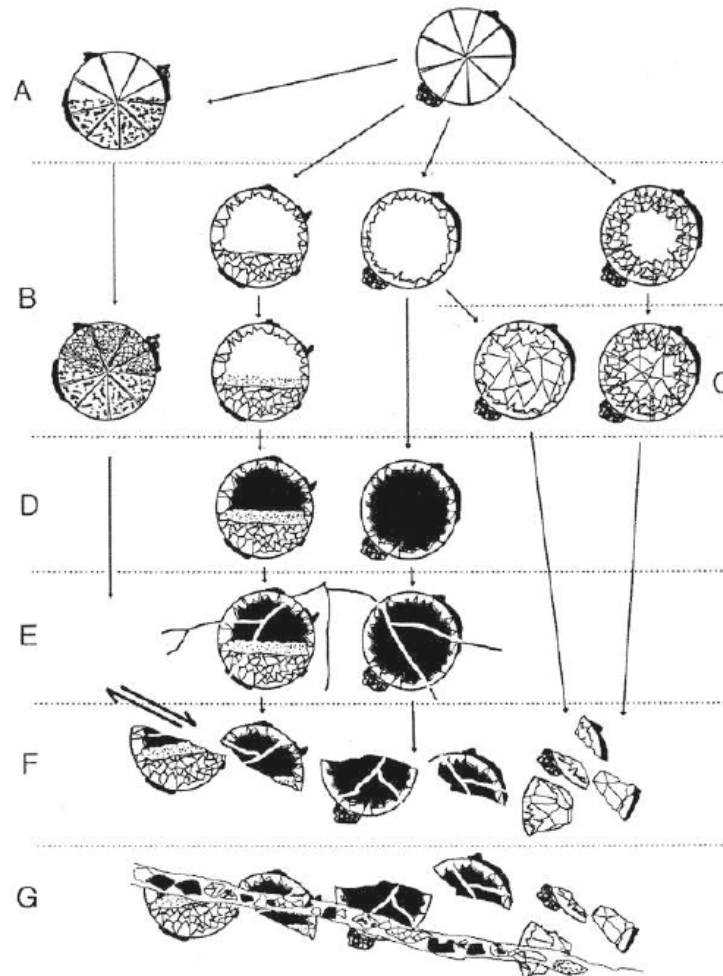


Diagenese

# Diagenese

**Soubor fyzikálních, chemických a biologických procesů, které vedou k přeměně nezpevněného sedimentu na sedimentární horninu**

- Diagenese může pokračovat i po zpevnění horniny a měnit její strukturu a mineralogické složení



**Fig. 7.15.** *Diagenetic changes of coral skeletons over time* demonstrated by diagenetic patterns of dendroid scleractinian corals. The sketch summarizes different preservation types and the course of diagenetic processes. The generalized drawings are based on thin sections (see Pl. 36/4) of Cretaceous coral limestones used as building stones in the giant wall of the Hittite capital Hattusa near Bogazköy, central Turkey.

**A:** The septal structure of the originally aragonitic dendroid corals showing biogenic encrustations is rarely completely preserved, whereby a geopetal infill indicates toppling of the corallites.

**B:** Preservation of coral structures can be enhanced by the precipitation of fine-crystalline drusy calcite mosaics between the septa. More often, however, the interior of the corallites is completely dissolved, producing open molds. The molds are stabilized by variously thick interior cement tapestries. Coral dissolution may occur under meteoric conditions both in subaerial and burial environments. The tapestries at the bottom of some molds are covered by gray crystal silt pointing to dissolution in a near-surface burial setting influenced by meteoric-vadose waters.

**C:** Some of the molds have been completely occluded by blocky burial cements.

**D:** Still open molds are now filled with red internal sediment, in places overlying the gray crystal silt. The red sediment is unfossiliferous weakly laminated micrite that might represent a reworked karstic residual sediment.

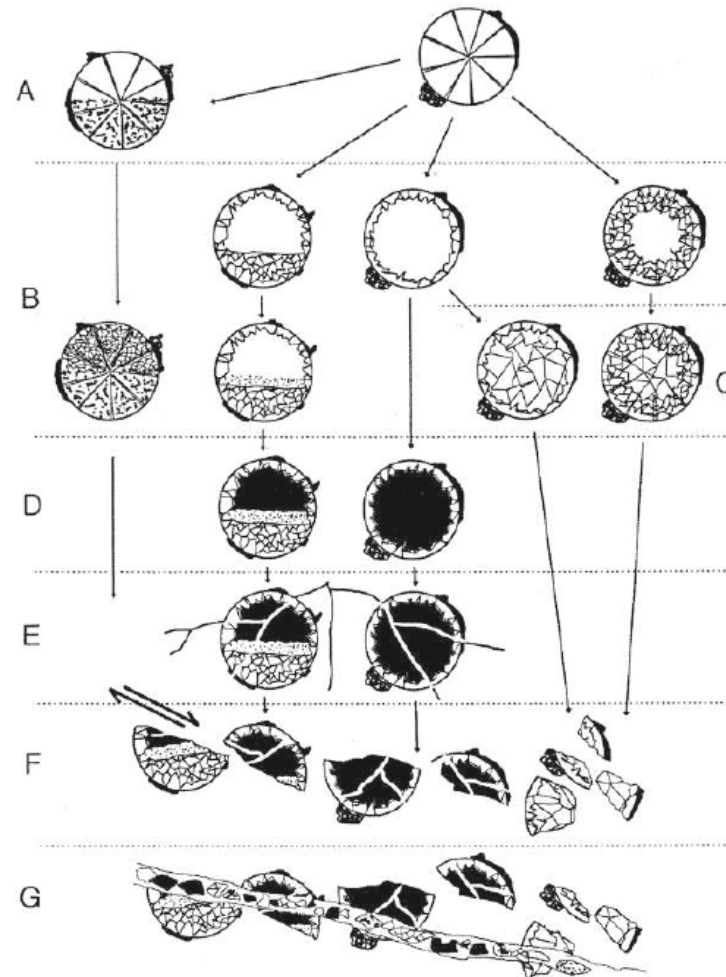
**E:** This stage is characterized by the formation of calcite-filled microcracks transecting both corals and packstone matrix during increasing burial conditions.

**F:** Deep burial compaction and shearing produces angular fragments showing plastic bending and grain breakage.  
**G:** The last stage is characterized by tectonic fissures filled with clasts consisting of reworked corals and matrix. After Flügel und Flügel-Kahler (1997).

# Diagenese

- K diagenezi dochází, pokud se minerály sedimentu v důsledku změny podmínek nebo chemismu stanou chemicky nestabilní (hranice mezi zrny a vodou nebo vzduchem – změna chemismu, změna tlaku, změna teploty při pohřbení/exhumaci)

- „Cílem“ systému je dosáhnout ekvilibria
  - nestabilní minerály (aragonit, high-Mg kalcit) -> stabilní minerály (low-Mg kalcit, dolomit)



**Fig. 7.15.** *Diagenetic changes of coral skeletons over time* demonstrated by diagenetic patterns of dendroid scleractinian corals. The sketch summarizes different preservation types and the course of diagenetic processes. The generalized drawings are based on thin sections (see Pl. 36/4) of Cretaceous coral limestones used as building stones in the giant wall of the Hittite capital Hattusa near Bogazköy, central Turkey.

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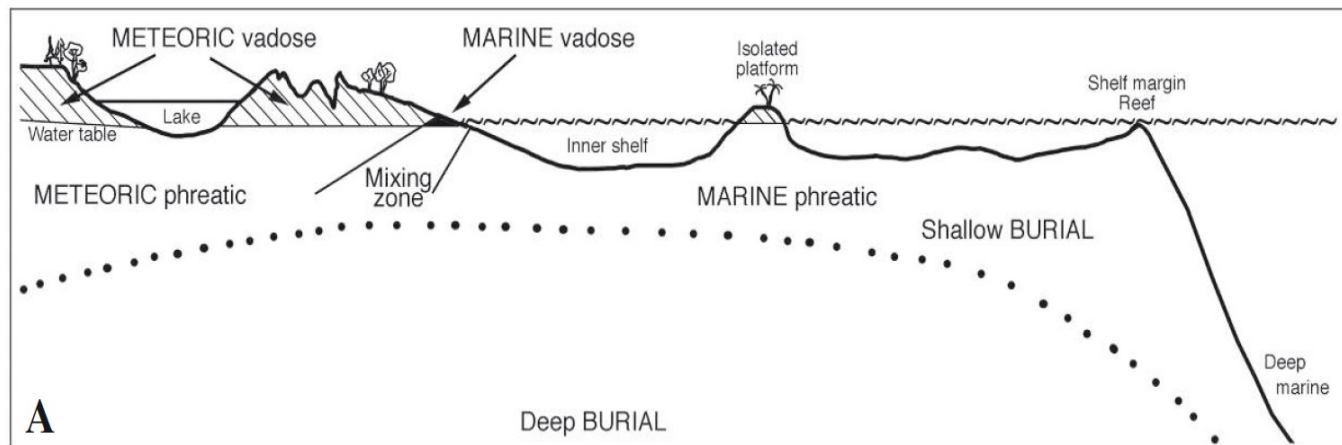
**G:** The last stage is characterized by tectonic fissures filled with clasts consisting of reworked corals and matrix. After Flügel und Flügel-Kahler (1997).

# Fluida při diagenезe

Fluida jsou přítomna v každém sedimentu

## Funkce fluid

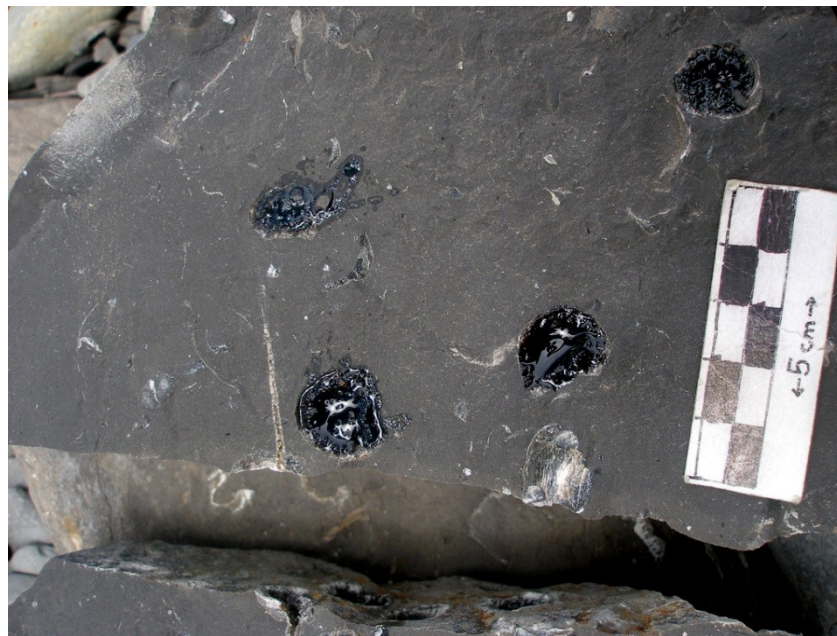
- Srážení cementů
- Tvorba autigenních a náhražkových minerálů
- Rozpouštění



## Změna složení fluid během diagenéze

### Typy fluid

- voda
  - syndepoziční (mořská i sladká)
  - meteorická fluida (sladká voda)
  - dehydratační rozklad minerálů
- metan
- uhlovodíky



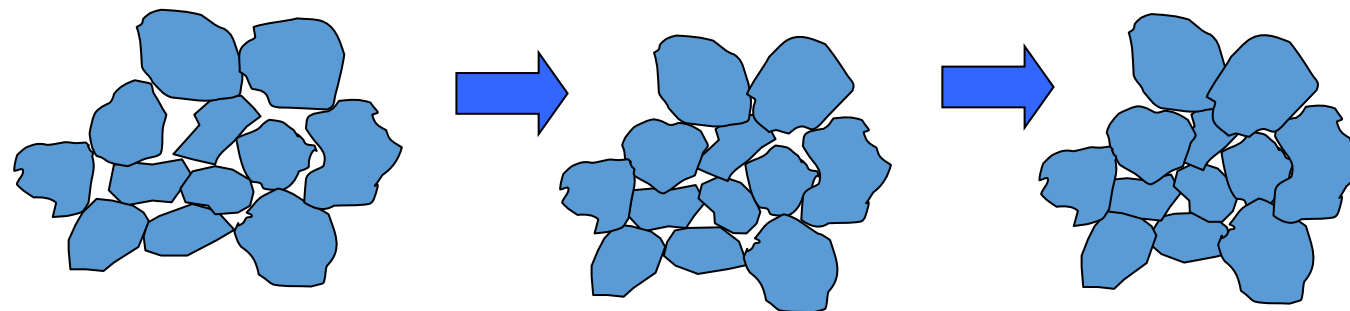
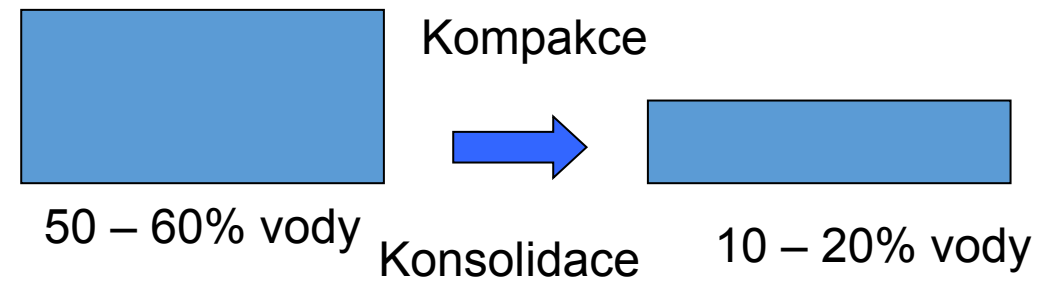
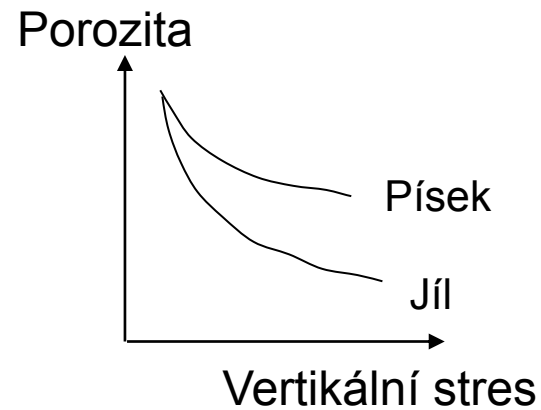
# **Diagenetické procesy**

# Kompakce

- Mechanická kompakce (necementované horniny)

Zvýšení tlaku nadloží při pohřbení  
Snížení porozity těsnějším uspořádáním díky stlačení  
Faktory, které ovlivňují možnou míru kompakce

- velikost zrna
- tvar zrna
- zaoblení
- třídění
- původní porozita
- objem fluid v pórech

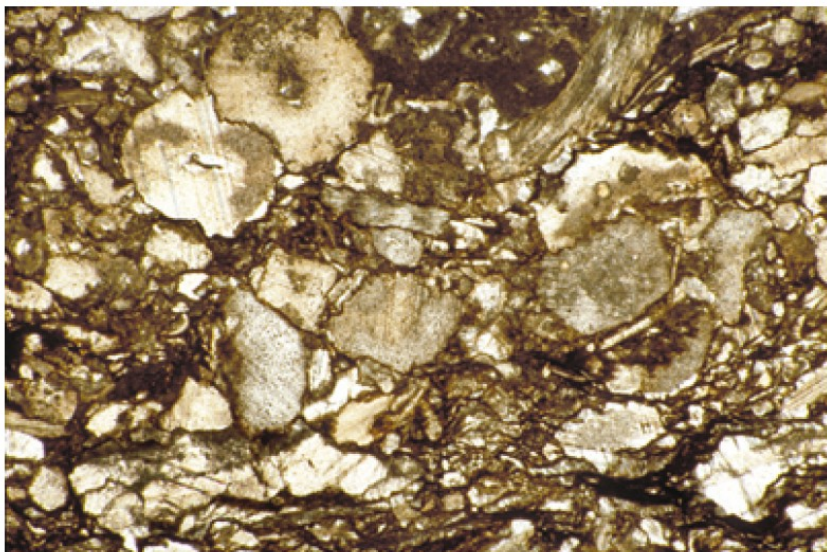
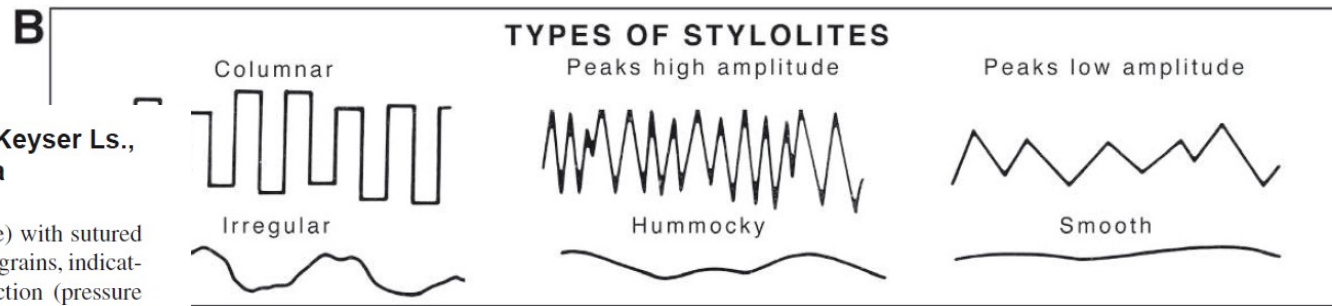
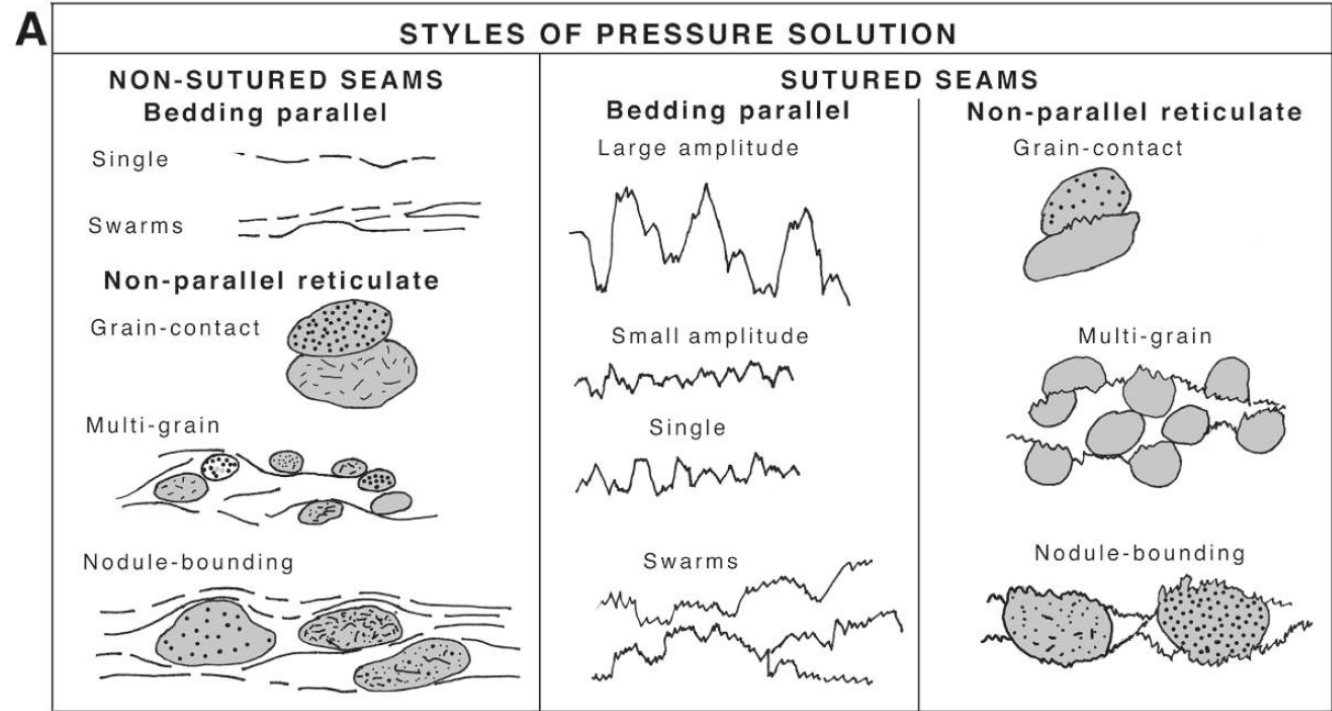
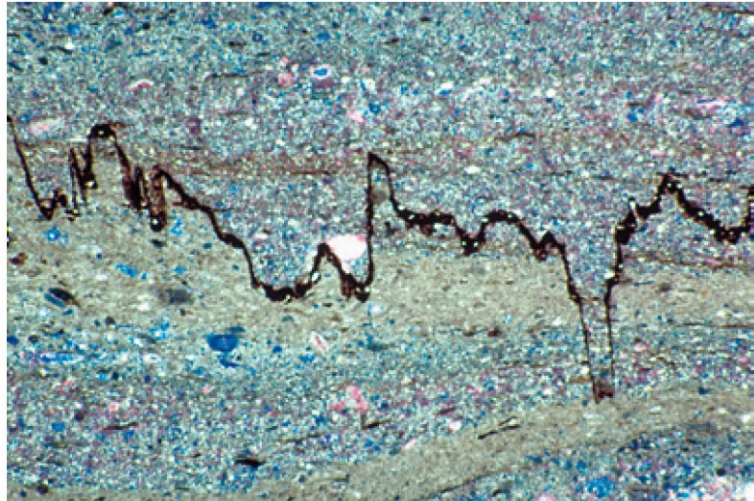


Redukce porozity  
změnou uspořádání  
částic

Další redukce porozity  
díky rozpuštění

# Kompakce

- Chemická kompakce (rozpuštění cementovaných hornin)



Up. Silurian Tonoloway-Keyser Ls., Mifflin Co., Pennsylvania

A crinoidal limestone (encrinite) with sutured contacts between most adjacent grains, indicating extensive chemical compaction (pressure solution) produced during burial of the limestone. The compaction postdates syntaxial overgrowths on some of the crinoids. Note the dark residues along the numerous solution contacts and the development of irregular solution laminae. Stylolites and solution seams commonly produce pseudo-bedding (also termed stylo-bedding) in limestones.

PPL, HA = 5.7 mm

# Hlíznaté vápence

Produkcce karbonátu  
- +



Zdánlivě homogenní směs karbonátu a siliciklastického materiálu

Kompakce



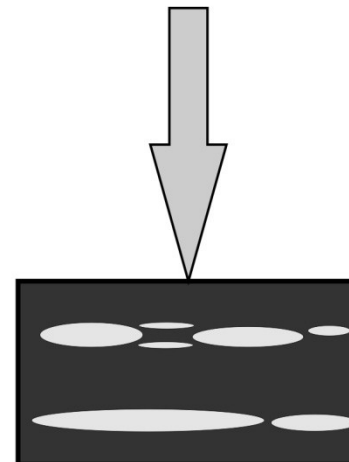
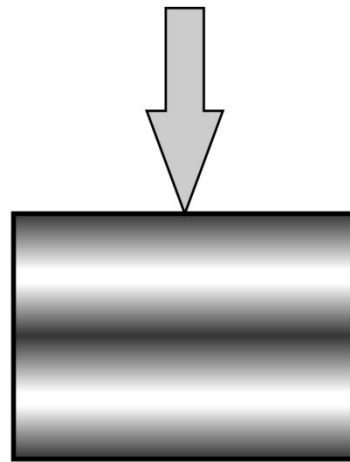
Rozpuštění

Srážení

Rozpuštění

Srážení

Rozpuštění



Především díky tlakovému rozpouštění -  
kompakce pohřbením a dále tektonické  
deformace

**Hlíznaté vápence –  
vznik především  
diferenciací karbonátu  
díky rozpouštění v  
polohách relativně  
chudých na karbonát a  
srážení rozpuštěného  
CaCO<sub>3</sub> v polohách  
bohatších na karbonát**



foto T.Kumpan

**Některé hlíznaté stavby však mohou  
vznikat primárně na mořském dně díky  
chemickému rozpouštění**



# Cementace

Krystalizace nových minerálů z roztoků v pórech horniny –**kalcit, aragonit, dolomit**  
(křemen, hematit, sádrovec)

- Snižování porozity, zpevňování

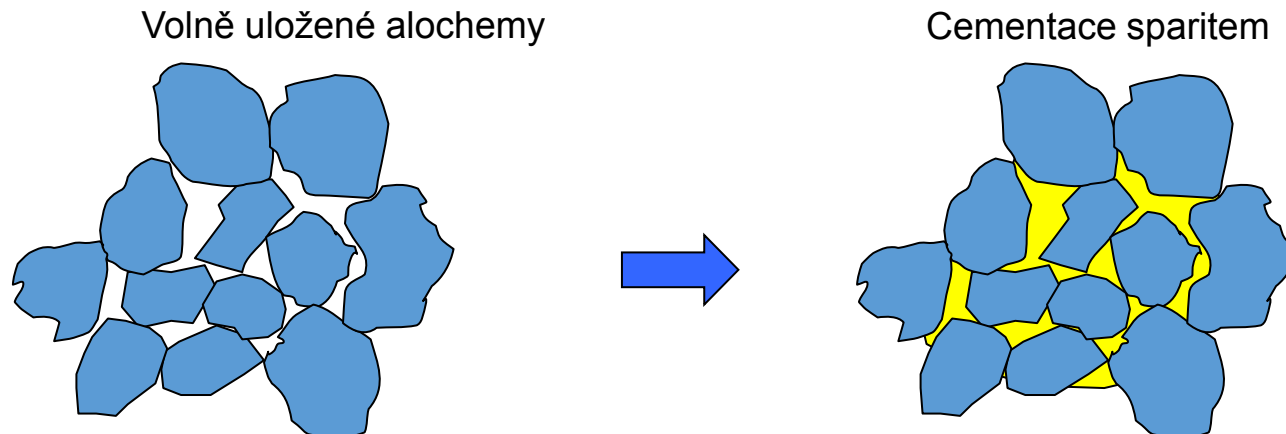
## Podmínky

- Průchod fluid póry, přesycení fluid vůči cementačnímu minerálu

**Původ iontů ve fluidech:**

- z mořské vody

- z rozpuštěné horniny



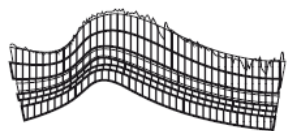
# Cementace

Morfologie cementu (tvar krystalových individuí):

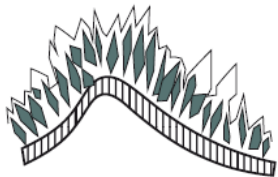
Jehlicovitý, čepelovitý, izometrický

Geometrie cementu (uspořádání krystalů v prostoru):

Izopachový, meniskový, polygonální, syntaxiální

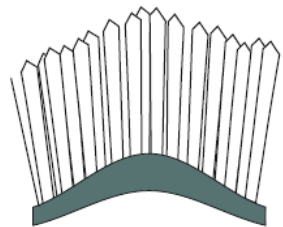
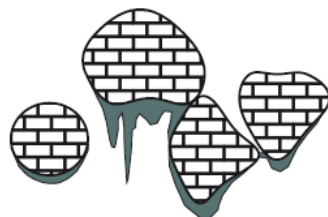


FIBRÁLNÍ TMEL



PSÍ ZUBY

MENISKOVÝ A KRÁPNÍKOVÝ TMEL



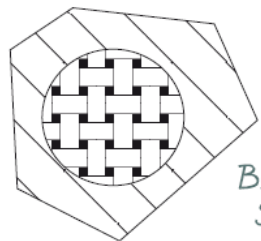
PALISÁDOVÝ



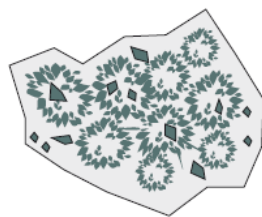
MOZAIKOVÝ TMEL



JEMNĚ KRÝSTALICKÝ,  
BIOGENNÍ TMEL

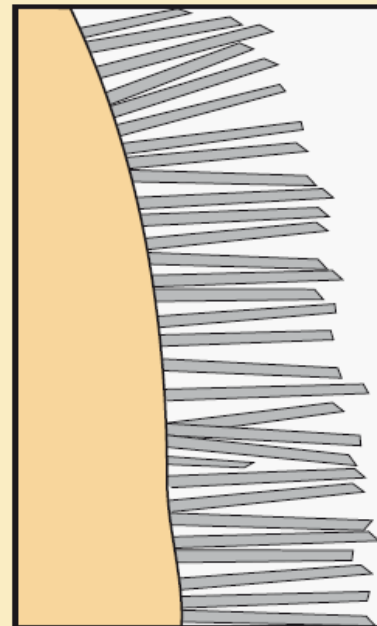


BLOKOVÝ  
SYNTAXIÁLNÍ



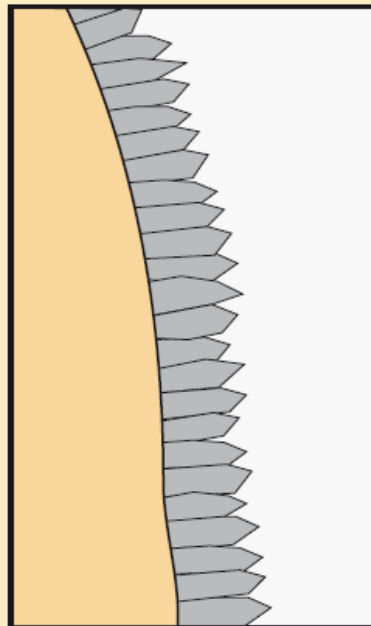
DISMIKRITOVÝ,  
Z VNITŘNÍCH PELOIDŮ

Fibrous



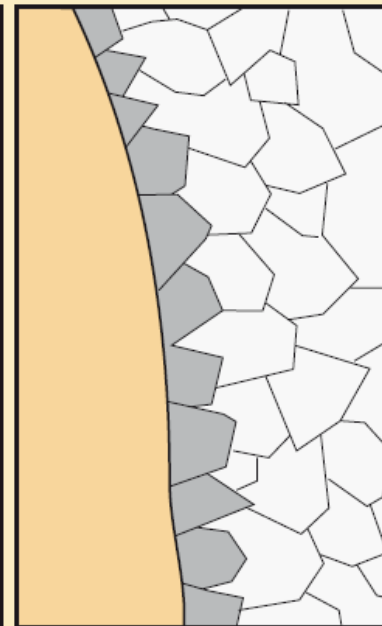
Axial ratio >6:1

Bladed



Axial ratio 6:1 to 1.5:1

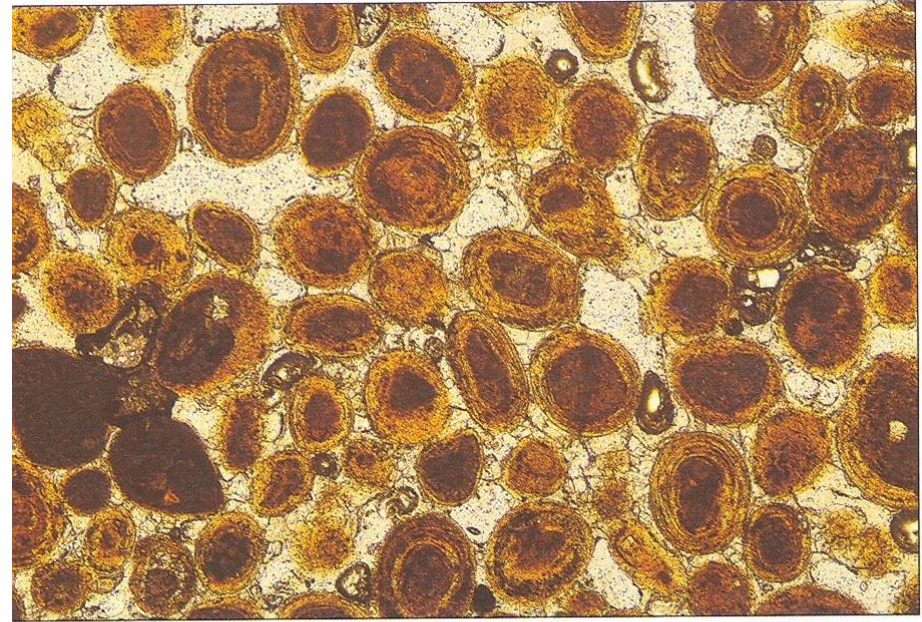
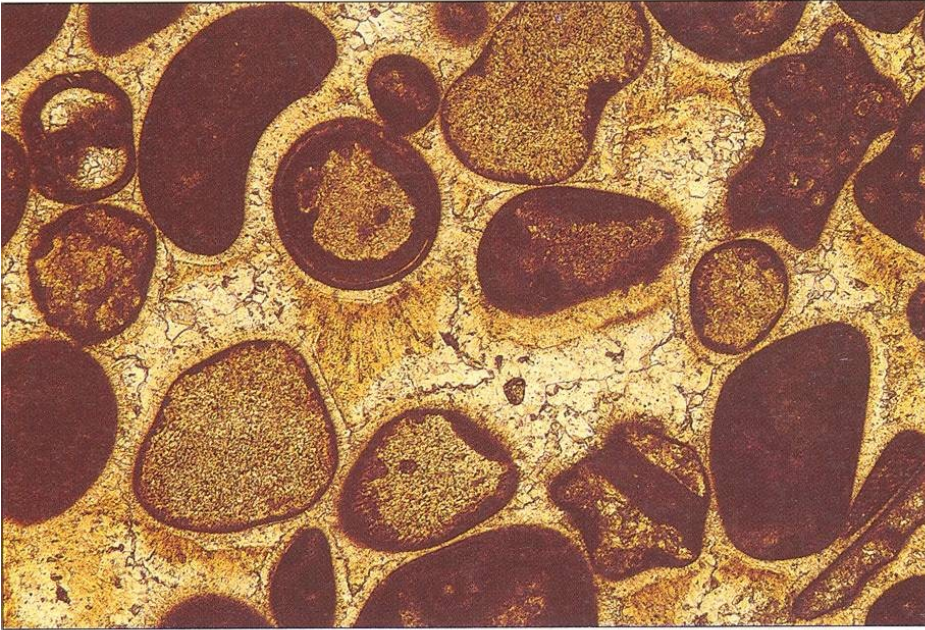
Equant



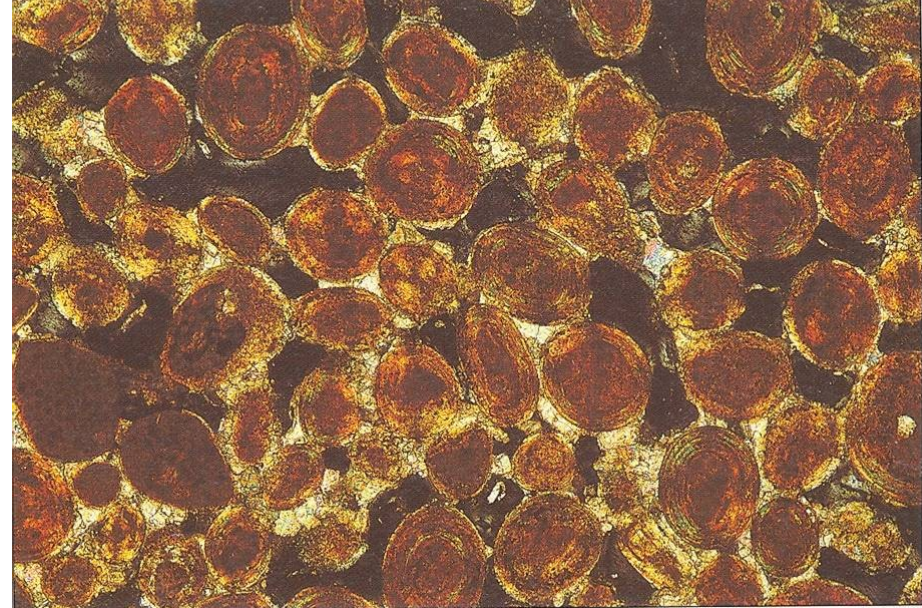
Axial ratio <1.5:1

Obr. 6b Základní typy tmelu, které zaplňují pórové prostory v karbonátové hornině.

# Cementy: izopachový, blokový (vlevo), meniskový (vpravo)

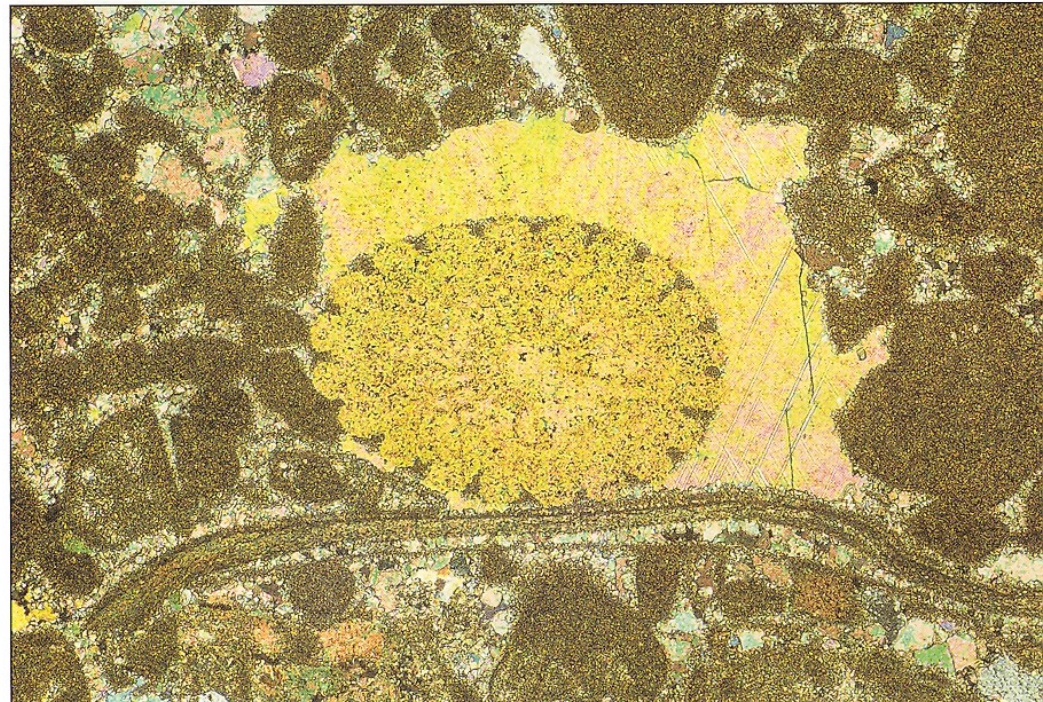


1:



1

# Syntaxiální cement



# Autigeneze

- Krystalizace nových minerálů
- křemen, živce, jíly, zeolity, kalcit, hematit, aragonit, sádrovec, dolomit, fosfáty (apatit)
- Snižování porozity, zpevňování

# Nahrazování

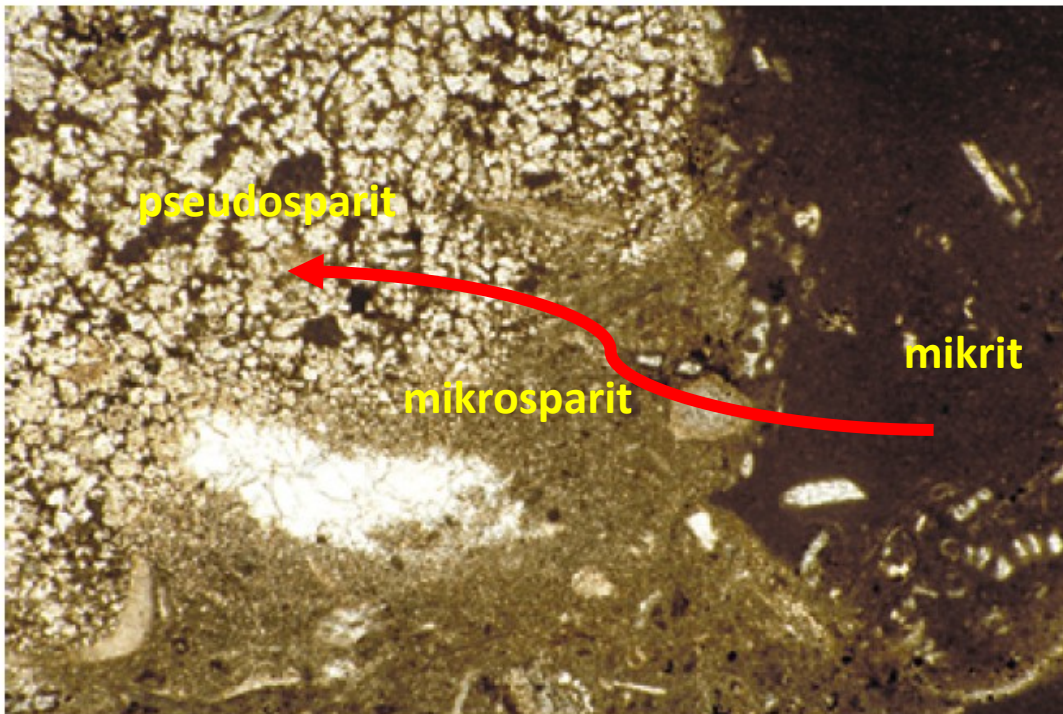
Nové minerály krystalizují na místě původních minerálů

- **Neomorfismus** – nové zrno je stejné fáze jako původní (stejný minerál)
  - rekrystalizace: např. zvětšování velikosti zrna (mikrit -> mikrosparit)
- **Pseudomorfismus** – nové zrno jiného minerálu napodobuje vnější tvar původního zrna
- **Alomorfismus** – nový minerál o jiném tvaru nahrazuje původní minerál
  - dolomit, opál, křemen, illit

# Rekrytalizace

Reorientace krystalových mřížek minerálů (chemismus se nemění)

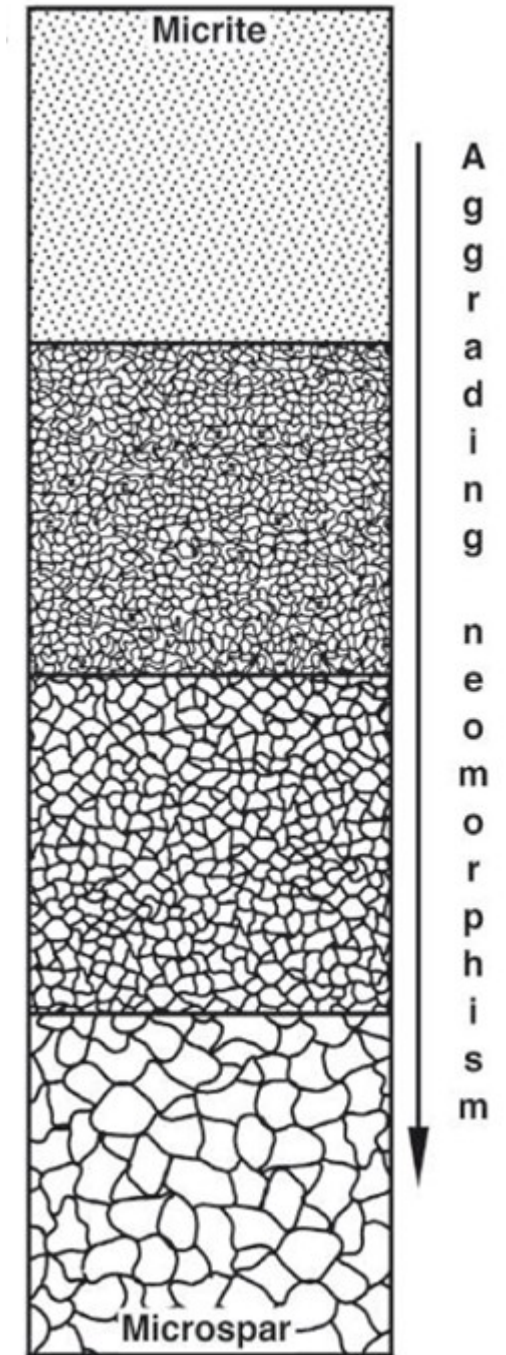
- Při změně tlaku, teploty, fluidní fáze
- Obecně zvyšování velikostí zrna – snížení povrchu zrn – snížení povrchové volné energie – ekvilibrium



Mid. Ordovician Chazy-Black River Fms., Mifflin Co., Pennsylvania

Micritic materials can be formed within carbonate rocks (as shown in earlier slides), but they can also be destroyed or transformed. This example shows a transition from micrite (right) to microspar (lower center) to pseudospar (upper left). Note the bladed or “loaf-shaped” shape of the pseudospar crystals and the remnants of matrix between those crystals. The causes of microspar and pseudospar recrystallization are not well defined, but early meteoric exposure and tectonic stresses have been implicated in some cases.

PPL, HA = 5.2 mm



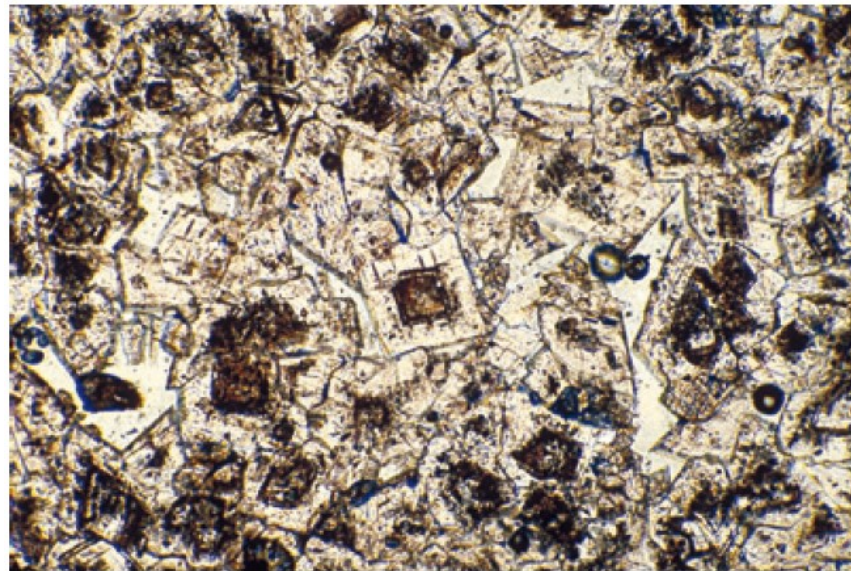
# Dolomitizace

## Nahrazování $\text{CaCO}_3$ dolomitem

Zdroj  $\text{Mg}^{2+}$ : mořská voda, jíly obohacené o  $\text{Mg}^{2+}$

## Procesy dolomitizace:

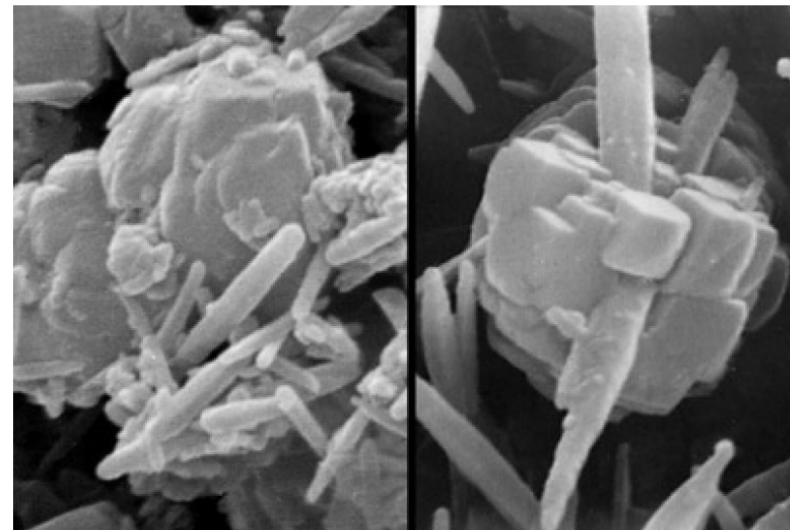
- Cementace (vzácně)
- Nahrazování



Oligocene Gambier Fm., coastal South Australia

An example of largely euhedral dolomite where the crystals have dark cores and limpid rims. This is an extremely common fabric in dolomites. The cloudy cores have been interpreted to reflect mixing zone conditions in which metastable, inclusion-rich dolomite formed. A shift to more marine conditions led to precipitation of the more inclusion-free, limpid dolomite outer zones that may, in part, be cements (Kyser et al., 2002). The rhombic outlines, zoning, and lack of twinning seen here are characteristics that allow recognition of most dolomites, even without staining. Photograph courtesy of Noel P. James.

PPL, HA = 1.0 mm

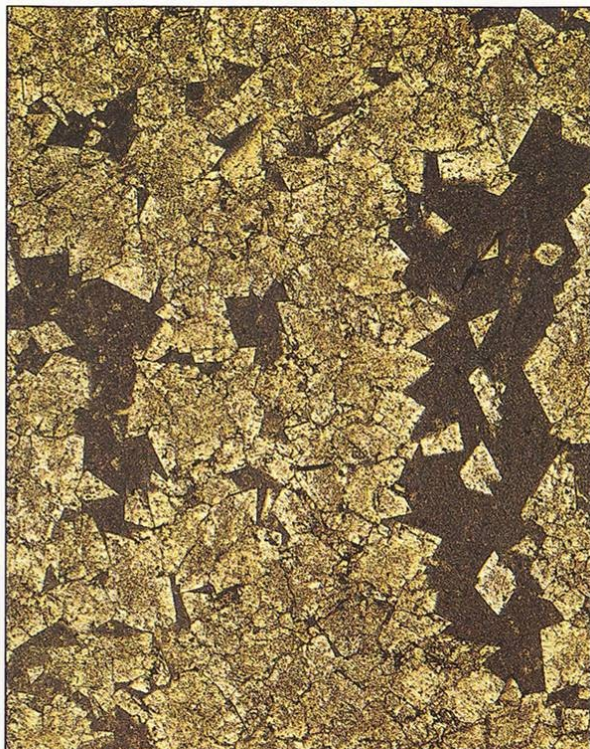
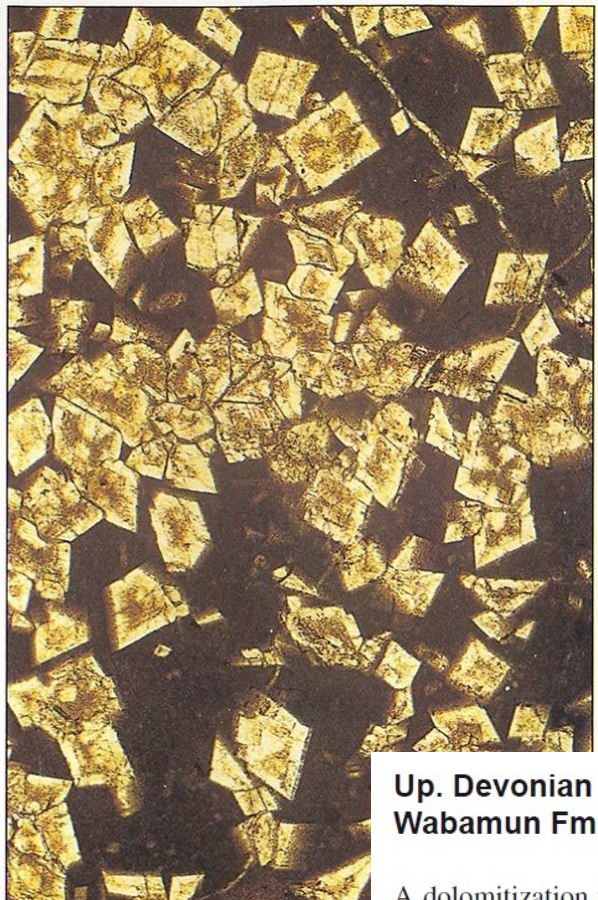
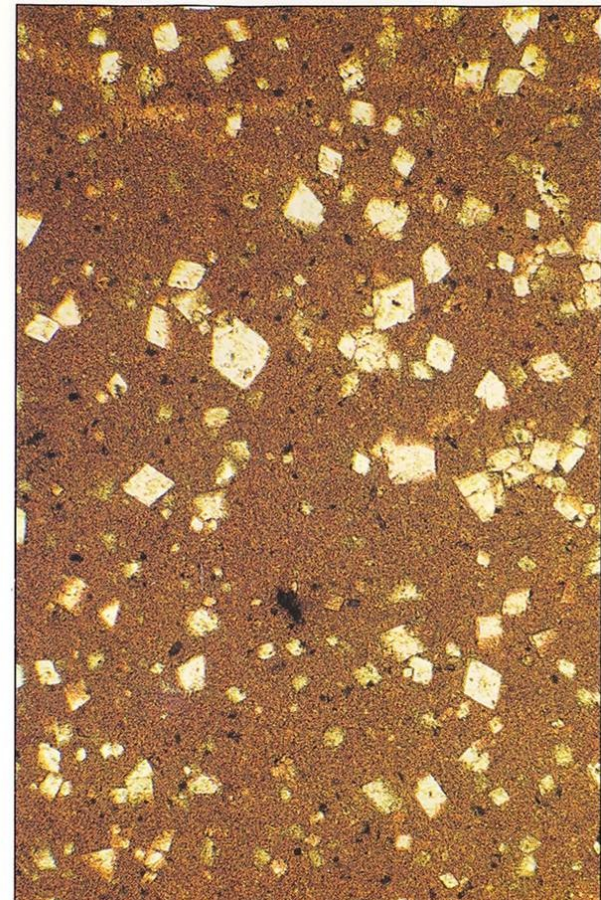


Holocene sediment, Abu Dhabi sabkha, United Arab Emirates

SEM images of partially dolomitized aragonitic carbonate mud from a pit dug beneath the sabkha one kilometer inland from the lagoonal shoreline. The dolomite crystals grow around, and perhaps partially replace, aragonite needles in pore space within a crust buried beneath the sabkha. Dolomite formation here occurred in warm (30-40°C), highly saline pore fluids with elevated Mg/Ca ratios (as a result of prior calcium sulfate precipitation). Bacterial sulfate reduction in organic-rich layers may also aid dolomitization. Photographs courtesy of Judith A. McKenzie (McKenzie, 1981).

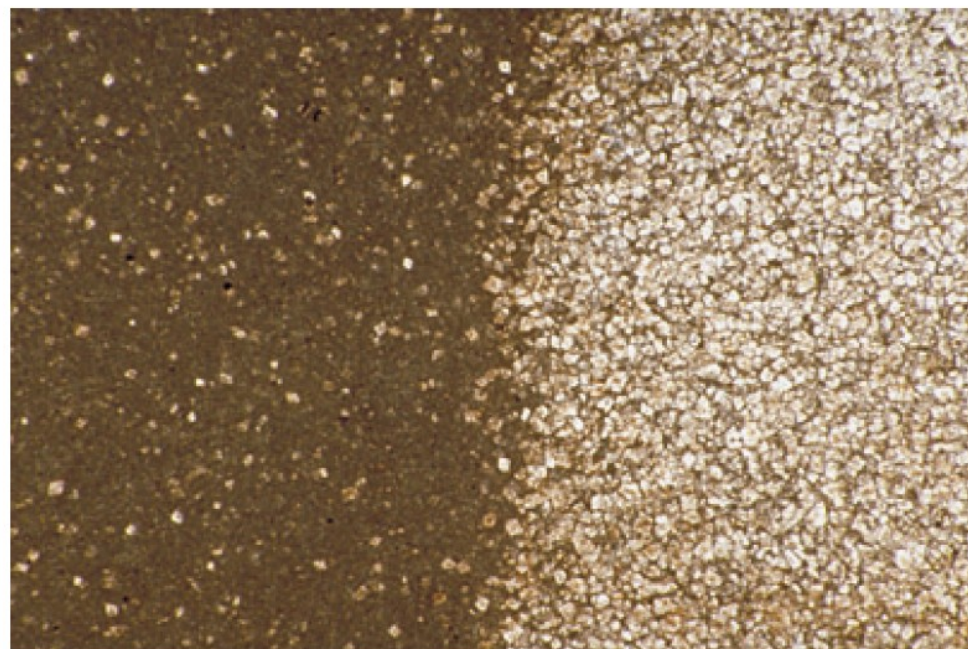
SEM, L: HA = ~4.2  $\mu\text{m}$ ; R: HA = ~3.4  $\mu\text{m}$





**Up. Devonian (Famennian)  
Wabamun Fm., Alberta, Canada**

A dolomitization front in a micritic limestone — dolomitization is complete on the right side and sparse on the left. In this case, the presence of permeable burrows led to highly heterogeneous replacement patterns as dolomitizing fluids moved preferentially through the burrows and altered material within, and directly adjacent to, those fluid conduits.



PPL, HA = 5.0 mm

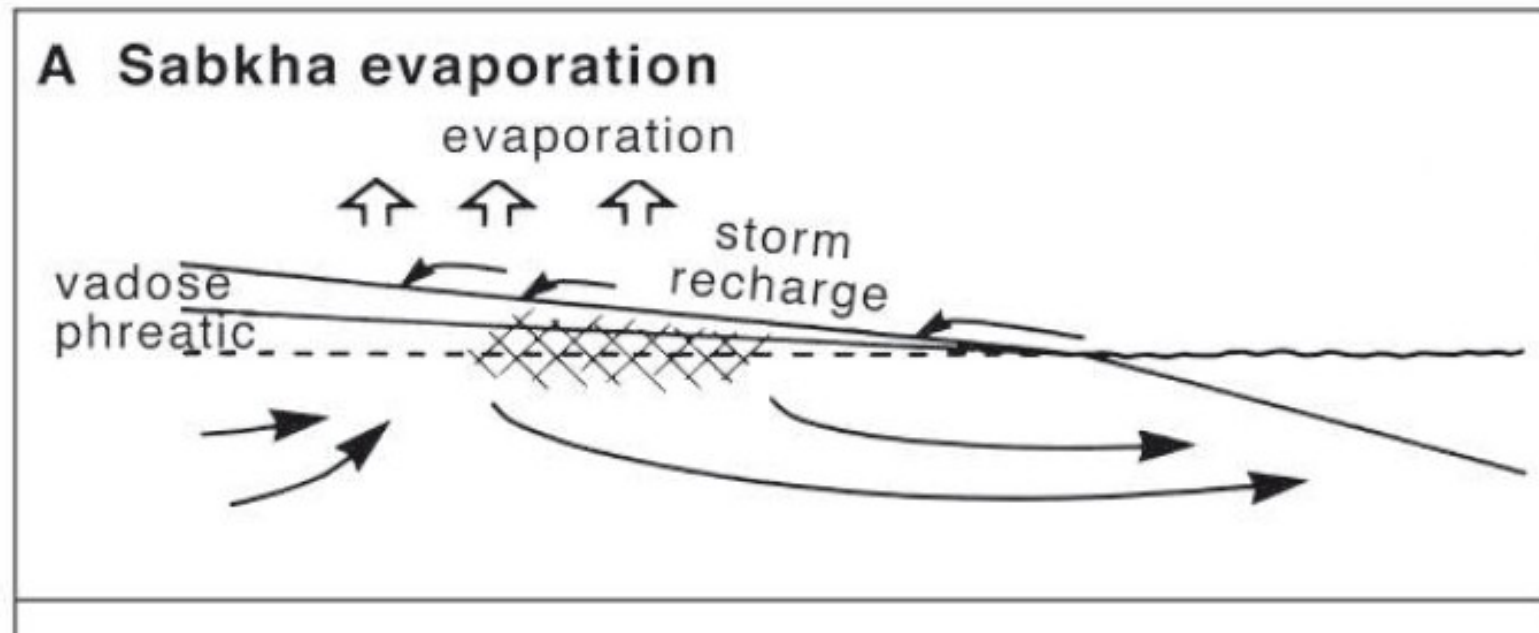
# Modely dolomitizace

## Evaporační dolomitizace

Aridní prostředí (sabkhy, solná jezera)

Kapilární vzlínání podzemní vody v důsledku odpařování vody

Míšení mořských a terigenních nasycených vod



# Modely dolomitizace

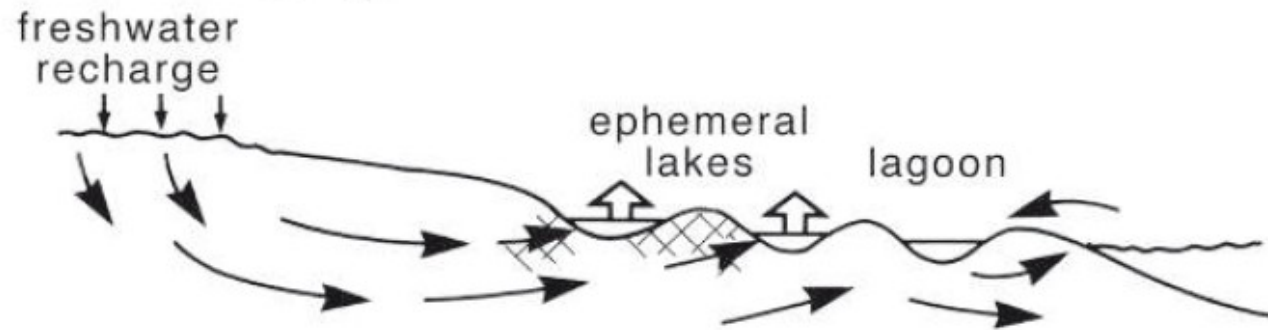
## Dolomitizace v zóně míšení

Míšení mořských a terigenních podzemních vod

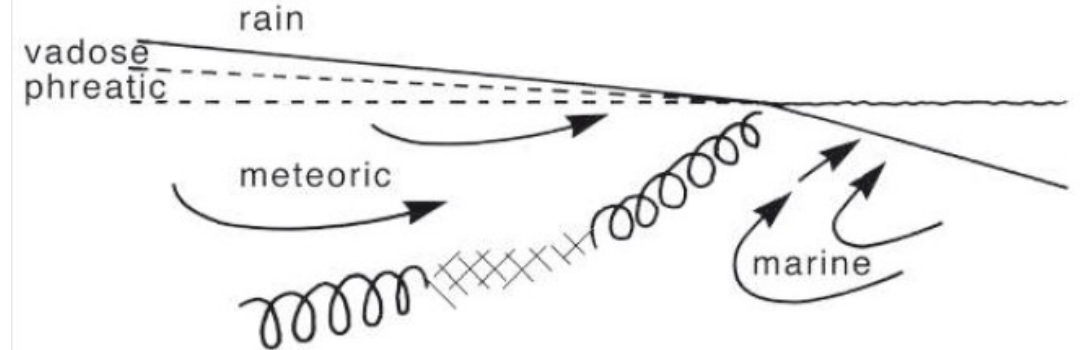
Mg z mořské vody

Terigenní voda: hybný mechanismus, pumpuje dolomitizující fluida horninou

### D Coroong-type



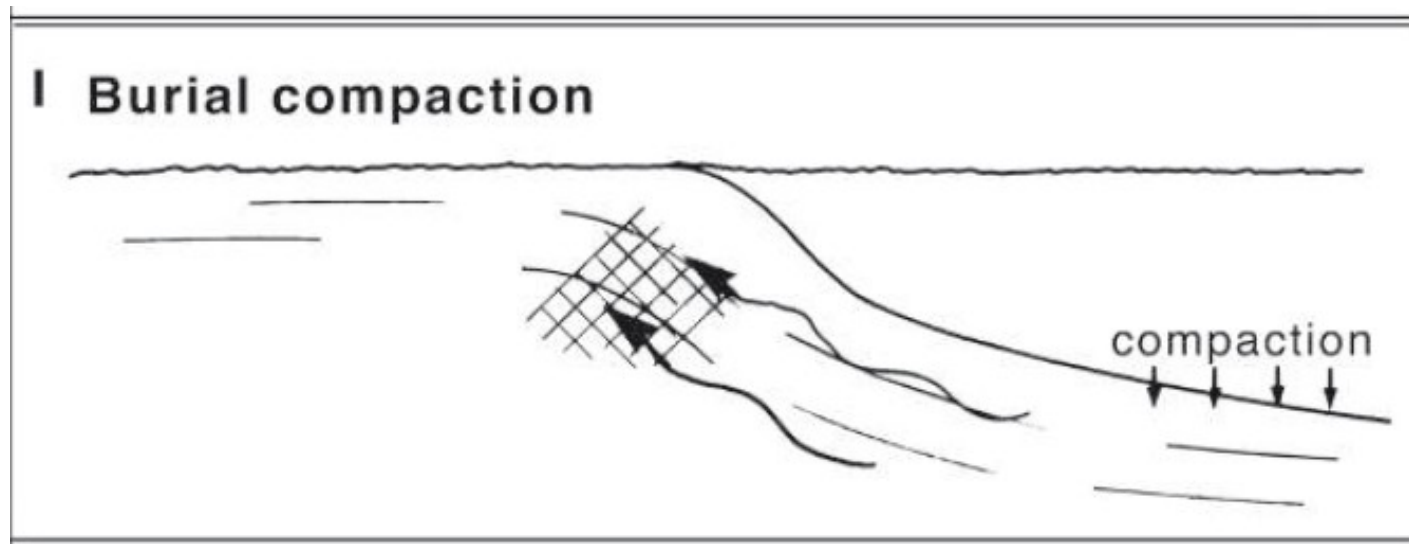
### E Mixing-zone, unconfined coastal aquifer



# Modely dolomitizace

## Dolomitizace pohřbením

- ▶ Ztráta vody kompakcí z jílových hornin a migrace fluid nasycených Mg
- ▶ Dolomitizace vápenců okraje šelfu



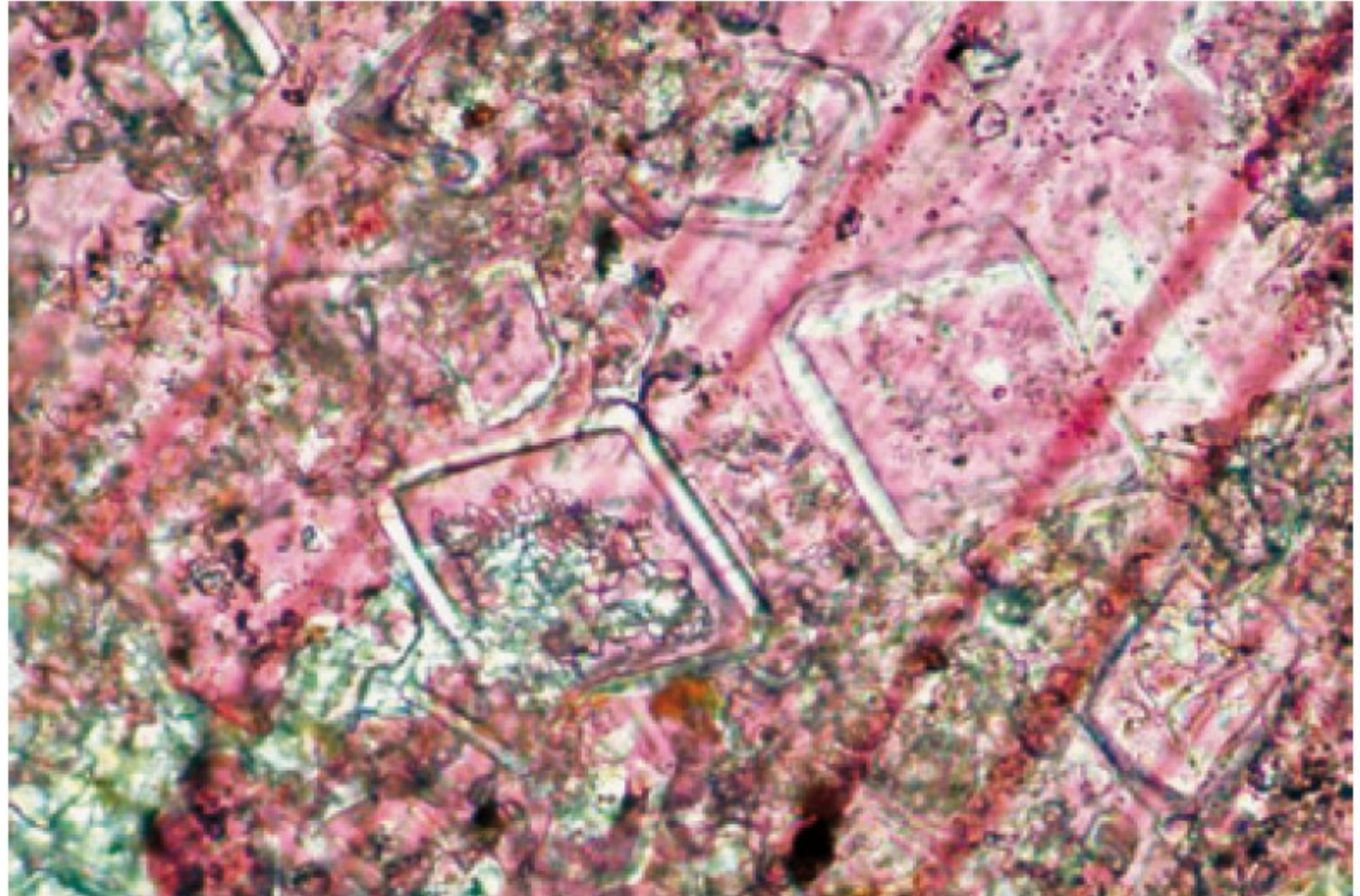
# Dedolomitizace

- Nahrazování dolomitu low-Mg kalcitem

## **Mississippian (Visean) Arroyo Peñasco Gp., Terrero Fm., Taos Co., New Mexico**

Dedolomitization (calcitization of dolomite) is demonstrated in this example by a combination of staining and observation of internal collapse fabrics. The cores and/or certain zones of the crystals are inferred to have been poorly ordered dolomite that was susceptible to dissolution. The residual zones of less soluble dolomite collapsed and formed geopetal mounds at the bottom of rhombic voids still rimmed by thin dolomite rinds. The void spaces from dolomite dissolution and collapse were cemented by calcite at a later stage.

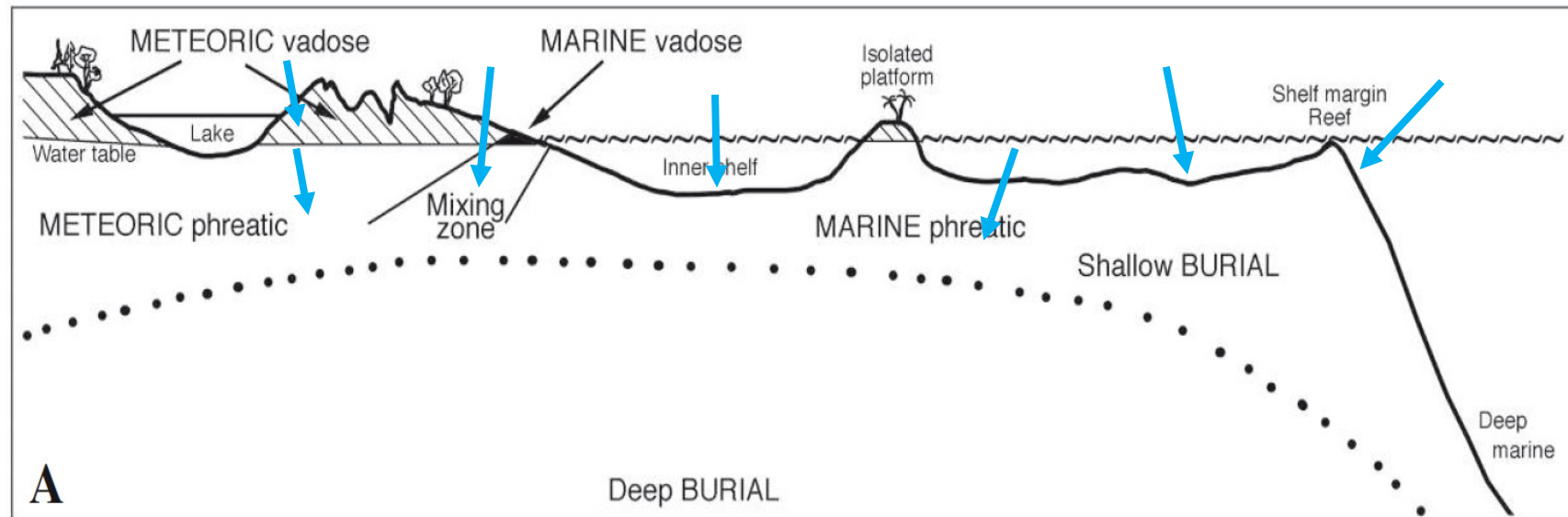
PPL, AS, HA = ~0.4 mm



# **Diagnostická prostředí a fáze**

# Fáze a místa diagenese

- **Raná mělká diagenese (eogeneze)** – na povrchu a při mělkém pohřbení (v zónách meteorické/marinní vadózní, meteorické/marinní freatické a v zóně míšení)
  - Vadózní zóna – nenasurovaná zóna (v pórech voda+vzduch)
  - Freatická zóna – saturovaná zóna



# Meteorická diagenéze

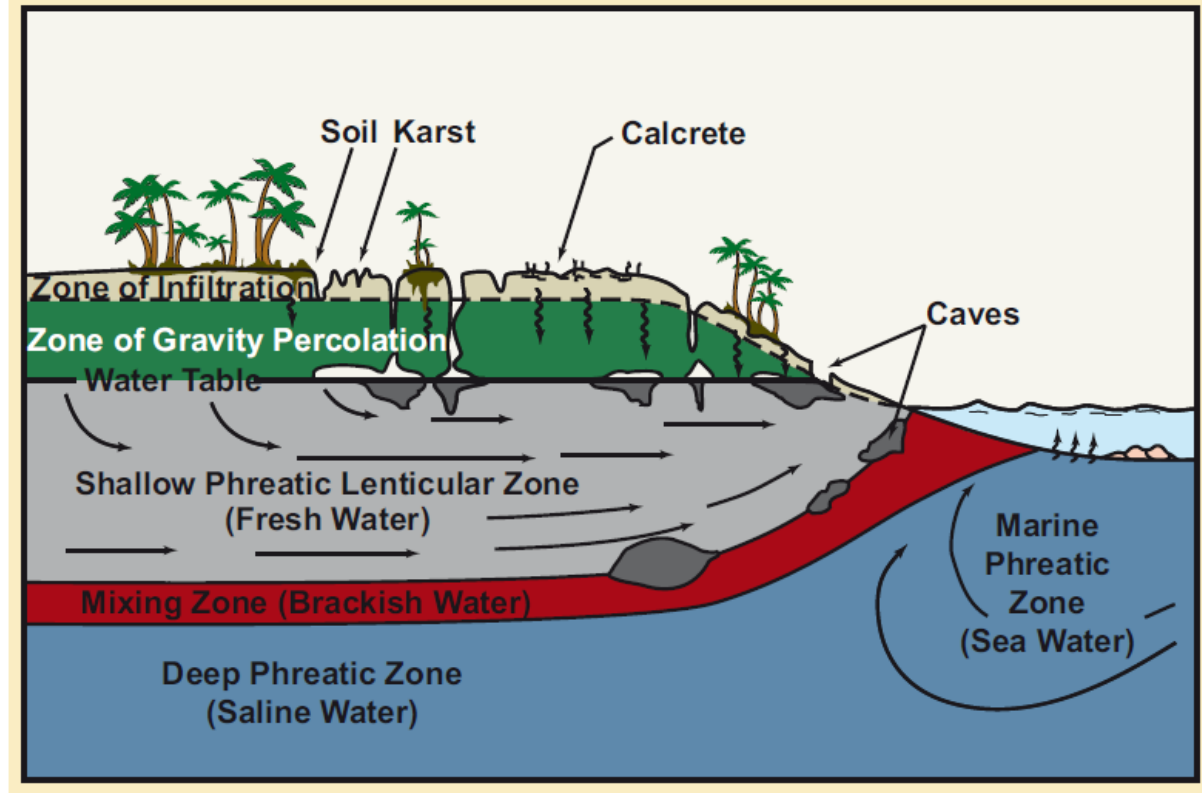
Procesy: rozpouštění, cementace,

Typy cementu:

Mikritové, low-Mg kalcit, meniskové

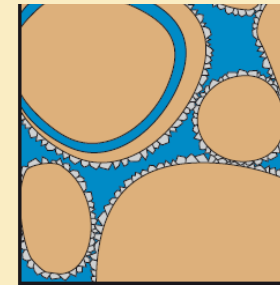
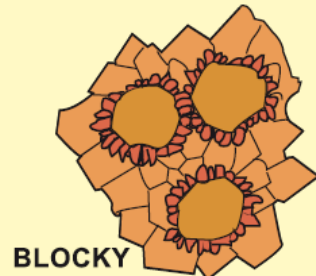
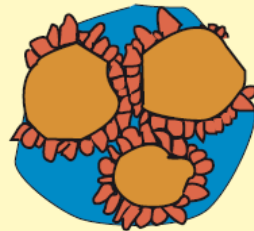
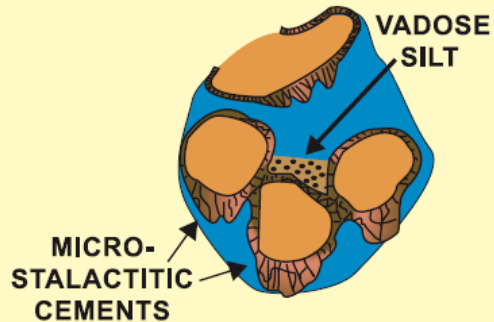
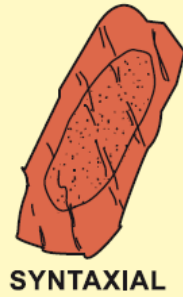
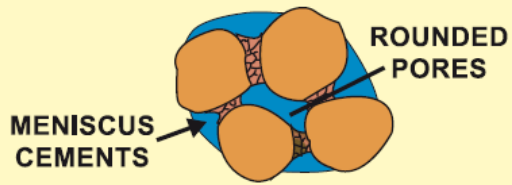
Kalkrety:

- V půdních horizontech,
- Mikritické – mikrosparitické cementy, výplň porů nebo nahrazování



## VADOSE ZONE

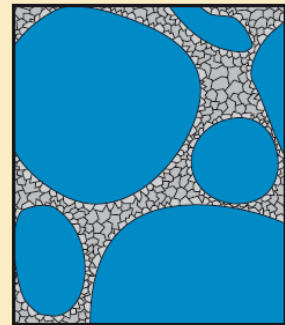
## PHREATIC ZONE



Partial phreatic cementation; incipient grain leaching

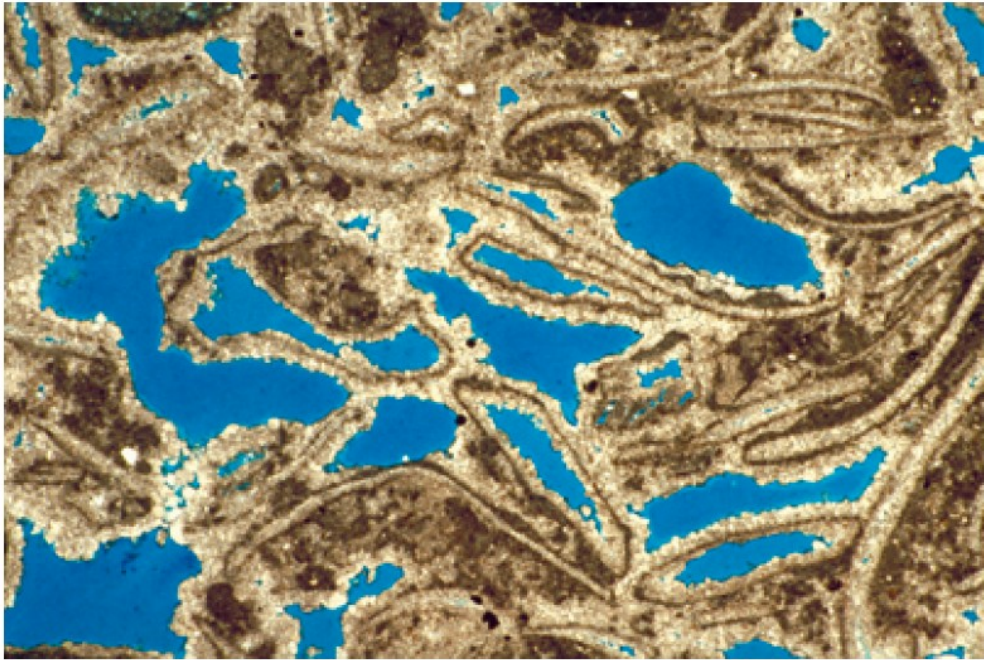


Complete phreatic cementation; moderate grain leaching



Meteoric porosity inversion; complete grain leaching



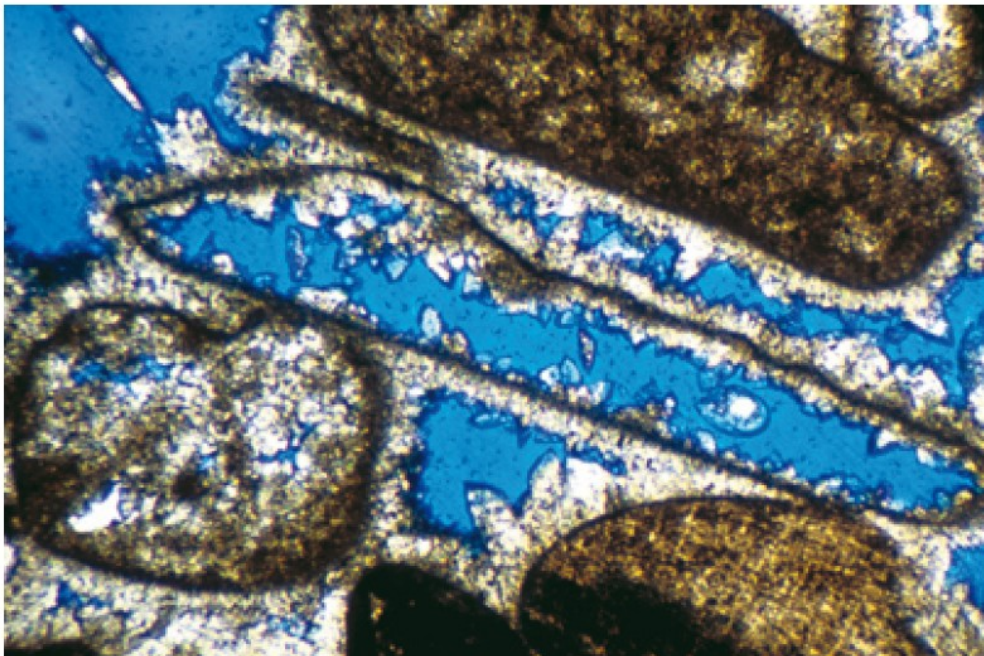


**Up. Permian Zechstein Ca1 unit,  
2,429 m depth, W of Gdansk,  
Poland**

The micrite envelopes that form around skeletal and other grains in the marine environment (discussed in the section on marine diagenesis) play a substantial role in fabric preservation during meteoric or early burial alteration. Here, micrite envelopes (probably originally high-Mg calcite) mark the locations of leached aragonitic grains. Most envelopes have a thin coating of probable phreatic calcite cement on their exterior (primary interparticle pore) surfaces and on their interior (secondary porosity) surfaces.

PPL, BSE, HA = 9.0 mm

Zachování původní biogenní stavby díky mikritizaci (mikritovým obálkám) kolem původních alochemů, které byly rozpuštěny.



**Up. Cretaceous limestone,  
Zakinthos, Ionian Islands, Greece**

A magnified view of a micrite envelope surrounding a leached aragonitic bioclast. Complete bladed calcite cement crusts surround the envelopes on their exterior surface and fewer and more isolated crystals are present on the inside surfaces. Although this may well reflect meteoric diagenetic processes, it could also be the product of shallow burial diagenesis (e.g., Melim et al., 2002).

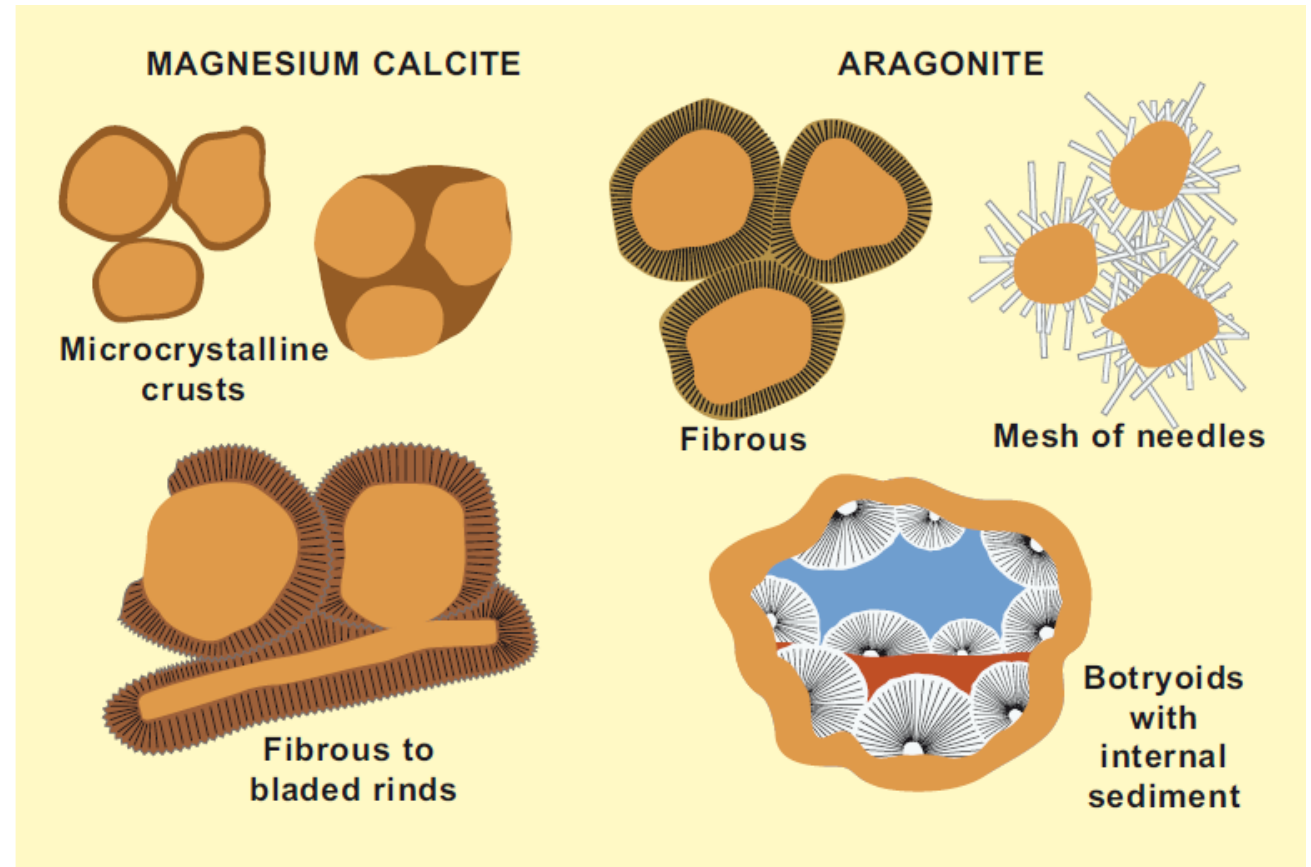
PPL, BSE, HA = 2.0 mm

# Marinní diageneze

## Marinní freatické prostředí:

- na mělkém či hlubokém mořském dně a přímo pod ním
- póry vyplněny mořskou vodou
- **mělkomořské prostředí:**
- vody přesycené k  $\text{CaCO}_3$  = rychlá cementace AR + HMC
- různé typy cementu (aragonitové - vějířový, jehlicový; HMC - blokový izometrický)
- roky až desítky tisíc let

- **hlubokomořské** a chladnovodní prostředí: vody podsyceny k  $\text{CaCO}_3$  – rozpuštění



# Marinní diagenéze

**Beachrock** (peritidální karbonáty): cementované sedimenty pláží, vrtání, mikritické a jehlicovité cementy,



# Marinní diagenese

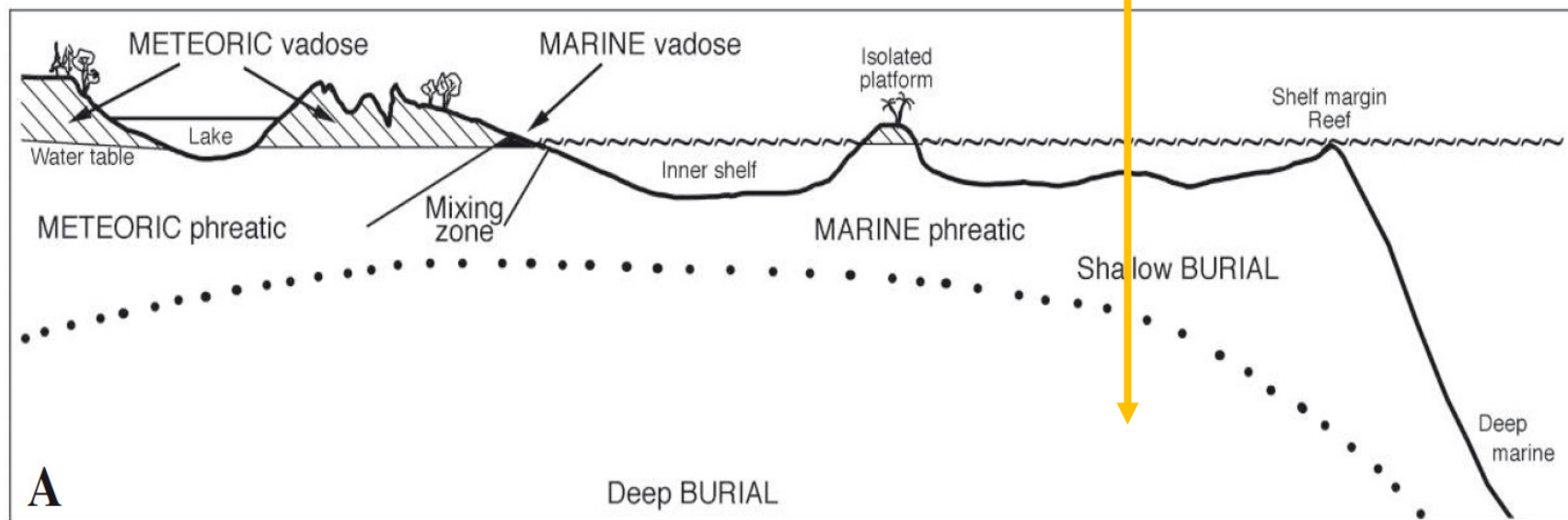
## Hardground:

- zpomalení sedimentace, diagenese v přípovrchové zóně sedimentu
- cementace mělce pod povrchem sedimentu (cementace mořského dna) – exhumace cementované vrstvy při bouři – osídlení pevného povrchu biotou
- mikritizace, bioturbace (typicky vrtby)
- bývá spojeno např. s chemogenní sedimentací – enkrustace Fe-Mn oxidů či hydroxidů, fosfatizace



# Fáze a místa diagenese

- Střední fáze diagenese (mesogeneze) – diagenese hlubokého pohřbení



# Diageneze pohřbením

póry vyplněny solankami (brakické až velmi slané)

Podmínky: tlak nadloží, zvýšená teplota, nízká porozita

Procesy: neomorfismus, chemická a mechanická kompakce (stylolitizace)

Typy cementu:

Izometrický, syntaxiální

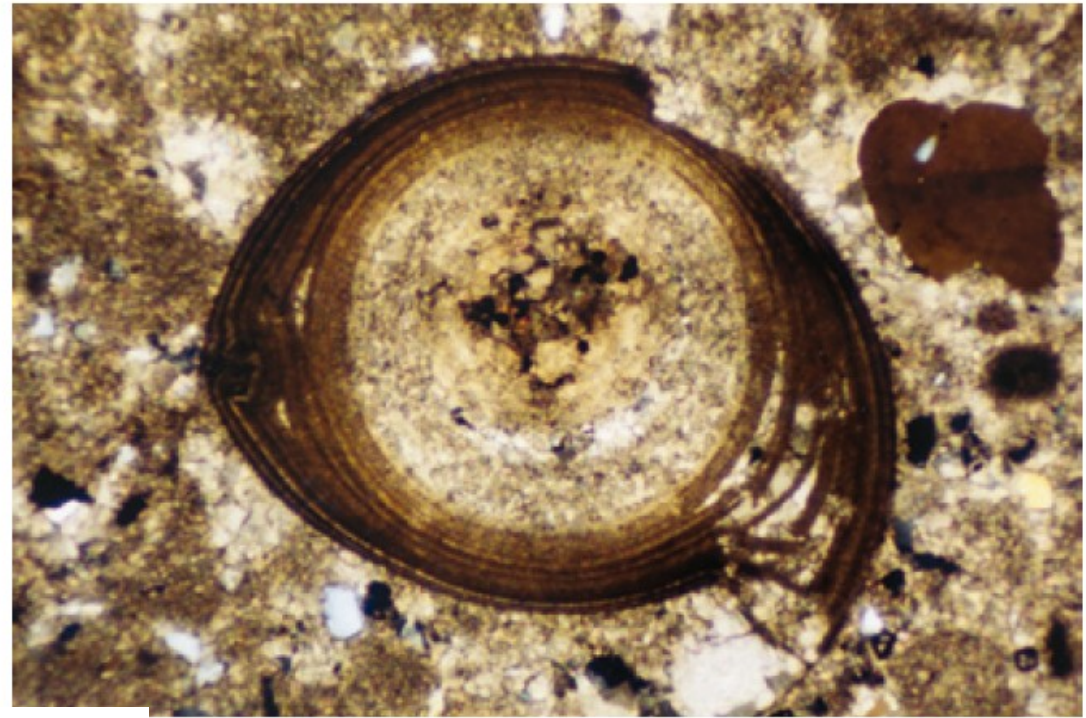
Hrubozrnný low-Mg kalcit, siderit, ankerit, dolomit

Miliony až stovky milionů let

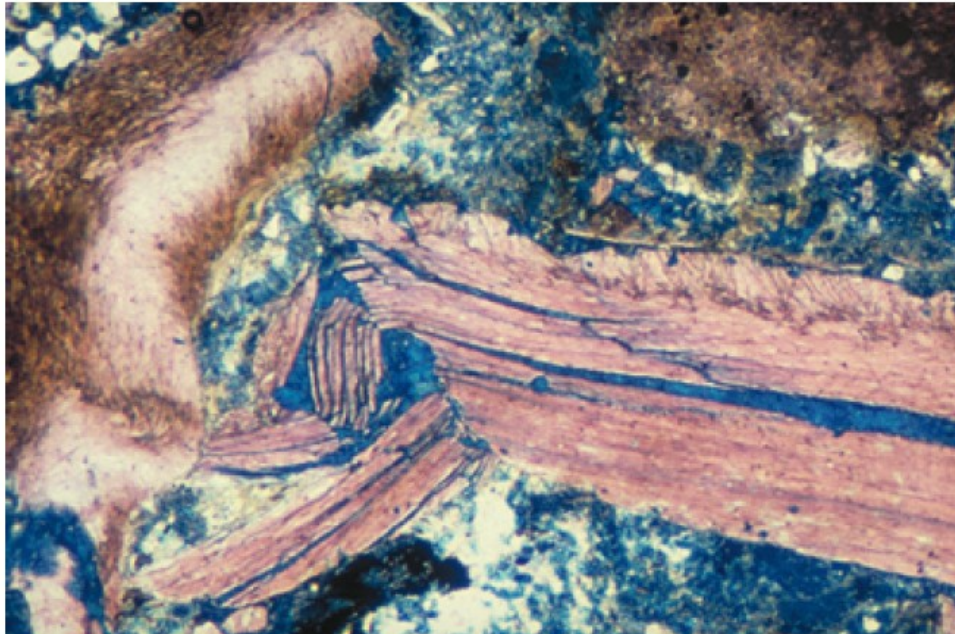


### Up. Cambrian Gatesburg Fm., central Pennsylvania

An example of a brittle deformation of an ooid showing outer concentric laminations that are sheared away from the rest of the ooid. Dissolution of thin interlayers within the ooid may have aided this deformation, but substantial overburden stress was also required. Such textures indicate that much of the cementation in this rock postdates compactional deformation.



XPL, HA = 2.8 mm



### Lo. Cretaceous Paw Paw Fm., Grayson Co., Texas

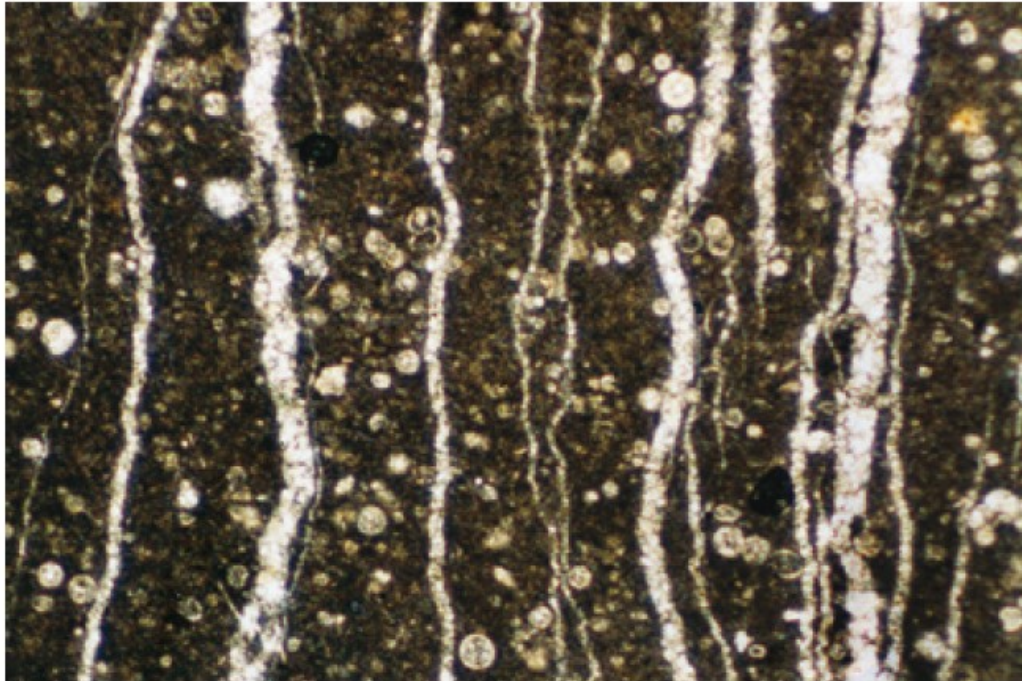
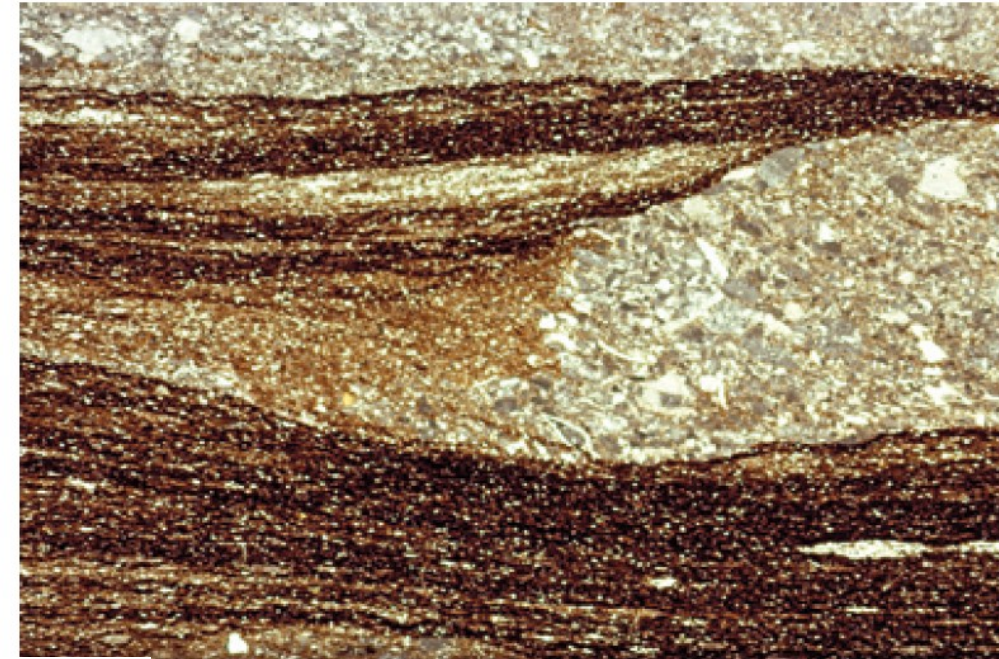
Compactional fracturing of robust oyster-like bivalve shells followed by late-stage ferroan calcite and minor siderite cementation. Breakage of strong, rigid grains occurs mainly in strata with little or no matrix in which large grains are in direct contact with each other. Each point contact then acts as a fulcrum for physical grain breakage or a high-stress site for chemical dissolution.

PPL, AFeS, BSE, HA = 1.6 mm

**Up. Permian (Guadalupian) Capitan Fm., subsurface, Eddy Co., New Mexico**

These dissolution structures resulted from chemical compaction around an early-formed carbonate nodule, probably created by preferential cementation of a crustacean burrow. Compaction here involved formation of numerous solution seams (brownish, irregular streaks) in areas not strongly cemented during early diagenesis. Solution seams are more planar than stylolites, involve less dissolution along any single surface, but occur in such numbers that, in aggregate, they can accomplish extensive alteration; the swarms of surfaces are sometimes called “horsetail seams”.

PPL, HA = 16 mm



**Up. Cretaceous Chalk, Yorkshire, England, U.K.**

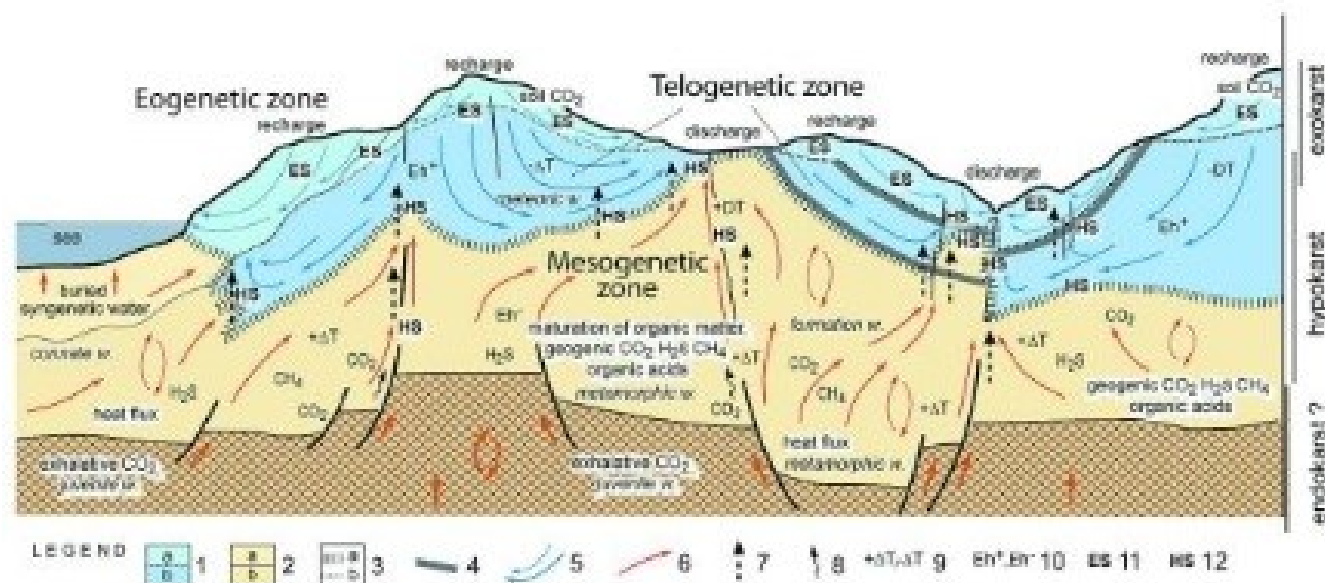
Calcite-filled fractures cutting a calcisphere- and foraminifer-rich chalk. The presence of fractures (when unhealed by calcite or other minerals) can, and in many cases does, greatly increase the effective permeability of chinks and other carbonate rocks, substantially improving hydrocarbon production. Some fracturing can occur in early-cemented limestones in both marine and meteoric settings. Extensive fracturing, however, is most commonly a burial diagenetic phenomenon and is one of the few burial-related processes that can lead to subsurface porosity increases.

PPL, HA = 3.5 mm



# Fáze a místa diagenese

- **Pozdní diagenese** (telogeneze) – po vyzvednutí, vliv meteorických fluid na exhumované fosilní vápence
- Rozpouštění (karstifikace), dedolomitizace, cementace (LMC)



POROZITA

# Porozita

- **Porozita – míra volného prostoru v hornině**
- Nevyplněný prostor mezi zrny, uvnitř zrn, napříč zrny
- Dutiny mikronových až metrových rozměrů
- Hlavní parametr uhlovodíkového průzkumu
- Vzorky se impregnují modrým epoxidem (pryskyřice), takže póry jsou dobře patrné (zároveň odliší „druhotnou“ porozitu, která může vzniknout až během tvorby výbrusu)

# Porozita

## Procesy které ovlivňují porozitu

- Rozpouštění = zvětšování pórů
- Cementace = redukce pórů
- Vnitřní sediment (často mikrit mikrobiálního původu) = zmenšování pórů

## Čas vzniku

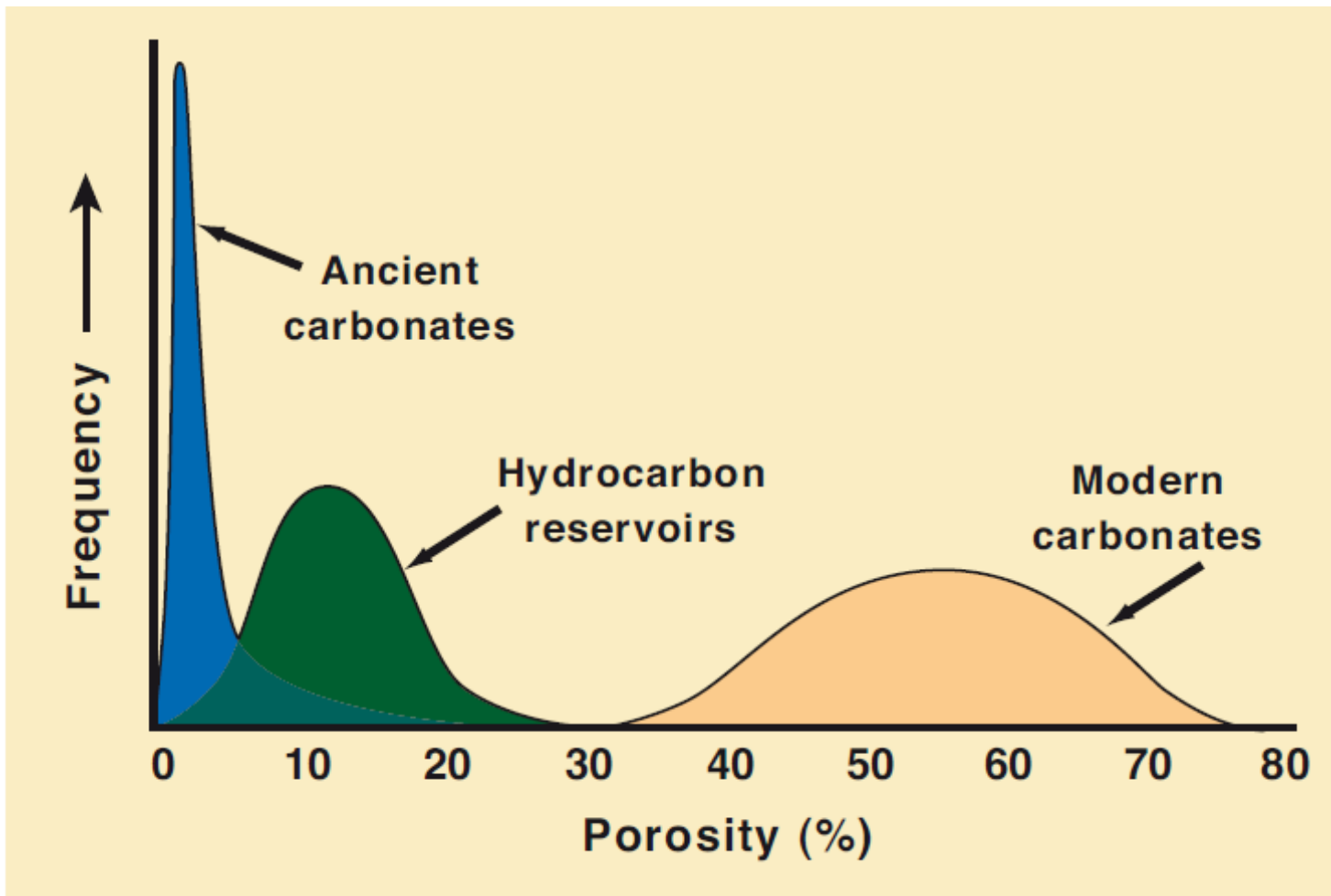
- Primární – depoziční
- Sekundární – eogenetická, mesogenetická, telogeneická

## Velikost pórů

- Mikropóry  $<0,063$  mm
- Mesopóry  $0,063 - 4$  mm
- Megapóry  $4 - 256$  mm
- Kavernózní póry  $>256$  mm

# Porozita

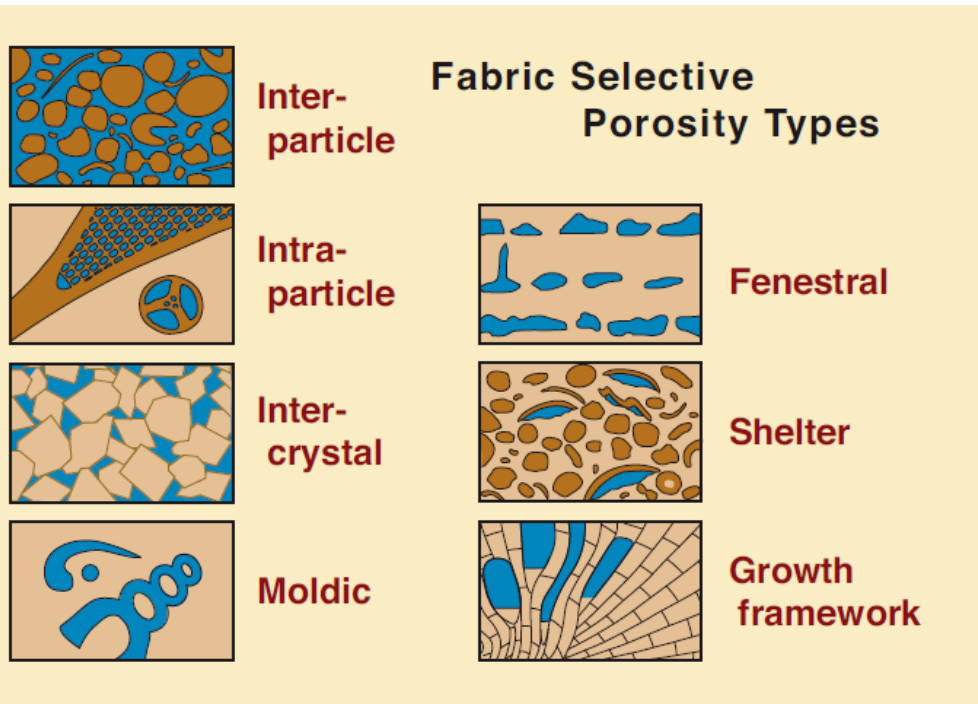
- (sub)recentní vápence mají poměrně vysokou porozitu: grainstones 35-45%, až 70% v kalových usazeninách
- Typické fosilní vápence mají průměrně porozitu menší než 5% - výrazná eliminace pórů při diagenézi



# Porozita

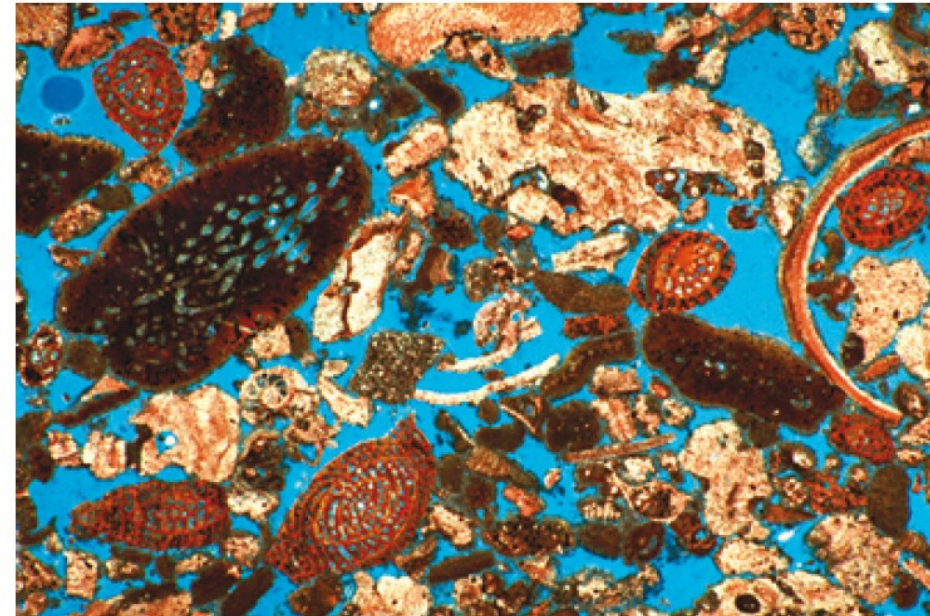
## Stavebně selektivní porozita

- Porozita řízena vnitřní/vnější stavbou – nepřekračuje primární hranice zrn/textur



### Recent sediment, Grand Cayman, Cayman Islands, B.W.I.

A modern calcarenite; a mixed algal-foraminiferal-molluscan limestone that has two types of initial porosity (shown in blue) — interparticle pore spaces (openings between framework grains) and intraparticle pore space (consisting of voids within the constituent grains). Intraparticle porosity is relatively minor in most of the grains, but is clearly visible in the *Halimeda* green algal plates and peneroplid foraminiferal tests.



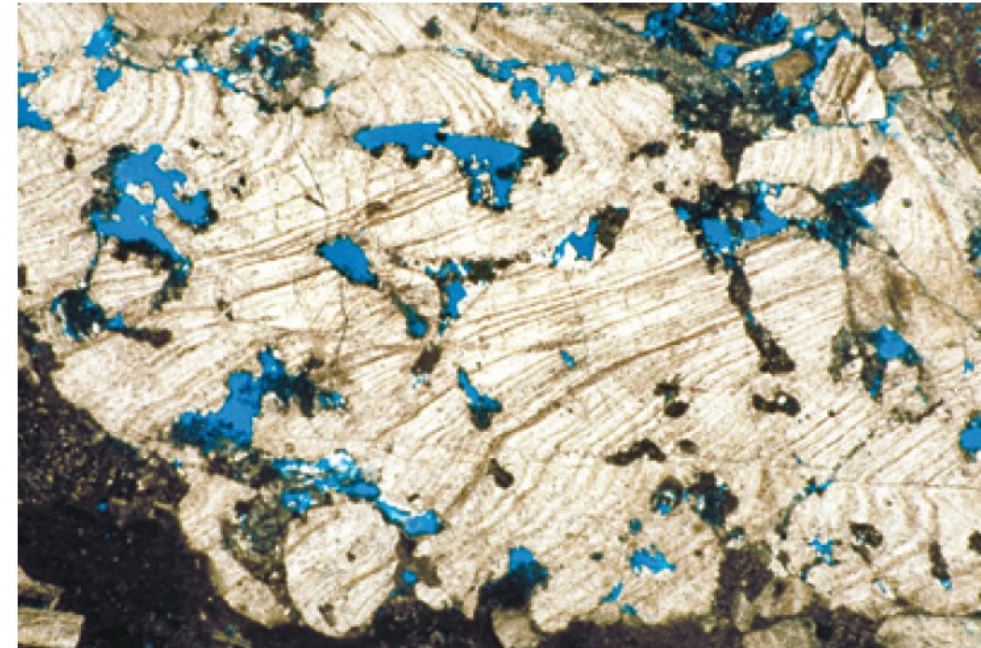
PPL, BSE, AFeS, HA = 6.0 mm

# Porozita

- *Nárůst porozity rozpouštěním uvnitř vrteb ve schránce rudisty (vrtby původně vyplněny mikritem, který byl rozpuštěn)*

## Lo. Cretaceous (Aptian-Albian) limestone, Cephalonia, Ionian Islands, Greece

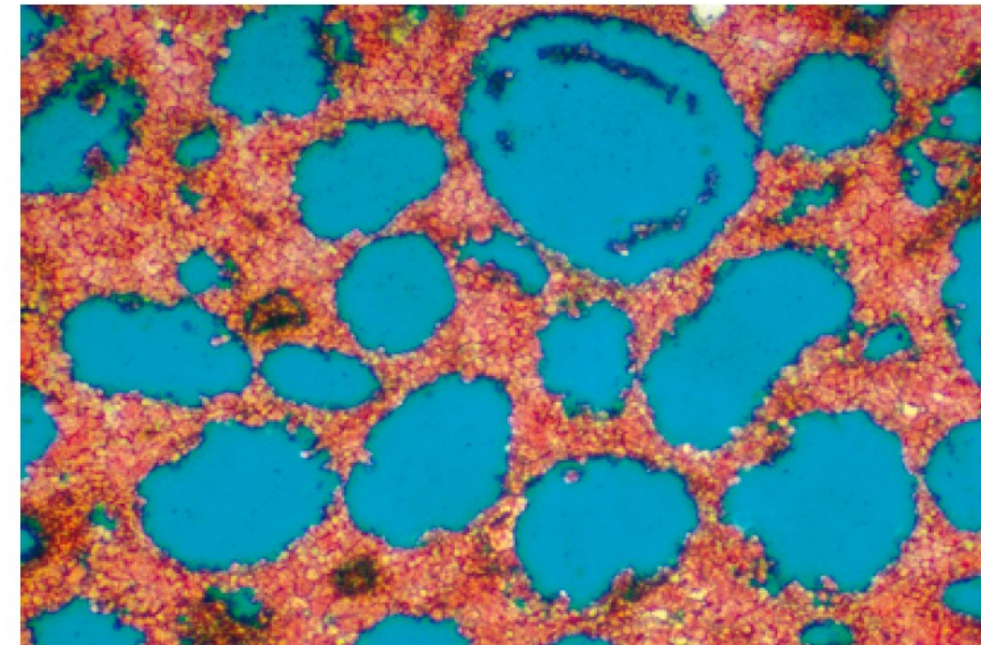
Solution-enlarged boring porosity is visible here within a massive rudistid bivalve fragment. The primary boring porosity was reduced by micrite infill or microcrystalline calcite cementation. Although individual grains can be extensively bored, boring porosity rarely is a major contributor to reservoir productivity.



PPL, BSE, HA = 8.0 mm

## Up. Permian Wegener Halvø Fm., Jameson Land, East Greenland

This sample shows extensive development of secondary porosity through leaching of ooids from a grainstone. The sample comes from just below a Permian subaerial exposure surface (a third-order sequence boundary). Vadose diagenesis led to complete filling of primary interparticle pores by blocky calcite cement and near-complete leaching of ooids, generating oomoldic secondary porosity. Although porosity remained high, permeability was substantially reduced because the moldic pores are poorly connected (mainly at point contacts or through intercrystal gaps).

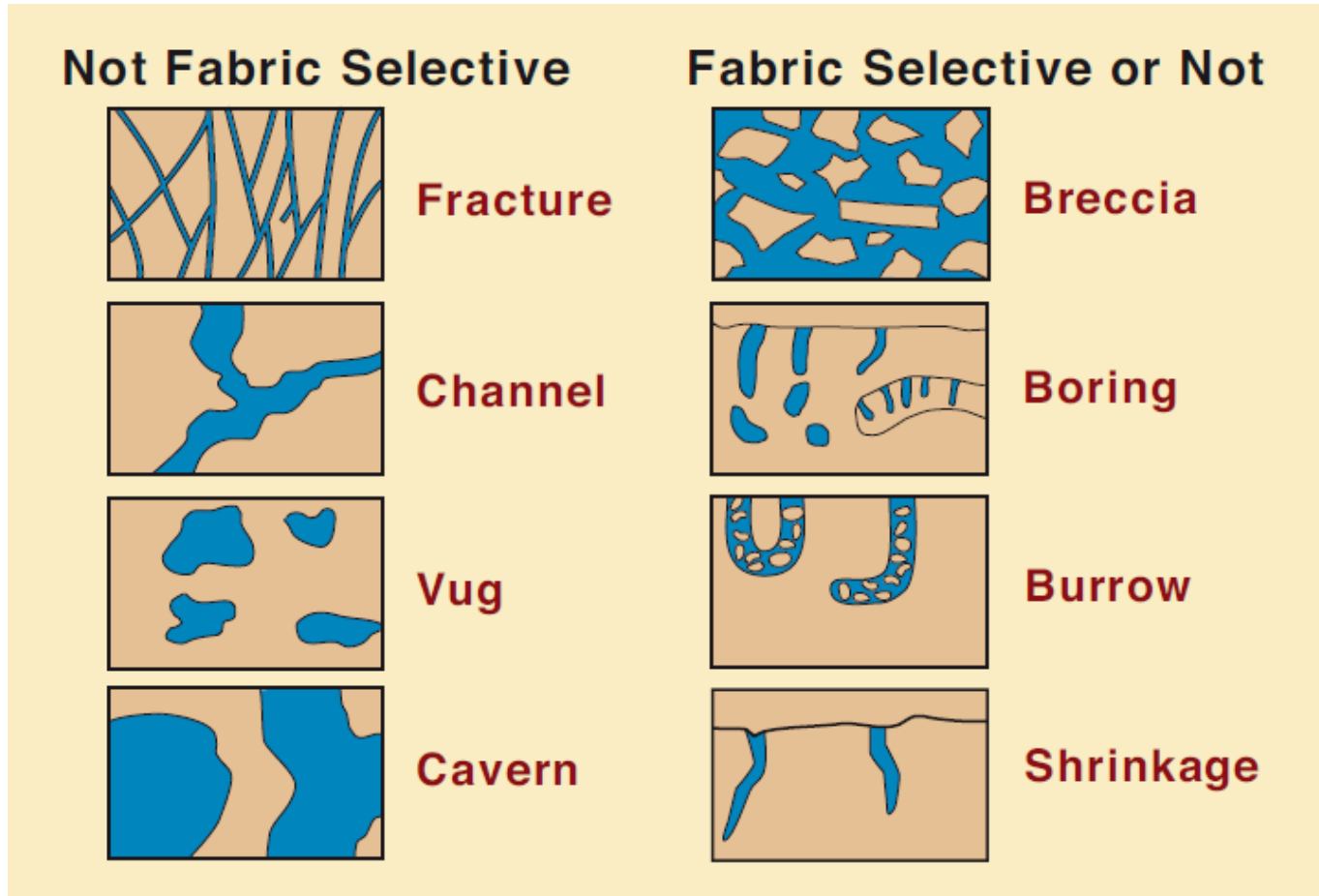


PPL, BSE, AFeS, HA = 3.2 mm

- *Druhotná porozita po rozpuštění ooidů*

# Porozita

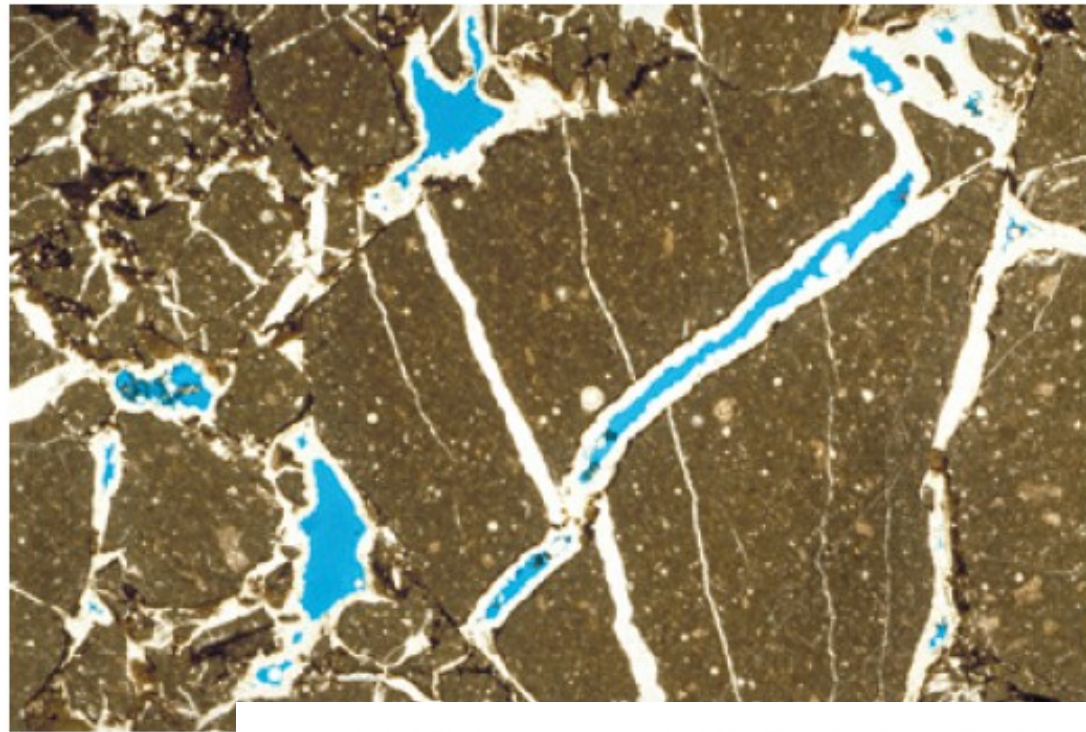
- Porozita nezávislá na stavbě/porozita částečně závislá na stavbě



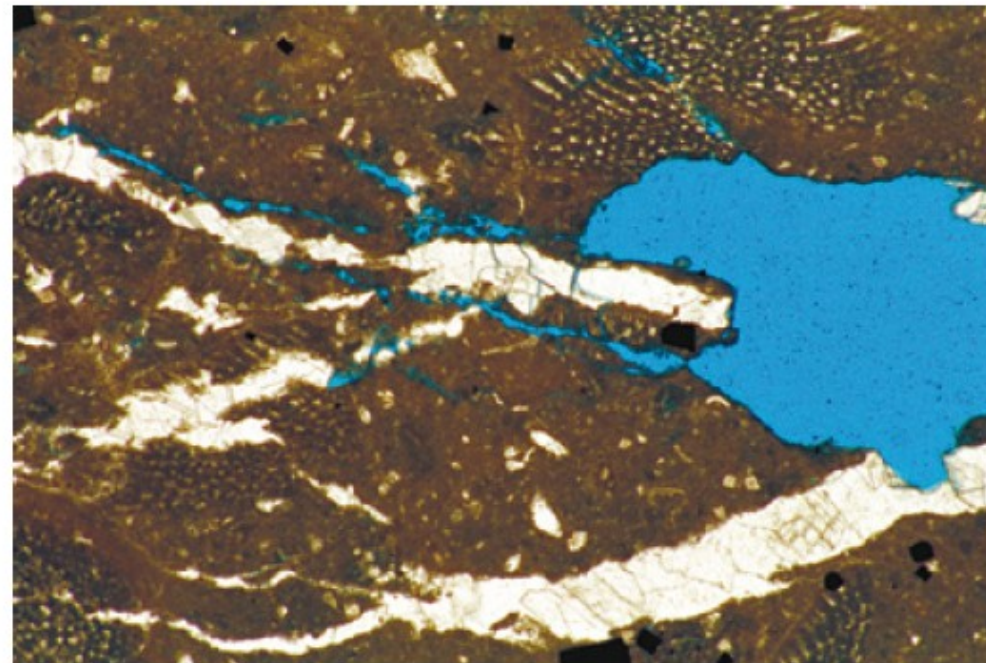


### Up. Permian (Guadalupian) Road Canyon Fm., Brewster Co., Texas

Multiple generations of cement-reduced fracture porosity in a shelf limestone. Note offset of an earlier generation of completely filled fractures by later, partially filled ones. Fracture porosity commonly constitutes only a few percent of total porosity in carbonate rocks; however, it can have a disproportionate importance to permeability and hydrocarbon production because it connects pores that may otherwise be largely isolated.



PPL, BSE, HA = 16 mm



### Lo. Cretaceous (Aptian) Shuaiba Fm., offshore Qatar

A large vug resulting from late-stage leaching in a partially dolomitized orbitolinid wackestone. Note the corrosion around earlier calcite-filled fractures indicating that dissolution occurred late in the diagenetic history of this rock. Petrographic observations such as these are essential for the proper understanding of the origin and timing of porosity development or retention in carbonate reservoir rocks.

PPL, BSE, AFeS, HA = 4.0 mm