

MICROFACIES OF CARBONATE ROCKS AND DEPOSITIONAL ENVIRONMENTS

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ACADEMIC ASPECT

Limestones and dolostones are well represented
during geological times

- global effects • reefal systems • CO₂ sinks ...



ECONOMIC ASPECT

Host rocks for oil-gas RR=40% (petroleum geology)

Host rocks for water (hydrology)

Host rocks for mineralizations (metallogeny...MVT)

Extractive industry (quarries, cement, lime, buildings –pyramids....)

Agriculture ('fertilizer' for acid soils)

Varia : glassware (melting), sugar industry....

USA AGASSIZ 1894 : Bahamas

1930 International Expedition – Bahamas : Carbonate Production

=> 'cementation' (algal binding) on the Banks

=> drilling : platform evolution

WWI-WWII : oil discoveries in carbonate reservoirs

=> Middle East

=> Reservoir Rocks

> 1950-1960 : facies analysis, carbonate petrology

=> *Henson, Newell, Rigby, Ginsburg (USA)*

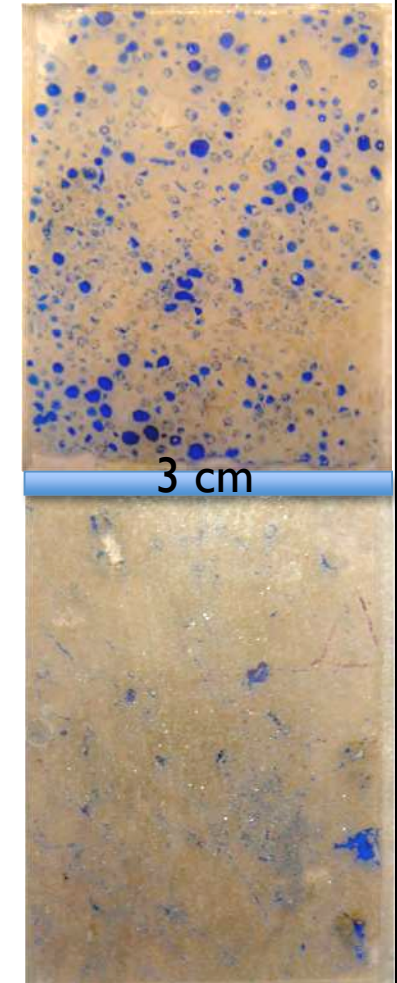
1957 GINSBURG cementation-burial >< vadose cementation

> 1960-1970 highlighting marine cementation

=> *1968 in the Bermuda reefs (Ginsburg, Shinn, Schroeder...) Recent*

=> *1969 in the Persian Gulf (Shinn, Taylor, Illing) Recent*

=> *1969 in the Jurassic of Paris Basin (Purser)*



NEED TO DEFINE and UNDERSTAND the CARBONATE FACIES in order to search the reservoir rocks

TODAY

GLOBAL APPROACH

=> academic

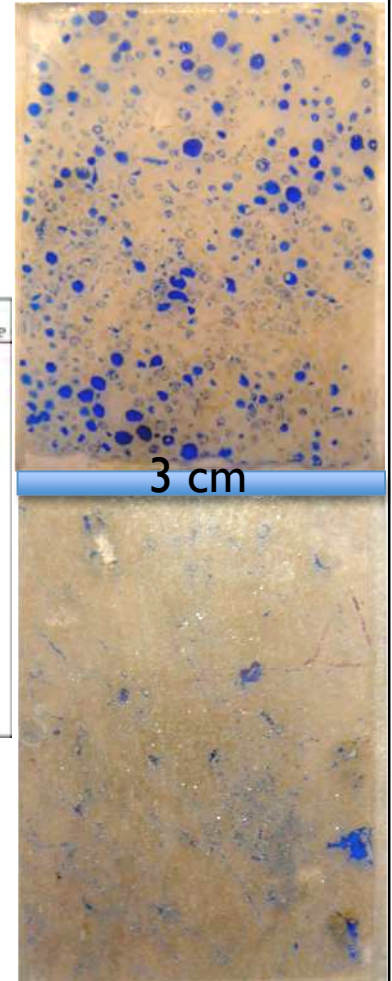
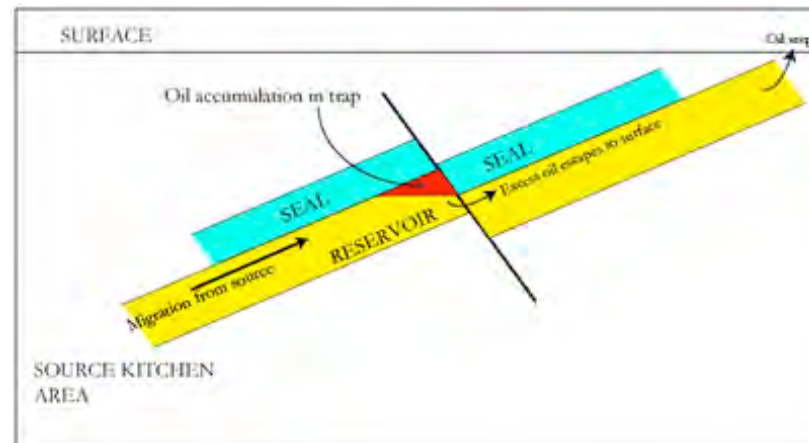
=> environment

APPLIED APPROACH

=> source rocks

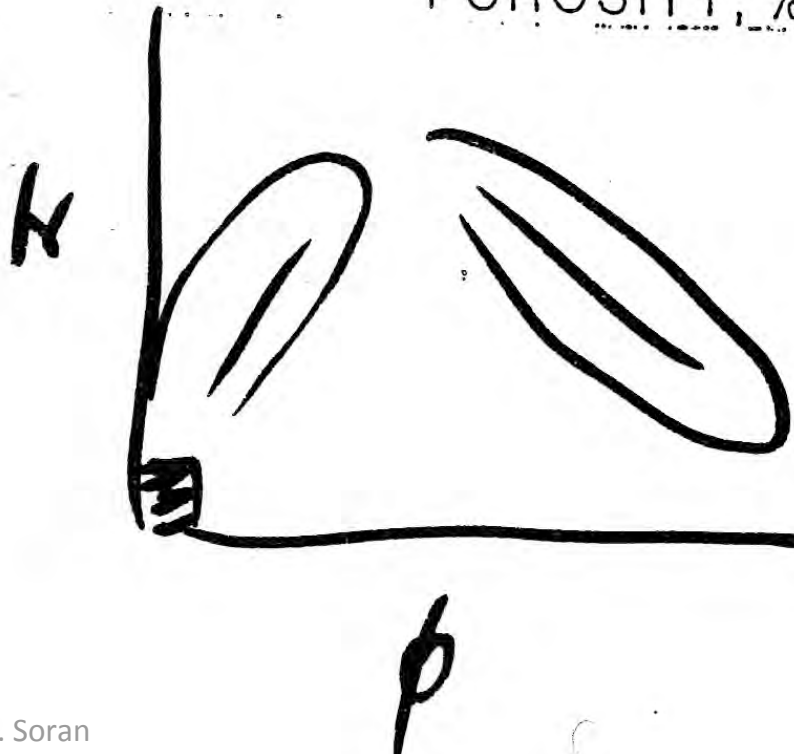
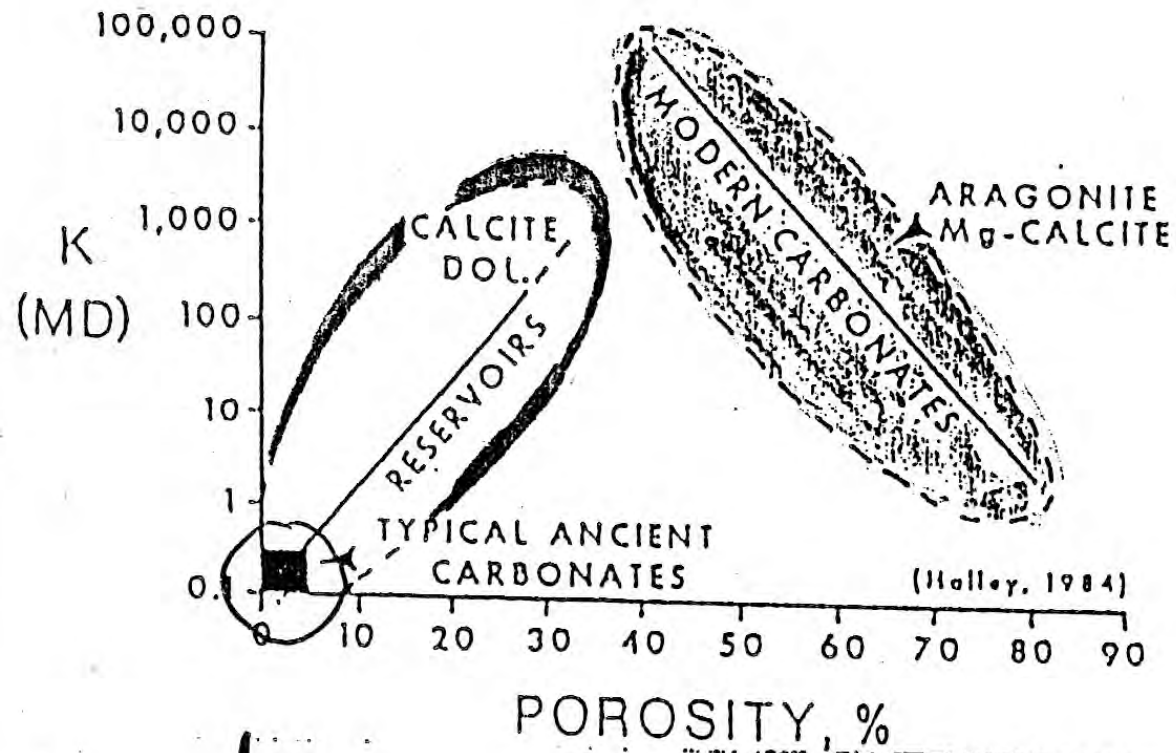
=> reservoir rocks

=> seal or cap rocks



Φ

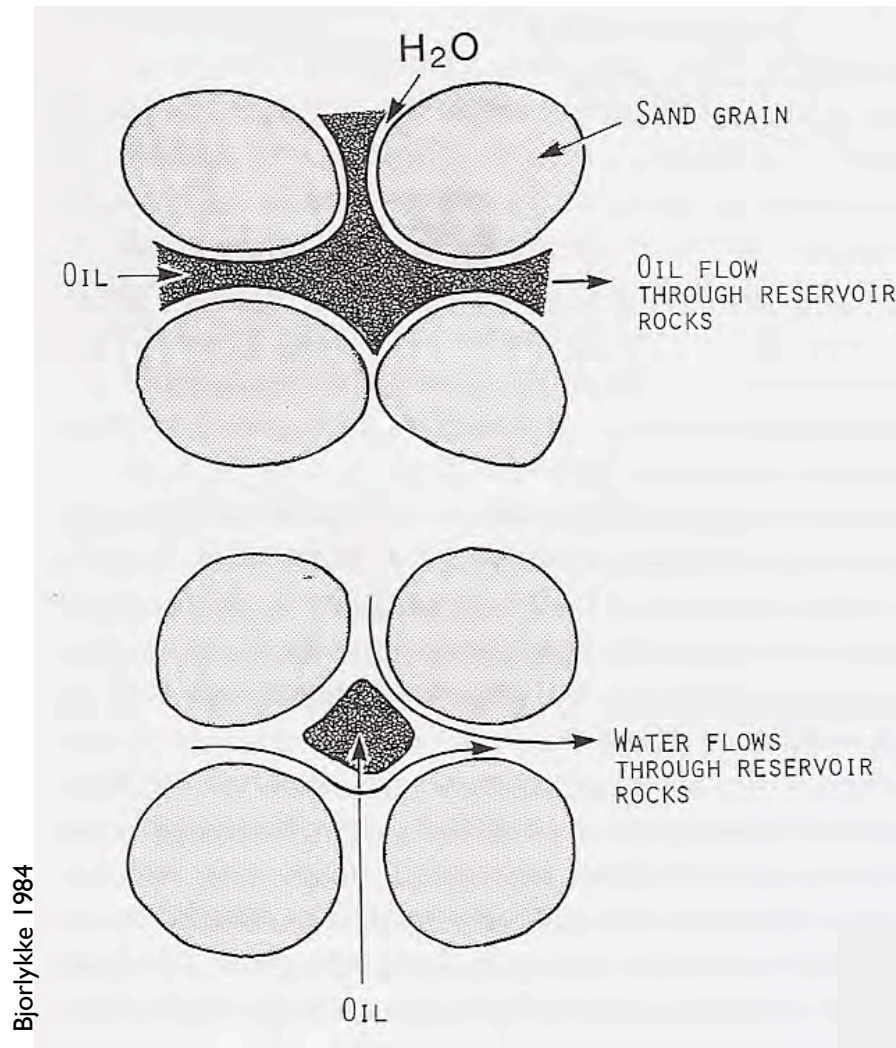
VS

 K 

Permeability = K
A permeable rock has the **capacity** to transmit a fluid. The unit for K is Darcy (D), although the K of many reservoirs is measured in mD.

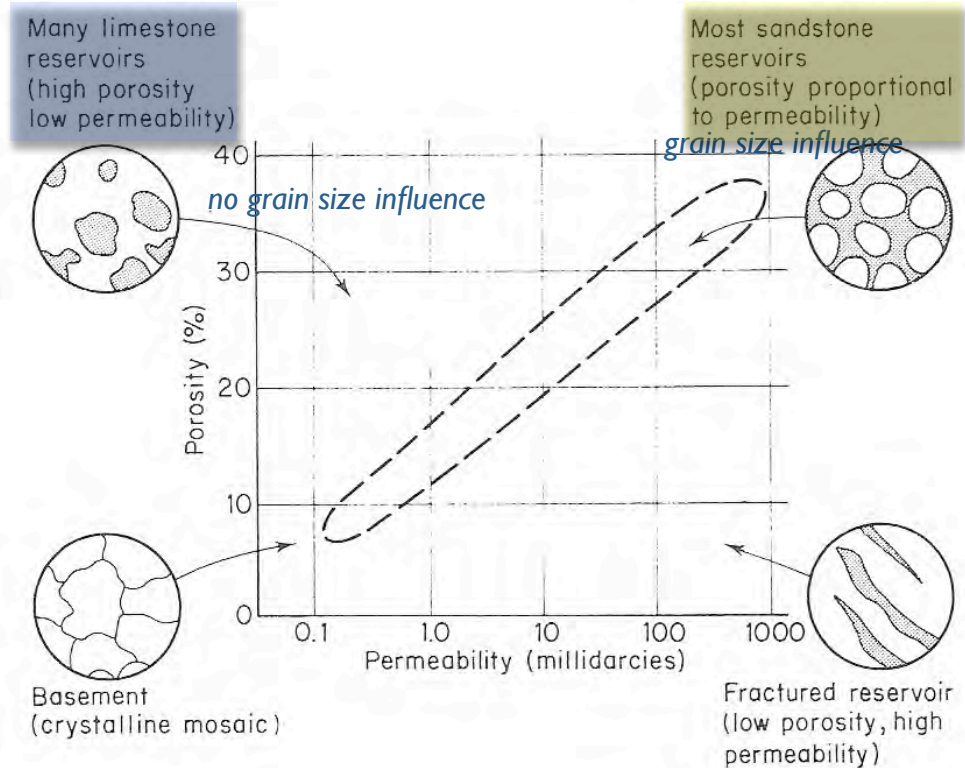
Typically K of the reservoirs is 10D or less. At lower end, gas may be produced from reservoirs of 0.1 mD, while oil reservoir needs to be 10x or 100x more permeable

Φ vs K



Oil is lighter than water => oil droplets will be able to move through pores in rock....
=> **EFFECTIVE or RELATIVE PERMEABILITY**

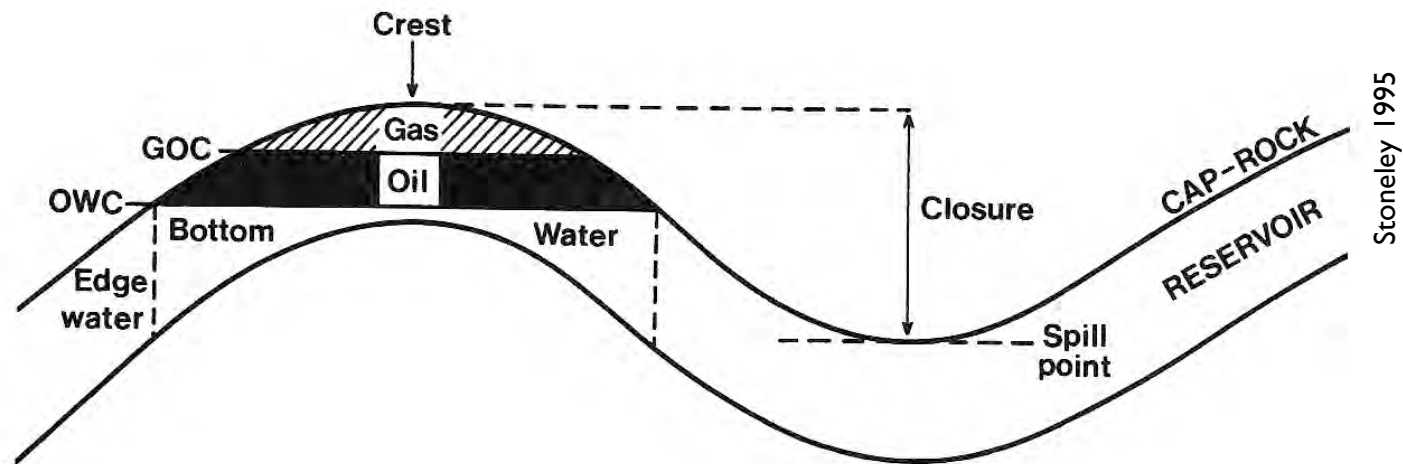
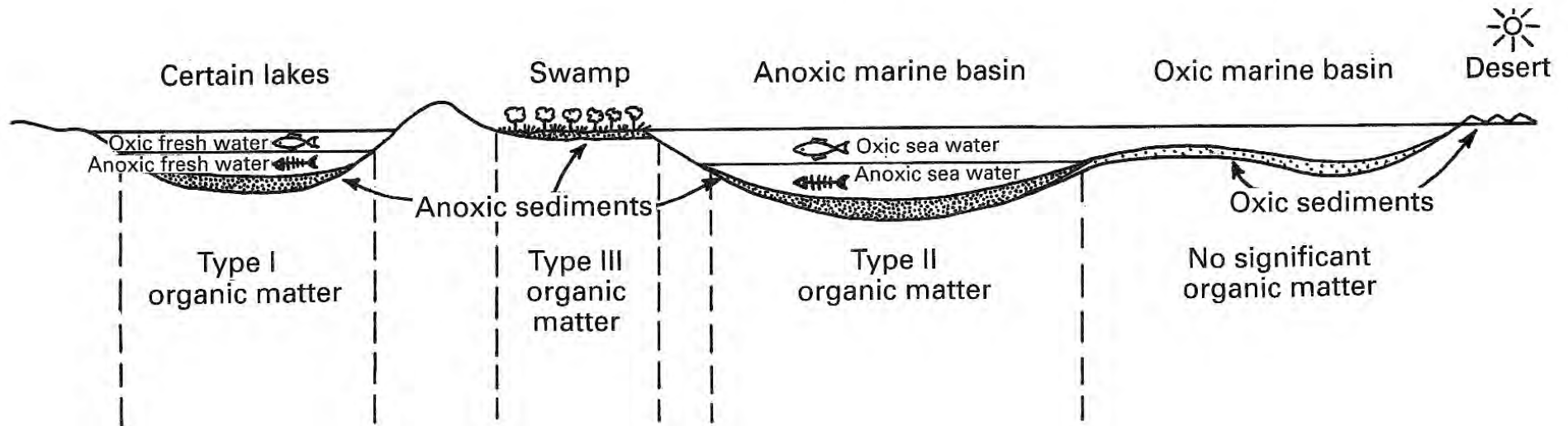
Selley 2000



For sandstones, Φ generally plots as a straight line against K on a logarithmic scale. Shales, chinks tend to be porous but impermeable.
Fractures increases K with generally little Φ increase.

Φ_I and Φ_{II}

Nature and environments of deposition of the types of organic matter that give rise to petroleum



Some terms used to define a trap, using a cross-section of a simple anticline as example

DIFFERENCES BETWEEN CARBONATES AND SILICICLASTICS

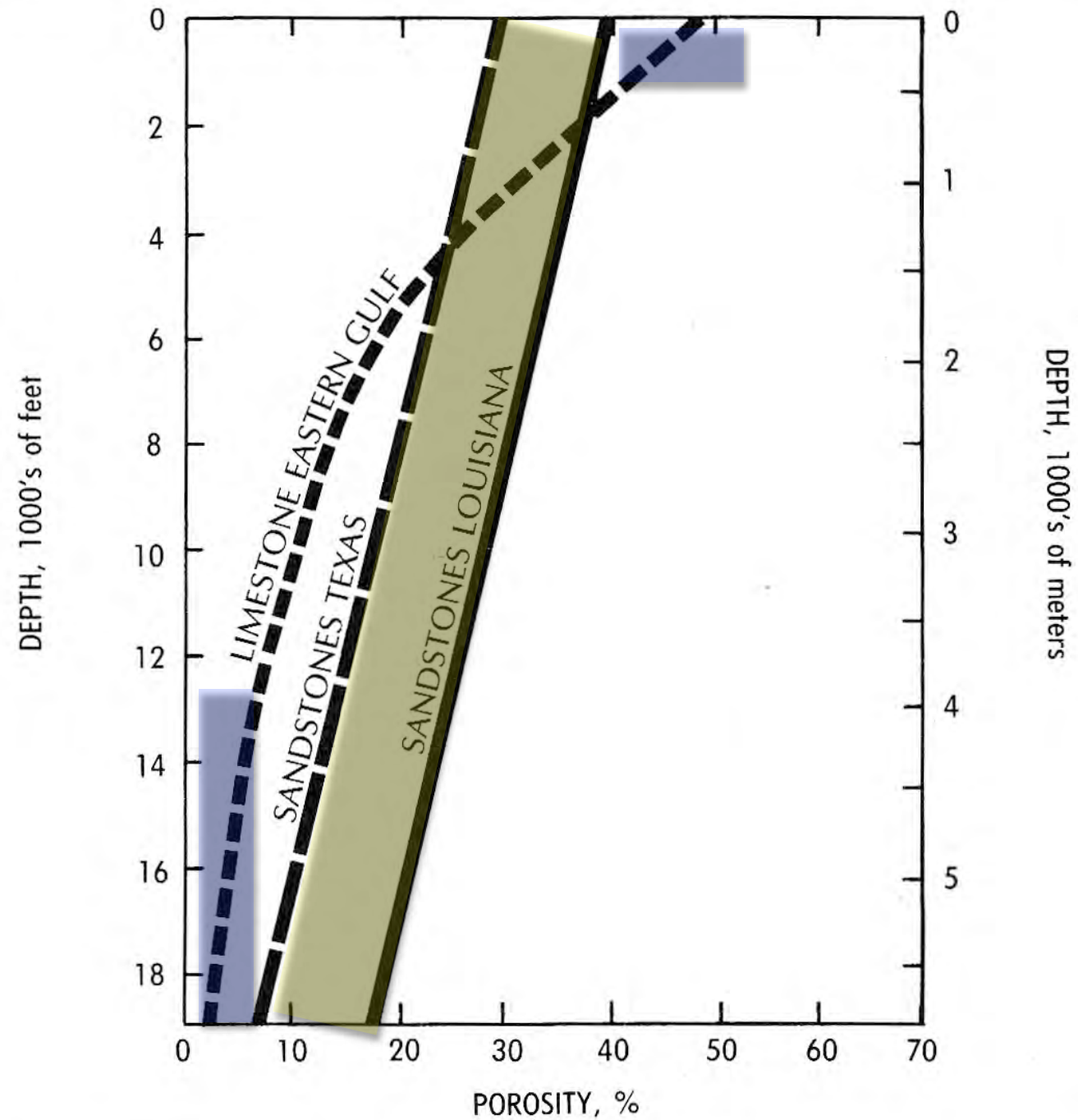
CARBONATE SEDIMENTS, ROCKS	SILICICLASTIC SEDIMENTS, ROCKS
Most occur in tropics	Climate, water depth no constraint
Most are marine	May be marine or non-marine
Organisms erect structure	No analogous process
Sediment texture controlled by growth form and ultrastructure of organisms	Sediment texture reflects hydraulic energy in environment of deposition
Grain composition directly reflects environment of deposition	Grain composition related to provenance of sediment, climate and tectonics of source
Shelf limestones often consist of numerous stacked shoaling upward sequences	Shelf clastics do not generally show cyclicity
Shelf undergoes predictable evolution in response to sea level because rate of carbonate production constant across shelf	Shelf evolution in response to sea level more complex because of potential changes in sediment availability through tectonism and climate at the source
Often cemented in marine environment	Seldom cemented in marine environment
Muds and grains may be formed by chemical precipitation	Muds and grains formed by breakdown of pre-existing rocks
Susceptible to early diagenetic overprint, porosity difficult to predict	Less susceptible to early diagenesis, porosity related to depositional environment, predictable
More susceptible to burial diagenesis, porosity basement relatively shallow	Less susceptible to burial diagenesis, porosity basement relatively deep

Moore 1989

<i>Aspect</i>	<i>Sandstone</i>	<i>Carbonate</i>
Amount of primary porosity in sediments	Commonly 25-40%	Commonly 40-70%
Amount of ultimate porosity in rocks	Commonly half or more of initial porosity; 15-30% common	Commonly none or only small fraction of initial porosity; 5-15% common in reservoir facies
Type(s) of primary porosity	$\pm\Phi I$ 'depositional' Almost exclusively interparticle	$\pm\Phi II$ 'diagenetic' Interparticle commonly predominates, but intraparticle and other types are important
Type(s) of ultimate porosity	Almost exclusively primary interparticle	Widely varied because of postdepositional modifications
Sizes of pores	Diameter and throat sizes closely related to sedimentary particle size and sorting	Diameter and throat sizes commonly show little relation to sedimentary particle size or sorting
Shape of pores	Strong dependence on particle shape—a "negative" of particles	Greatly varied, ranges from strongly dependent "positive" or "negative" of particles to form completely independent of shapes of depositional or diagenetic components
Uniformity of size, shape, and distribution	Commonly fairly uniform within homogeneous body	Variable, ranging from fairly uniform to extremely heterogeneous, even within body made up of single rock type
Influence of diagenesis	Minor; usually minor reduction of primary porosity by compaction and cementation	Major; can create, obliterate, or completely modify porosity; cementation and solution important
Influence of fracturing	Generally not of major importance in reservoir properties	Of major importance in reservoir properties if present
Visual evaluation of porosity and permeability	Semiquantitative visual estimates commonly relatively easy	Variable; semiquantitative visual estimates range from easy to virtually impossible; instrument measurements of porosity, permeability and capillary pressure commonly needed
Adequacy of core analysis for reservoir evaluation	Core plugs of 1-in. diameter commonly adequate for "matrix" porosity	Core plugs commonly inadequate; even whole cores (~3-in. diameter) may be inadequate for large pores
Permeability porosity interrelations	Relatively consistent; commonly dependent on particle size and sorting	Greatly varied; commonly independent of particle size and sorting

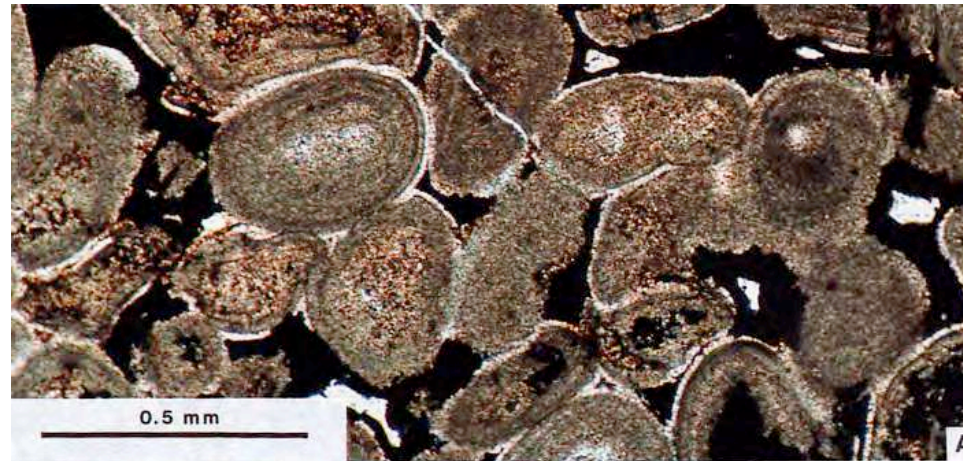
Choquette and Pray, 1970

Porosity-burial depth relationships for carbonates and sandstones across the Gulf of Mexico (Halley & Schmoker 1983)

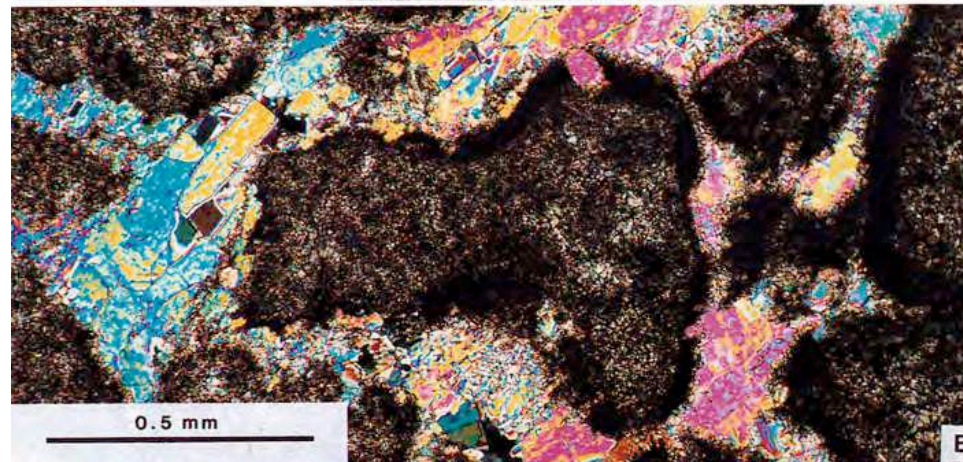


Unrestricted dolomites Zechstein Reservoirs *Permian, The Netherlands*

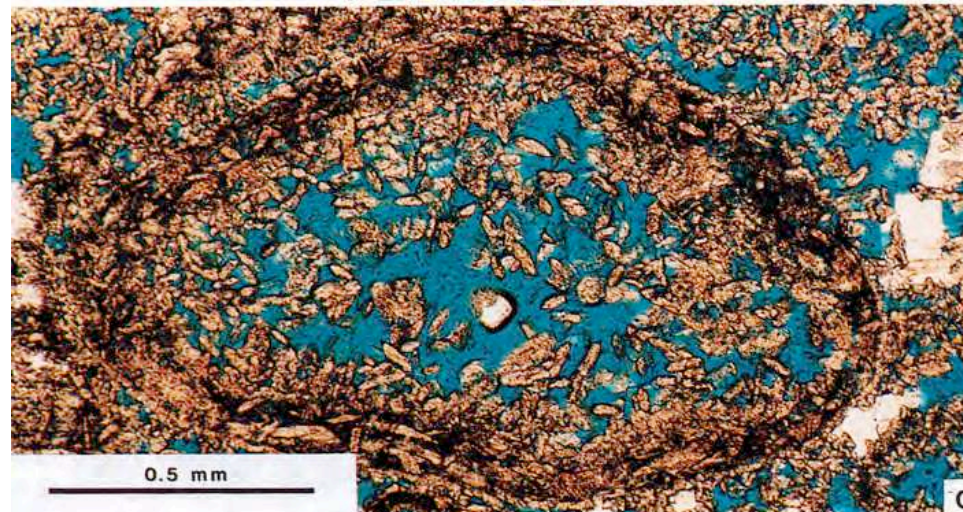
Interparticle depositional porosity
plugged by solid hydrocarbons
(black)



Diagenetic-destroying porosity
by anhydrite pore plugging



Vuggy porosity in a coated
'intraclast', due to early diagenetic
meteoric water infiltration



Van der Baan 1990

Permeability (K) : 10^{-4} to 10^{+8} mD = strong variations
 K 10-100mD are good, and above = exceptionnally high (RR)

Permeability	Pervious				Semi-Pervious				Impervious				
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel		Very Fine Sand, Silt, Loess, Loam								
Unconsolidated Clay & Organic					Peat		Layered Clay		Unweathered Clay				
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	
κ (cm ²)	0.001	0.0001	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷	10 ⁻⁸	10 ⁻⁹	10 ⁻¹⁰	10 ⁻¹¹	10 ⁻¹²	10 ⁻¹³	10 ⁻¹⁴	10 ⁻¹⁵
κ (millidarcy)	10 ⁺⁸	10 ⁺⁷	10 ⁺⁶	10 ⁺⁵	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001

Source: modified from Bear, 1972
 from Wikipedia 2013

K low to nul : $< 10^{-15}$ mD

K moderate : 15-50 mD

K good : 50-250 mD

K very good : 250-1000 mD

K excellent : > 1000 mD (> 1 D)

DIAGENESIS (...)

ARAGONITE + HMC → LMC +(DOLOMITE)

dissolution, neomorphism, cementation (...)

COMMON CARBONATE MINERALS

LMC

HMC

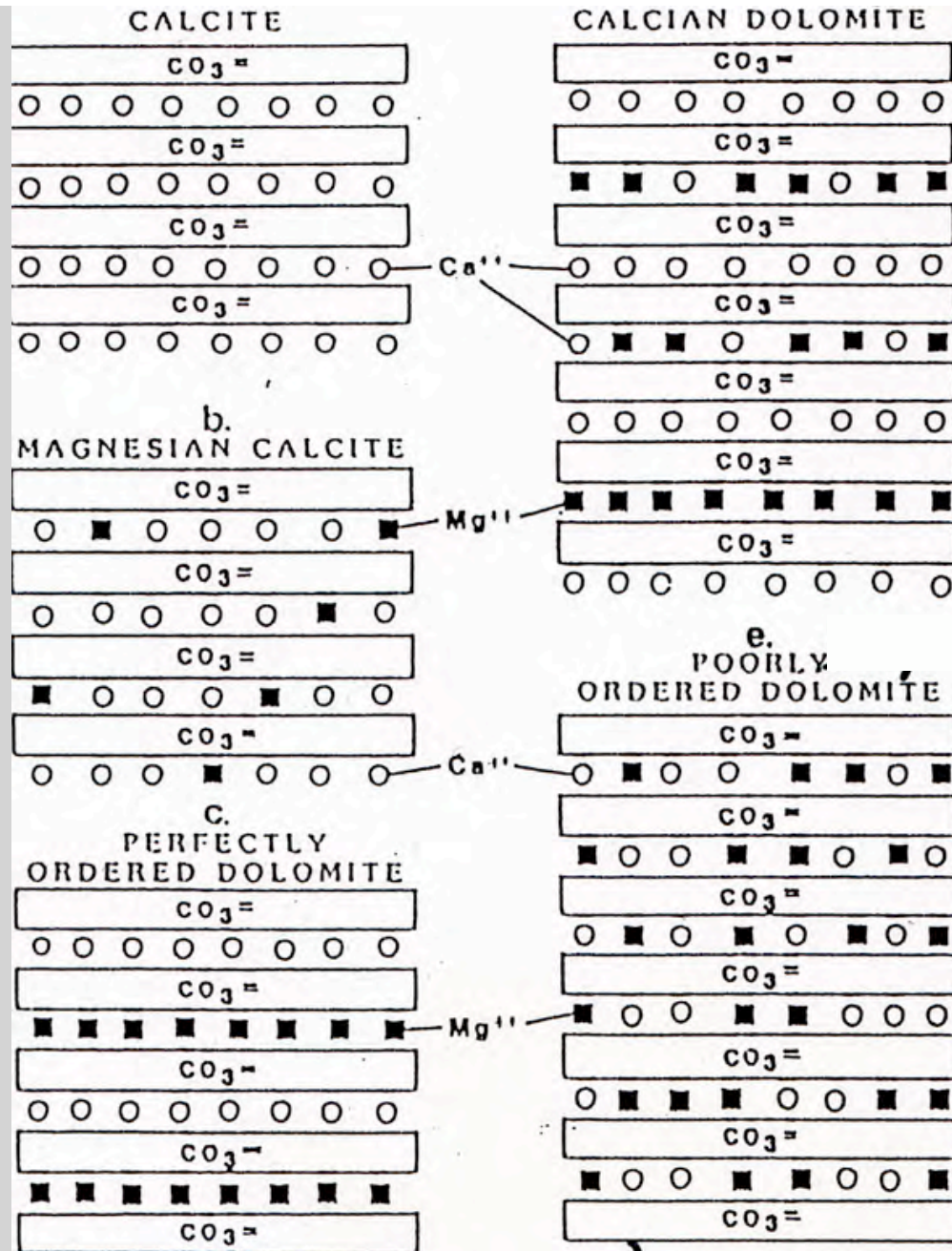
if >4
mole%
 MgCO_3

Ca:Mg 1:1
HT>300°C

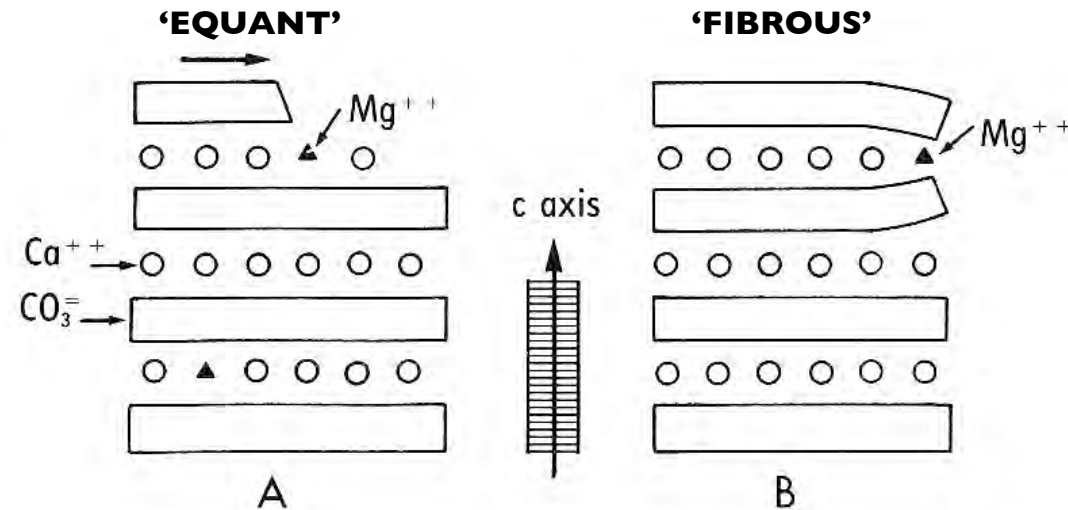
protodolomite



primary
or
penecontemporaneous
1-2 μm



CARBONATE CRYSTALLOCHEMISTRY



From Folk, 1974

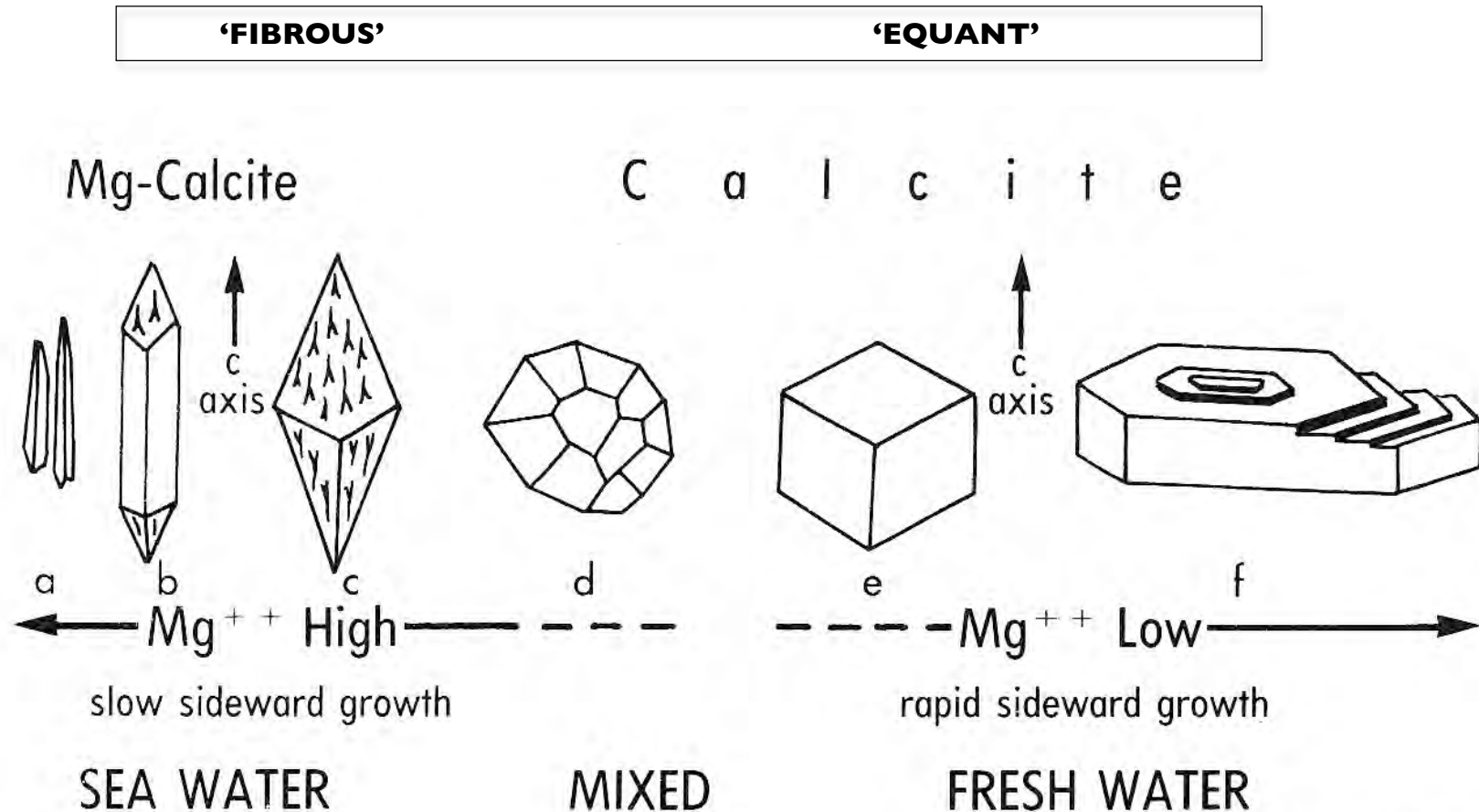
Morphology of calcite crystals as controlled by selective 'Mg-poisoning'.

A If a Mg ion is added to the end of growing crystal it can be easily overstepped by the next succeeding CO_3 layer **without harm to the crystal growth.**

B If the small Mg ion is added to the side of the crystal, the adjacent CO_3 sheets are distorted to accomodate it in the lattice, hampering further sideward growth
=> **growth of small, fibrous crystals.**

CARBONATE CRYSTALLOCHEMISTRY

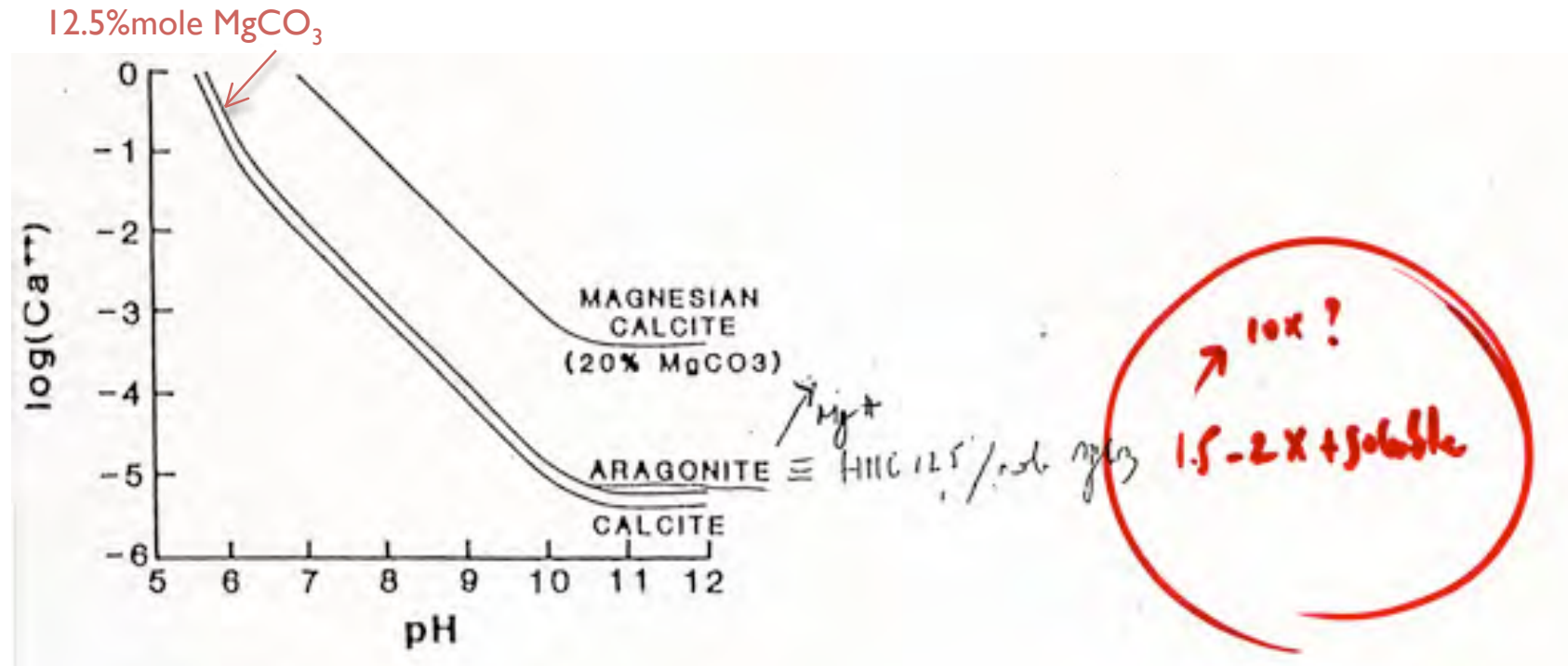
1960' Calcite crystal growth habit as a function of Mg/Ca ratio
nb : 1990' availability CO_3^{2-}



From Folk, 1974

CARBONATES : BORN IN THE SEA

MINERALOGY-DIAGENESIS



From METASTABLE (ARAG+HMC) TO STABLE (LMC+DOL) MINERALOGY

RECOGNITION
OF INVERTEBRATE
FOSSIL FRAGMENTS IN
ROCKS AND THIN SECTIONS

BY

OTTO P. MAJEWSKE

The School of Geology
Louisiana State University and
Agricultural and Mechanical College
Baton Rouge, Louisiana

With 280 Photomicrographs and 19 Diagrams



LEIDEN
E. J. BRILL
1974



Horowitz · Potter

Introductory Petrography of Fossils

1971



A. PREAT U.Brussels/U. Soran

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SKELETAL MICROSTRUCTURES – INVERTEBRATE FOSSILS

1. HOMOGENEOUS PRISMATIC

//N and NX: aggregates of tiny uniform indistinguishable crystals at <500x calcite (common), aragonite (rare), no visible structure,

❖ forams, , ostracods, trilobites, (sometimes mollusks).

2. NORMAL PRISMATIC

XN: aggregates of 'normal' prisms (longitudinal section) and 'aggregates' (transverse section). The prisms are normal to the surface of the shell.

=> based on the form, there are 4 types : 1-2 = inner layer of brachiopods, 1-3-4 (mollusks), calcite (common), aragonite (rare).

❖ brachiopods, mollusks

3. COMPLEX PRISMATIC

XN: aggregates of complex prisms (longitudinal section) and 'aggregates' (transverse section). Prisms are composed of aggregates of fibrils having same extinction position under crossed polarizers. Radial distribution of the fibrils along a central axis,

❖ only mollusks

SKELETAL MICROSTRUCTURES – INVERTEBRATE FOSSILS

4. COMPOSITE PRISMATIC

Transverse section : 3 composite 'prisms' giving the appearance of a simple prism.

Each composite prism is formed by an aggregate of tiny prisms (normal or complex) distributed radially from a central axis. Compared to [3], the aggregates are larger and oriented with their larger size in the plane of the shell layer

❖ only mollusks.

5. FOLIATED and NACREOUS (vs mineralogy)

FOLIATED = LMC, thin flat sheets or folia

NACREOUS = Aragonite, , thin flat sheets or folia

=> Foliated : important size variations, folia orientations and/or optical axes

❖ only brachiopods, bryozoans (not all), annelids (not all), sometimes mollusks

=> Nacreous : more uniform

❖ only mollusks.

6. MONOCRYSTALLINE

= single calcite crystal

XN: extinction, N//: cleavage traces with organic residues

under crossed polarizers. Radial distribution of the fibrils along a central axis,

❖ all the echinoderms, rare mollusks, bryozoans, sponge spicules

SKELETAL MICROSTRUCTURES – INVERTEBRATE FOSSILS

7. CROSSED-LAMELLAR

Layer built up of larger 'lamels' (first order), each rectangular, short axis generally vertical. Length of the single 'lamel' may be several mm. Each large 'lamel' is built up of smaller 'lamels' (second order) each one is a single crystal individual.

Acute angles between first and second order 'lamels' is around 41° or more,

=> flame microstructure

=> herringbone microstructure

=> 'parquet', 'pijama', 'plaid' microstructure

❖ only mollusks.

8. FIBER FASCICULATE

Fiber fascicles stacked one on top of the other in inclined rows forming a spherulitic fascicle which has crystallized about a point center.

❖ only corals (septa...).

tiny uniform crystals
not visible <500x
forams, ostracods, trilobites (mollusks)

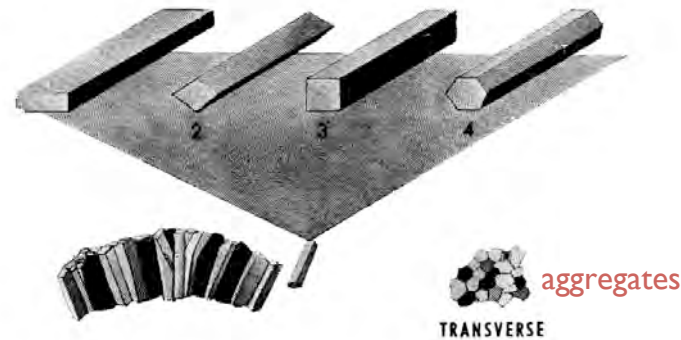
A.



Homogeneous prismatic

1, 2 internal layer *brachiopods*
1,3,4 *mollusks*

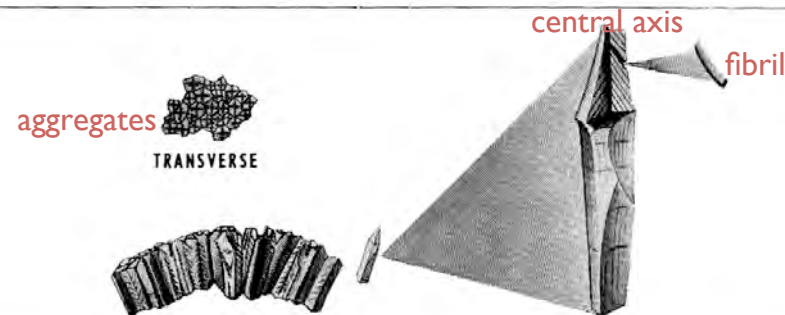
B.



Normal prismatic

mainly *mollusks*

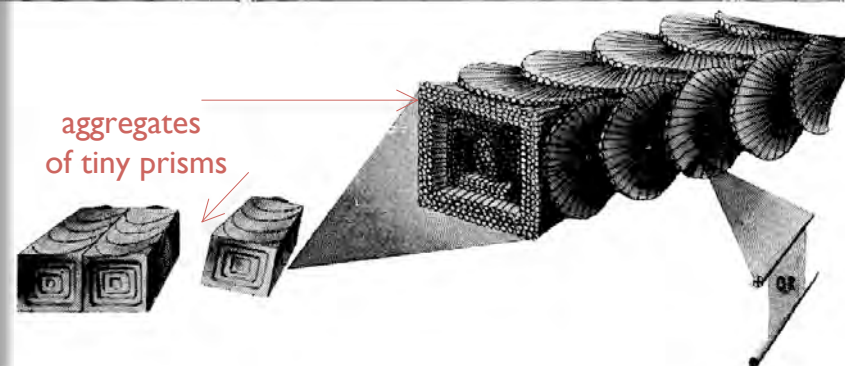
C.



Complex (composite)
prismatic

only *mollusks*

D.



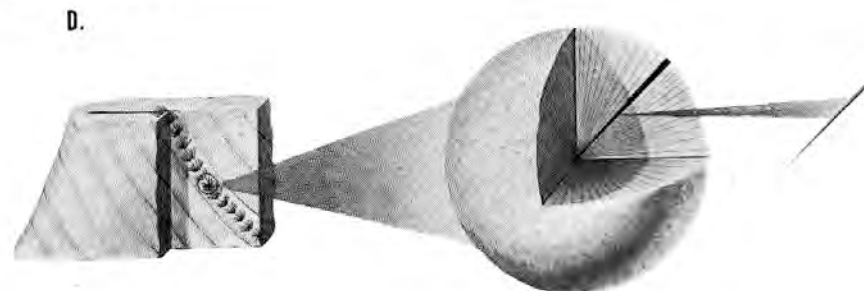
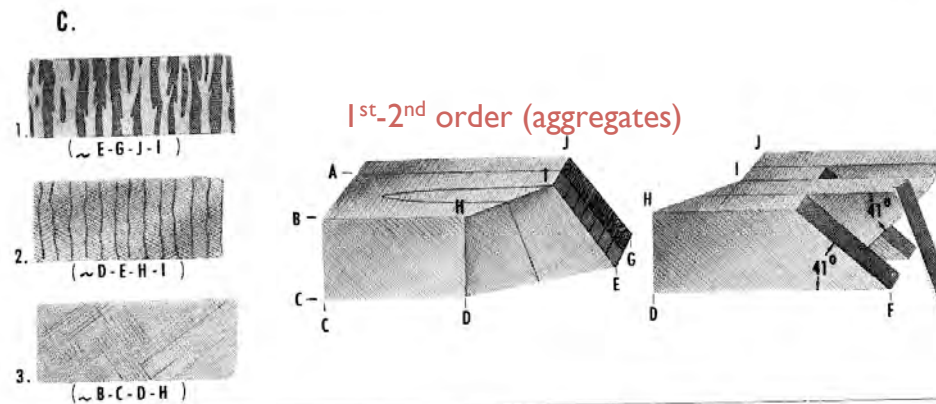
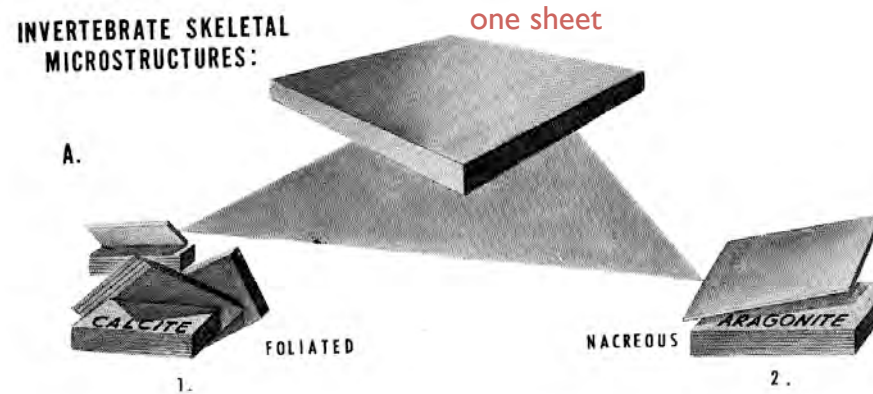
Composite prismatic

Foliated

△ orientation
△ size
△ optical axes

oysters
brachiopods
annelids
bryozoa

INVERTEBRATE SKELETAL MICROSTRUCTURES:



Nacreous

slight △

mollusks

Monocrystalline

ALL *echinoderms*

Crossed lamellar

mollusks

Fibrous fascicular

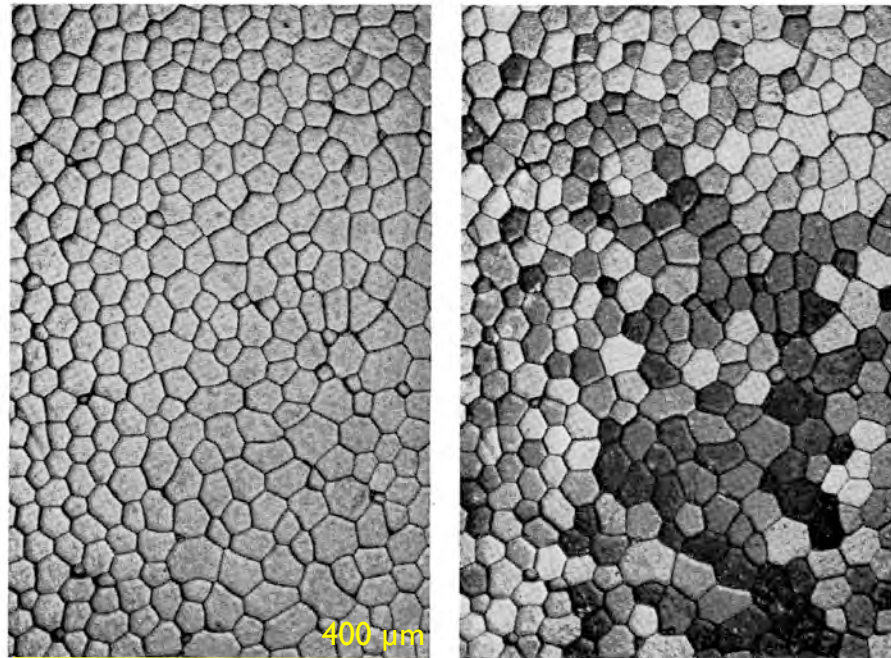
corals



Inoceramus sp., K, S Dakota
LMC

NX
L section

Normal prismatic



N//+NX
L sections

Atrina sp., Recent, Gulf of Mexico



Busycon sp., Recent, Gulf Mexico
ARAGONITE (second-o. cross at 73° and 107°)



Crossed lamellar



idem = HERRINGBONE PATTERN
(in a different part of the shell)



Crossed lamellar





N//



Homogeneous prismatic



NX

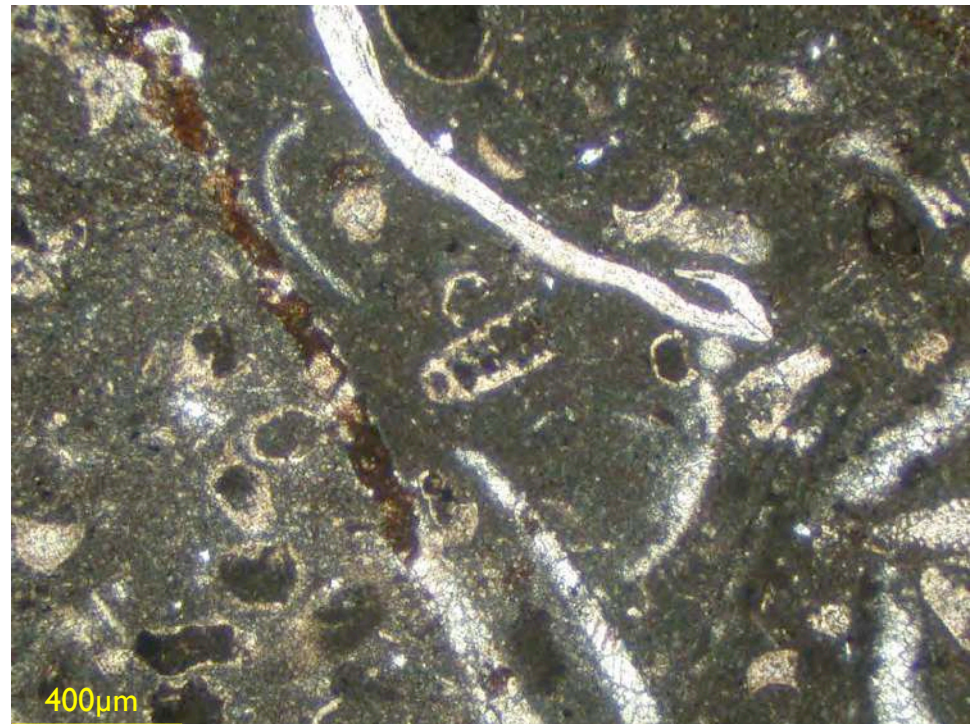


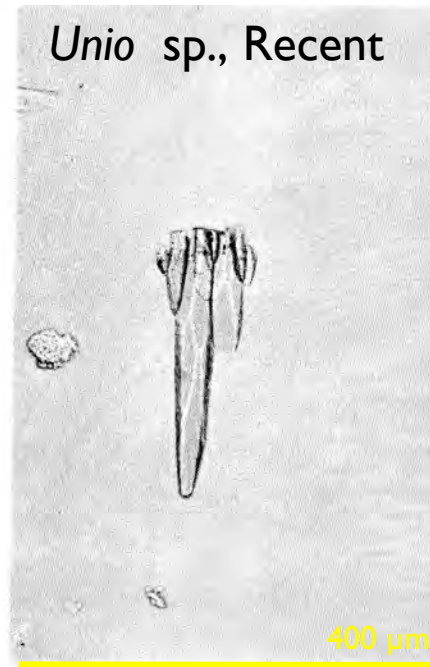
Typical trilobite sections

with algae (*Kamena*, *Proninella*)



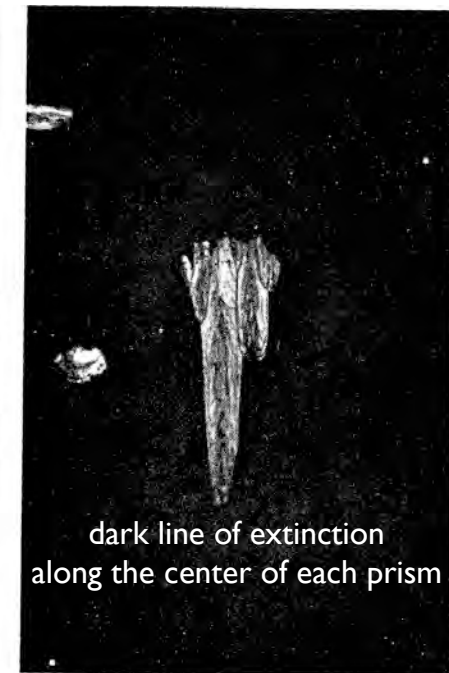
Early Givetian (Middle Devonian), Givet, France, Pr  at 2010



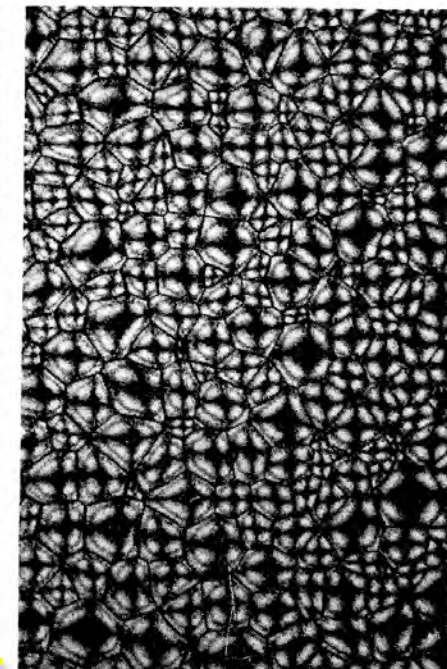
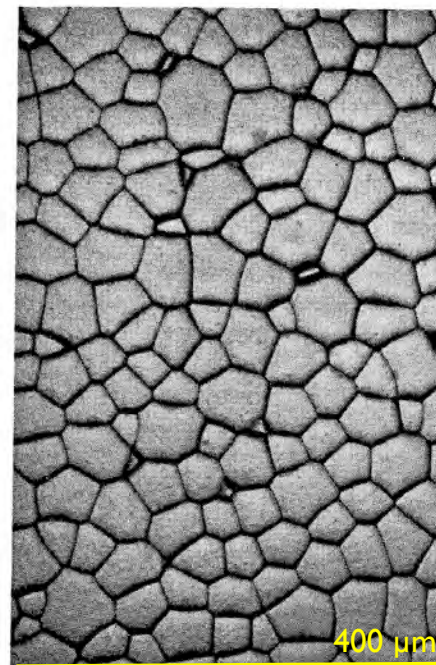


N//

Complex prismatic



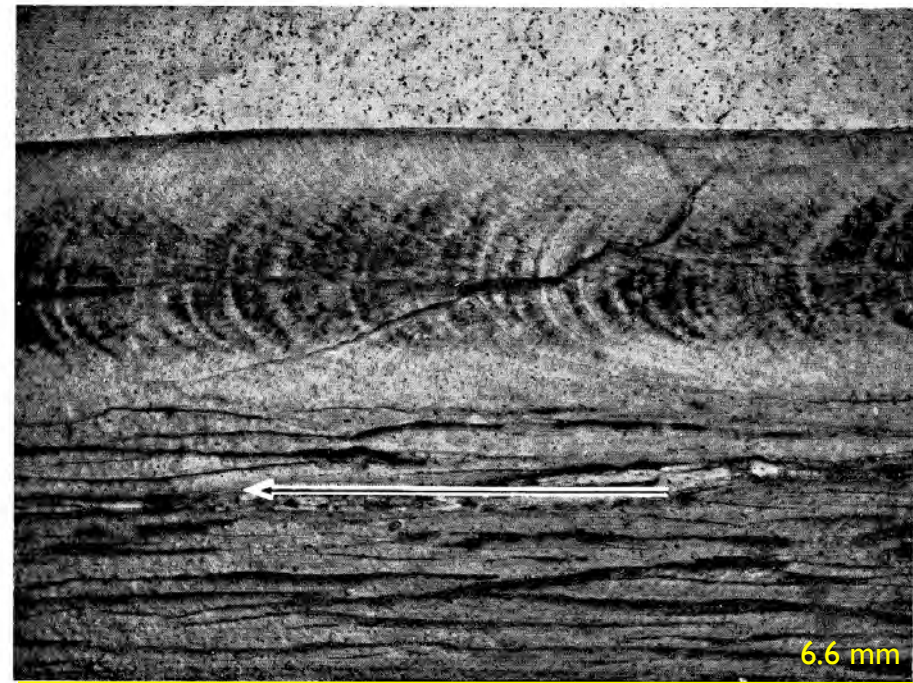
NX



extinction swings with rotation



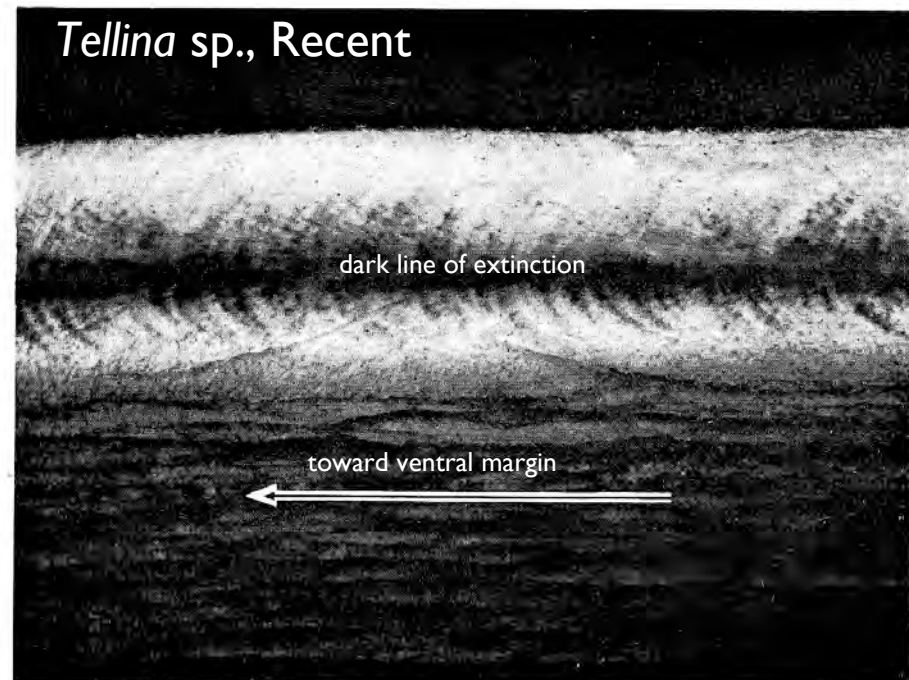
N//



Composite prismatic

Tellina sp., Recent

NX





N//



Foliated



N//





Dictyoclostus sp. (Brachiopod)

Pennsylvanian, Texas

LMC, very regular foliation

slight undulation of the folia = 'pseudopunctae'



Foliated (top) and Nacreous (bottom)

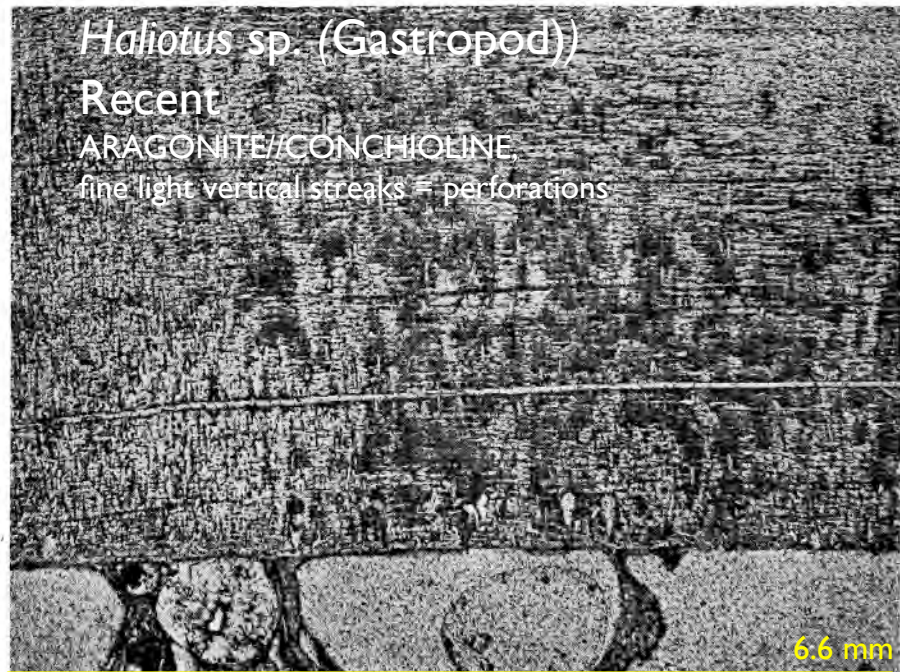


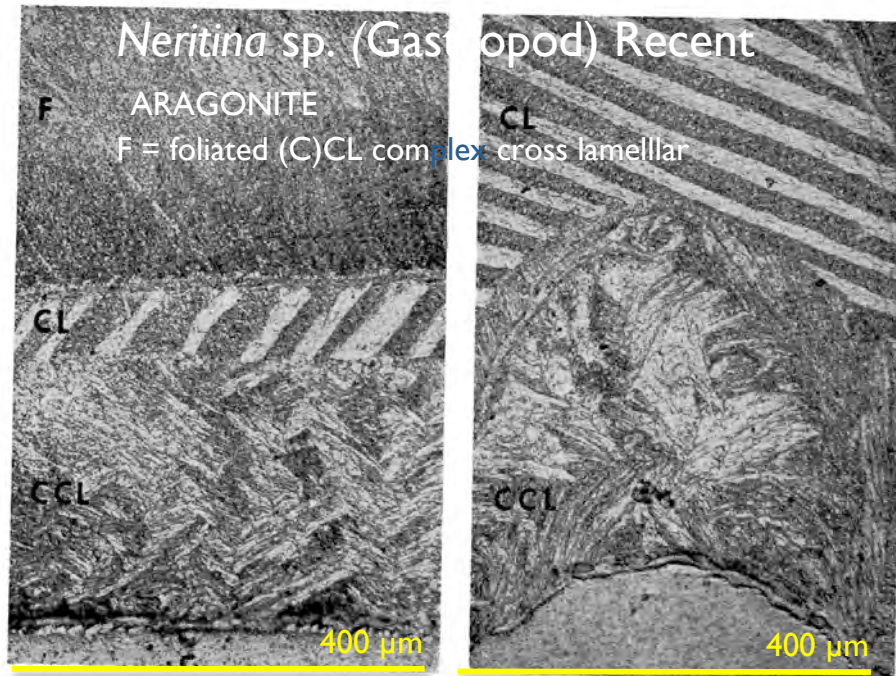
Haliotis sp. (Gastropod)

Recent

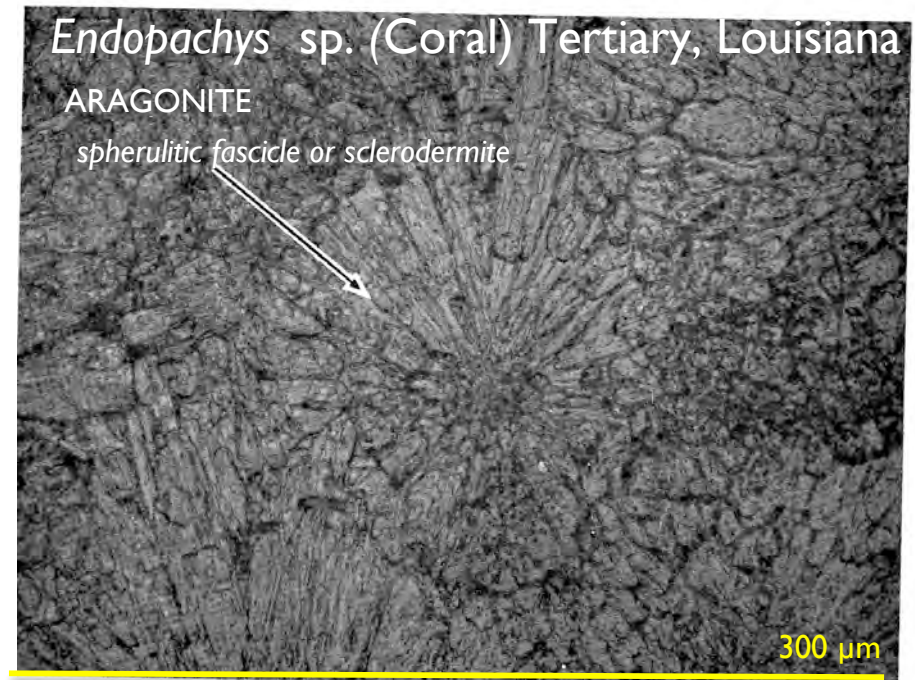
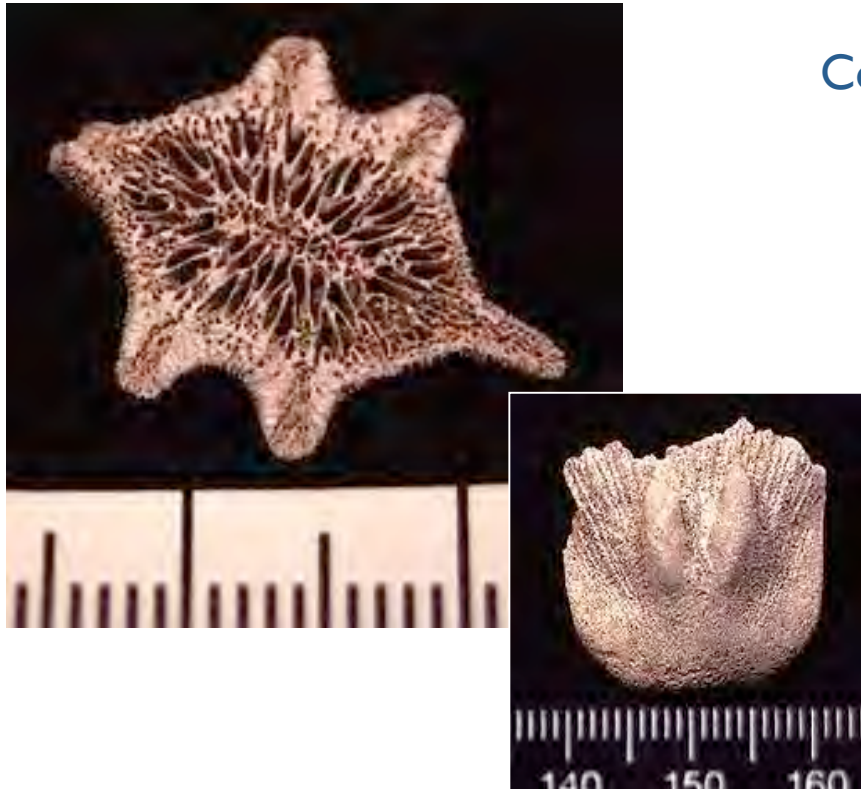
ARAGONITE/CONCHIOLINE

fine light vertical streaks = perforations

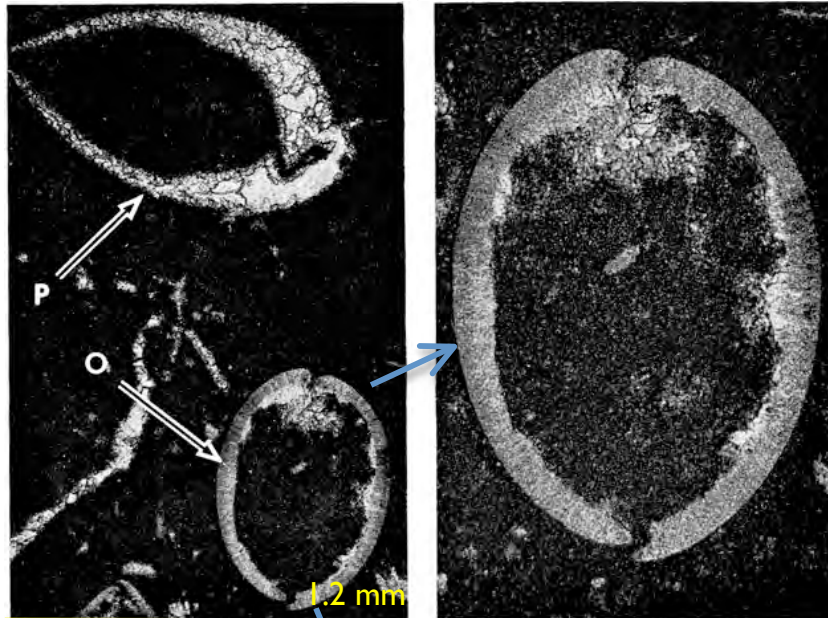




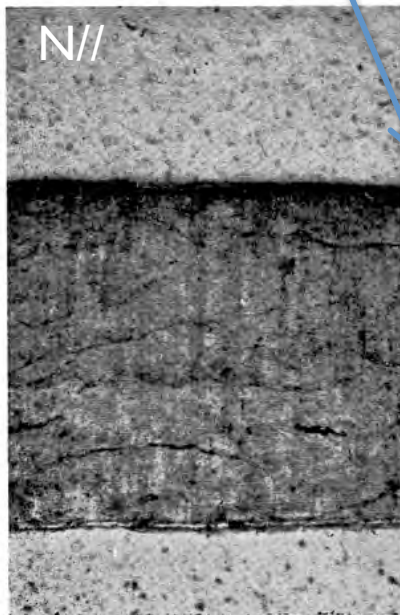
Complex cross lamellar (top) and Fiber fascicles (bottom)



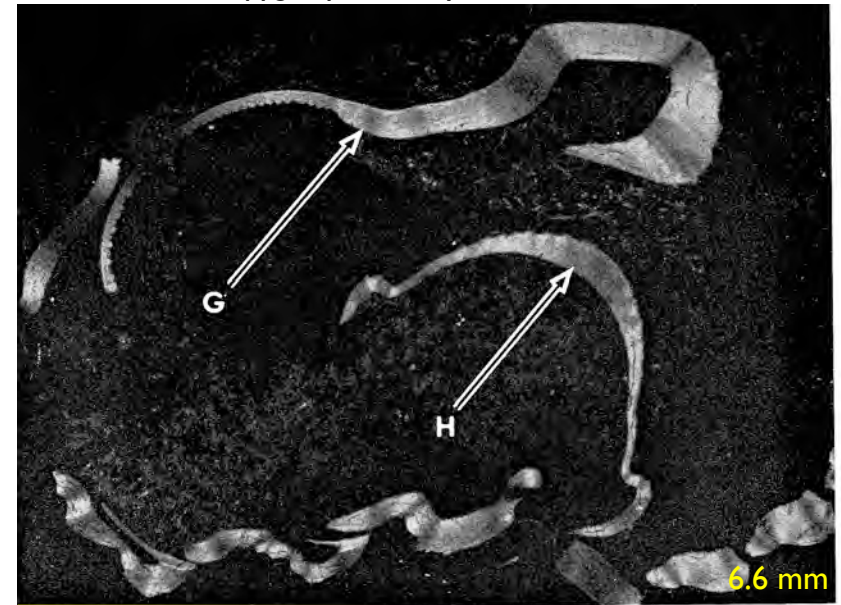
Ordovician, Dakota



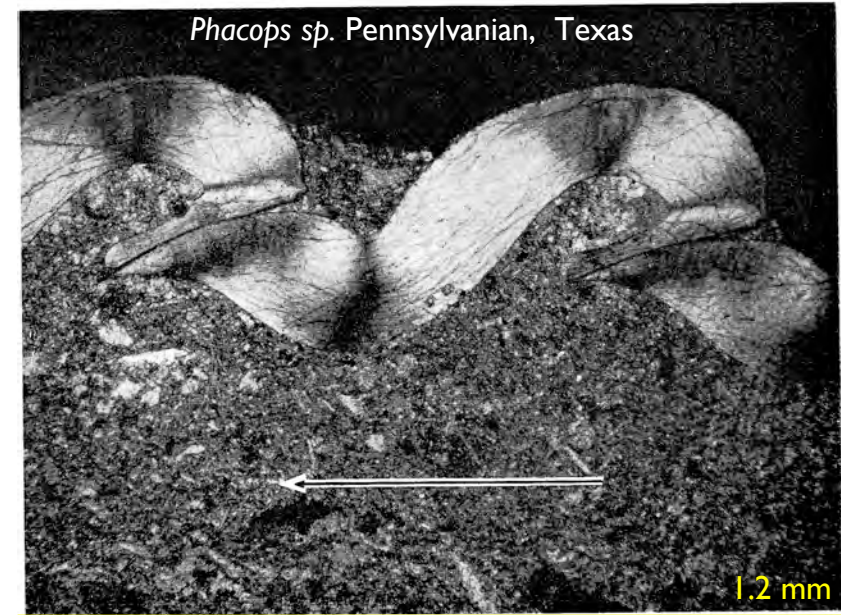
Ostracod carapace (O) and Pelecypod shell (P)



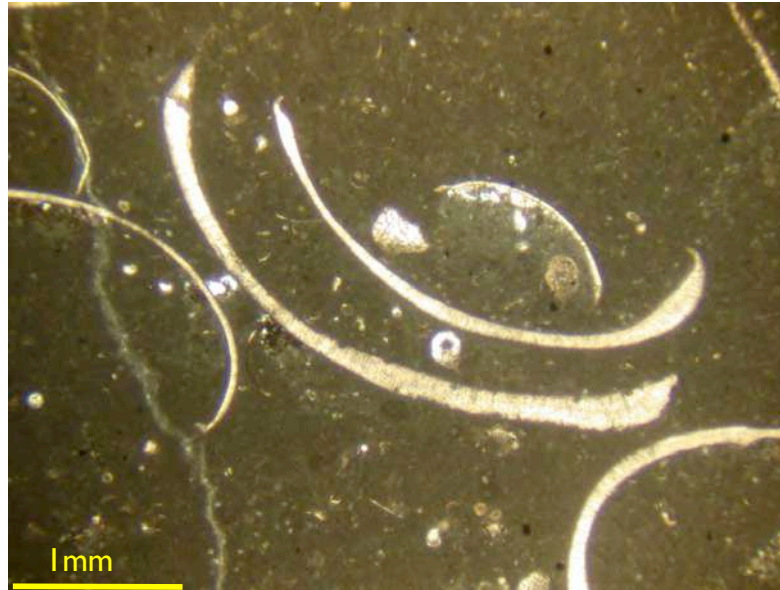
Ditomopyge sp. Pennsylvanian, Texas



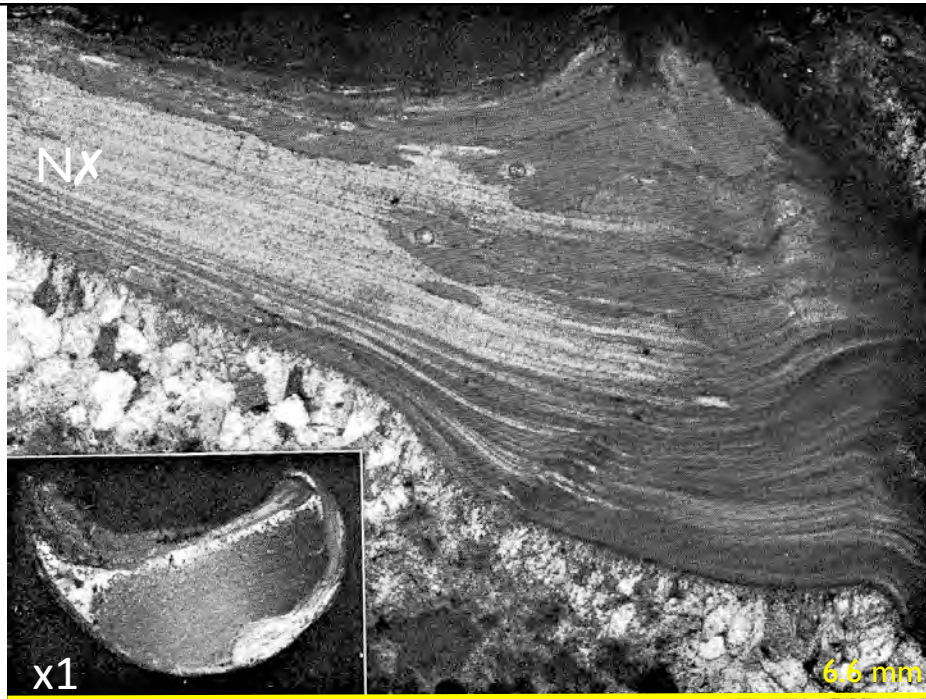
Phacops sp. Pennsylvanian, Texas



Leperdicopida sp. (ostracode), lagoonal environment
Trois-Fontaines Fm, Resteigne, Belgium
Early Givetian, Pr  at 2009



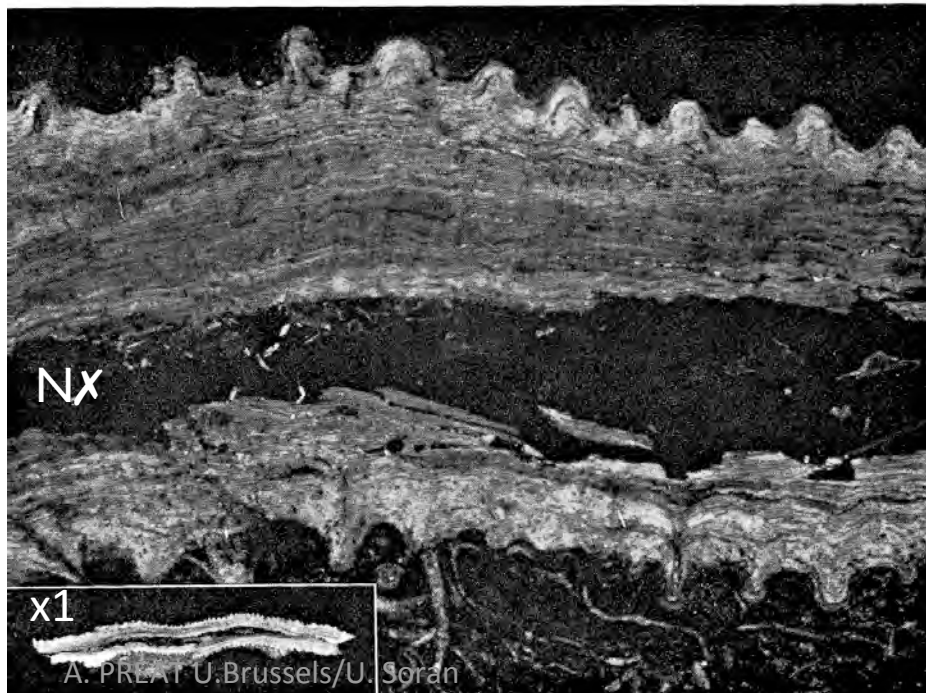
Stacked ostracode, mid-ramp setting,
Trois-Fontaines Fm, Givet, France
Lower Givetian, Pr  at 2010



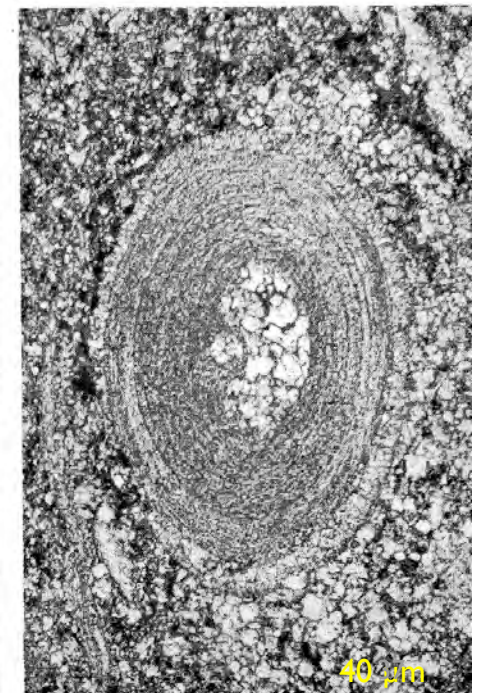
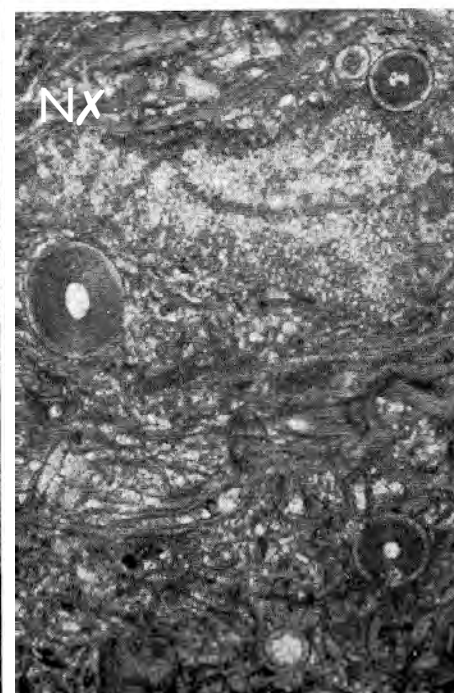
Dictyoclostus sp. (Productacea), Pennsylvanian, Texas

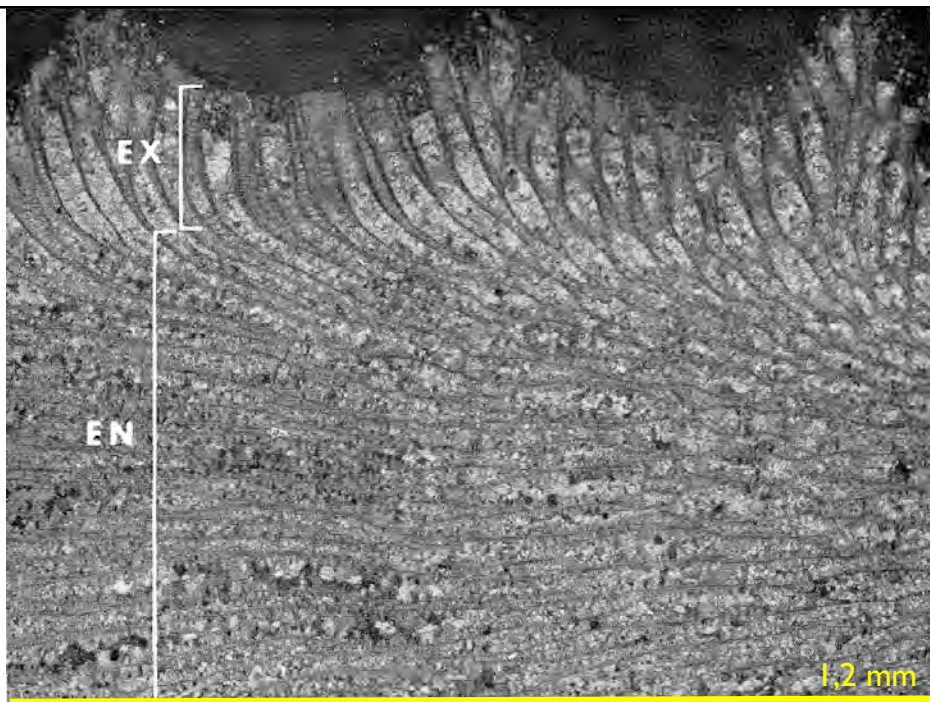


with spines (external layer)

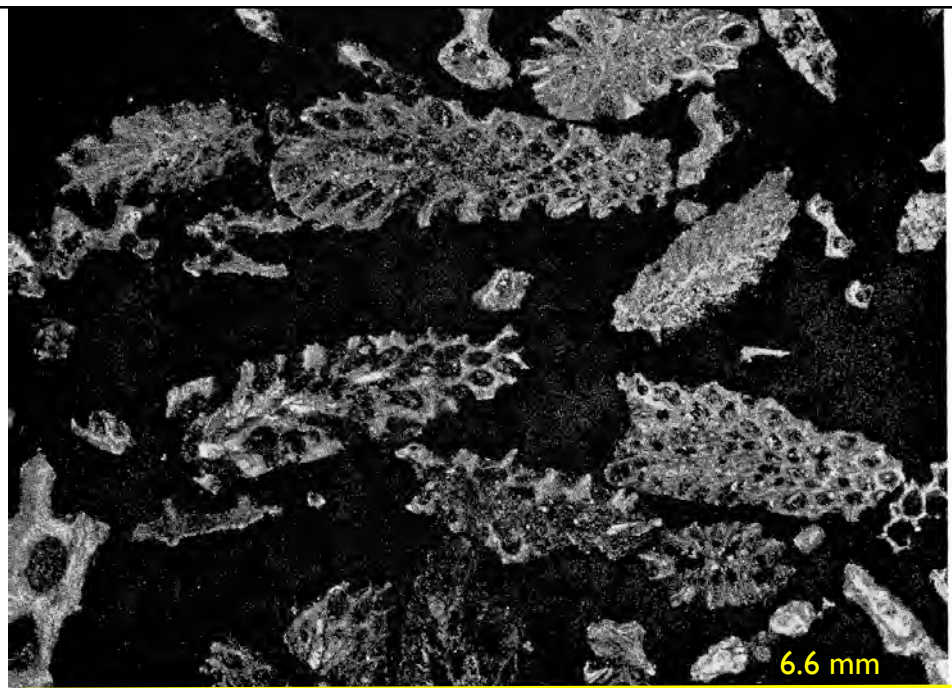


A. PREAT U.Brussels/U. Soran

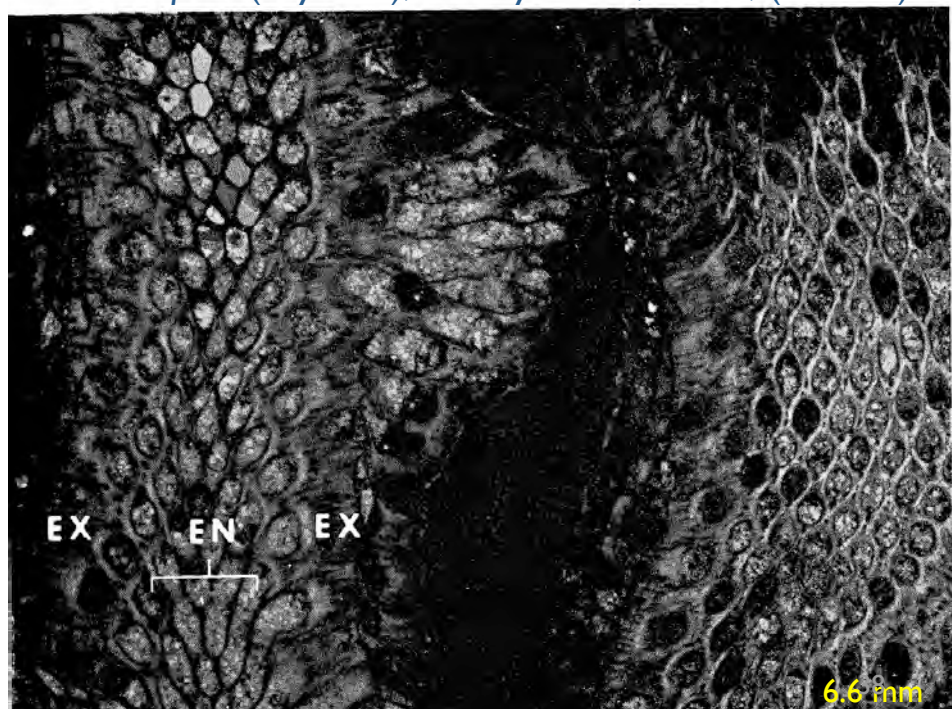
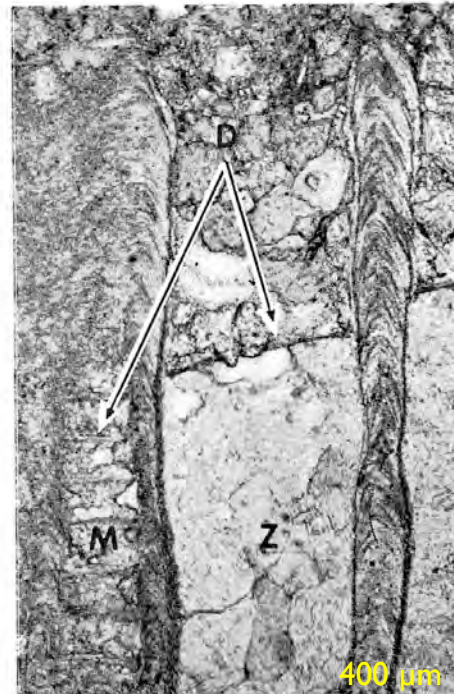
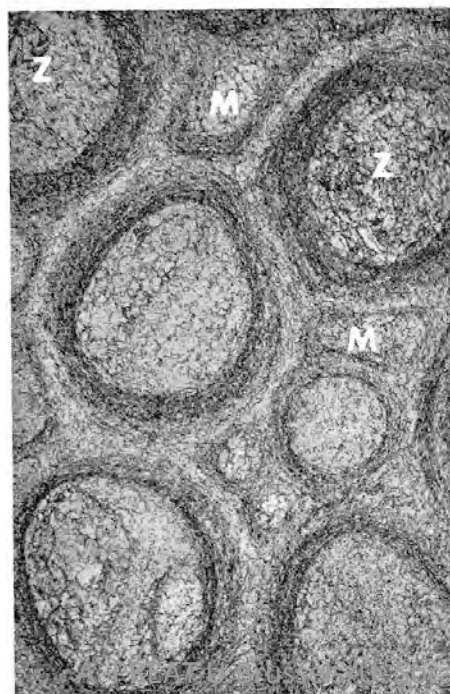


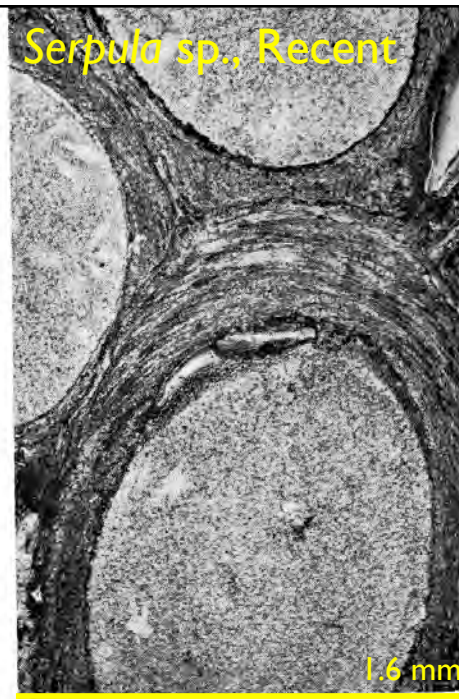
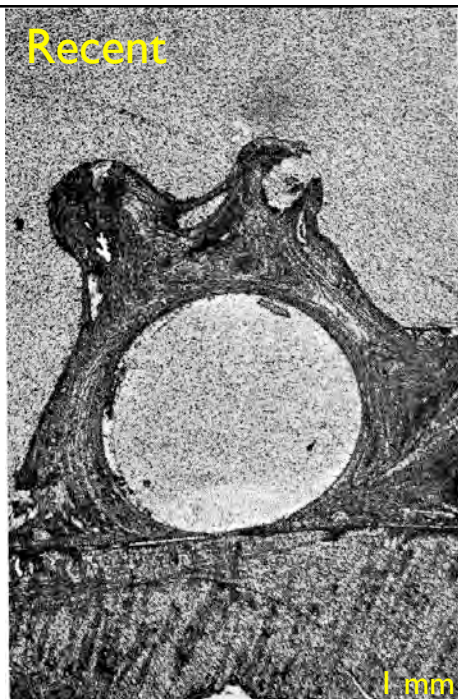


Colony of *Hallopore* sp. (Treptosoma Bryozoa), Ordovician, Ohio [Z = zoecia, M = mesopore, D = diaphragm]

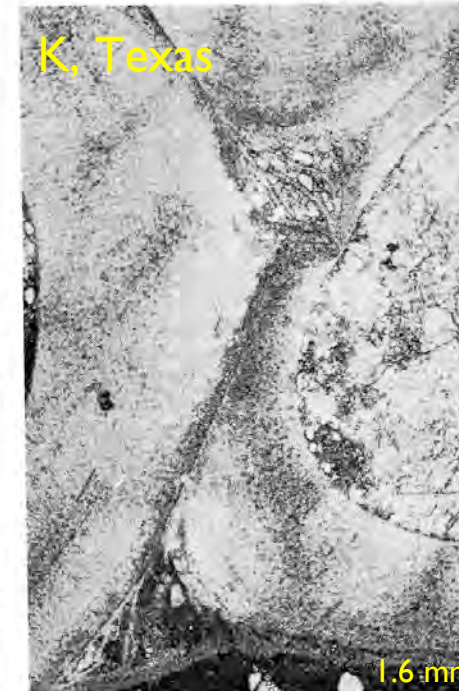


Cryptosome Bryozoa, Devonian, Michigan (top)
Rhombopora (Bryozoa), Pennsylvanian, Texas, (bottom)





Transverse section of a worm encrusting the inner nacreous layer of a *Haliotis* shell (upper left picture).



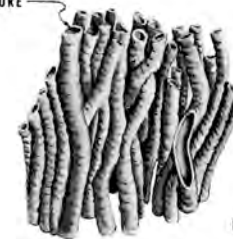
ANNELID WORMS

ANNELID WORMS:

TUBES



APERTURE



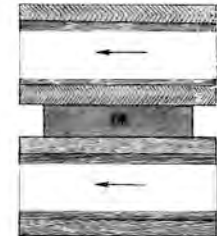
DIRECTION
OF
GROWTH

TUBE MICROSTRUCTURE

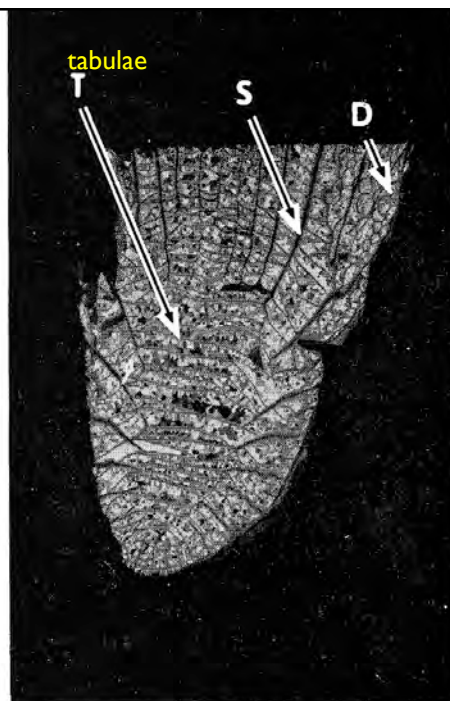
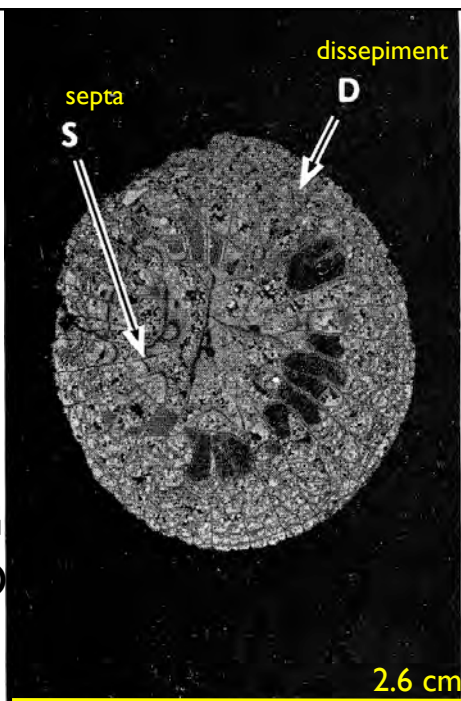
TRANSVERSE SECTION



LONGITUDINAL SECTION

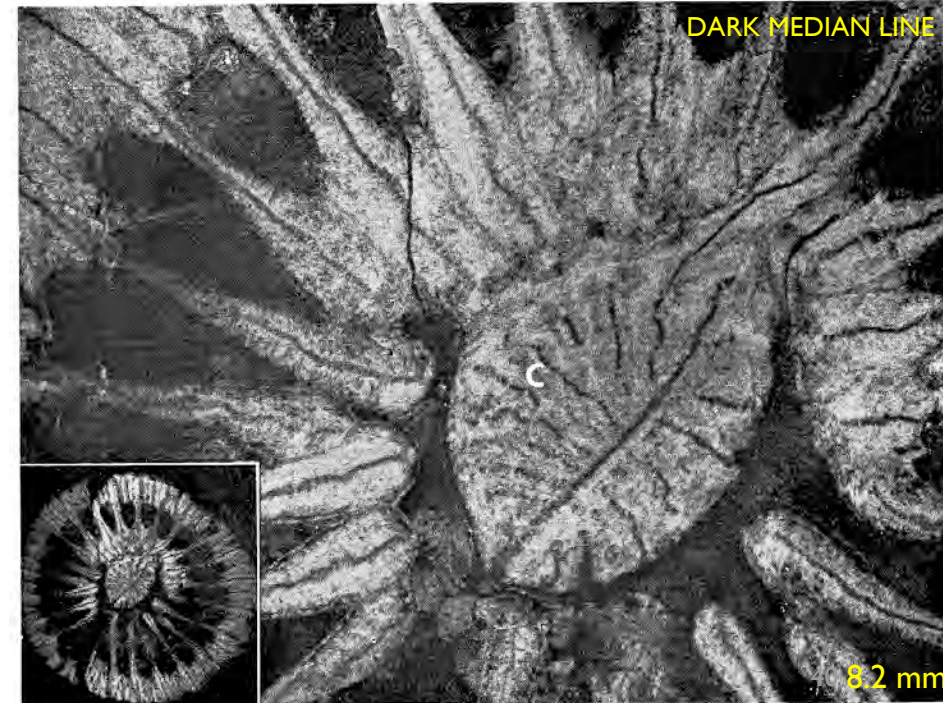
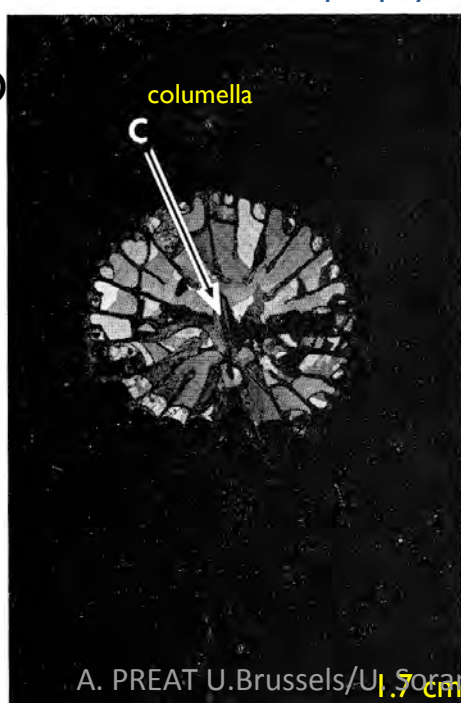


RUGOSA CORALS

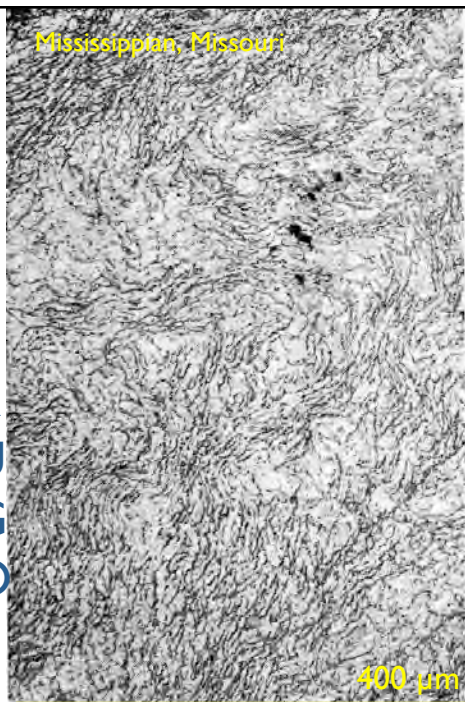


T & L sections of *Caninia* sp., Pennsylvanian, Texas (top)
T & L sections of *Lophophyllidium* sp., Pennsylv., Texas (bottom)

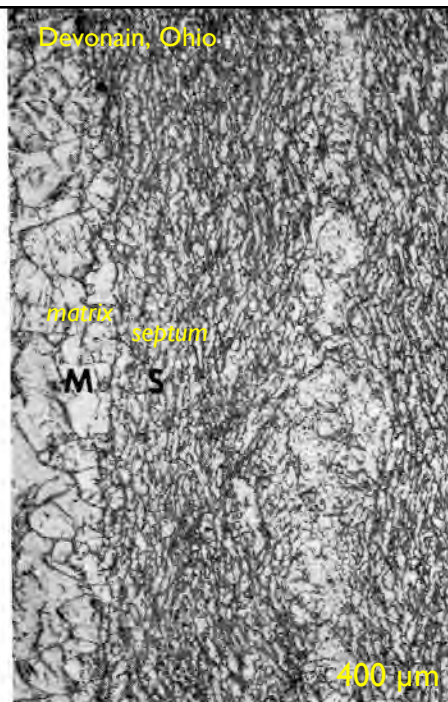
T section of *Cyathaxonia* sp., Mississippian, Missouri (top)
T section of *Lophophyllidium* sp., Pennsylv., Texas (bottom)



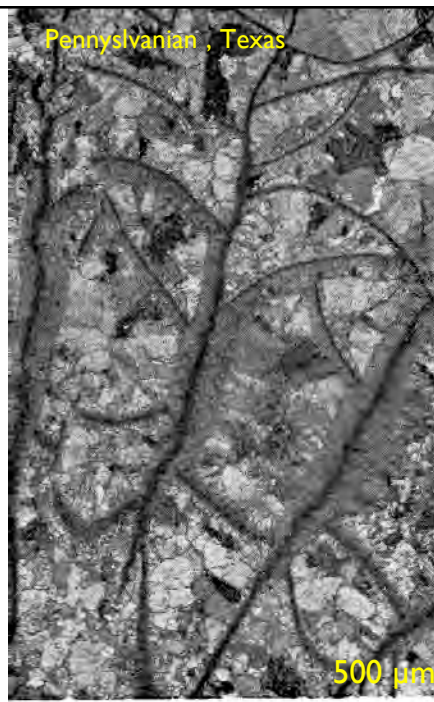
RUGOSA CORALS



T section of *Cyathaxonia* sp.



T section of *Heterophrentis* sp.
T section of *Lophophyllidium* sp.

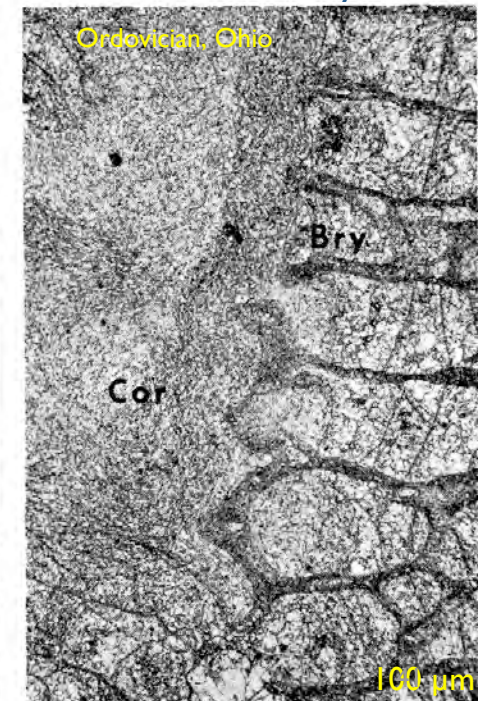
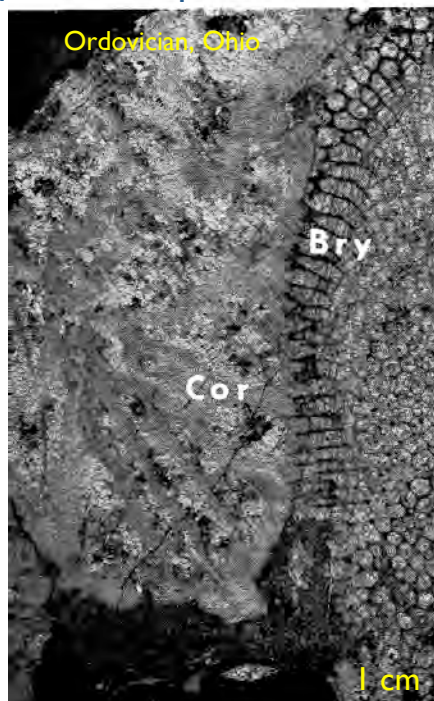
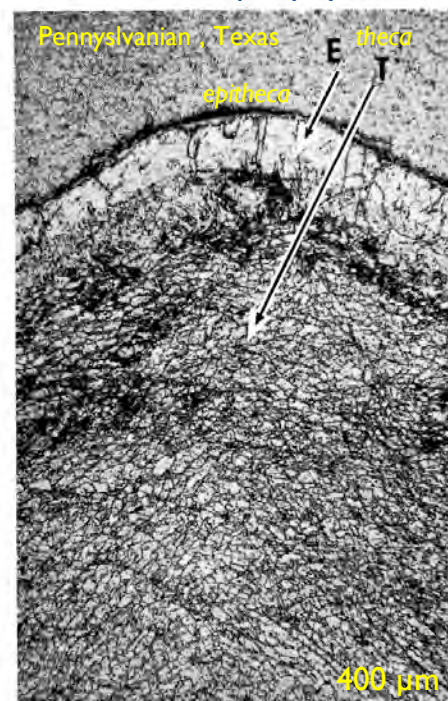


T section of *Caninia* sp.



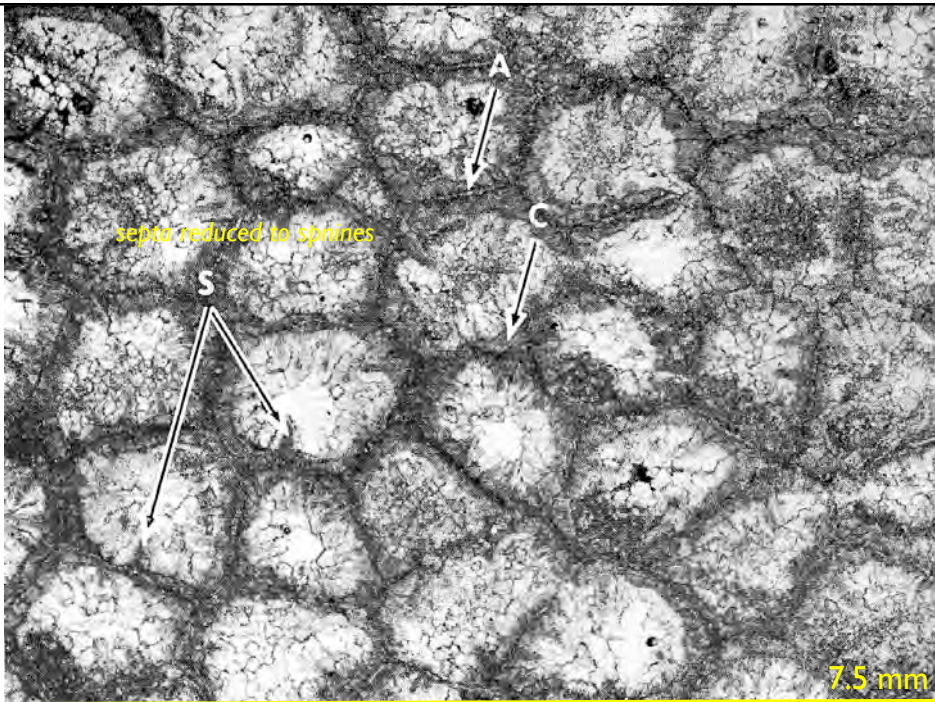
L section of *Caninia* sp.

Comparison skeletal microstructure coral/bryozoa



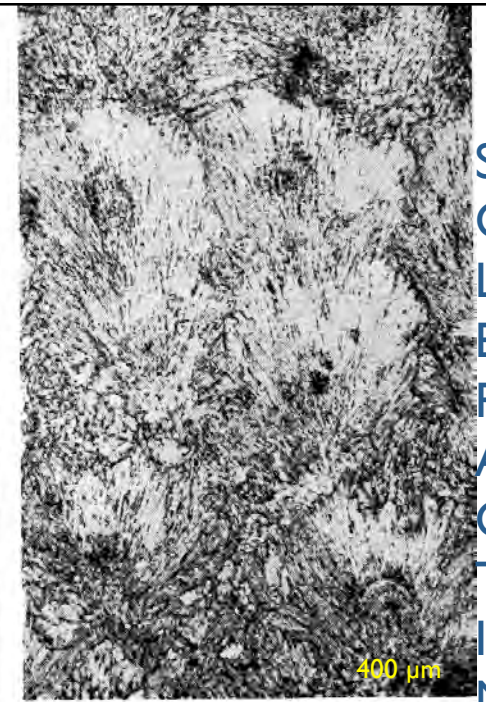
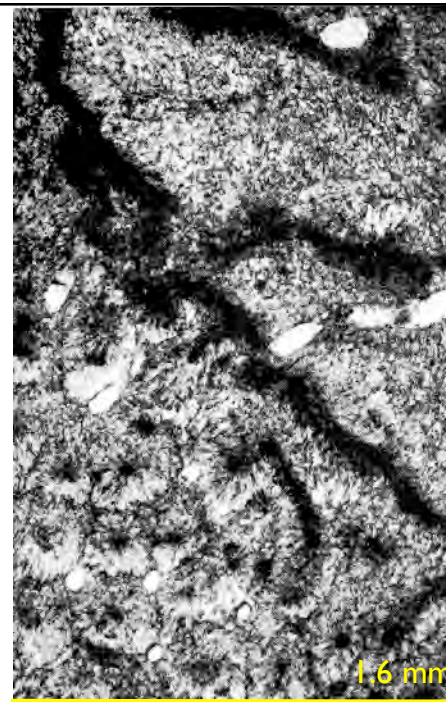
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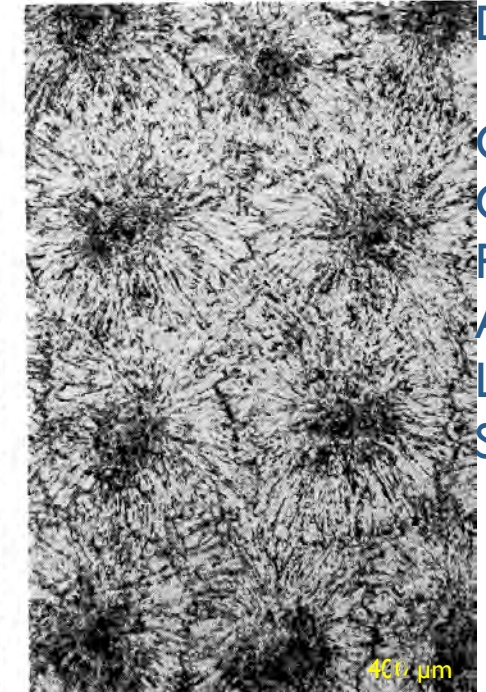
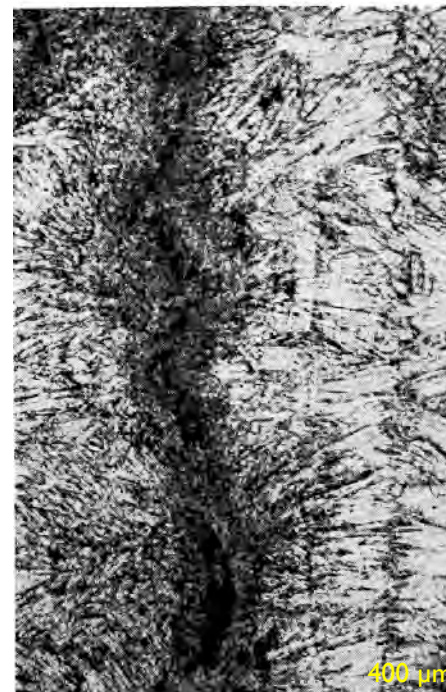
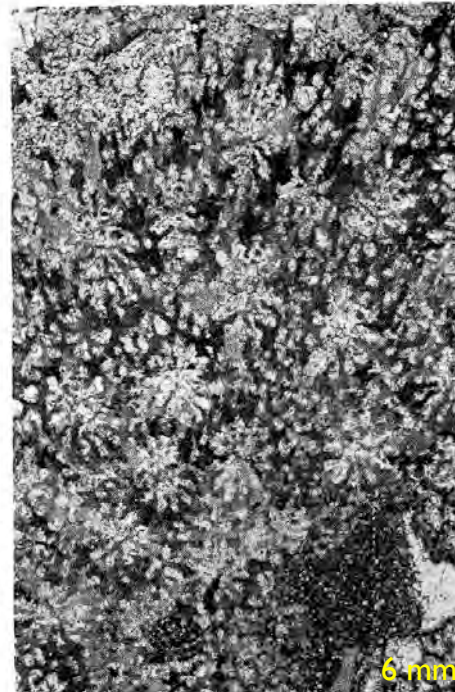


T section of *Favosites* sp., Silurian, Texas

L section of *Thamnopora* sp., Dev/, Dakota + T section in *Thecia?* sp.



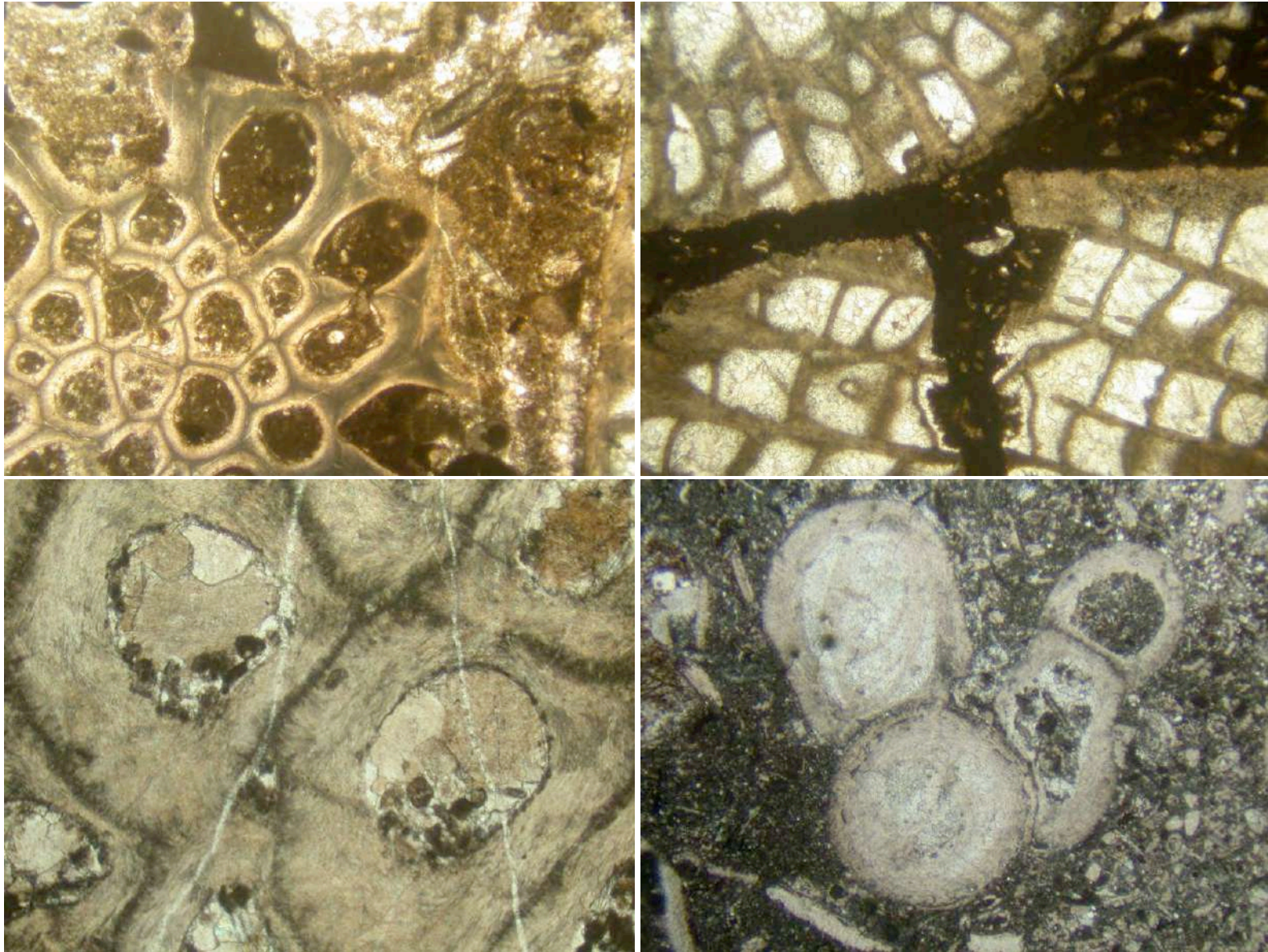
Endopachys sp., Tertiary, Louisiana



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Givetian Corals (Tabulata), Belgium



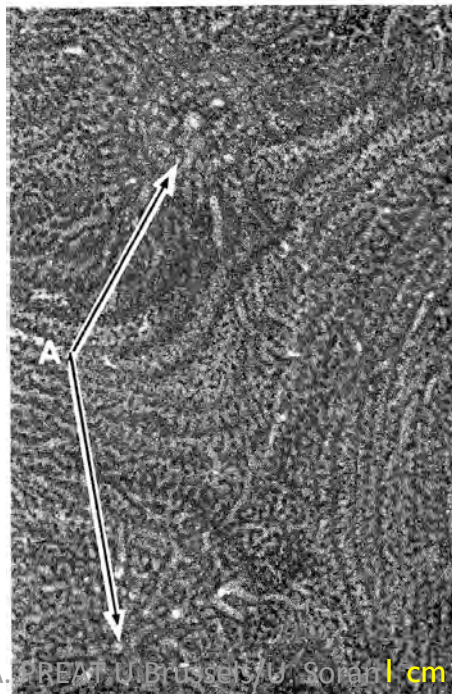
mm-(cm)

Préat 1999

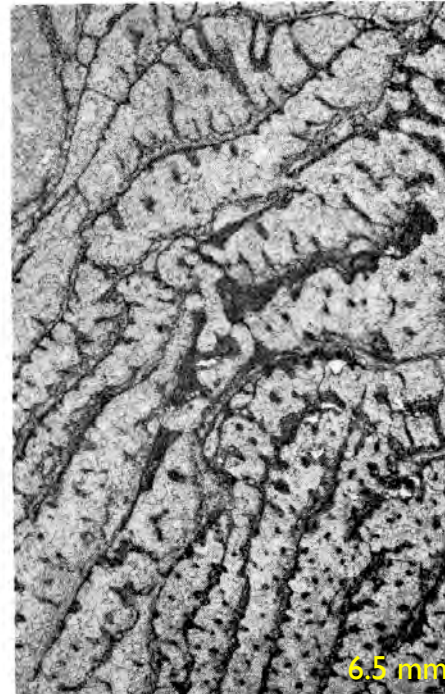
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Laminae and pillars + astrorhizae (A)
Devonian, N Dakota and Silurian, New Mexico)



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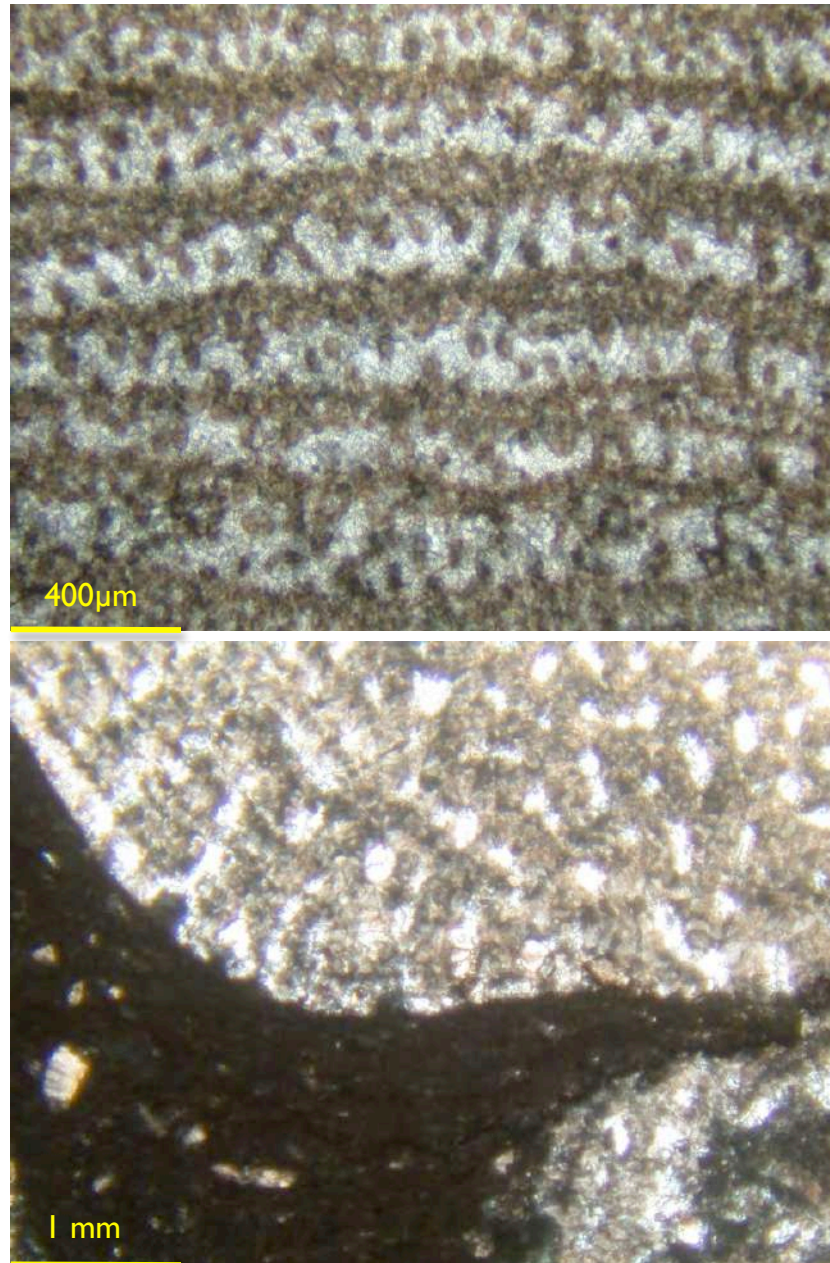
Flohimont, Givetian (France)



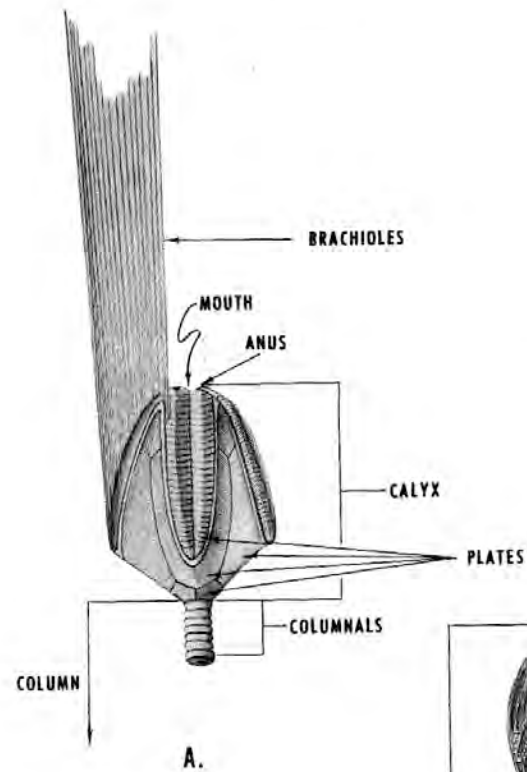
Stromatoporoid Biostrome, Givetian
Meseta-Morocco



Laminae and pillars
(thin section)
Late Givetian, Belgium,
Préat



ECHINODERMS - BLASTOIDS & CRINOIDS:

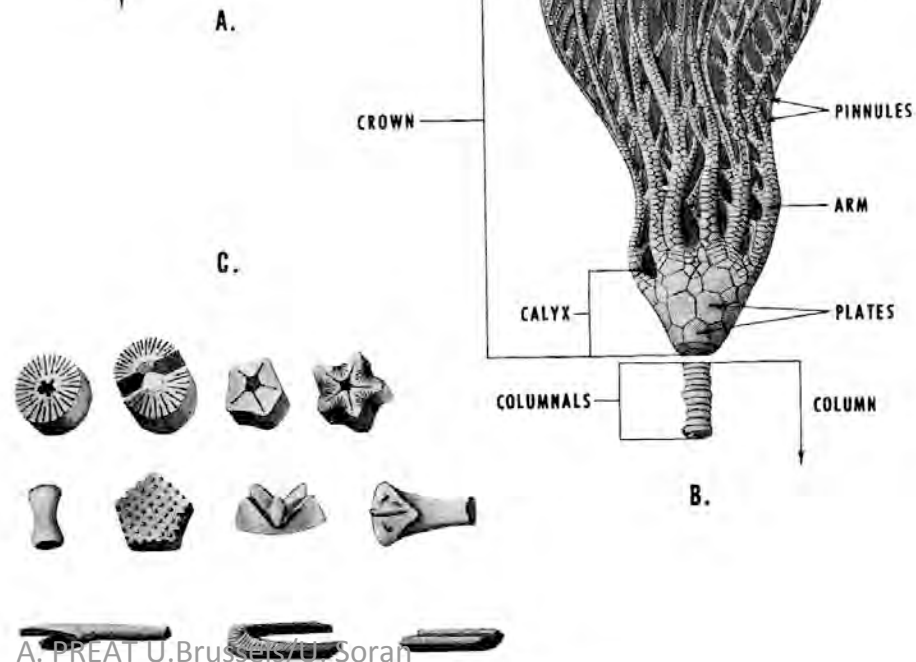
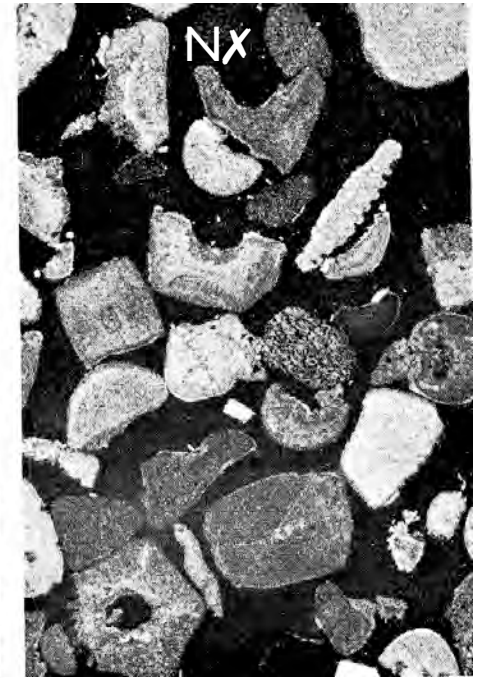
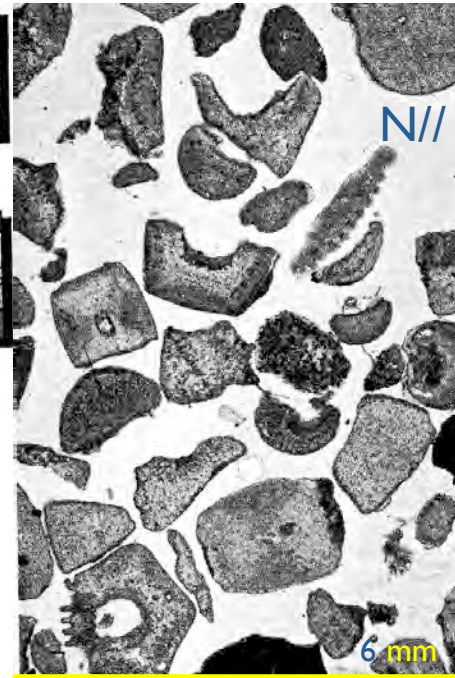


SKELETAL MICROSTRUCTURE

(ORDINARY LIGHT)



(CROSSED NICOLS)

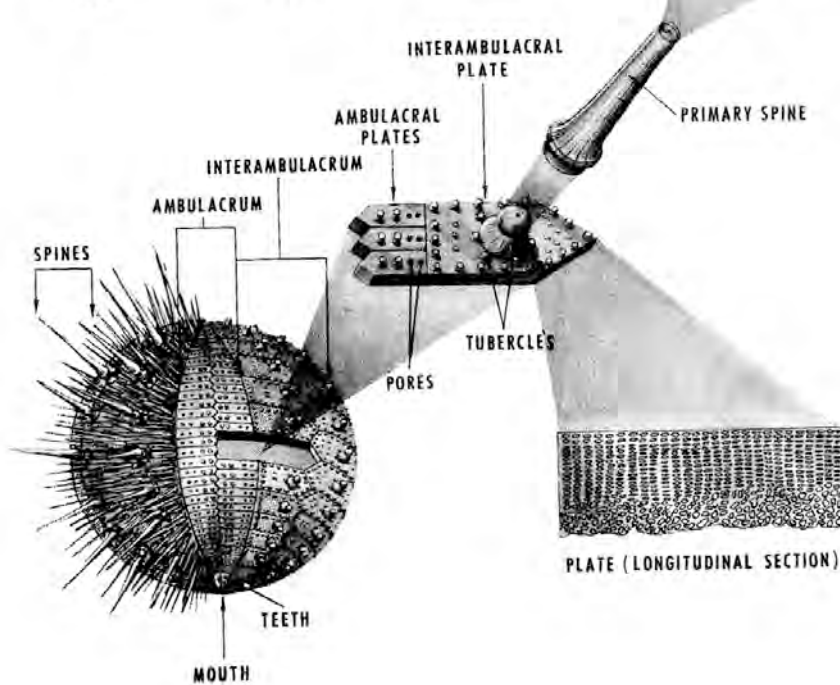
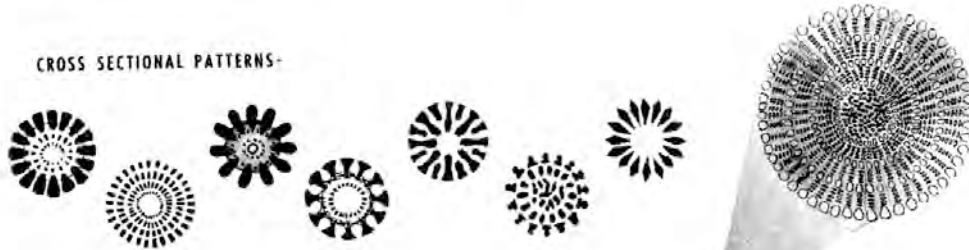


ECHINODERMS - ECHINOIDS:

PRIMARY SPINES-

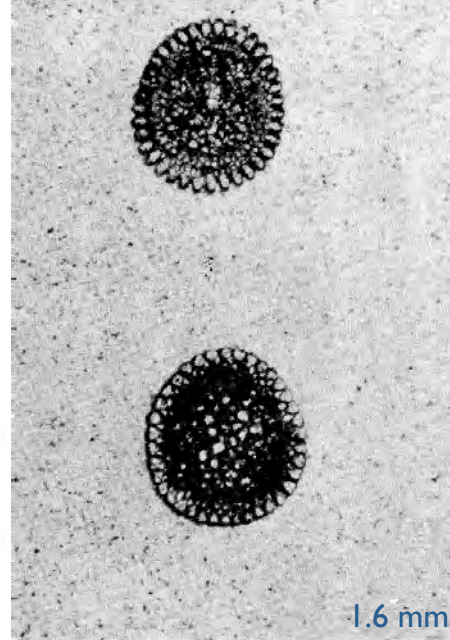


CROSS SECTIONAL PATTERNS-



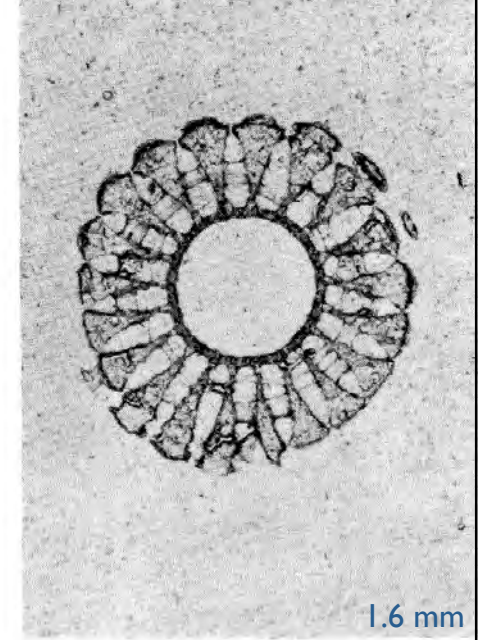
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PRIMARY ECHINOID SPINES



1.6 mm

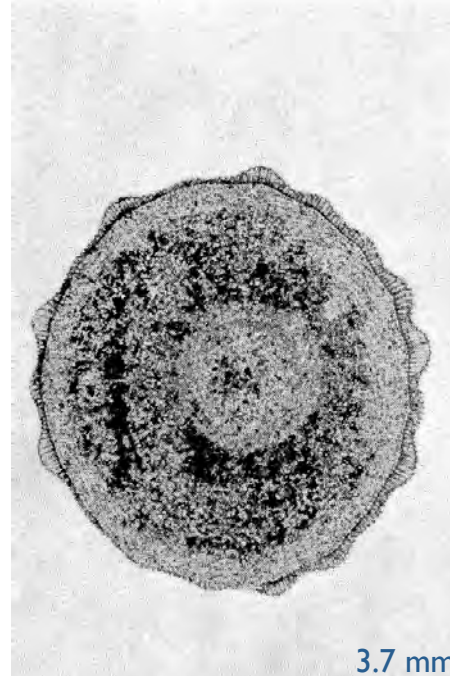
Mellita? sp., Recent, Texas



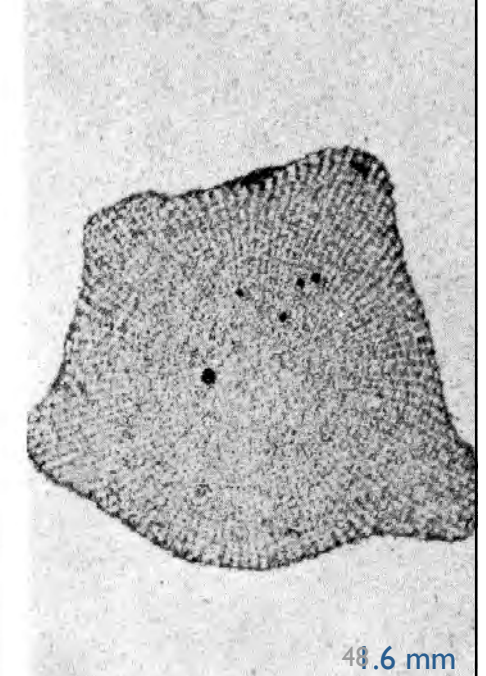
1.6 mm

Diadema sp., Recent, Florida

Cidaroid echinoid, Rec, Florida. *Paleocidaris* sp. Pennsylv., Tex



3.7 mm

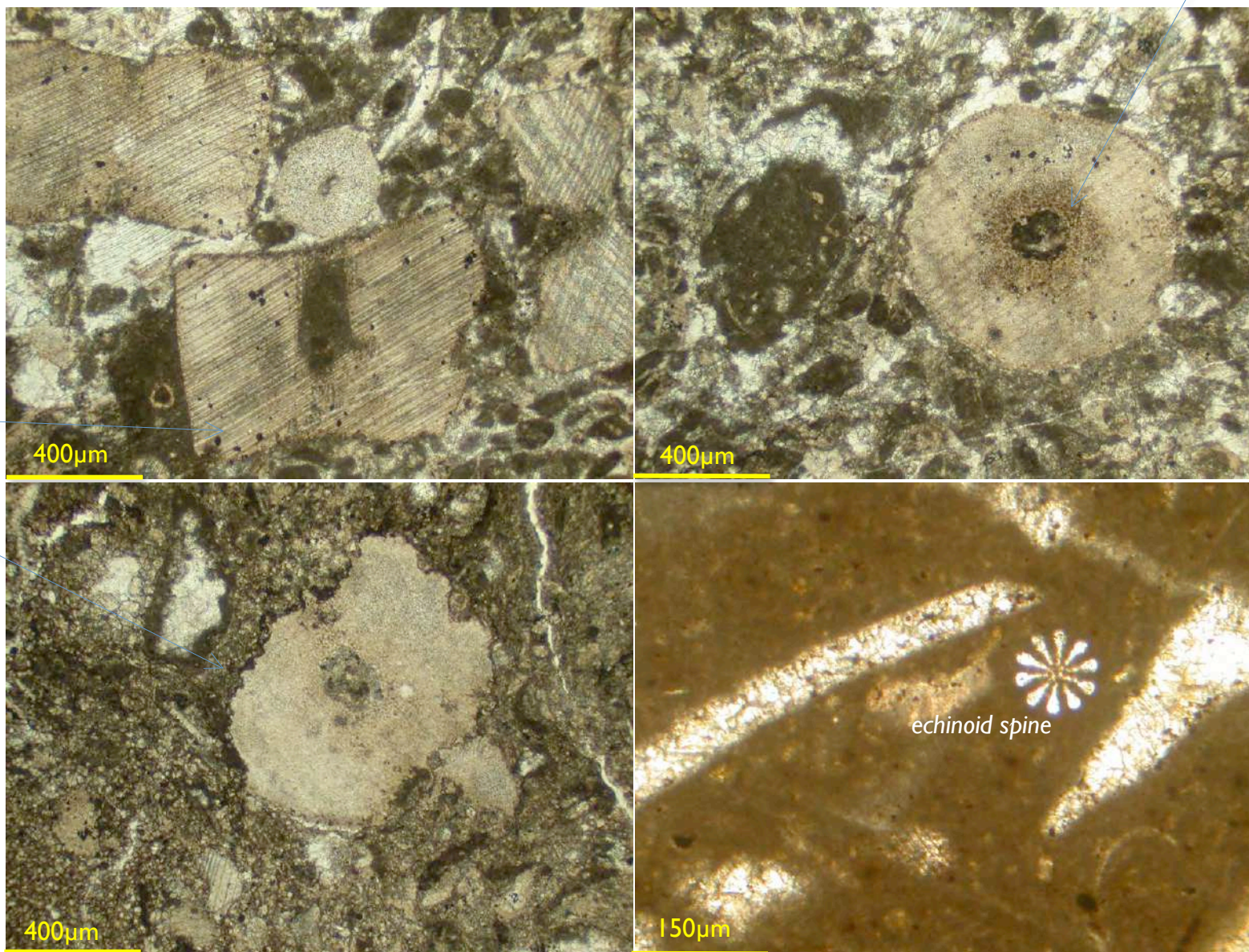


48.6 mm

Echinoderm packstone, Early Givetian, France

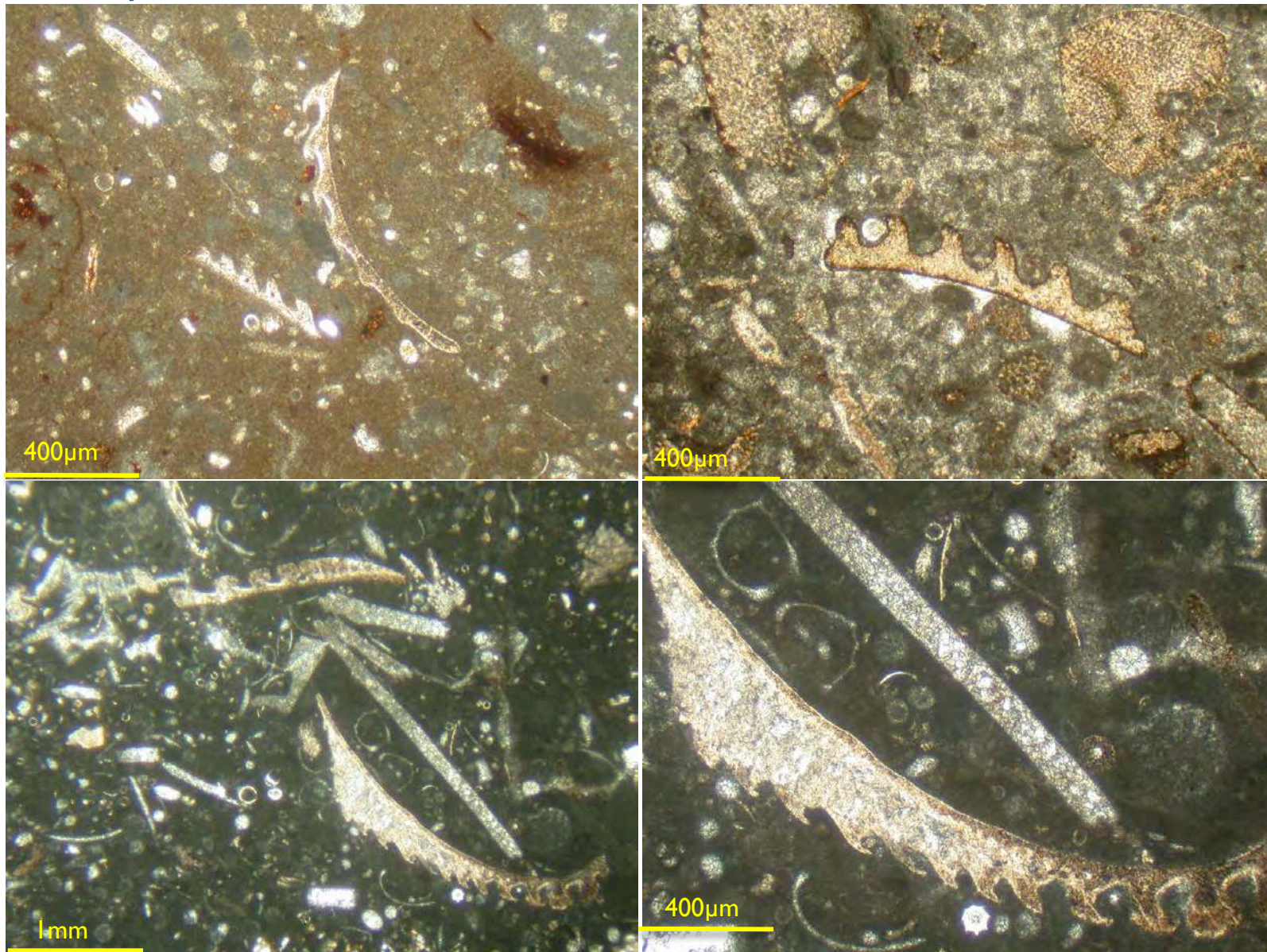
micritization

pitting
corrosion



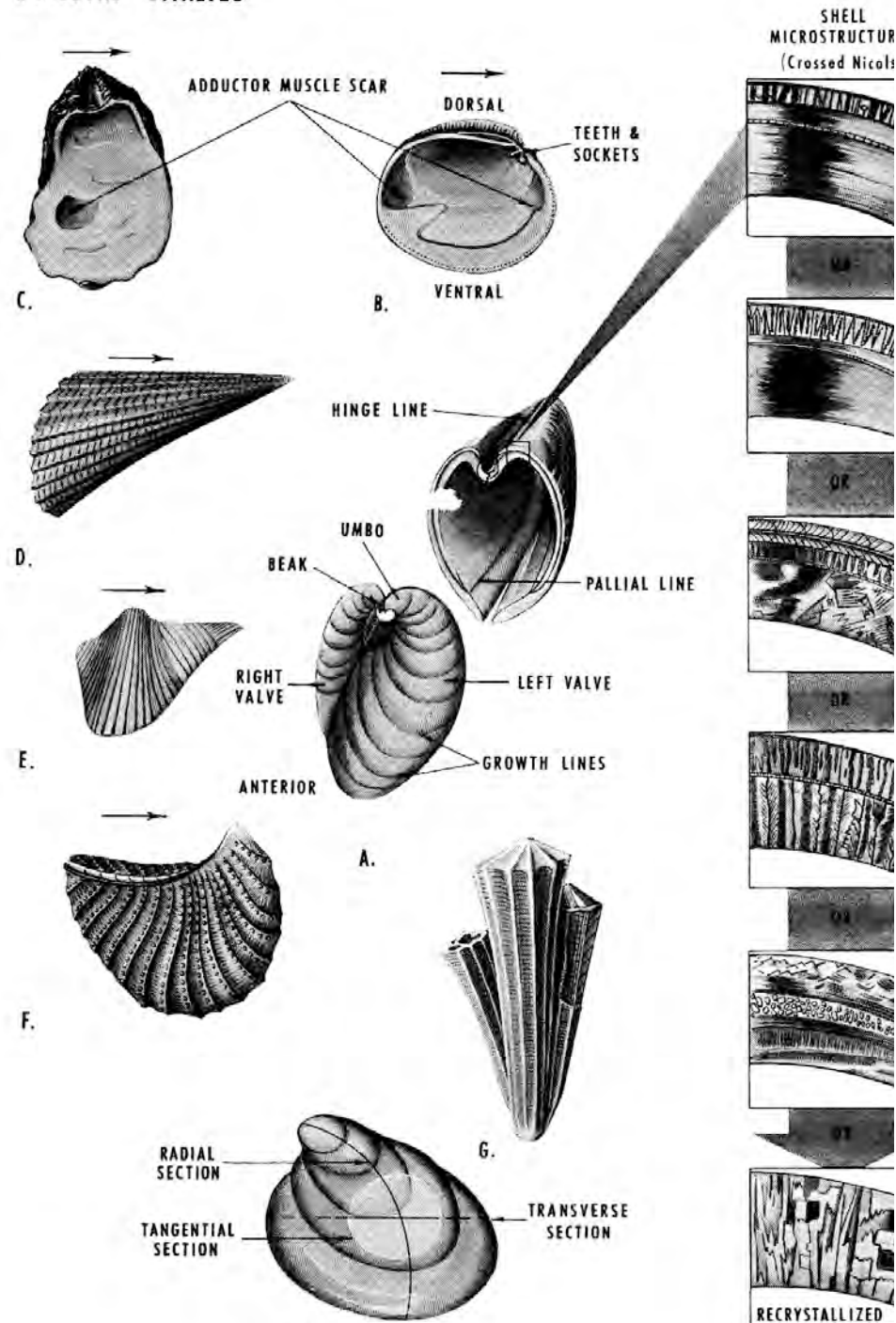
Préat 2009

Poorly sorted holothurian sclerite wackestone in a dense micrite.

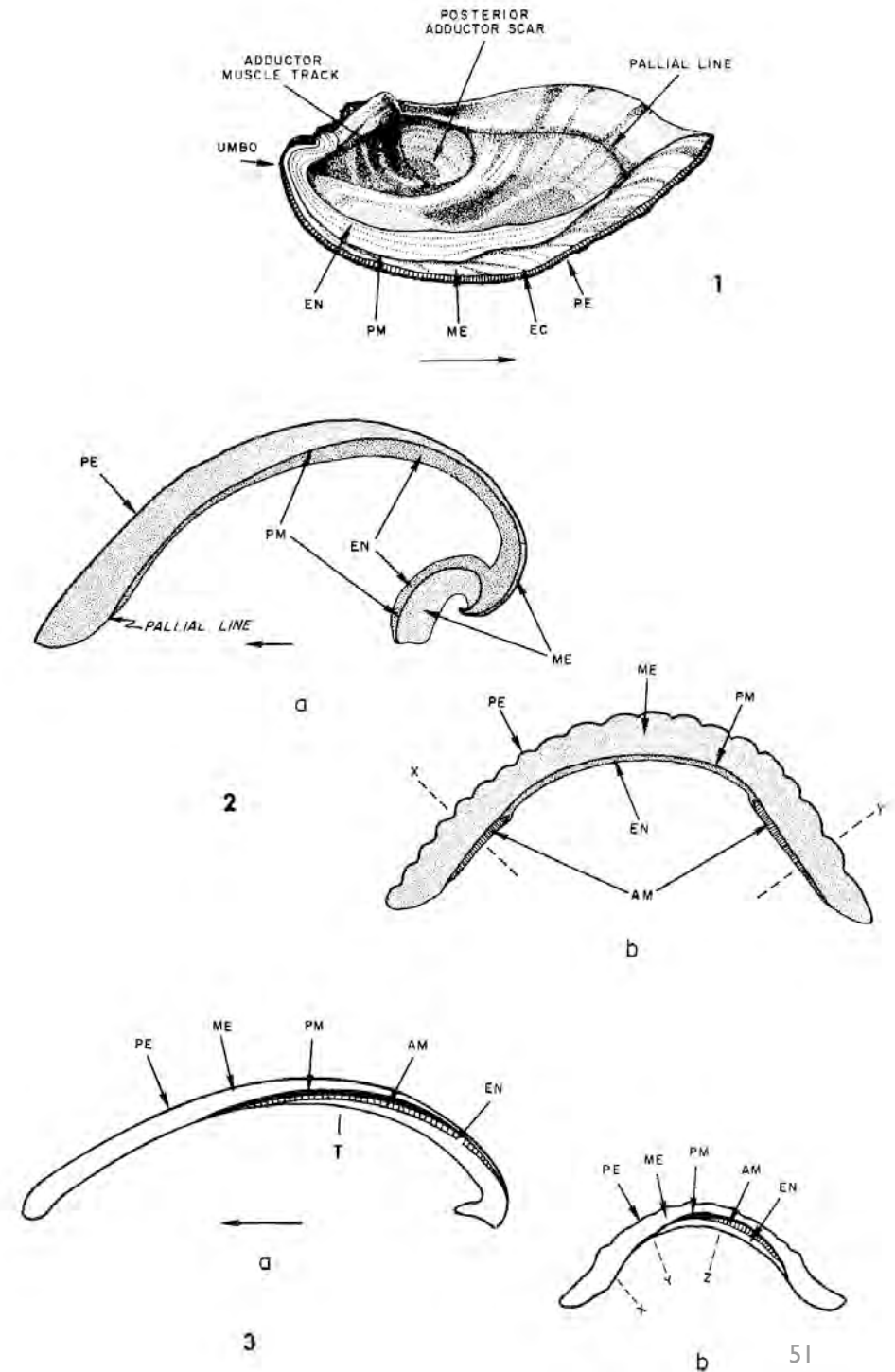


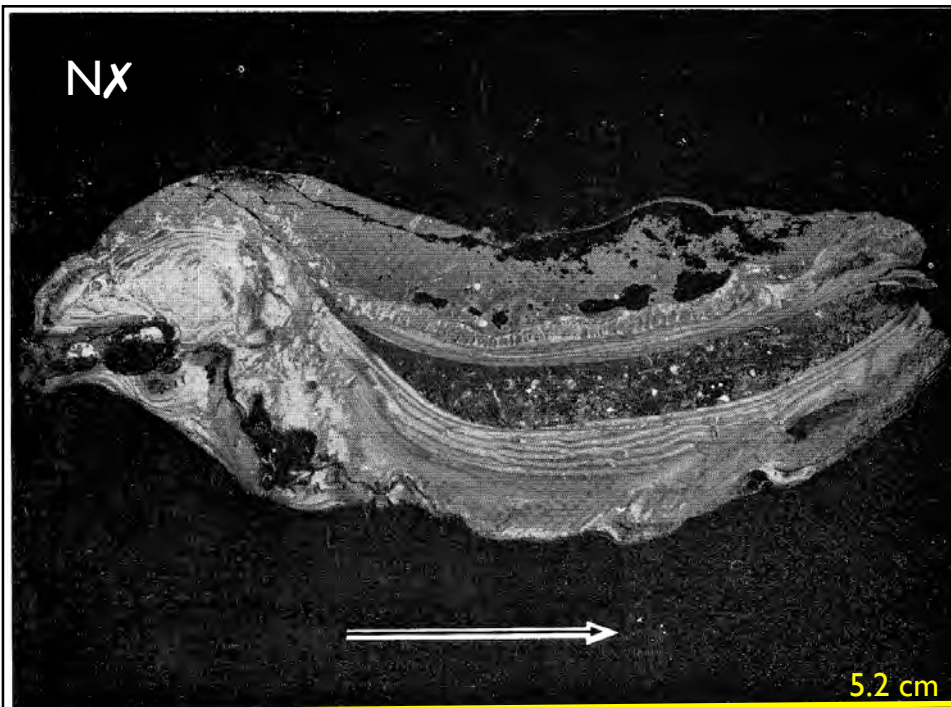
Rosso Ammonitico Superiore, Kimmeridgian-Tithonian, Sicily, Pr  at et al. 2011

MOLLUSKS - BIVALVES:

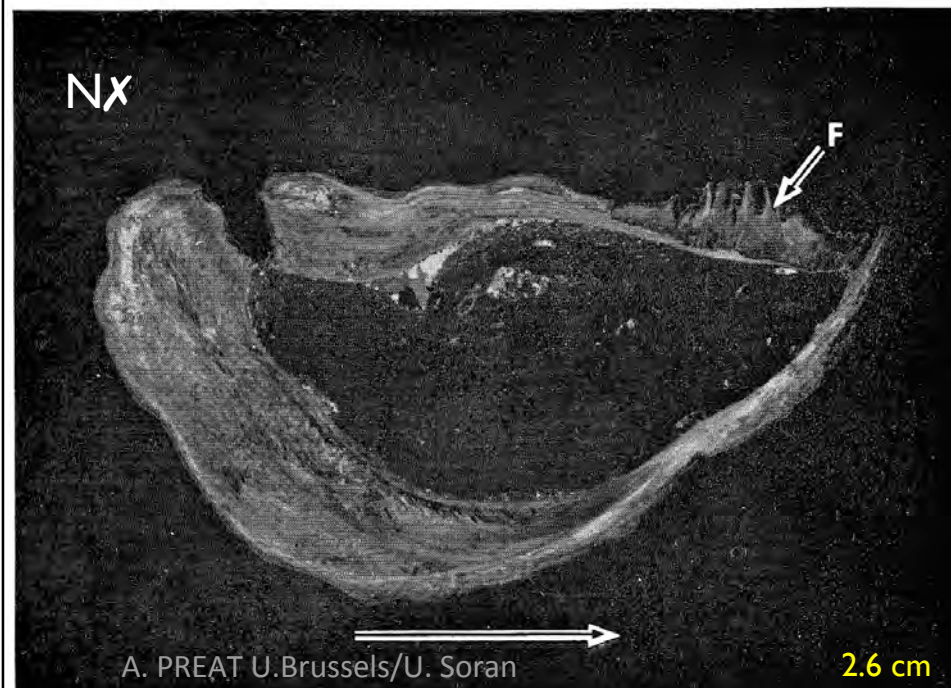


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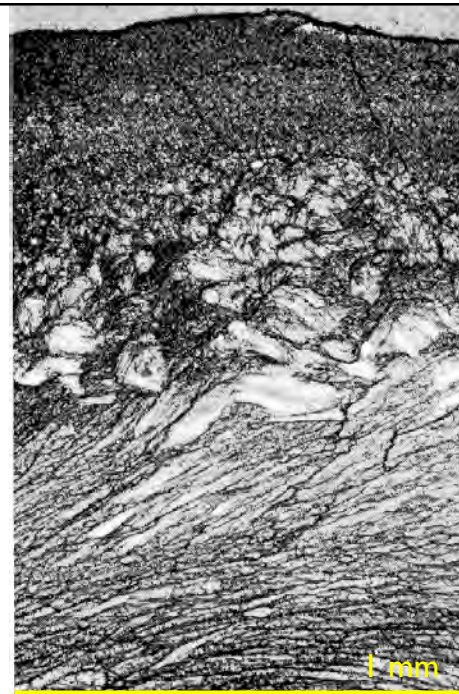


Ceratostreon texanum (Ostreidae), K, Texas
Texigryphaea sp. (Ostreidae), K, Texas

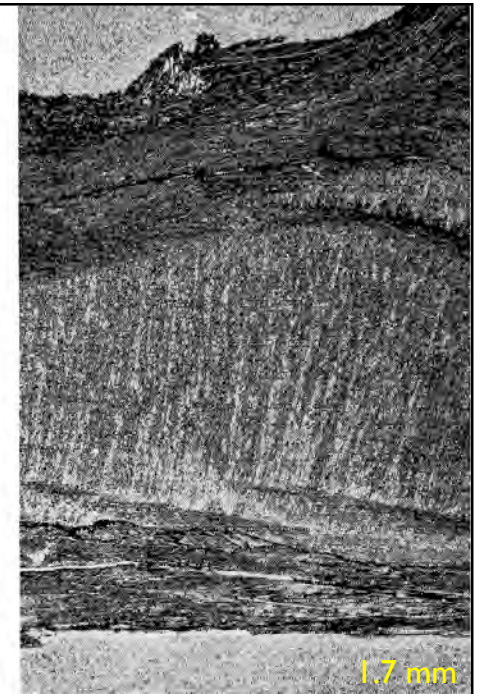


A. PREAT U.Brussels/U. Soran

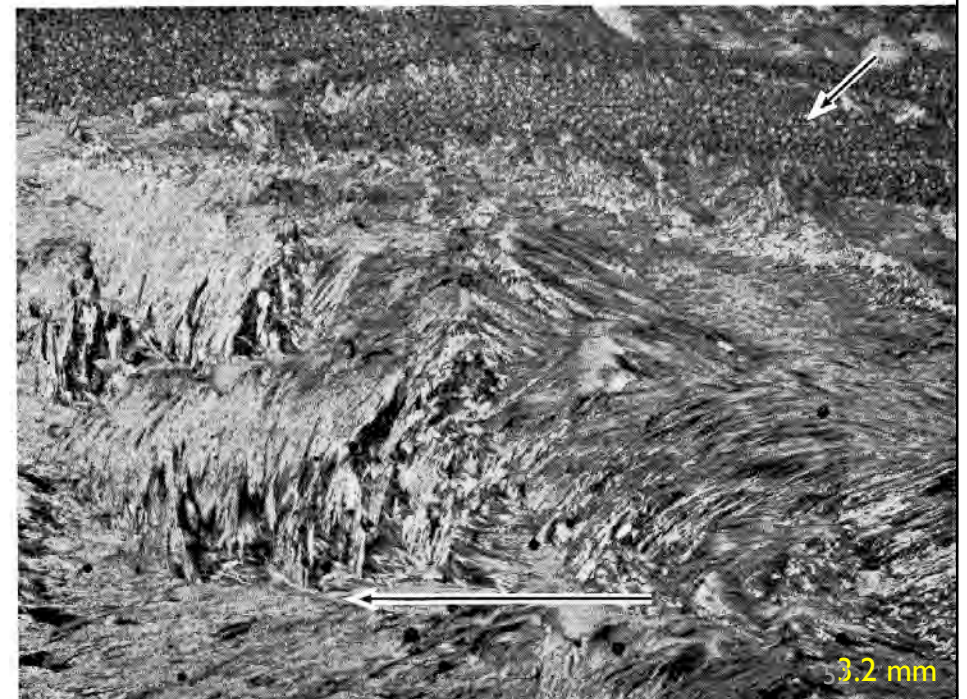
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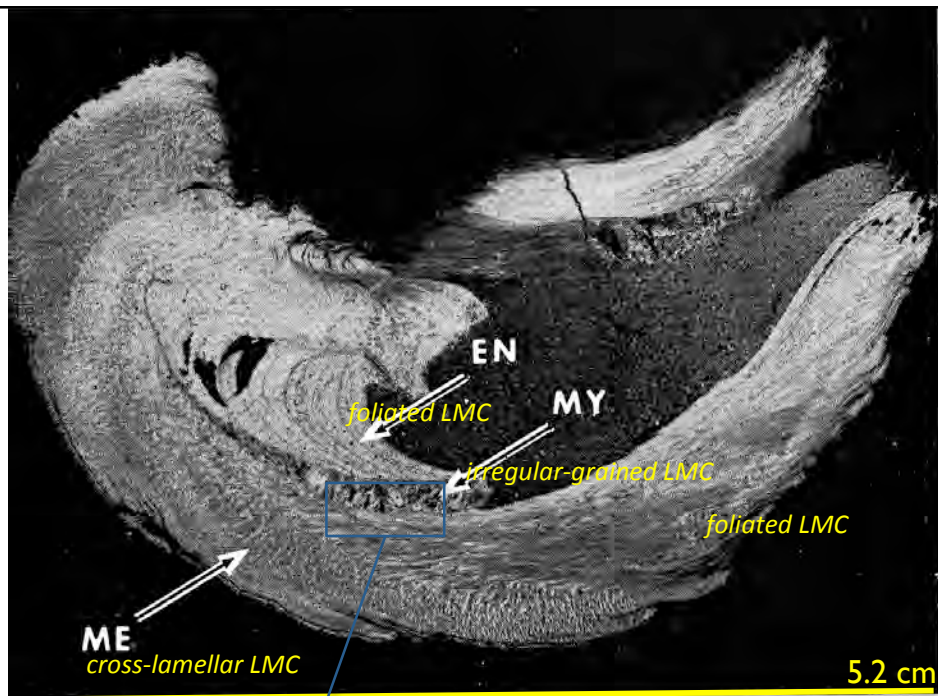


Ceratostreon sp., K



Ostrea plicata (Ostreidae), Eocene, U.K.
Texigryphaea sp., K, Oklahoma



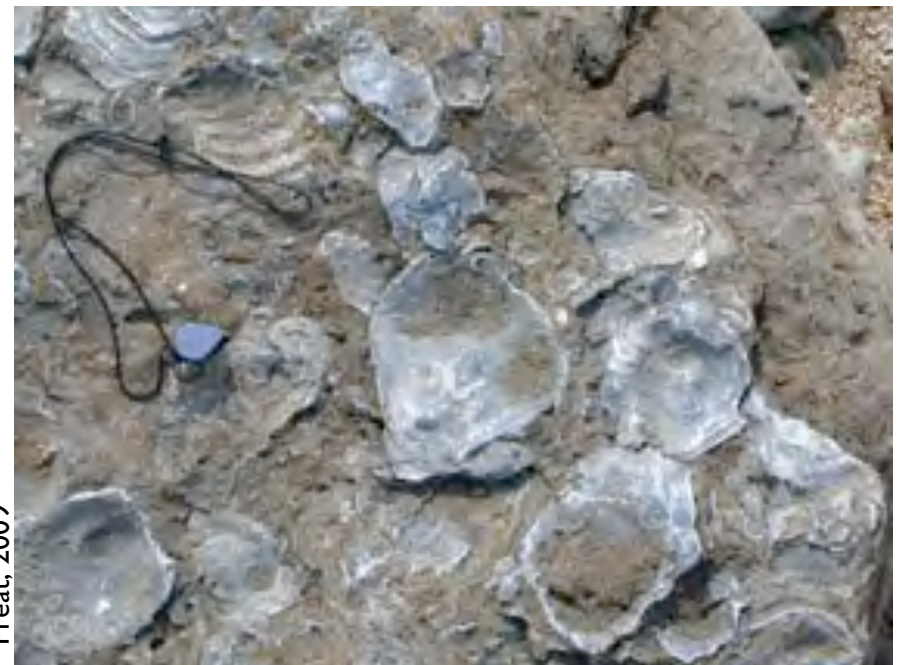


Gryphaea arcuata (Ostreidae), J, UK

Aucella sp., K, California



Gryphaea sp., J, Normandy, France

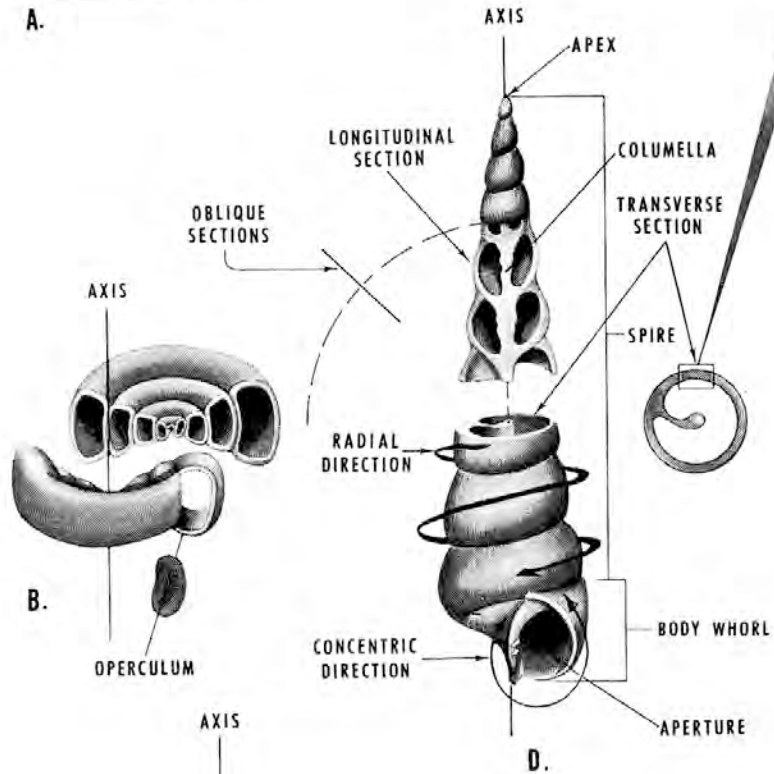


Préat, 2009

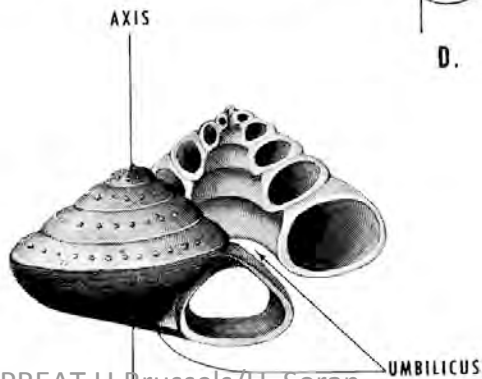
MOLLUSKS-GASTROPODS:



A.



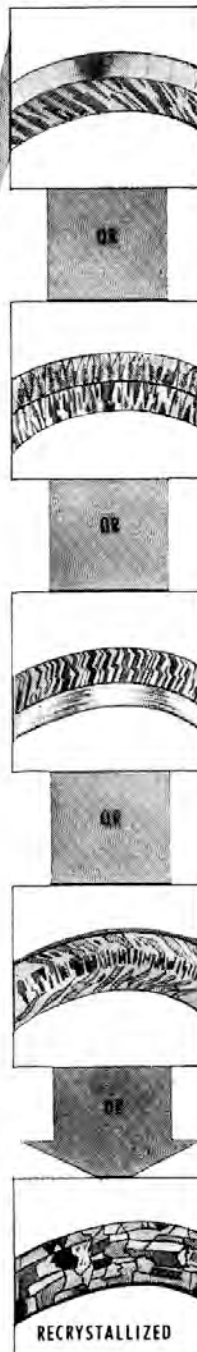
B.



C.

A. PREAT U.Brussels/U. Soran

SHELL
MICROSTRUCTURES
Commonly:



Jurassic, Normandy, France

MICROBES (*bacteria, fungi*) and STROMATOLITES

ALGAE (red, green, '*blue green*' = *cyanophyta*)

ARCHEOCYATHS (SPONGES)

SPONGES

STROMATOPOROIDS

CORALS (*rugosa, tabulata, scleratinids*)

TRILOBITES

GRAPTOLITES

OSTRACODES

BRACHIOPODS (....)

MOLLUSKS (*pelecypods* = *bivalves* , *gastropods, cephalopods, scaphopods, criccoconarids*)

BRYOZOA

ANNELIDS

ECHINODERMS (*crinoids, sea urchins,*)

VERTEBRATES (REMAINS)

'INCERTAE SEDIS' abundant in geology!

'MICROPROBLEMATICA' abundant in geology!

Conodonts

Spongiostromids (Spongiostromata)

Radiolarians = *siliceous (opaline) shell* < 1 mm

PRIMARY skeletal mineralogy of organisms

- dominant mineralogy
- less common mineralogy

many authors,
in Flügel 2004

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

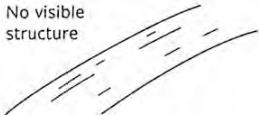



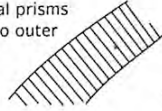
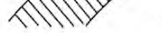






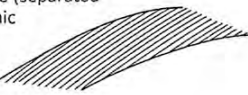





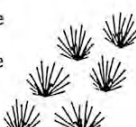

S Y N T H E S I S

‘Skeletal Architecture’

1. welded prisms = ISOGYRES ⇔ trilobites
2. homogeneous = ‘dark micrite’ ⇔ foraminifers, ostracods, mollusks
3. normal prismatic ⇔ pelecypods, brachiopods
4. composite prismatic ⇔ mollusks
5. complex prismatic ⇔ mollusks
6. foliated ⇔ brachiopods, pelecypods (ostreidae), bryozoa, annelids LMC
7. crossed-lamellar ⇔ mollusks (excepted cephalopods)
8. nacreous ⇔ mollusks ARAGONITE
9. monocrystalline ⇔ echinoderms
10. fiber fasciculate ⇔ corals

nb stromatoporoids, algae, conodonts, vertebrates (fishes...), sponges

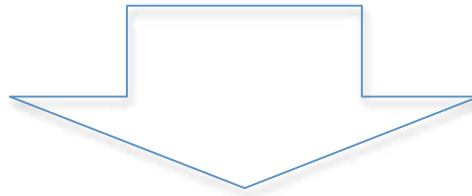
SYNTHESIS 'Skeletal Architecture'

Microstructure Common minerals (rare minerals in parenthesis)	Appearance of thin section in ordinary transmitted light	Appearance of thin section under crossed polars	Examples
<i>Homogeneous prismatic Calcite (Aragonite)</i>	No visible structure 	Extinction in one direction; optic axes parallel and usually normal to surface of skeleton 	Trilobites, ostracods
<i>Granular Calcite Aragonite</i>	Irregular grains (if fine and uniform in size, sometimes referred to as sugary or sucrosic) 	Random orientation of optic axes 	Foraminifer:
<i>Normal prismatic Calcite (Aragonite)</i>	Polygonal prisms normal to outer surface  Long  Transverse 	Each prism extinguishes as a unit  Long  Transverse 	Punctate brachiopods <i>Inoceramus</i>
<i>Foliated Calcite</i>	Thin parallel leaves of calcite often having a wavy banded appearance 	Variable orientation of optic axes of leaves 	Bryozoans, pseudopunc; brachiopods, worm tubes, oysters
<i>Nacreous Aragonite</i>	Regular thin parallel leaves of aragonite (separated by organic films) 	Parallel extinction 	Mollusks
<i>Single crystal Calcite</i>	Coarse single calcite grain showing cleavage 	Grain extinguishes as a unit 	Echinoderms, sponge spicu;
<i>Crossed lamellar Aragonite (Calcite)</i>	Layer of large lamellae, each lamella composed of small flat crystals, uniformly inclined in plane of larger lamella, giving herringbone pattern 	Uniform orientation of optic axes in small crystals sometimes causes large lamellae to extinguish as a unit 	Mollusks
<i>Spherulitic fascicle Aragonite (Calcite)</i>	Fibers radiating fanlike outward from a point center that is dark due to the concentration of very fine crystals 	Each fiber extinguishes as a unit 	Coelenterates

THIN SECTIONS
± 30µm thick

BIOCLASTS in THIN SECTION?

- i) preservation of organic material
- ii) random section : useful or not i.e. diagnostic or not
- iii) sometimes only one diagnostic section (ex. foraminifers)
- iv) personal experience: morphology, mineralogy, microstructure, diagenesis....



ORIGINAL COMPOSITION OF ORGANISMS

cf. list of phyla...

- carbonates : LMC, HMC, ARAGONITE, VATERITE, ?DOLOMITE, AMORPHOUS...
- silica : QUARTZ, OPALE ...
- phosphates : DAHLITE, FRANCOLITE, HYDROXYAPATITE, COLLOPHANE ...
- oxydes ...
- sulfates ...
- fluorides...
- oxalates ...

BIOCLASTS in THIN SECTION?

ORIGINAL COMPOSITION OF ORGANISMS

cf. list of phyla...

- + (partially) preserved ORGANIC MATTER (chitine conchioline, spongyne = 'proteins'), rarely preserved in old bioclasts => need chemical analyses (both Fossil and Recent)
- mineralogical composition is related to genetic and/or environmental factors (T°, salinity...) => potential PALEOECOLOGY
- the dominant mineralogy in the Invertebrates is **CALCITE** and **ARAGONITE** (together or not in the different shell layers)
=> Rec. organisms : coloration of aragonite with Feigl's (1937) and Friedman's (1959) solutions

Feigl F 1937. Quantitative analysis by spot tests. Nordemann Publ. Co. NY, 400p.

Friedman GM 1959. Identification of carbonate minerals by staining methods. JSP, 291, 87-97.

- fossils : original composition is deduced from the present-day microstructure....

BIOCLASTS in THIN SECTION?

- fossils: original composition is deduced from the present-day microstructure....

ARAGONITE if microstructure partially or totally destroyed

=> 'calcite or 'sparite' mosaic (LMC) implying **dissolution**

= => micro- or MACRO-scale dissolution with or without development of **MOLDIC** porosity

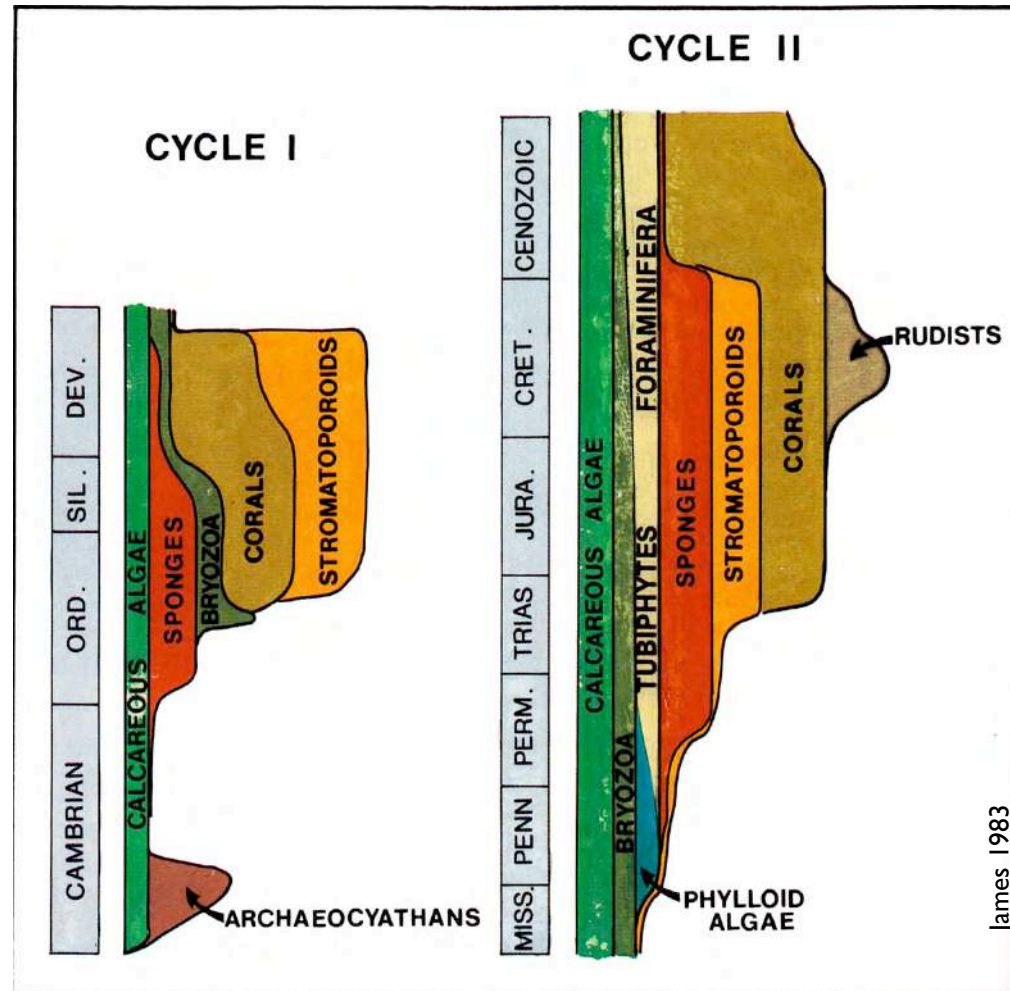
HMC with preservation of the microstructures

RELATED TO DIAGENESIS

PRESENT DAY RESEARCHES

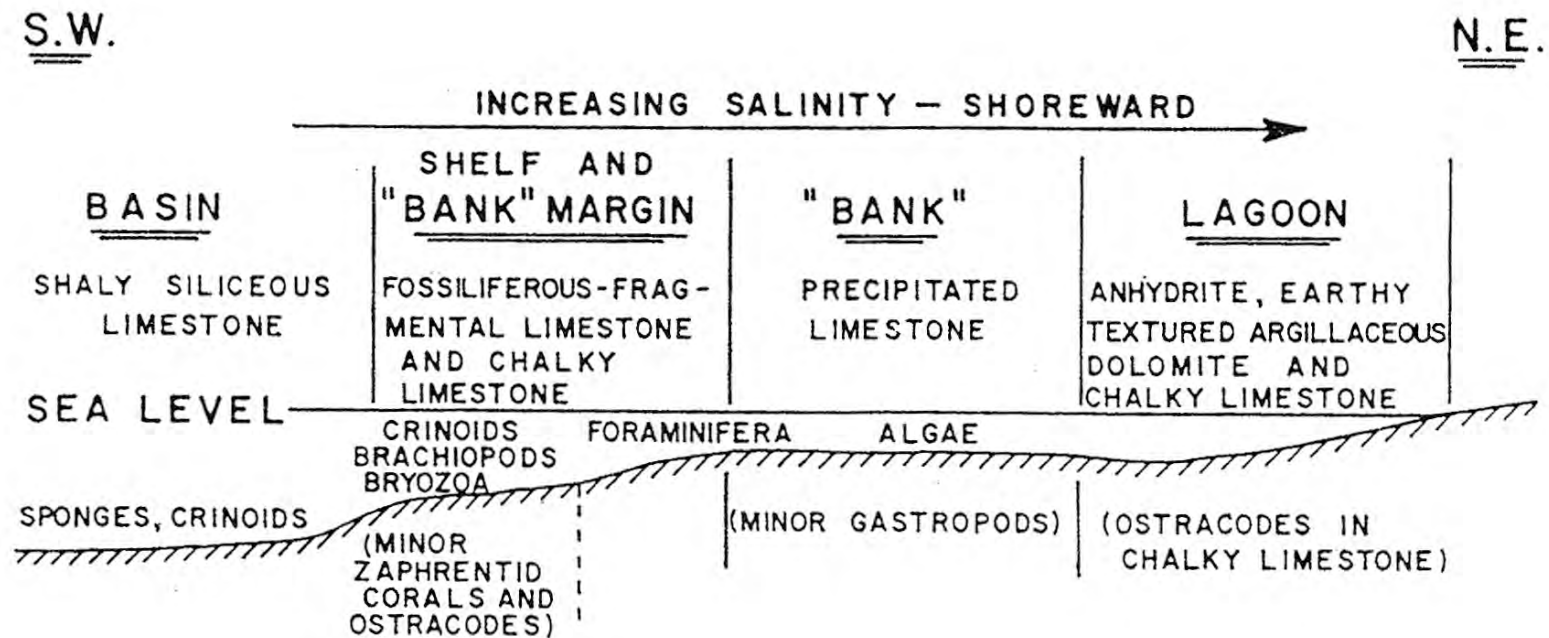
microstructures =biocrystals formed from an organic matrix ...cf DNA, RNA.... and medical applications

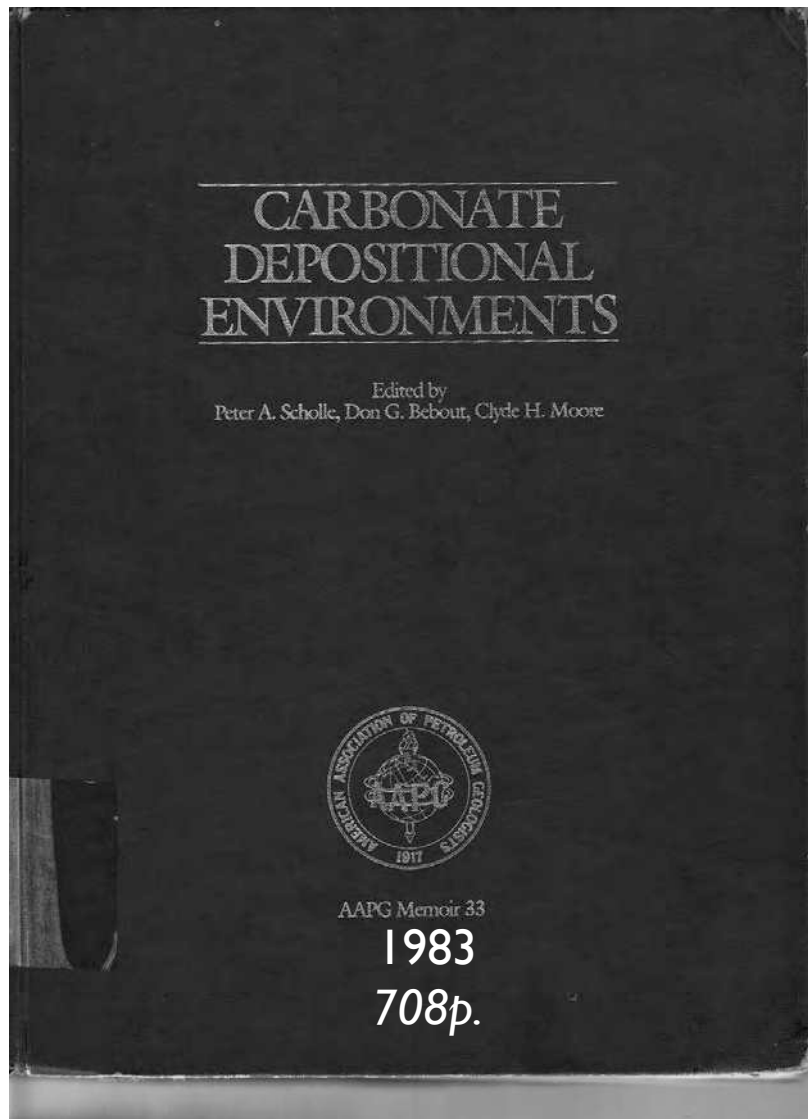
MAIN BIOTIC CONSTITUENTS OF CARBONATE BUILDUPS AGAINST GEOLOGIC TIME FOR THE PHANEROZOIC



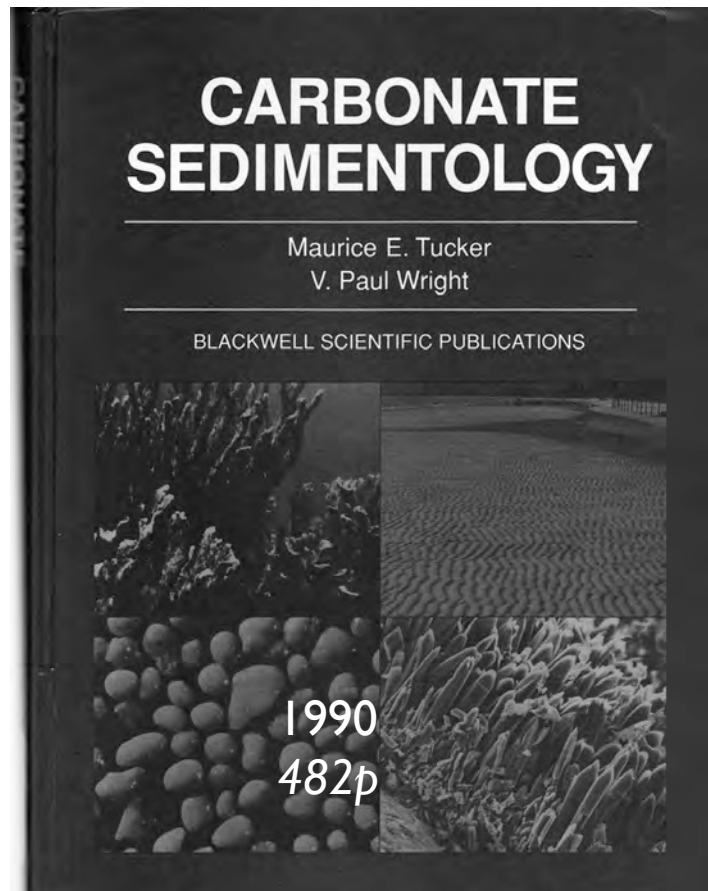
nb *Tubiphytes* microfossil of unknown systematic position = encruster (with algae...)

Among the **FIRST** carbonate models (Edie, 1958)





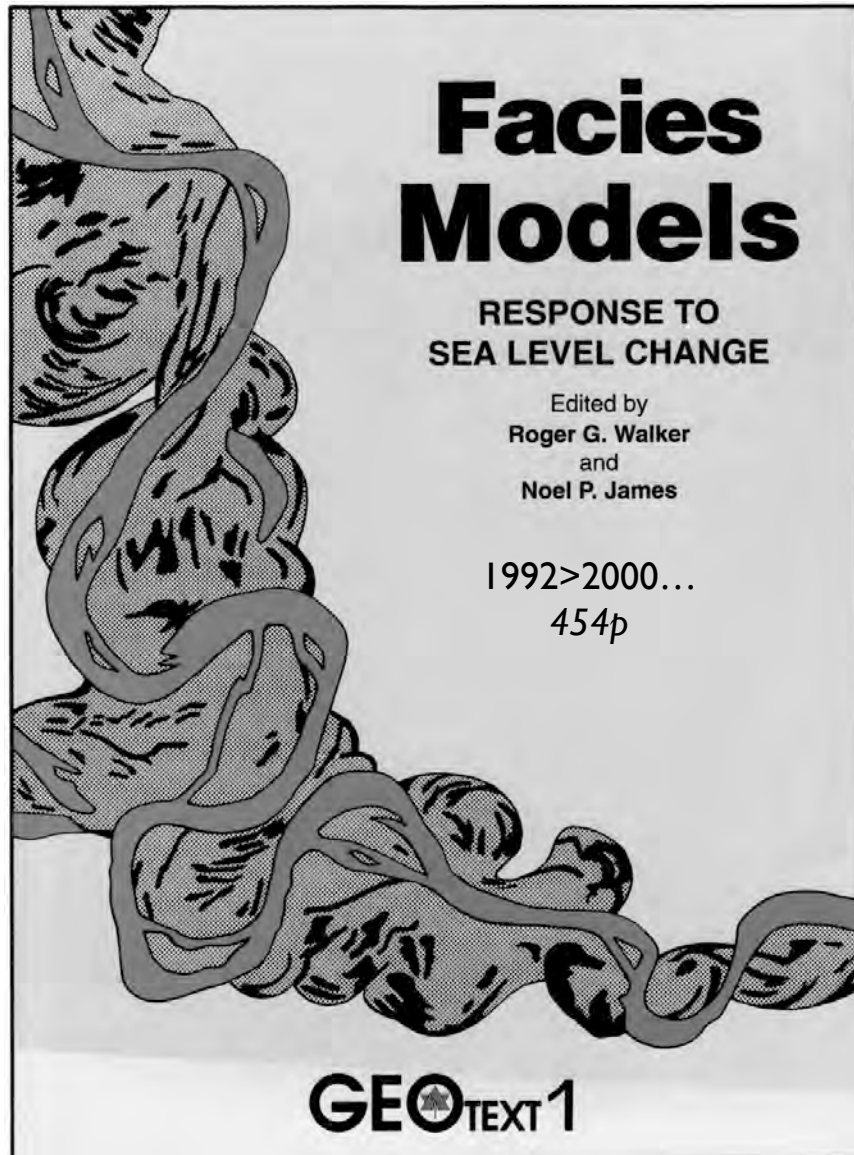
- 1 Subaerial Exposure
- 2 Lacustrine
- 3 Eolian
- 4 Tidal Flat
- 5 Beach
- 6 Shelf
- 7 Middle Shelf
- 8 Reef
- 9 Bank Margin
- 10 Fore-reef Slope
- 11 Basin Margin
- 12 Pelagic



..... *introduction*.....

- 3 Modern Carbonate Environments
- 4 Shallow-Water and Lacustrine Carbonates
- 5 Pelagic and resedimented limestones

...*carbonate geochemistry-mineralogy*



..... introduction.....

5 Glacial Depositional Systems

6 Volcaniclastics

7 Alluvial Deposits

8 Eolian Systems

9 Deltas

10 Barriers and Estuaries

11 Tidal Systems

12 Wave- and Storm-Dominated Shallow Marine Systems

13 Turbidites and Submarine Fans

14 Carbonate and Evaporite Models

15 Platform Systems

16 Peritidal Carbonates

17 Reefs and Mounds

18 Carbonate Slopes

19 Evaporites

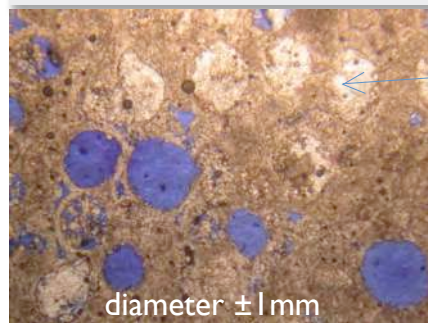
BIOCLASTS or GRAINS

ARAGONITE if microstructure partly or totally destroyed

=> 'calcite or 'sparite' mosaic (LMC) implying dissolution

= => micro- or MACRO-scale dissolution with or without development of **MOLDIC** porosity

RELATED TO DIAGENESIS



anhydrite

