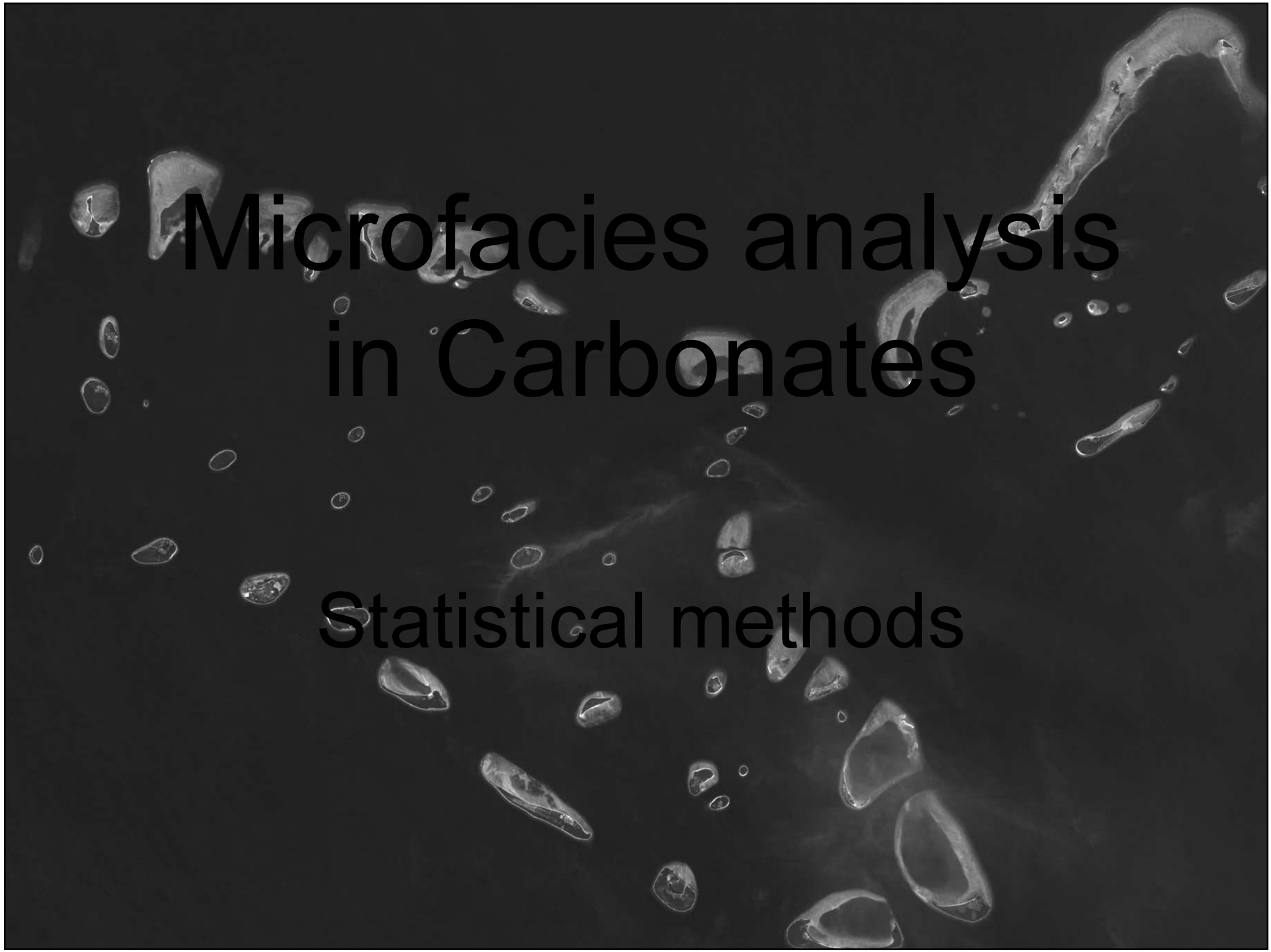
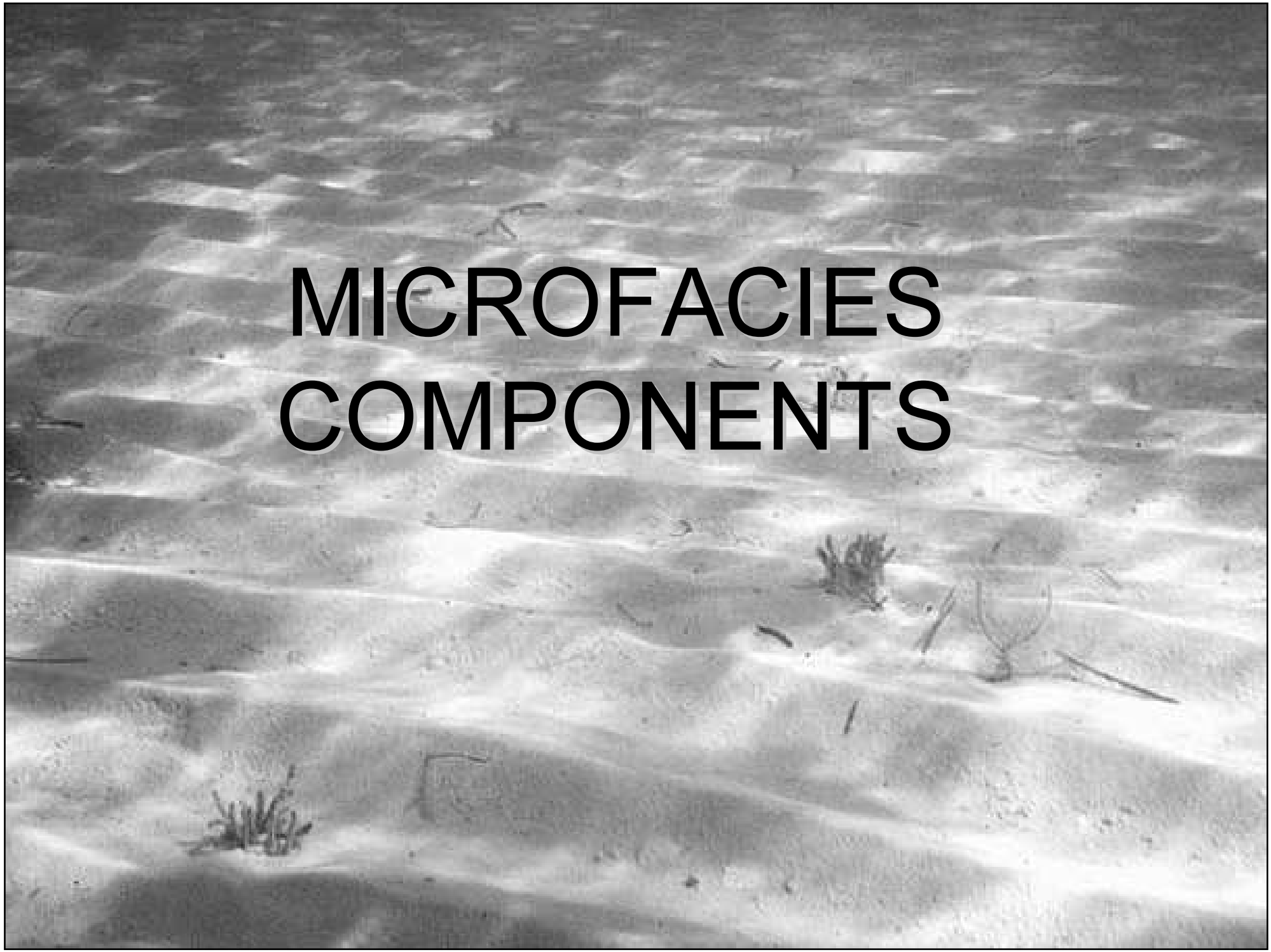

Microfacies analysis
in Carbonates
Statistical methods

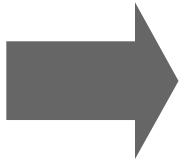
TOPICS

- Basics and components
- Clustering
- Principal component analysis (PCA)
- Correspondence Analysis (CA)
- Markov Chains
- Your data


MICROFACIES
COMPONENTS

In the field a limestone is characterized by:

- Colour = pale grey, reddish, dark..
- Bedding type = thick bedded, thin bedded, massive, wavy, nodular..
- Sedimentary structures = cross bedded, laminated, bioturbated, burrowed, mottled..
- Macro- to micro-components visible with a hand-lens = clasts, macro-fossils, clastic grains, ooids..



MACROFACIES

Mokra Quarry, Czech Republic, Late Tournaisian, basinal to lower slope deposit

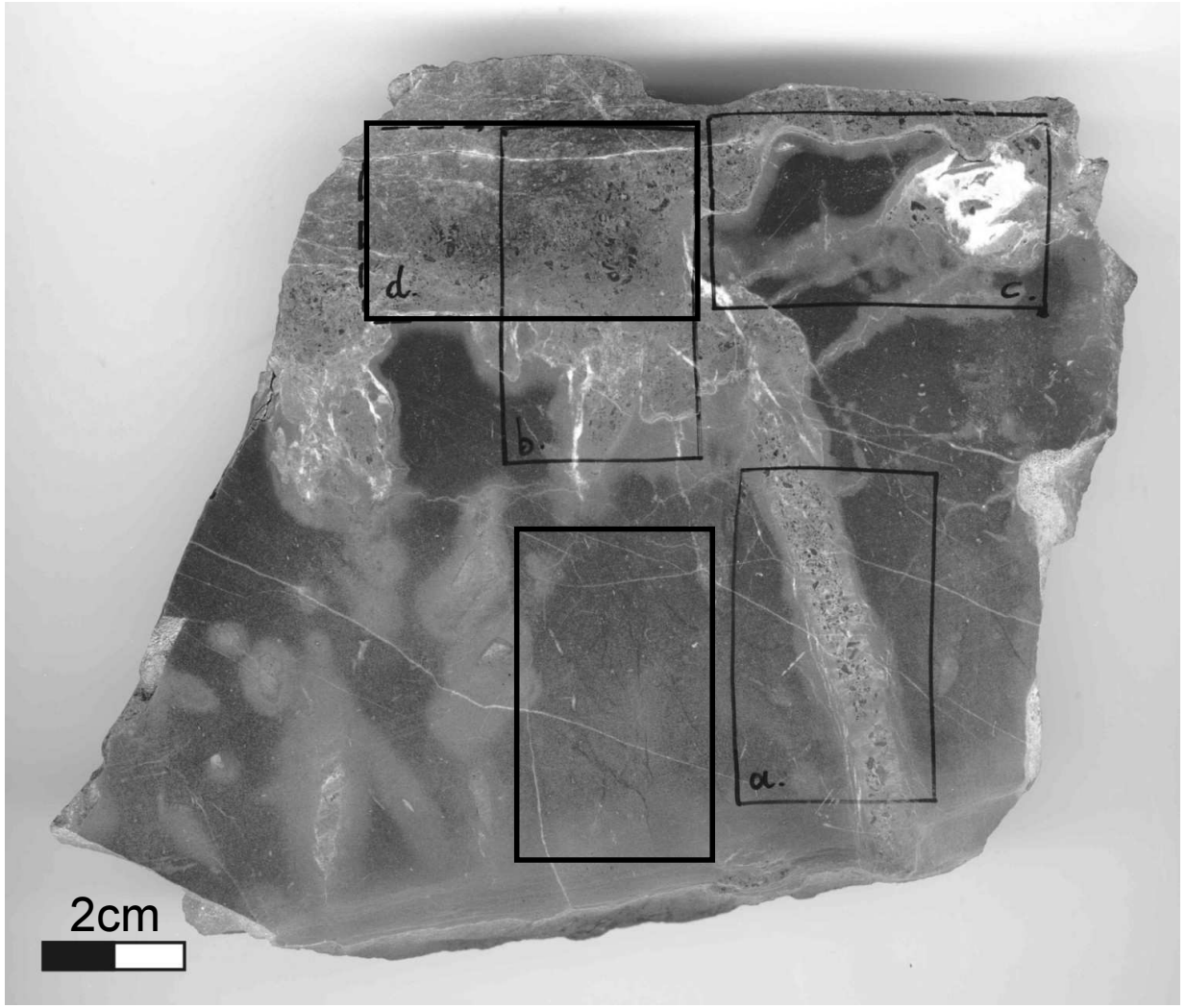

Nikon

Microfacies

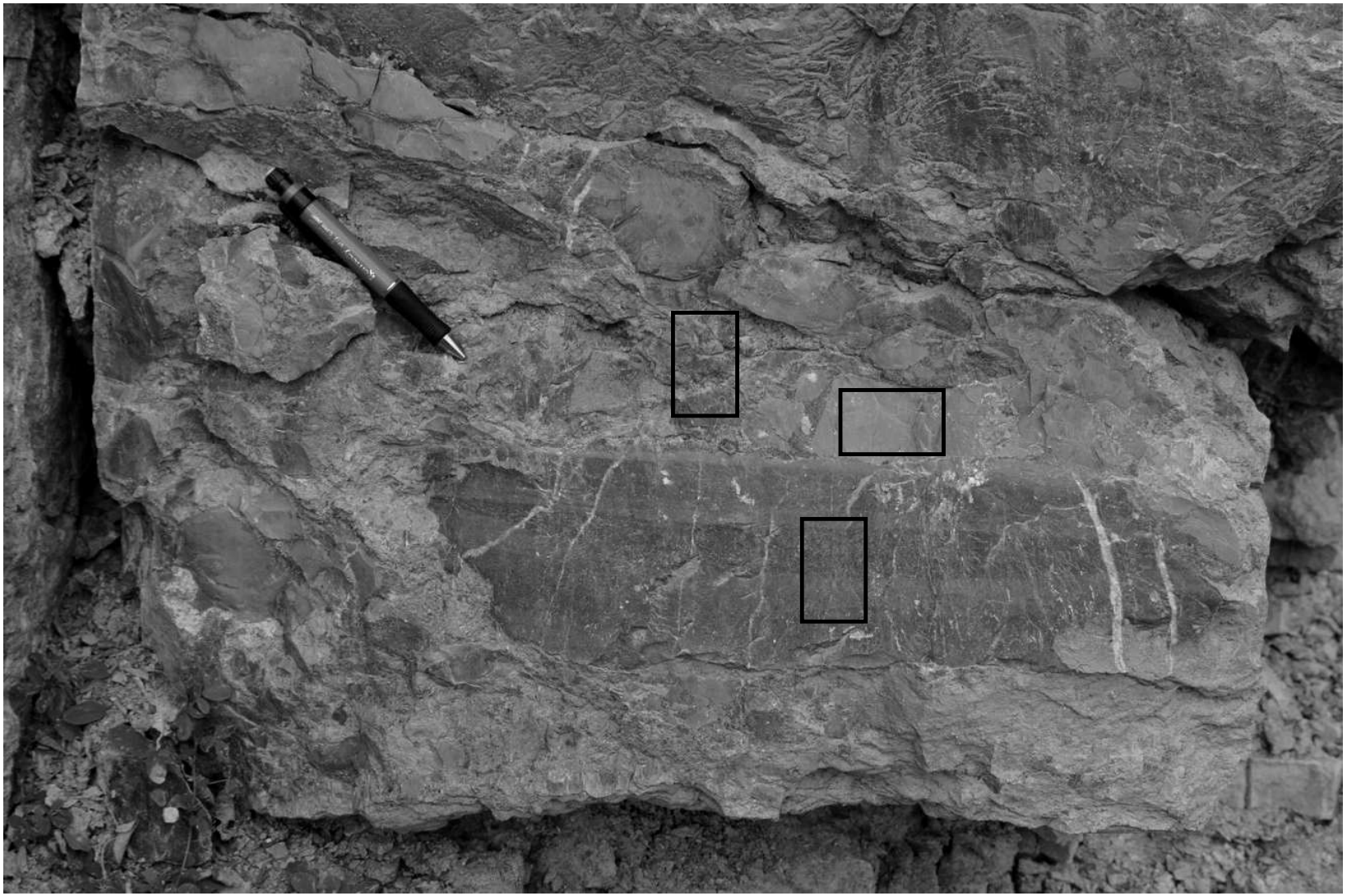
- In carbonates the macrofacies is generally not enough to understand the sedimentary environement and a petrographic study is necessary.

- The microfacies is the equivalent of the macrofacies but in thin-sections. It is fundamental to keep in mind the scale of the observations!

Namur-Dinant Basin, Belgium, Late Tournaisian, outer-slope deposit



Mokra Quarry, Czech Republic, Late Tournaisian, basinal to lower slope deposit



Microfacies components

- Texture: Dunham or Folk
- ‘grains’ = allochems (allochemical grains), bioclastic or non-bioclastic
- micro-sedimentary or biogenic structures (partly in texture)
- Special diagenetic features (partly in text.)
- Non carbonate grains

Texture: Dunham classification

<table>
<tr><td colspan="6">Allochthonous limestone
original components not organically
bound during deposition</td><td colspan="3">Autochthonous limestone
original components organically
bound during deposition</td></tr>
<tr><td colspan="4">Less than 10% >2 mm components</td><td colspan="2">Greater than
10% >2 mm
components</td><td colspan="3">Boundstone</td></tr>
<tr><td colspan="3">Contains lime mud (<0.02 mm)</td><td>No
lime
mud</td><td rowspan="3">Matrix
supported</td><td rowspan="3">>2 mm
component
supported</td><td rowspan="4">By
organisms
which
act as
barriers</td><td rowspan="4">By
organisms
which
encrust
and
bind</td><td rowspan="4">By
organisms
which
build
a rigid
framework</td></tr>
<tr><td colspan="2">Mud supported</td><td colspan="2" rowspan="2">Grain
supported</td></tr>
<tr><td>Less than
10% grains
(>0.02 mm
to <2 mm)</td><td>Greater
than
10%
grains</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Floatstone</td><td>Rudstone</td><td>Bafflestone</td><td>Bindstone</td><td>Framestone</td></tr>
</table>

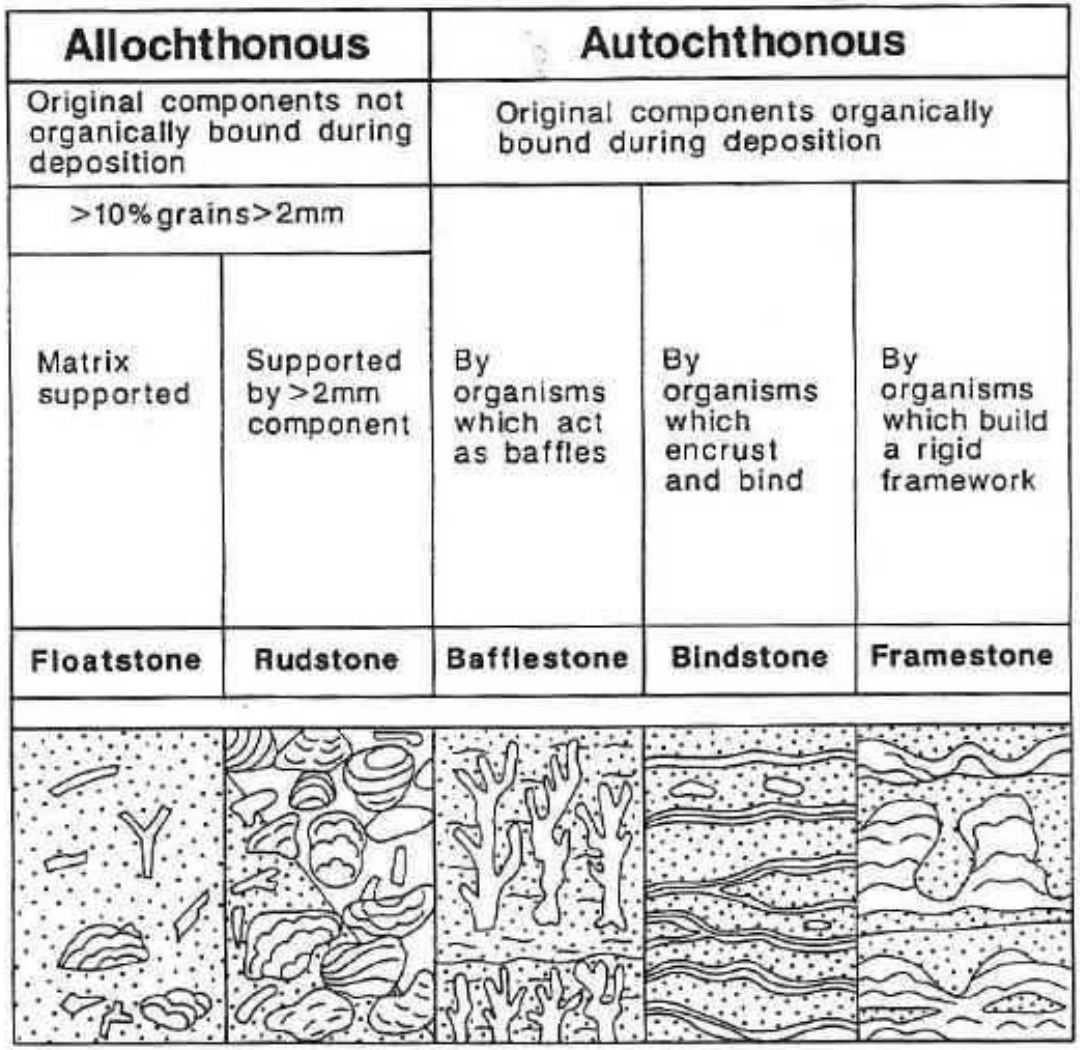
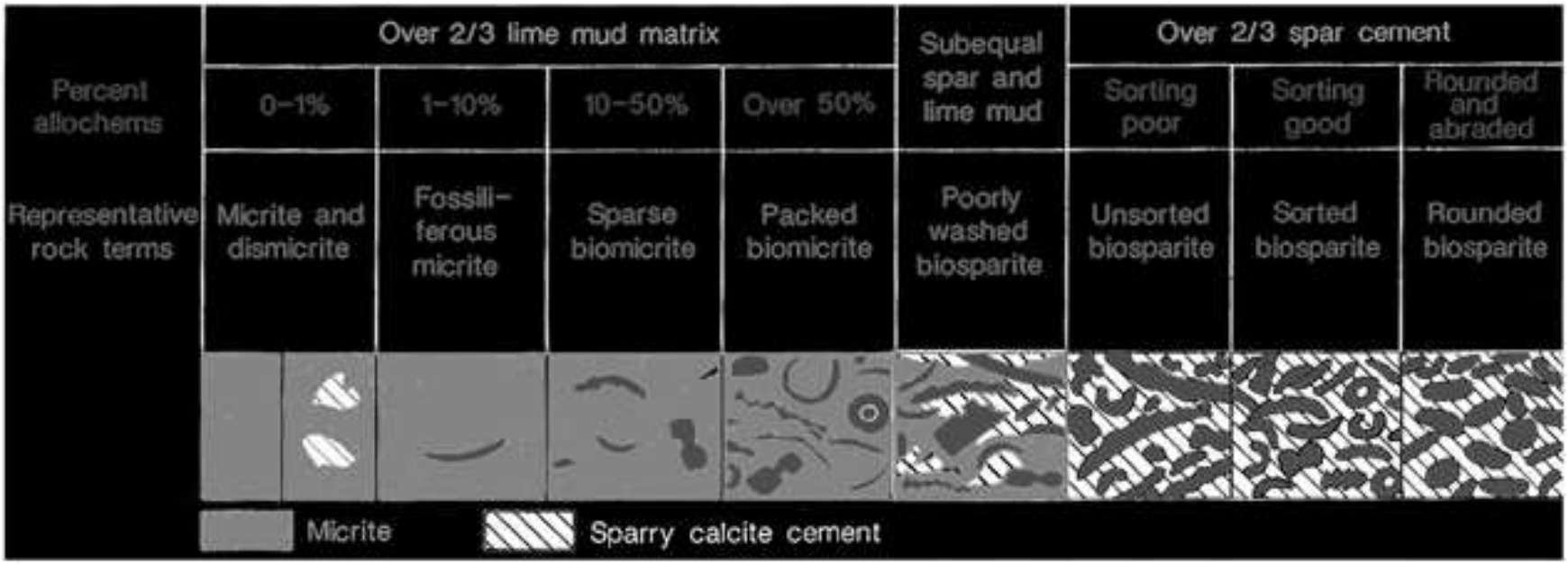
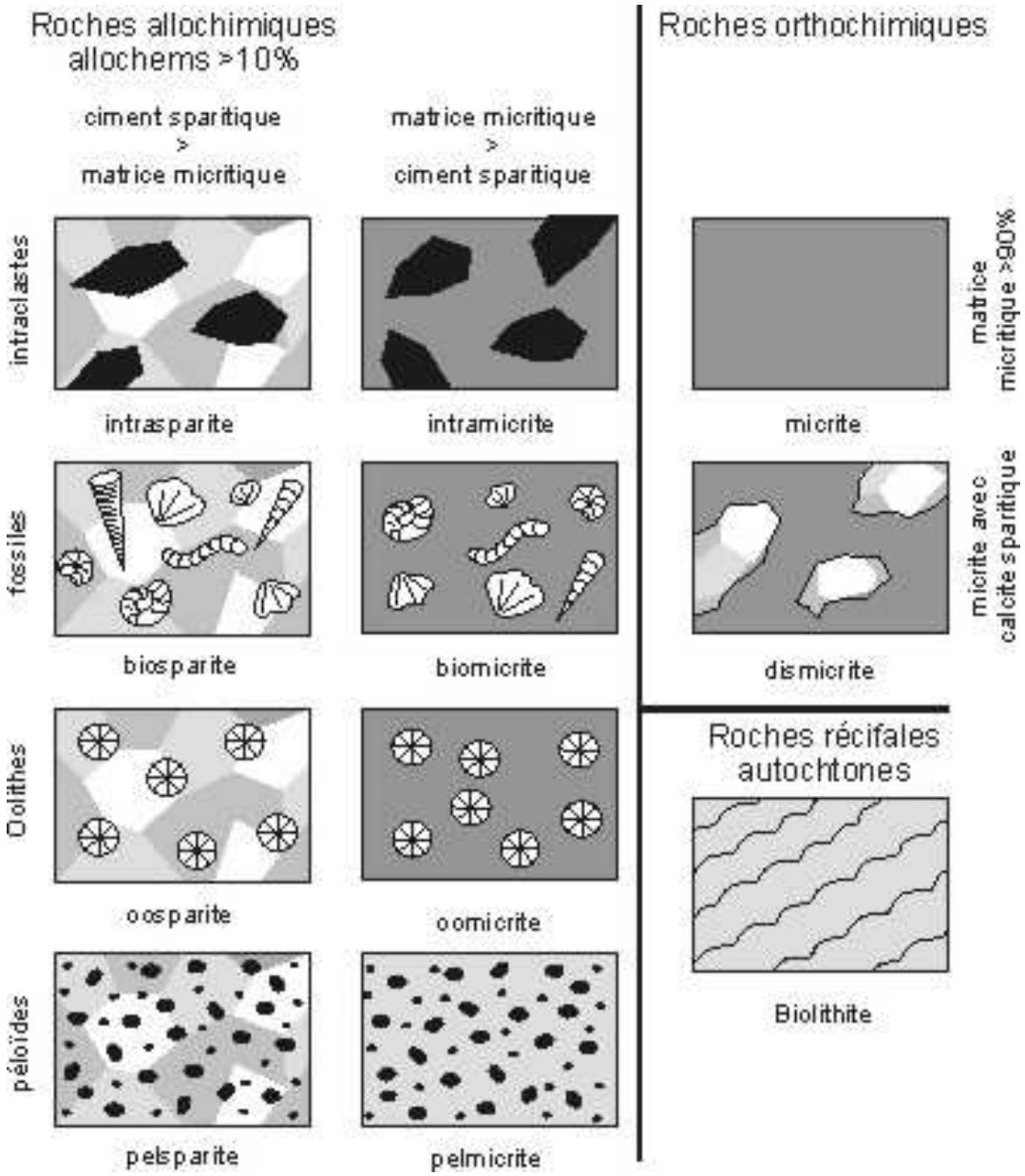


Fig. 4.94 *Textural classification of reef limestones. Based on Embry & Klovan (1971) and James (1984b).*

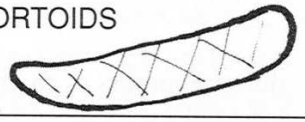
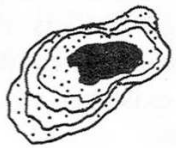
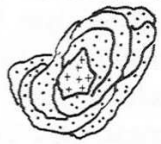
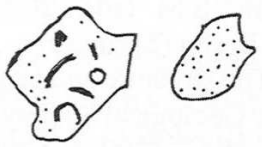
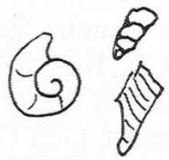
Texture: Folk classification



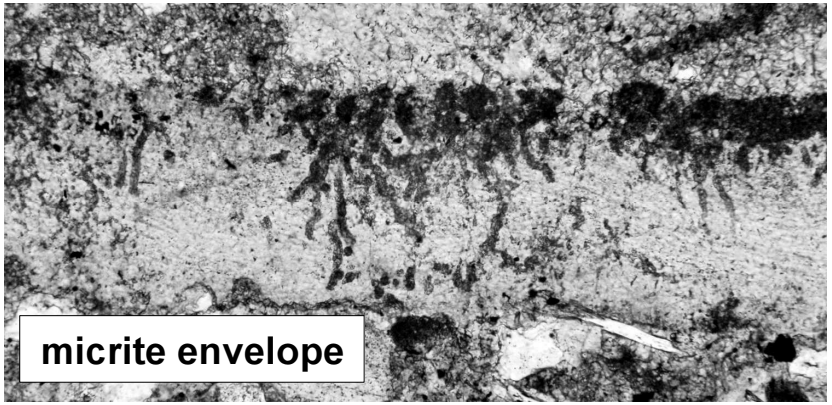

Roches allochimiques
allochems >10%
ciment sparitique
>
matrice micritique
matrice micritique
>
ciment sparitique
Roches orthochimiques
intraclastes
intrasparite
intramicrite
micrite
matrice micritique >90%
fossiles
biosparite
biomicrite
dismicrite
micrite avec calcite sparitique
Oolithes
oosparite
oomicrite
Roches récifales autochtones
péloïdes
pelsparite
pelmicrite
Biolithite

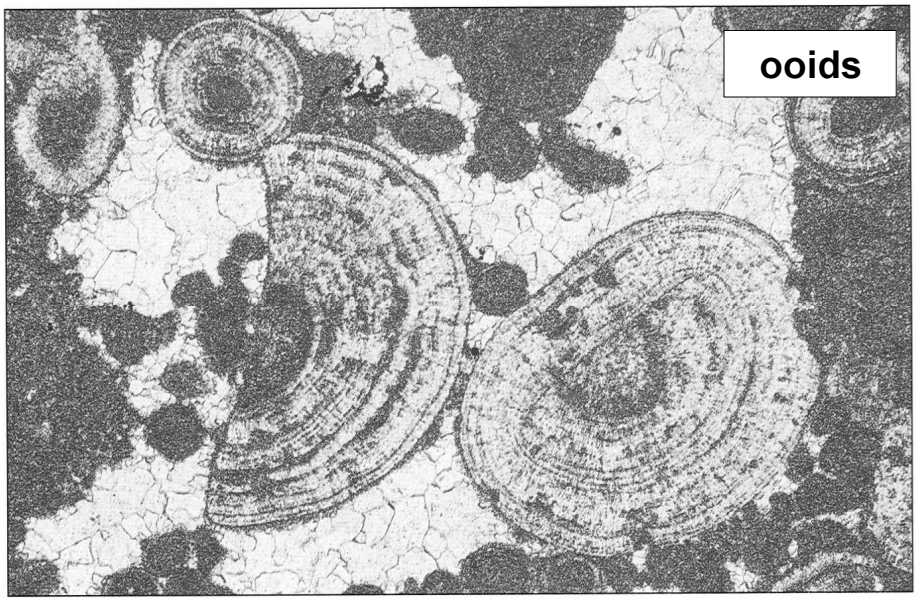
Main carbonate grains

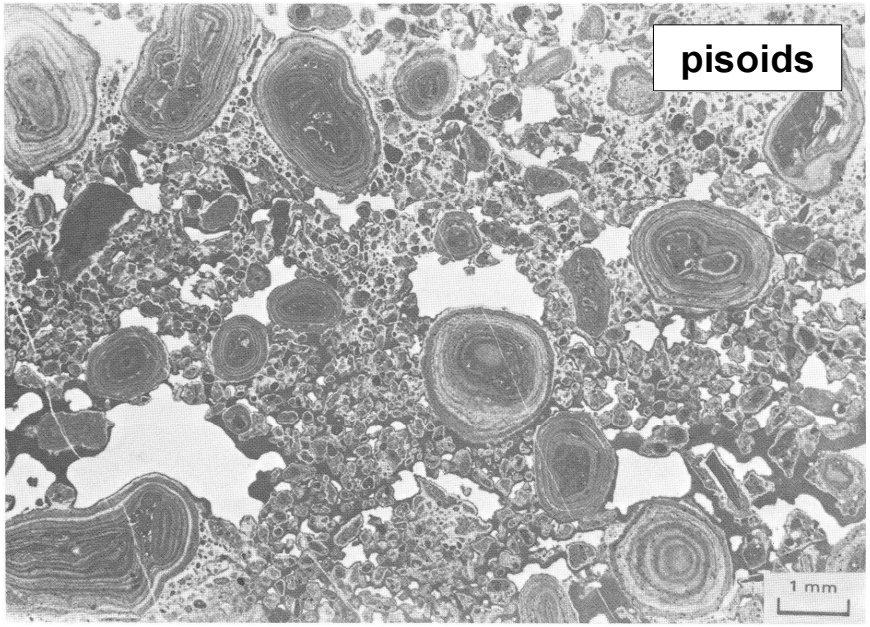
- Coated grains
- Peloids, intraclasts, lithoclasts, aggregates
- Bioclasts: recognized by their shape (3D to 2D) and the structure of the skeleton/wall/shell.

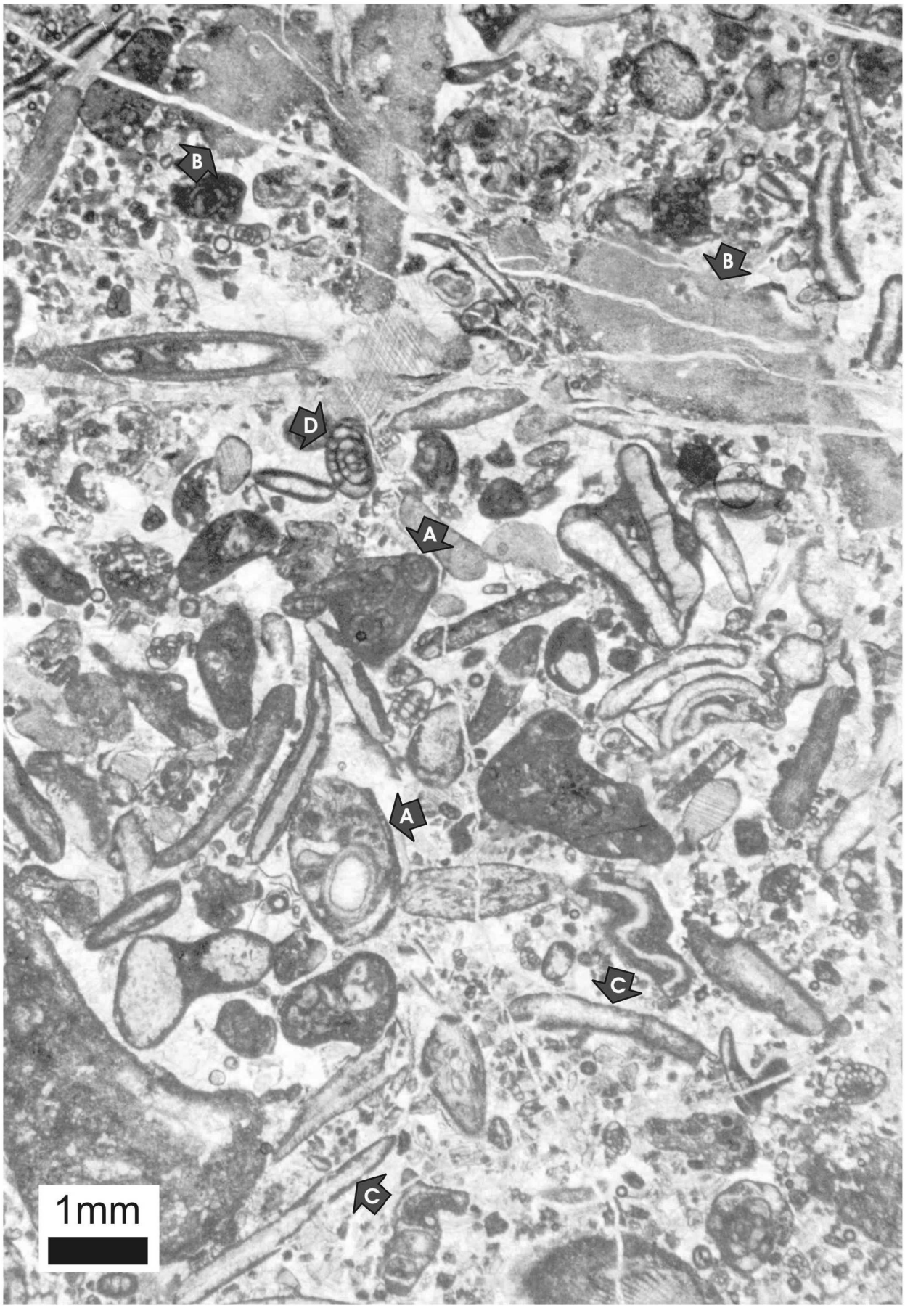
PELOIDS		Small micritic grains, commonly without internal structure. Subrounded, spherical, ovoid or irregular in shape. Size between <0.02 and about 1 mm, commonly 0.10 to 0.50 mm.
COATED GRAINS	CORTOIDS 	Rounded skleletal grains and other grains covered by a thin micrite envelope. Boundary between the central grain and the envelope indistinct. Size between <1 mm to a few centimeters.
	ONCOIDS 	Large and small grains consisting of a more or less distinct nucleus (e.g. a fossil) and a thick cortex formed by irregular, non-concentric, partially overlapping micritic laminae. Laminae may exhibit biogenic structures. No tendency to increase sphericity during growth. Size from <1 mm to a few decimeters.
	OOIDS 	Spherical or ovoid grains, consisting of smooth and regular laminae formed as successive concentric coatings around a nucleus. Laminae may exhibit tangential and radial microfabrics. Size between 0.20 and about 2 mm, commonly between 0.5 and 1 mm.
	PISOIDS 	Large subspherical and irregularly shaped grains, consisting of a mostly non-biogenic nucleus and a thick cortex formed by conspicuously, often densely spaced laminae exhibiting tangential and radial microfabrics. Pisoids occur as isolated grains or are incorporated in crusts. Size generally >2 mm, up to >1 cm.
GRAIN AGGREGATES		Compound grains consisting of two or more originally separated particles (e.g. ooids, skeletal grains) that have been bound and cemented together, forming grape-like or rounded lumps. Intergrain spaces filled with micrite or spar. Outline irregular lobular or rounded. Size 0.5 to more than 2 mm.
CLASTS		Synsedimentary or postsedimentary lime clasts, reworked partly consolidated carbonate sediment or already lithified material. Shape and size are highly variable: angular to rounded. Size ranges between <0.2 mm and several decameters. Very small clasts are hardly distinguishable from peloids.
SKELETAL GRAINS		Fragmented or complete skeletons of organisms. Size from 0.05 mm to many centimeters.

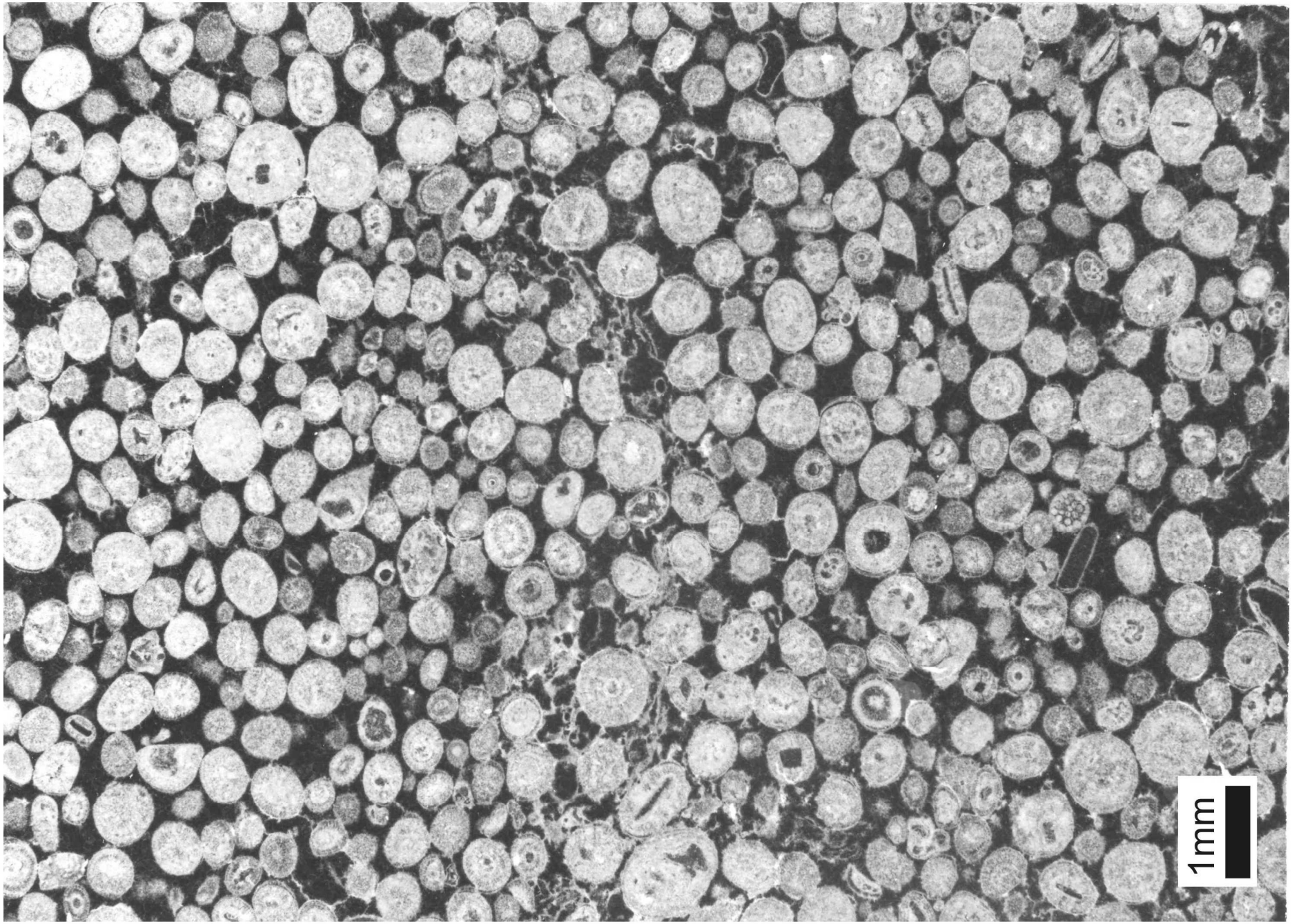
COATED GRAINS



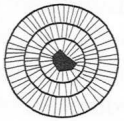
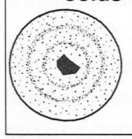


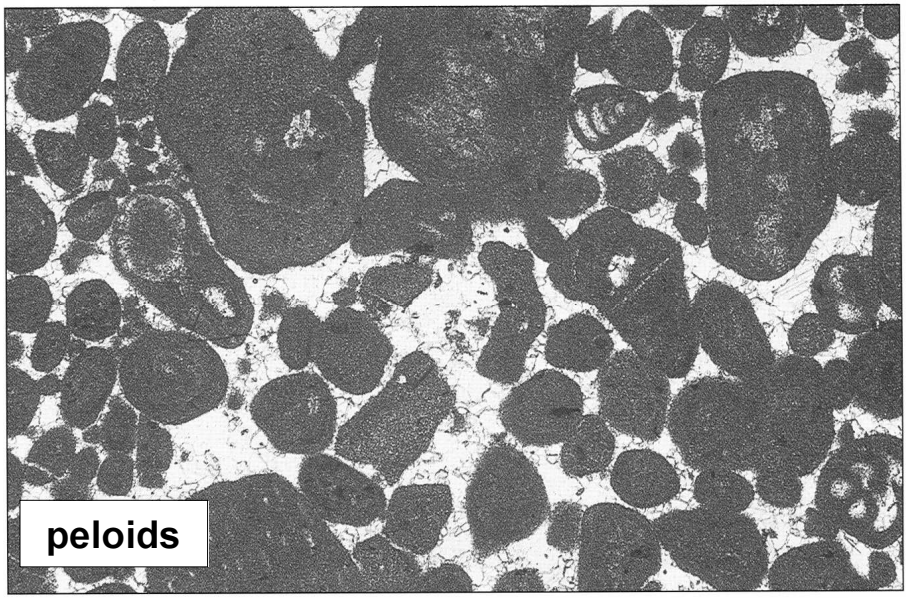


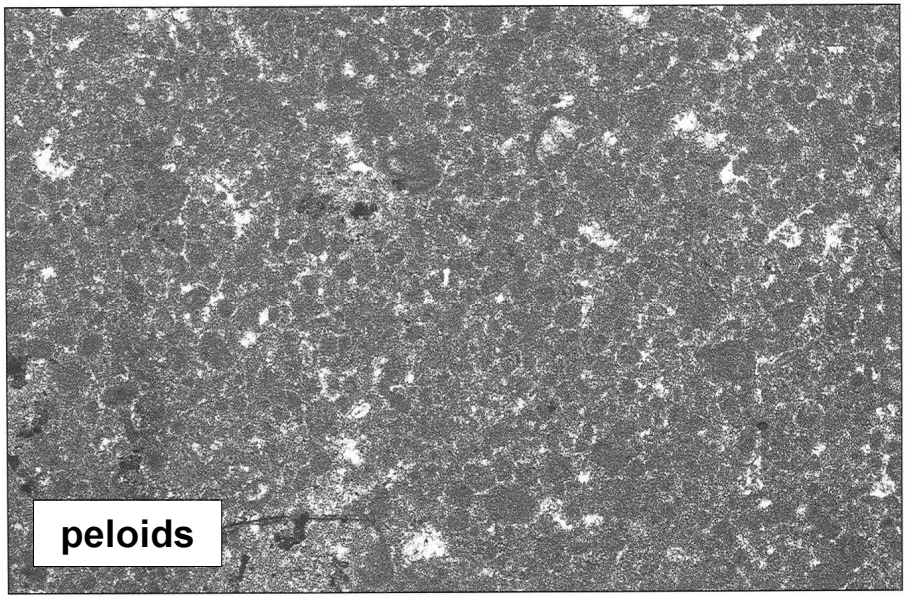

B
B
D
A
A
C
C
1mm

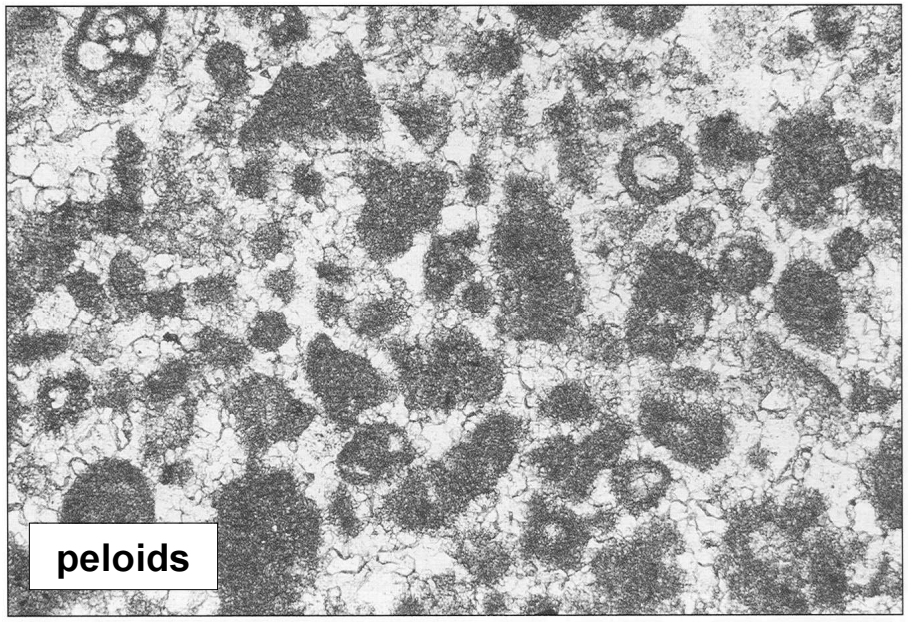

1mm

Sub-types of ooids:

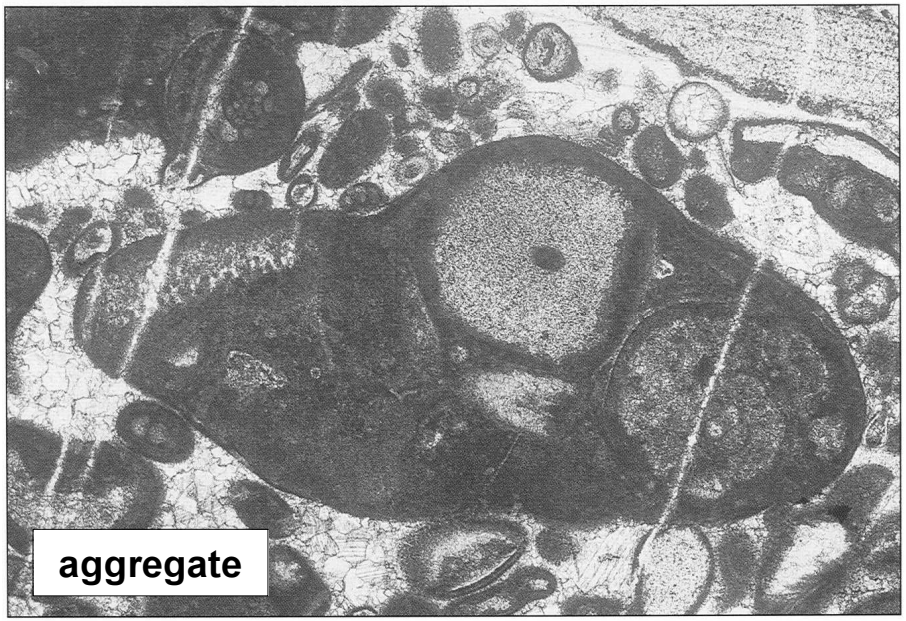
	Microfabric of the cortex	Mineralogy, modern examples	Environment
Concentric (tangential) **ooids** 	Concentric laminae consisting of tangentially arranged crystals whose long axes are aligned to the surface of the laminae. High microporosity	Aragonite: Bahamas, Yucatan, Abu Dhabi, Persian Gulf	Very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

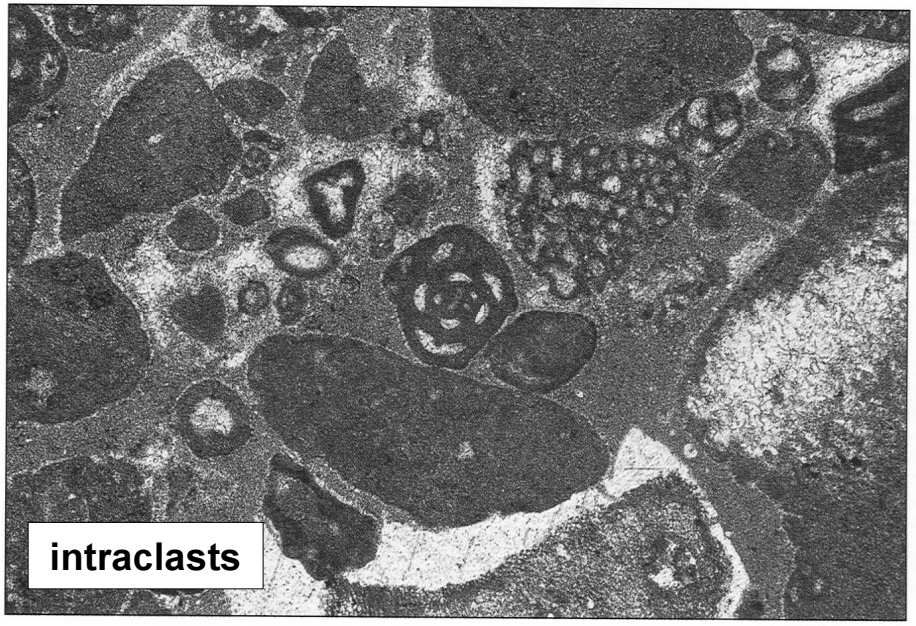

peloids

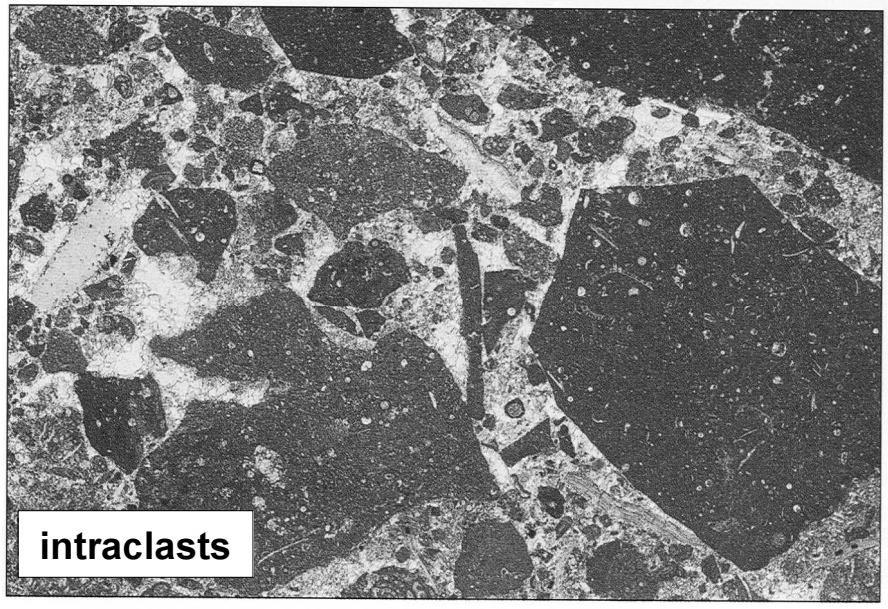

peloids

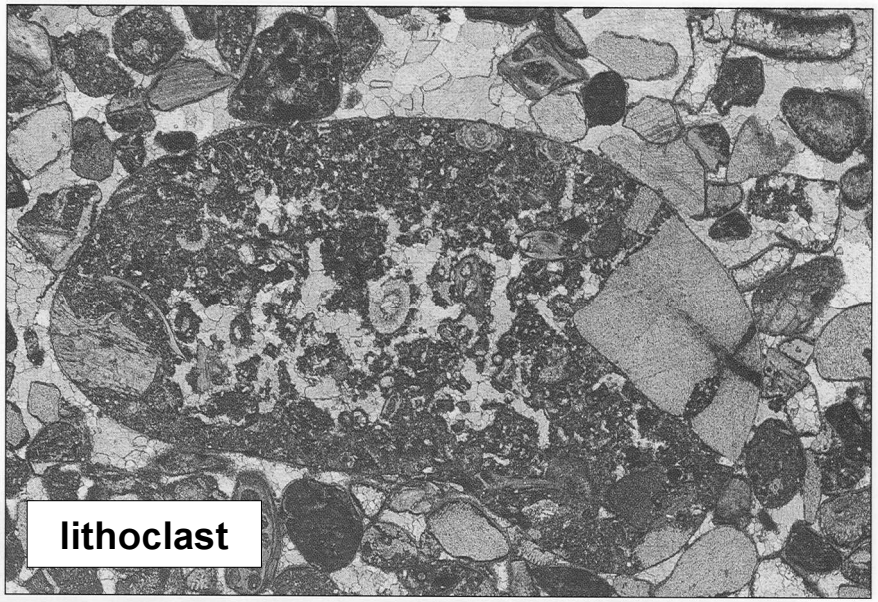

peloids


aggregate
1 mm


aggregate

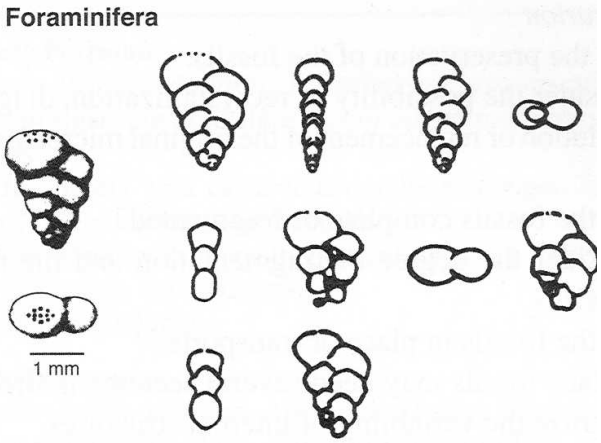

intraclasts

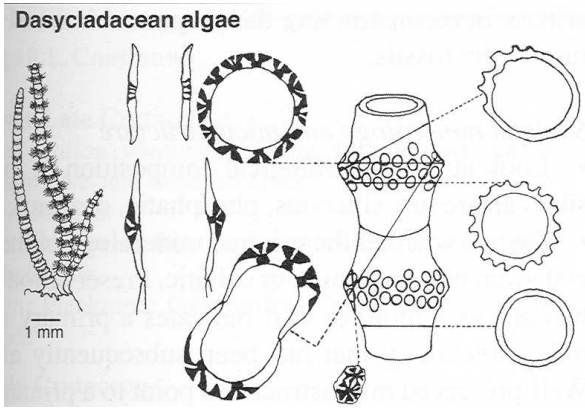

intraclasts


lithoclast

BIOCLASTS

Shape + mineralogy

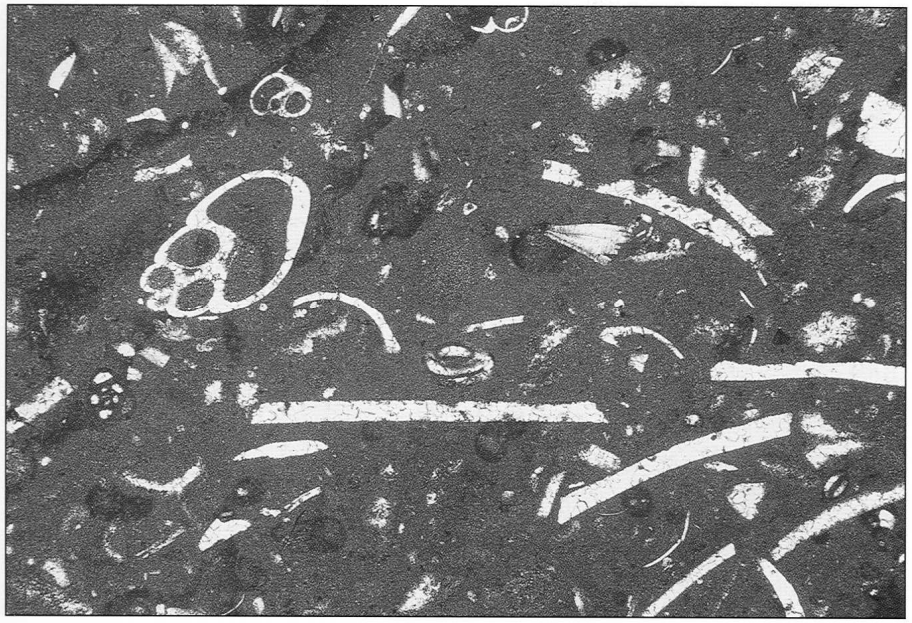




		Aragonite	Low-Mg Calcite	High-Mg Calcite	Aragonite + Calcite	Ca-Phosphates	Silica
Cyanobacteria		o	●	o			
Pyrrhophyta:	Calciodinoflagellata		●				
Chrysophyta:	Diatoms						●
	Coccolithophorida		●				
Chlorophyta:	Dasycladaceae	●					
	Udoteaceae	●					
	Gymnocodiaceae	●					
	Charophyceae		●	●			
Rhodophyta:	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						●	

MOLLUSCS

- Pelecypods (bivalves)
- gastropods
- cephalopods



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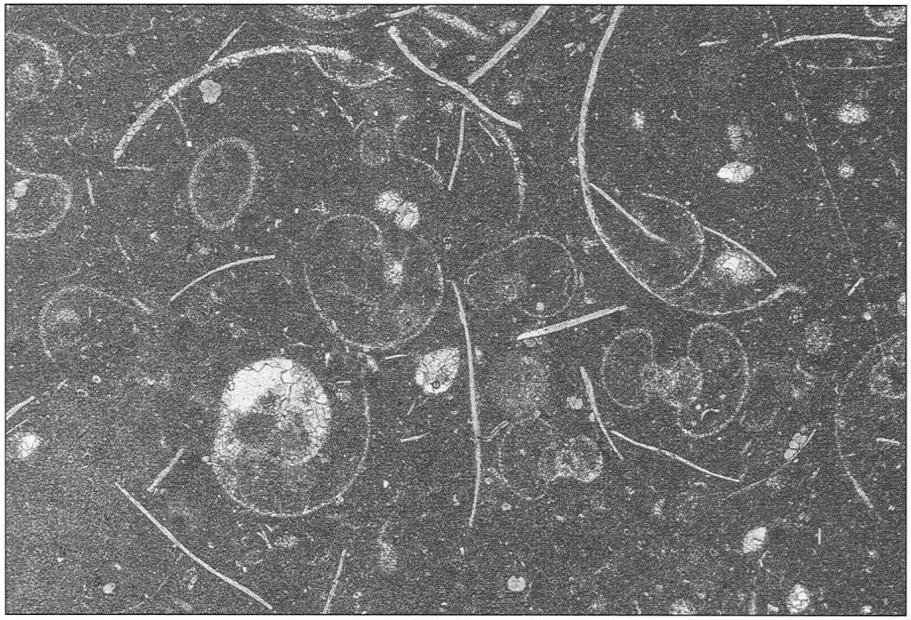

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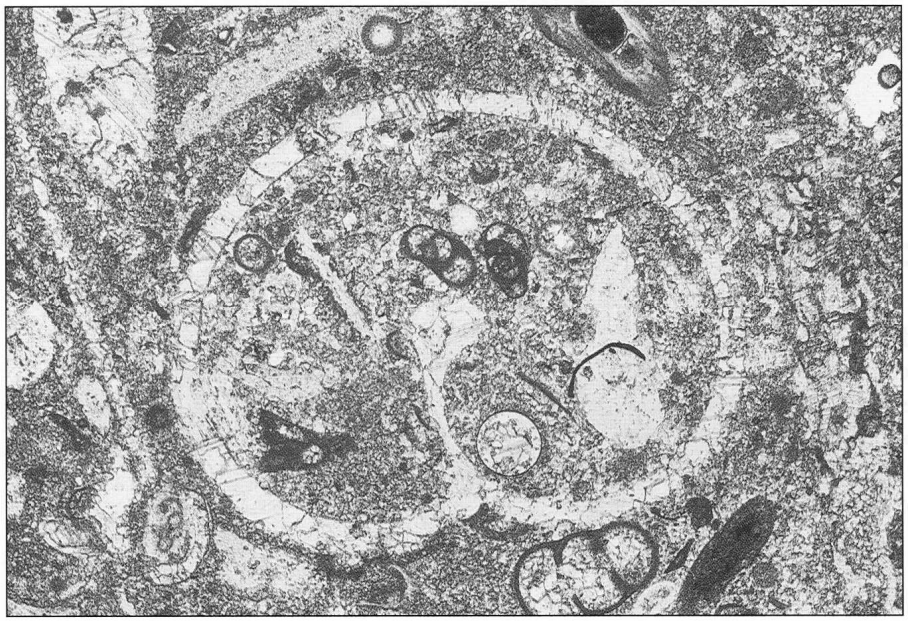

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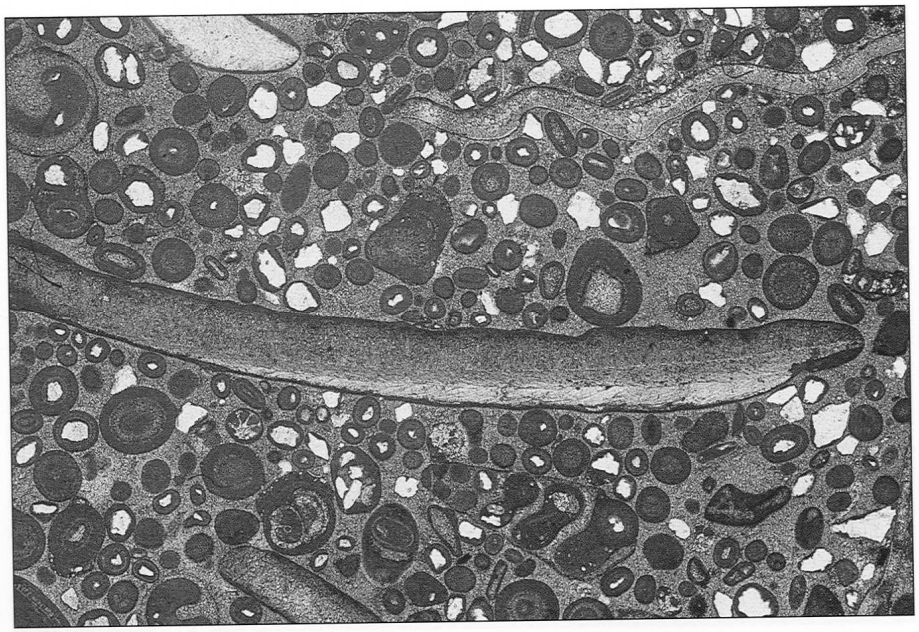


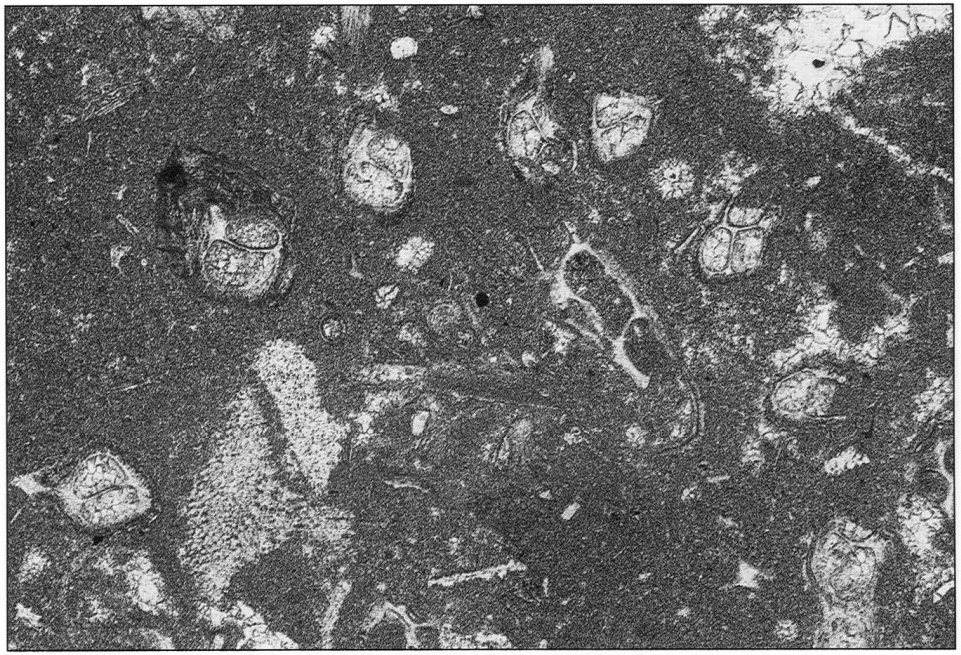
1

BRACHIOPODS

- punctate
- pseudopunctate
- impunctate

BRYOZOANS

- stick
- encrusting
- fenestrate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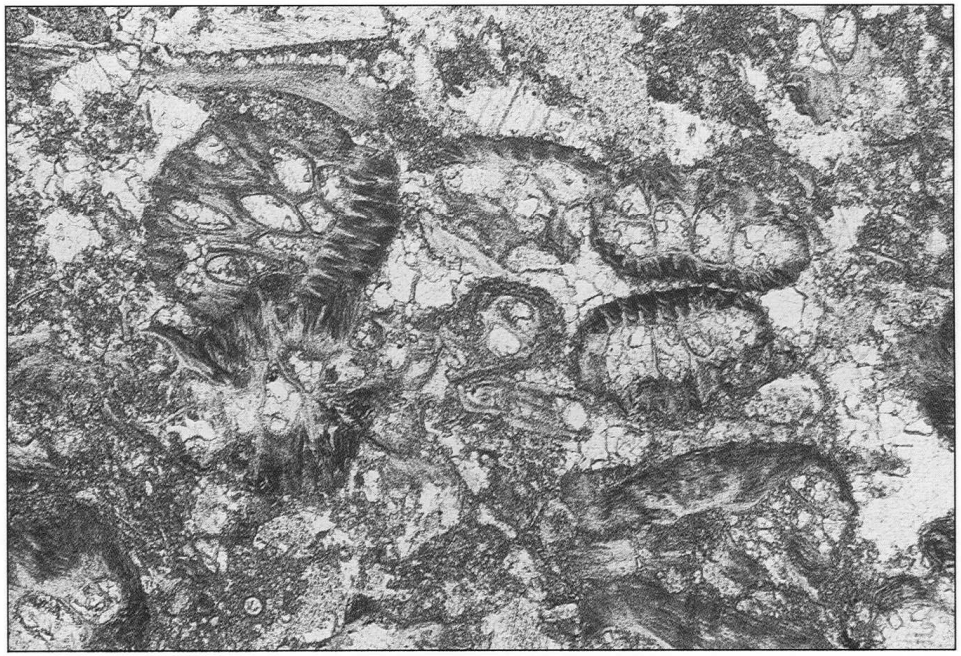
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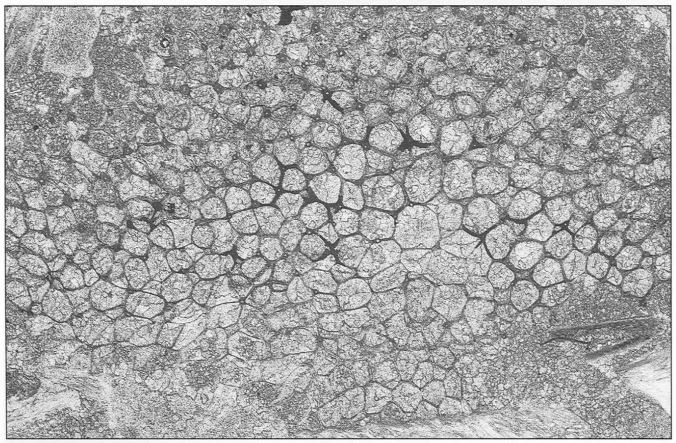
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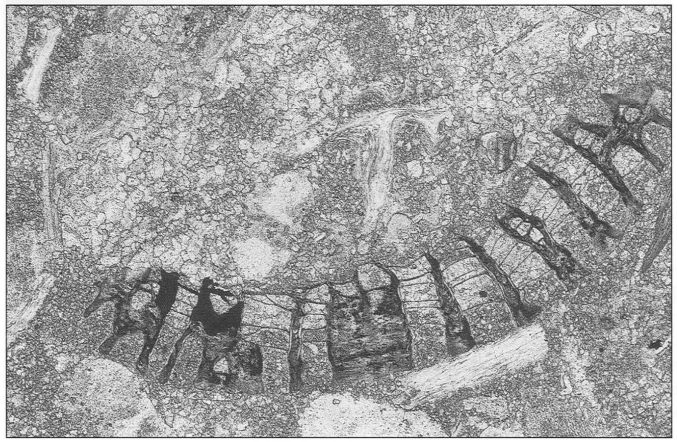
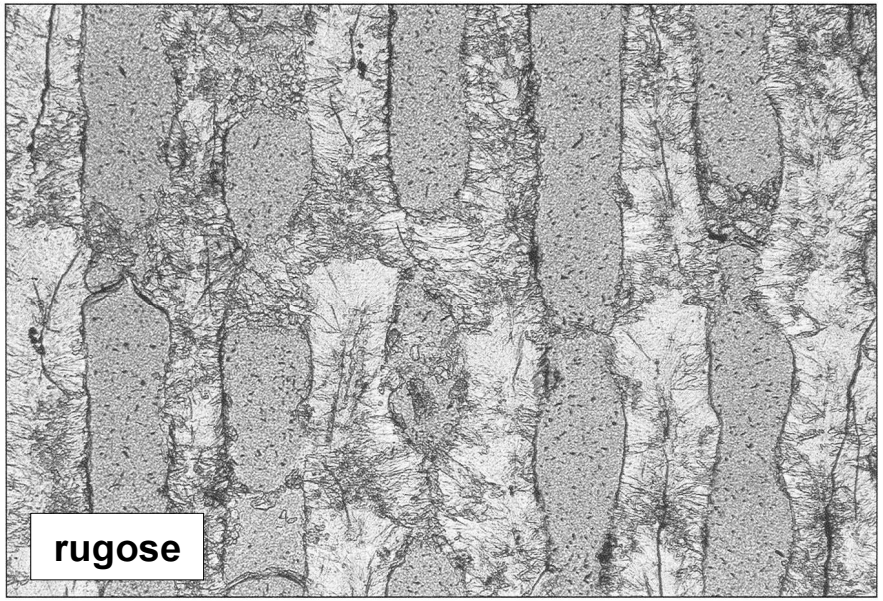
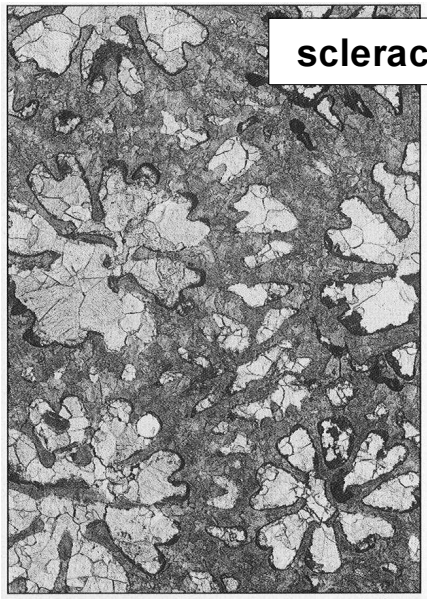
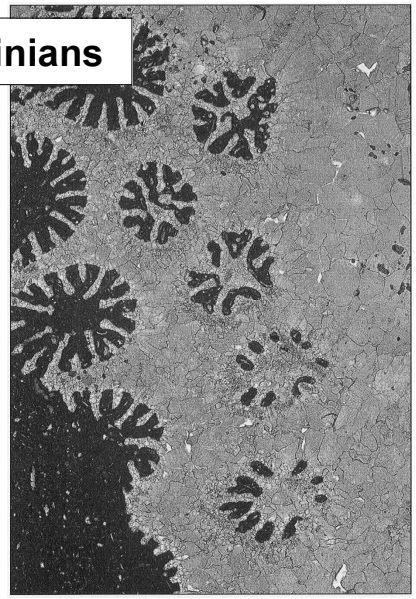

1

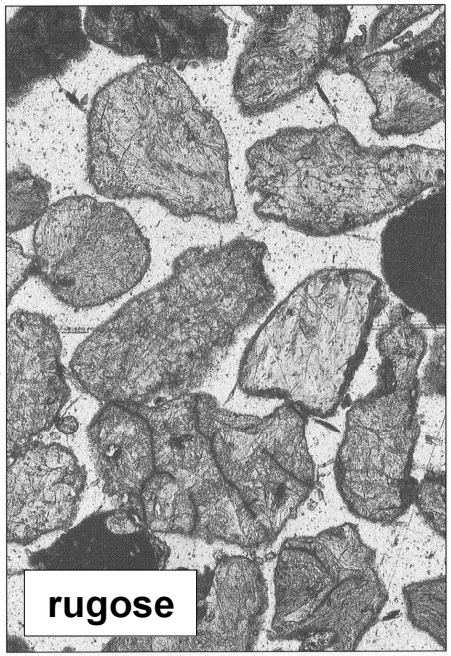
CORALS

- Rugosa (Ordovician to late Permian)
- Tabulata (early Ordovician to late Permian)
- Heterocorallia (latest Devonian to early Carboniferous)
- Scleractinia (aragonite, mid-Trias to Holocene)


rugose


scleractinians

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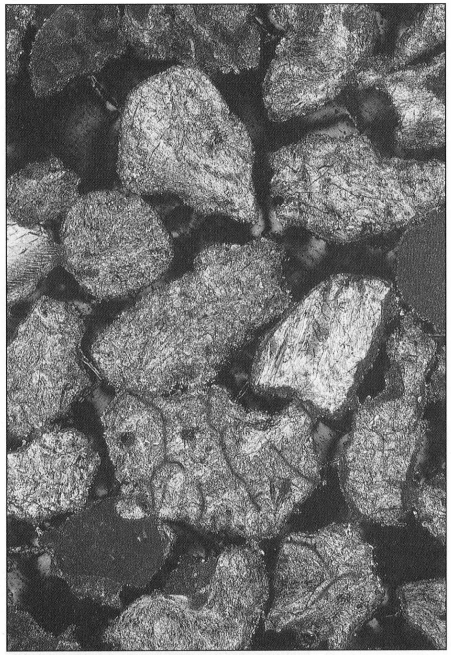

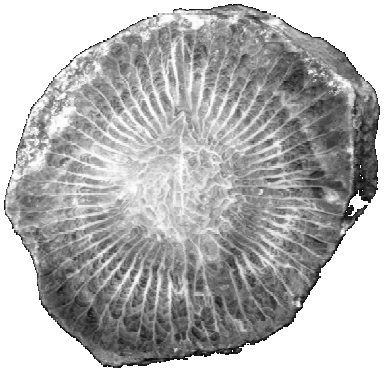
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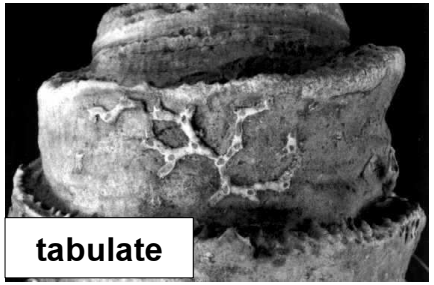
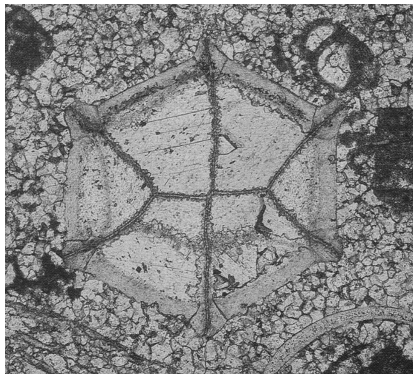

tabulate


heterocoral

SPONGES

- $CaCO_3$
- SiO_2