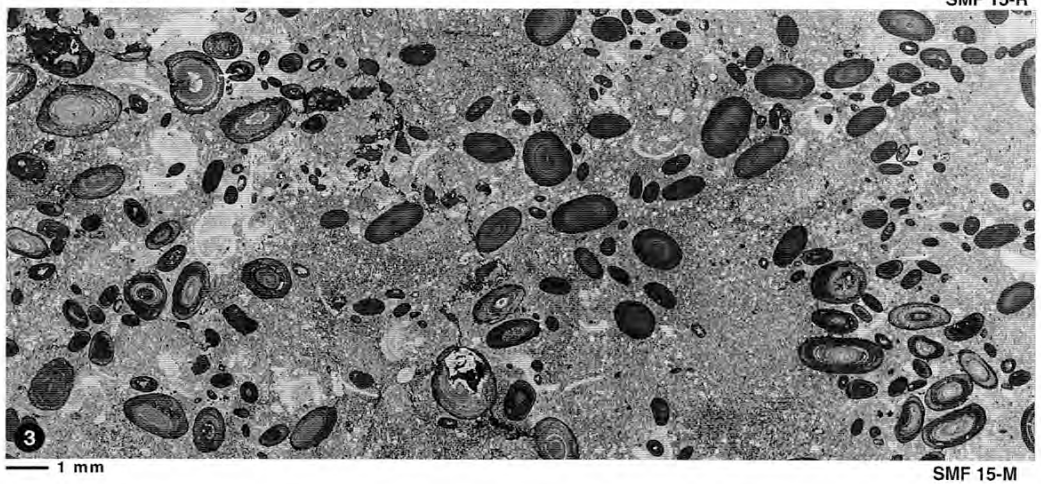
Ooid grainstone (**drusy cement**) with concentric ooids, multiple-coated, well sorted. Some are micritized and dissolved. *Late Triassic, N Alps, Austria [arrows = tangential structures]*



Ooid grainstone with radial ooids [arrows], multiple-coated, poorly sorted, irregularly shaped, reworked and broken. Also composite ooids, *Early Cretaceous, Apennines.*



Quartz-bearing ooid wackestone with micritic ooids. Poorly sorting and Fe-coatings (black). Ooids are allochthonous redeposited in a deep outer ramp, *Oxfordian, Spain (Zaragoza).*



Flügel 2004

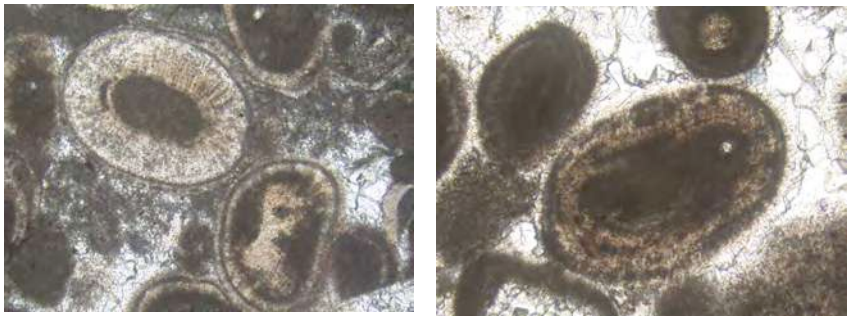
A. PREAT U. Brussels/U. Soran

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

SHAPE and SIZE : Ooids occur as single or compound (**complex**) ooids
= 'poly-ooid' i.e. two or more ooids bound together.
'Multiple ooids' result from the intergrowth of several ooids
….
Most ooids are spherical, the shape often results from the shape of the nuclei,
Size and sorting = clues to the hydrodynamic condition

THE CORTEX OF MODERN OOIDS CONSISTS OF ARAGONITE, HMC or LMC
Aragonite and HMC can co-occur in alternating laminae (Precambrian and much of the Paleozoic)

Most MODERN ARAGONITIC OOIDS FORMED IN THE MARINE ENVIRONMENT exhibit a concentric-tangential microfabric, rarely preserved in ANCIENT ONES



Neoproterozoic, Congo-Brazzaville, Préat 2012

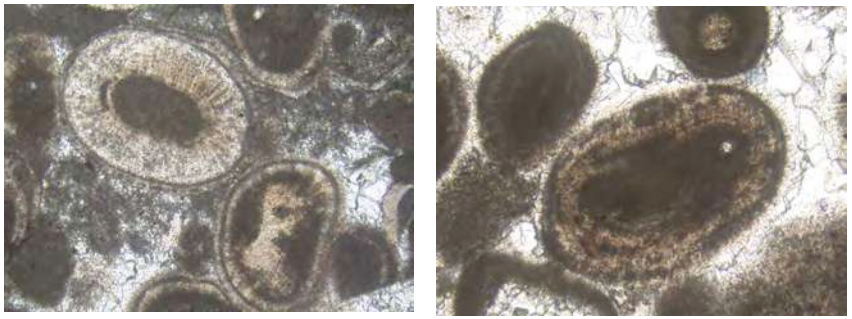
Neoproterozoic, Gabon, Préat 2008

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

MARINE LOW-ENERGY OOIDS = RADIAL-FIBROUS FABRIC
ALSO KNOWN FROM HYPERSALINE ENVIRONMENTS

LMC OOIDS FORMED IN FRESHWATER ENVIRONMENTS

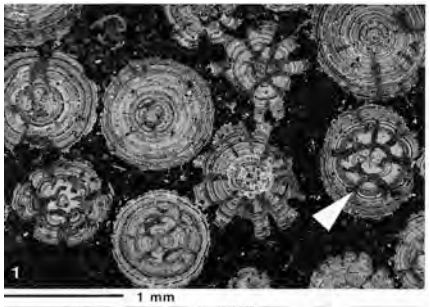
Original mineralogy of ancient ooids is inferred from preserved fabrics (diagenesis)
…



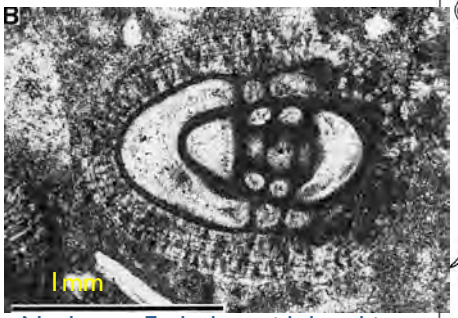
Neoproterozoic, Congo-Brazzaville, , Préat 2012

Neoproterozoic, Gabon, , Préat 2008

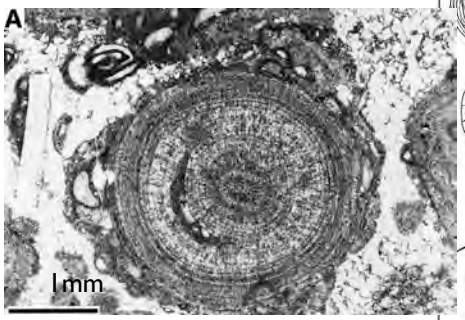
Common specific ooids (Flügel 2004)



Tangential, primarly HMC 'cerebroid', *Early Triassic (playa lake), Kalkowsky 1908*



Nucleus = Endothyranid benthic foram, *Early Carboniferous, Austria*



Encrusting forams (mobile sands) *Late Triassic, Austria*

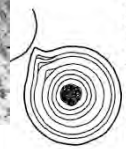
Cerebroid ooids (Graf and Lamar 1960; Carozzi 1962)
Criteria: Indented periphery. Mottled appearance of the cortex. Sectors made of tangentially arranged laminae and radial micritic sectors which often start at former depressions of the nucleus surface.
Occurrence: Marine and non-marine. Often associated with stromatolites.
Interpretation: The indented periphery of the ooids has been explained as a result of a peripheral replacement. The formation of the micritic sectors is ascribed to bacterial dissolution and precipitation (Kahlke 1974).

Asymmetrical and eccentric ooids (Gasiewicz 1984)
Criteria: Small spherical and ovoid composite grains consisting of superficial ooids acting as eccentric nuclei for successively formed ooids whose growth takes place preferrentially upward. Alternation of very thin oolitic laminae (white) and micrite envelopes (black). Ooid size commonly < 0.30 mm. Rare in wackestones and grainstones, common in packstones, associated with abundant peloids. Eccentric ooids should not be confused with oomolds with eccentric nuclei.
Occurrence: Low-energy shallow-marine lagoonal and lacustrine environments, periodically without agitation.
Interpretation: The ooid laminae are explained as resulting from short periods of water agitation, the micritic envelopes correspond to longer non-turbulent periods. Eccentric growth is controlled by changes from suspension to saltation and traction processes at the sea floor. Top: A superficial ooid formed in suspension and deposited on the sea floor is the base of a micrite envelope and forms the eccentric nucleus of a subsequent new superficial ooid. Bottom: Ongoing ooid formation subsequent to rolling and turning.

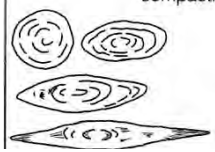
Broken and regenerated ooids (Carozzi 1961a)
Criteria: Fragments of radial or tangential ooids that act as nuclei for new ooids are surrounded by ooid laminae. The ooids are characterized by alternating concentric ooid laminae and micritic laminae (white).
Occurrence: Common in high- and low-energy settings, occurring together with partly cracked ooids and regular ooids.
Interpretation: These ooids indicate multiple synsedimentary reworking and breaks in the formation of ooids, commonly associated with redeposition. Also known from ferruginous ooids ('hiatus ooids', Berg 1944).

Distorted ooids (Carozzi 1961b; Conley 1977)
Criteria: Characterized by notched and stretched, sometimes flattened ooid grains, or grains connected by narrow apophyses, or series of grains linked in zigzag chaines parallel to bedding. The distortion has commonly preceded cementation and strong compaction. These ooids co-occur with other distorted grains (e.g. micritized intraclasts) in irregular pockets or in zones parallel to the bedding.
Occurrence: Restricted to specific limestone horizons, affected by strong waves or currents. Common also in non-carbonate oolitic deposits.
Interpretation: The shapes of distorted ooids illustrate a complete gradation from initial rupture and plastic deformation of soft grains to the rupture of rigid bodies. Explanations include fracture and plastic alteration of soft ooids in a turbulent environment, sediment sliding, or compaction. Deformation occurs when uncemented or poorly cemented ooids are buried (Pl. 13/8, Pl. 36/5). The term also is used for pitted ooids and cracked ooids which result from mechanical distortion and pressure solution. These ooids exhibit displaced and sometimes broken laminae (Pl.150/2).

Half moon and shrunken ooids (Wherry 1916; Mazzullo 1977)
Criteria: Ooids in which the interior cores have dropped to the bottom of the concentric outer layers, forming a geopetal fabric. Cross sections commonly exhibit a 'half-moon' aspect characterized by an internal dividing line convex upward which separates an upper light part (frequently calcite-filled) and a lower dark part.
Occurrence: Rare in carbonate-evaporite series, but also known from meteorically influenced carbonates.
Interpretation: These ooids may be products of evaporite-carbonate or aragonite solution diagenetic processes (Carozzi 1963) and may indicate vanished evaporites in associated rocks (Folk and Pittman 1971; Folk and Siedlecka 1974). Geopetal ooids, however, can also result from the selective aggrading recrystallization of the ooid nuclei during a period of meteoric diagenesis (Mazzullo 1977).

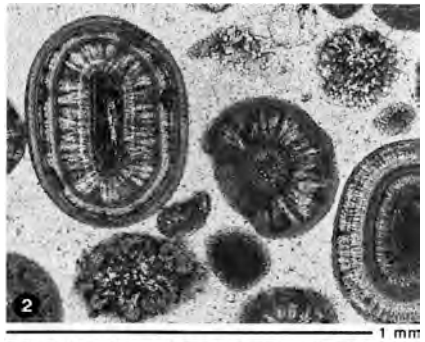


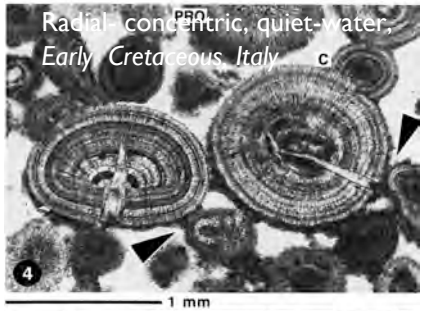
Spiny ooids (Davaud et al. 1990)
Criteria: Characterized by external cortices exhibiting spines. The external cortices are detached from the underlying cortices near the points of contact between ooid grains, suggesting a postdepositional origin for the spines. The external cortices (white) are not stretched or broken and fit perfectly into the underlying cortices (densely arranged laminae) in undeformed areas.
Occurrence: Lagoonal beach sands cemented in a vadose environment.
Interpretation: The ooids are explained by tangential compressive deformation due to crystal growth in the outer cortices during early subaerial deformation. Spiny ooids differ from distorted ooids formed during burial compaction; these ooids display convex forms pointing into the pore space.

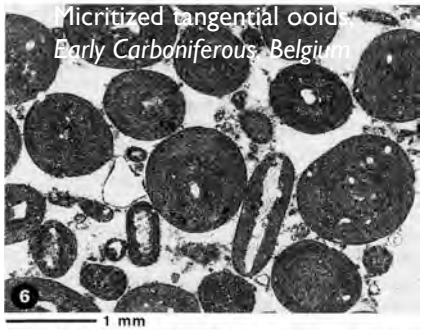


Deformed ooids (Cloos 1947; Nissen 1964; Badoux 1970)
Criteria: Originally spheroidal ooids are distinctly elongated, flattened and stretched. Microfabric structures recognizeable in traces only or completely destroyed.
Occurrence: Described from folded carbonate series. Indicate tectonic style and timing of plastic deformations.
Interpretation: Intensive tectonic stress results in elongations parallel to the schistosity planes.

Modern arag radial and radial-concentric, *Great Salt Lake, Utah*

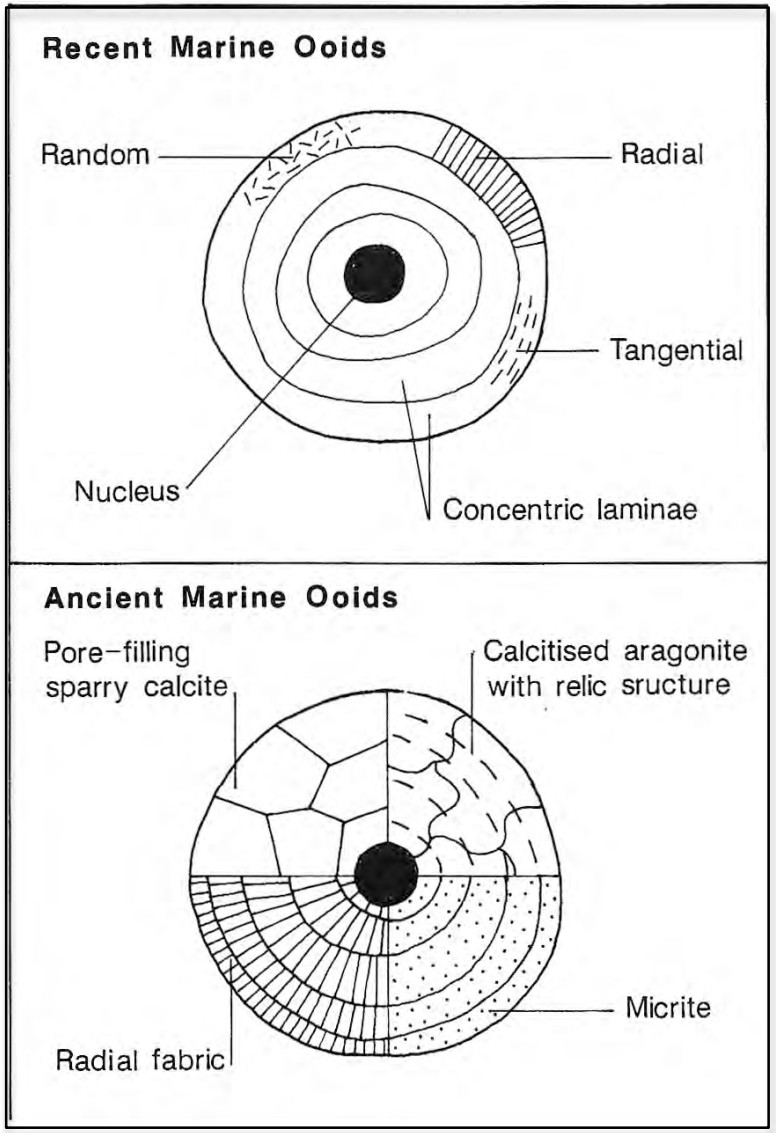






PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

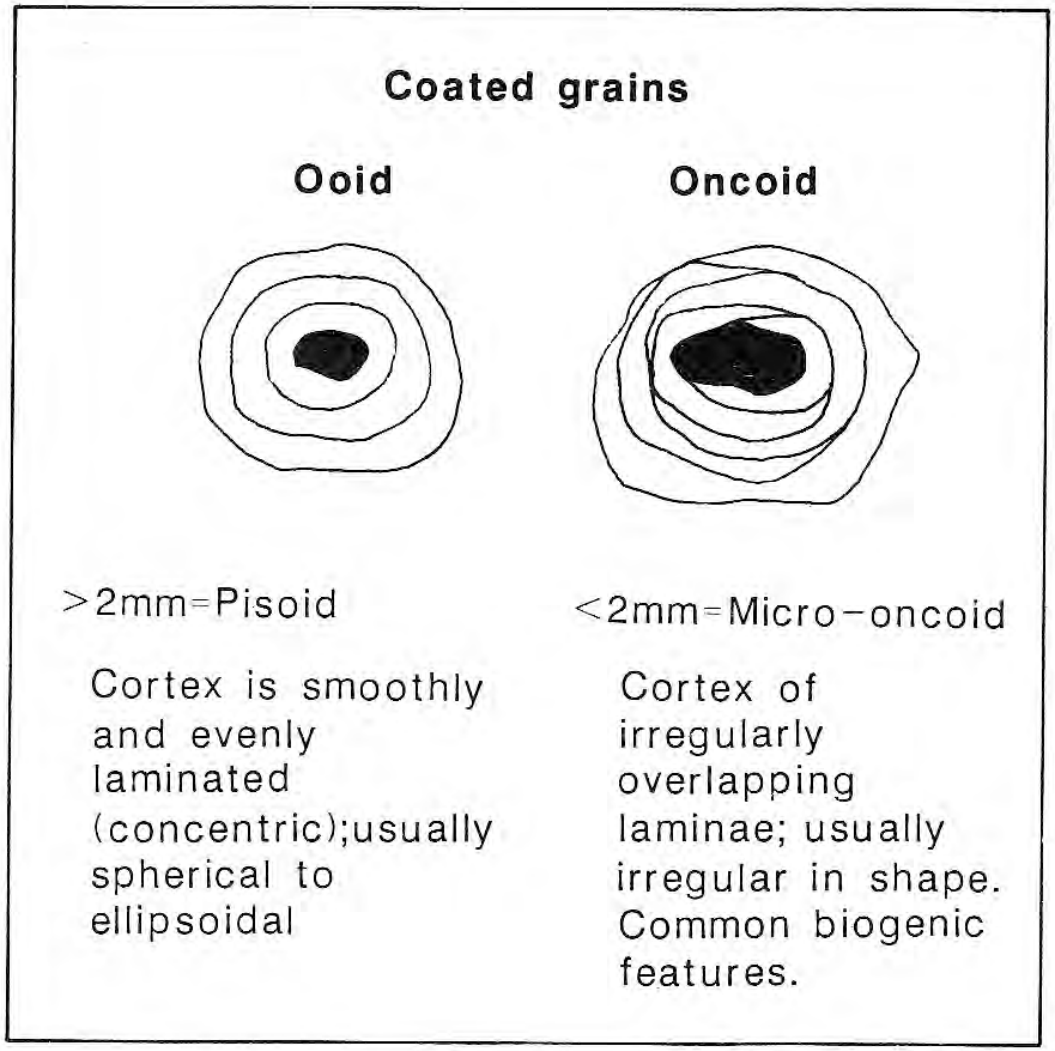
Modern ooids
Three main microfabrics
TANGENTIAL
aragonite rods
without crystal terminations
1µmL (max3µm) x0.1-0.3µm
RADIAL
fibrous/bladed arag-LMC-HMC
needles 10-50µmLx2-5µm
less common
RANDOM
arag rods or equant grains
(and microbial micritization)



Tucker & Wright 1990

Ancient ooids
more complex
DIAGENESIS
vs
PRIMARY
…

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.2 OOIDS

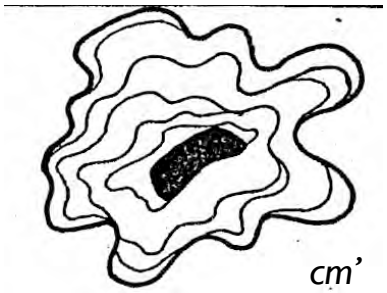


Tucker & Wright 1990

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.3 ONCOIDS

ONCOIDS ARE mm- to cm-sized ROUNDED or IRREGULARLY GRAINS WITH A LAYERED MICRITIC CORTEX AND A **BIO**- or LITHOCLASTIC NUCLEUS



✓ the term is not genetic => purely descriptive

✓ = pisoid or 'pisolith' in America!

=> also other ancient names: 'algal balls', 'algaly-coated grains', 'osagid grains' …

✓ formed by microbes, algae and other encrusting organisms

=> common in platform, reef and slope environments

✓ TWO MAJOR CATEGORIES

=> ONCOIDS formed by calcibionts and algae

=> RHODOIDS formed by calcareous red algae (Late Mesozoic to Cenozoic)

✓present-day oncoids => wide variety of environments (≠ooids)

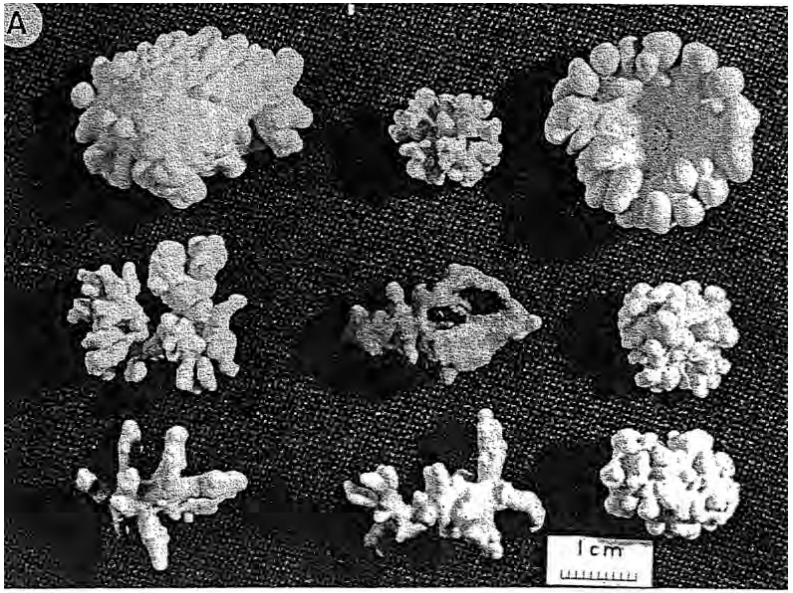
=> freshwater lakes, streams, marshes to marine inter- and subtidal conditions

=> the concentric laminae are formed by adhesion of fine grains of sediment to the mucilaginous surface of algal mats AND also by precipitation of $CaCO_3$ by algae as a result of the photosynthesis)

=> common sizes 1cm-10cm (up to 25cm). Ancient oncoids have about the same size.

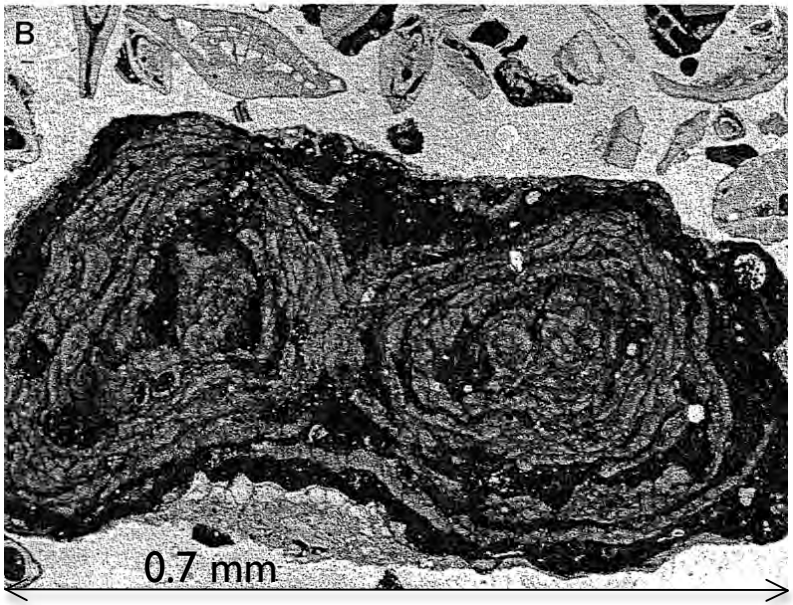
PETROGRAPHY OF CARBONATES
3. GRAINS = 3.3 ONCOIDS

Rhodoids
with different
morphologies



PERSIAN GULF

Section trough
one of these rhodoids



Purser 1980

PETROGRAPHY OF CARBONATES

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✓ TERMINOLOGY : 'CONFUSED'

=> SPONGIOSTROMATE vs POROSTROMATE ONCOIDS

Spongiostromata (from Carboniferous of Belgium) = nodules with defined growth forms but without (or rarely) visible organic structures => microbial (cyanobacterial? origin + diagenesis)

Porostromata exhibiting preserved tubular microstructures

= => spongiostromate oncoid and porostromate oncoid : laminated dense micritic or spongy fabric without or with fine micritic –walled tubes < 100µm in size

=> ONCOIDS and STROMATOLITES, unattached *vs* attached, related to 'algal' mats = 'microbialites' …

=> CYANOLITE or CYANOID: cortex with calcified filamentous and coccoid cyanobacteria ….

=> RHODOLITE or RHODOID : cortex predominantly with coralline algae

=> NON-ALGAL ONCOIDS and MACROOIDS : cortex with bryozoans, serpulids, forams (sessile) …

=> COMPOSITE ONCOIDS : cortex = association of different (micro)-organisms

=> MICRITIC ONCOIDS : no distinct lamination but comparable in shape to other oncoid types

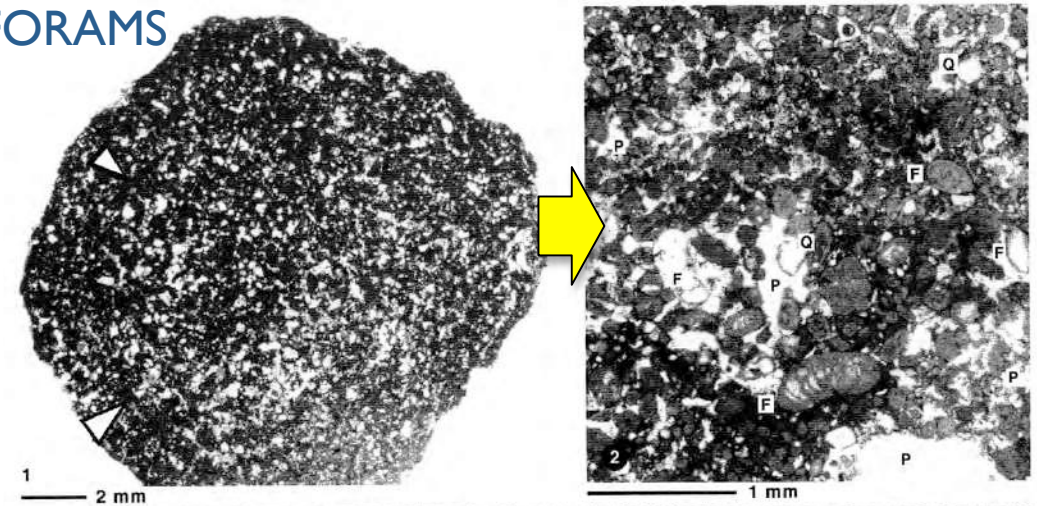
=> …

✓ SIZE CATEGORY : MICROID (<2mm), PISO-ONCOID (2-10mm), MACROOIDS (>10mm)

✓ NON-CARBONATE ONCOIDS : phosphatic oncoids (Mesozoic pelagic swell), Fe-Mn oncoids (Jurassic of Italy, Spain …) associated with hardgrounds, also pyrite oncoids (pelagic)

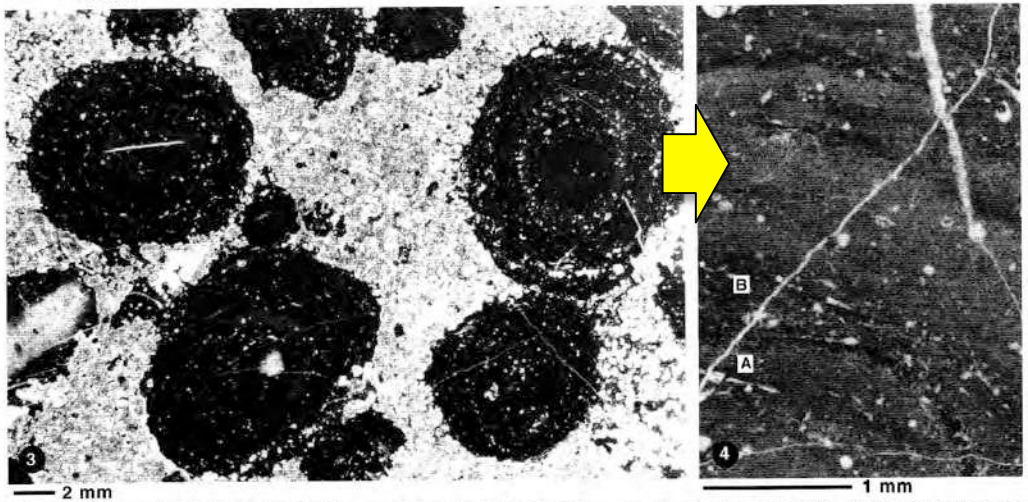
ONCOID –MICROBES/FORAMS

Micritic oncoid with a poorly developed laminar fabric (arrows) from a quartz bearing sand
Red Sea, Sinai, Egypt



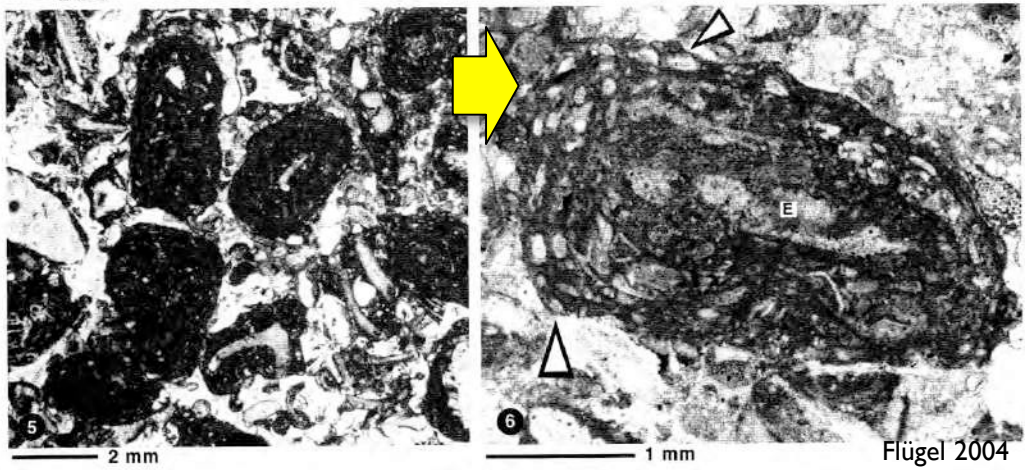
Sediment-trapping on the slimy surface of microbial film
Q = Qz
F= foram
P = open interparticle porosity

Spheroidal spongiost/porostr oncoids
Intergranular pores are occluded sparitized LMC rhombs after dedolomitization processes
Jurassic, Slovenia



B = horizontally growing *Girvanella*-like tubes

Foraminiferal oncoids in a bioclastic grainstone,
High energetic shoals, Bajocian, Bourgogne, France



Nubecularia oncoid
E = echinoderm fragment (nucleus)
Arrows: chambers of foram

Flügel 2004

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.3 ONCOIDS

Oncoid around a gastropod-shell
Concentric annual couplets (porous/dense)
Ore Lake, Michigan

Jones & Wilkinson 1983

Weiss 1969

Oncoid around a gastropod-shell
Flagstaff Limestone, Paleocene-Eocene

Oncoid, Flagstaff Limestone, Green River Formation, Paleocene-Eocene
Weiss 1969

PETROGRAPHY OF CARBONATES

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ONCOIDS ARE mm- to cm-sized ROUNDED or IRREGULARLY GRAINS WITH A LAYERED MICRITIC CORTEX AND A **BIO**- or LITHOCLASTIC NUCLEUS

✓ INTERPRETATION : key parameters

=> the shape, internal structures and biotic compositions = paleoenvironmental conditions (e.g. water energy, sedimentation rates, redox potential), salinity) and specific settings

Example : water-energy levels

- stationary growth => asymmetrical shapes and asymmetrical widths of laminations
- rolling => subspherical shapes, well-laminated cortices, concentric symmetrical growth patterns, abrasion of algal or cyanobacterial structures
- cessation of rolling => strongly encrustated laminae surfaces
- lack of rolling => branched and lobate oncoid shapes
- common rolling to less frequent rolling: multistage oncoids, laminar => lobate

….

- redeposition: smoothing and breaking

….

✓ FACIES : predominantly wackestones, packstones and floatstones in varous settings

✓ **RESERVOIR ROCKS : micritic oncoid limestones are poor reservoirs (but they are exceptions...).**

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.3 ONCOIDS

✓ **ANCIENT** ONCOIDS

Most consist of calcite, sometimes with minor admixtures of clays, quartz and organic matter.
They are MARINE or NON MARINE

- Non marine oncoids

• lakes (since Precambrian) including soda lakes (Tertiary) or hypersaline lakes
=> insights into regional climate and lake level fluctuations
=> common sizes: 1.5cm-20cm
(freshwater and saline oncoids can be separated by different types of bioclastic nuclei)

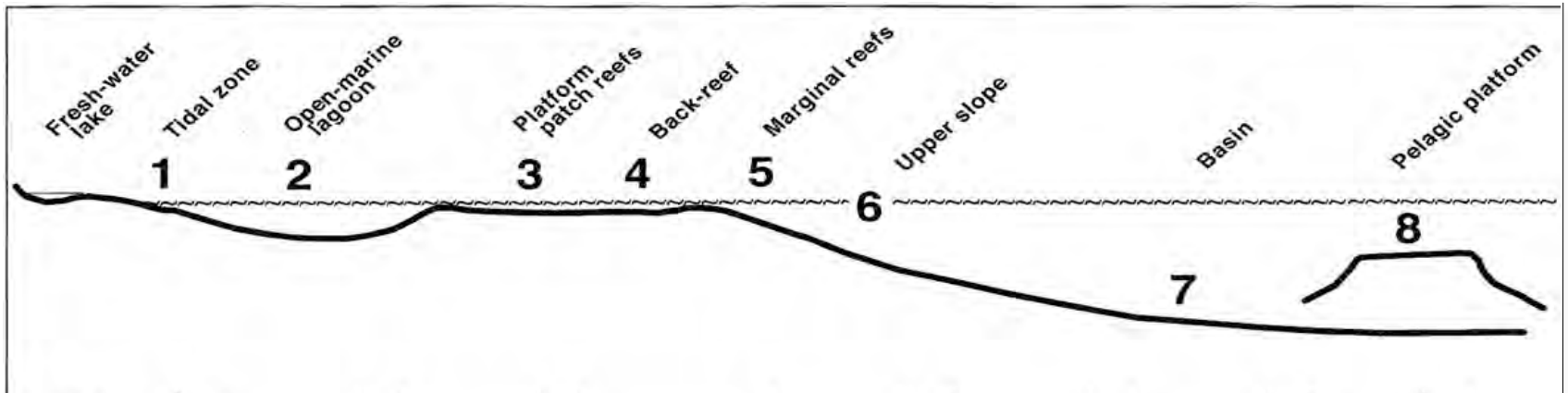
• near-shore environments
=> often with high energy mixed siliciclastic-carbonates

• fluvial channels
• ponds
• deltaic settings (boundary continent/sea)

- Marine oncoids

• tidal influenced marginal-marine
• open-marine shelf lagoons
• platform patch reefs
• back-reef areas
• platform margin reefs
• upper slope
• basin
• pelagic platforms

PETROGRAPHY OF CARBONATES
3. GRAINS = 3.3 ONCOIDS



Location	1	2	3	4	5	6	7	8
Depositional texture	Wackestone Packstone Bindstone	Wackestone Packstone Floatstone	Wackestone Packstone Floatstone	Grainstone Rudstone Wackestone	Packstone Rudstone	Wackestone Floatstone	Floatstone	Grainstone Packstone
Associated grains	Peloids Cortoids Stromatolites Birdseyes	Bioclasts	Bioclasts Peloids	Cortoids Bioclasts Intraclasts	Bioclasts Lithoclasts	Bioclasts	Bioclasts	Peloids
Associated fossils	Foraminifera Algae	Mollusks Foraminifera Algae	Foraminifera Reef biota	Foraminifera Calcar. algae Mollusks	Reef biota	Mollusks Echinoderms	Ammonites	Planktonic foraminifera
Type of oncoid	Simple Multiple	Simple	Simple Multiple	Simple	Simple	Simple	Simple	Simple
Prevailing size	10 - 50 mm	< 2 mm 5 -60 mm	2 - >10 mm	2 - 10 mm	2 - 20 mm	10 - 20 mm	30 - 300 mm	1 - 2 mm
Growth type	Concentric Lobate Radial	Lobate Concentric	Concentric Radial Lobate	Concentric	Concentric Inverse	Elliptical	Concentric Radial Inverse	Concentric

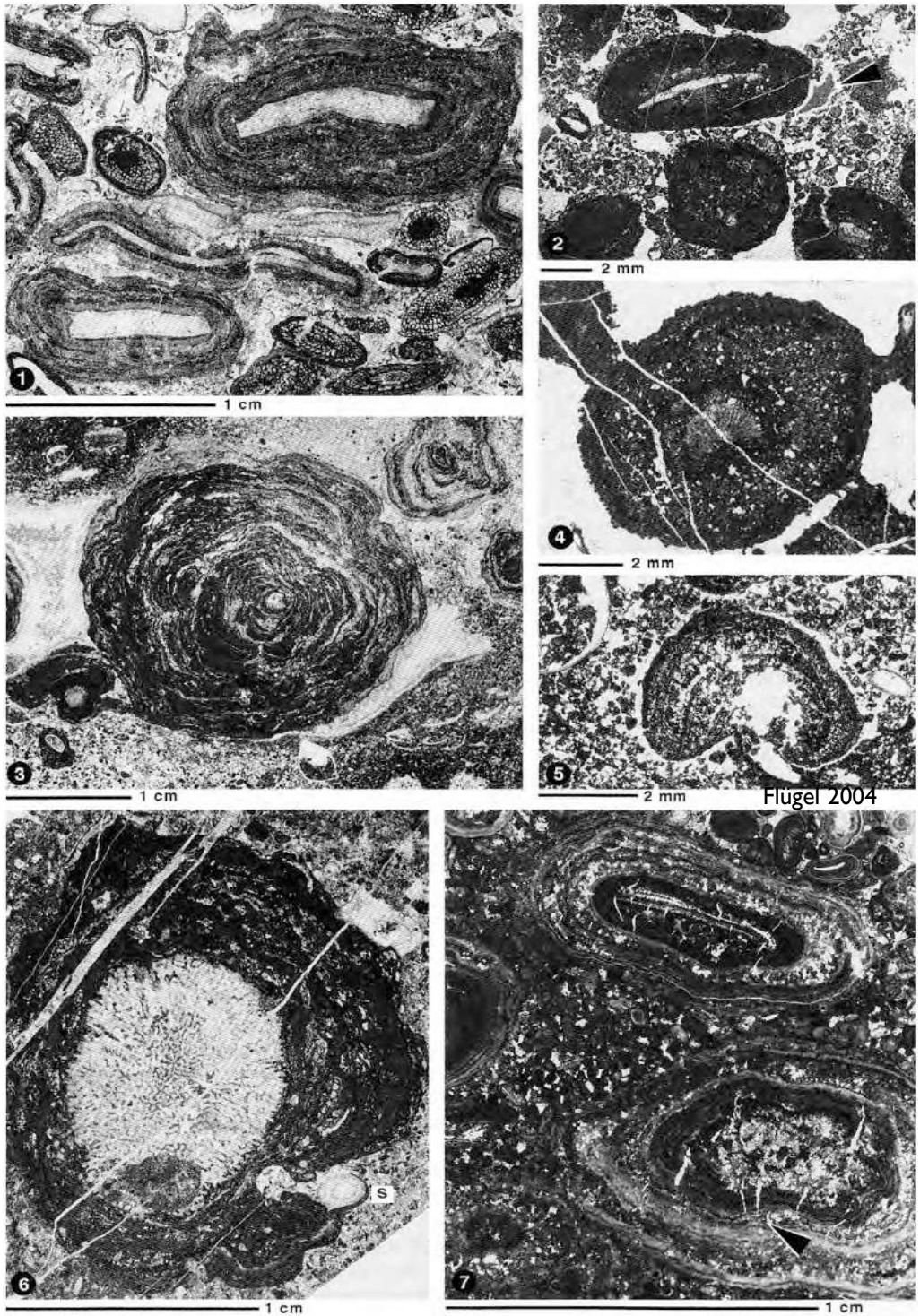
many authors… *in* Flügel 2004

Depositional environments and characterstics of Late Jurassic (Oxfordian-Kimmeridgian) oncoids.

Cyanoids (calcified porostromate cyanobacteria). Irregular discoidal, breaks in growth layers. Cores are platy phylloid calcareous algae. *Early Permian, Carnic Alps , Austria and Italy*

Porostromate oncoids ?green-algae or cyanobacteria). *Fore-reef slope, Late Devonian (Frasnian), Canning basin, Australia.* Commonly associated with lamellar stromatoporoids.

Rhodoid spheroidal, laminar corallinaceae (black)/encrusting foram (white chambers) and serpulid worms (S). Nucleus = poritid coral. *Shallow subtidal back-reef, Early Tertiary, Austria*



Micrite oncoids = micritization of microbial oncoids, aggregates, peloids. Nuclei = shells and forams. *Open marine platform, Early Jurassic, Greece*

Two-stage oncoids Microbial laminae *(Bacinella)*, nucleus = coral+sponge, *High energy subtidal env., Late Jurassic, Austria.*

Modern soft lacustrine oncoid : cyanobacteria and algae, asymmetrical growth… *in 0.5-1.5 m water, Lake Constance, S Germany*

Brackish-water oncoids : cyanobacteria and algae, elliptical. Discontinuous laminae and shrinkage structures. Coastal pond, *Late Jurassic, Portugal.*

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.4 PISOIDS-VADOIDS

GRAINS similar to ooids, but have a DIAMETER > 2mm
CARBONATE or NON-CARBONATE

✓ **DIFFERENT NAMES FOR THE 'PISOIDS'** from *pisum* = Latin for pea

- diagenetic ooids
- cave pearls in speleothems
- caliche ooids
- vadose ooids or vadoids => influence of freshwater vadose or marine vadose environment
  => specific cements
- coniatoids : carbonate crusts of uniformly thick coatings of ARAG lamellae, supratidal zone, Persian Gulf
- macrooids
- ….

✓ **CHARACTERISTICS**

- generally larger than most marine ooids, dense or irregular laminations around a NON-skeletal nucleus
- generally no encrusting biota (≠ oncoids)

- Shape cf. energy

- HE : increasing roundness in continuously agitated water
  => cave pearls, geyser waters
- LE : irregular layers and strong deviations from the spherical shape in quiet-
  => asymmetrical, downwarp or upwpard thickening, lateral elongation = 'in-situ' growth
- HE/LE => broken and recoated pisoids (alternating periods of fracturing/reworking/growth)

- Nucleus

- fragment of pisoids, cement crusts, lithoclasts, mineral grains
- sometimes more than one nucleus

- Cortex

- concentric of very densely spaced dark [=? microbial] and light [=microspar] laminae

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.4 PISOIDS-VADOIDS

GRAINS similar to ooids, but have a DIAMETER > 2mm
CARBONATE or NON-CARBONATE

✓ MODERN PISOIDS : various climate zones

- hypersaline settings (Persian Gulf) = ARAG and/or HMC
- chemical precipitation from carbonate-saturated agitated water (cave pearls or 'thermic pisoids [Mamooth Hot Springs, Yellowstone]
- chemical and biochemical precipitation in low-energy environment (vadose, fluvial, hypersaline …)
- concretionary growth in arid and semi-arid pedogenic layers (caliche)
- …

✓ ANCIENT PISOIDS

- FROM PRECAMBRIAN to PLEISTOCENE
- generally altered by diagenesis => sparitic laminae caused by meteoric-phreatic inversion of originally aragonitic laminae into granular calcitic laminae without a distinct dissolution phase

=> 'brick-like microfabric'

=> primary marine pisoids are known from Paleozoic and a few Triassic and Jurassic occurrences

=> in contrast to the scarce Paleozoic marine pisoids, those **in Proterozoic are abundant** and associated with ooids, stromatolites, intraformational conglomerates =? different degree of carbonate supersaturation…

✓ NON-CARBONATE PISOIDS

- feruginous (Fe related to volcanism and weathering), phosphatic and siliceous

=> laterite and bauxite profiles …

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.4 PISOIDS-VADOIDS

GRAINS similar to ooids, but have a DIAMETER > 2mm
CARBONATE or NON-CARBONATE

✓ IMPORTANT POINTS

- concerning **texture :** inverse grading is common in authochtonous pisoids formed *in situ*
- common association with fenestral carbonates, tepees, diagenetic grainstones, vadose crusts
- **sea-level fluctations** : pisoids may indicate breaks in sedimentation caused by drops in sea level
  => association with karstification phases (supra- and intertidal members, shallowing-upward cycles)
- **paleoclimate** : cave and caliche pisoids reflect seasonal changes and longer term climatic changes
- …

✓ ECONOMIC IMPORTANCE

- **Pisoid limestones are important reservoir rocks (Permian of West Texas, Mississippian of North Dakota. Porosity is enhanced by subaerial and vadose dissolution related to pisoid formation.**

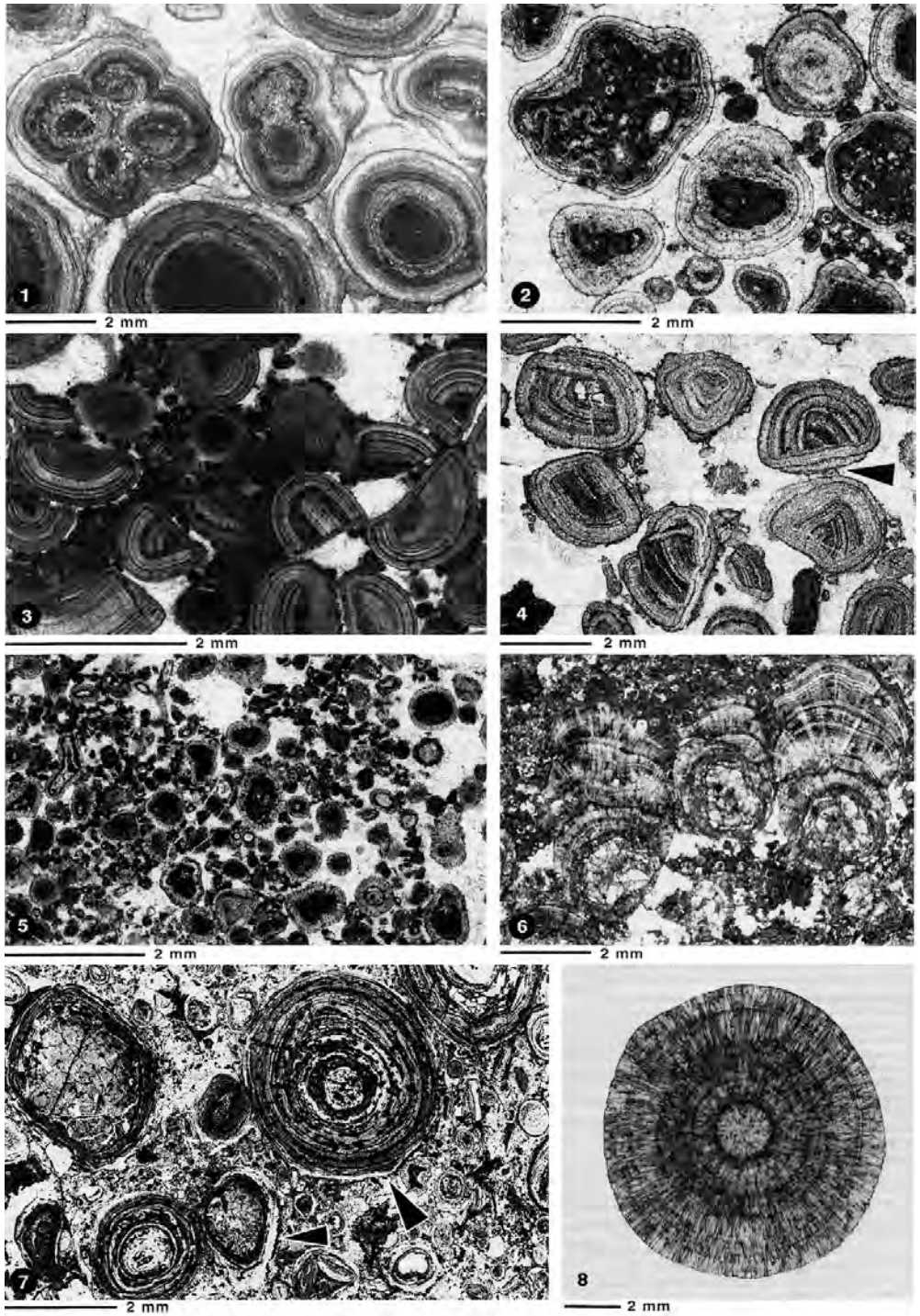
PISOIDS
in Flügel 2004

Vadose-marine pisoids, accretionary growth on a shelf crest within shoaling upwards sequence in a protected hypersaline environment. White areas = neomorphic carbonate.
Late Permian, New Mexico, USA

Broken and reworked pisoids
Cretaceous, Apennines, Italy

'Coniatoids' with large non-skeletal nucleus
Early Carboniferous, Cracow area, Poland

Siliceous pisoids
Bauxite paleokarst surface, with shrinkage pores (arrows)
Cretaceous, Subsurface Ras al Khaimah, U.A.E.



'Coniatoids'
Irregular, non-spheroidal grains with marine nuclei (aggregate grains). Supratidal.
Early Carboniferous, Cracow area, Poland

Vadose pisoids
meniscus cement (arrow)
Late Permian (Zechstein), Subsurface,N Germany .

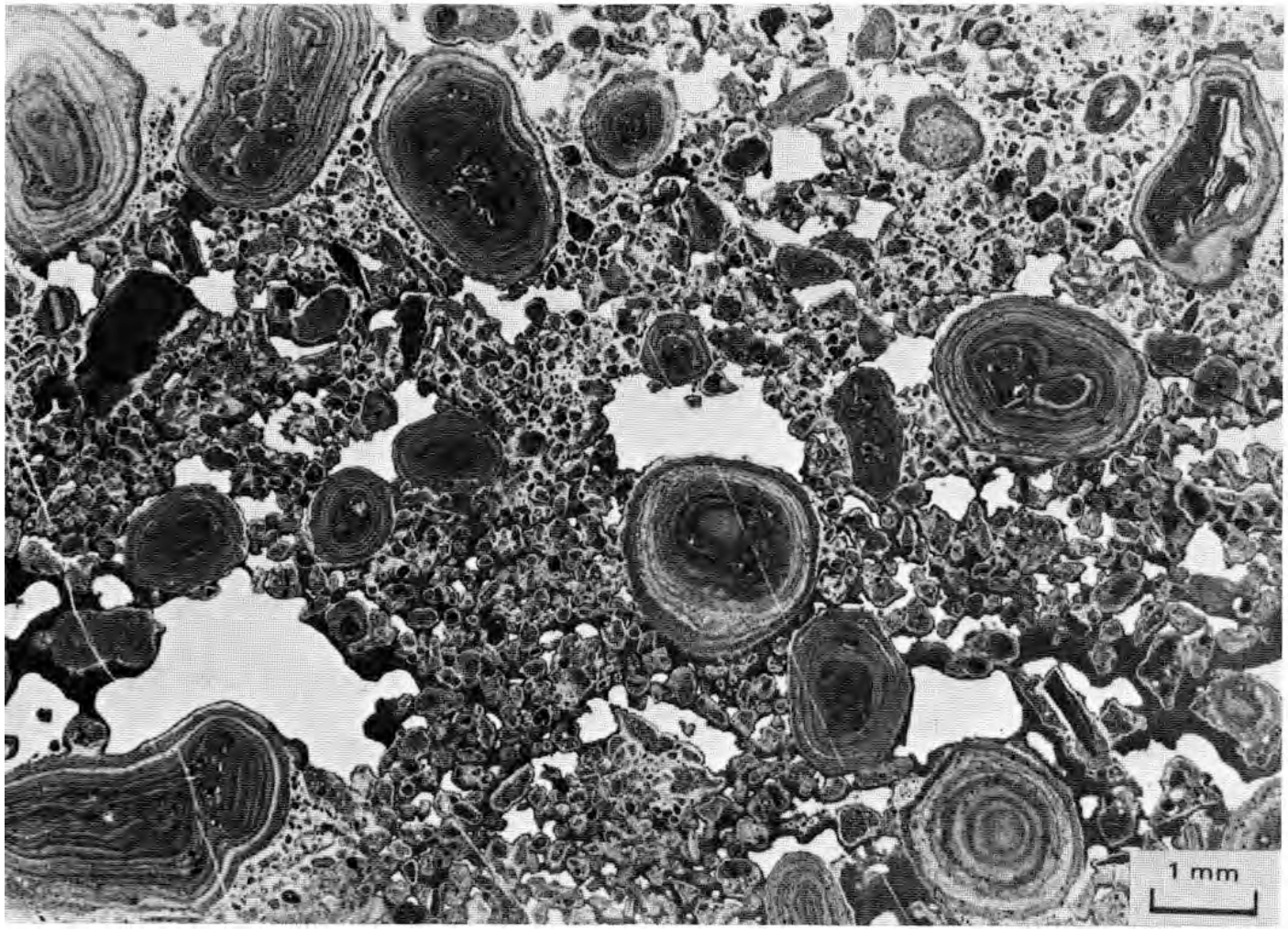
Caliche pisoids
top of lacustrine stromatolites. Upward growth, vadose and phreatic
Early Permian, Germany

Cave pearl
of a modern speleothem, vadose and phreatic,
Subrecent, Austria

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.4 PISOIDS-VADOIDS

GRAINS similar to ooids, but have a DIAMETER > 2mm
CARBONATE or NON-CARBONATE



Asymmetrical (vadose) caliche (pisoid). Some pisolites are composite
Elf Aquitaine, 1975

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.4 PISOIDS-VADOIDS

GRAINS similar to ooids, but have a DIAMETER > 2mm
CARBONATE or NON-CARBONATE

Cave pearls and laminated cavern sediment with **reverse-grading** (coarsening upward grain size arrangements). Esteban & Klappa 1983.

Caliche layers, Pleistocene eolianite, Yucatan Peninsula. Micritized eolianite is overlain by conglomeratic layer with **crude reverse-grading**. McKee & Ward 1983.

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.5 AGGREGATES

=grapestones-lumps-composite grains

COMPOSITE GRAINS of ooids, skeletal material and peloids

✓ **AGGREGATE GRAINS** first studied in the Bahama => **'BAHAMITES'**

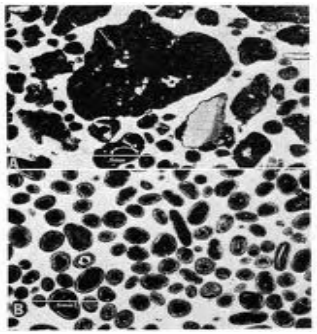
- common on shallow-marine carbonate platforms in lagoonal settings
- the grains are bound together by organic films and ARAG or HMC cements
- typical lobate shapes
- encrusted by forams, algae or serpulids (worms)

✓ **GENESIS**

- stabilization of the individual particles during reduced phase of deposition in environments with restricted circulation
  => cementation on the sea bototm and periodical reworking
  => bioflims, microbially induced early cementation between particles
  = > absence of mud

✓ **CARBONATE CLASSIFICATION**

- included aggregate grains in the intraclast or lithoclast categories…



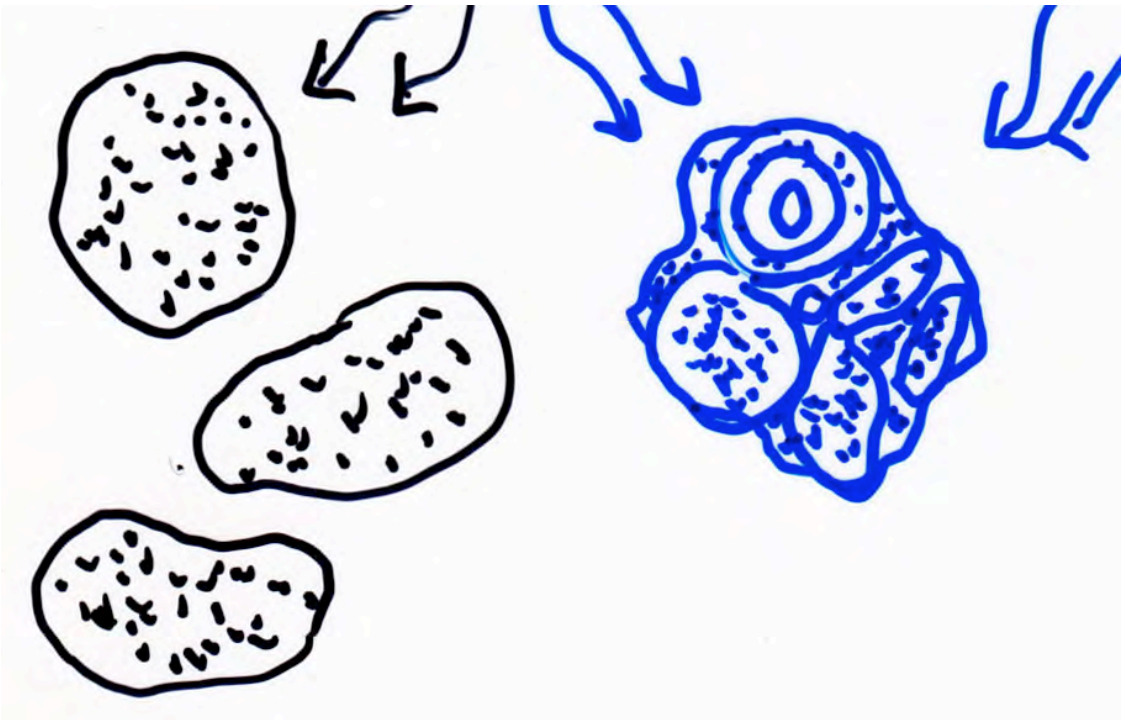
Bahama Banks, intermittent agitation

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.5 AGGREGATES

=grapestones-lumps-composite grains

COMPOSITE GRAINS of ooids, skeletal material and peloids



PETROGRAPHY OF CARBONATES

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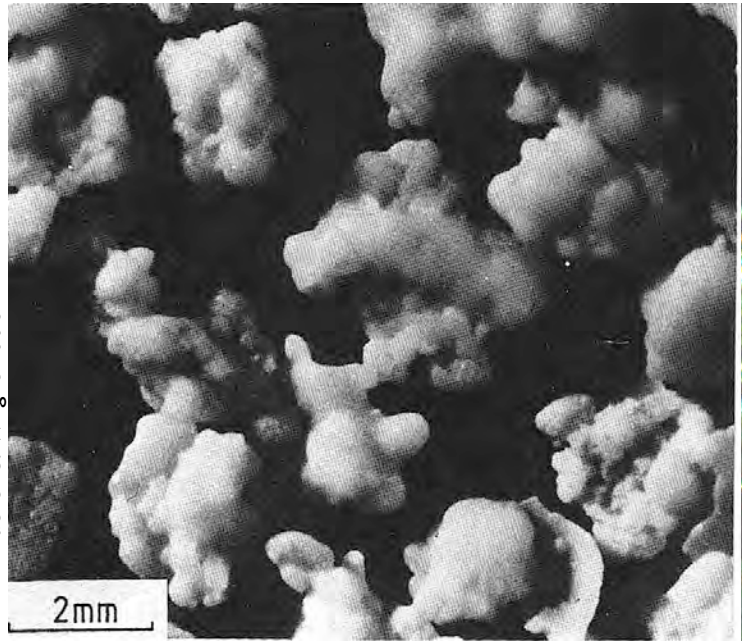
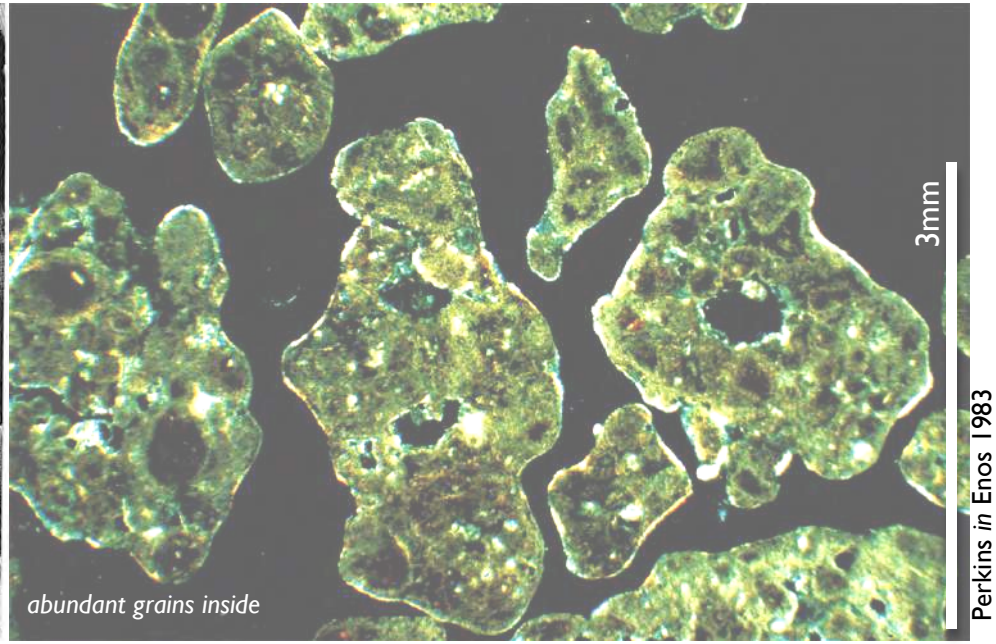


Till *in Tucker & Wright 1990*

Grapestones = aggregate grains of bioclasts and peloids cemented by micritic aragonite



Perkins *in* Enos 1983

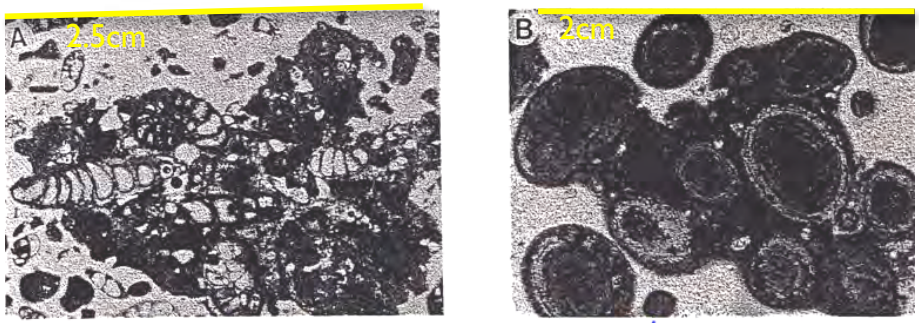
Grapestones from the Great Bahama Bank (cross polarized light)

PETROGRAPHY OF CARBONATES

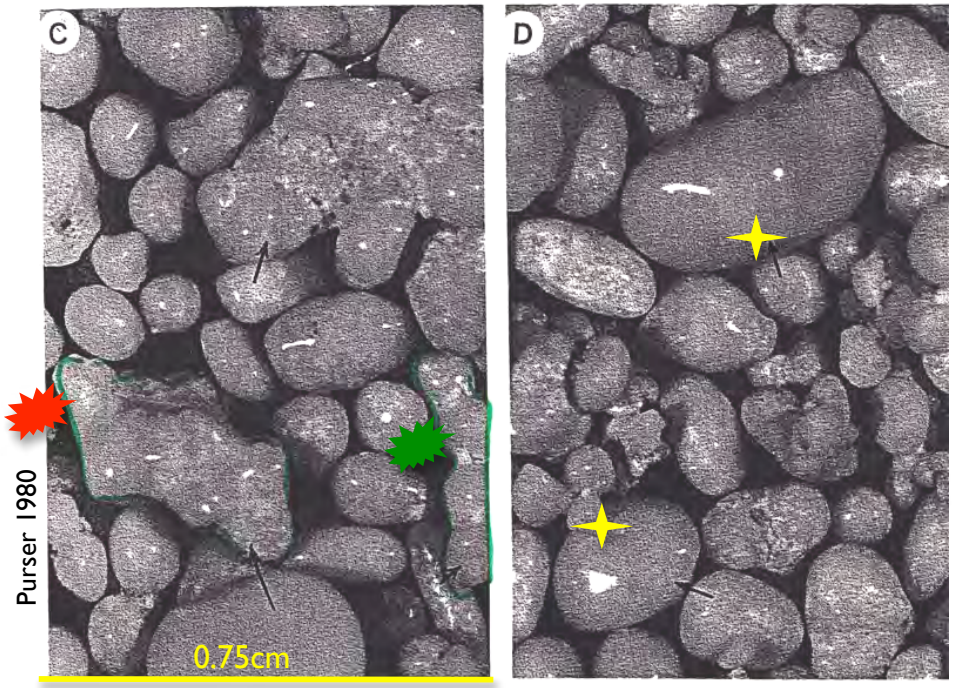
3. GRAINS = 3.5 AGGREGATES

=grapestones-lumps-composite grains

COMPOSITE GRAINS of ooids, skeletal material and peloids



LUMPS - GRAPESTONES = AGRÉGATS



Purser 1980

A. aggregate of cemented forams, Abu Dhabi
B. aggregate of oolites, Bahamas
C. aggregate of oolites with typical **grapestones** Bahamas
D. aggregate covered by an oolitic cortex = **'botryoidal lump'** (scale as C.)

'BAHAMITES'

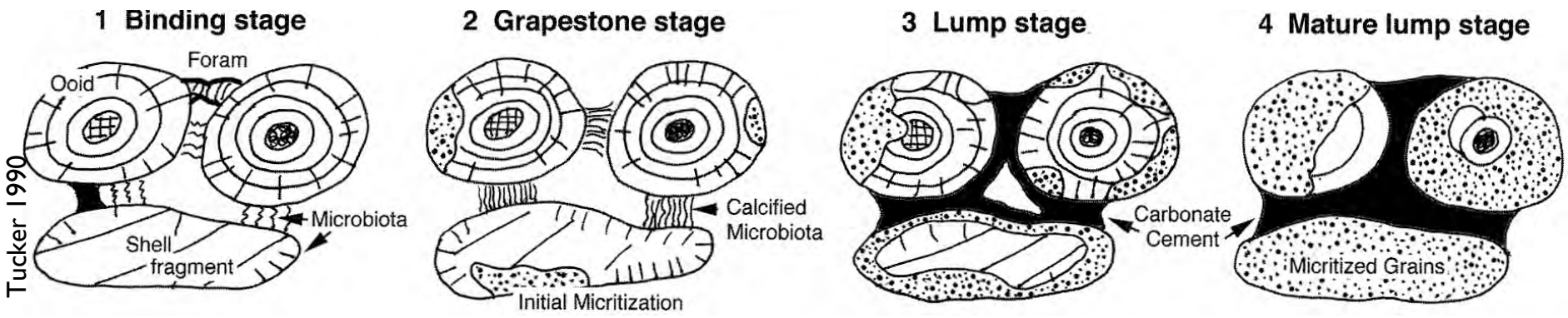
PETROGRAPHY OF CARBONATES

3. GRAINS = 3.5 AGGREGATES

=grapestones-lumps-composite grains

COMPOSITE GRAINS of ooids, skeletal material and peloids

Multi-stage formation of aggregate grains (grapestones and lumps)



Tucker 1990

microbial filament stabilization

increasing calcification
+ microborers=>micritization

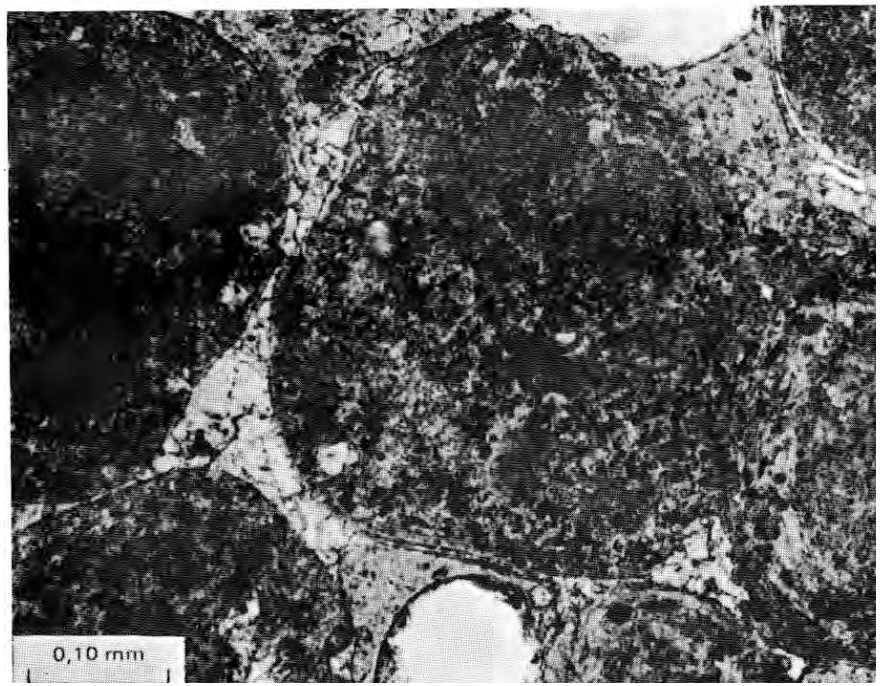
increasing calcification
increasing micritization and cementation…

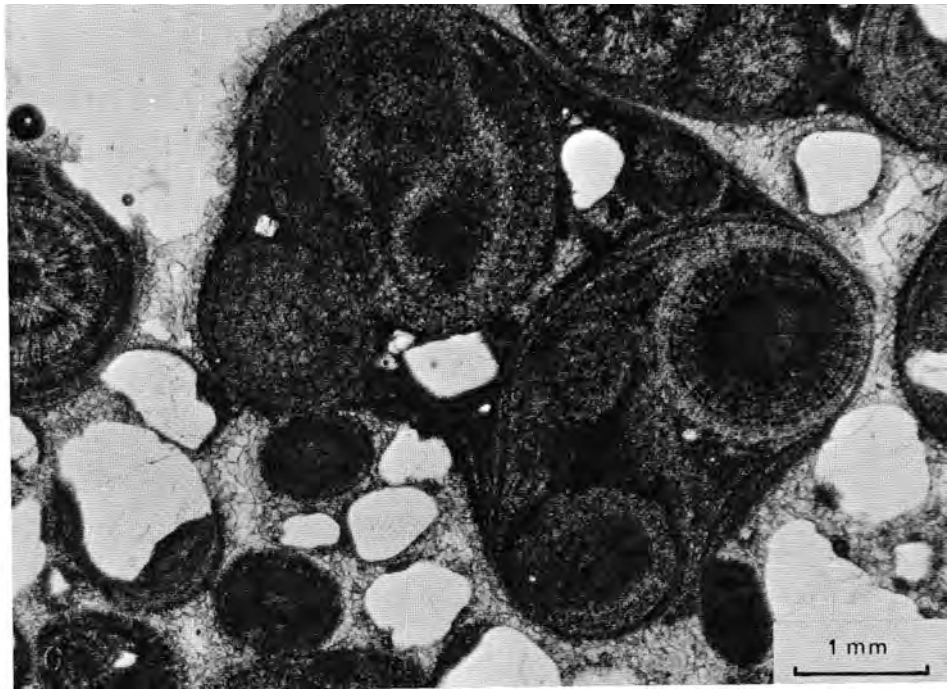
PETROGRAPHY OF CARBONATES

3. GRAINS = 3.5 AGGREGATES

=grapestones-lumps-composite grains

COMPOSITE GRAINS of ooids, skeletal material and peloids

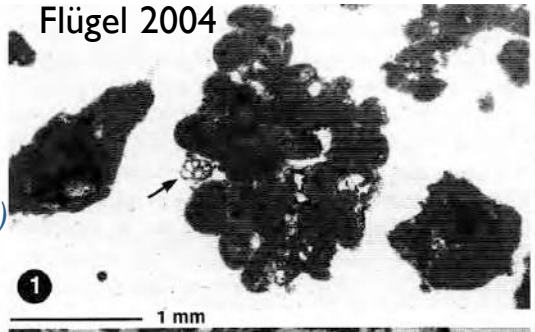


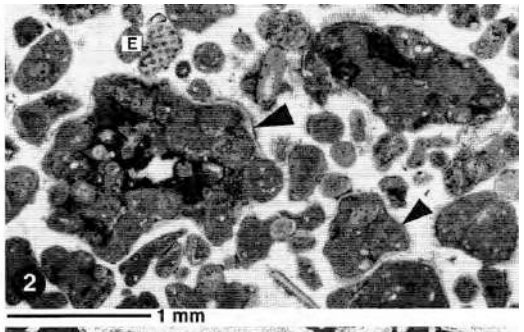


Aggregates of ooids with micritic cement and a thin external film (microbial or? algal).
Aggregates enclosed rare grain quartz .
Elf Aquitaine, 1975

Flügel 2004

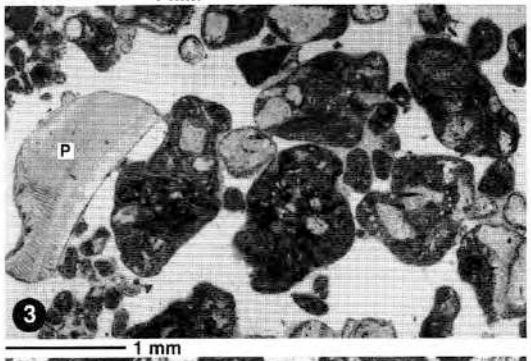
Modern aggregate ('grapestone') with ooids, peloids, forams,
Great Bahama Bank (3-15m depth)

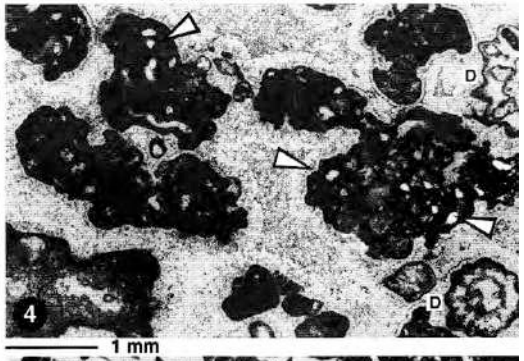




Pleistocene aggregate grains forming weakly lithified sands. Thin cements on grains (arrows)
E= Echinoid.
San Salvador Island, Bahamas

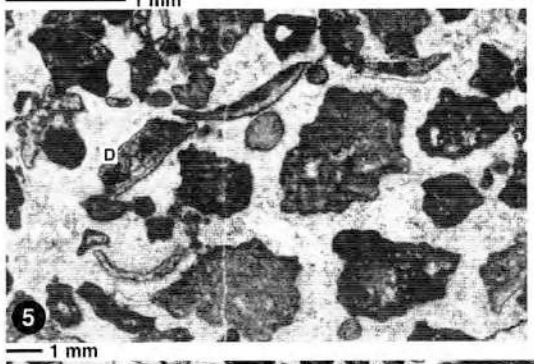
Pleistocene aggregate grains ('lumps' due to ab micrite) with ooids,, forams).
P = pelecypod (LMC) shell
San Salvador Island, Bahamas

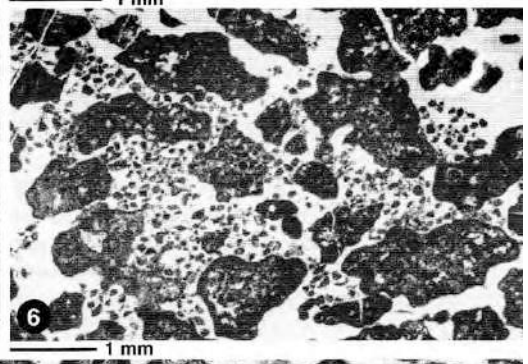




Encrusted (forams/chambers) aggregate grains
Very irregular outlines
D= Dasyclad green alga with ooids, forams).
Middle Permian, Croatia

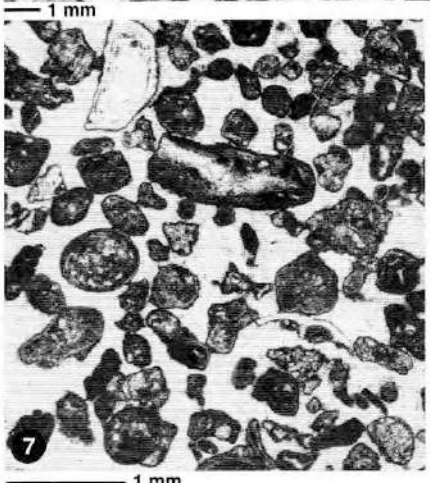
Microbial lumps and micritized Dasyclad algae (D).
Middle Triassic, Italy

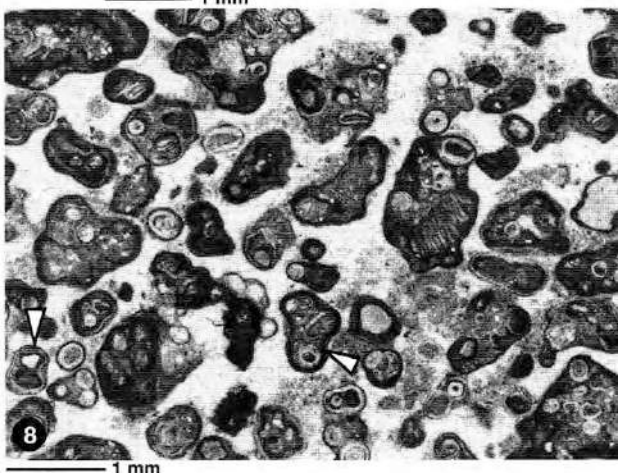




Aggregate grains (lumps) with loose peloids ('lumps' due to ab micrite)
Early Jurassic, Tunisia

Aggregate grains of (abundant) reefal biota.
Late Triassic, Austria





Aggregate-grain grainstone = 'grapestones'of ooids and fossils. Thin oolitic coating (arrows, 'botryoidal lumps')
Middle Triassic, Italy

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.5 AGGREGATES

=grapestones-lumps-composite grains

COMPOSITE GRAINS of ooids, skeletal material and peloids

✓ **ANCIENT AGGREGATE GRAINS**

- from Precambrian
- Phanerozoic records of limestones with abundant aggregates = platforms
  => they are concentrated in specific time intervals: Dev, Late Permian, Middle-Late Triassic, Jurassic, Cretaceous
  => behind and adjacent to shelf-margin reefs AND transitional areas on the seaward side of ooid shoals and green algal-foraminiferal sands and the landward side
- indicate low to moderate and changing water energy levels, tropical and sub-tropical warm water conditions, low nutrient environments and low sedimentation rates
- generally associated with attached or isolated platforms (during sea level highstand phases).

✓ **ECONOMIC POTENTIAL**

- **good reservoir rocks in association with oolites (Cretaceous of the Near East)**

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.6 PELLETS and PELOIDS

micron-mm sized ±STRUCTURELESS SUBROUNDED micritic grains

✓ **PELLETS** = grain of fecal origin => subrounded or rounded, marine or non-marine

- common on shallow-marine carbonate platforms in lagoonal settings
- dimensions => silt- to fine-sand-sized, a few mm, genrally > 500 µm and diameters < 200 µm smaller than ooids, pisoids, oncoids
- UNIFORM SHAPES (+ carbon, phosphorus….)
- typical of certain organisms (mollusks, crustaceans = *Favreina, Callianassa,* worms, holothurians, gastropods, etc

✓ **PELOIDS**

- polygenetic grains composed of micro- and cryptocrystalline carbonate (micrite) with fine-grained skeletal debris and other grains
- constitute grain- or mud-supported fabrics (wackestone, packstone, grainstone)
- isolated or amalgamated, within layered or **clotted** textures
- common in shallow—marine tidal and subtidal shelf carbonates, in reef and mud mounds, also deep-water
- absent or rare in non-tropical cool-water carbonates.

✓ **CARBONATE CLASSIFICATION**

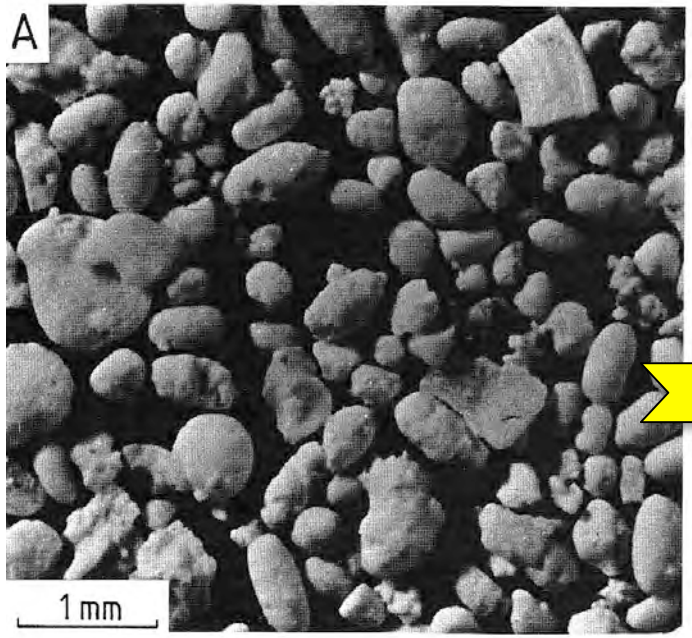
- included aggregate grains in the intraclast or lithoclast categories…

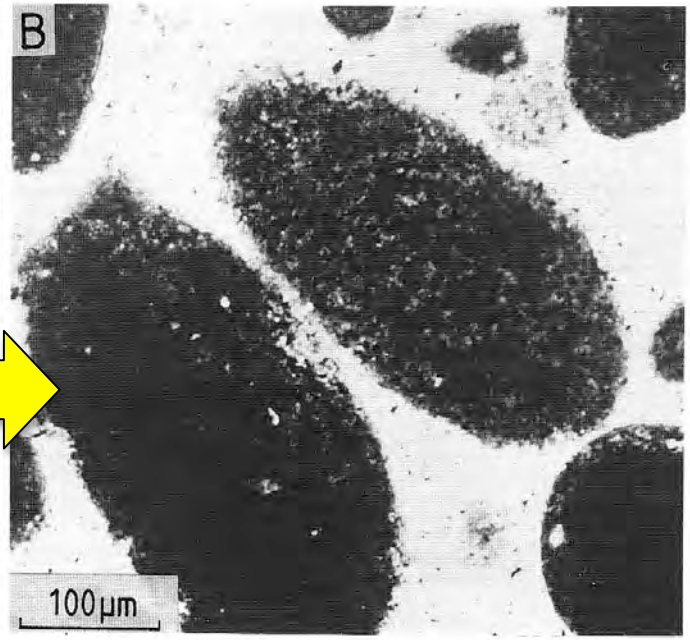
PETROGRAPHY OF CARBONATES

3. GRAINS = 3.6 PELLETS and PELOIDS

micron-mm sized ± STRUCTURELESS SUBROUNDED micritic grains

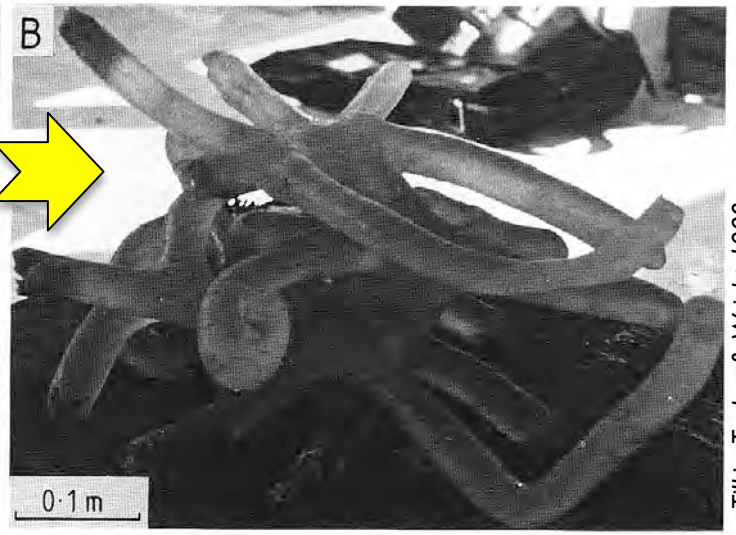
Peloidal skeletal sand washed out of sandy mud *Bahamas*





peloid displaying homogeneous micrite

Conical mounds 0.1-0.2m across produced by *Callianassa* (crustacean) in 0.5m water depth.
Also thin dark surficial microbial mat. Lagoon. *Bahamas*



Burrow system of *Callianassa* preserved in resin

Till in *Tucker & Wright 1990*

Worm ‘fecal’ production in quartzose silty (present-day) sediment, Brittany, France

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.6 PELLETS and PELOIDS

micron-mm sized ±STRUCTURELESS SUBROUNDED micritic grains

✓ **FECAL PELLETS**

- produced by organisms that eat mud, digest organic matter from the mud and excrete the non-digested lime-mud
- the dark color of the grains or the peripheral rim is caused by the high content of organic matter or iron sulfides
- fossilization requires bacterial decomposition of the organic mucus and **intragranular** cementation by HMC or ARAG => warm shallow waters that are supersaturated with respect to $CaCO_3$.
- non-marine fecal pellets => salt lakes, freshwater lakes, soils.

✓ **THE PELOIDAL QUESTION?**

- THE ORIGIN OF ANCIENT PELOIDS IS OFTEN IN DOUBT
  => <u>difficult to distinguish fecal pellets, *in situ* precipitation or 'alteration' of former micritic grains</u>…
- consitute grain- or mud-supported fabrics (wackestone, packstone, grainstone)
  => different subcategories have been established ....

The term 'peloid' is only **descriptive**, until thin-section studies provide genetic information

Origin		Types	Diagnostic criteria
Biotic Origin	Lithified organic excrements	1 **Fecal pellets**	Rounded elongated, rod-shaped or ovoid dark-colored micritic grains, rarely spherical. Commonly homogeneous or with silt-sized inclusions; rarely with defined internal structures. Sizes <100 μm to several millimeters. Sometimes associated with bioturbation structures . . . . . Pl. 136/8
	Abrasional products of algae and calcimicrobes	2 **Algal peloids**	Irregularly shaped, rounded micritic grains, exhibiting gradations from grains with relicts of algal structures to homogeneous grains. Size <20 μm to ~2 mm . . . . . Pl. 136/4
	Grains resulting from hard-part-boring and rasping activity of organisms	3 **Bioerosional peloids**	Scoop-shaped subrounded and angular grains. Sizes from 20 μm to 100 μm
Reworking of Mud and Grains	Synsedimentary and post-sedimentary reworking of carbonate mud and micrite	4 **Mud peloids** (Lithic peloids)	Variously shaped micritic grains, commonly without internal structures. Wide size ranges, poor sorting. Frequent occurrence within distinct beds or laminae . . Pl. 10/2, Pl. 121/2
	Internal micritic molds of bivalved shells	5 **Mold peloids**	Ovoid micritic grains, sometimes with relicts of still undissolved shells (ostracods, small bivalves). . . . . Pl. 132/8
Alteration of Grains	Ooids and rounded skeletal grains whose microstructures have been lost through micritization	6 **Bahamite peloids**	Round micritic grains, some of which with relicts of the primary microstructures. Association of peloids, aggregate grains and ooids. Transition of micritized bioclasts to peloids of the same size. Larger than algal peloids . . . . . Pl. 10/3, Pl. 43/1
	Ooids and skeletal grains; microstructures destroyed by recrystallization	7 **Pelletoids**	Microcrystalline grains, in places exhibiting vague residual internal structures. Diffuse outlines due to amalgamation and compaction . . . . . Pl. 38/6
In-situ Formation	Biochemical precipitation triggered by microbes and organic substances	8 **Microbial peloids**	Rounded micritic grains associated with laminated and clotted fabrics. Sizes from <80 μm to >600 μm . . . . . Pl. 8/6, Pl. 10/1
	Chemical precipitation of carbonate cements with or without organic controls	9 **Precipitated peloids**	Tiny peloids within carbonate cements; consisting of a cloudy micritic center sourrounded by clear exterior rims of crystals. Occurrence in cavity fill precipitates (e.g. in reefs) . . . . Pl. 8/5

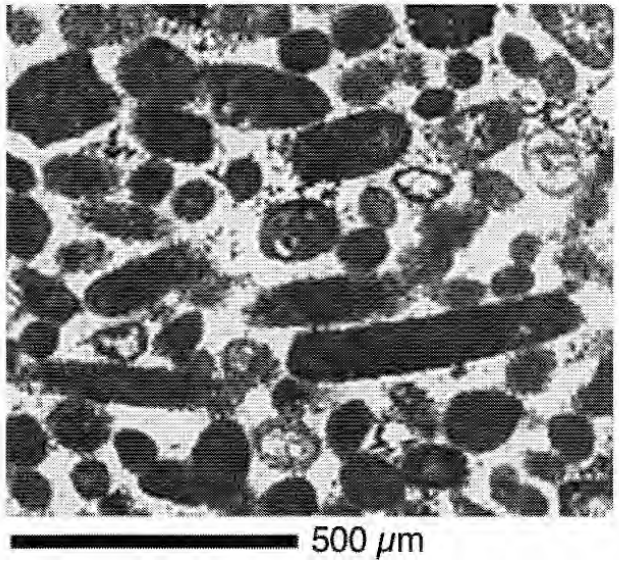
Flügel 2004

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.6 PELLETS and PELOIDS

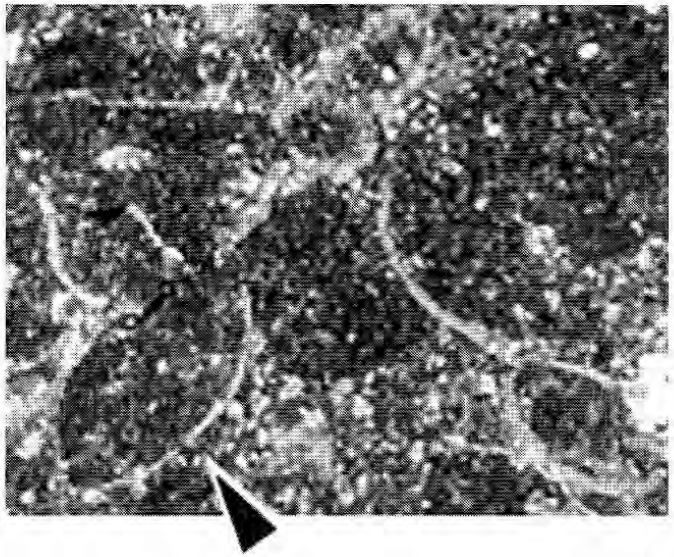
micron-mm sized ±STRUCTURELESS SUBROUNDED micritic grains

Fecal pellets



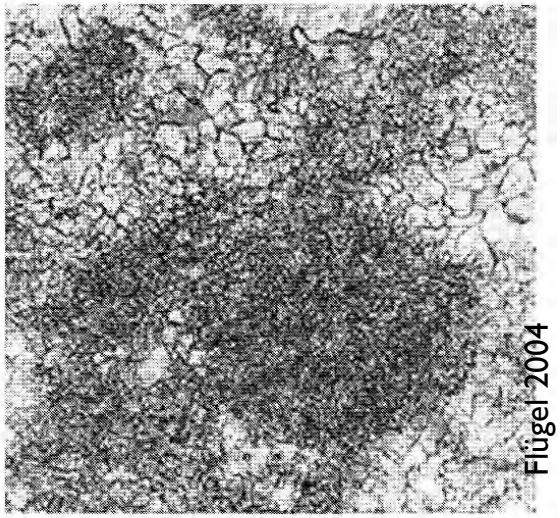
Early Cretaceous lagoonal limestone, rounded, elongated fecal pellets of different size.

Mold peloids



Middle Devonian shelf limestone, molds peloids are steinkerns of ostracods whose valves have been dissolved.

Pelletoids



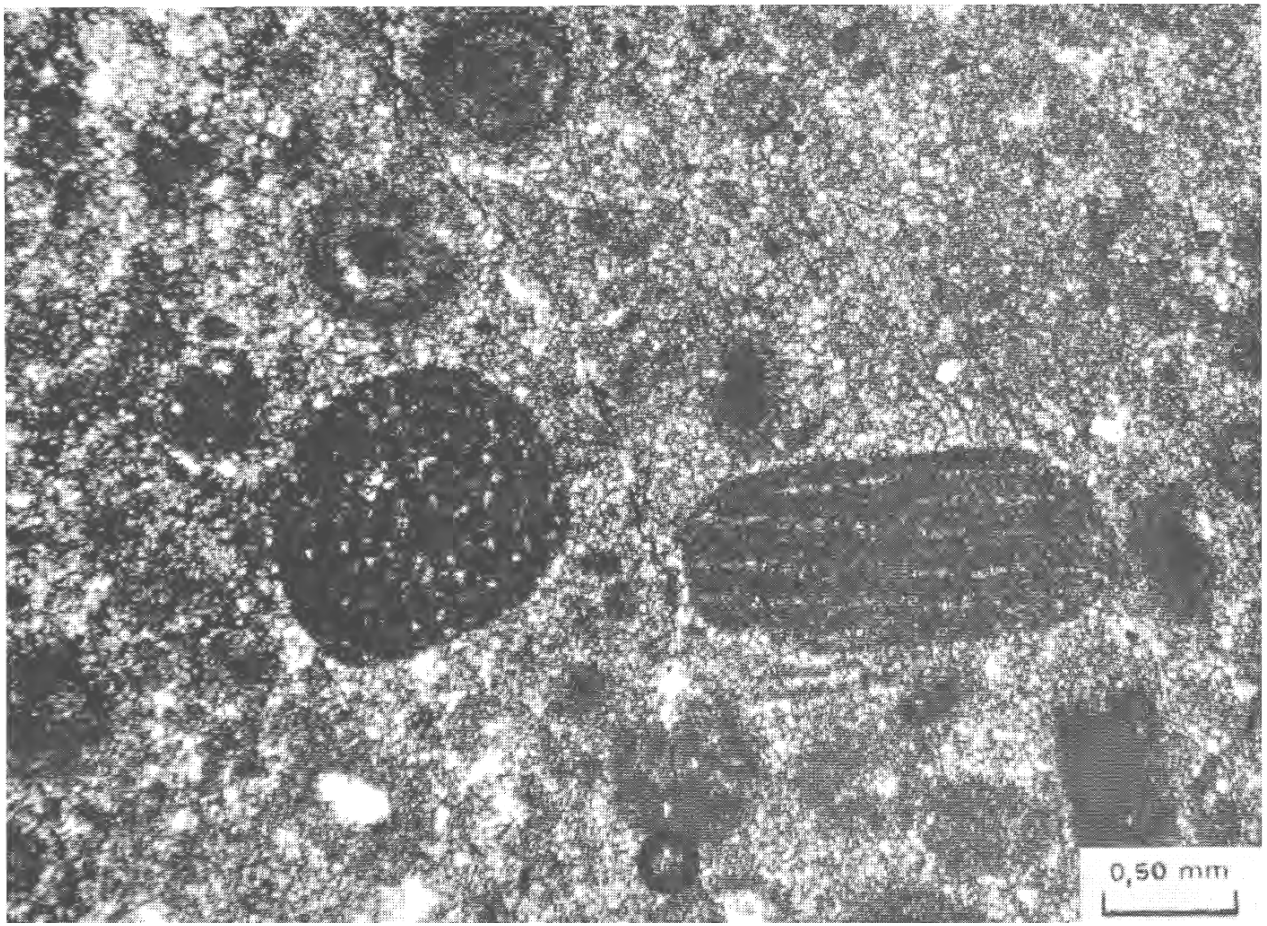
Flügel 2004

Carboniferous, strongly recrystallized limestone with round micritic pelletoids and spar-filled intergranular pores.

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.6 PELLETS and PELOIDS

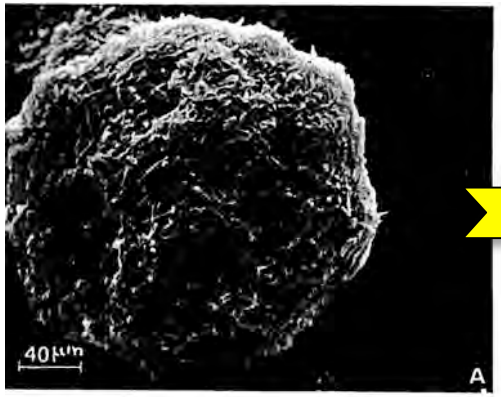
micron-mm sized ±STRUCTURELESS SUBROUNDED micritic grains

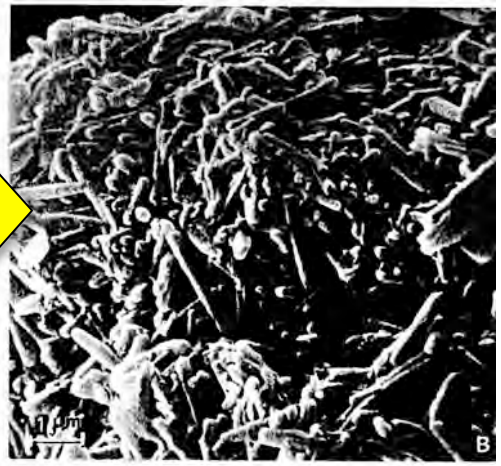


Crustacean coprolites in cross section (rounded) and longitudinal section
Elf Aquitaine, 1975

ABU DHABI
Loreau 1982

Intertidal fecal pellet

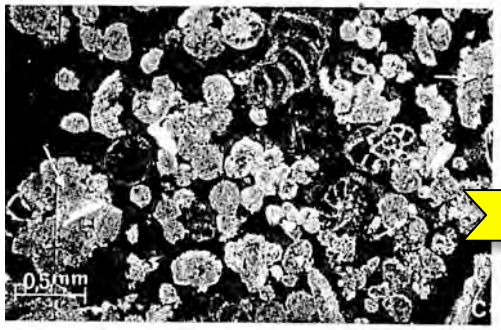


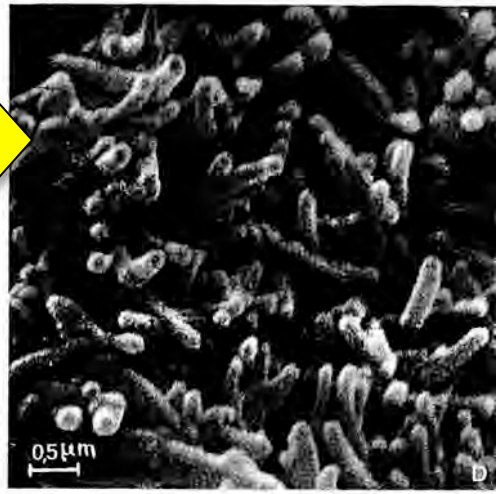


nanostructure

anhedral-subhedral rods

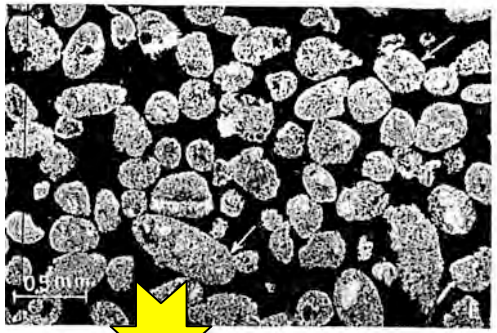
Lagoon -15m
Sand with forams and pellets …



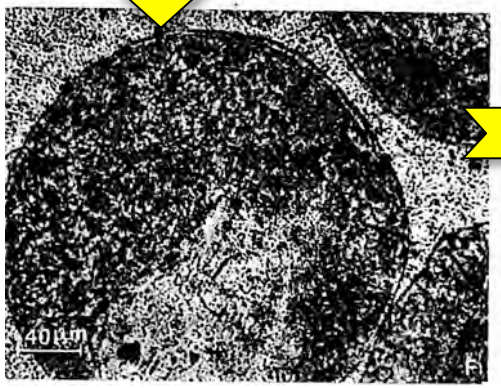


surface of a fecal pellet

loose anhedral rods
0.1-0.3 µm x 1-2µm



Lagoon -15m
Forams+pellets …
with a thin oolite layer



surface of oolite layer

packed rods

loose rods

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.6 PELLETS and PELOIDS

micron-mm sized ±STRUCTURELESS SUBROUNDED micritic grains

✓ **ANCIENT PELOID LIMESTONES**

- account for 1000' km^3 of lagoonal, shelf, bank, reef-core (and mud mound) deposits
- fine-grained peloidal limestones => shallow, low-energy, restricted marine environments

=> if higher energy = => they can be allochthonous (transported to shallower or deeper environments)

✓ **COMMON FABRICS IN PELOIDAL LIMETONES**

- USUALLY INTERPRETED AS PRODUCTS OF MICROBIALLY OR BIOLOGICALLY INDUCED CARBONATE PRODUCTION

= micritic clotted fabric
= sparry peloidal fabric
= thrombolitic peloidal fabrics
= biocemenstones

Micritic clotted fabric (Pl. 10/1)

Texture: Densely spaced, variably sized globular and irregular peloids forming amalgamated clots; commonly within a microspar, micrite or spar matrix.

Origin: (a) Recrystallization of carbonate mud and peloidal micrite (Cayeux 1935; Bathurst 1970; Leeder 1982), (b) diagenetic alteration of soft-pellet grainstones to wackestones (Bathurst 1970) (c) diagenetic amalgamation of precipitated peloids (Reid 1987), (c) diagenetic alteration of soft-bodied organisms (Bourque 1984), (d) diagenetically modified algal debris (Coniglio and James 1985), (e) products of in situ calcified mats of benthic coccoid cyanobacteria (Kazmierczak et al. 1996), and (f) grazing and decay of algal mats (Pratt 1982).

Occurrence: Common in tidal laminated carbonates, in mud mounds, and reefs (Sun and Wright 1983; Neuweiler 1993) as exemplified by Triassic reefs, where about 75% of the reef core framework can consist of precipitated peloids occurring in cavities, intraskeletal voids and organic crusts (Reid 1987).

Sparry peloidal fabric (Pl. 8/5)

Texture: Abundant, very small peloids formed in situ and consisting of a microcrystalline core surrounded by a dentate crystal rim (Type 9: Fig. 4/11). The peloids are part of submarine carbonate cements.

Origin: Chemical or biochemical precipitation (type 9, Fig. 4/11).

Occurrence: Common in intra- and interskeletal voids of reef rocks similar to clotted fabrics, associated with internal sediments and carbonate cements and within crusts associated with corals and sponges.

Thrombolititic peloidal fabrics (Pl. 50/5)

Texture: Non-laminated structure. Abundant peloids of irregular shape and size, some retaining filamentous structures. Common calcite 'spherulites' (peloids) consisting of radially-oriented, non-ferroan calcite, typically 12–20 μm in diameter with a cloudy micrite core, 1–10 μm in diameter.

Origin: (a) In-situ precipitation. The formation of in-situ spherulites within the sediment is controlled by supersaturation of $CaCO_3$ in solution and a site for nucleation. Supersaturation of $CaCO_3$ is caused by (a) the release of CO_2 and NH_4 on the decay of organic matter and (b) bacterial sulphate reduction. Bacteria can form spherulites in aerobic, anaerobic, agitated and non-agitated laboratory conditions, but experimental precipitation of spherulites without the presence of bacteria points to the possibility that spherulitic textures also can form as a by-product of decayed organic matter. Spherulites in stromatolites have been interpreted as calcified cyanobacteria. (b) Allochthonous grains. Deposition of small allochthonous fecal pellets and algal peloids within cavities (James et al. 1976) or formation of pellets by cryptic filter feeders (e.g. clionids: Land and Moore 1980). These interpretations are supported by the fact that peloids can settle at the base of cavities.

Occurrence: Thrombolitic fabrics occur in lacustrine limestones (Pl. 131/5) and beachrocks, and are common in laminated tidal and subtidal carbonates (stromatolites) as well as in subtidal shelf carbonates, mud mounds and non-skeletal microbialite reef frameworks (particularly in the Carboniferous and Permian, Jurassic and Cretaceous).

Flügel 2004

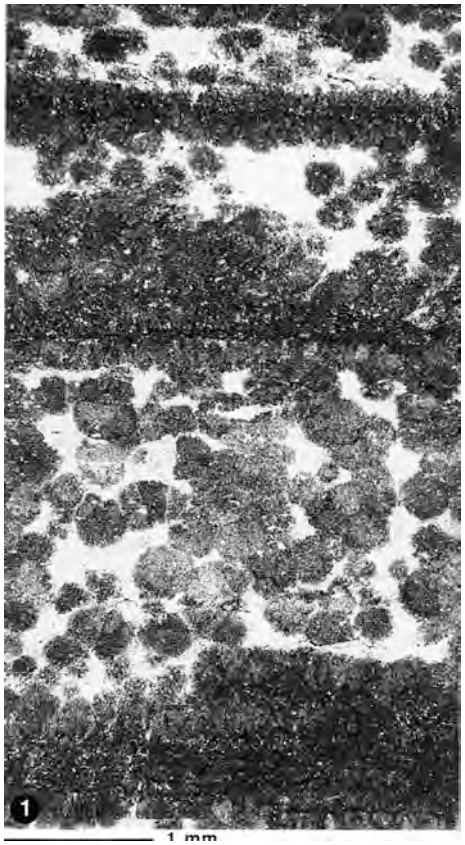
Biocementstones (Tsien 1981) - Sect. 8.2

Texture: Fine-grained micritic limestones consisting of peloids, delicate small and/or poorly calcified organisms contained within abundant, localized carbonate cement.

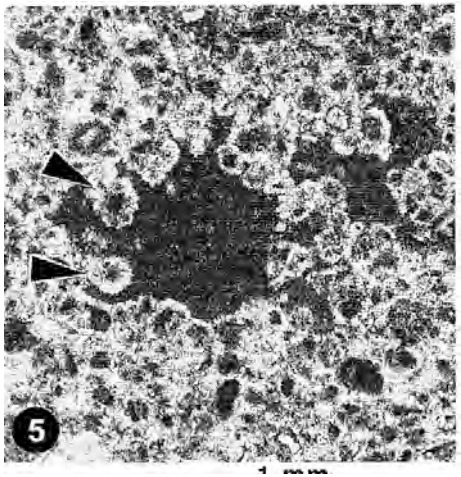
Origin: Fabric, formed by free-living microorganisms (cyanobacteria, algae, sulfur-reducing and sulfate-reducing bacteria) and small encrusting benthic invertebrates, which trap and build carbonate mud from bottom waters, resulting in the formation of small micritic 'protopeloids' (Tsien 1985). Amalgamation of the peloids leads to the formation of peloidal automicrite. A large part of the limestones is formed by biologically induced carbonate cements.

Occurrence: Reef frameworks, specifically in the Permian and Triassic (Webb 1996).

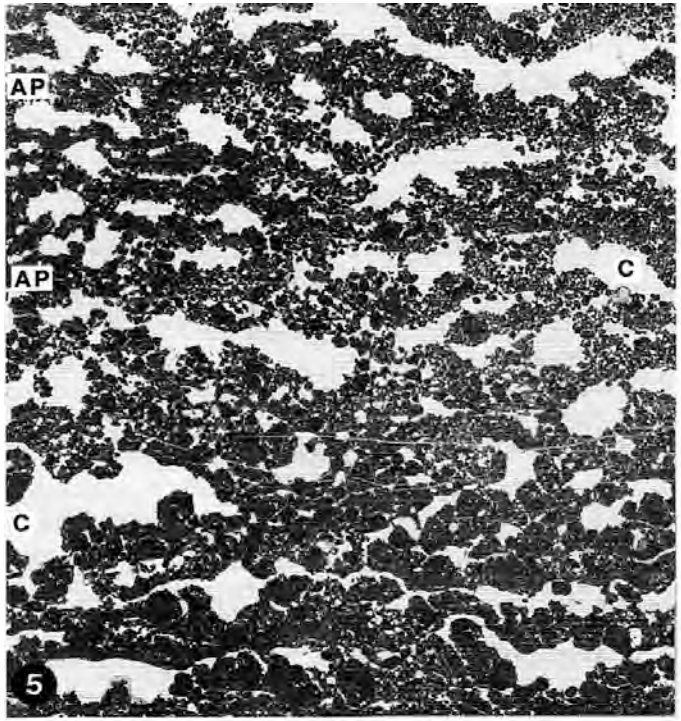
Clotted fabric
Microbial peloids
in situ within algal-cyanobacterial mats
Late Permian (Zechstein) Germany



Sparry peloidal fabric
'Black/white' peloids
In situ cavity-fill precipitates or laminanetd crust, microbial mediation
Middle Permian, Slovenia



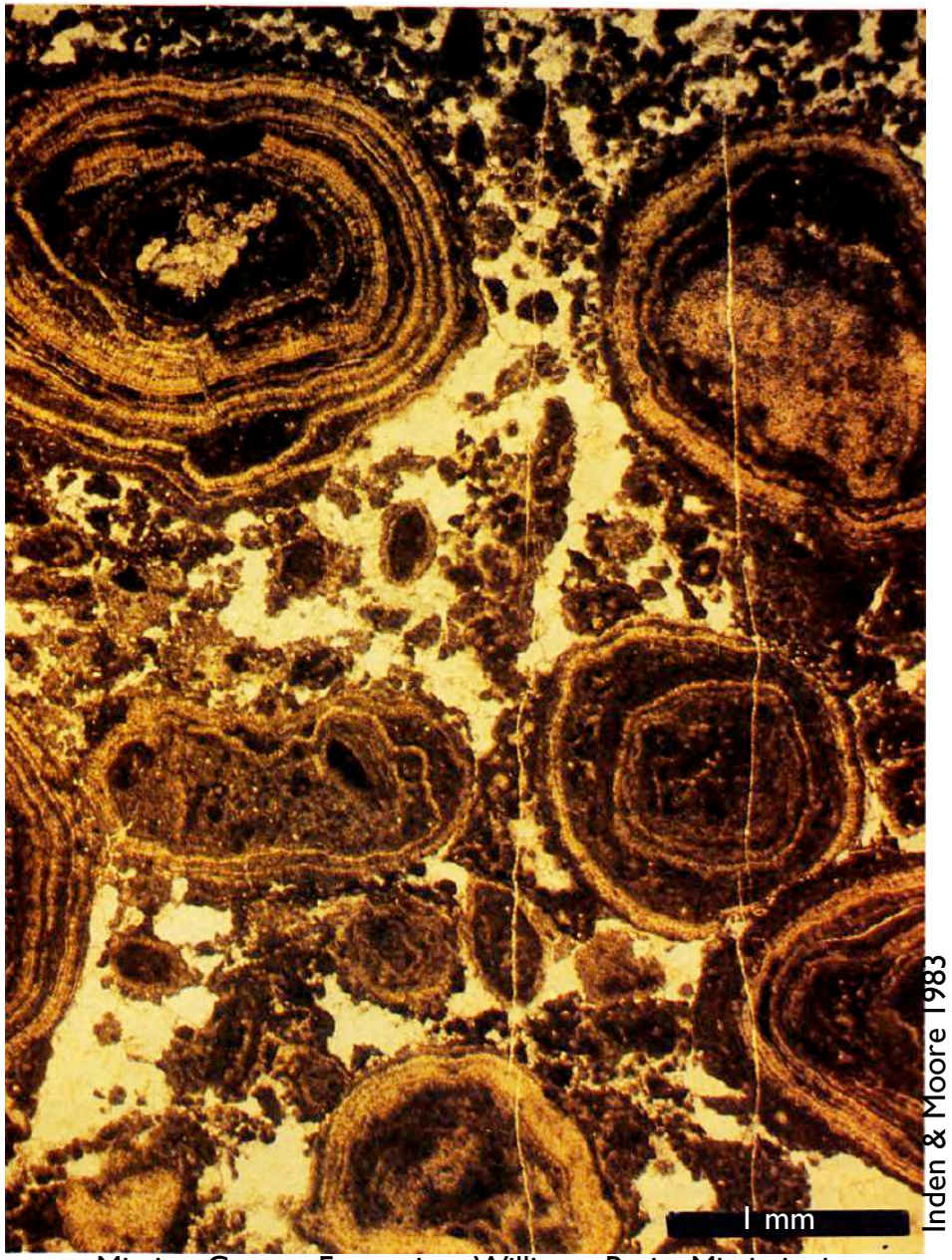
Flügel 2004



Thrombolite fabric
or
Laminoid fenestral fabric
Microbial peloids
Agglutinated microbialite
Late Triassic, Slovenia

AP amalgamated peloids
c cavity

Lacustrine oncoid with thrombolite structure (T)
with a clotted structure
clots =? coccoid and filamentous microbes
Early Permian, Germany



Inden & Moore 1983

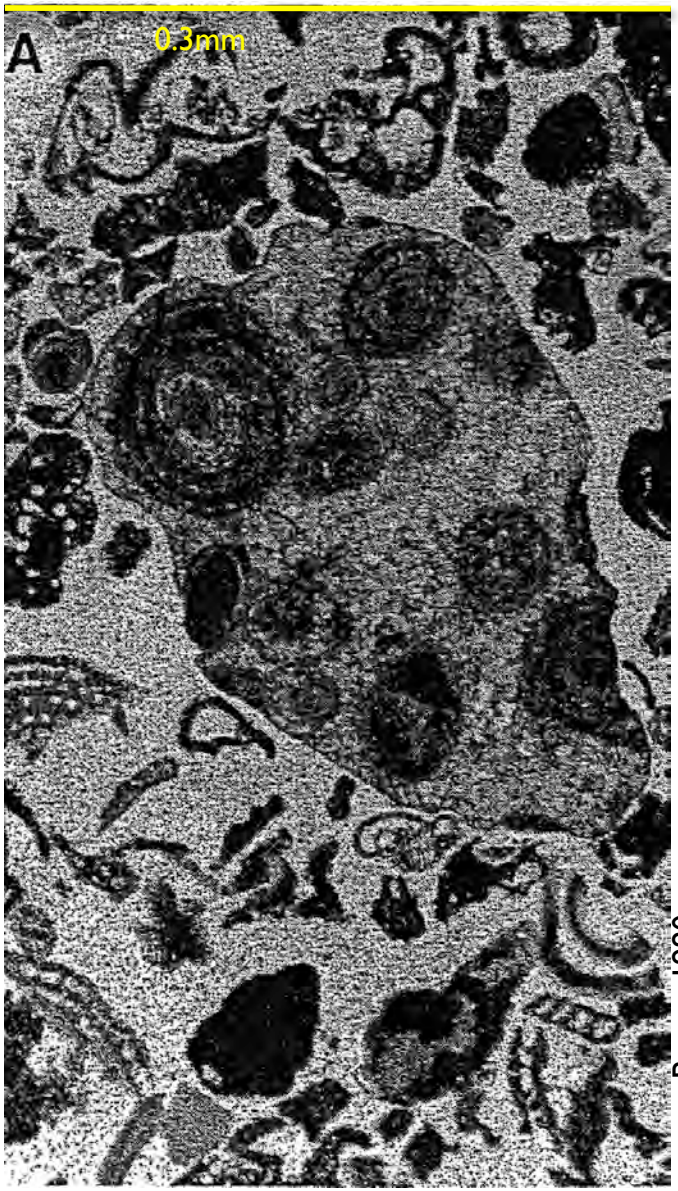
Mission Canyon Formation, Williston Basin, Mississippian
Regressive sequence with well-sorted and rounded pisoid-ooid-pellet grainstone.
Irregular fibrous laminae of pisoids indicates deposition in a hyersaline environment (near a beach)

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS

Pleistocene, Bahamas
oolite **intraclast**
the intraclast does
not come from the sediment itslelf

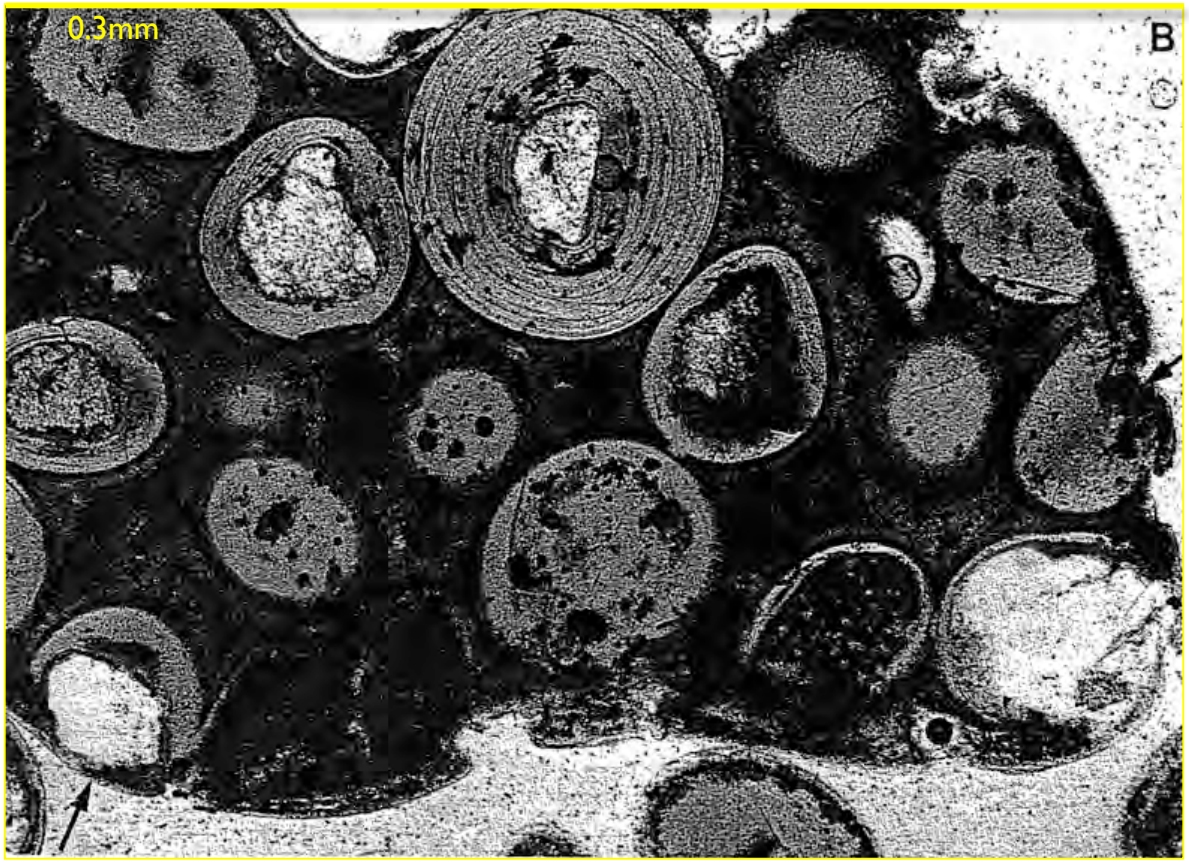


Purser 1980

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS



Purser 1980

Recent, Persian Gulf

oolite **intraclast** with truncated oolite (arrow)

the intraclast come from the sediment itslelf

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS

✓ **GENESIS**

- currents (e.g. storms), **desiccation muds**, local sliding, burrowing and grazing activities of organisms, redeposition, …. and diagenetic changes in volume during dehydratation, compaction or leaching…
  - differential dolomitization leads to 'false' intraclasts i.e. 'residual',
  - early lithification surfaces (hardground) in shallow water series AND condensed series = 'hiatus concretions'
- 'TRUE' INTRACLASTS => HIGH ENERGY => basin analysis (e.g. sea level drop, uplift….)
- common in shallow-marine environment (waves, tides, storms)
  => also 'rip-up clasts' in inter- and supratidal environments where scouring undermines lithified mud beds
- commonly associated with cross-bedded channels
- intraclasts + extraclasts = **lithoclasts :** in practice somewhat tricky… to distinguish…

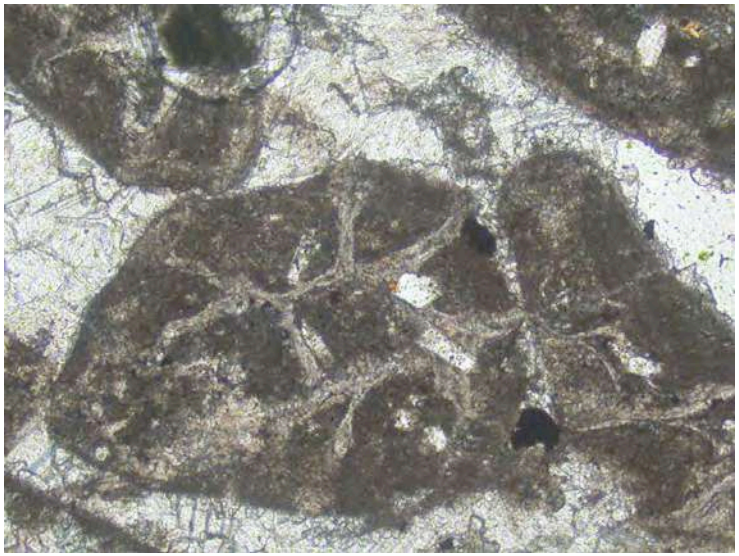
✓ **A PARTICULAR CASE : collapse breccia** <u>not true intraclasts</u> … = mud flakes breccias formed by desiccation, dehydration and cementation/sparitizationin evaporitive settings.
= FLAT-PEBBLE or EDGE-WISE BRECCIAS/CONGLOMERATES (no energy!)

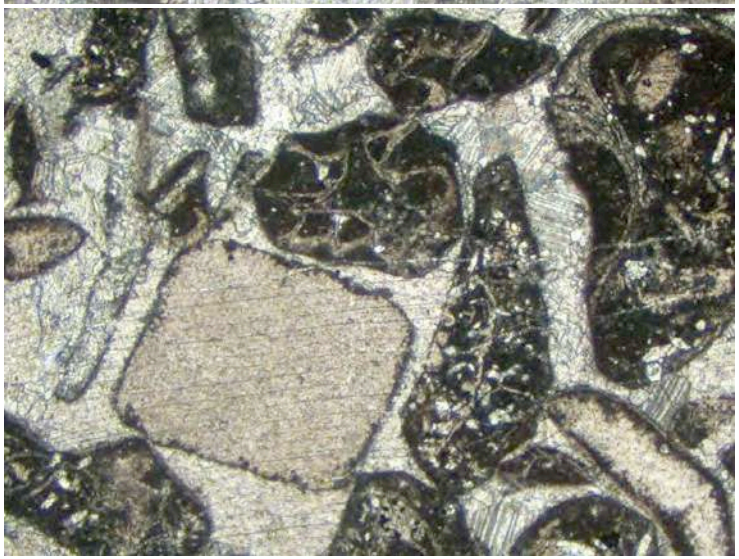
PETROGRAPHY OF CARBONATES

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

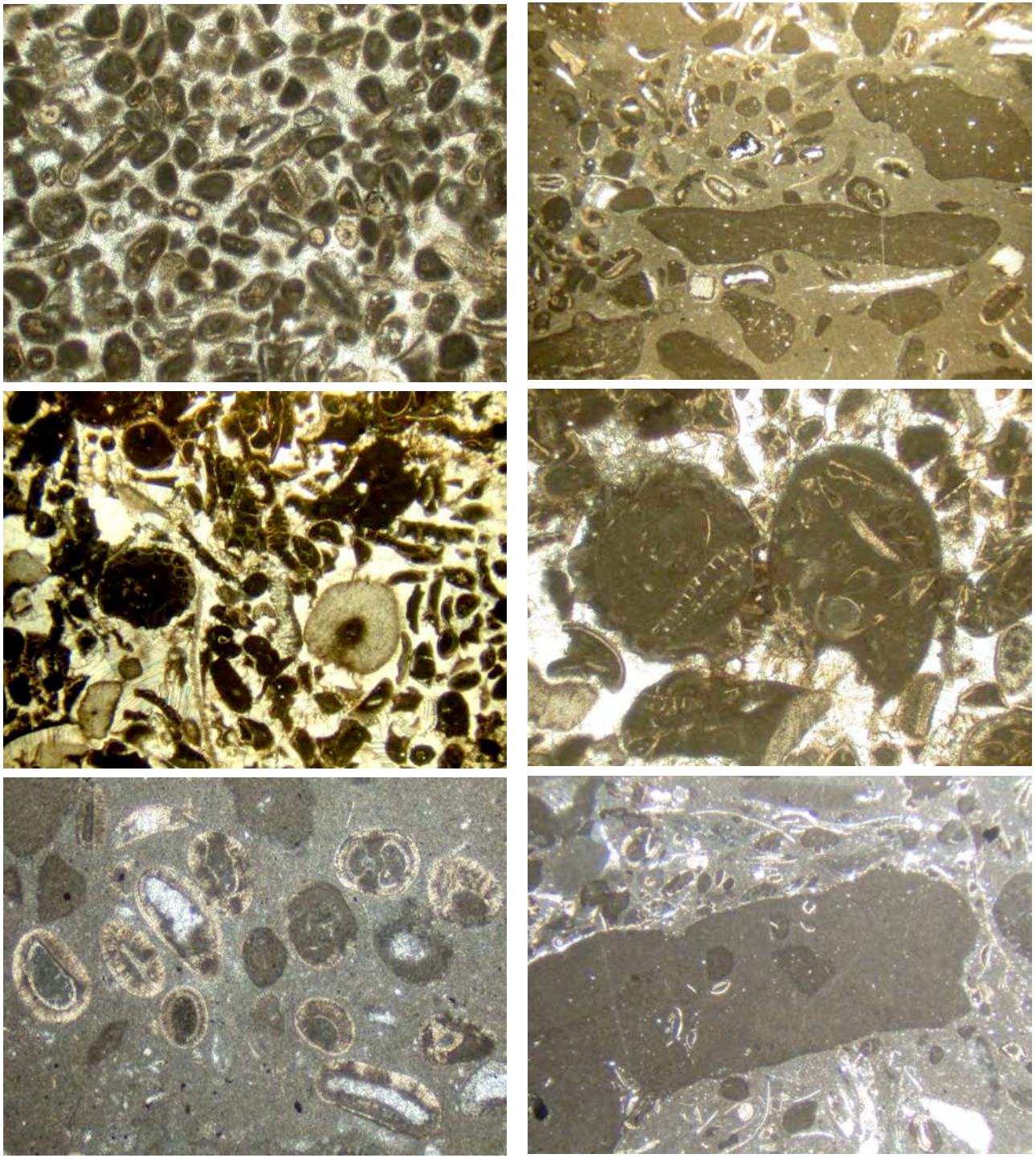
Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS

Grainstone with bryozoans and bioclastic packstone subrounded and subangular intraclasts.
Syntaxial cement around the echinodermal plate and micritized bioclasts.
Open marine setting (mid-ramp).
Storm reworking in *Middle Devonian, Belgium, Préat.*





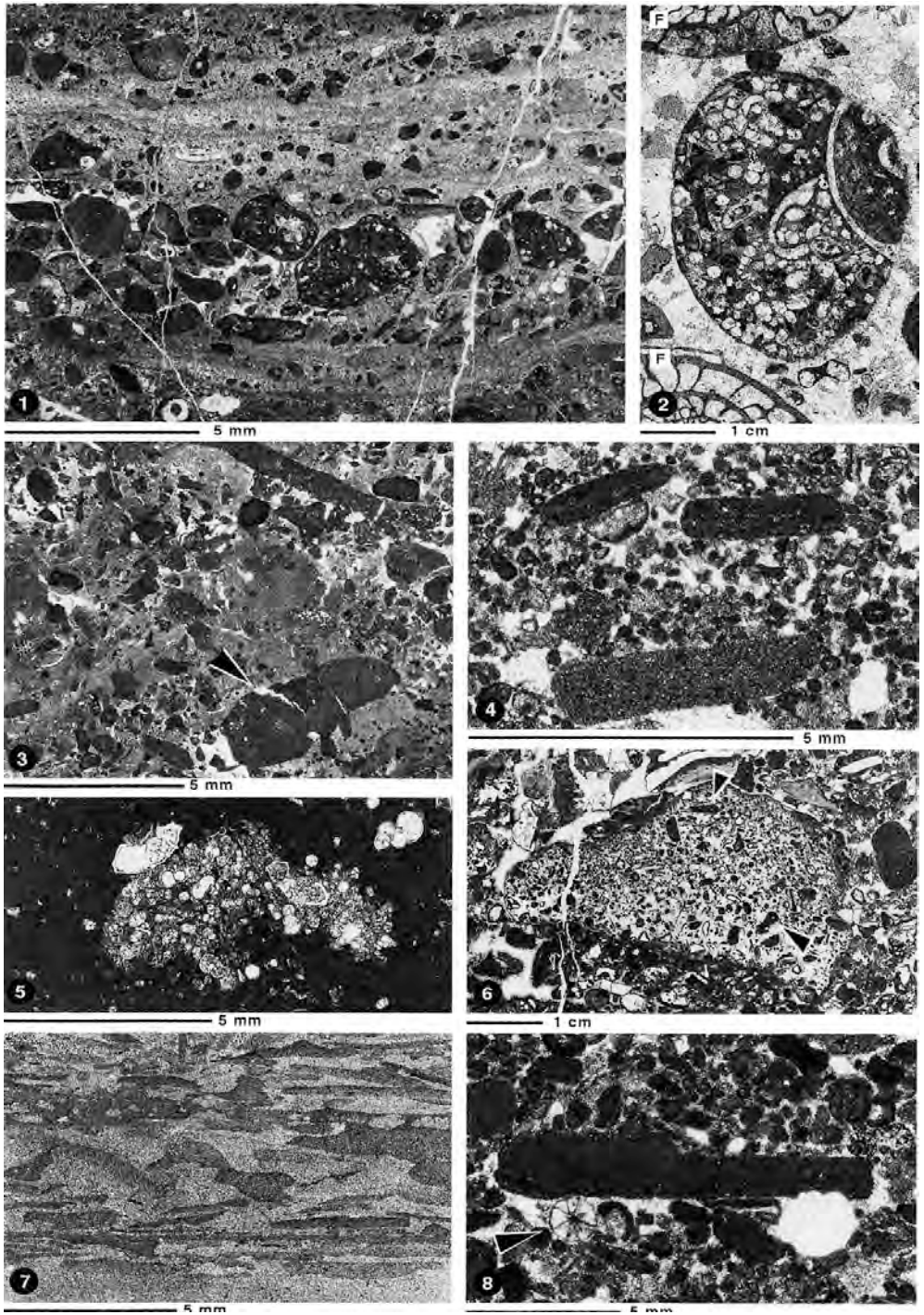
Grainstone and packstone. Well-sorted ooids in a shoal and intraclast-ooid in a fore-shoal area. Open marine facies, Mid-ramp setting.
Middle Devonian, Belgium, Préat.



Flügel 2004

Intraclasts reworked by storms and deposited in floatstone-rudstone layers.
Early Tertiary, Austria

Well-rounded **extraclast** with algal spores and shells. Truncation of the gastropod at the boundary of extraclast. Fusulinid (F) foram in the host rock.
Early Permian, Austria.



Poorly-sorted **intraclast** wackestone Strong reworking of semi-lithified sediment (siez, shape and orientation. Dark clasts = 'black pebbles' with rootlets (arrow.)
Late Jurassic, Switzerland

Siltstone **extraclast** (storm-derived).
Early Carboniferous, Poland.

Accumulation of planktonic forams in a **clast** in pelagic wackestone containing the same forams.
Late Cretaceous, Tunisia

Fine-grained peloidal grainstone **intraclast** adjacent to a reef zone.
Late Jurassic, Germany

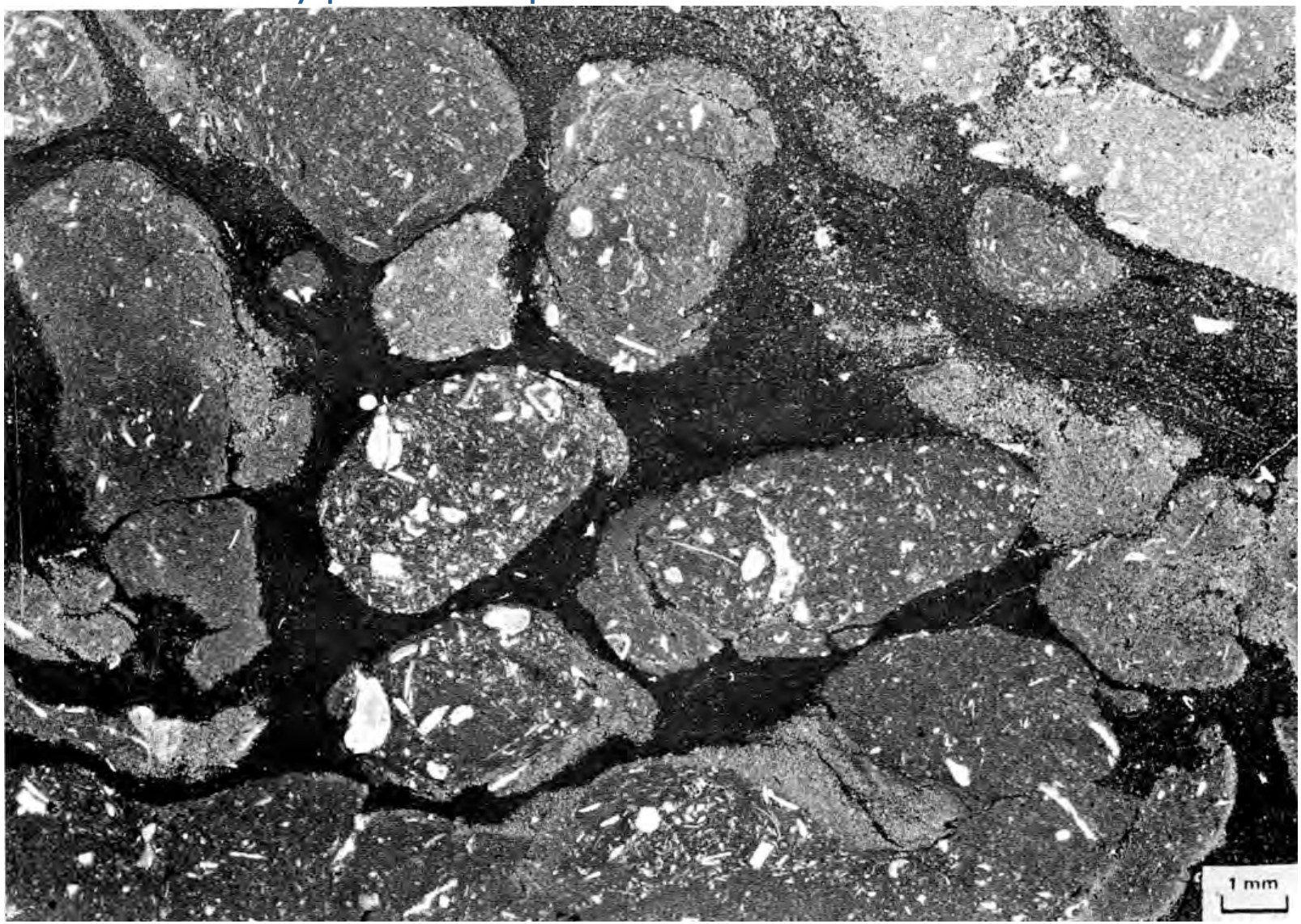
Tidal **intraclasts** formed as lag deposit in tidal channels.
Late Jurassic, Germany

Precambrian **intraclasts** together with ooids.
Montana, USA.

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS



Intraclasts in an argillaceous matrix, *Elf Aquitaine 1973*

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS

✓ INTRACLASTS vs EXTRACLASTS

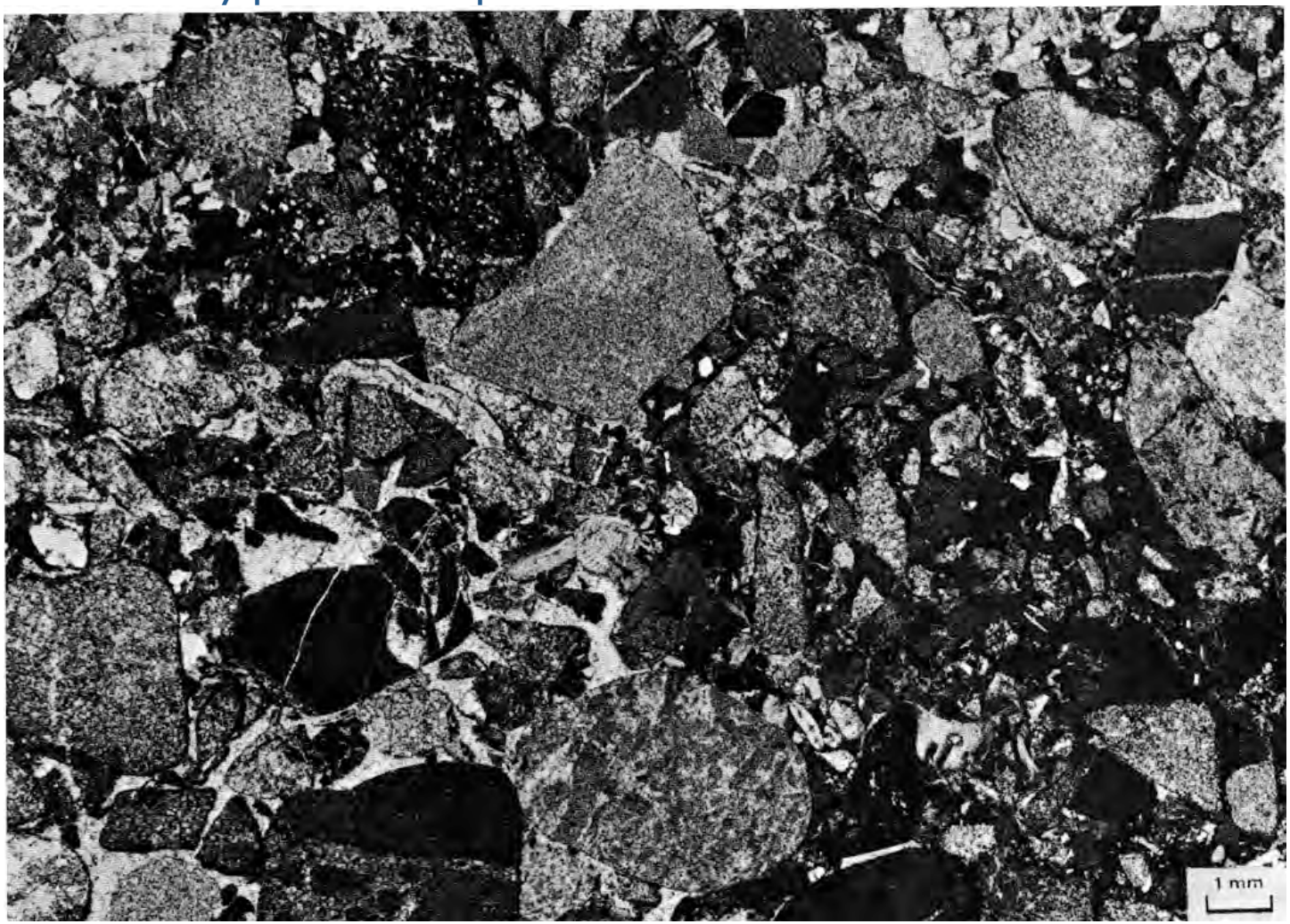
- intraclasts => fragments weakly consolidated ==> soft or lobate outlines ≠ extraclasts round or angular
- fossils and other grains are truncated within the extraclast at the extraclast boundary
- extraclasts should contain stratigraphically 'older' fossil than the matrix
- many extraclasts exhibit criteria poitning to recrystallization, dolomitization, tectonic deformation prior to deposition of clasts

- extraclasts originate from the drainage of rivers in near-coastal regions, rock-fall at coasts, deposition of erosional material by debris and turbidity flows, also by eolian transport.

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.7 INTRACLASTS-*MICROBRECCIAS*

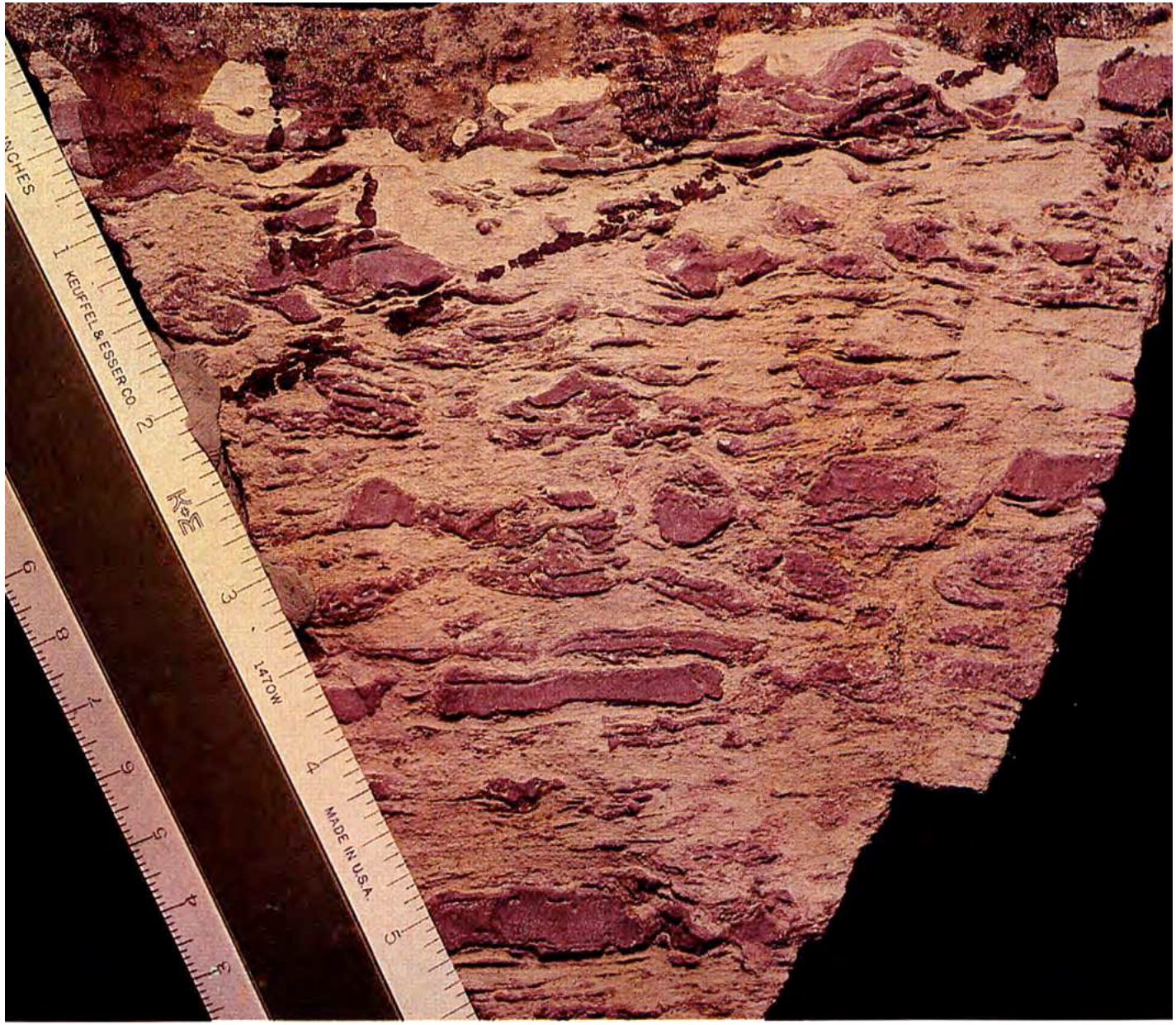
Carbonate FRAGMENT of lithified or semi-lithified sediment derived from the erosion of nearby penecontemporaneous sediment > < EXTRACLASTS



Extraclasts (=lithoclasts s.s.), generally angular = 'breccia' with diversified fragments (micritic, dolomicrosparitic, argillaceous-sandy) with extremely reduced micritic to microsparitic cement, *Elf Aquitaine 1973*

NOT TRUE INTRACLASTS...!

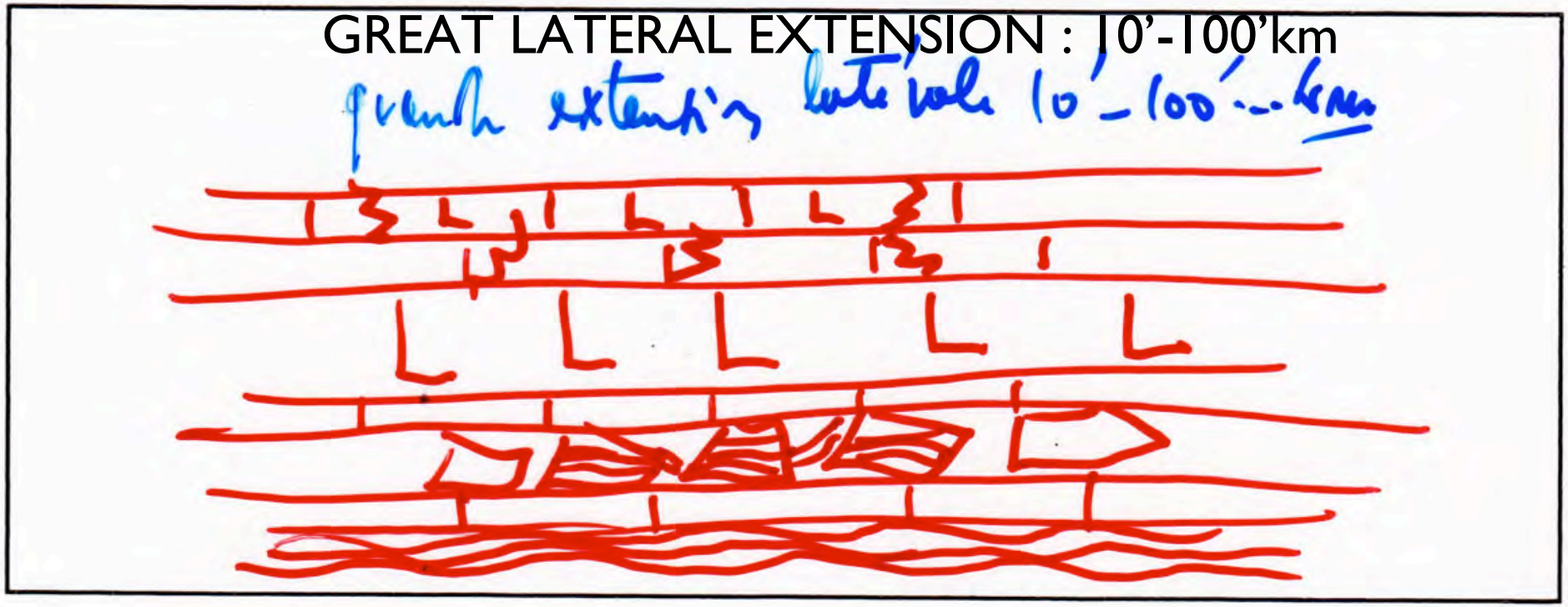
Limestone lenses = rounded mudcrack polygons that escaped early dolomitization in a tidal flat setting. Ordovician, Maryland, Shinn 1983.

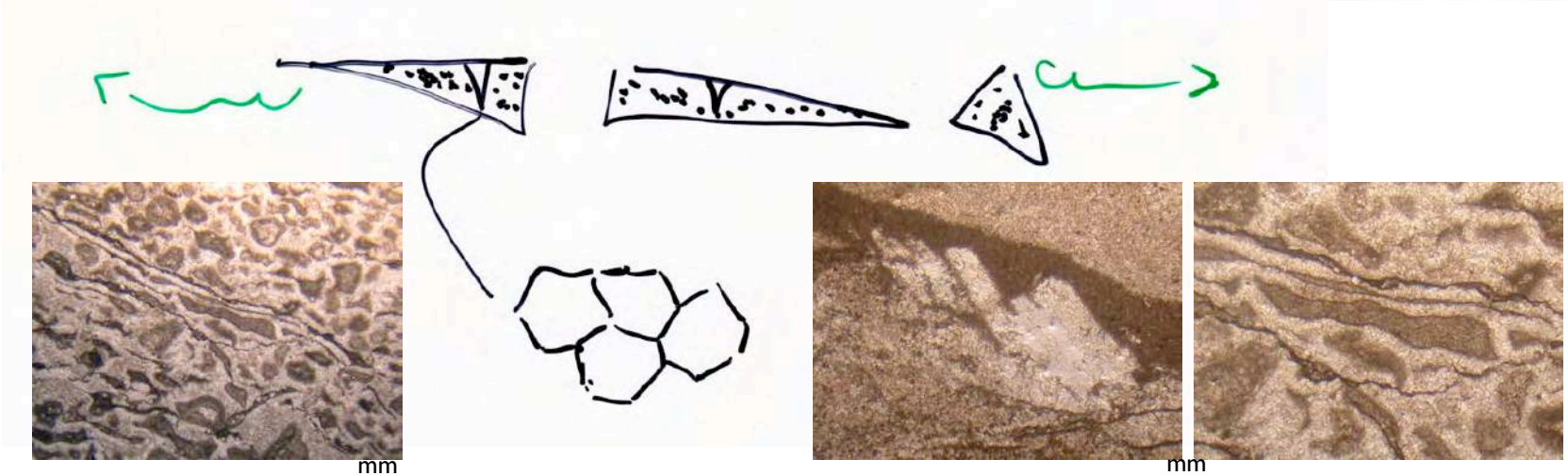


TRUE INTRACLASTS…!

= **FLAT PEBBLES** from a cyclical tidal flat sequence in a bioclastic (hash) basal channel deposit. Cambro-Ordovician. Shinn 1983.

GREAT LATERAL EXTENSION : 10'-100'km





Néoprotérozoïque Congo-Brazza, Préat 2012

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.8 MICRITIZED GRAINS

GRAINS EXHIBITING MICRITIC ENVELOPES

G E N E S I S

The margins of the grains or the total volume of grains are **replaced** by crypto- or micro-crystalline micrite (= MICRITIZATION PROCESS) a a result of microborers and microbes.

Micritized ooids in an ooid grainstone. The irregular shape of some ooids results from biogenic encrustations, indicating only weak reworking of the grains.
Circumgranular LMC cements, due to meteroric-phreatic overprint.
Late Jurassic, Switzerland
(Flügel 2004)

TOTAL REPLACEMENT

PETROGRAPHY OF CARBONATES

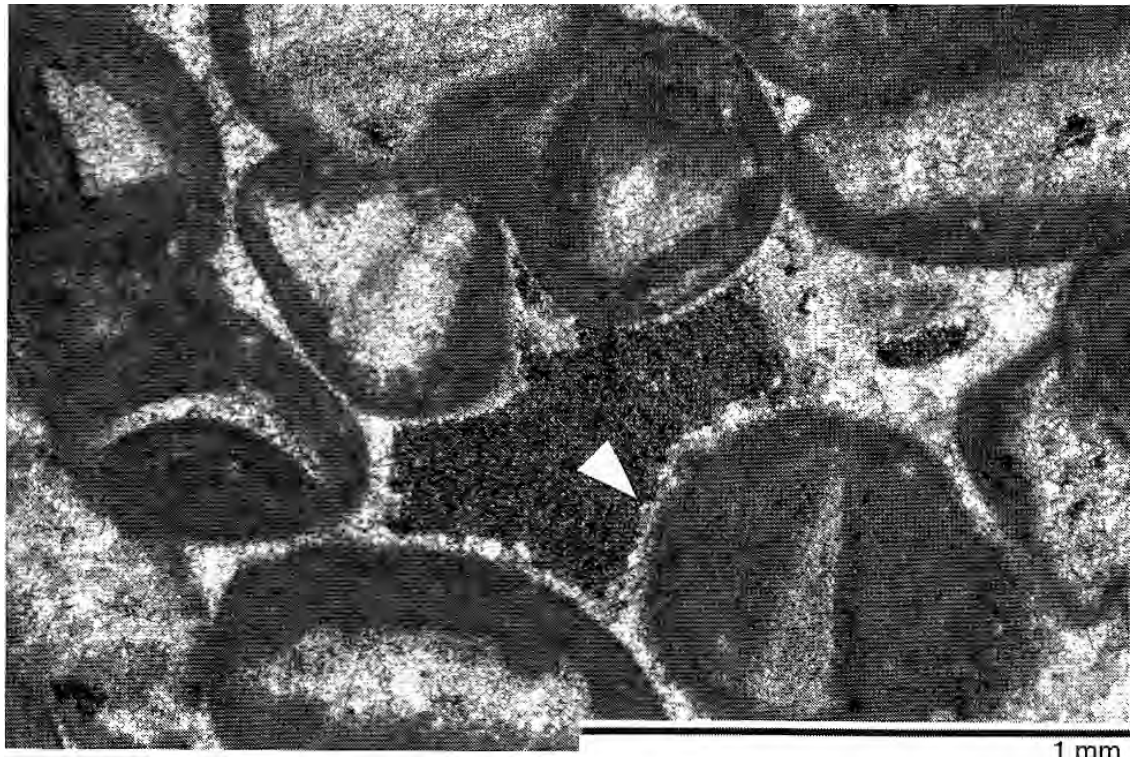
3. GRAINS = 3.8 MICRITIZED GRAINS

GRAINS EXHIBITING MICRITIC ENVELOPES

G E N E S I S

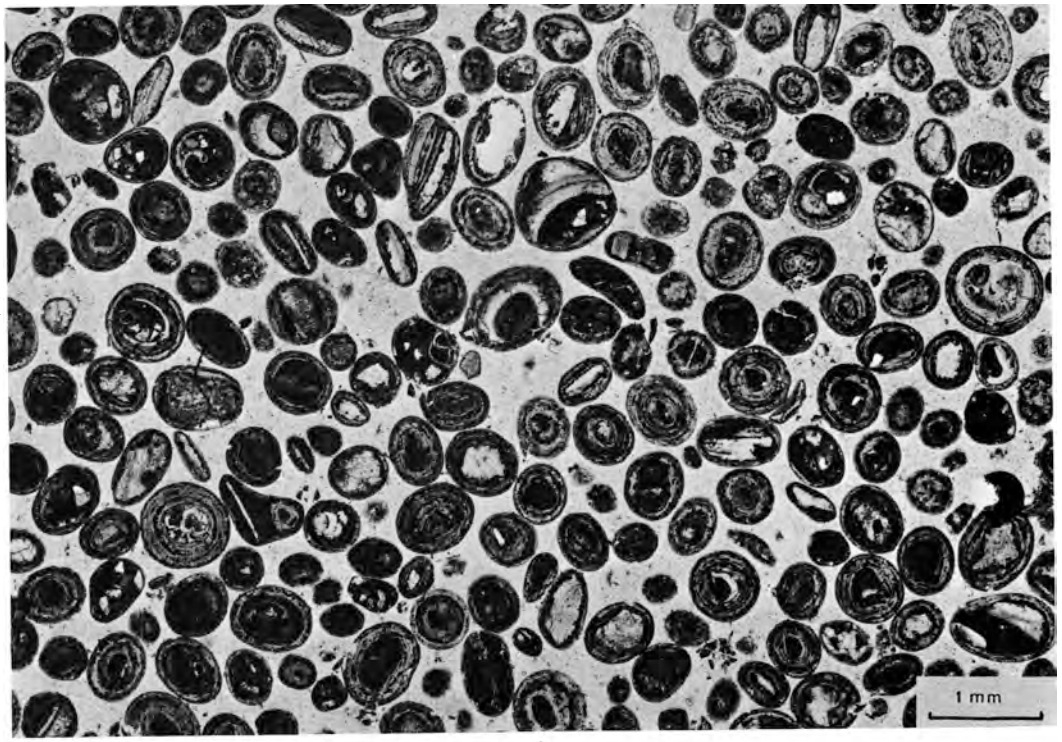
The margins of the grains or the total volume of grains are **replaced** by crypto- or micro-crystalline micrite (= MICRITIZATION PROCESS) a a result of microborers and microbes.

Partlly micritized bioclasts
from a platform-marginal shoal.
adjacent to a grapestone facies.
Jurassic, Iran
(Fürsich et al 2003 *in* Flügel 2004)



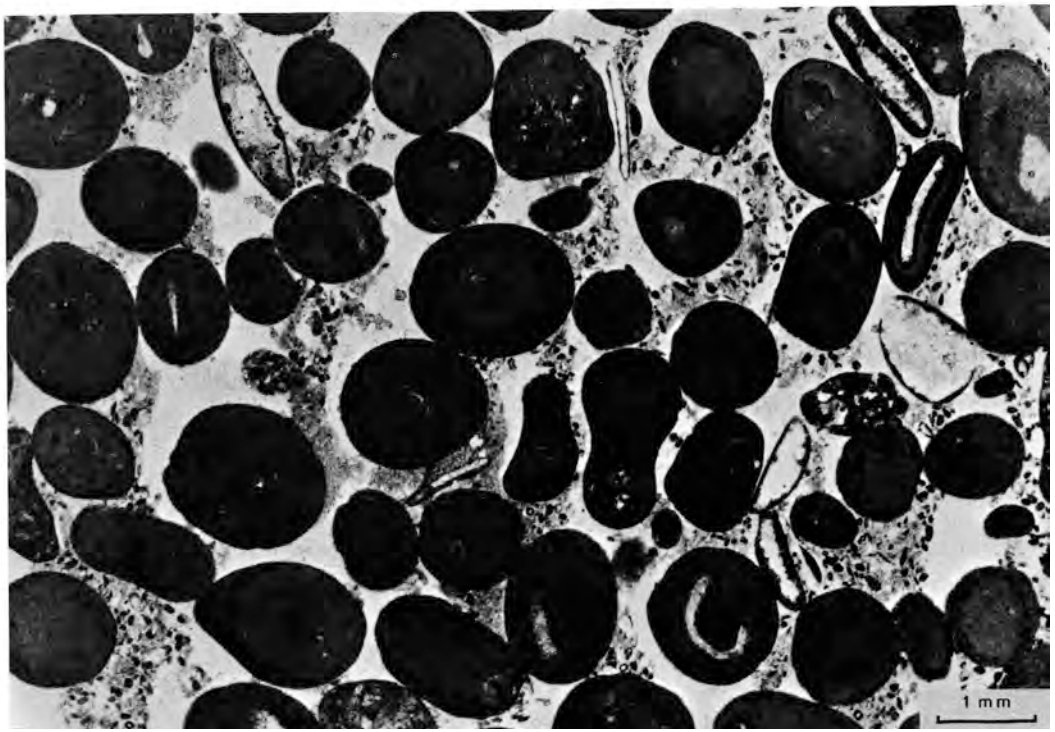
PARTIAL REPLACEMENT

Well developed concentric structure in ooids, apart a few specimen with a reduced cortex (= proto-ooids).
Elf Aquitaine, 1975



1

Micritized ooids.
Notice how the differences in the form of the nucleus influence the general form of the ooid.
Elf Aquitaine, 1975



PETROGRAPHY OF CARBONATES

3. GRAINS = 3.8 MICRITIZED GRAINS

GRAINS EXHIBITING MICRITIC ENVELOPES

✓ **GENESIS AND OCCURENCES**

- MICRITIZATION processes are controlled by biological and chemical factors and take place <u>in shallow- and deep-marine as well as in terrestrial and lacustrine environments</u>
  => described in great detail on aragonite skeletal grains from the Bahamas and the Persian
  => on HMC skeletal grains from Florida and Belize
  = = > loosening the surface, abrading and rounding carbonate grains, completely destroying the original structures
- persistent micritization => formation of carbonate mud (micrite)

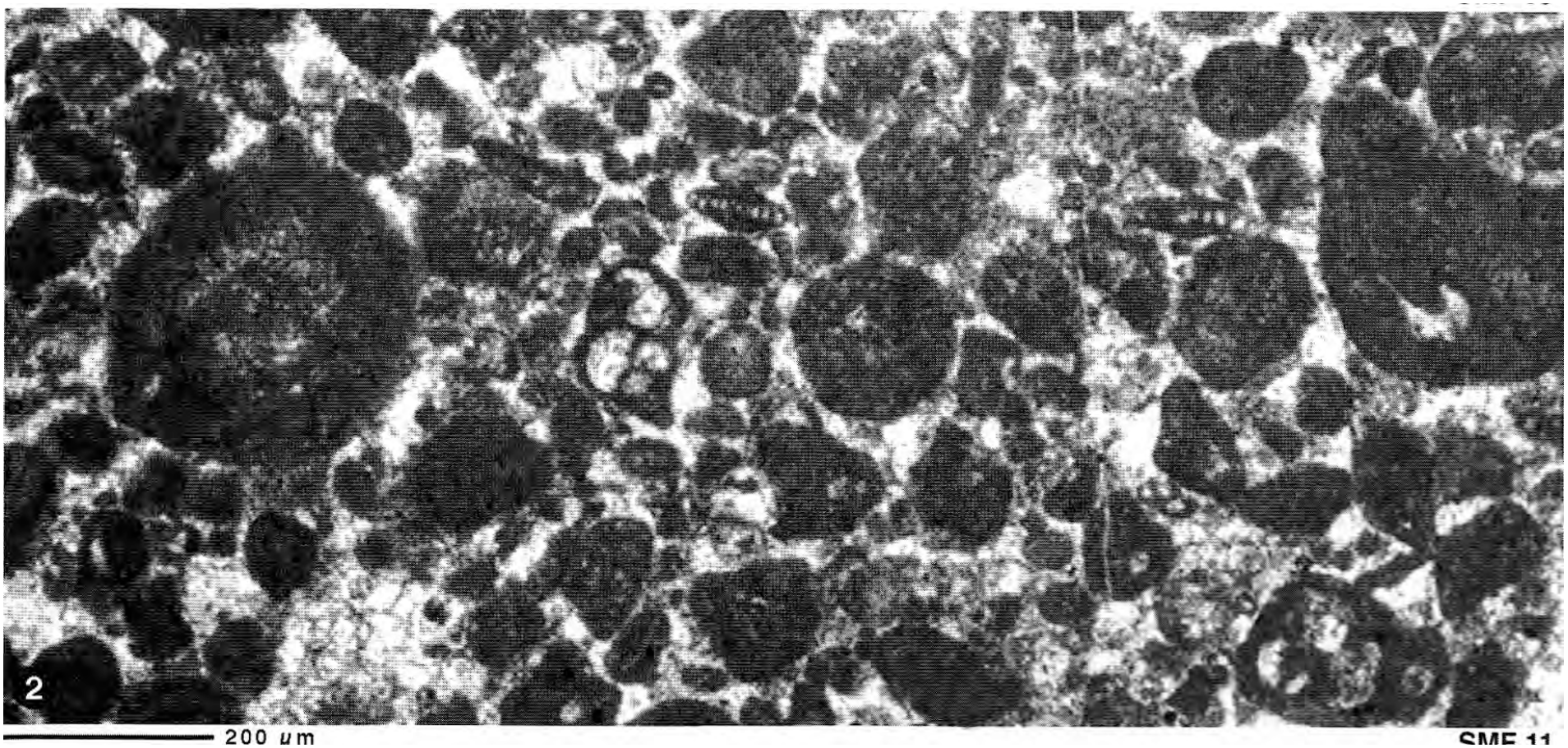
- 'MICRITE ENVELOPE' (Bathurst 1964) : thin a few µm-500µm, laminated coating of very fine micrite around carbonate grains (particularly skeletal grains and ooids) => <u>modern envelope = aragonite</u>

- micritized grains = 'mud coated grains'

PETROGRAPHY OF CARBONATES

3. GRAINS = 3.8 MICRITIZED GRAINS

GRAINS EXHIBITING MICRITIC ENVELOPES



Coated bioclastic grainstone : strongly micritized skeletal grains associated with small-sized benthic foraminifera. Isolated Bahamian-type carbonate platform, Middle Jurassic, Monte Kumeta, Sicily (in Flügel 2004).

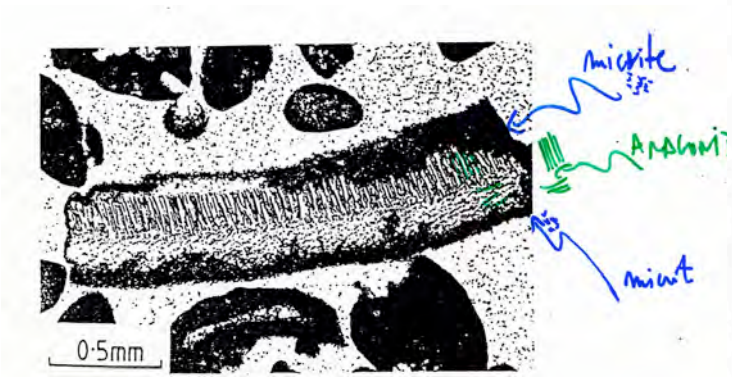
PETROGRAPHY OF CARBONATES

3. GRAINS = 3.8 MICRITIZED GRAINS

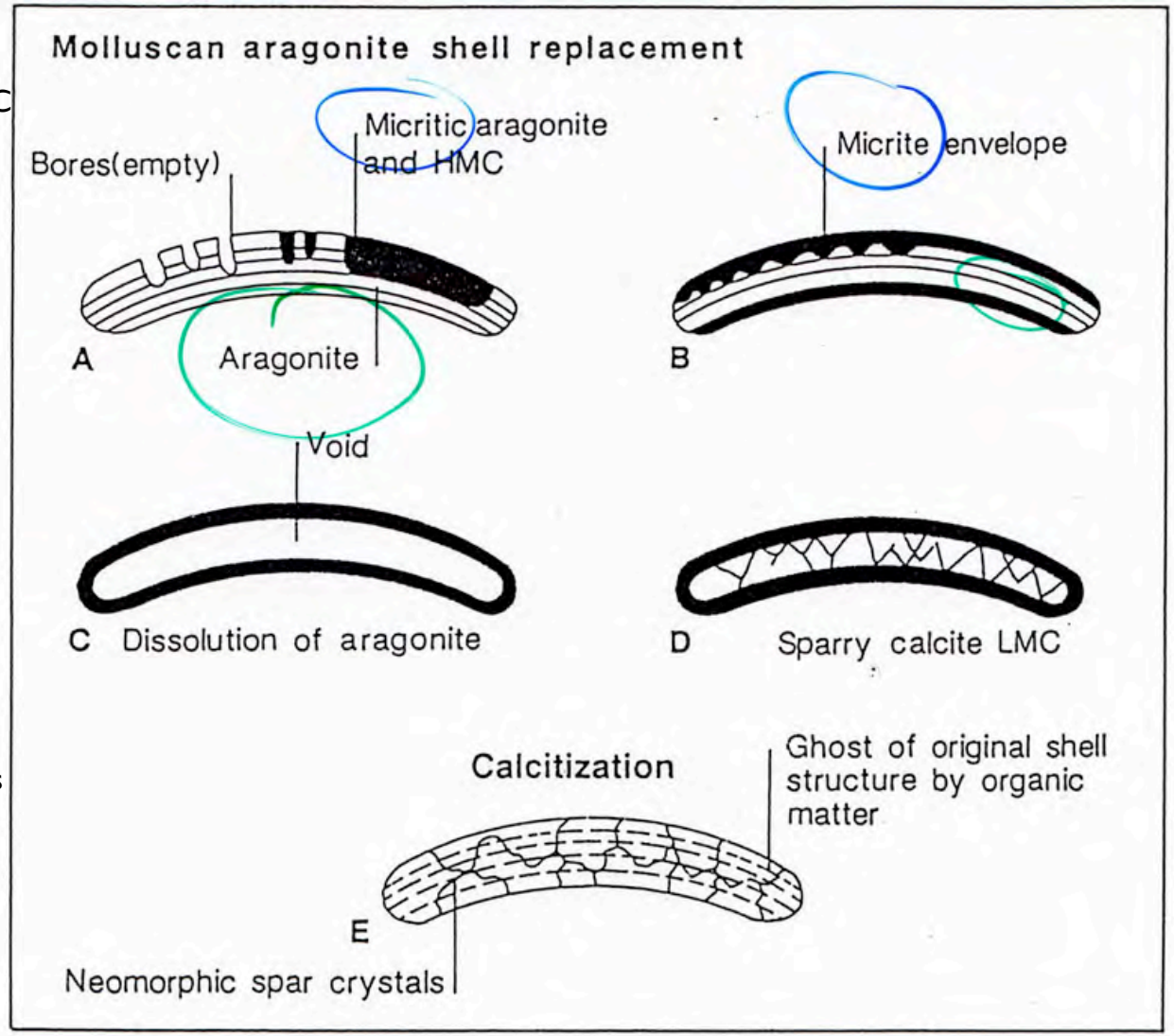
GRAINS EXHIBITING MICRITIC ENVELOPES

Dissolution of skeletal aragonite is a widespread diagenetic process. Most aragonite shells undergo **complete** dissolution and passive mould filling HMC

The shell shape is preserved in limestone because they are defined by micrite envelopes



Skeletal debris lying on the sea floor is attacked by endolithic (boring) microorganisms (algae, cyanobacteria, fungi) => the individual microborings become filled with micritic cement when vacated = = > rim or envelope



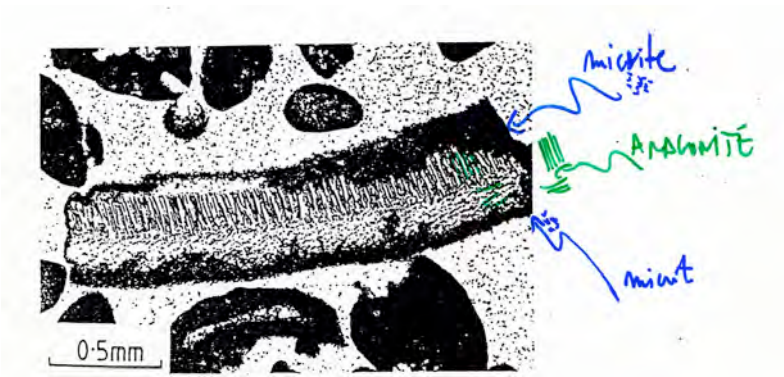
PETROGRAPHY OF CARBONATES

3. GRAINS = 3.8 MICRITIZED GRAINS

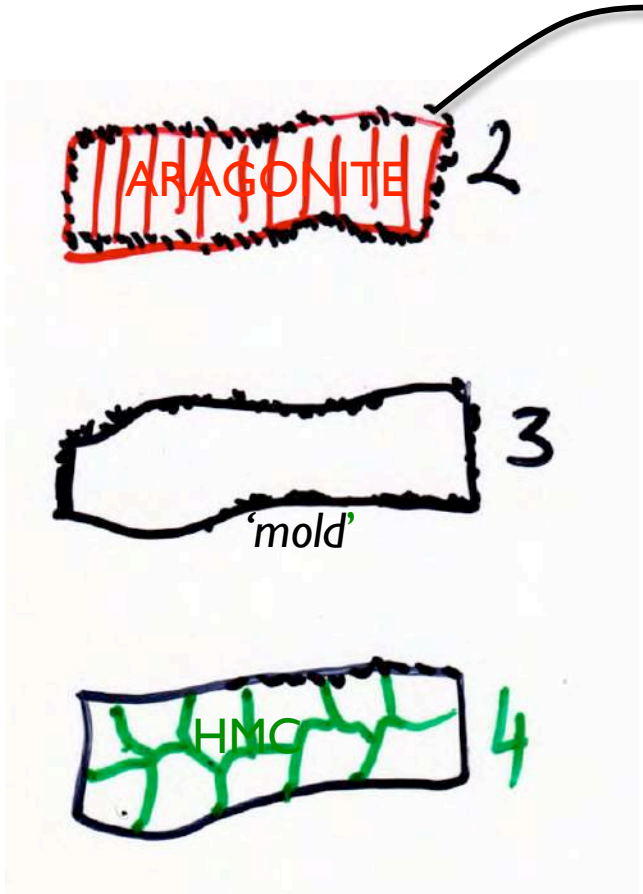
GRAINS EXHIBITING MICRITIC ENVELOPES

Dissolution of skeletal aragonite is a widespread diagenetic process. Most aragonite shells undergo **complete** dissolution and passive mould filling HMC

The shell shape is preserved in limestone because they are defined by micrite envelopes



Skeletal debris lying on the sea floor is attacked by endolithic (boring) microorganisms (algae, cyanobacteria, fungi) => the individual microborings become filled with micritic cement when vacated = = > rim or envelope



1 Bivalve, or algal fragment or ooid….
2 Microbial micritization (also sponges)
3 exondation, dissolution arag preservation envelope
4 LMC

2-3-4 shallow nearshore facies salinity waters

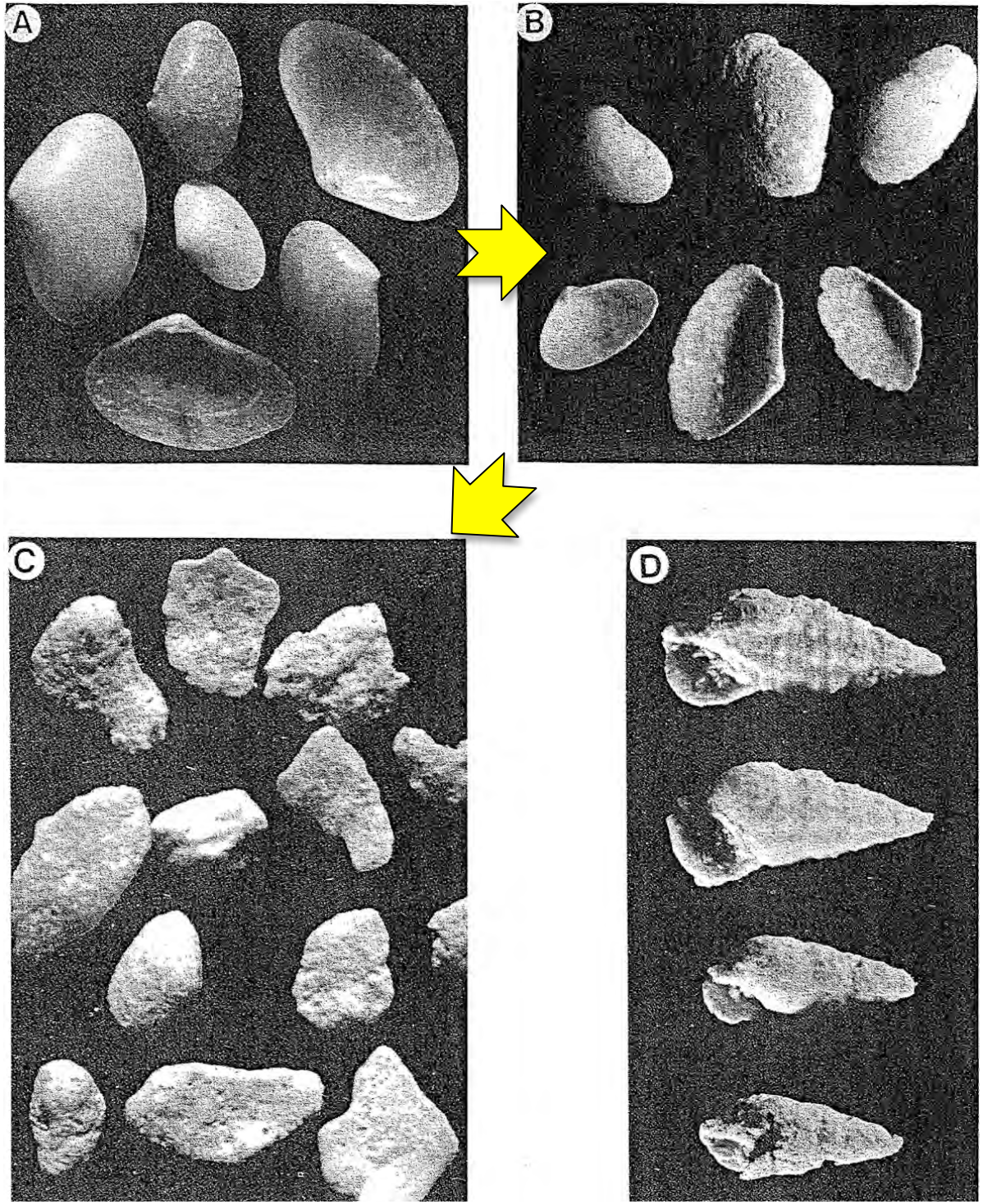
confusion with lumps….

PERSIAN GULF

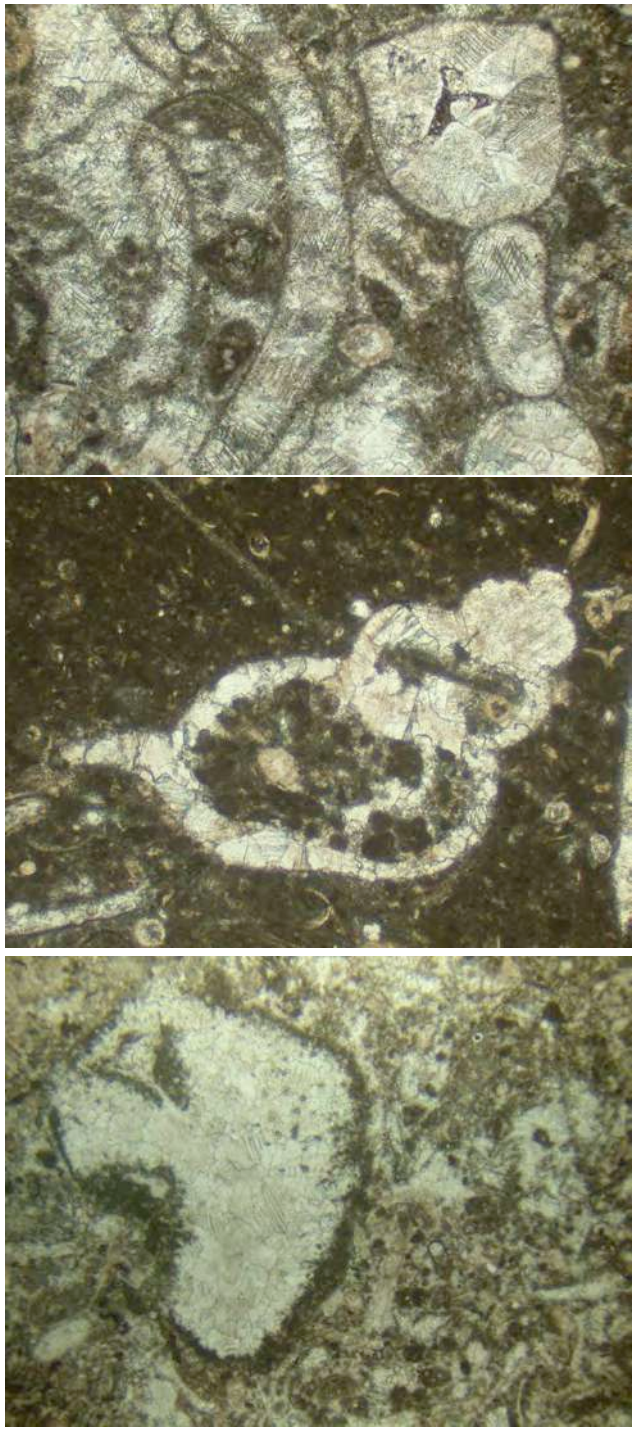
Purser 1980

Bivalve (*Ervillea*) A-C
A.well preserved, non micritized,
B.chalky surface, worn, micritized,
C. strongly micritized

D.Gastropod (*Cerithium*)
increased micritization from top to bottom



Molluskan packstone.
Organisms : micritized, dissolved, filled with LMC.
Middle Devonian, Belgium, Préat



Natural accumulation of certihid gastropods each encrusted with aragonite.

In shallow depression in the higher part of the supratidal zone.

Persian Gulf,
Purser & Loreau 1973

PETROGRAPHY OF CARBONATES

1. MATRIX

2. CEMENT

3. GRAINS

A carbonate grain tells a story ≠ A clastic grain
(‘highly sensitive’ > < ‘inert’)

4 . FABRICS