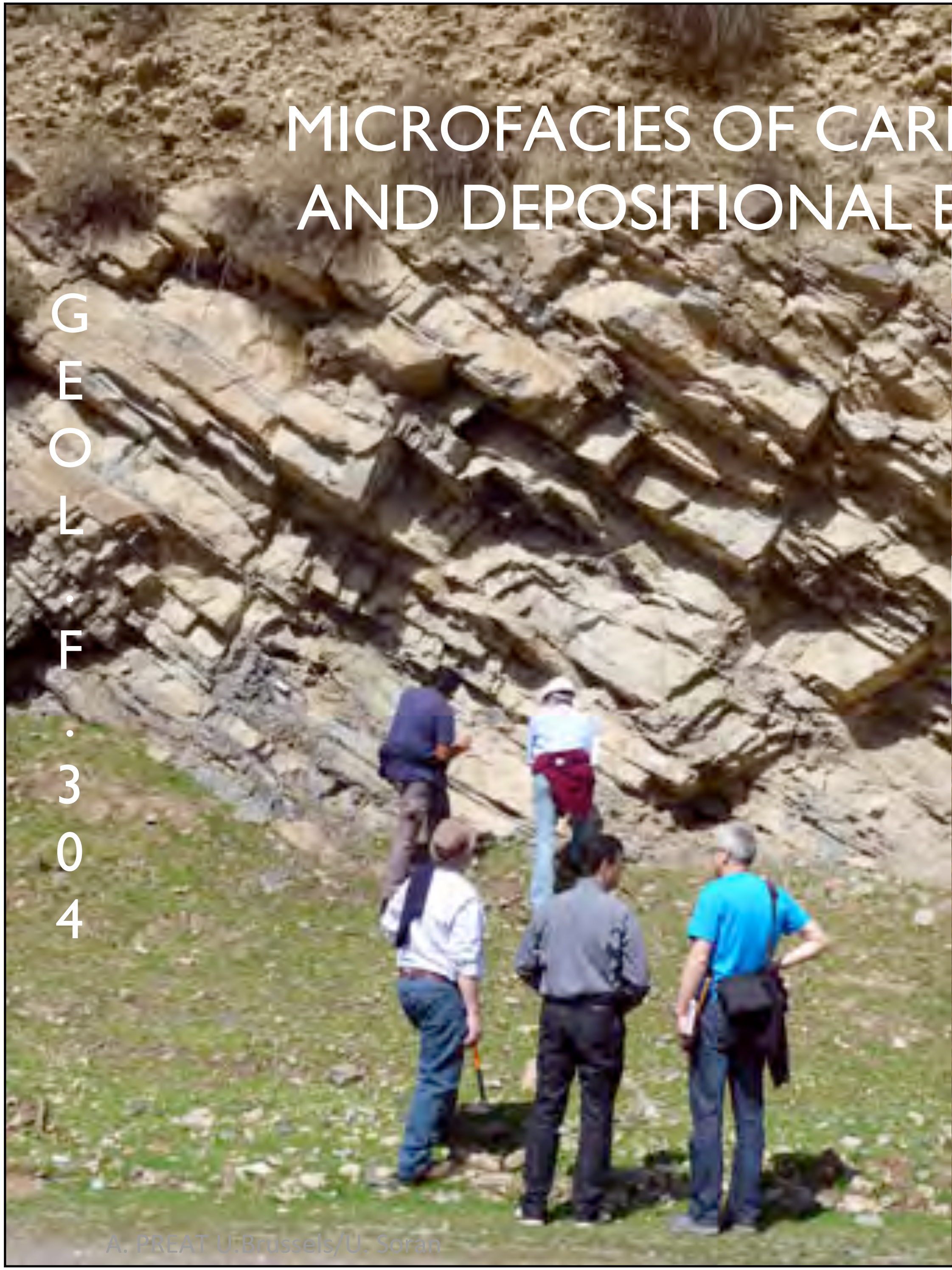
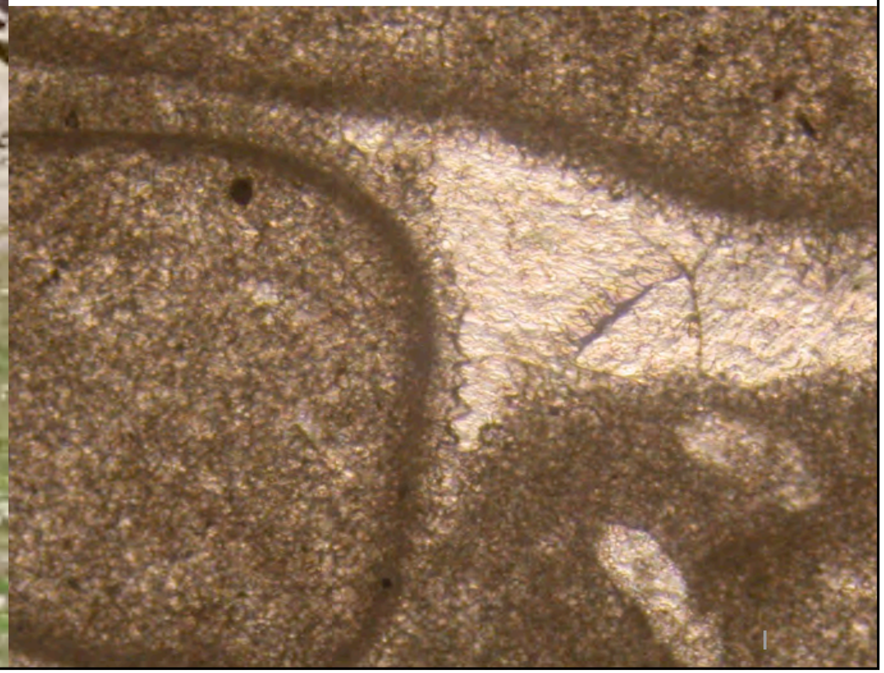
MICROFACIES OF CARBONATE ROCKS AND DEPOSITIONAL ENVIRONMENTS

GEOL.F.304



Prof. Alain Préat
Free University of Brussels



ACADEMIC ASPECT

Limestones and dolostones are well represented during geological times

• global effects • reefal systems • CO_2 sinks …

MODELLING ⇅ *DIAGENESIS*

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

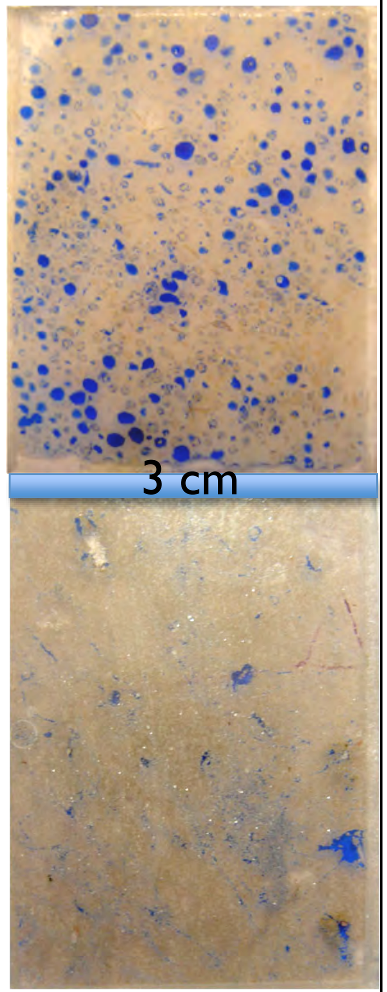
1930 International Expedition – Bahamas : Carbonate Production
=> 'cementation' (algal binding) on the Banks
=> drilling : platform evolution

WW1-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)*

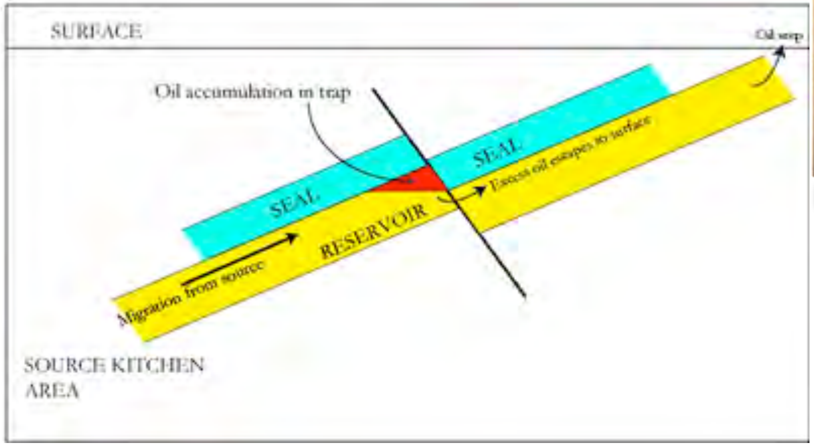


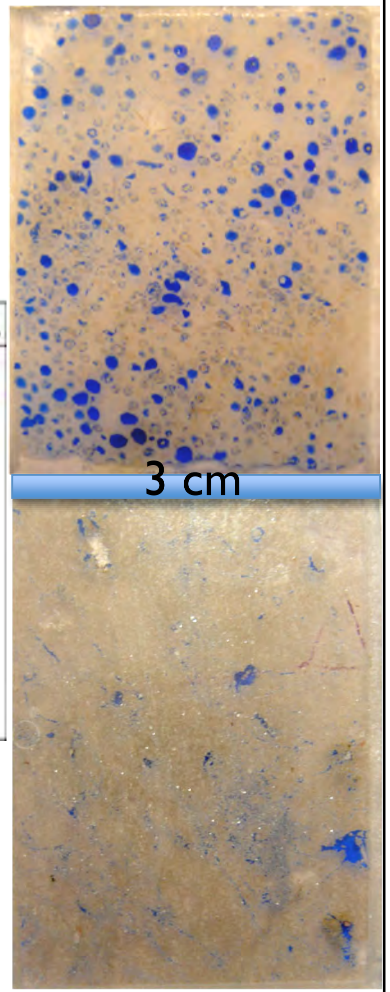
NEED TO DEFINE and UNDERSTAND the CARBONATE FACIES in order to search the reservoir rocks

TODAY

GLOBAL APPROACH
=> academic
=> environment

APPLIED APPROACH
=> source rocks
=> reservoir rocks
=> seal or cap rocks

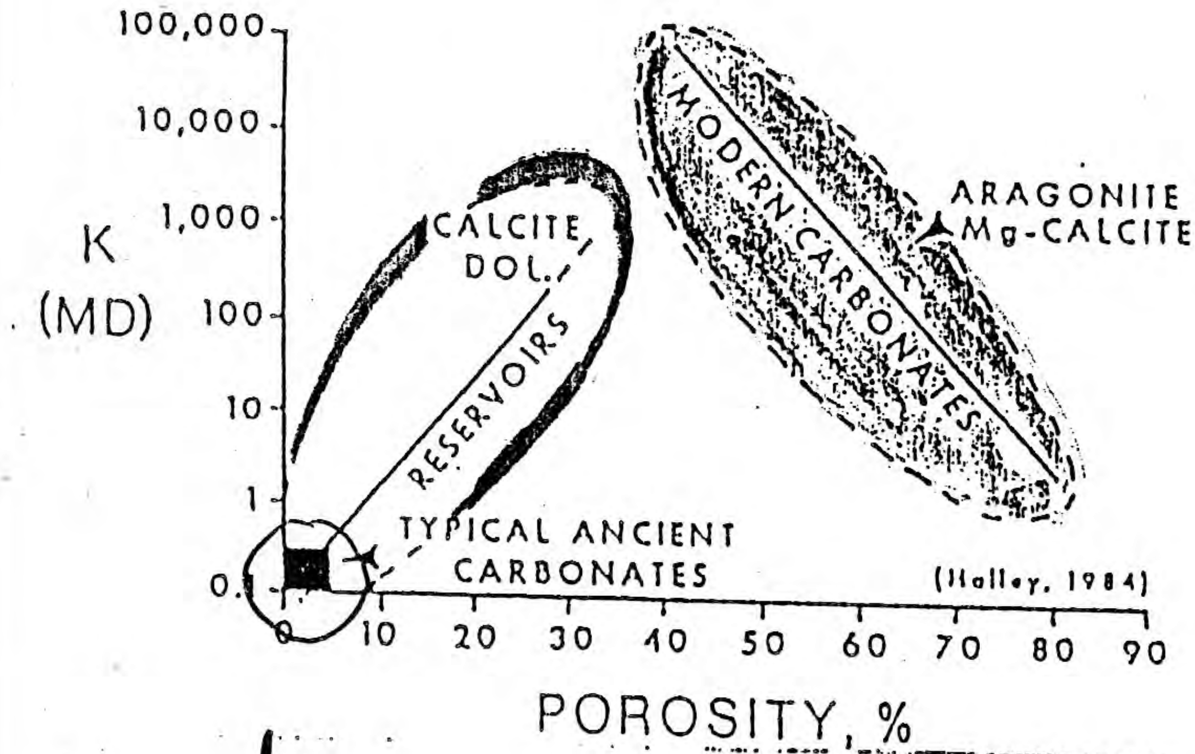


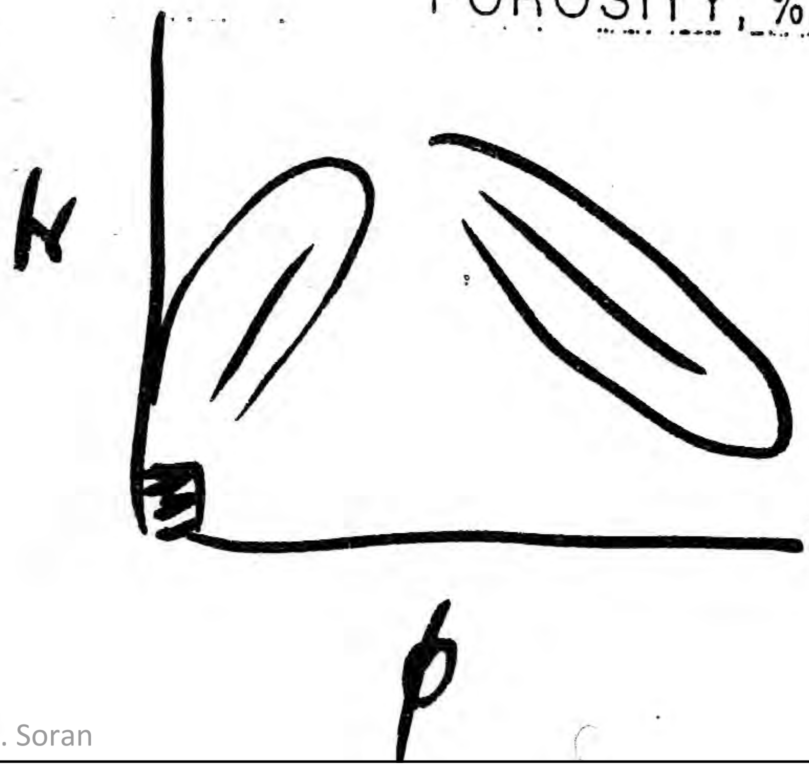


Φ

vs

K

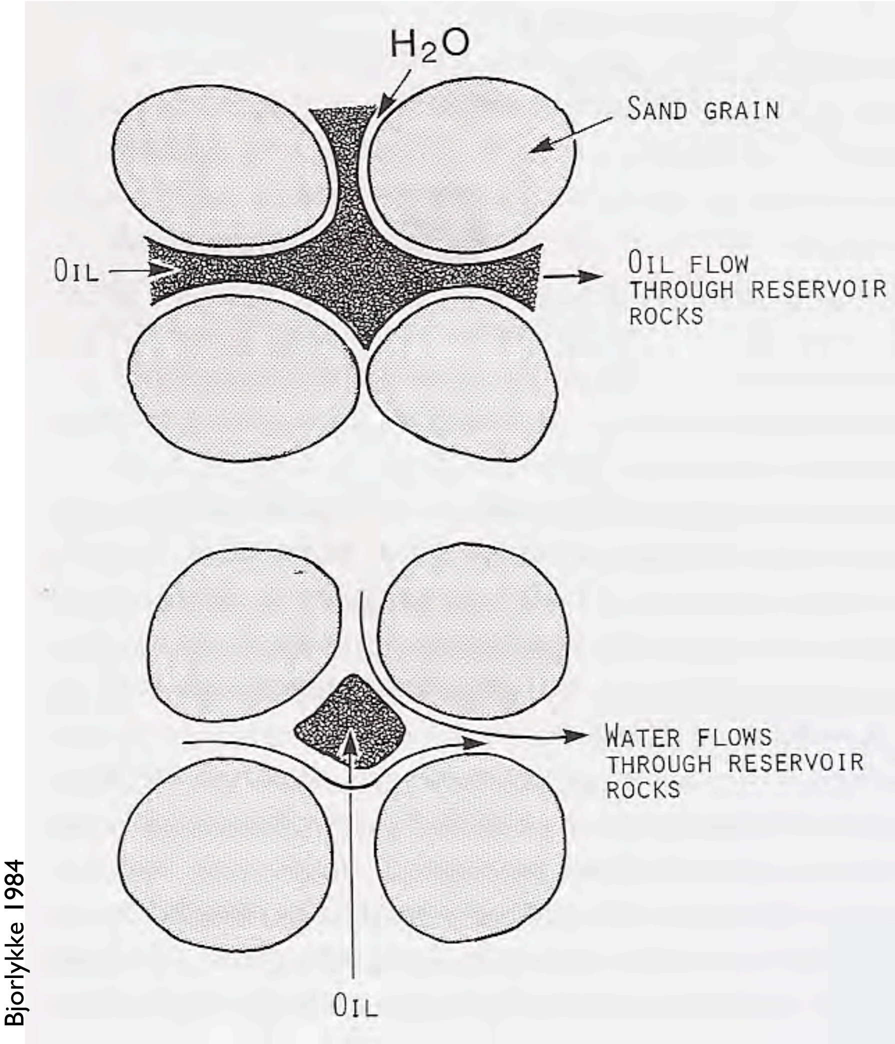




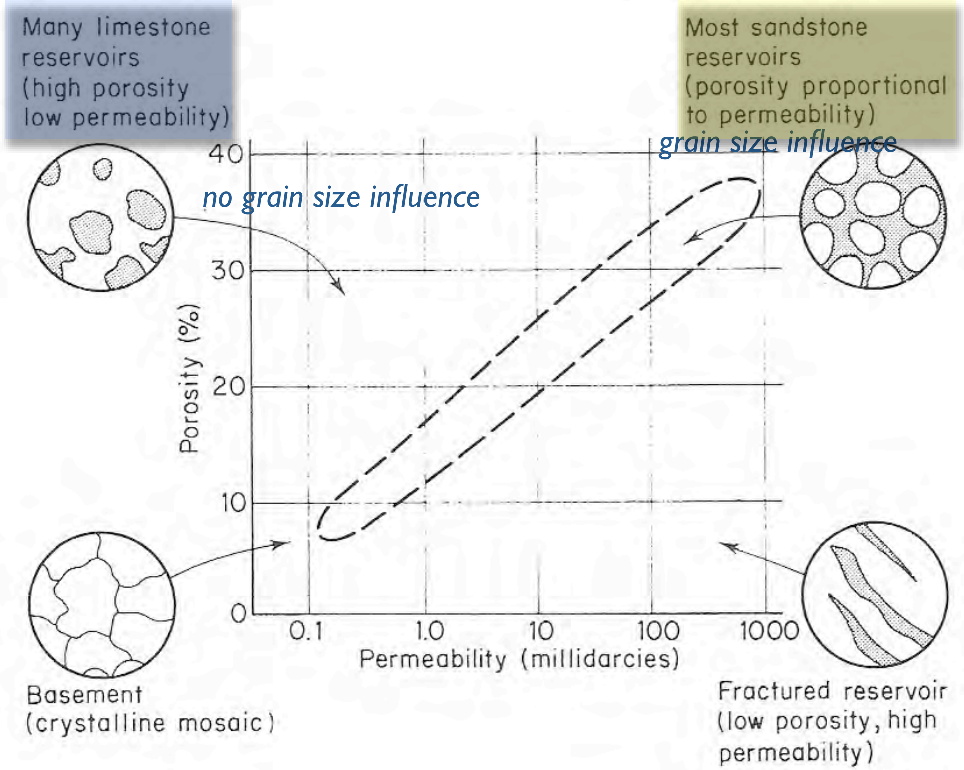
Permeability = K
A permeable rock has the **capacity** to transmit a fluid. The unit for K is Darcy (D), although the K of many reservoirs is measured in mD.

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



Bjorlykke 1984



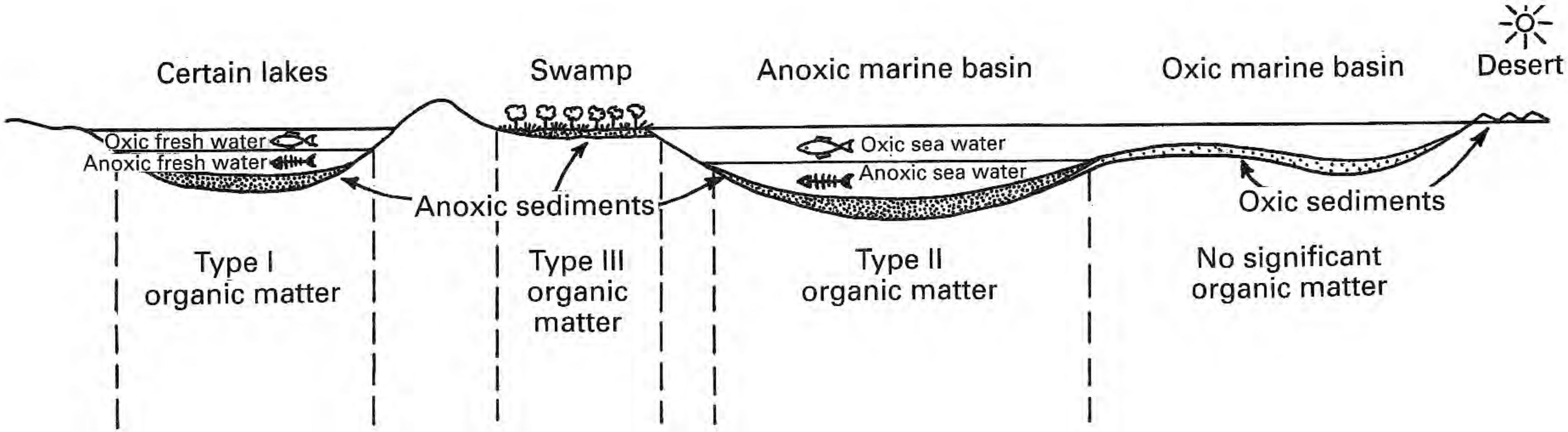
Selley 2000

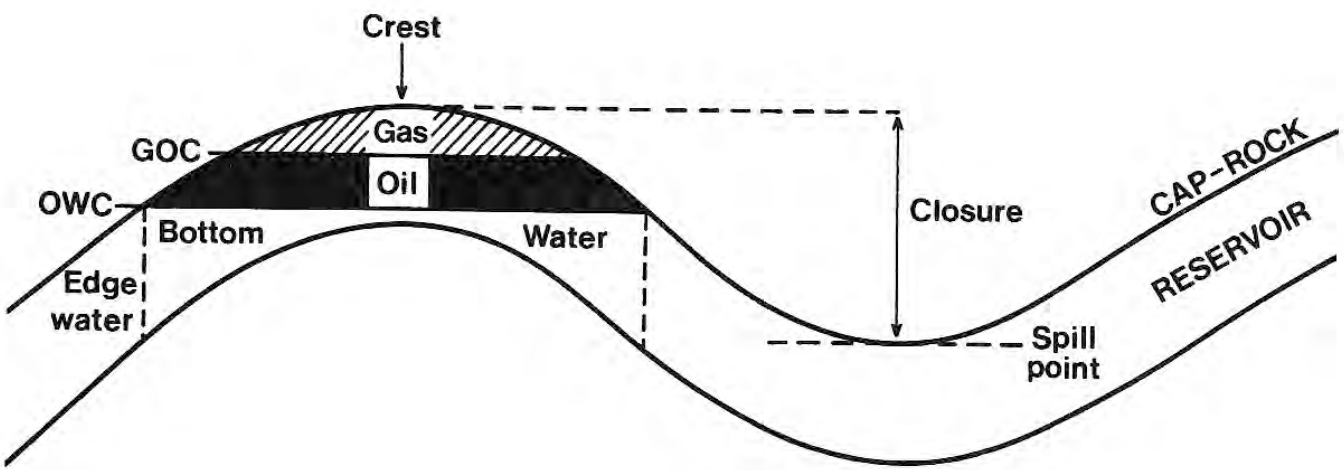
Oil is lighter than water => oil droplets will be able to move through pores in rock….
=> EFFECTIVE or RELATIVE PERMEABILITY

For sandstones, Φ generally plots as a straight line against K on a logarithmic scale. Shales, chalks 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





Stoneley 1995

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

DIFFERENCES BETWEEN CARBONATES AND SILICICLASTICS

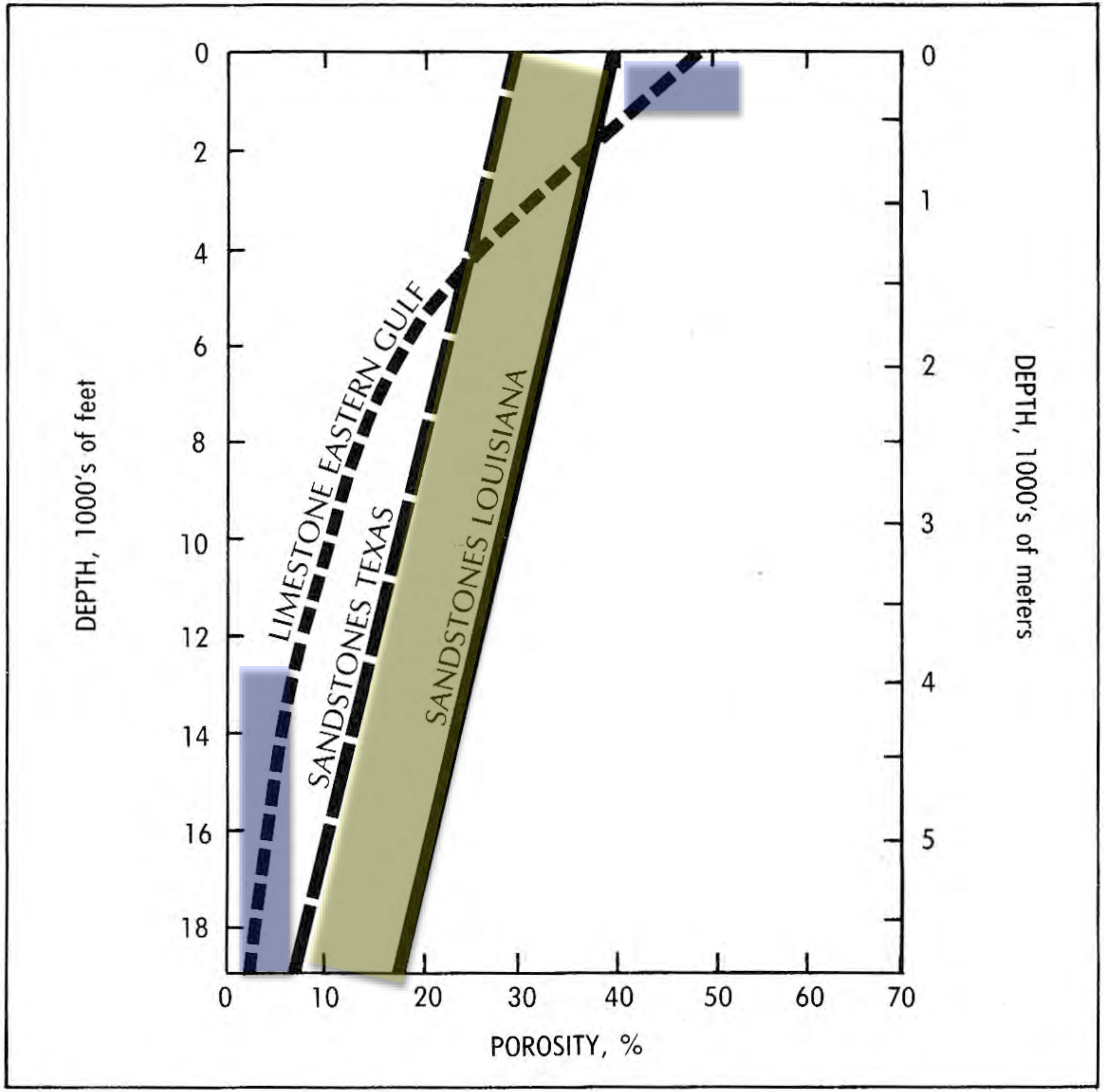
CARBONATE SEDIMENTS, ROCKS	SILICICLASTIC SEDIMENTS, ROCKS
Most occur in tropics	Climate, water depth no constraint
Most are marine	May be marine or non-marine
Organisms erect structure	No analogous process
Sediment texture controlled by growth form and ultrastructure of organisms	Sediment texture reflects 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 tectonisim 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

Aspect	*Sandstone*	*Carbonate*
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 ±ΦI 'depositional'	Commonly none or only small fraction of initial porosity; 5-15% common in reservoir facies ±ΦII 'diagenetic'
Type(s) of primary porosity	Almost exclusively interparticle	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)

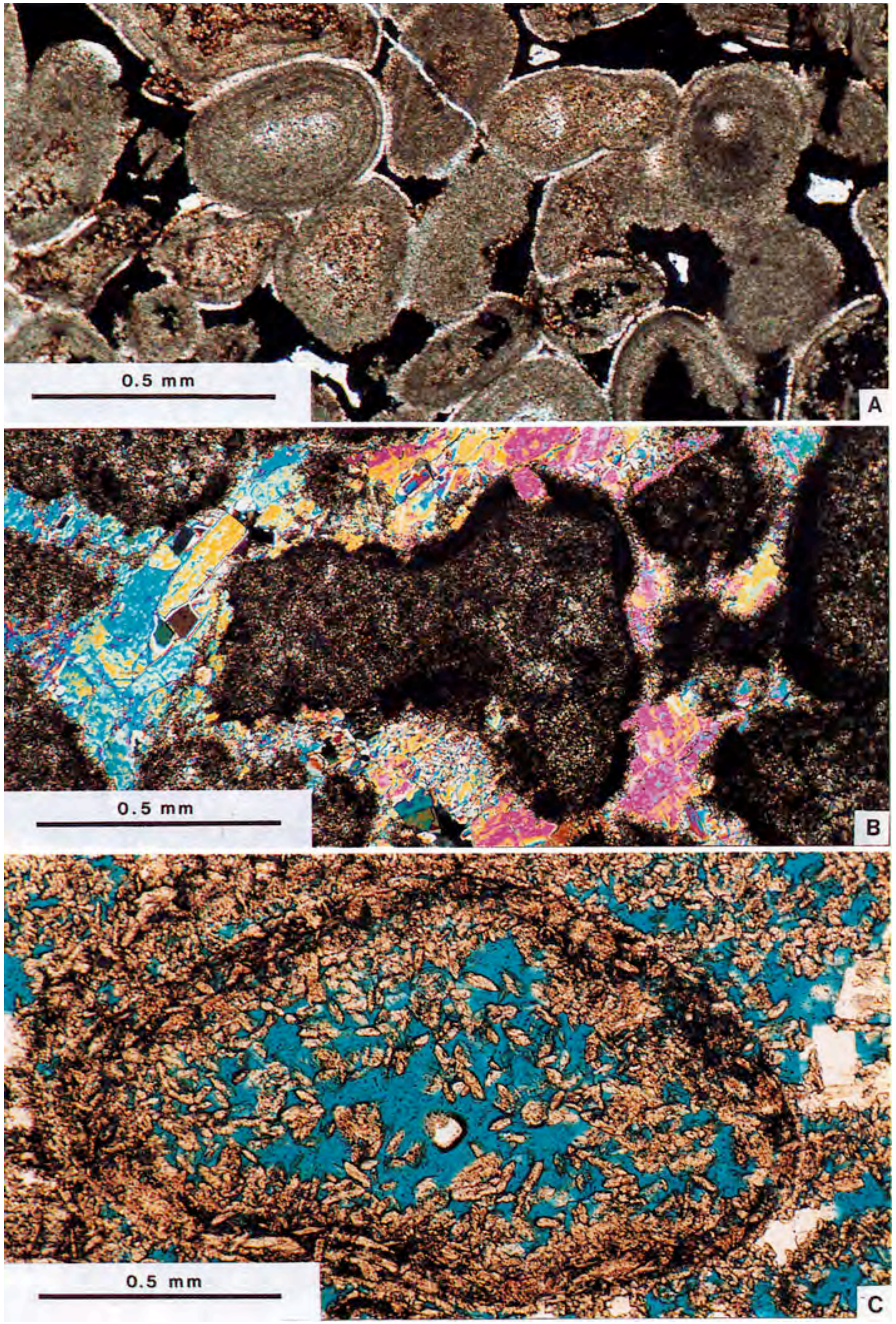


Unrestricted dolomites
Zechstein Reservoirs
Permian, The Netherlands

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 (cm²)	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 : < 1^{-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)

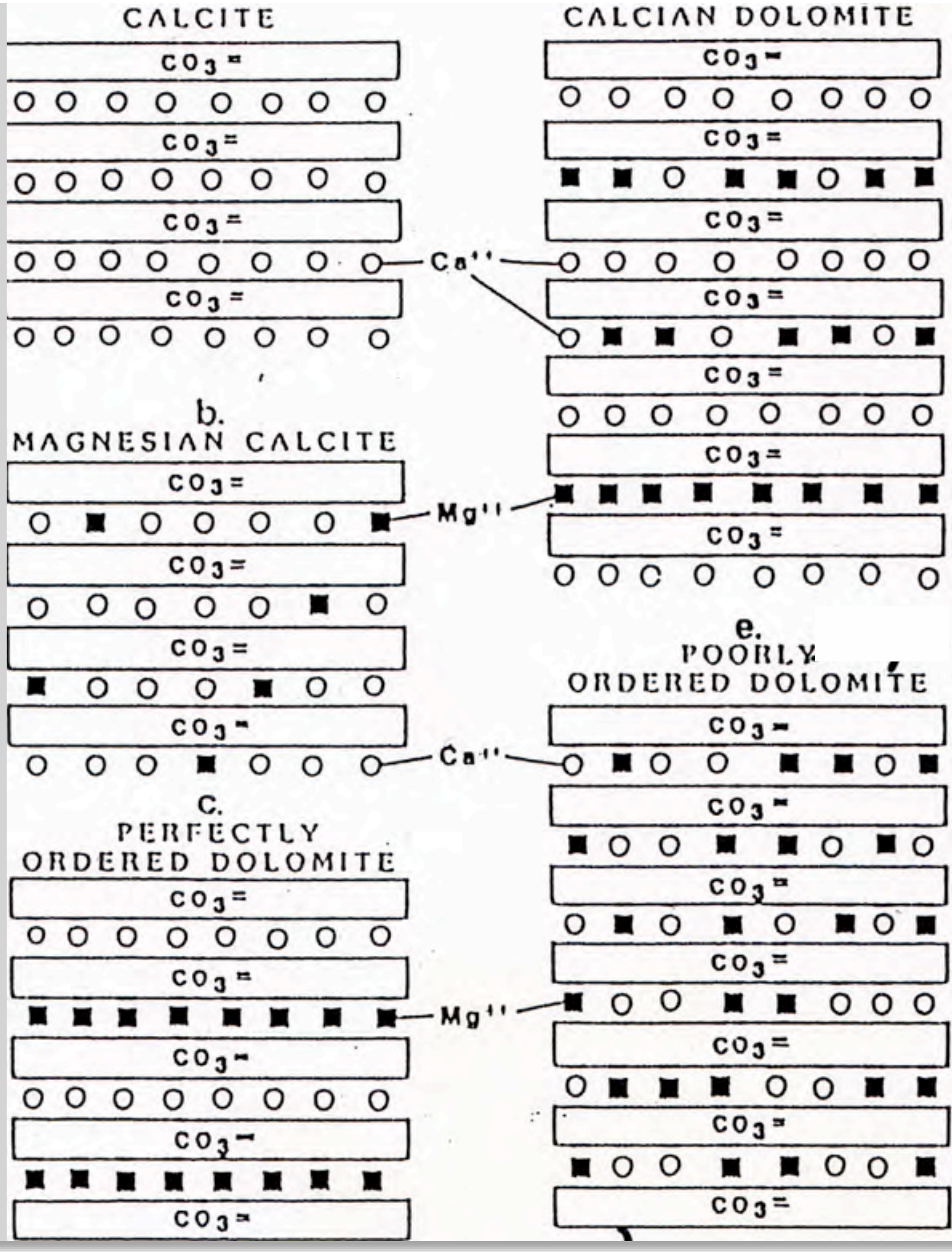
dissolution, neomorphism, cementation (…)

COMMON CARBONATE MINERALS

LMC

HMC
if >4 mole% $MgCO_3$

Ca:Mg 1:1
HT>300°C

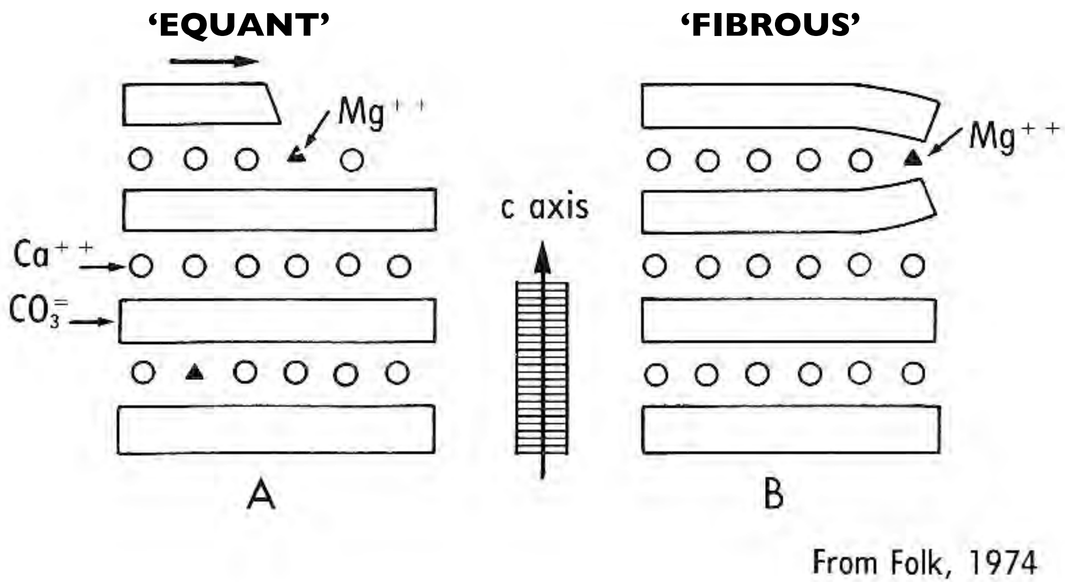


protodolomite

$Ca_{55}Mg_{45}(CO_3)_2$

primary
or
penecontemporaneous
1-2 µm

CARBONATE CRYSTALLOCHEMISTRY



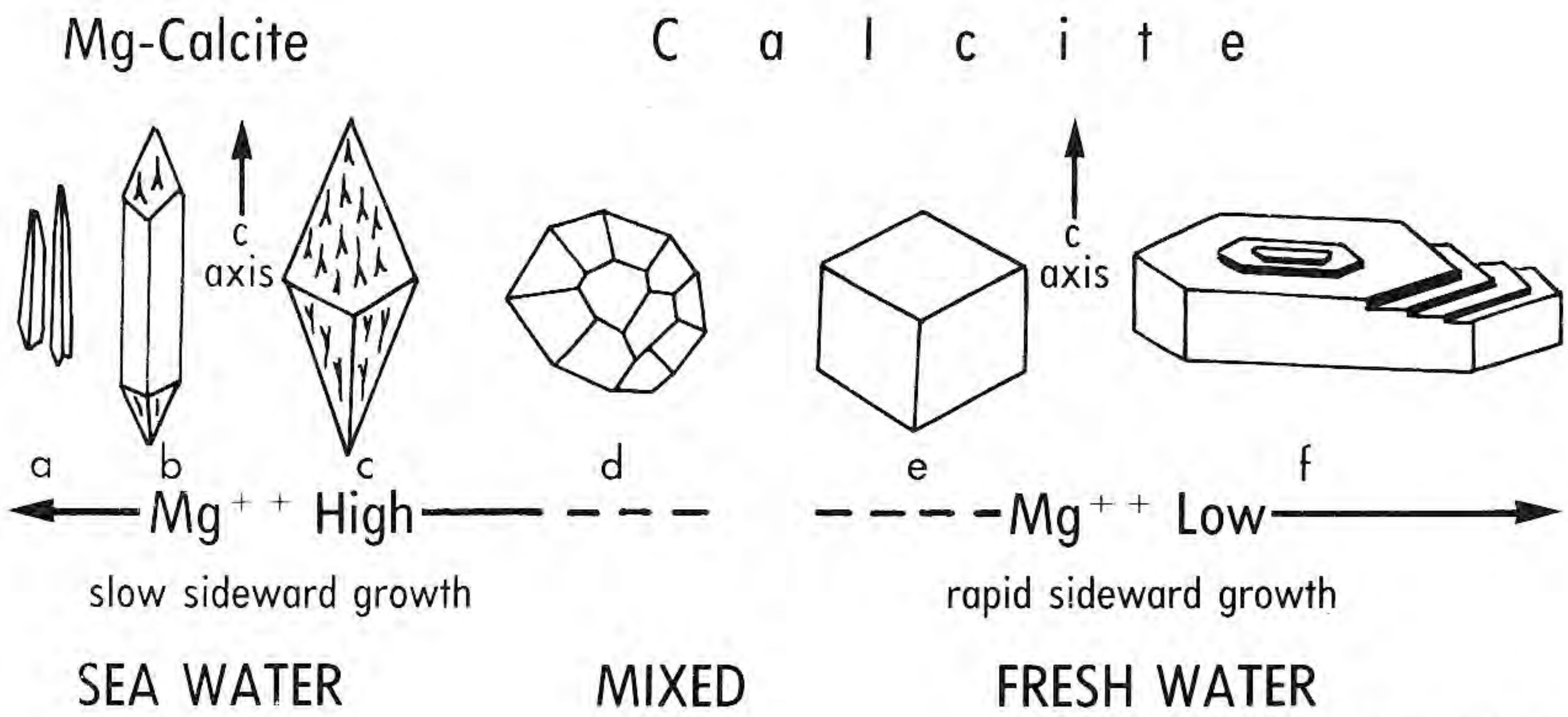
Morphology of calcite crystals as controlled by selective 'Mg-poisoining'.
A If a Mg ion is added to the end of growing crystal it can be easily overstepped by the next succeeding CO_3 layer **without harm to the crystal growth.**
B If the small Mg ion is added to the side of the cystal, the adjacent 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

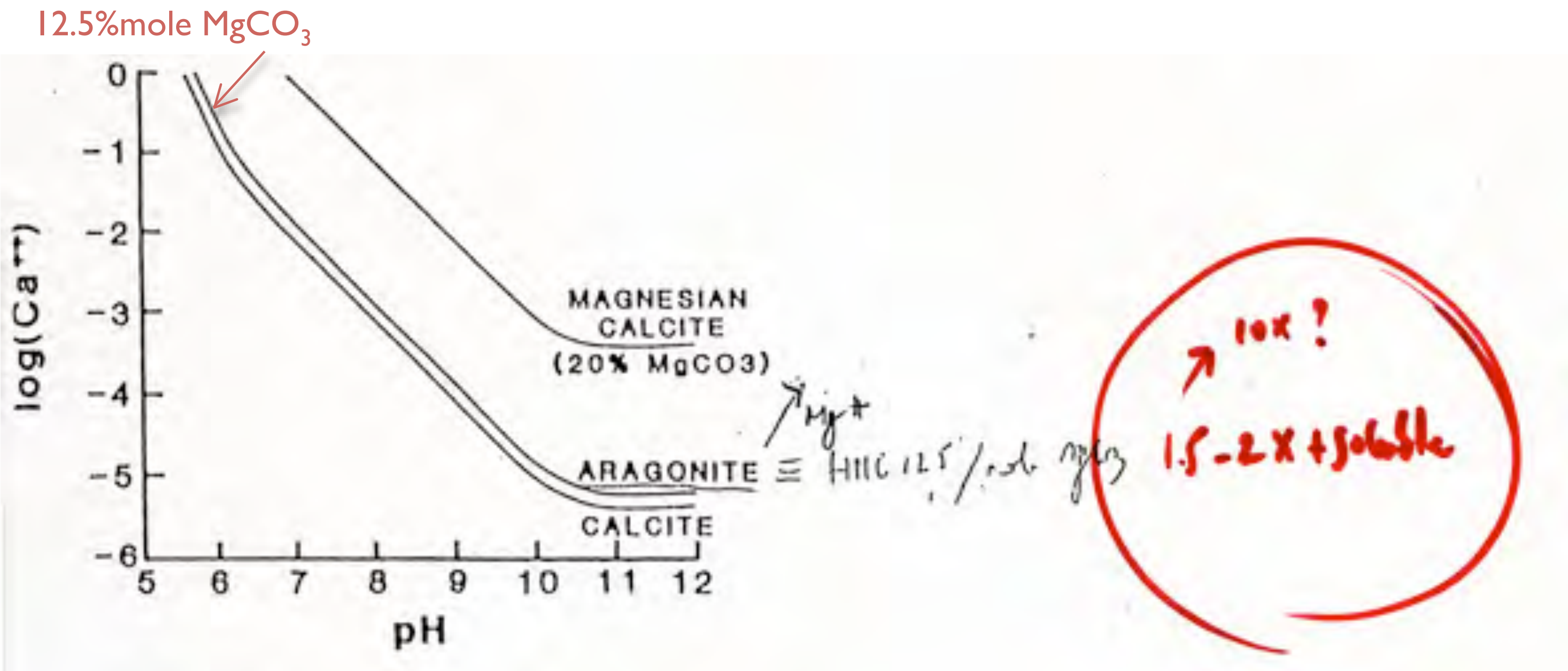
nb : 1990' availability CO_3^{2-} ....

'FIBROUS'	'EQUANT'



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

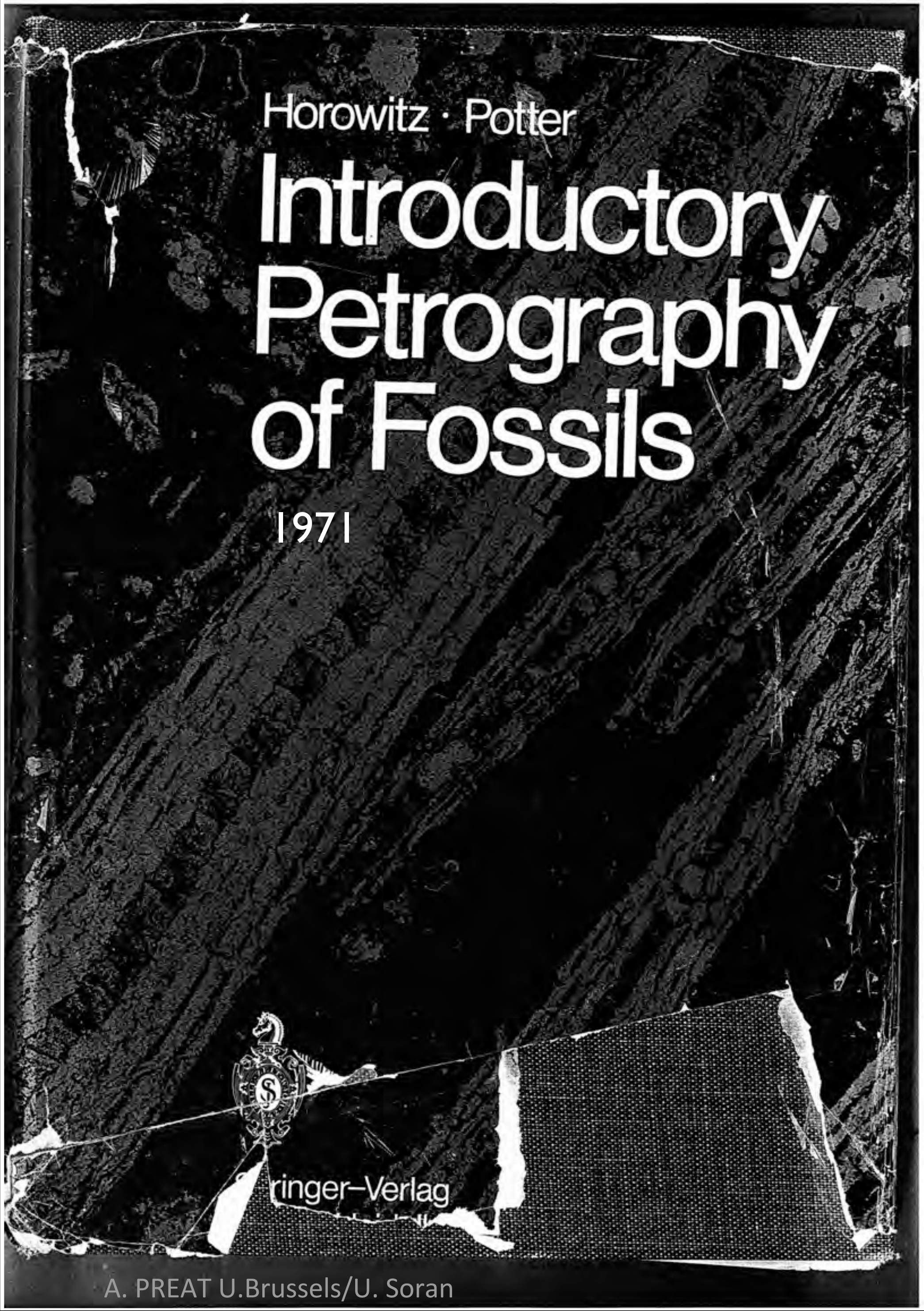
OTTO P. MAJEWSKE

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

With 280 Photomicrographs and 19 Diagrams

TUTA SUB AEGIDE PALLAS · EJB ·

LEIDEN
E. J. BRILL
1974



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SKELETAL MICROSTRUCTURES – INVERTEBRATE FOSSILS

1. HOMOGENEOUS PRISMATIC
   //N and N✗: aggregates of tiny uniform indistinguishable crystals at <500x
   calcite (common), aragonite (rare), no visible structure,
   - ❖ forams, , ostracods, trilobites, (sometimes mollusks).

2. NORMAL PRISMATIC
   ✗N: aggregates of 'normal' prisms (longitudinal section) and 'aggregates' (transverse section). The prisms are normal to the surface of the shell.
   => based on the form, the are 4 types : 1-2 = inner layer of brachiopods, 1-3-4 (mollusks), calcite (common), aragonite (rare).
   - ❖ brachiopods, mollusks

3. COMPLEX PRISMATIC
   ✗N: 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

✗N: 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)

Homogeneous prismatic

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

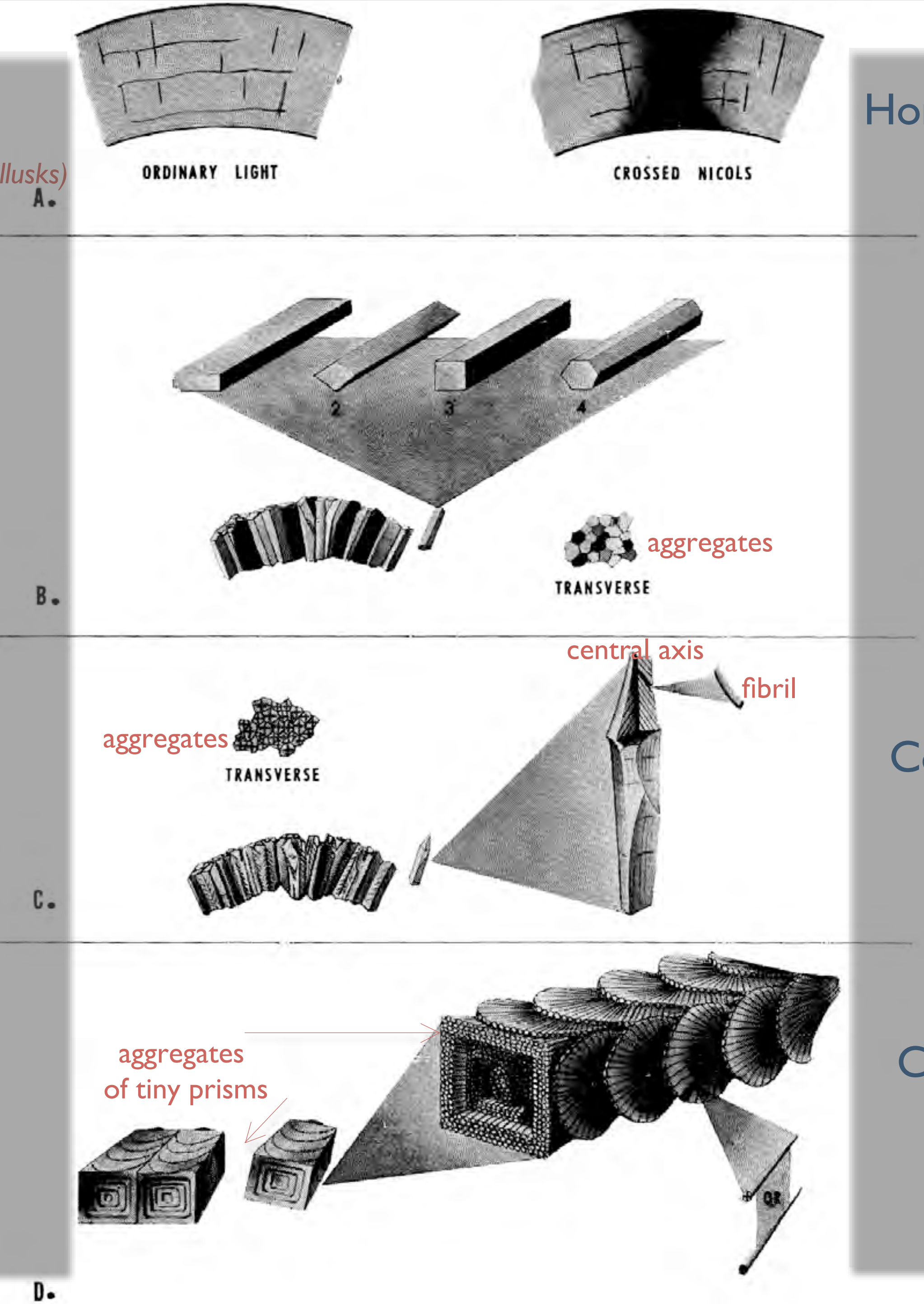
Normal prismatic

mainly *mollusks*

Complex (composite) prismatic

only *mollusks*

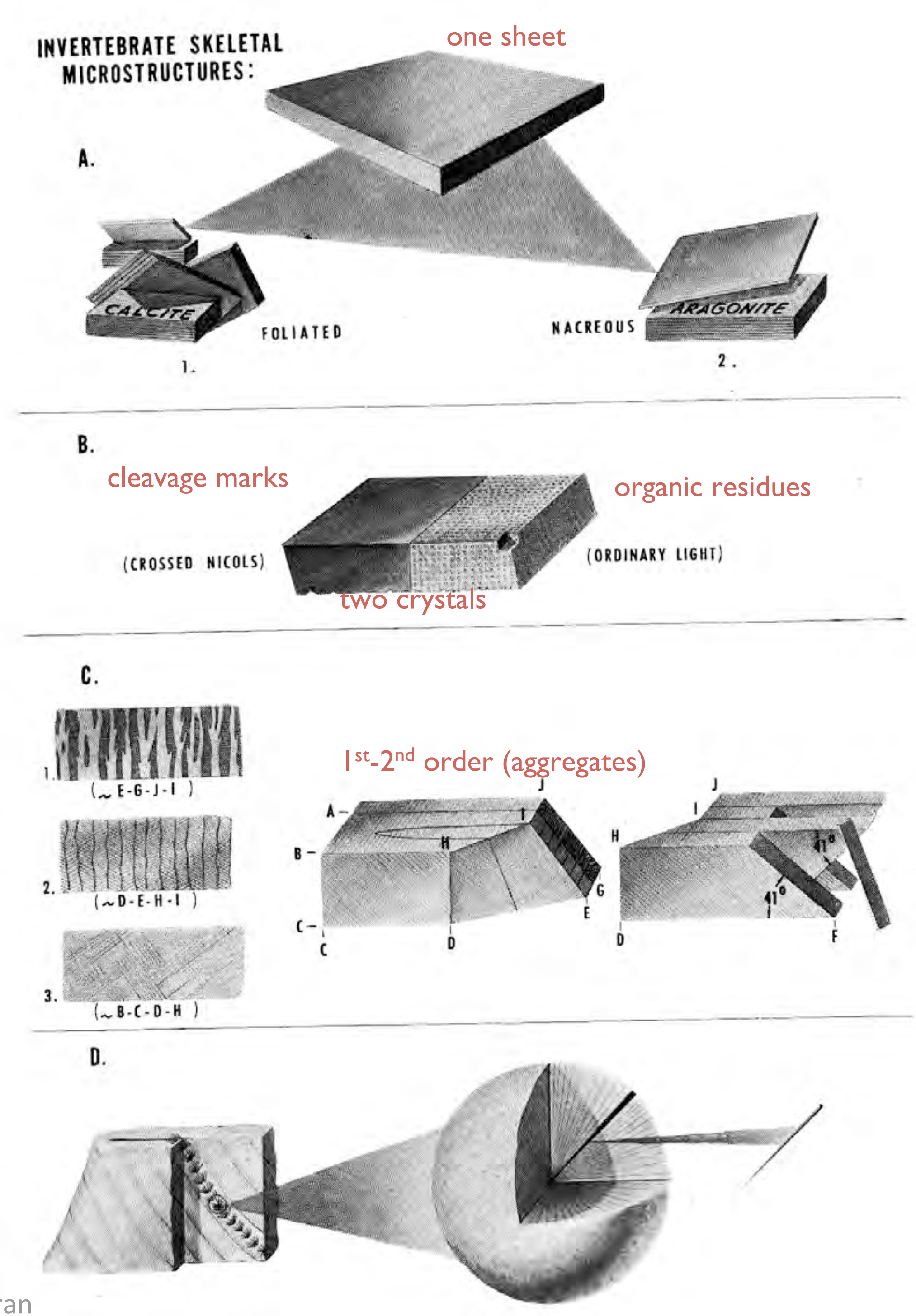
Composite prismatic



Foliated

Δ orientation
Δ size
Δ optical axes

oysters
brachiopods
annelids
bryozoa



Nacreous

slight Δ

mollusks

Monocrystalline

ALL *echinoderms*

Crossed lamellar

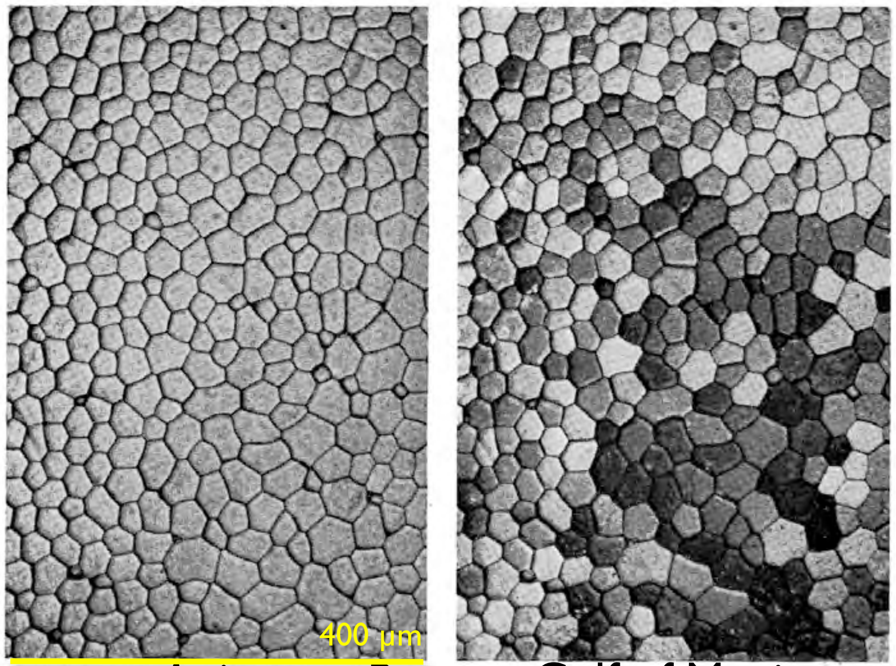
mollusks

Fibrous fascicular

corals

NX
L section

Normal prismatic



N//+NX
L sections

Atrina sp., Recent, Gulf of Mexico

Crossed lamellar

Crossed lamellar

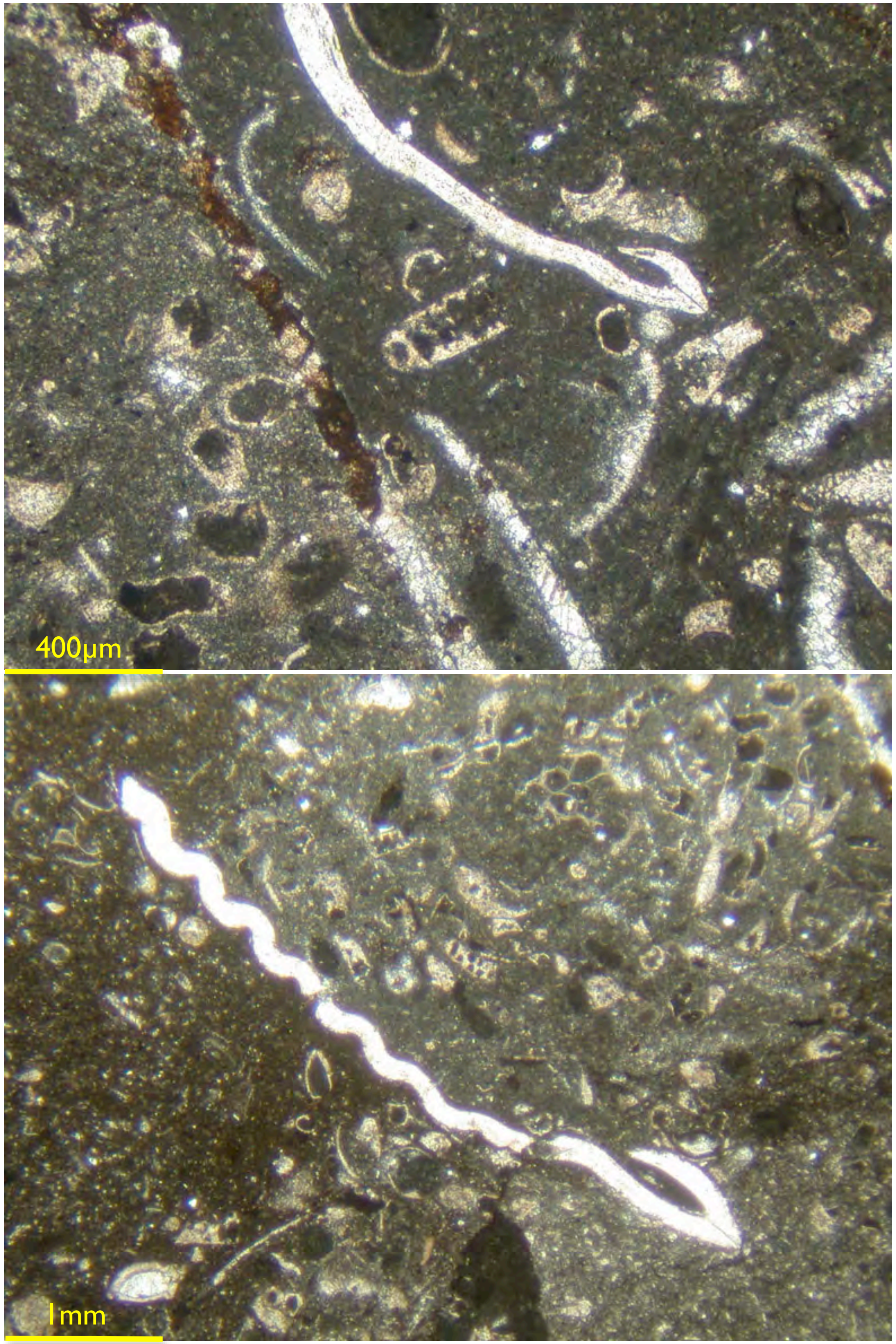
N//

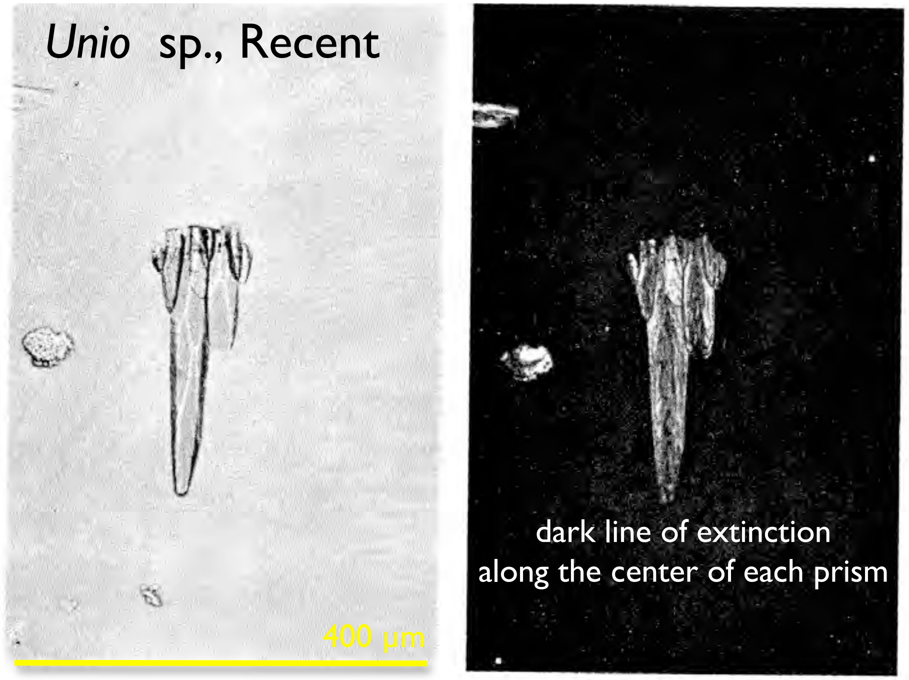
Homogeneous prismatic

N✗

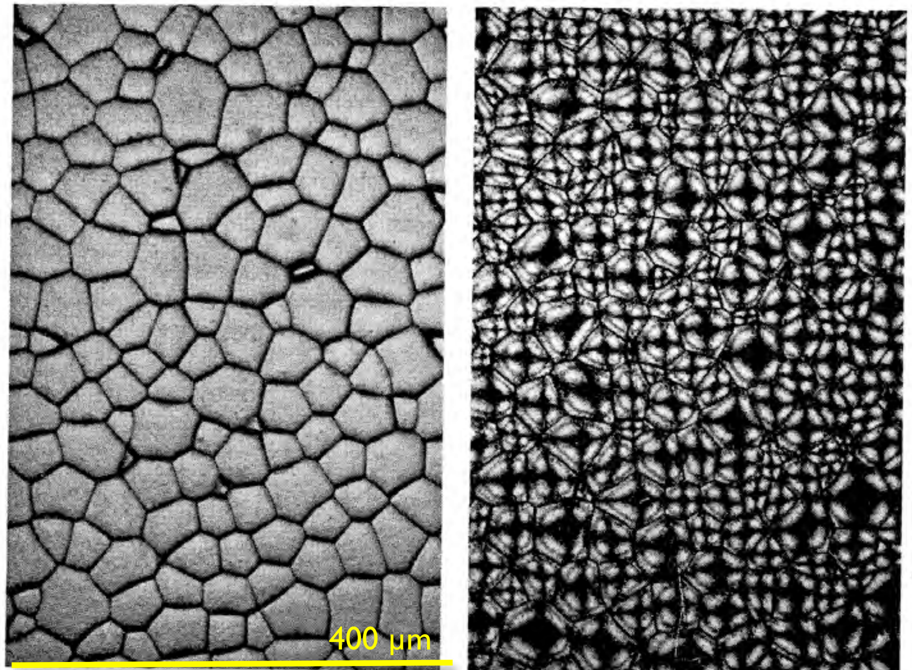
Typical trilobite sections
with algae (*Kamena*, *Proninella*)

Early Givetian (Middle Devonian), Givet, France, Préat 2010



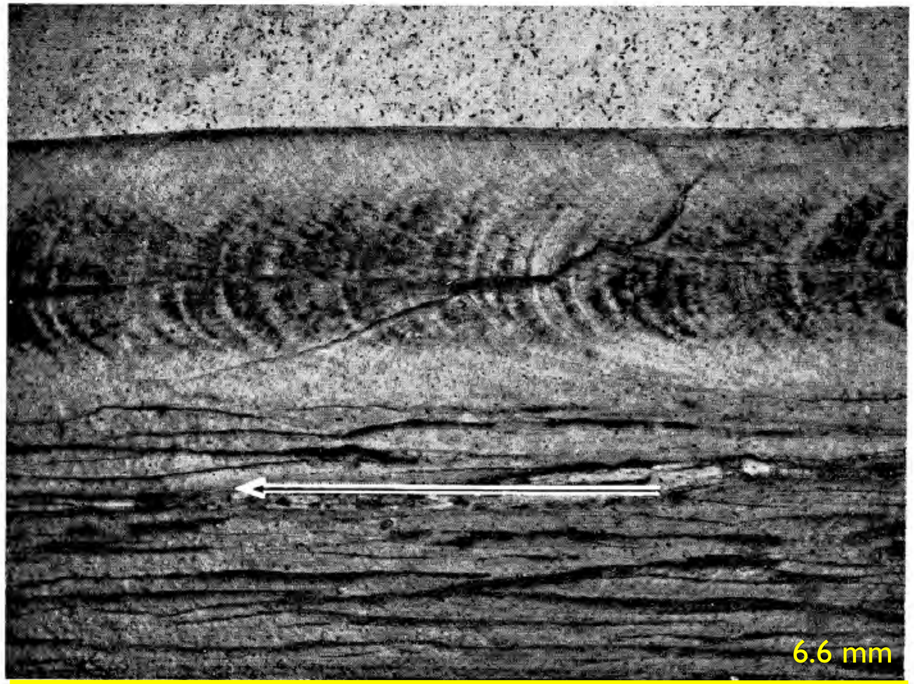


N// **Complex prismatic** N✗

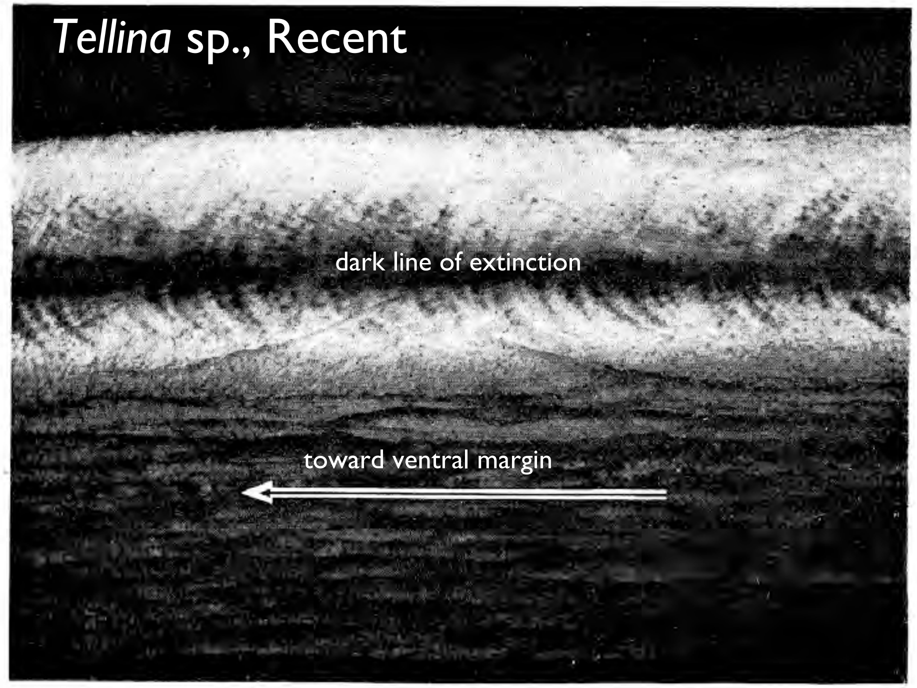


extinction swings with rotation

N//



Composite prismatic



N✗

N//

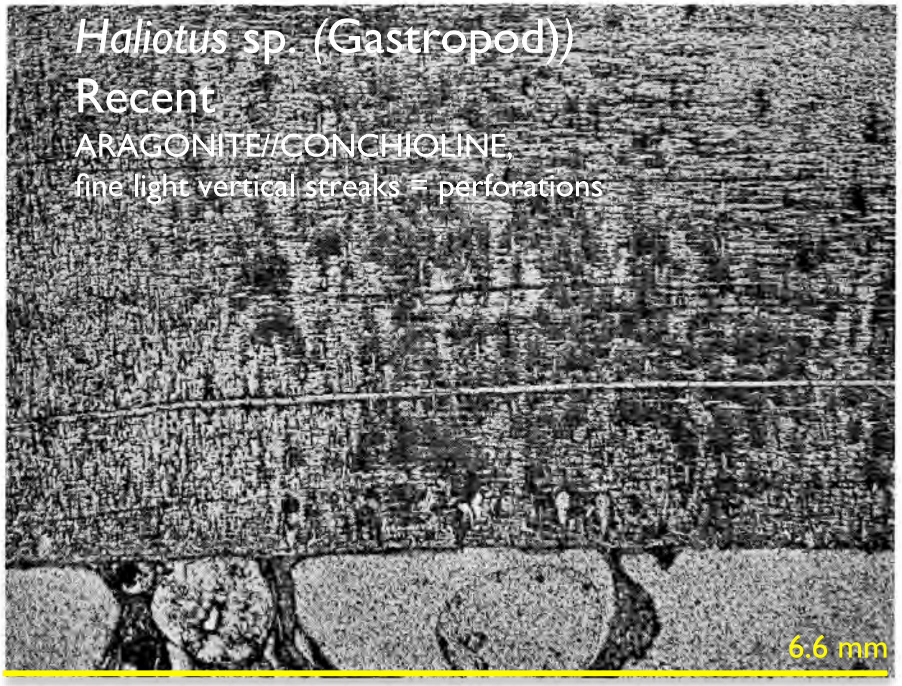

Ceratostreon (Ostreidae) sp., K, Texas
oriented bundles of thin LMC lamellae producing
an effect similar to cross-bedding
6.6 mm

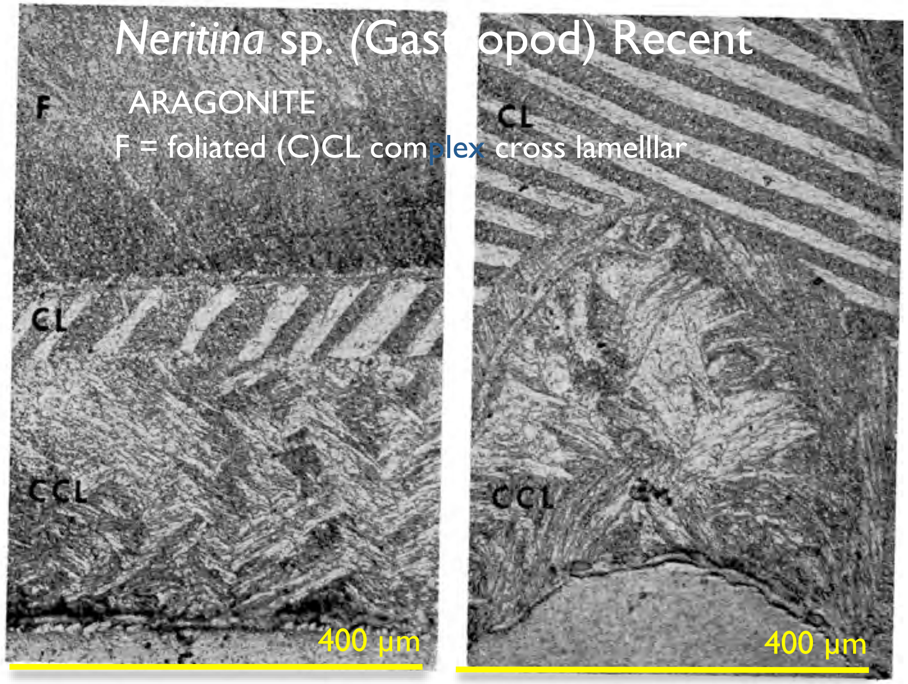
Foliated

N//

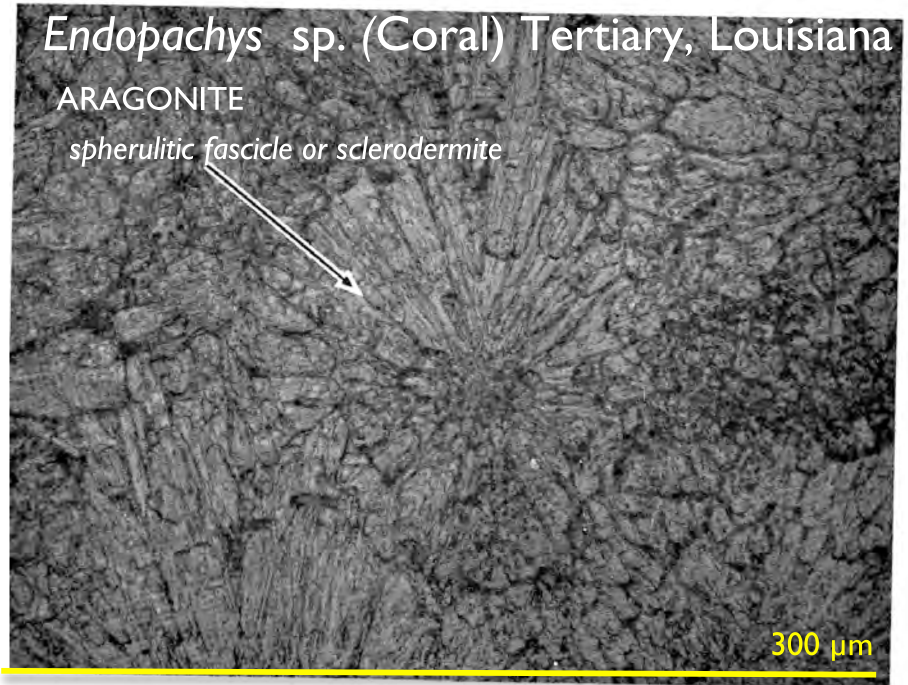

Gyrostrea n (Ostreidae) sp., K, Mexico
2 mm

Foliated (top) and Nacreous (bottom)

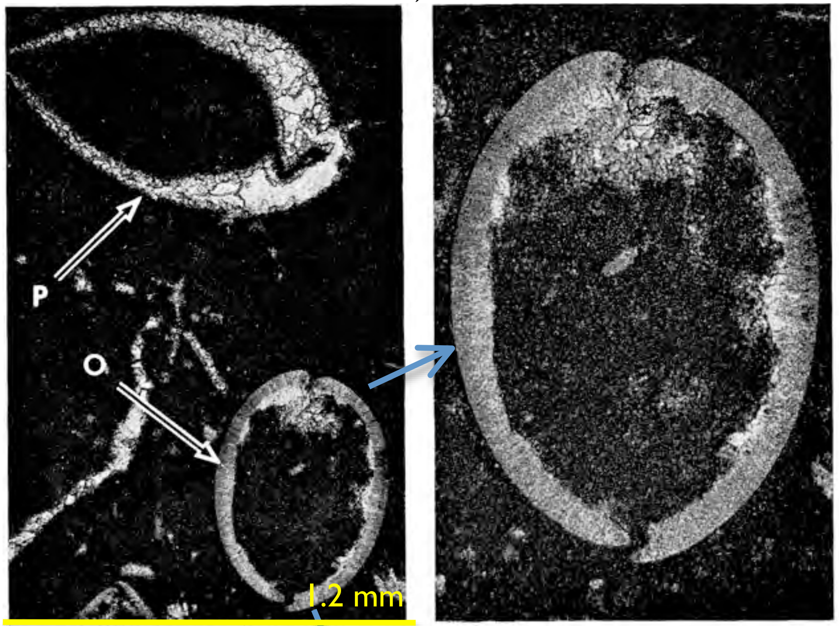




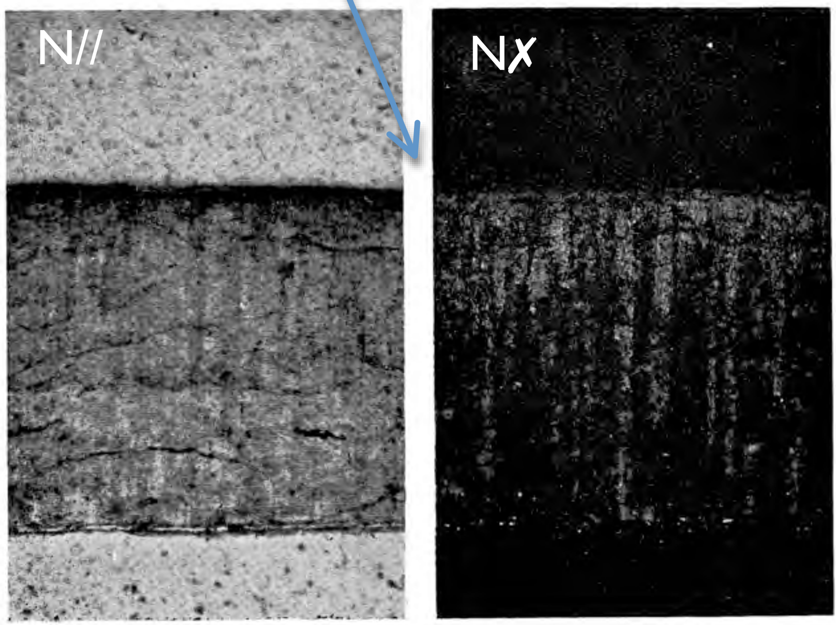
Complex cross lamellar (top) and Fiber fascicles (bottom)



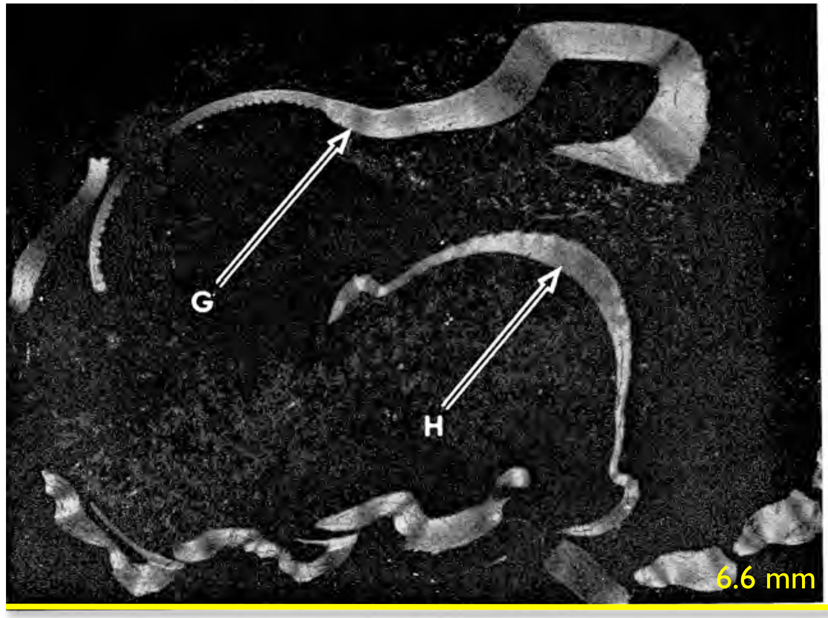
Ordovician, Dakota



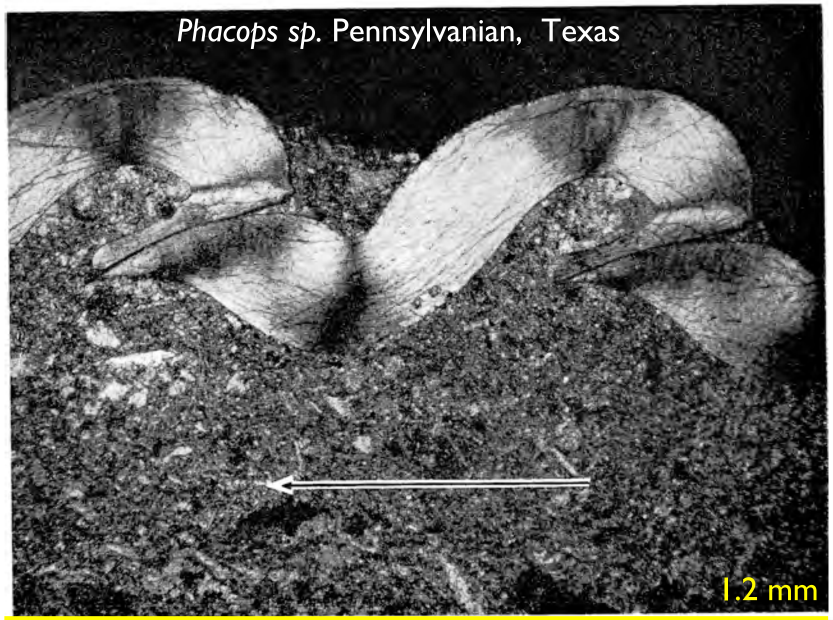
Ostracod carapace (O) and Pelecypod shell (P)



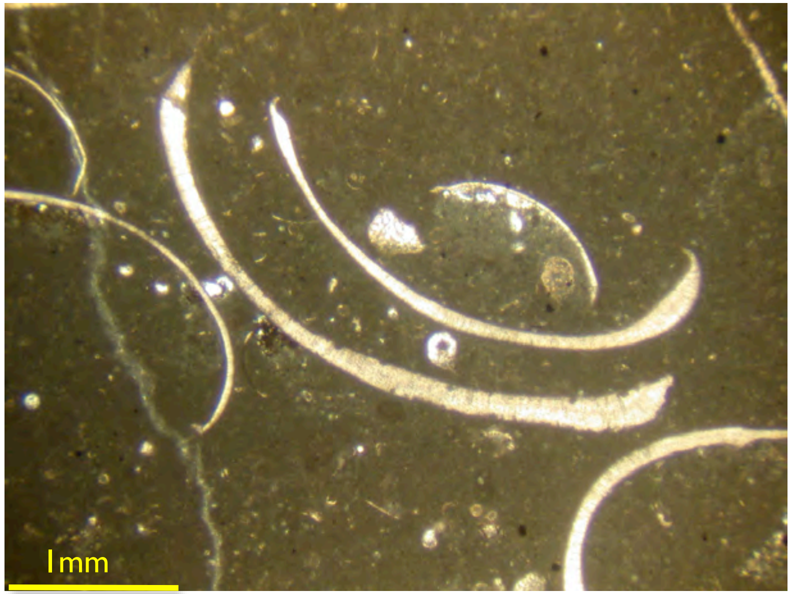
Ditomopyge sp. Pennsylvanian, Texas



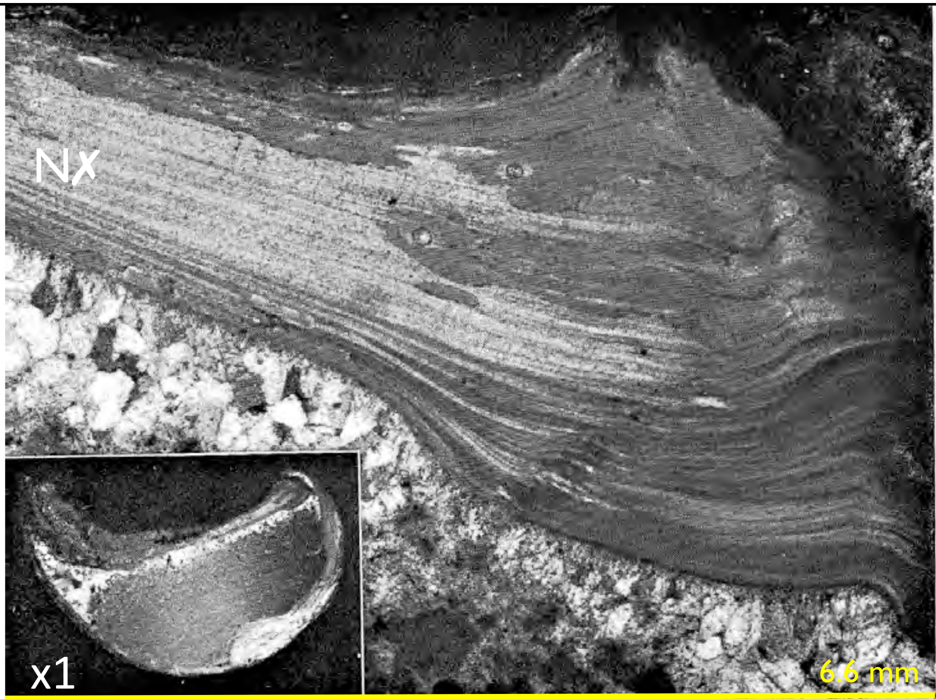
Phacops sp. Pennsylvanian, Texas



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

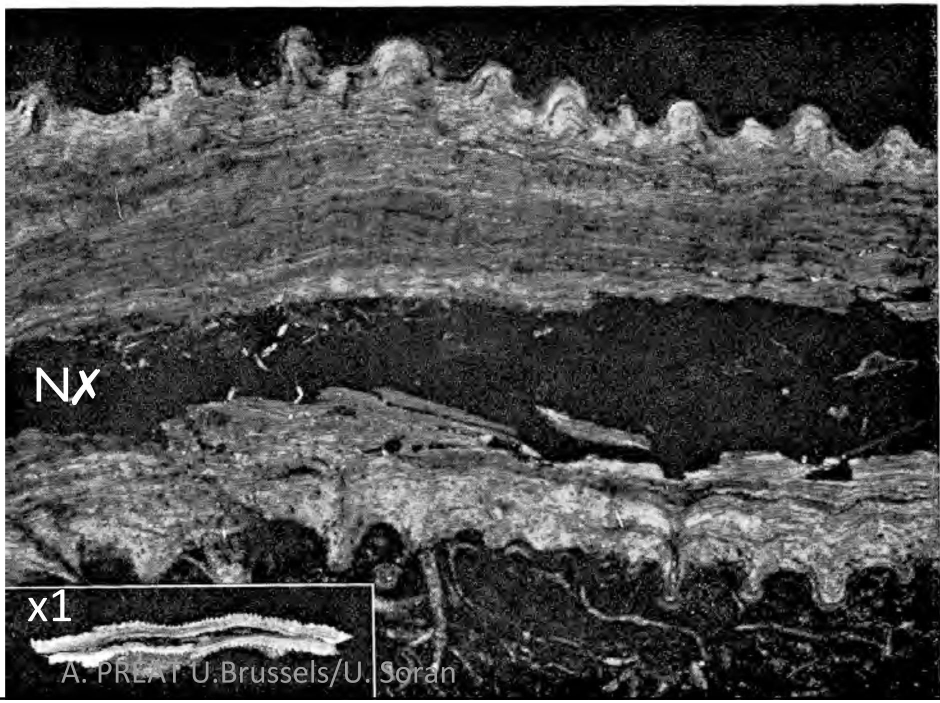


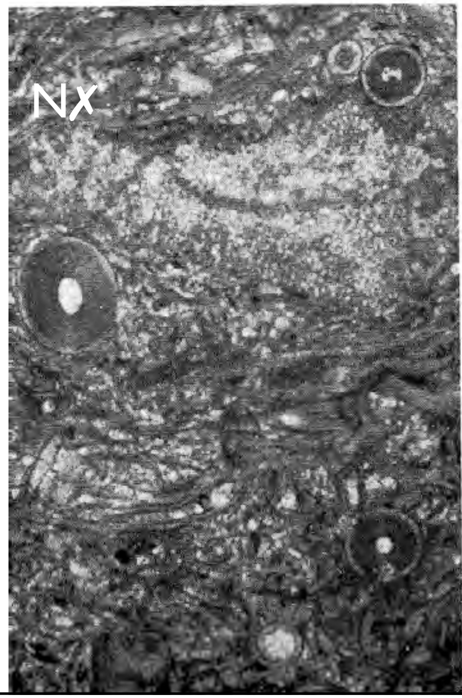
Stacked ostracode, mid-ramp setting,
Trois-Fontaines Fm, Givet, France
Lower Givetian, Préat 2010

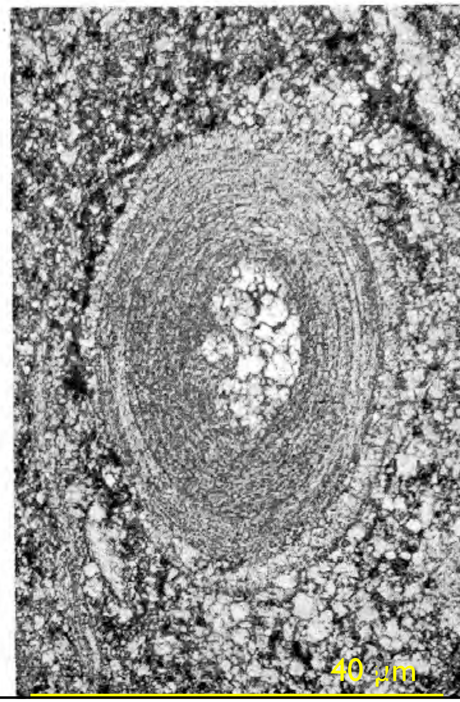


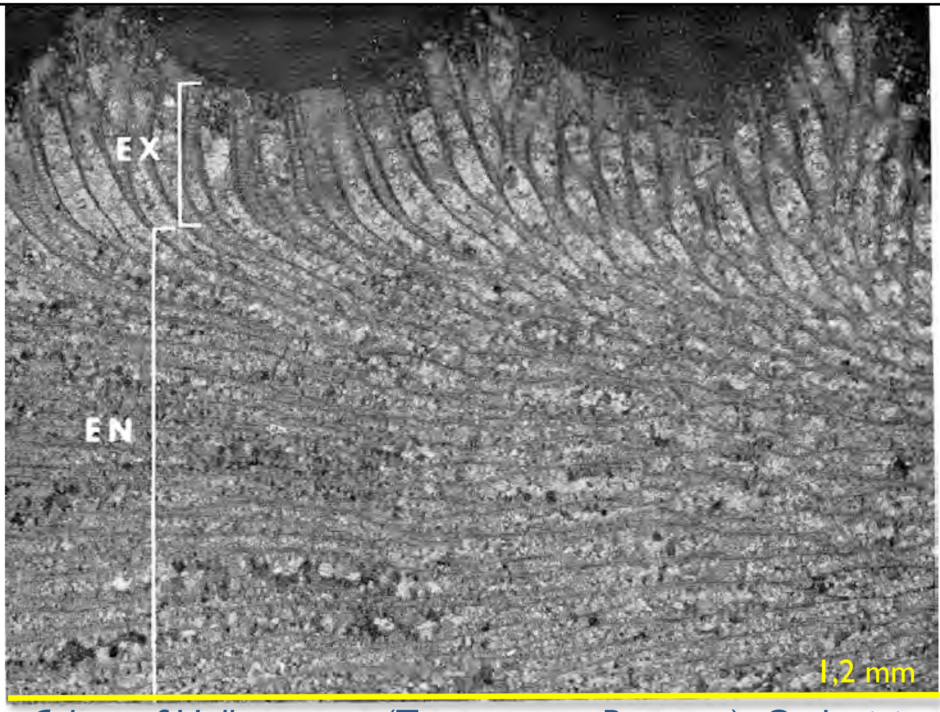
Dictyoclostus sp. (Productacea), Pennsylvanian, Texas

with spines (external layer)

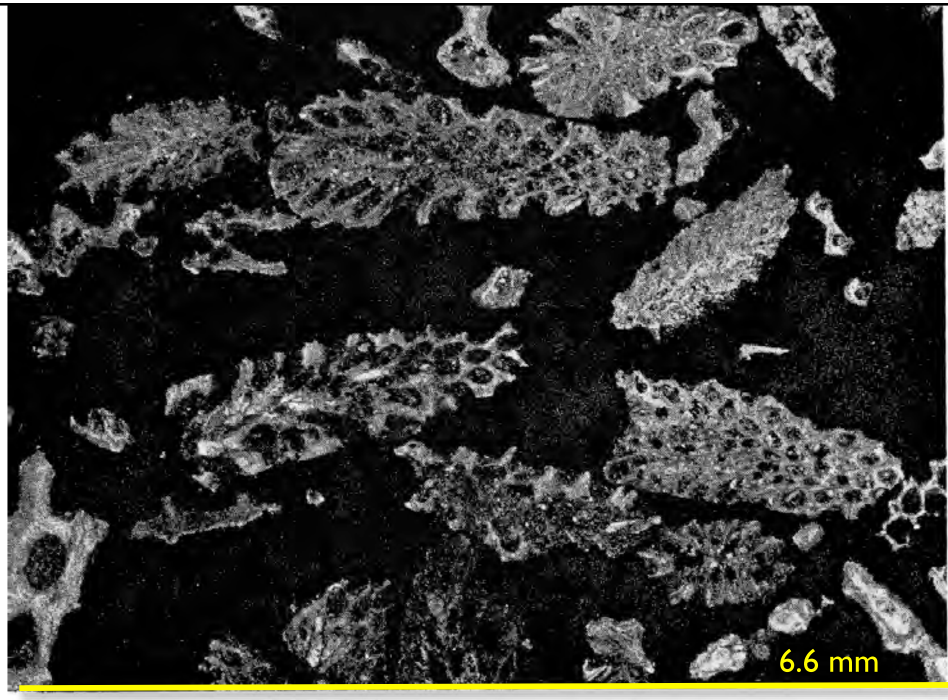




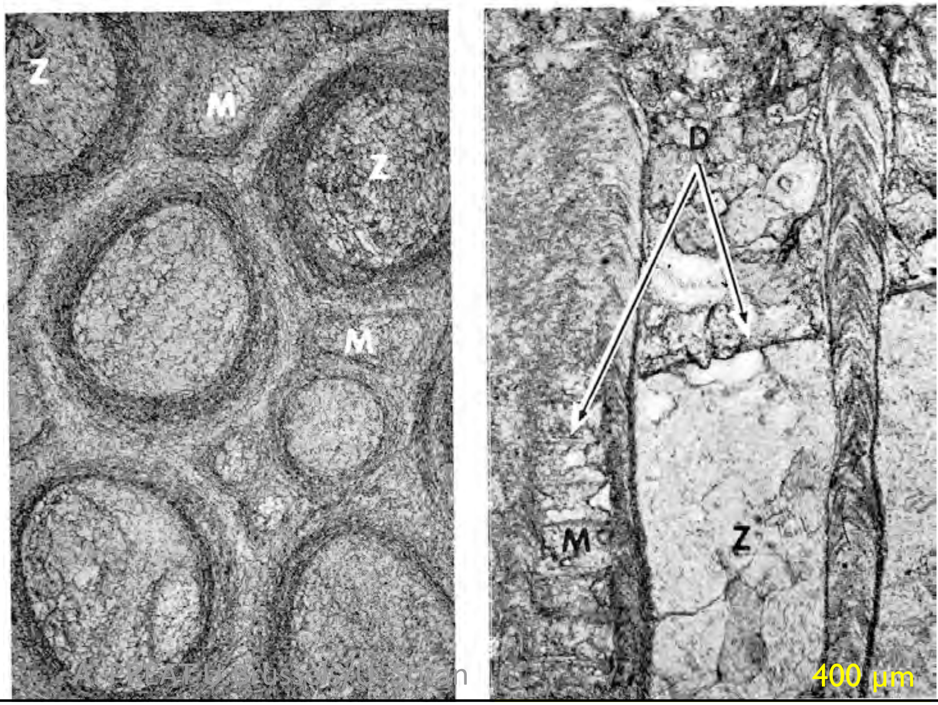


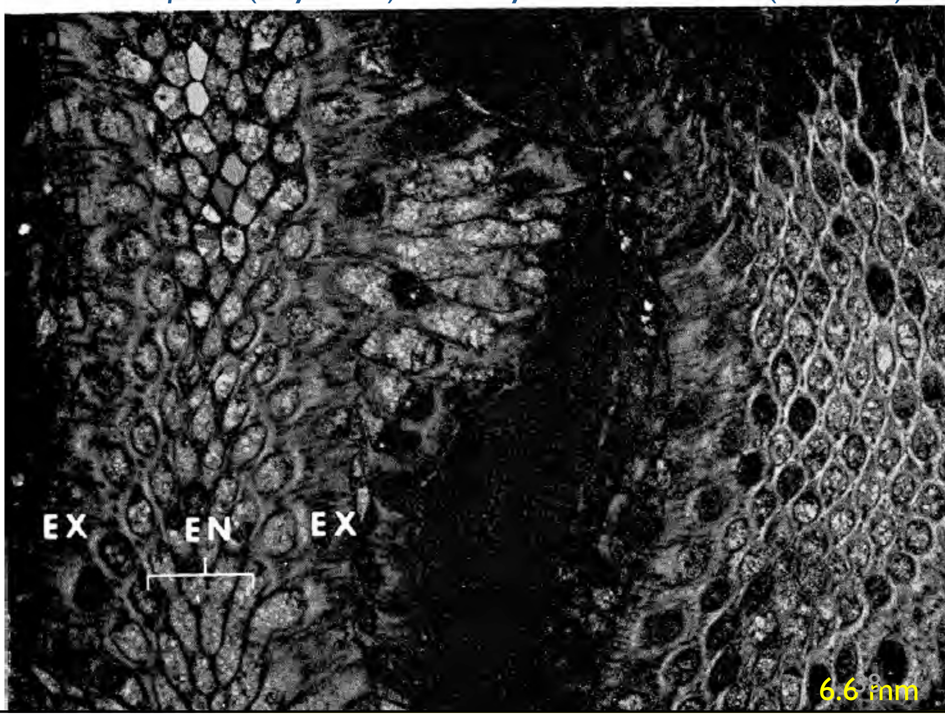


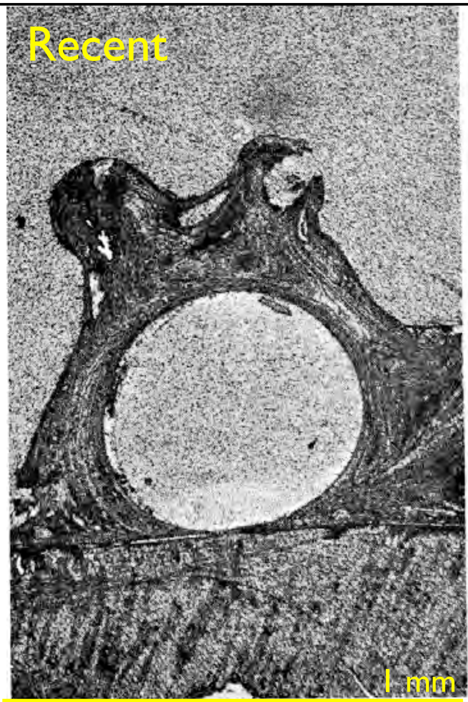
Colony of Hallopora sp. (Treptosome Bryozoa), Ordovician, Ohio [Z = zoecia, M = mesopore, D =diaphragm]

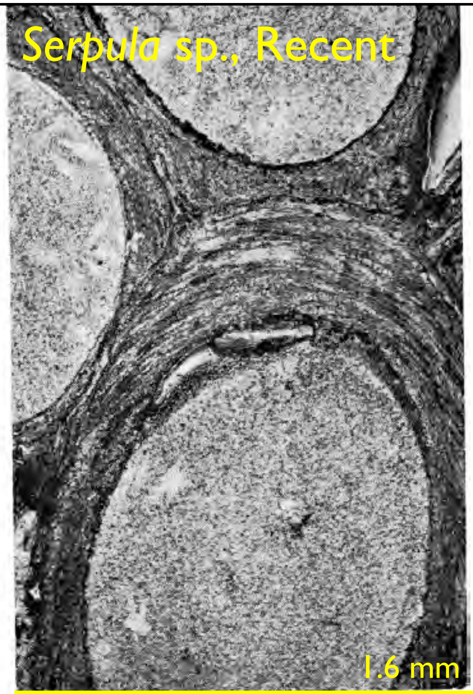


Crytposome Bryozoa, Devonian, Michigan (top)
Rhombopora (Bryozoa), Pennsylvanian, Texas, (bottom)

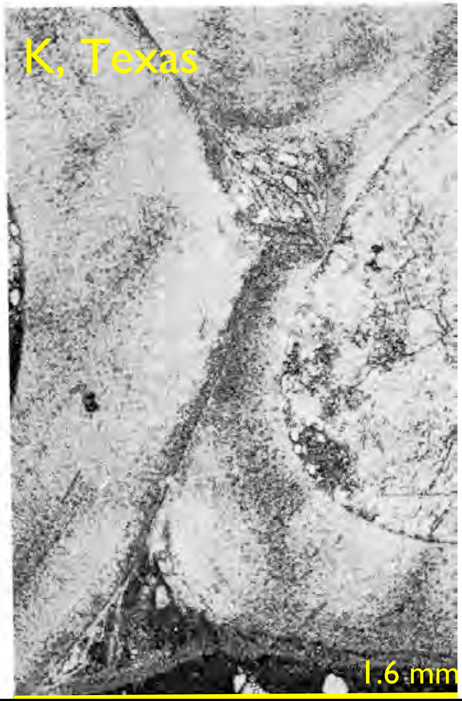




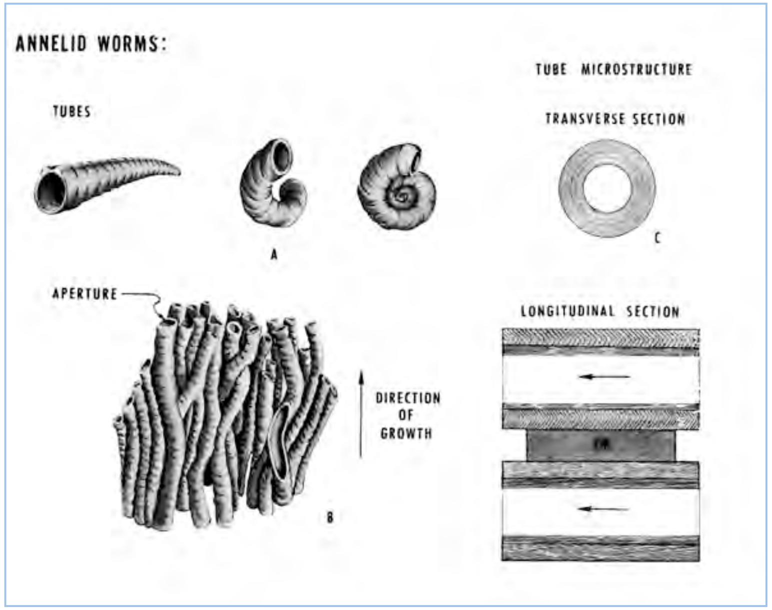




Transverse section of a worm encrusting the inner nacreous layer of a *Haliotus* shell (upper left picture).



ANNELID WORMS



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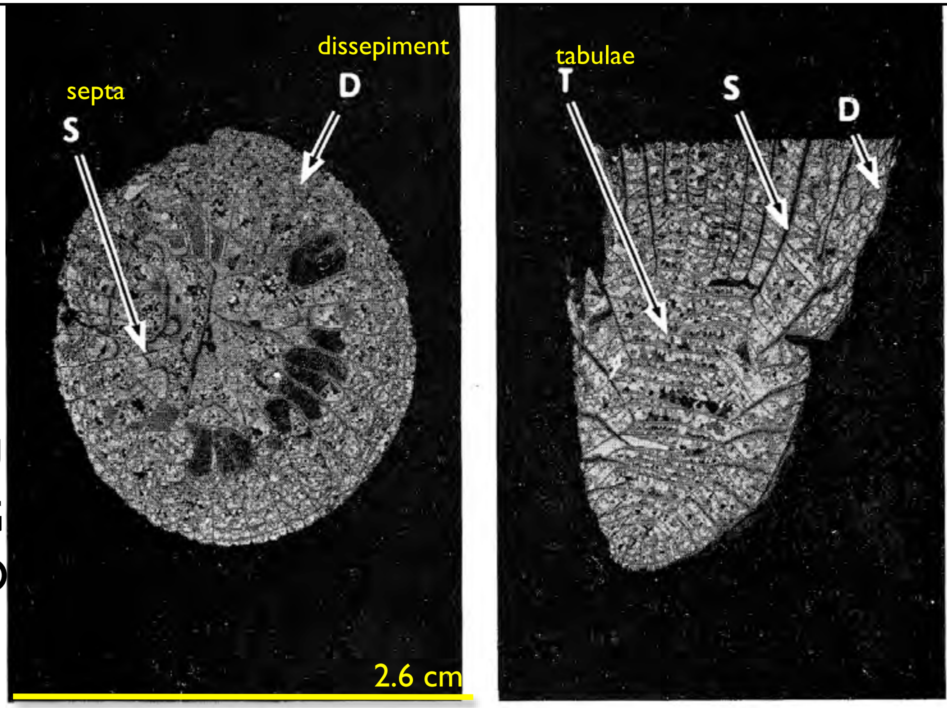
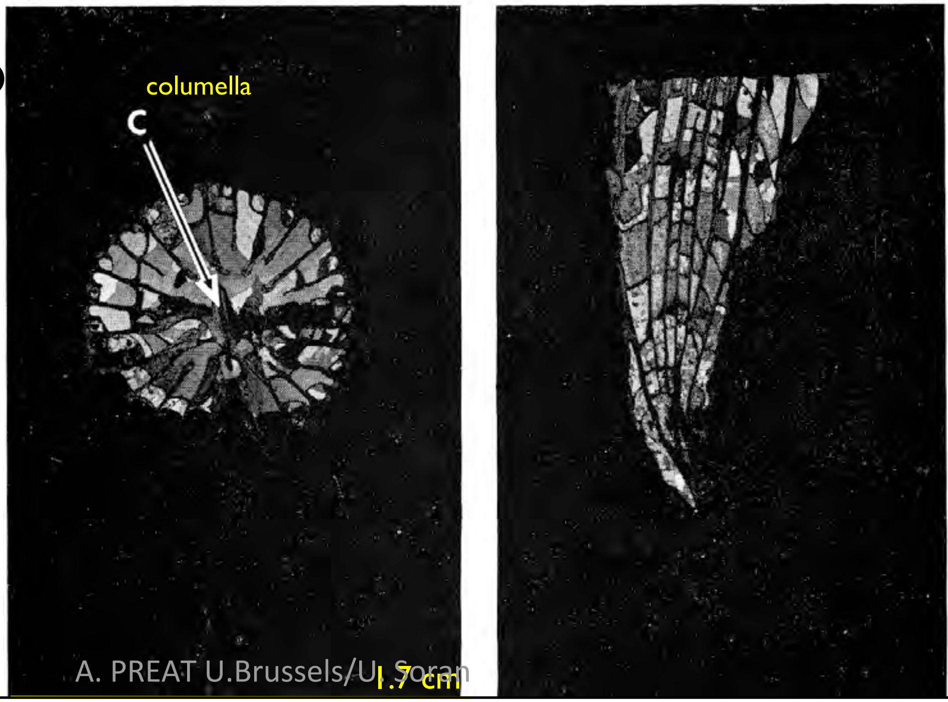
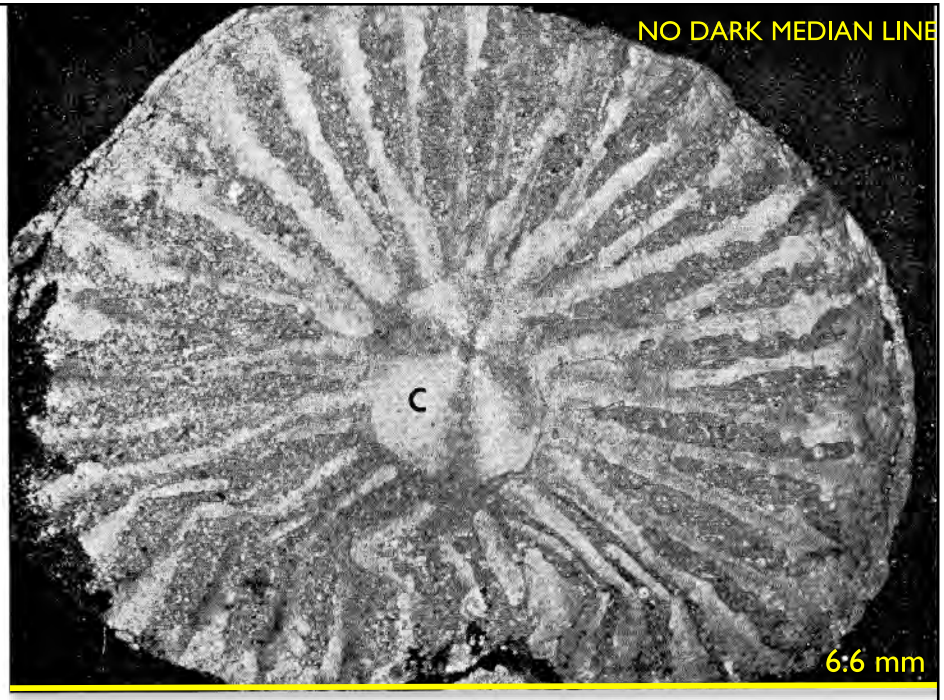
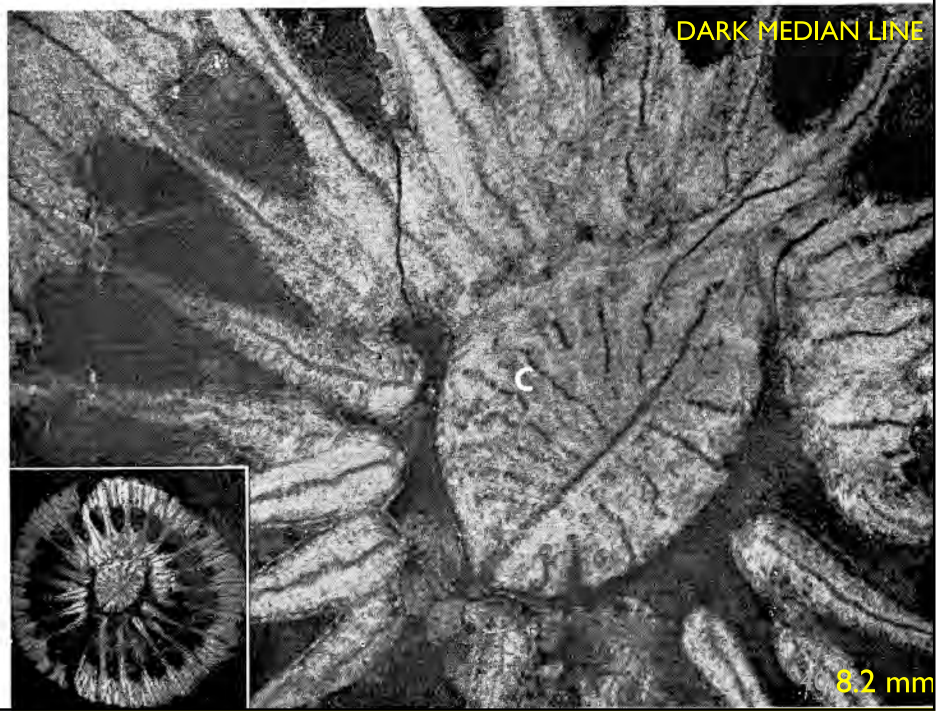


T & L sections of *Caninia* sp., Pennsylvanian, Texas (top)
T & L sections of *Lophophyllidium* sp., Pennsyl., Texas (bottom)

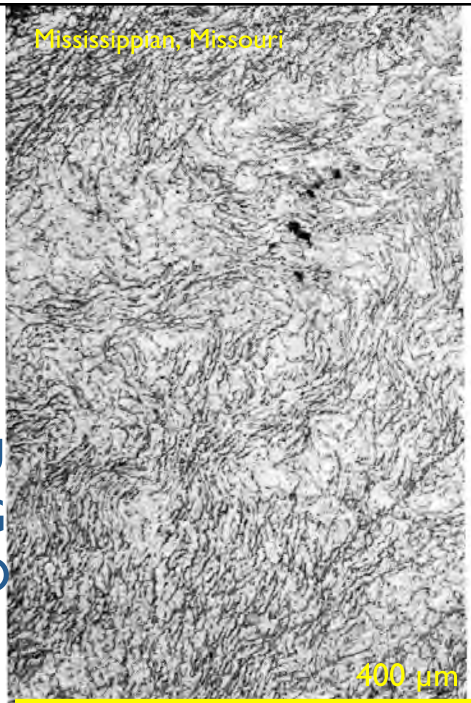




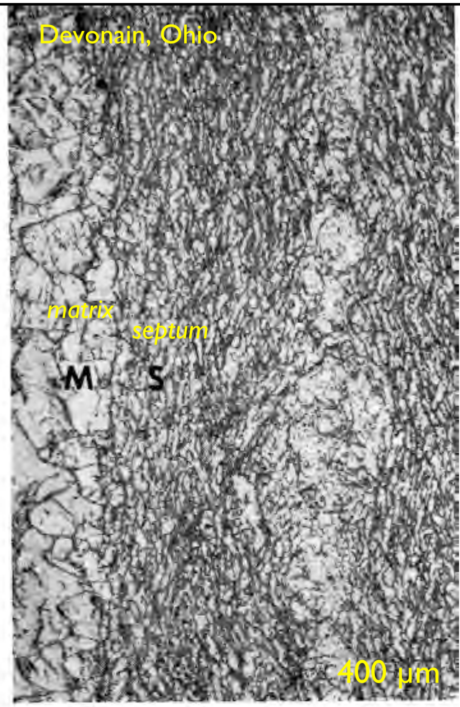
T section of *Cyathaxonia* sp. , Mississippian, Missouri (top)
T section of of *Lophophyllidium* sp., Pennsyl., Texas (bottom)



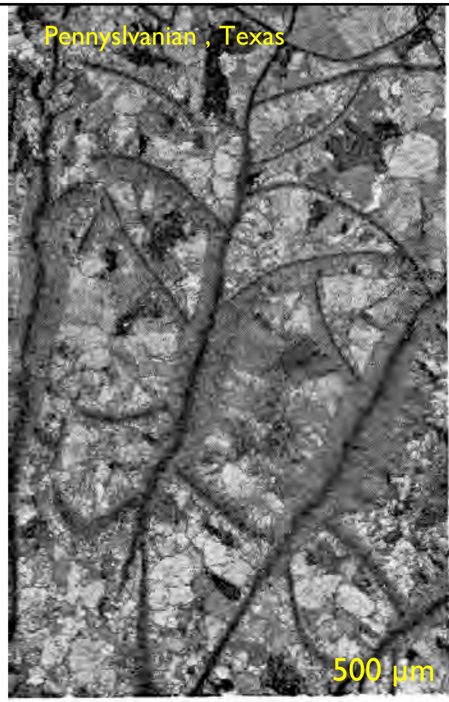
RUGOSA CORALS



T section of *Cyathaxonia* sp.

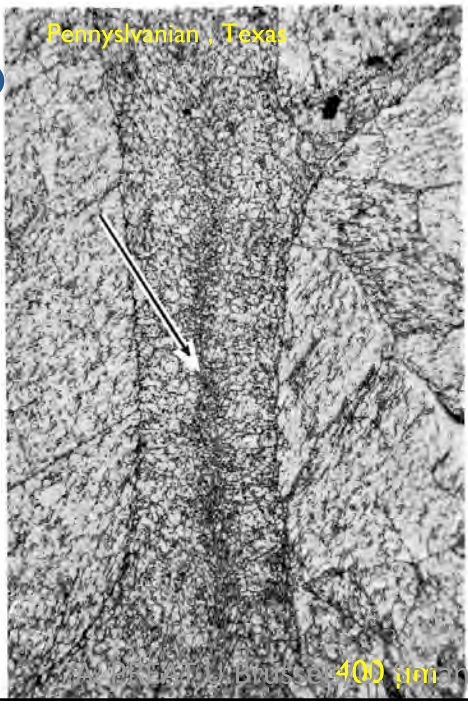


T section of *Heterophrentis* sp.

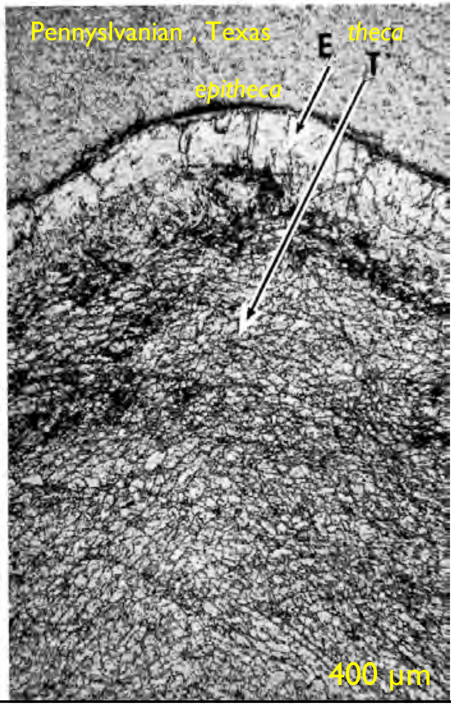


T section of *Caninia* sp

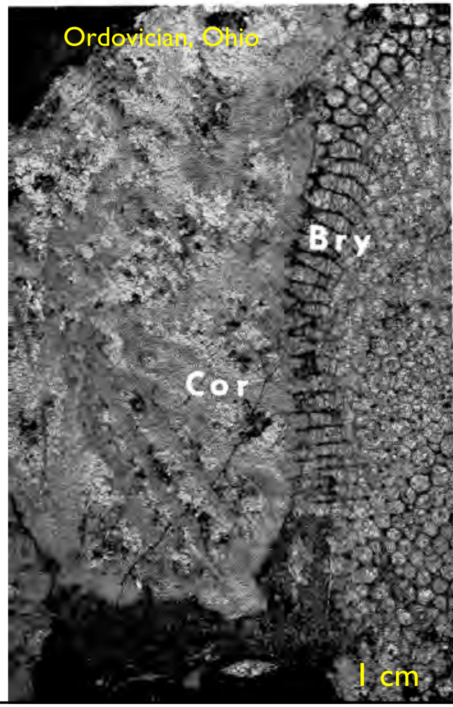
L section of *Caninia* sp.

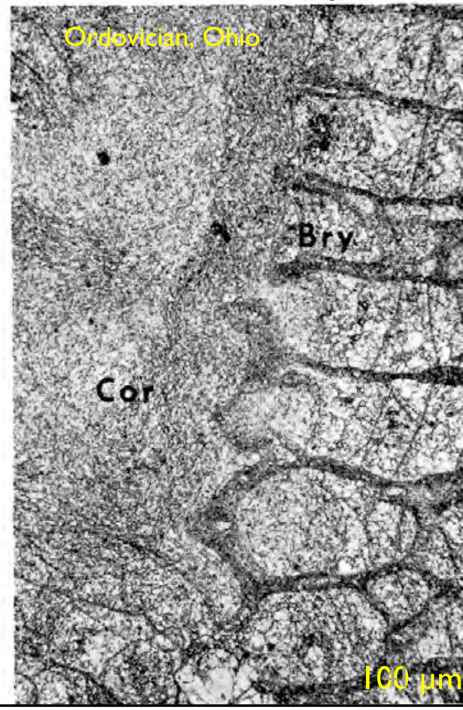


T section of *Lophophyllidium* sp.



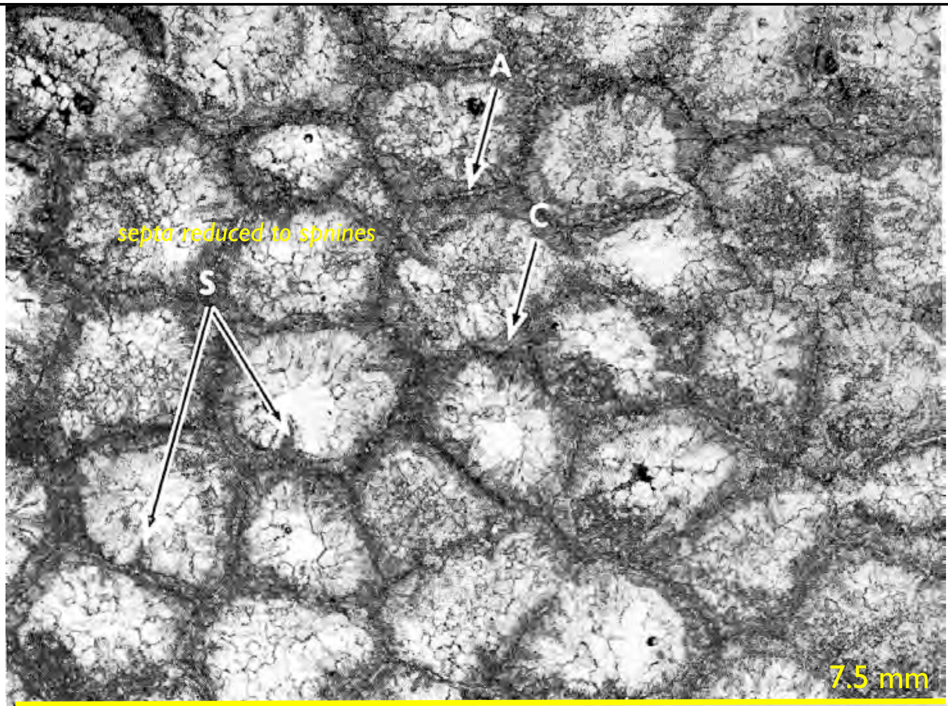
T section of *Lophophyllidium* sp.

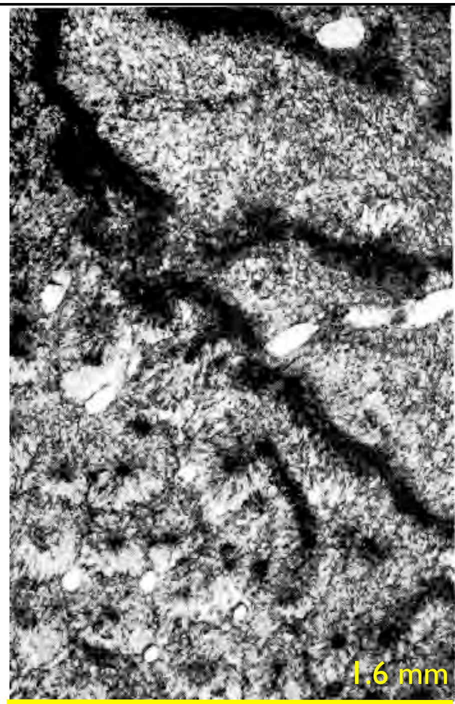


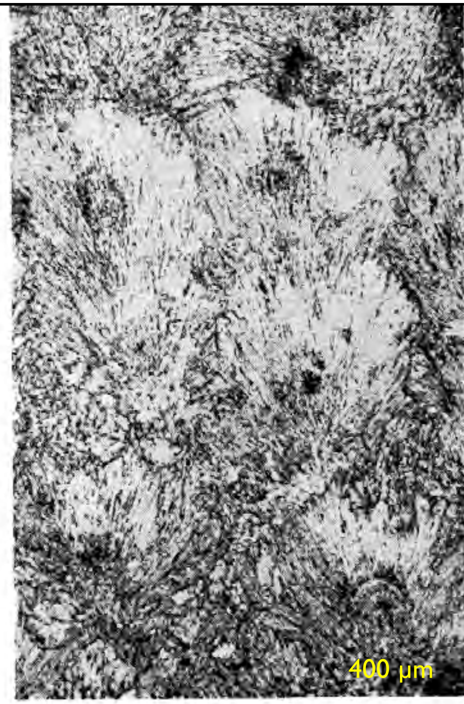


Comparison skeletal microstructure coral/bryozoa

TABULATA CORALS



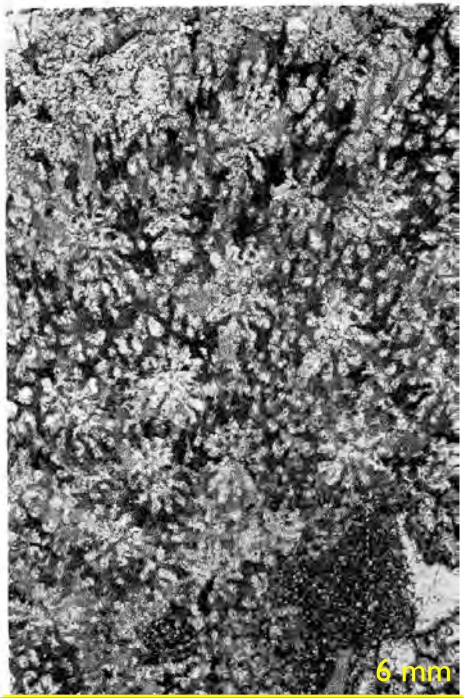


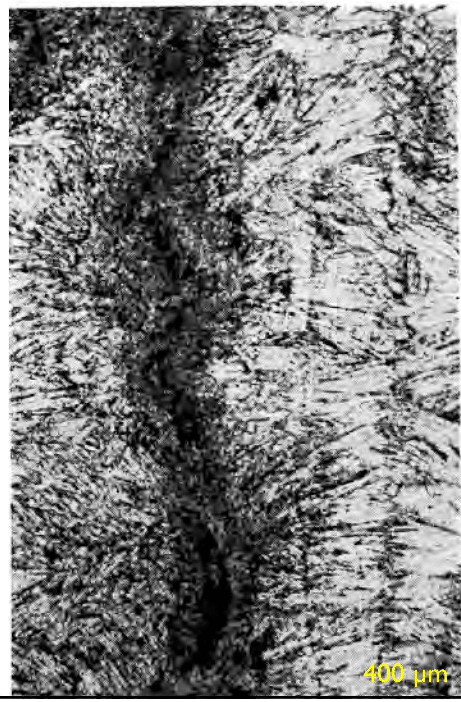


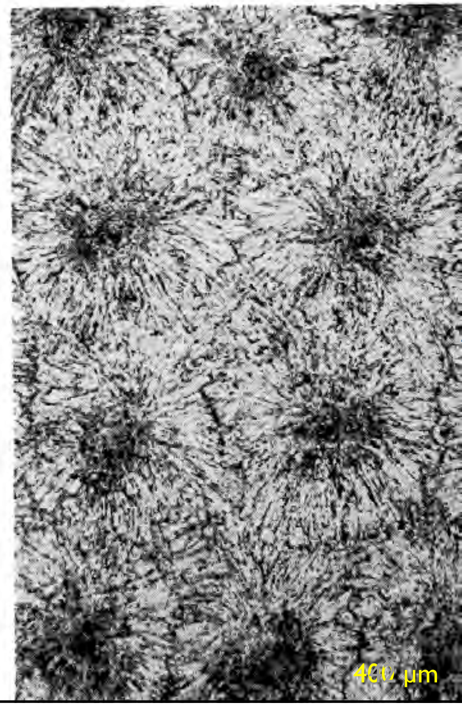
T section of *Favosites* sp., Silurian, Texas

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

Endopachys sp., Tertiary, Louisiana

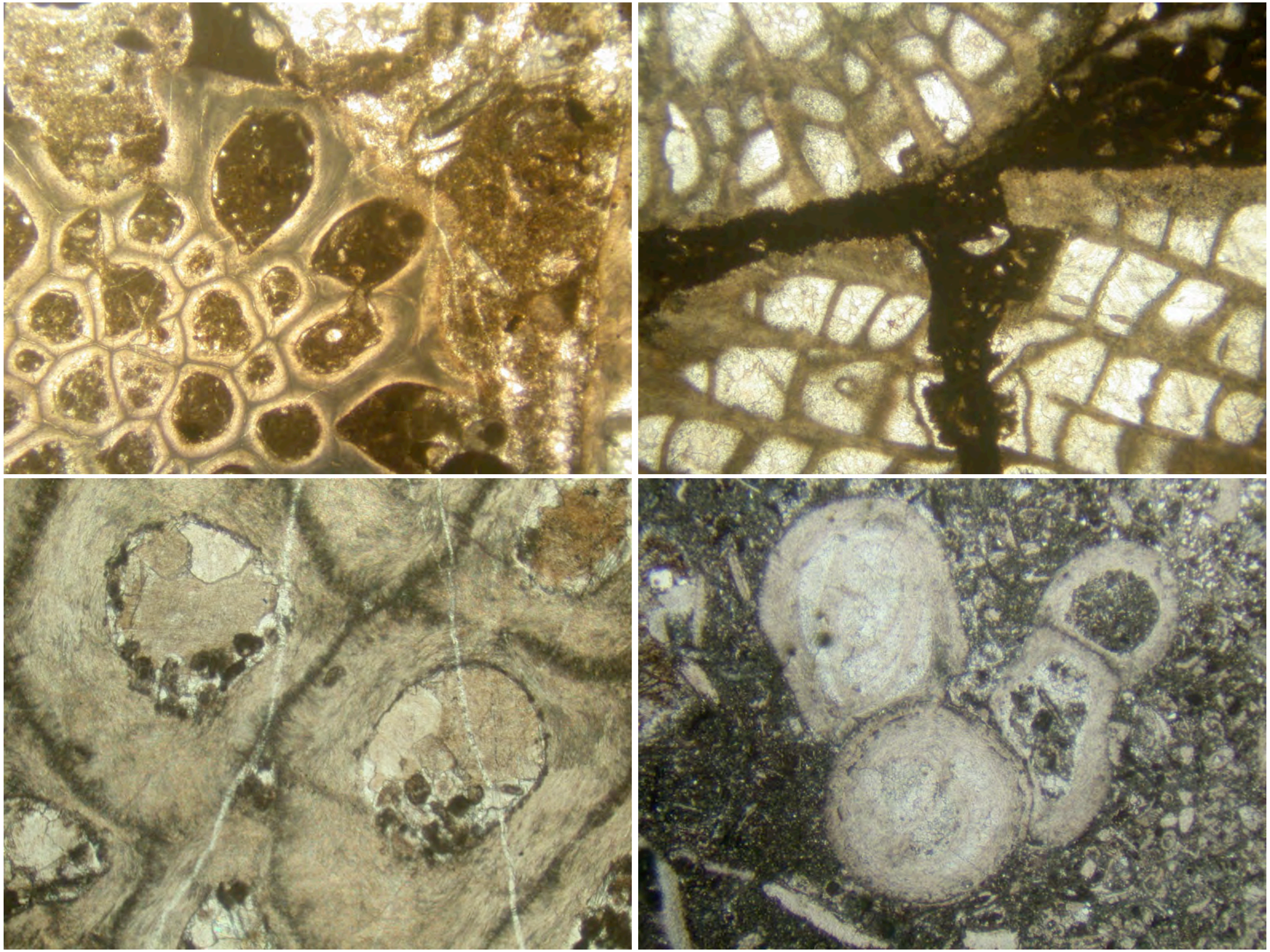






SCLERACTINID CORALS

Givetian Corals (Tabulata), Belgium



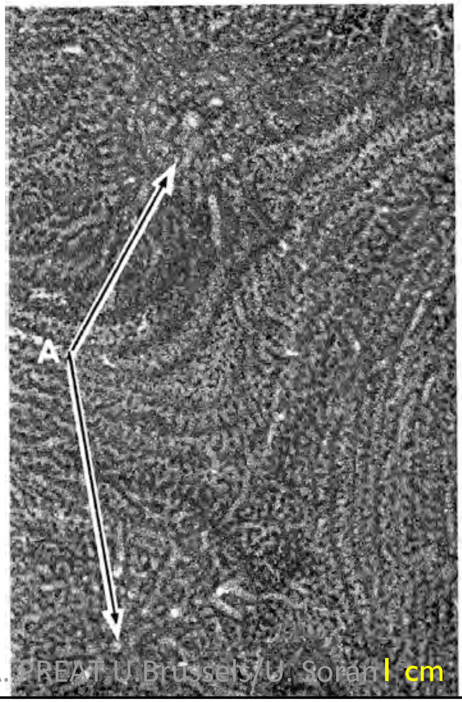
Préat 1999

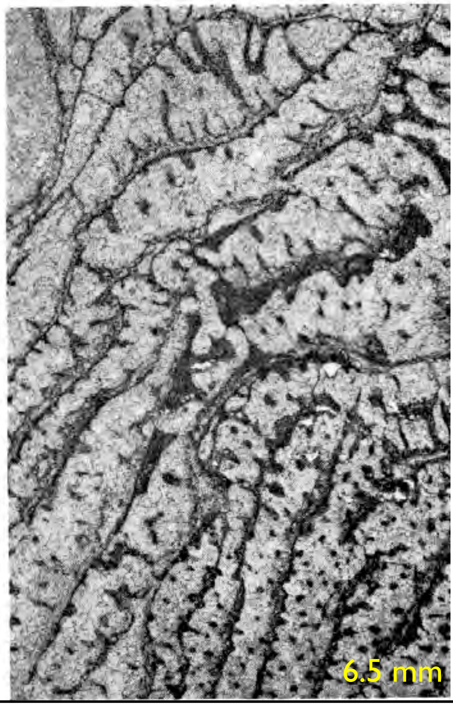
mm-(cm)

STROMATOPOROIDS

Laminae and pillars + astrorhizae (A)

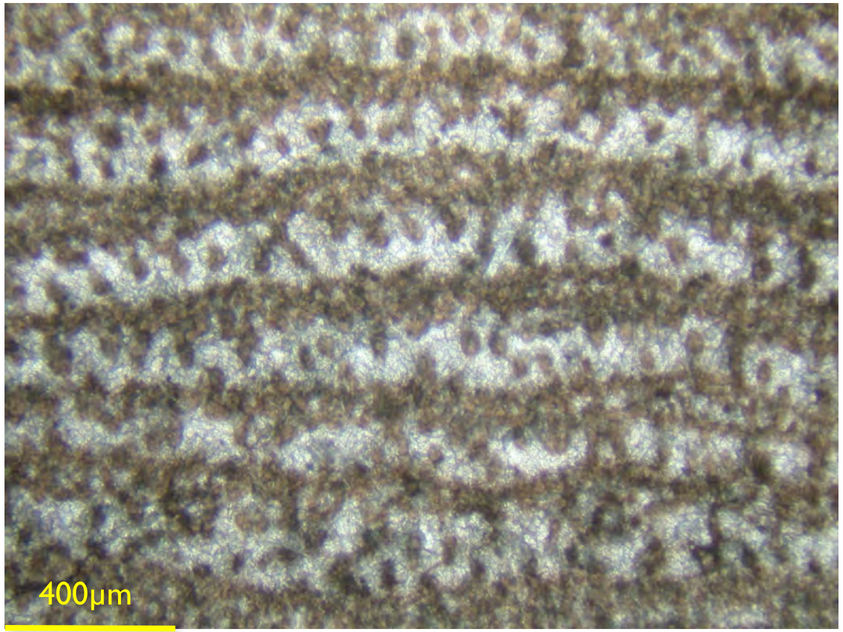
Devonian, N Dakota and Silurian, New Mexico)

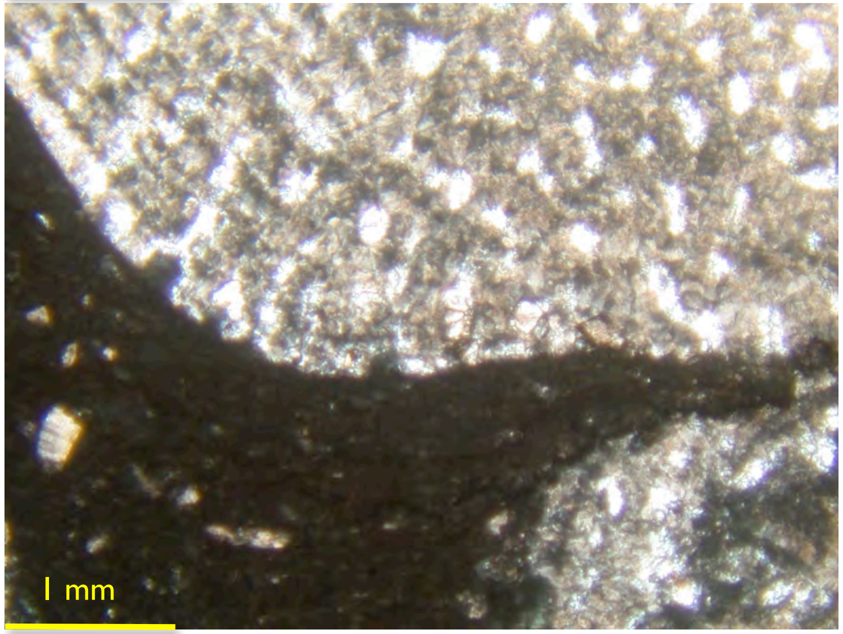




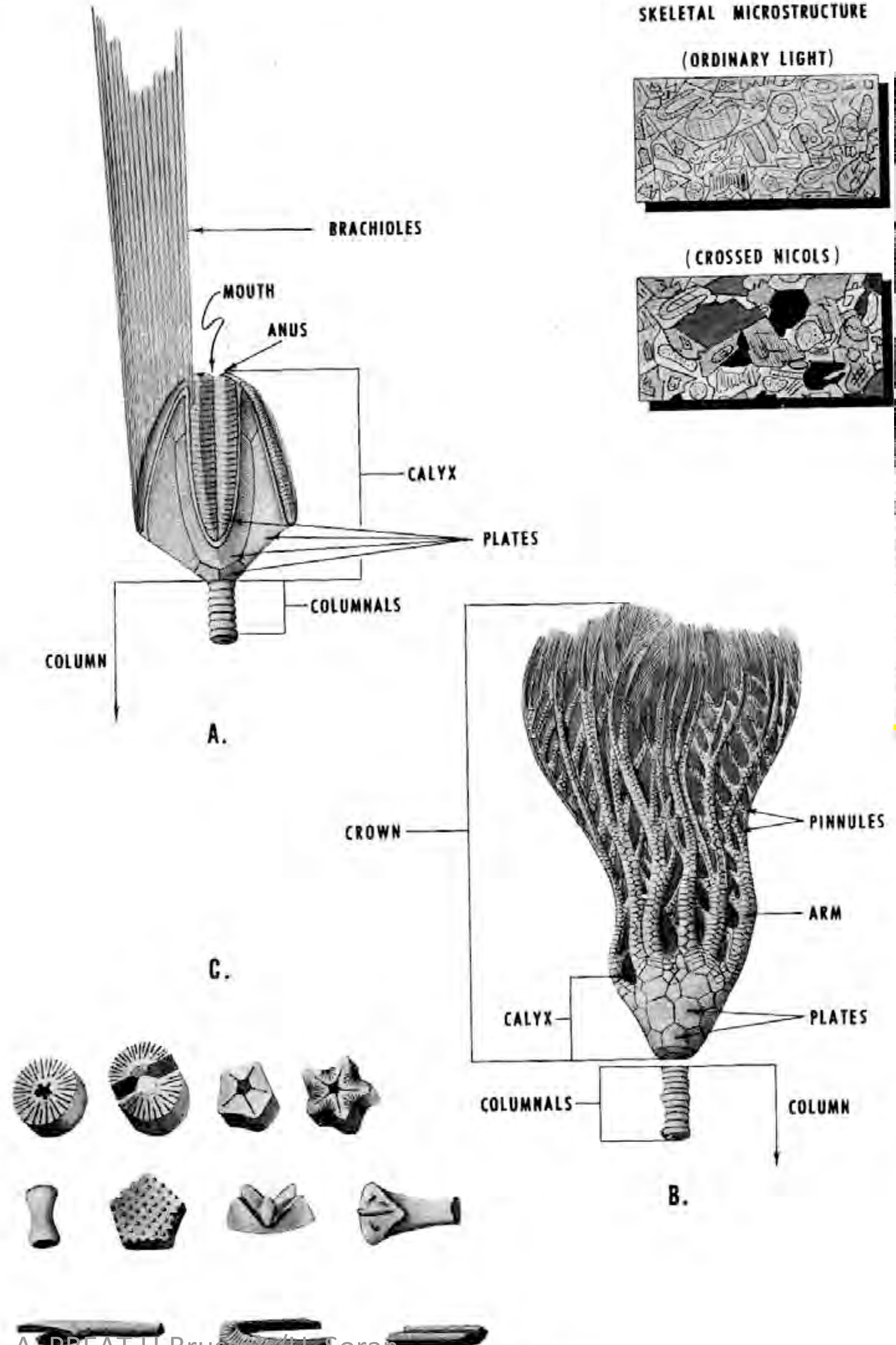

Stromatoporoid Biostrome, Givetian
Meseta-Morocco

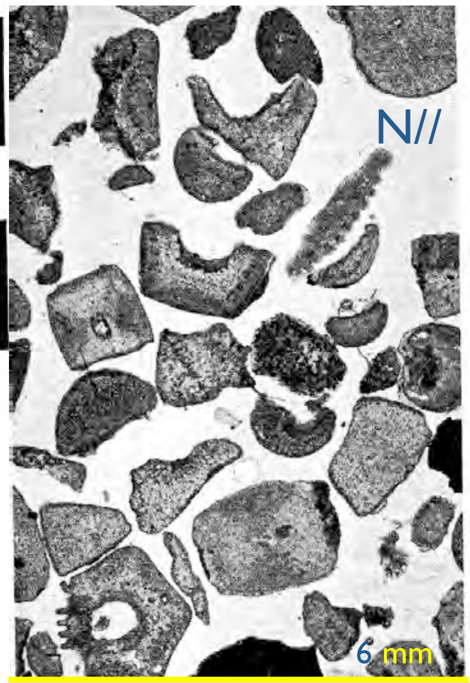
Laminae and pillars
(thin section)
Late Givetian, Belgium,
Préat

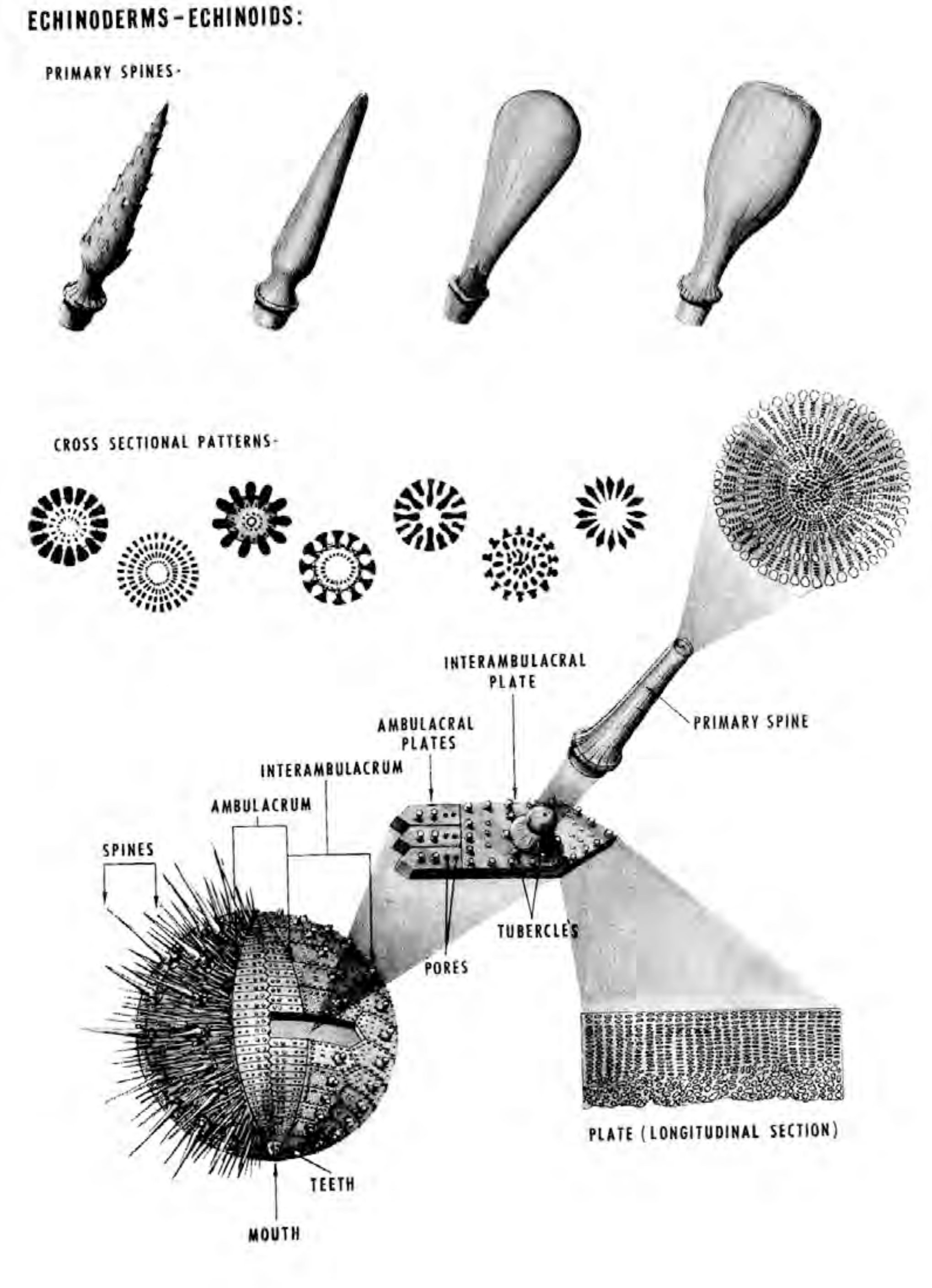




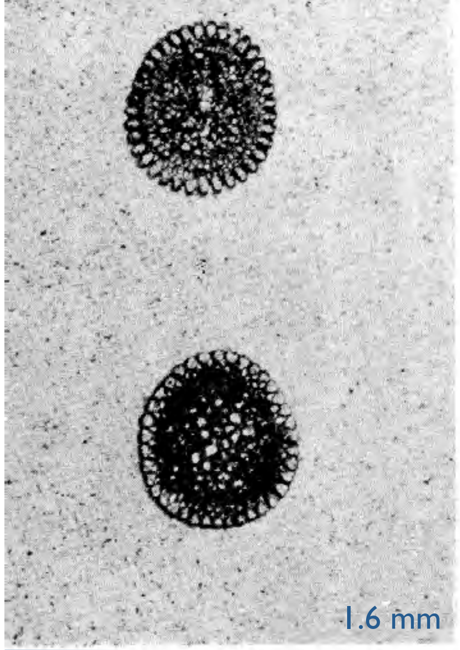
ECHINODERMS - BLASTOIDS & CRINOIDS:



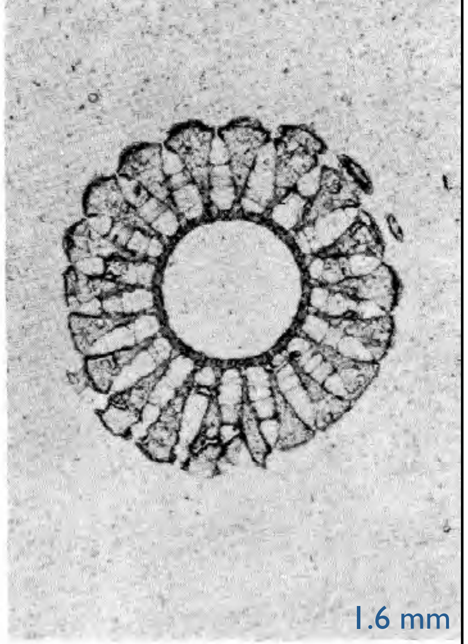




PRIMARY ECHINOID SPINES

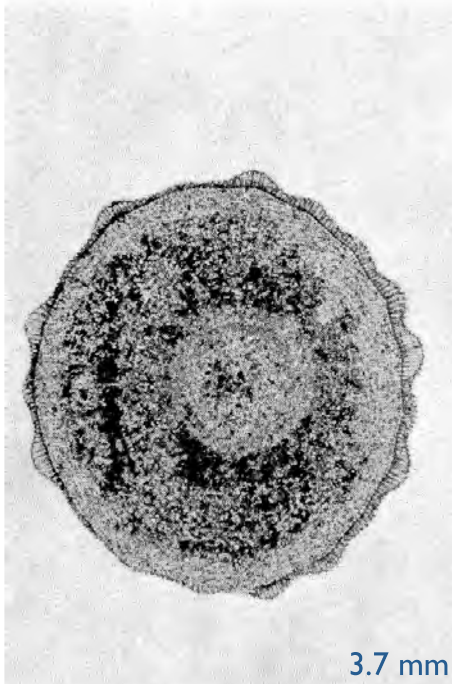


Mellita? sp., Recent, Texas

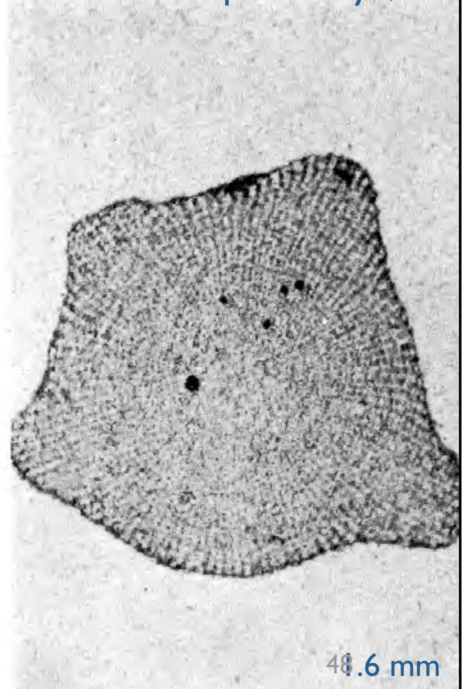


Diadema sp., Recent, Florida

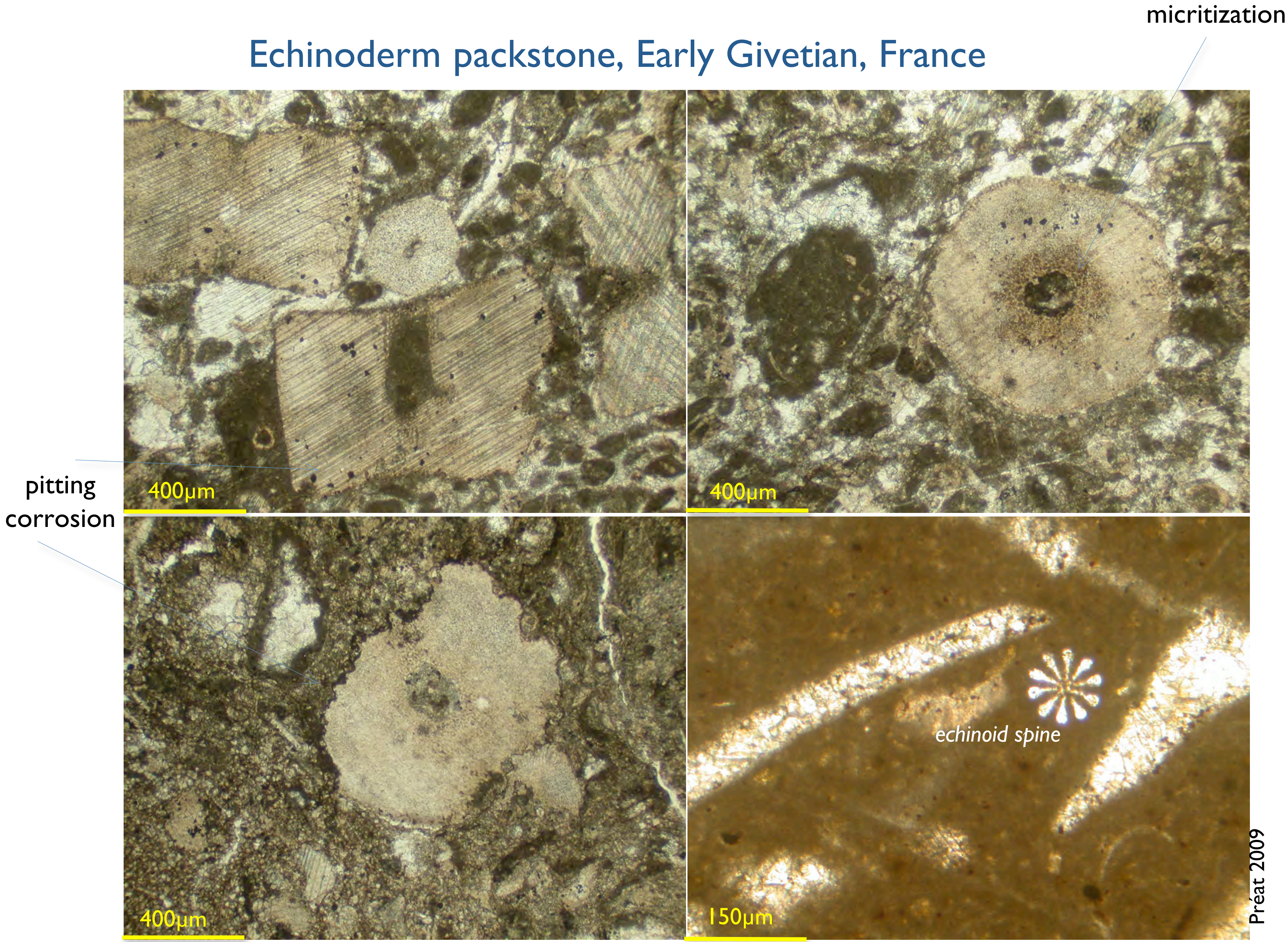
Cidaroid echinoid, Rec, Florida.



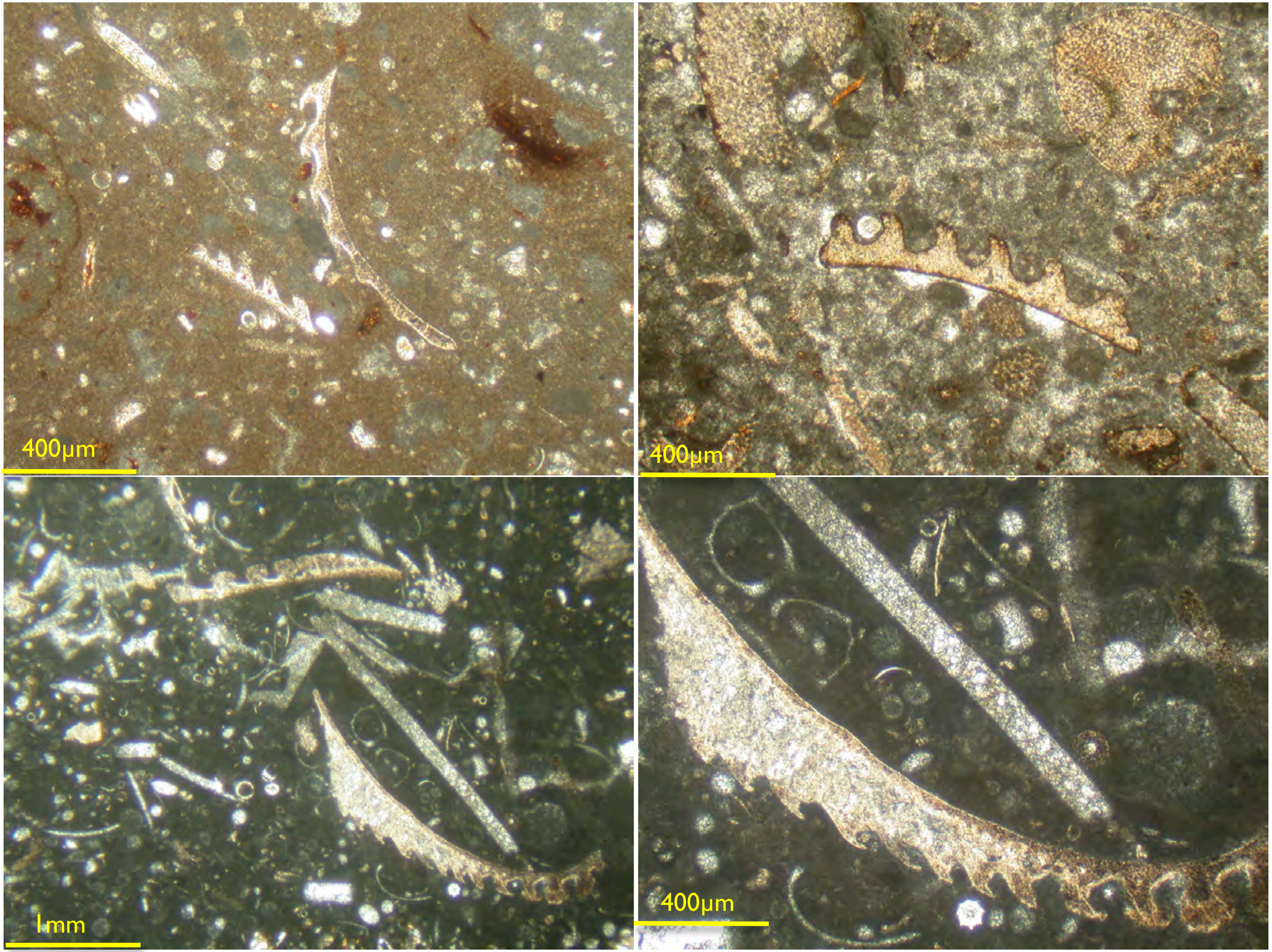
Paleocidaris sp. Pennsyl., Tex



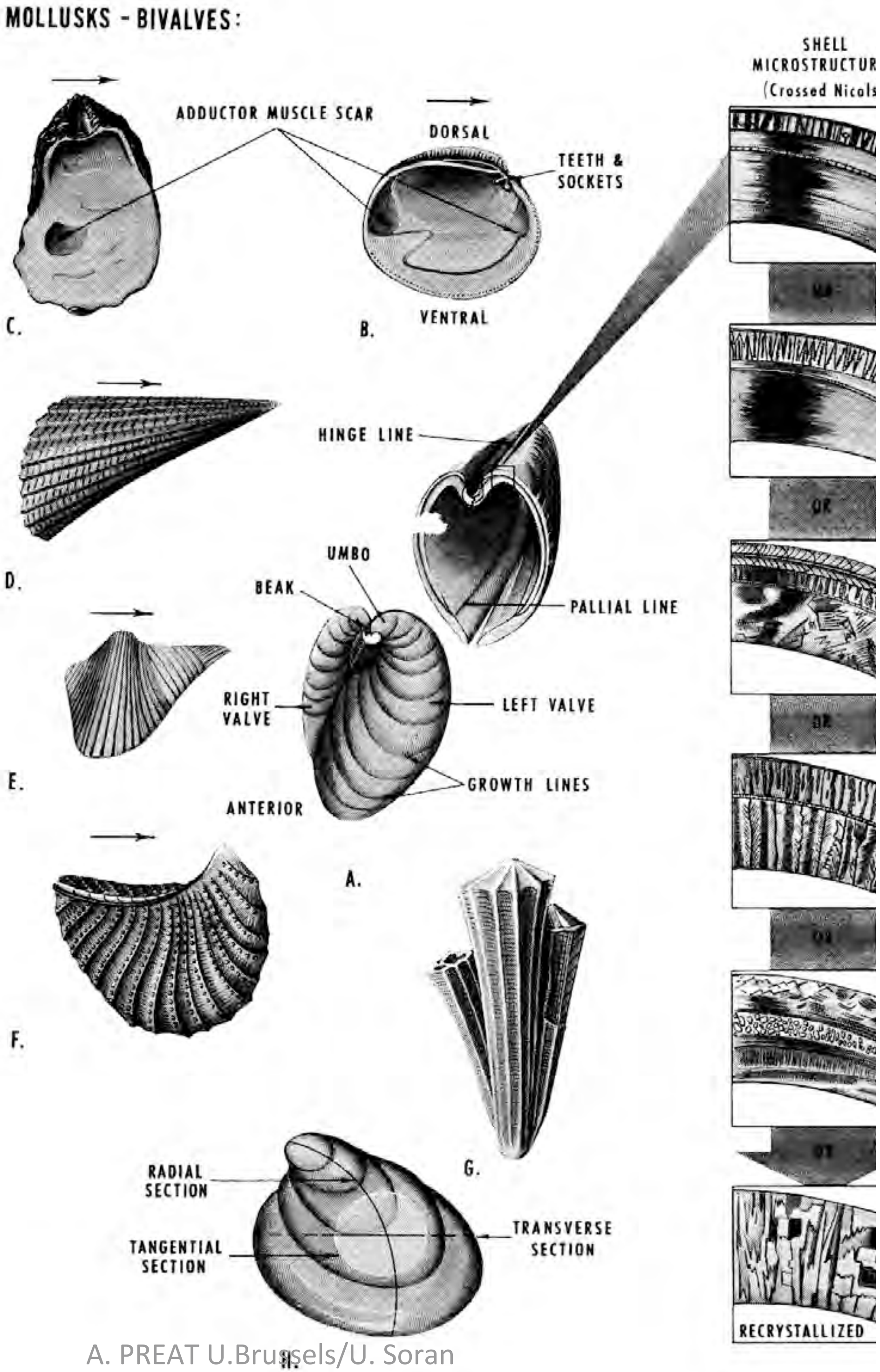
Echinoderm packstone, Early Givetian, France

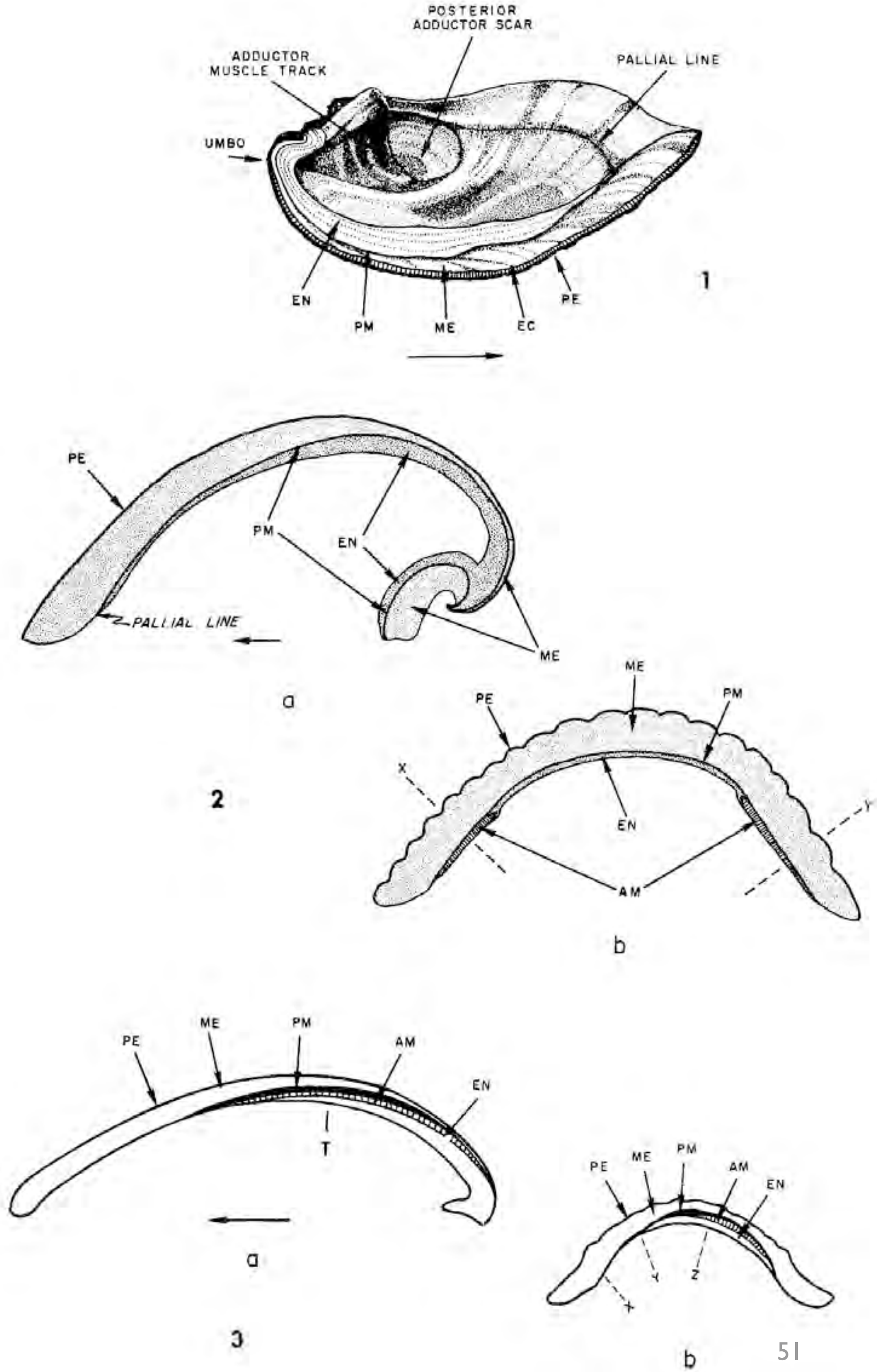


Poorly sorted holothurian sclerite wackestone in a dense micrite.



Rosso Ammonitico Superiore, Kimmeridgian-Tithonian, Sicily, Préat et al. 2011


MOLLUSKS - BIVALVES:
SHELL
MICROSTRUCTUR
(Crossed Nicols
ADDUCTOR MUSCLE SCAR
DORSAL
TEETH & SOCKETS
VENTRAL
C.
B.
D.
HINGE LINE
UMBO
BEAK
PALLIAL LINE
RIGHT VALVE
LEFT VALVE
GROWTH LINES
ANTERIOR
E.
A.
F.
G.
RADIAL SECTION
TANGENTIAL SECTION
TRANSVERSE SECTION
RECRYSTALLIZED


POSTERIOR ADDUCTOR SCAR
ADDUCTOR MUSCLE TRACK
PALLIAL LINE
UMBO
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EN
PALLIAL LINE
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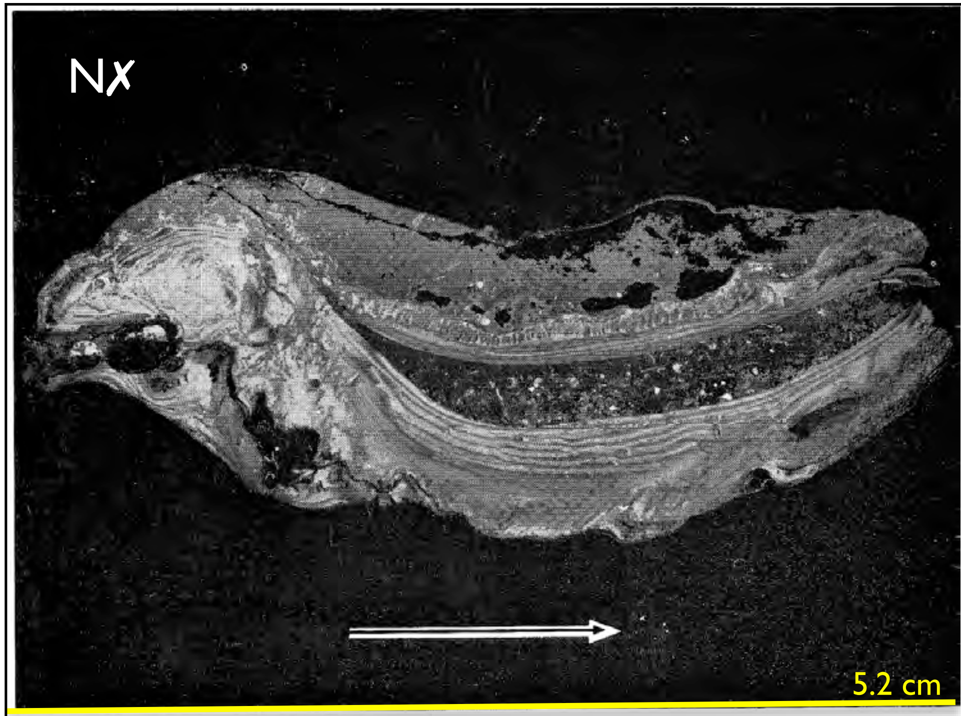
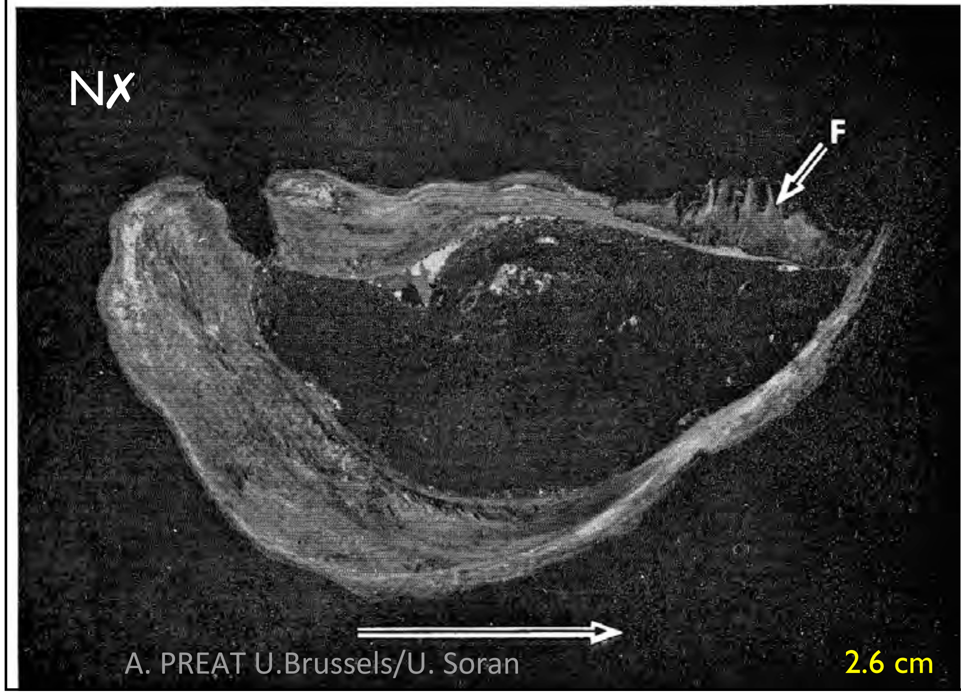


Ceratostreon texanum (Ostreidae), K ,Texas

Texigryphaea sp. (Ostreidae), K, Texas



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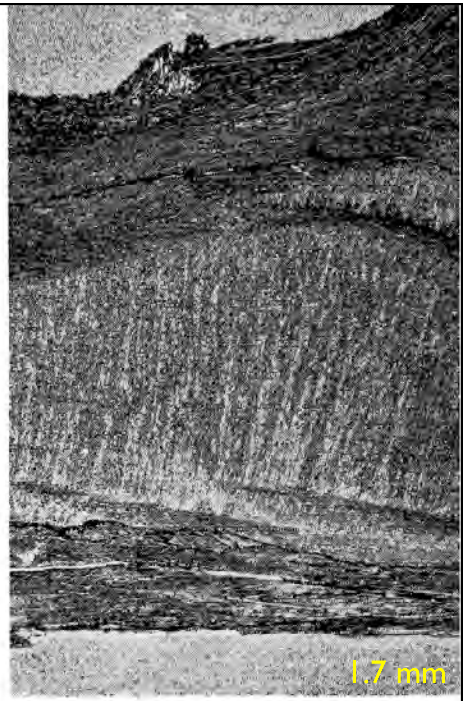
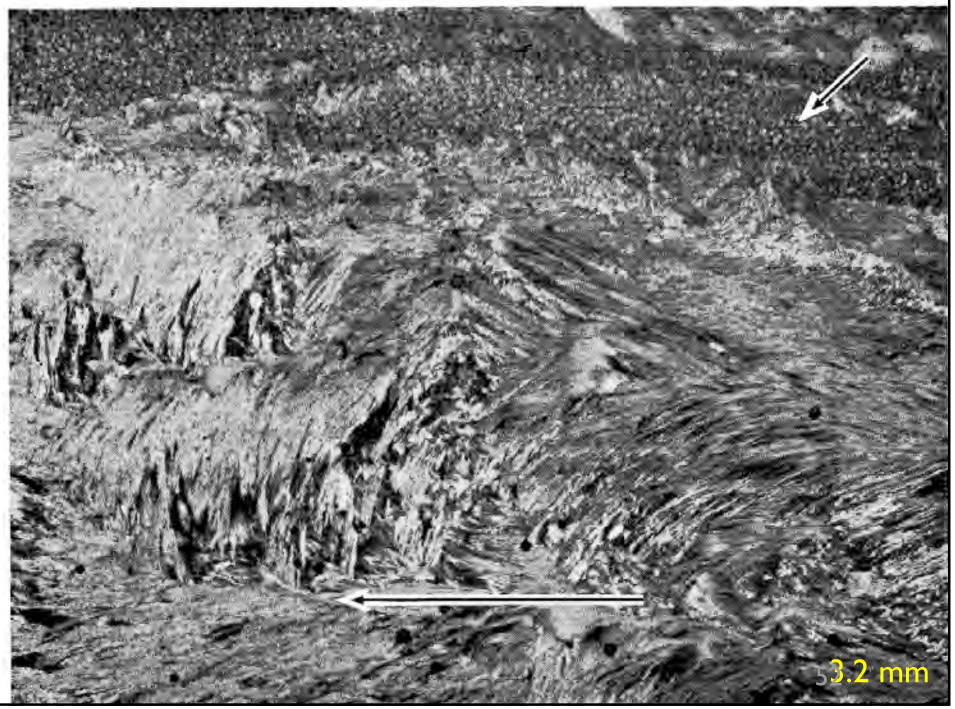
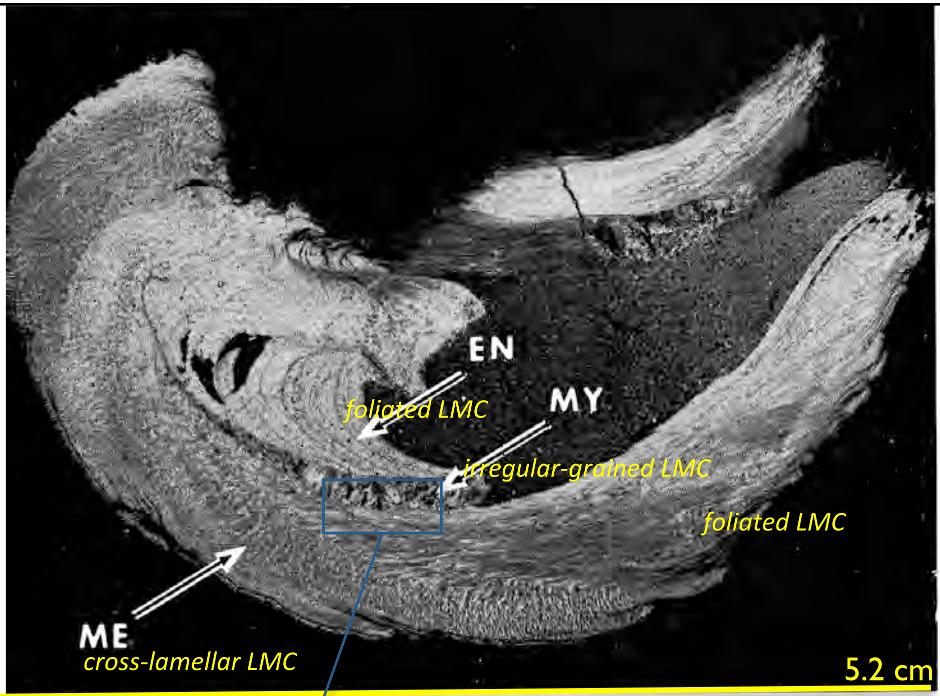


Ceratostreon sp., K *Ostrea plicata* (Ostreidae), Eocene, *U.K.*

Texigryphaea sp., K, Oklahoma



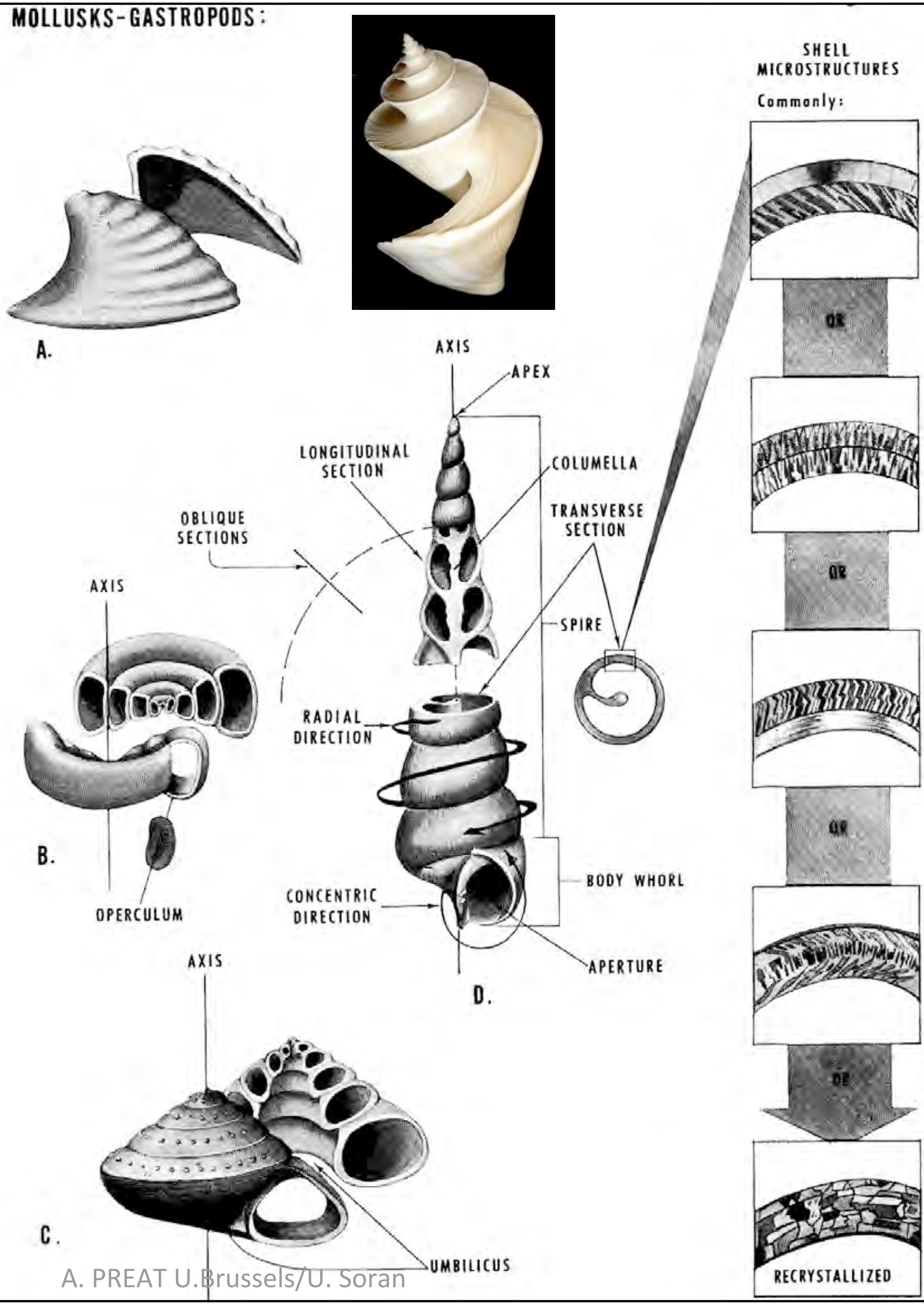


Gryphaea arcuata (Ostreidae), J ,UK

Aucella sp., K, California

Gryphaea sp., J, Normandy, France

Préat, 2009



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 < 1mm

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		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						●	

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 ….

S Y N T H E S I S
'Skeletal Architecture'

THIN SECTIONS
± 30µm thick

Microstructure Common minerals (rare minerals in parenthesis)	Appearance of thin section in ordinary transmitted light	Appearance of thin section under crossed polars	Examples
Homogeneous prismatic Calcite (Aragonite)	No visible structure	Extinction in one direction; optic axes parallel and usually normal to surface of skeleton	Trilobites, ostracods
Granular Calcite Aragonite	Irregular grains (if fine and uniform in size, sometimes referred to as sugary or sucrosic)	Random orientation of optic axes	Foraminifer
Normal prismatic Calcite (Aragonite)	Polygonal prisms normal to outer surface Long / Transverse	Each prism extinguishes as a unit Long / Transverse	Punctate brachiopods *Inoceramus*
Foliated Calcite	Thin parallel leaves of calcite often having a wavy banded appearance	Variable orientation of optic axes of leaves	Bryozoans, pseudopunc brachiopods, worm tubes, oysters
Nacreous Aragonite	Regular thin parallel leaves of aragonite (separated by organic films)	Parallel extinction	Mollusks
Single crystal Calcite	Coarse single calcite grain showing cleavage	Grain extinguishes as a unit	Echinoderms sponge spicu
Crossed lamellar Aragonite (Calcite)	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
Spherulitic fascicle Aragonite (Calcite)	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

BIOCLASTS in THIN SECTION?

i) preservation of organic material
ii) random section : uselul or not i.e. diagnostic or not
iii) sometimes only one diagnosctic 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, spongine = '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

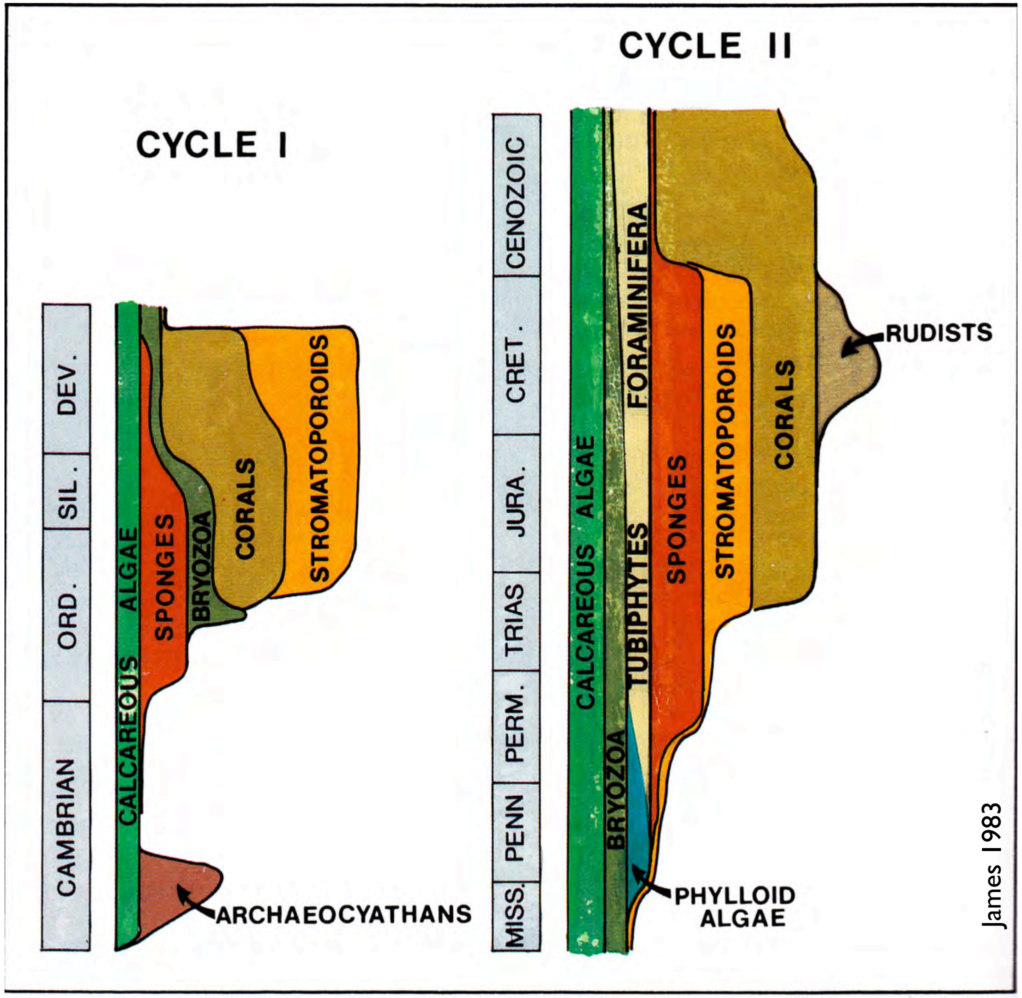
HMC with preservation of the microstructures

RELATED TO DIAGENESIS

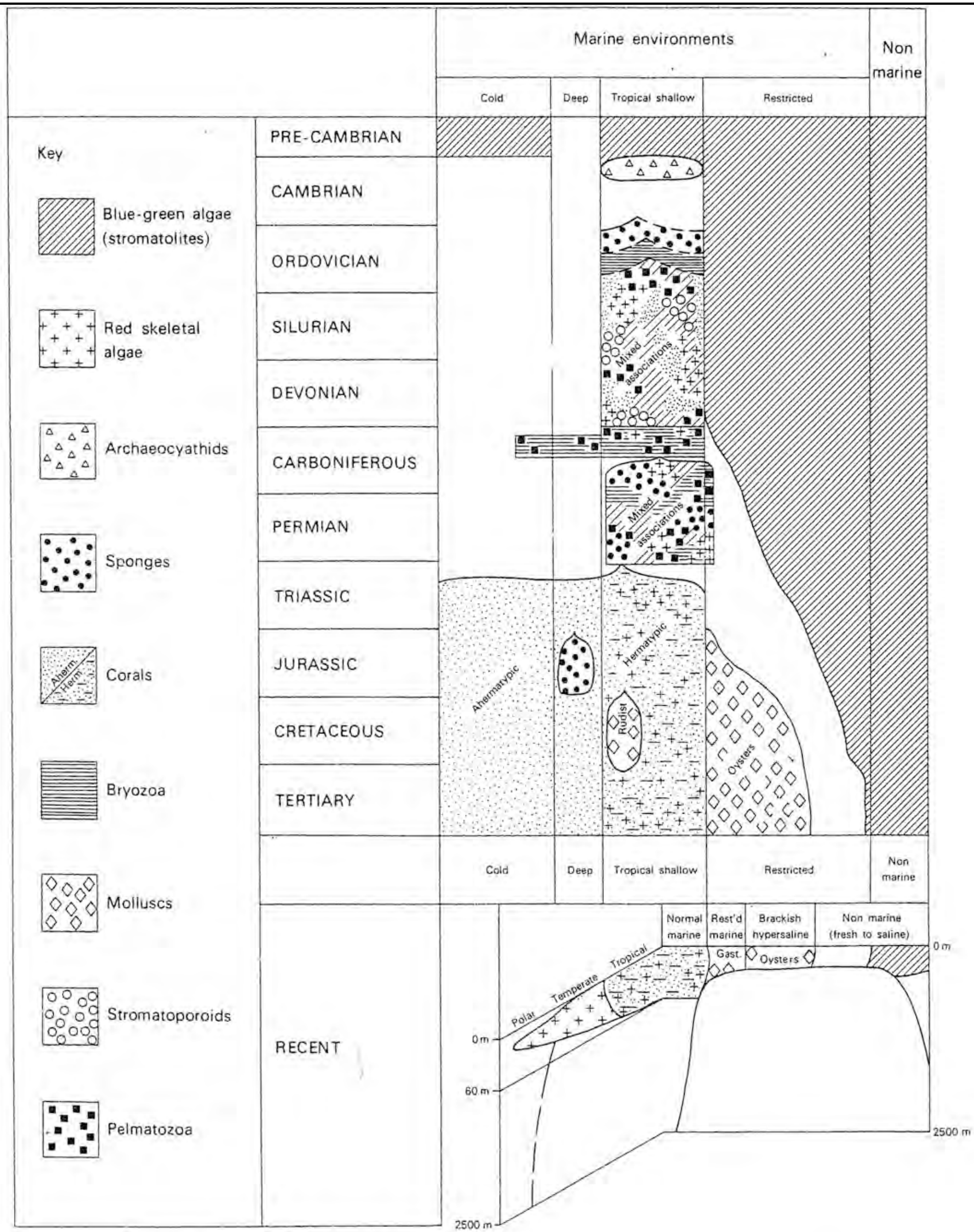
PRESENT DAY RESEARCHES

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

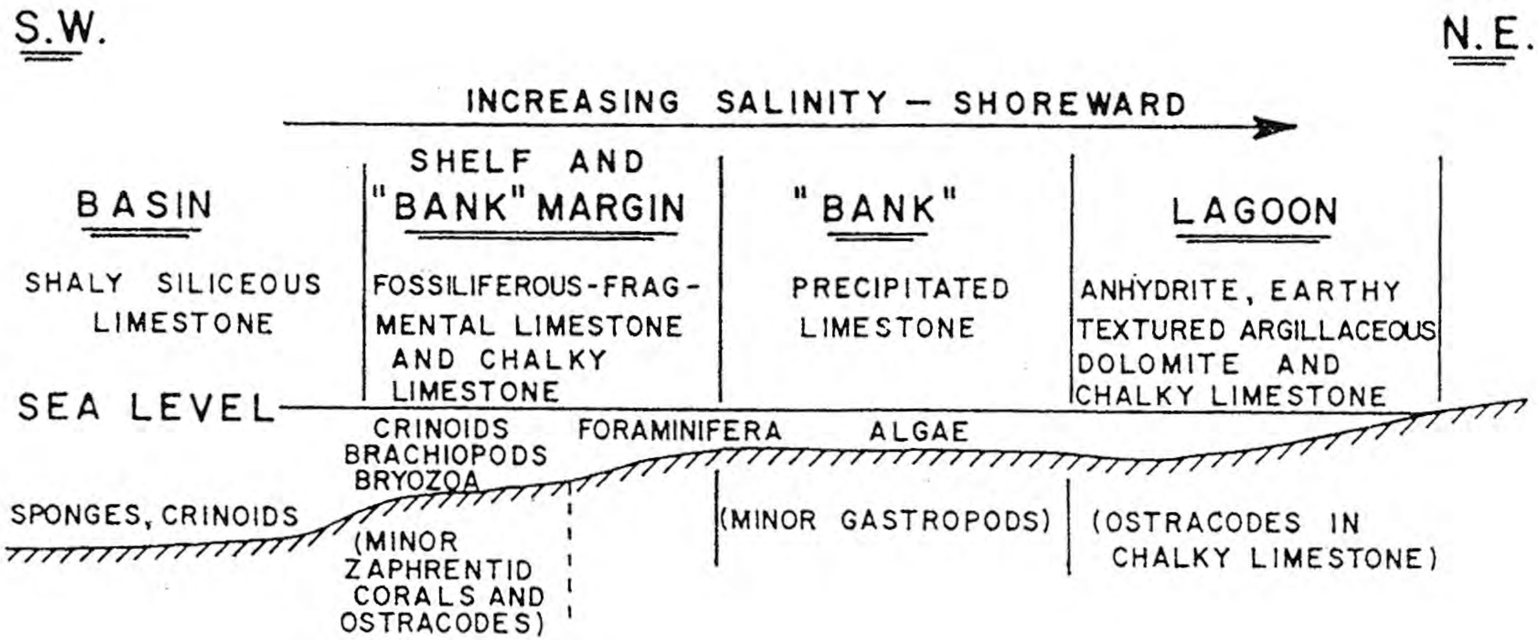


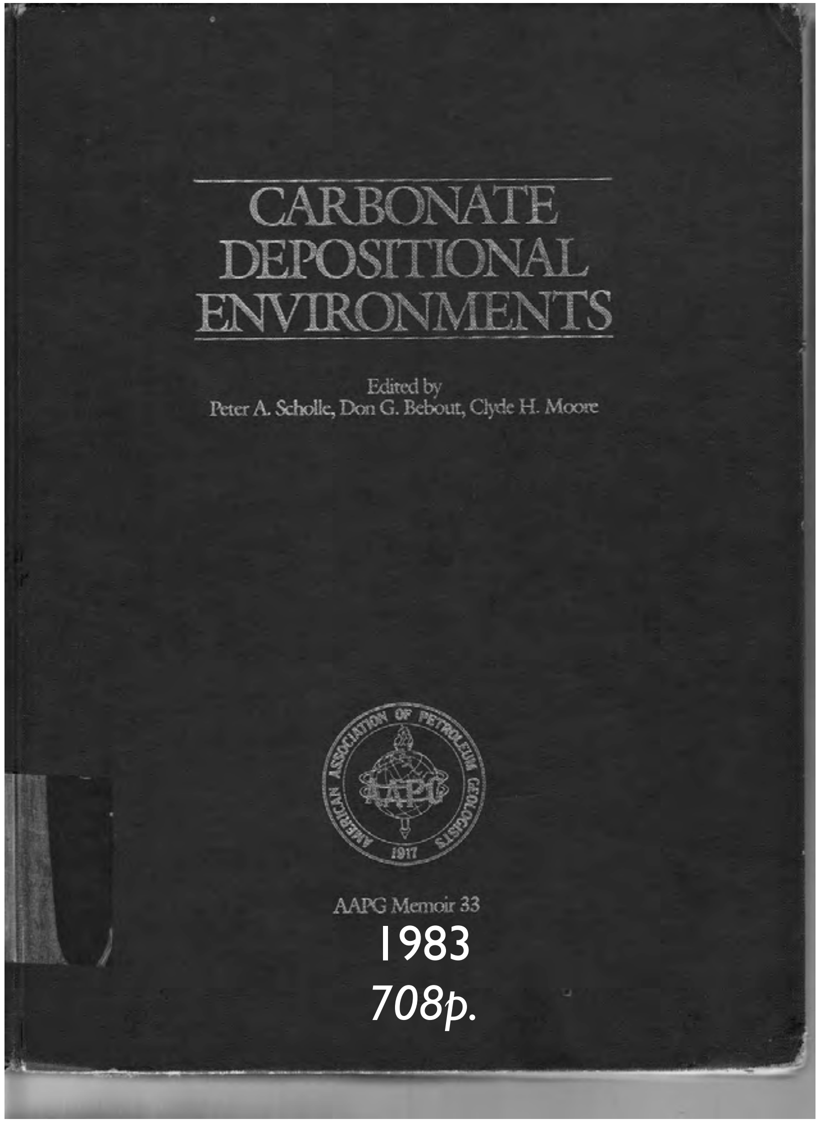
nb *Tubiphytes* microfossil of unknown systematic position = encruster (with algae…)



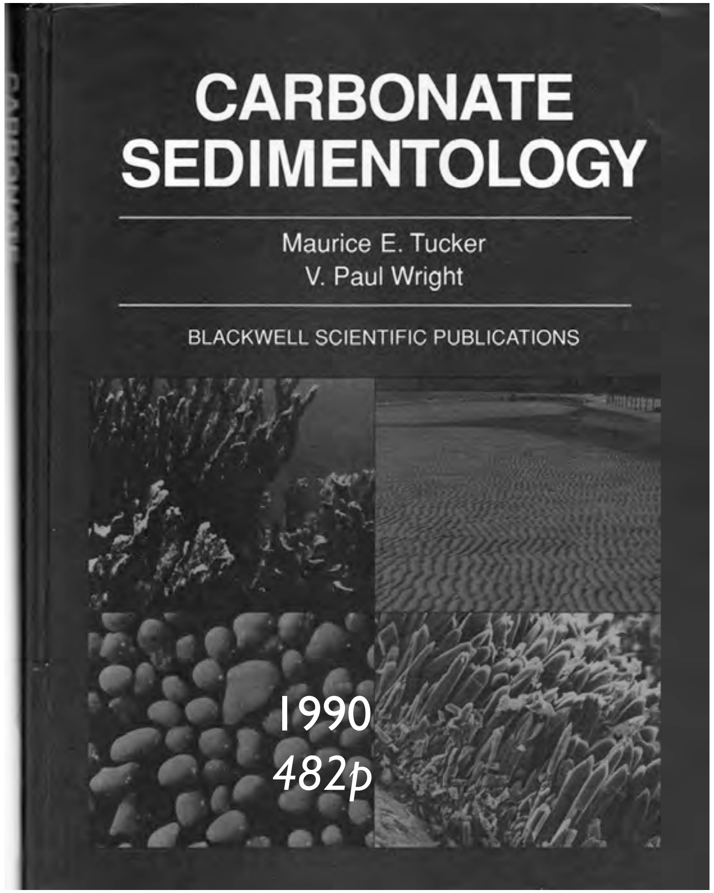
Marine environments
Non marine
Cold
Deep
Tropical shallow
Restricted
Key
Blue-green algae (stromatolites)
Red skeletal algae
Archaeocyathids
Sponges
Corals
Bryozoa
Molluscs
Stromatoporoids
Pelmatozoa
PRE-CAMBRIAN
CAMBRIAN
ORDOVICIAN
SILURIAN
DEVONIAN
CARBONIFEROUS
PERMIAN
TRIASSIC
JURASSIC
CRETACEOUS
TERTIARY
RECENT
Mixed associations
Ahermatypic
Hermatypic
Rudist
Oysters
Normal marine
Rest'd marine
Brackish hypersaline
Non marine (fresh to saline)
Gast.
Polar
Temperate
Tropical
0 m
60 m
2500 m

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





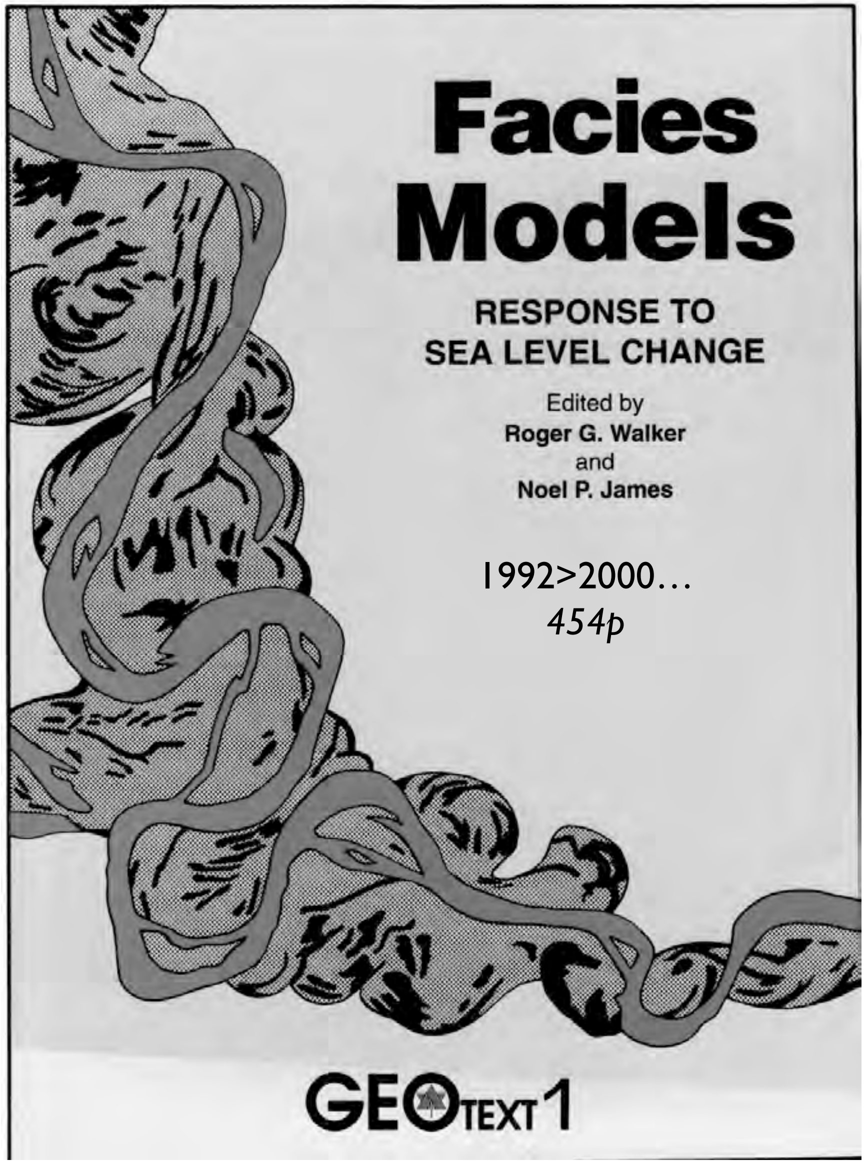
1 Subaerial Exposure
2 Lacustrine
3 Eolian
4 Tidal Flat
5 Beach
6 Shelf
7 Middle Shelf
8 Reef
9 Bank Margin
10 Fore-reef Slope
11 Basin Margin
12 Pelagic



….. introduction….

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

…carbonate geochemistry-mineralogy



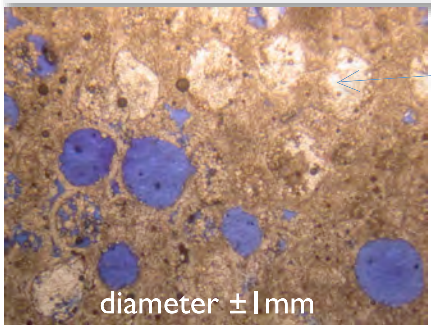
1992>2000…
454p

….. introduction….

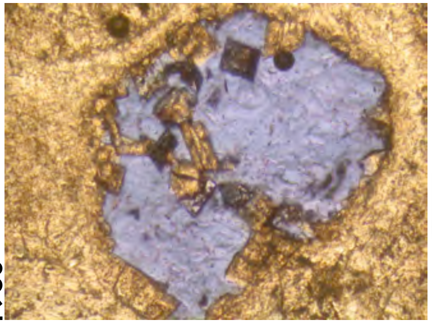
5 Glacial Depositional Systems
6 Volcaniclastics
7 Alluvial Deposits
8 Eolian Systems
9 Deltas
10 Barriers and Estuaries
11 Tidal Systems
12 Wave- an Storm-Dominated Shallow Marine Systems
13 Turbidites and Submarine Fans
14 Carbonate and Evaporite Models
15 Platform Systems
16 Peritidal Carbonates
17 Reefs and Mounds
18 Carbonate Slopes
19 Evaporites

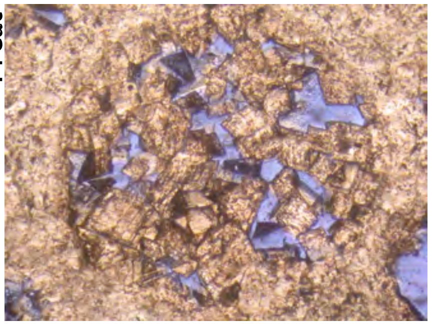
BIOCLASTS or GRAINS

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





Préat 1986