Diagenesis of sedimentary rocks

a general introduction

Diagenesis: any chemical, physical, biological change after deposition.

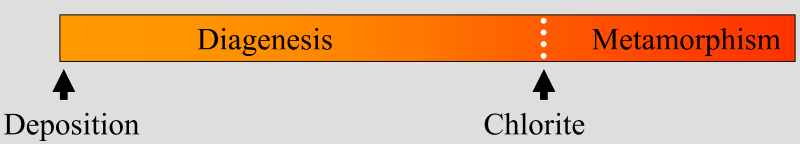
It does not include metamorphism.

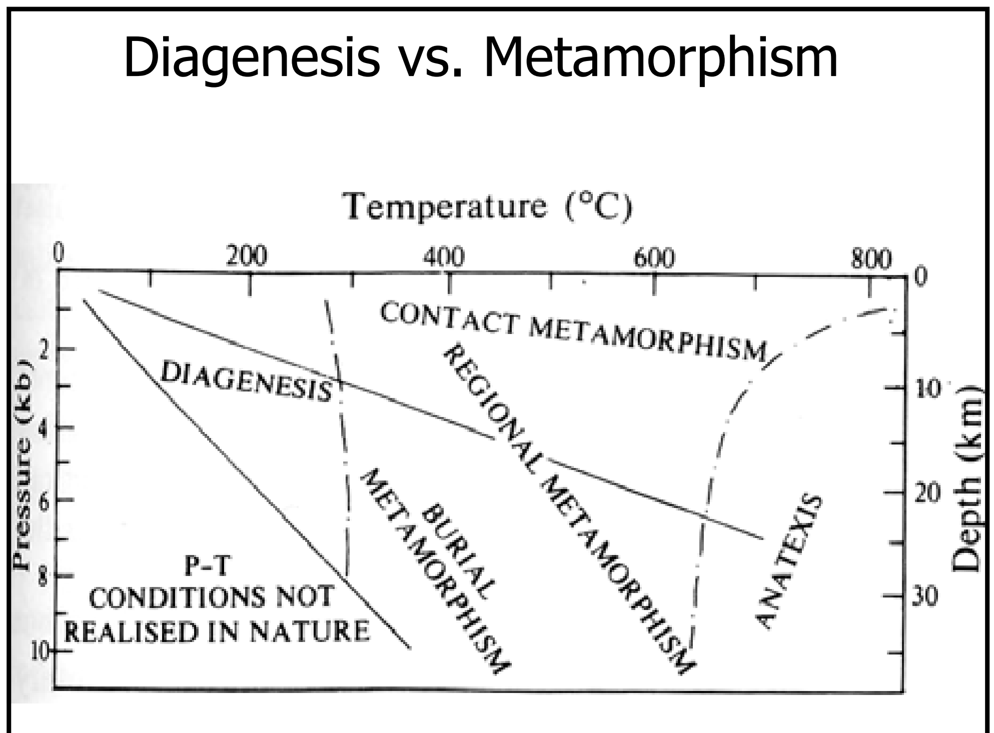
Diagenetic processes can occur also at relatively low temperatures and pressures and cause changes to original mineralogy and texture.

The boundary of pressure and temperatures where diagenesis passes into metamorphism is not clearly defined.

Diagenesis

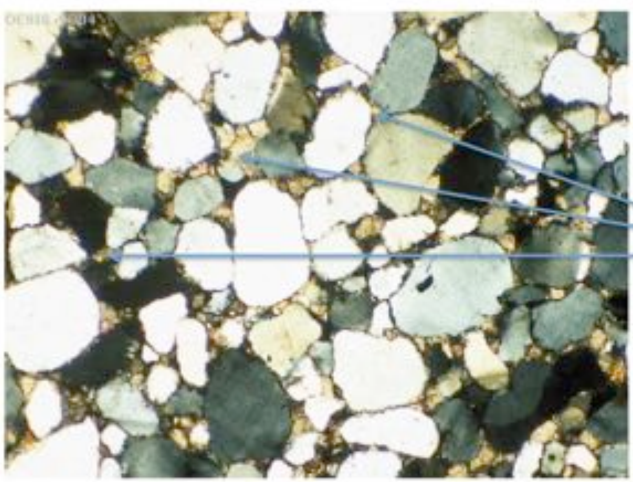
Diagenesis: all changes to sediment/sedimentary rock from the time of deposition to the onset of metamorphism.





From the instant sediments are deposited, they are subjected to physical, chemical and biological forces that define the type of rocks they will become.
The combined effects of burial, bioturbation, compaction and chemical reactions between rock, fluid and organic matter, collectively known as diagenesis, will ultimately determine the potentiality (for a sedimentary deposit) to be a **reservoir** and **source rock**

- The transformation of a sediment into a rock:
- Compaction / recrystallization / dissolution / authigenesis (growth of new minerals) and cementation
- Important economically in terms of porosity (Φ) and permeability (K) and in the formation of oil.



Porosity and permeability of this sandstone has been greatly reduced by the precipitation of calcite cement in between the pore spaces

tp://www.earth.ox.ac.uk/~oesis/micro/medium/sandstone2_pm13-19.jpg

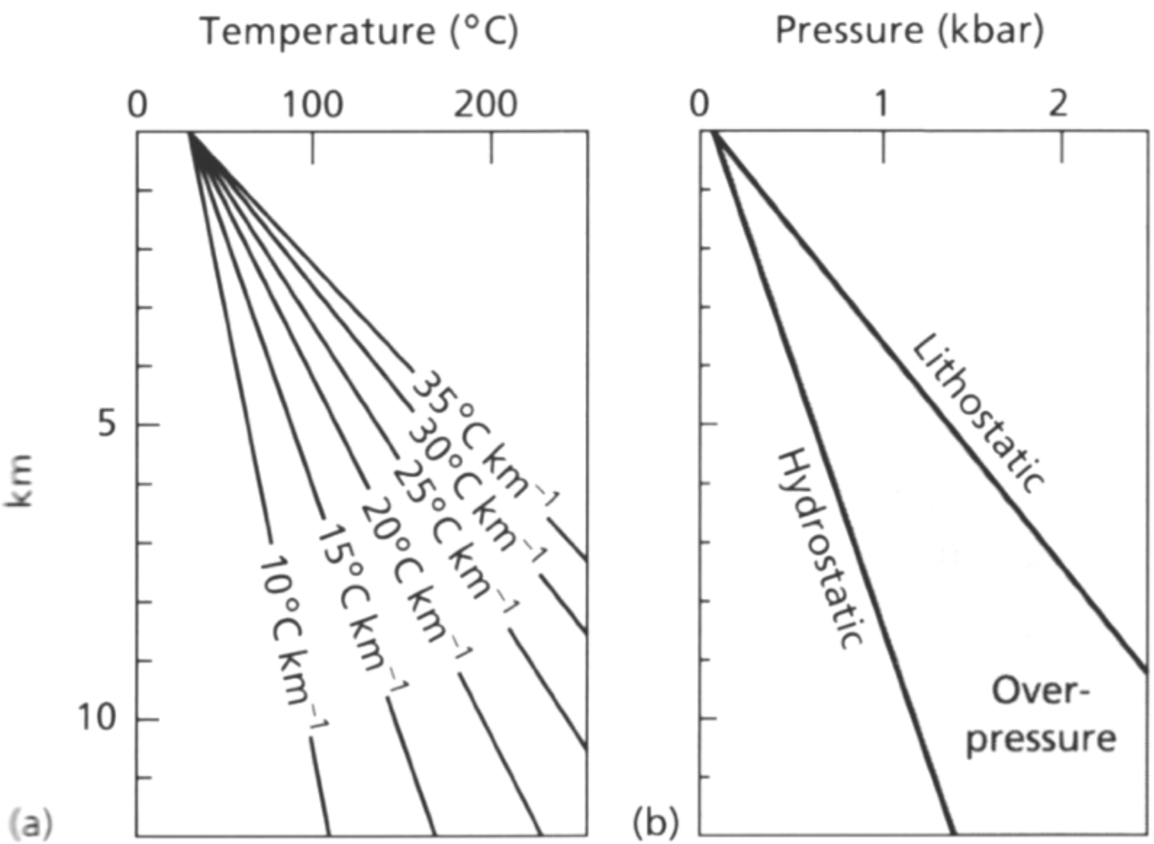


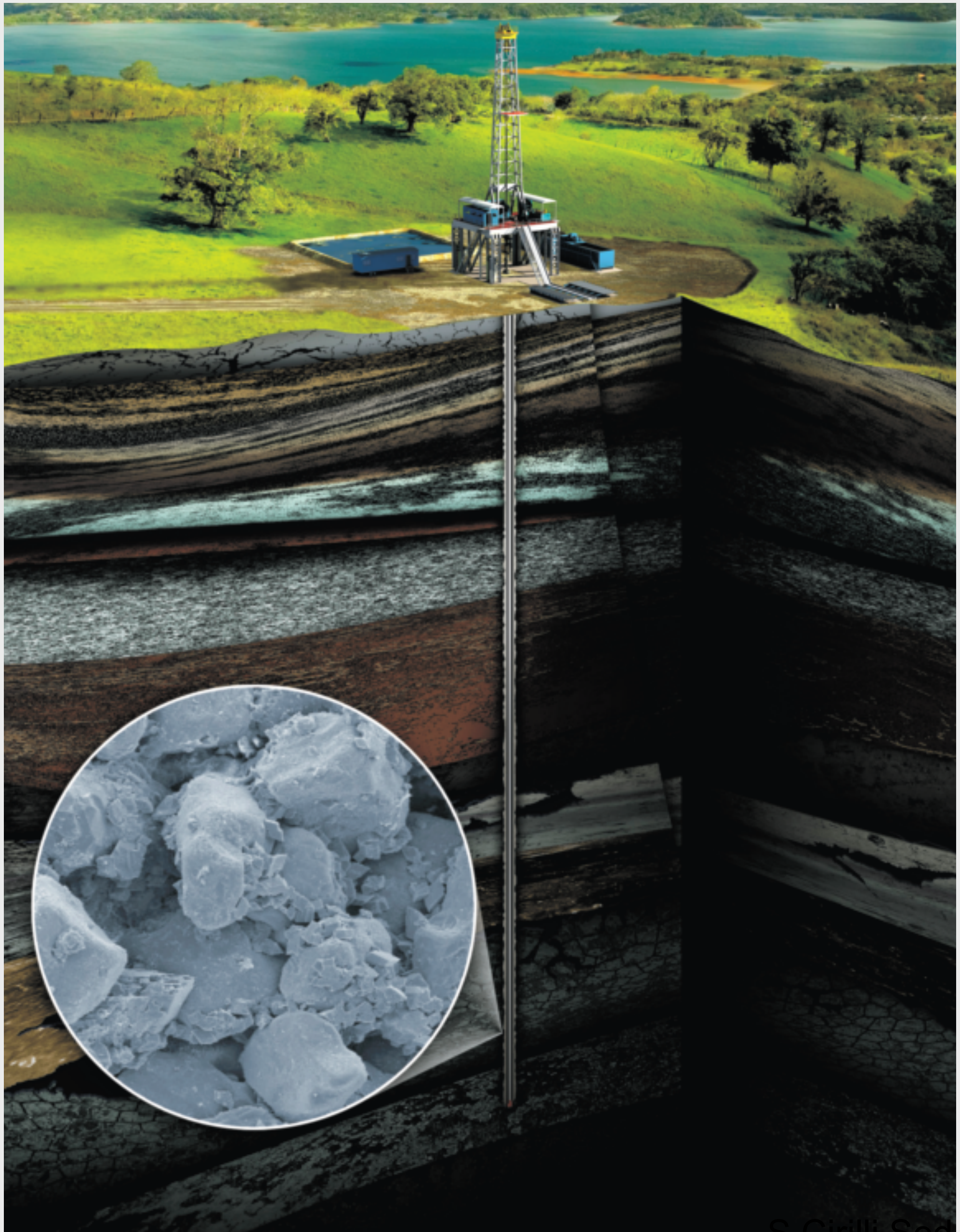
Fig. 2.53 (a) Increase in temperature with increasing depth for different geothermal gradients. (b) Increase in hydrostatic and lithostatic (overburden) pressure with increasing depth.

The range of physical and chemical conditions included in diagenesis is:

- 0 to 200°C,
- 1 to 2000 bars
- and water salinities from fresh water to concentrated brines

The range of diagenetic environments is potentially large

diagensis can occur in any depositional or post-depositional setting in which a sediment or rock may be placed by sedimentary or tectonic processes. This includes deep burial processes but excludes more estensive high temperature or pressure metamorphic rocks.



The study of diagenesis continues to be an active field of research in sedimentary geology, in part because the variety and complexity of the processes involved has left many uncertainties, but also because of the importance of diagenesis to petroleum geology, as diagenesis is a significant control on porosity and permeability of deeply buried sedimentary rocks, comprising the fine siliciclastic source beds, the coarser reservoir rocks, and the seals that cause those reservoir rocks to be petroleum reservoirs.

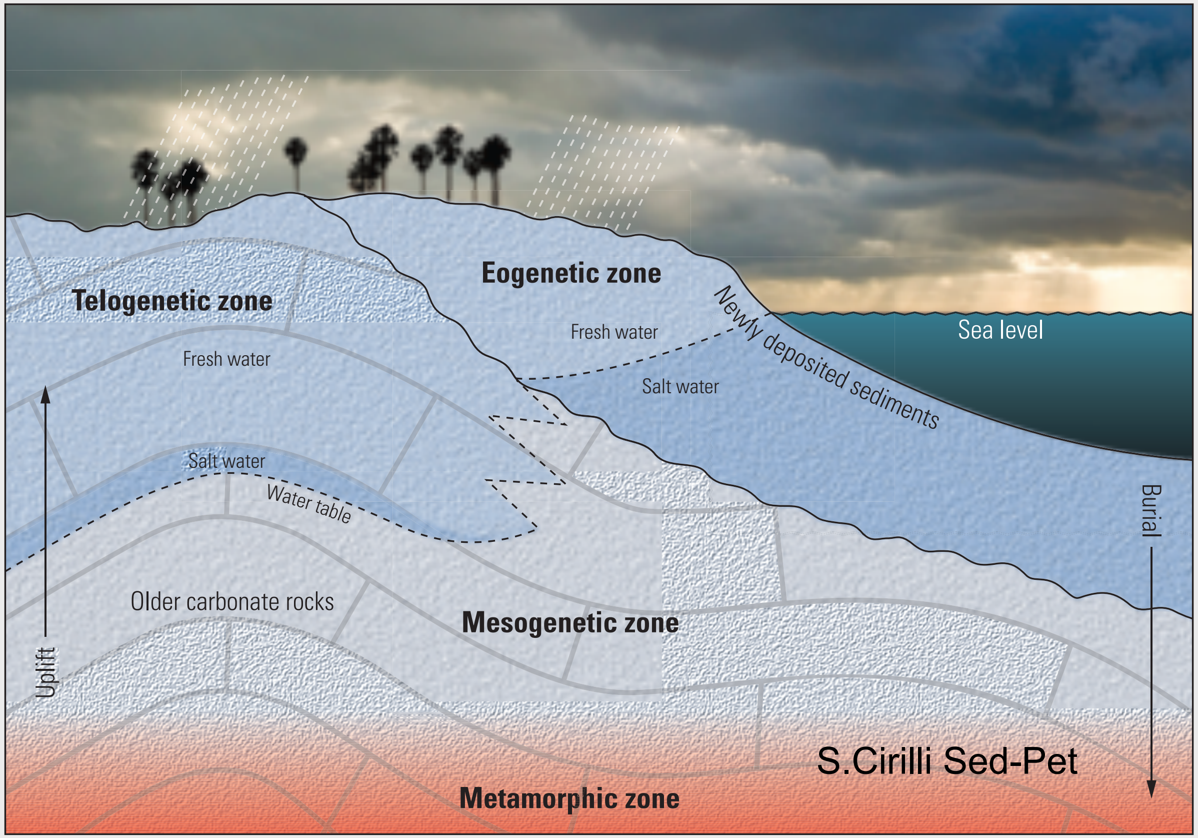
Diagenesis strongly controls the petrophysical properties of sedimentary rocks, although quite different in processes and effects for silicoclastic and carbonate rocks.

Aspect	Sandstones	Carbonates
Amount of primary porosity	Commonly 25% to 40%	Commonly 40% to 70%
Amount of ultimate, postdiagenetic porosity	Commonly half or more of initial porosity: typically 15% to 30%	Commonly none or only a small fraction of initial porosity: 5% to 15%
Types of primary porosity	Almost exclusively interparticle	Interparticle commonly predominates; intraparticle and other types important
Pore diameter and throat size	Closely related to particle size and sorting	Commonly bear little relation to particle size or sorting
Uniformity of pore size, shape and distribution	Fairly uniform	Variable, ranging from fairly uniform to extremely heterogeneous, even within a single rock type
Influence of diagenesis	May be minor: reduction of primary porosity by compaction, cementation and clay precipitation	Major: can create, obliterate or completely modify porosity; cementation and solution important
Influence of fracturing	Generally not of major importance	Of major importance, when present
Permeability-porosity interrelations	Relatively consistent: commonly dependent on particle size and sorting	Greatly varied: commonly independent of particle size and sorting

e.g. : Porosity comparison. In both sandstones and carbonates, porosity is greatly affected by diagenesis— perhaps more so in carbonates. (Adapted from Choquette and Pray, 1970 by Ali et al., 2010

An appreciation of the diagenetic development of a sedimentary succession can also help in understanding of its tectonic history and the kinds of fluids that have moved through it.

This is VERY important information for the mineral and hydrocarbon industries as it relates to the porosity (spaces within a rock expressed as Φ) and Permeability (expressed as K).



Rocks with high Φ and K make excellent reservoirs for oil gas or water.

Diagenesis is also important in understanding the various process that convert organic material in sediments into oil and gas.

Diagenesis is the term used for all of the changes that a sediment undergoes after deposition and before the transition to metamorphism.

Diagenesis is the lithification of loose sediment into solid rock through compaction, cementation, and dissolution.

Diagenesis includes different processes (chemical, physical, and biological) such as:

compaction
deformation,
dissolution,
cementation,
authigenesis,
replacement,
recrystallization,
hydration,
bacterial action
bioturbation

Compaction mostly occurs as sediments **are buried**.

Some minerals will be **recrystallized** or **dissolved**.

New minerals may also grow (**authigenesis**).

Grains become **cemented** by minerals that precipitate from solutions moving through pore spaces.

Generally **porosity decreases during diagenesis**, apart from where **dissolution of minerals** occurs and during **dolomitization**.

Compaction

- Loosely packed sand porosity approaches 25%; saturated mud 60-80% water. Porosity reduced during burial due to overburden pressure
- Fabrics may form identifiable in thin section including: deformation, distortion, flattening
- *Pseudomatrix* formation when rock fragments alter to clays under pressure – looks like a primary clay matrix
- Pressure solution where grain boundaries undergo dissolution and crystallization

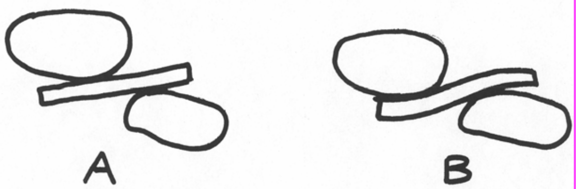
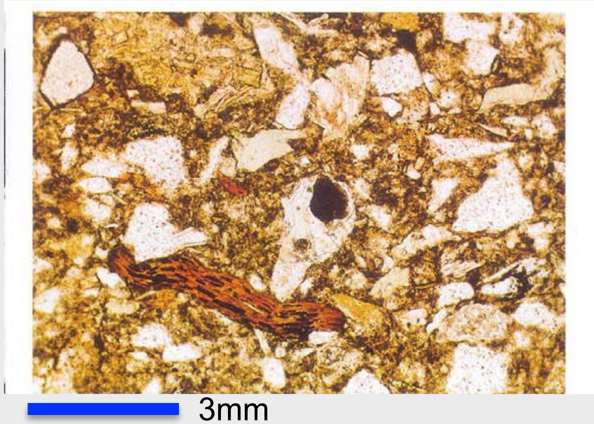
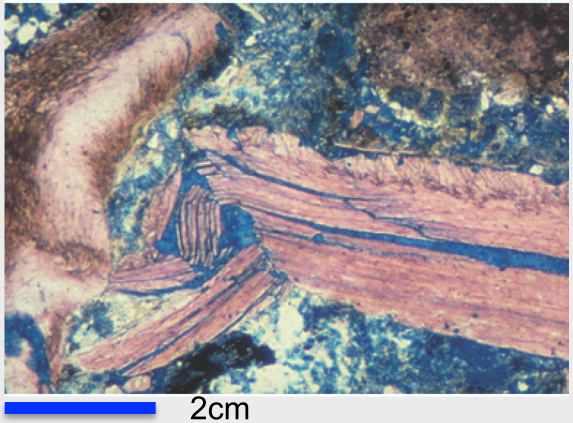


Figure 7-3. Deformation of a muscovite flake between two rigid detrital grains. A) Before deformation; B) after deformation.



Deformed biotite



Deformed-broken bioclast

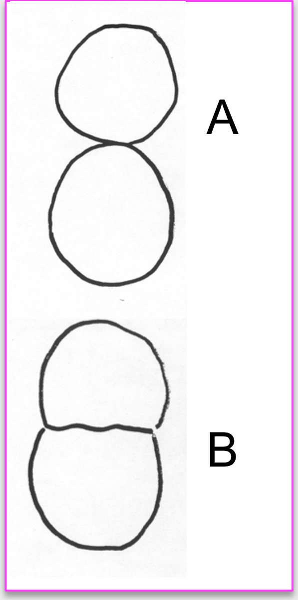
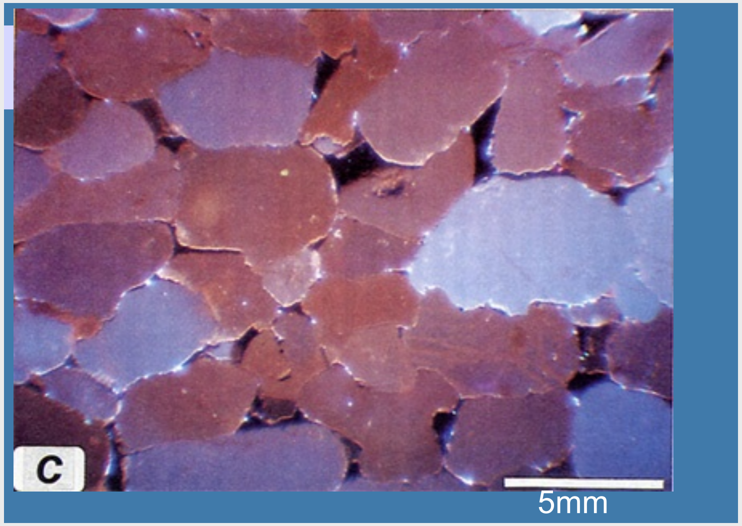
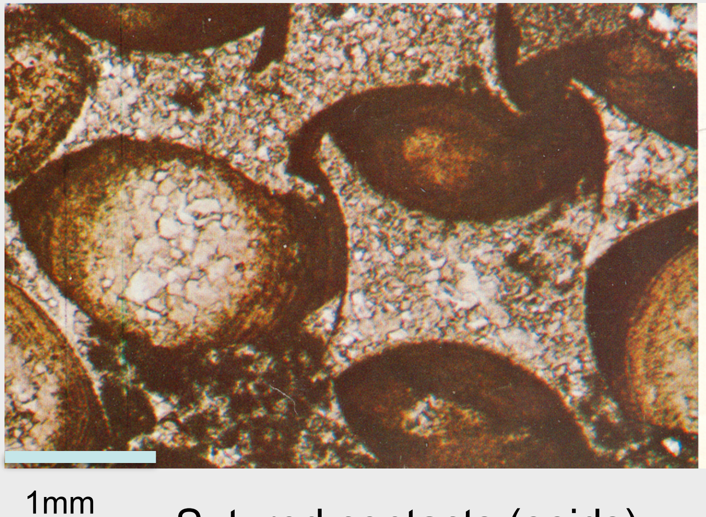


Figure 7-5. Suturing of quartz grains. A) Before suturing; B) after suturing.



Sutured contacts (quartz grains)



Sutured contacts (ooids)

Cementation

- Development of new precipitates in pore spaces

Cementation: pore-filling minerals precipitated into voids within sediment/sedimentary rocks.

- Quartz
- Chert
- Chalcedony
- Opal

- Hematite
- Limonite
- Phosphate
- Clay
- Glauconite

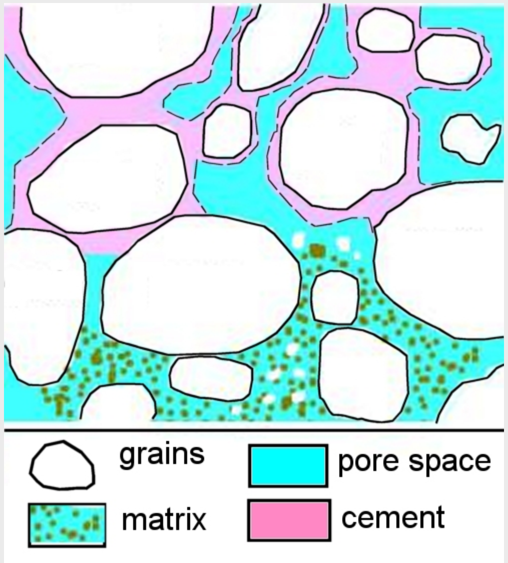
- Calcite
- Aragonite
- Mg-calcite
- Dolomite
- Siderite
- Etc.

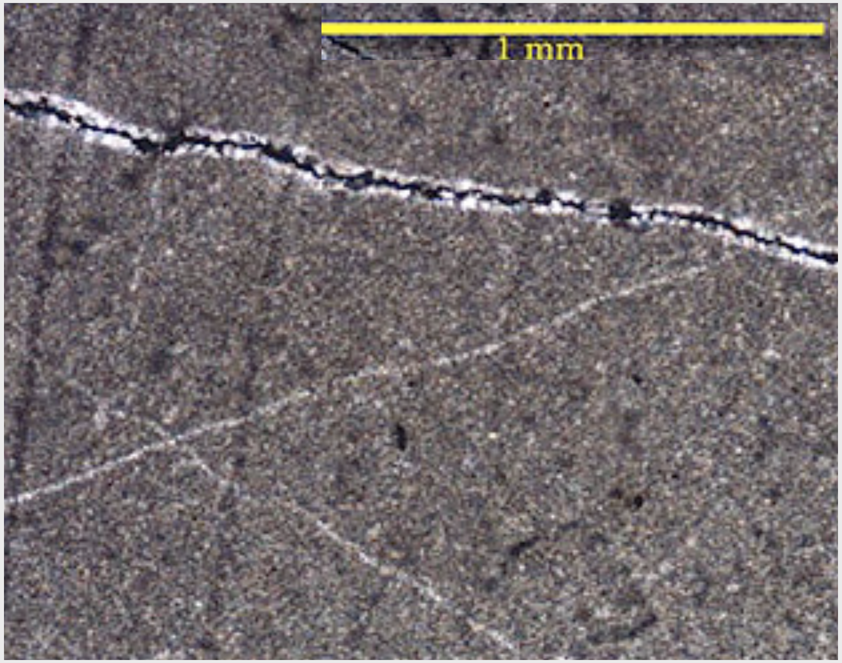
cements: quartz (syntaxial overgrowths,..), carbonate, authigenic feldspars (overgrowths), clay minerals, zeolites, haematite, barite

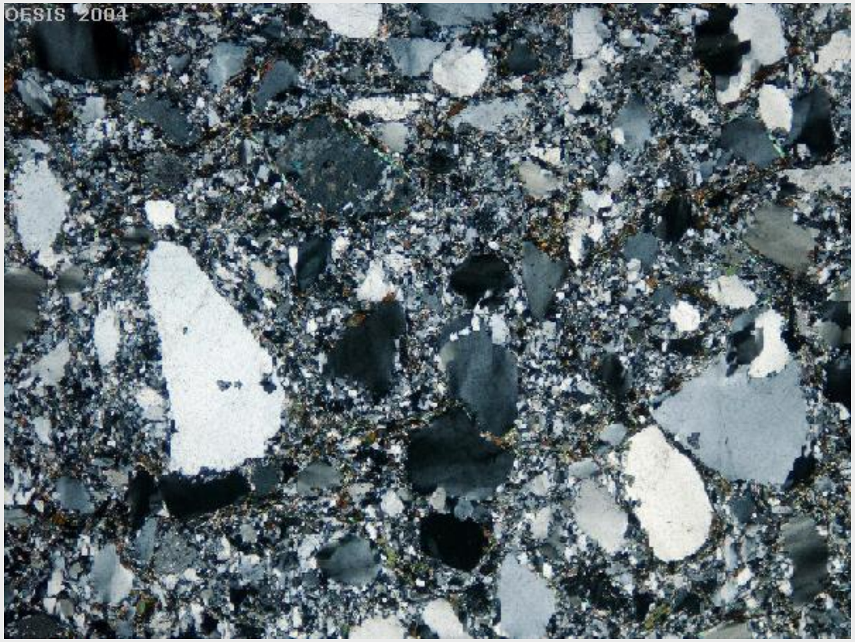
Matrix versus cement

Matrix: grained material deposited simultaneously with larger particles.

Cement: a chemical precipitate between grains from pore-water long after deposition







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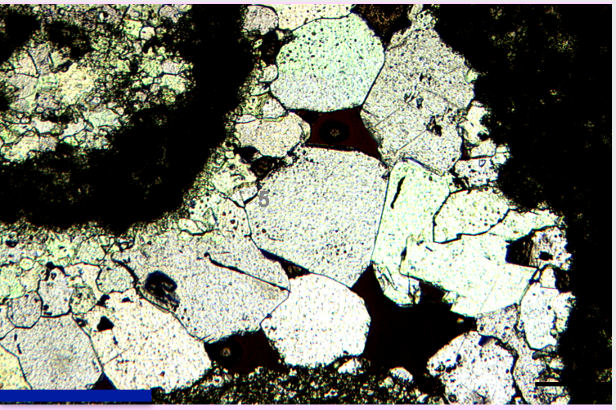
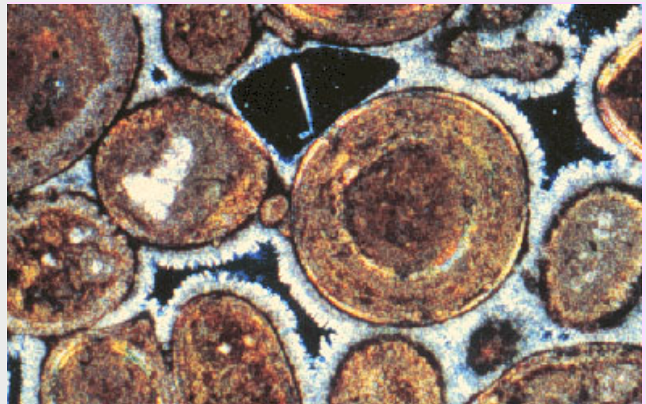


3mm



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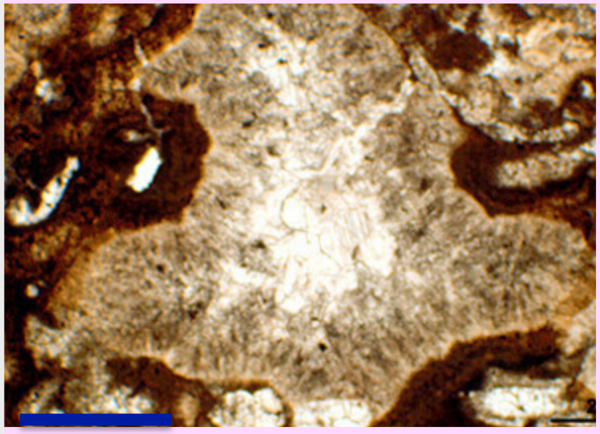

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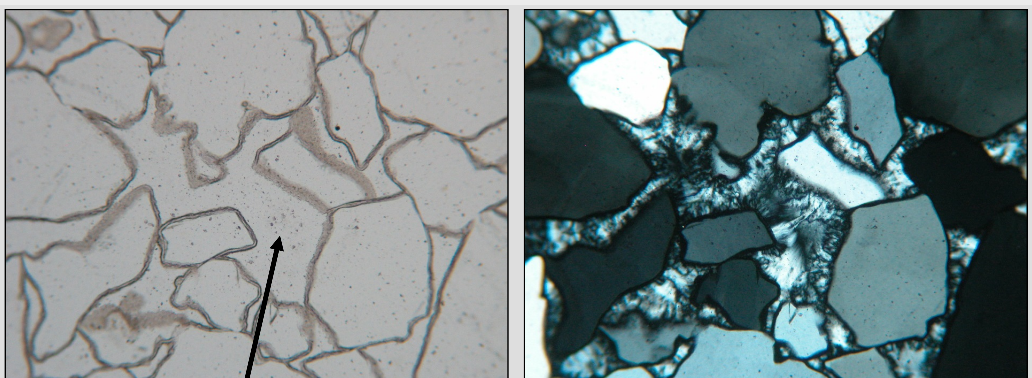


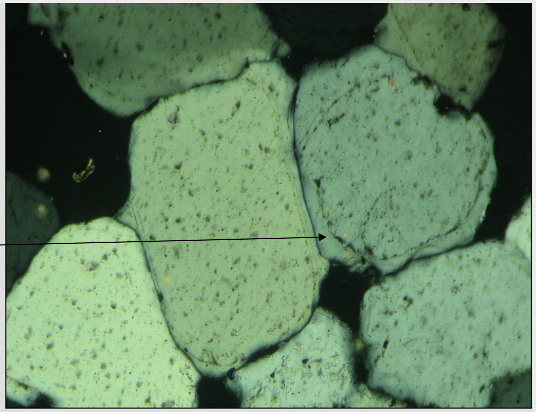
ppl

xn

300 µm

chalcedony

Quartz overgrowth cement



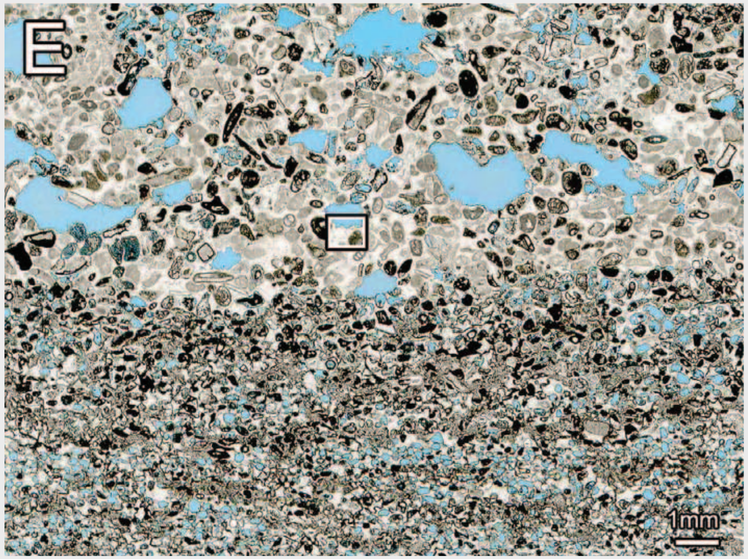
ppl

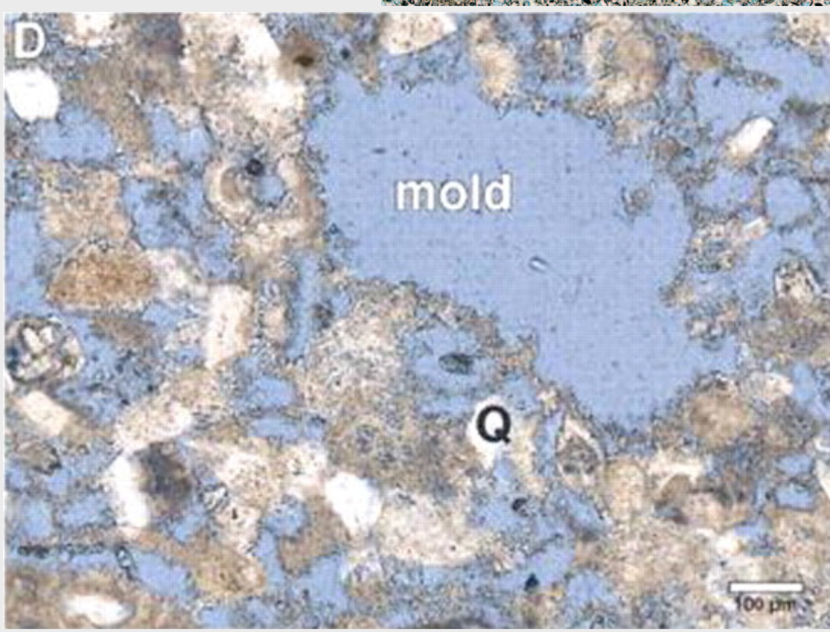
0.25 mm

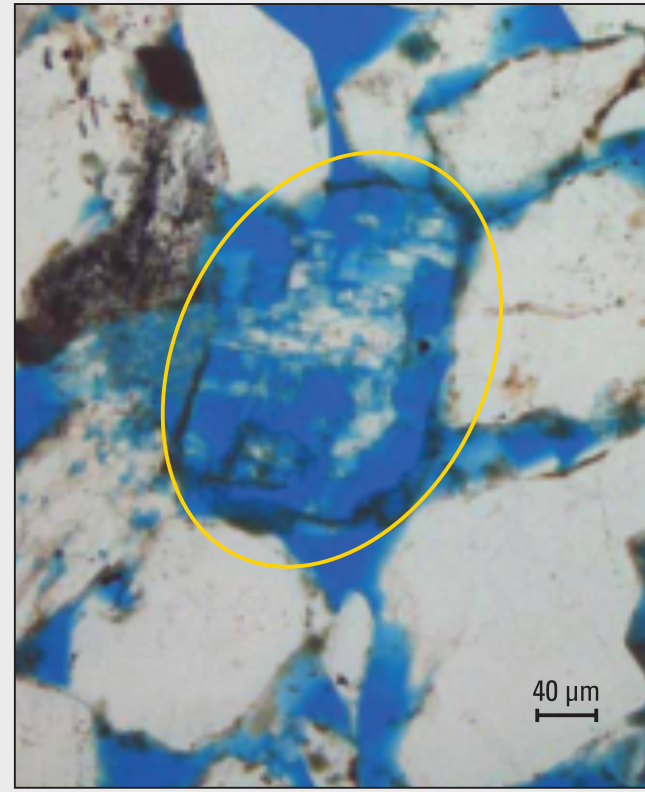
Dissolution

Silicate and carbonate minerals dissolved under peculiar chemical and physical conditions

Plane- light micrograph of skeletal grainstone with vuggy and moldic pores







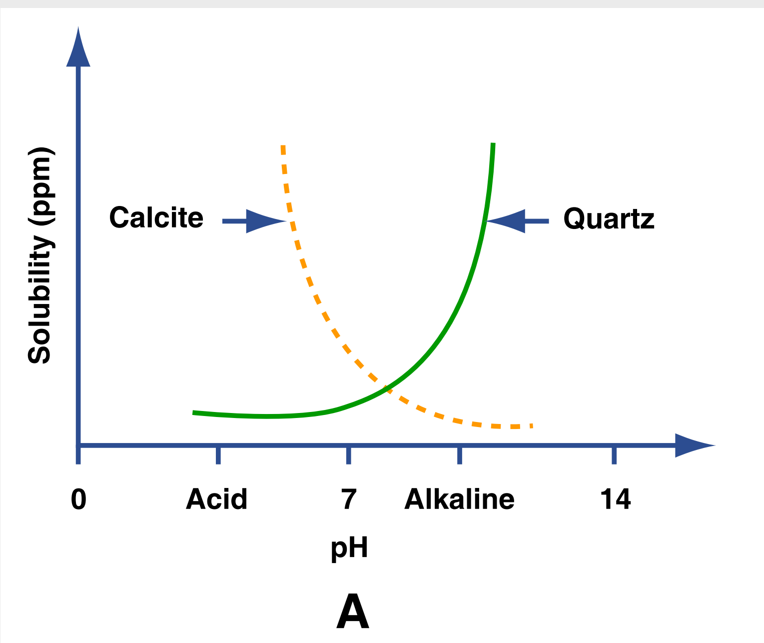
Partial grain dissolution. This thin-section photograph highlights reservoir porosity (blue)
in this poorly sorted, medium- grained sandstone. A feldspar grain (blue crystal, circled) shows signs of partial grain dissolution. Secondary porosity in this form can marginally enhance reservoir producibility

The solubility of calcite and silica are unaffected by Eh but are strongly affected—and in opposing ways—by pH.

Silica solubility increases with pH, whereas calcite solubility decreases with pH.

Thus in acidic pore fluids, like meteoric waters, calcite tends to dissolve and quartz overgrowths are precipitated, whereas in alkaline waters calcite cements precipitate and may even replace quartz.

For mildly alkaline fluids (pH 7–10) both quartz and calcite cements may form.



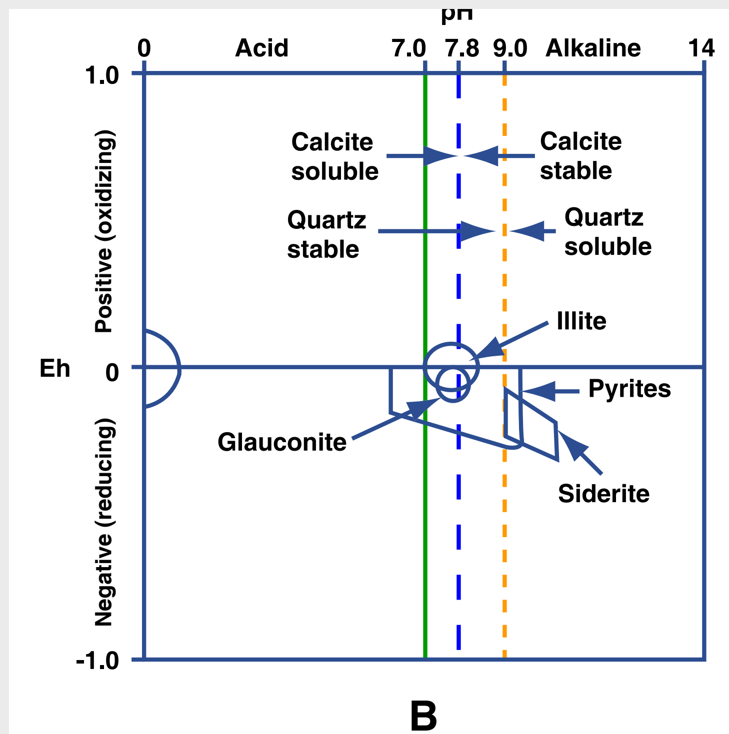
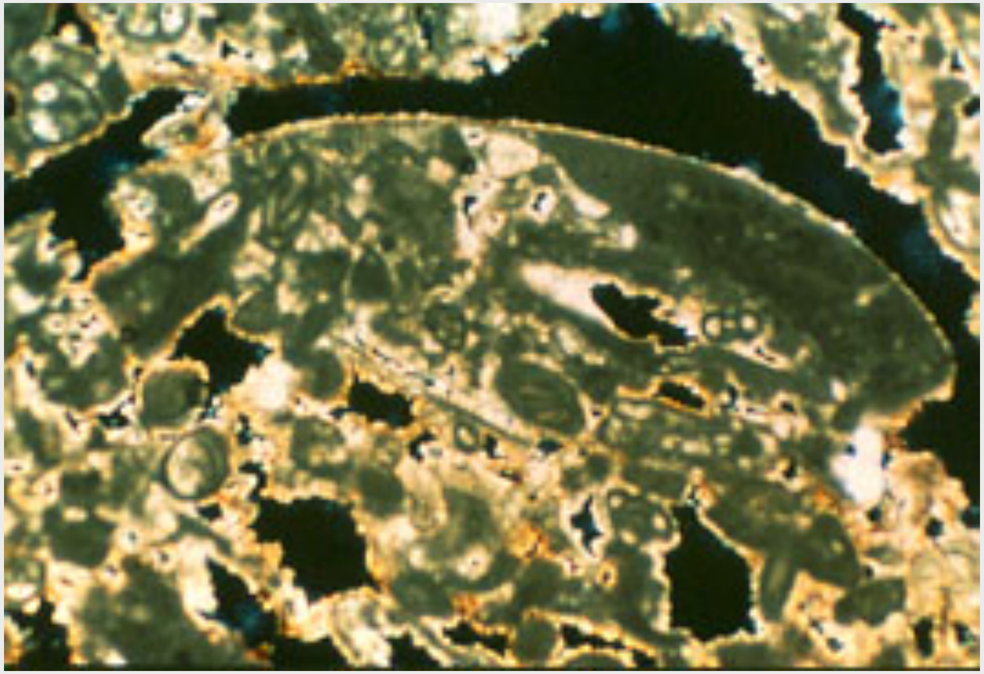
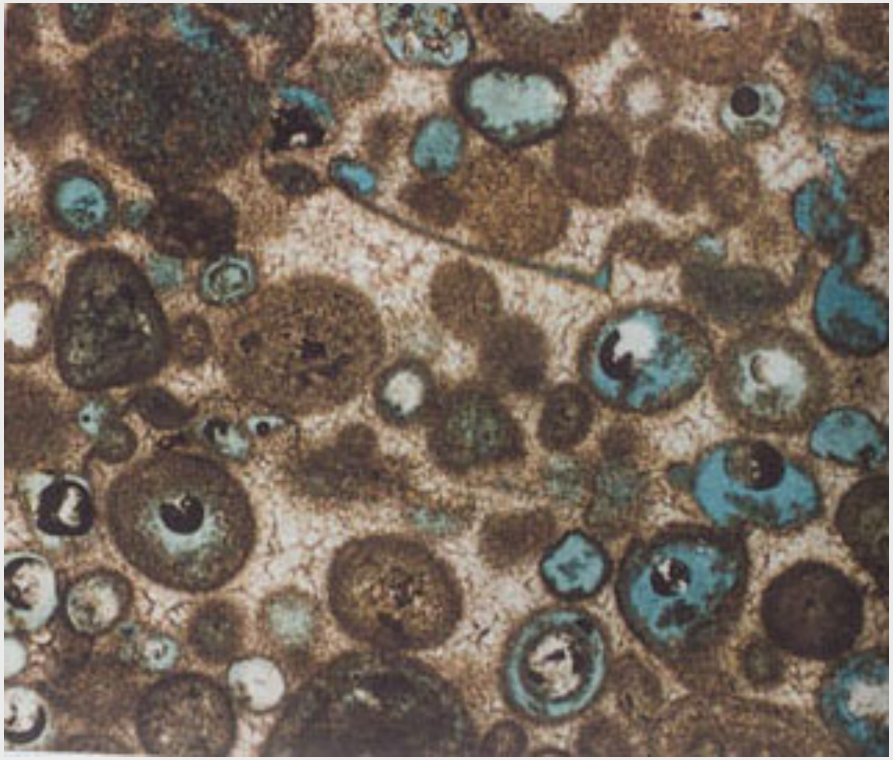


Figure: (A) Solubility of calcite and quartz vs. pH.

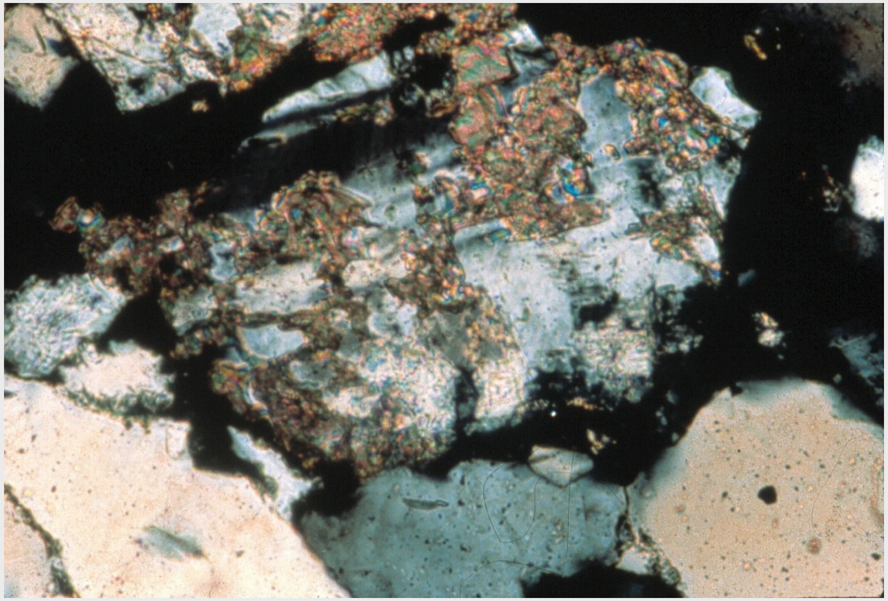
(B) Stability of various diagenetic minerals in terms of pH and Eh

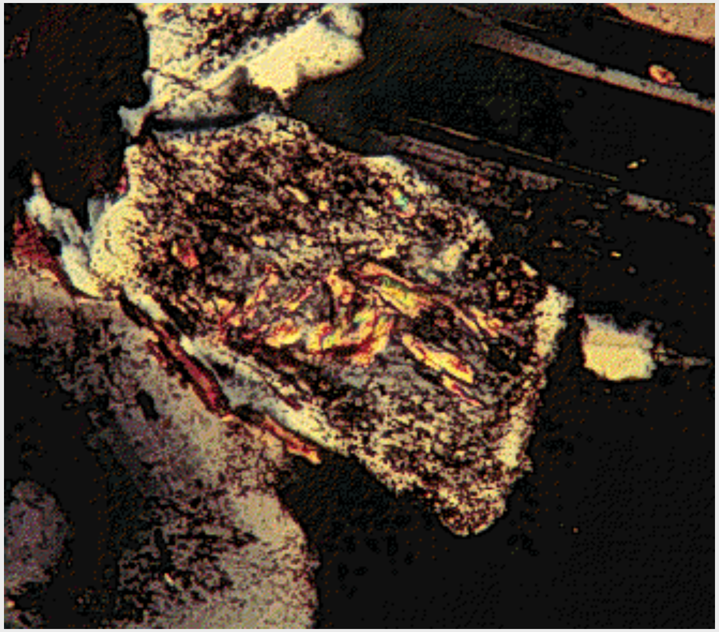




Dissolution of carbonate particles (moldic porosity)

Dissolution by chemical alteration (e.g hydrolisis) of Feldespars

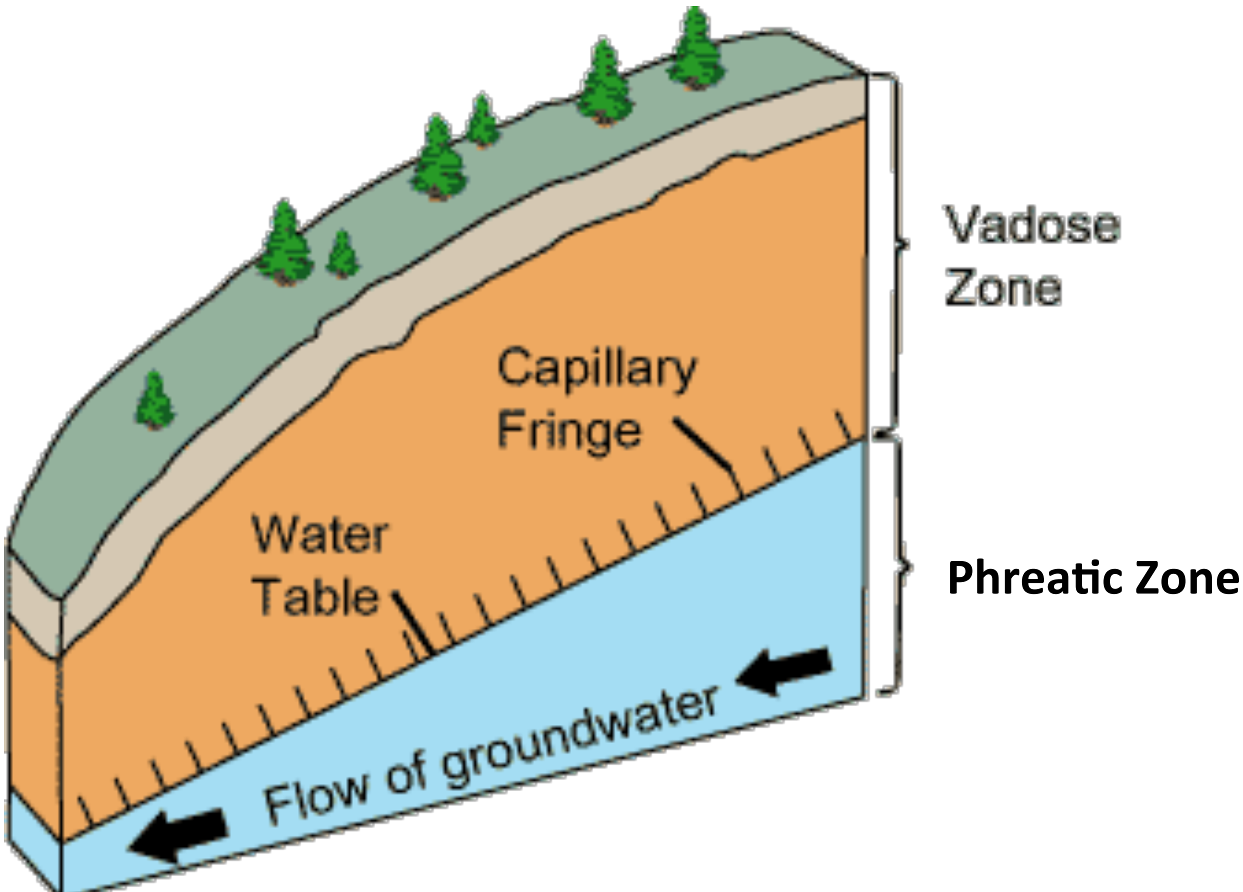




formation of clay minerals

Diagenetic Zones:

- Different diagenetic processes will occur at different depths of burial and in different environments: marine vs terrestrial
- Different sediments will behave differently in these zones



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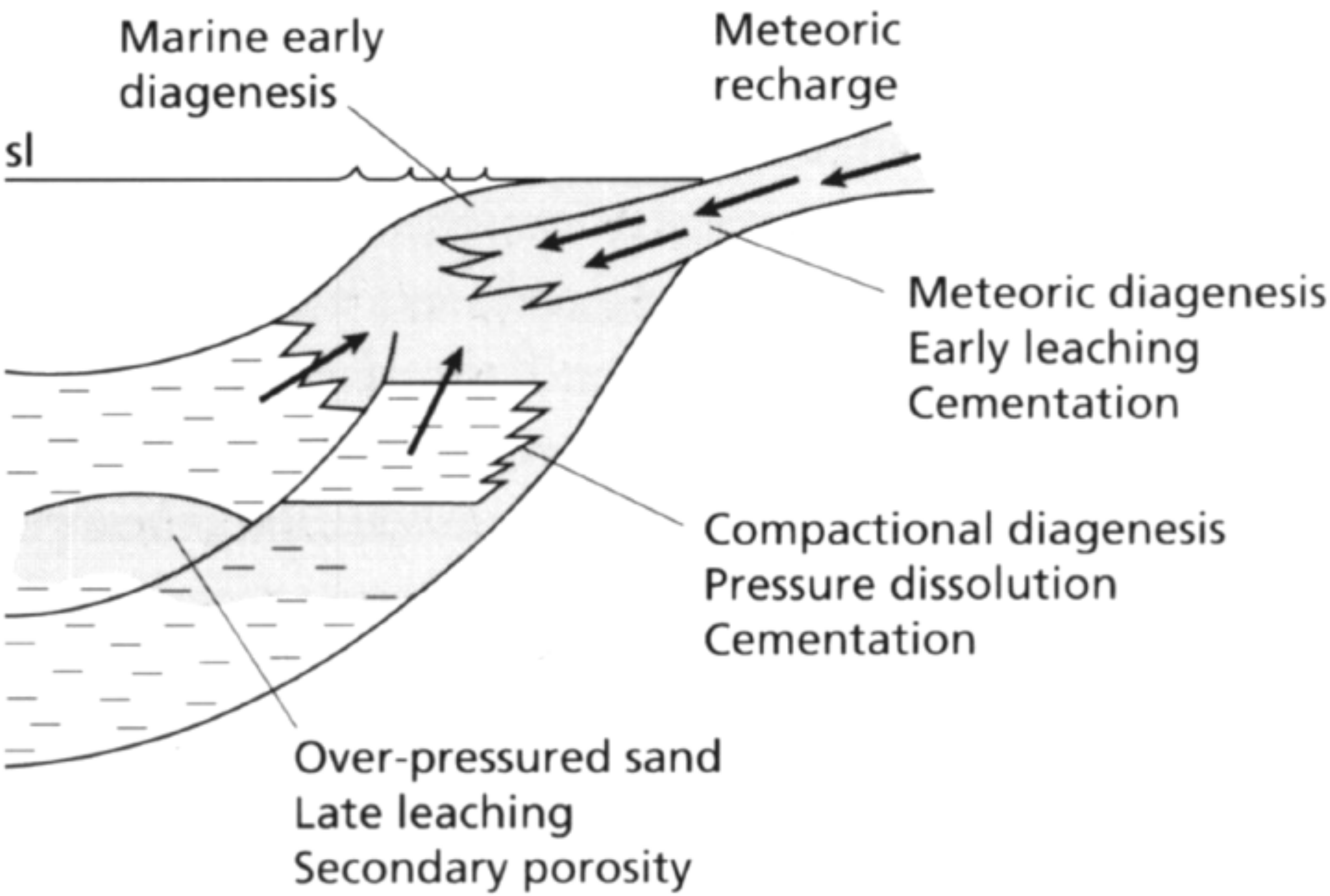

Fig. 2.57 Sketch illustrating main siliciclastic diagenetic environments. After Bjørlykke (1988).

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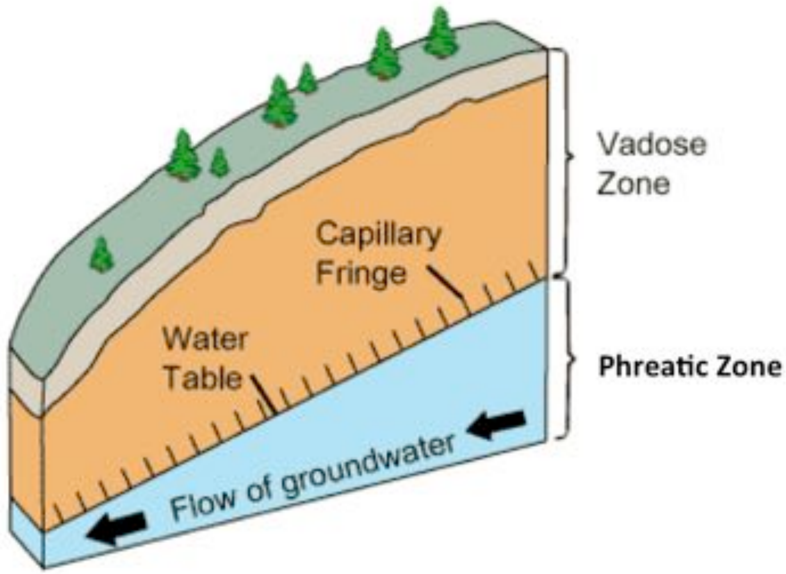

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http://upload.wikimedia.org/wikipedia/commons/f/f2/Vadose_zone.gif

1. The Vadose zone is the position at which the groundwater (the water in the sediments pores) is at atmospheric pressure

2.The phreatic zone (zone of saturation) = portion of an aquifer, below the water table where pores and fractures are saturated with water. The phreatic zone may fluctuate during wet and dry periods.

Early and Burial Diagenesis

Early diagenesis

refers to changes occurring in the sedimentary environment up to a few hundred meters (shallow burial), where elevated temperatures are not encountered (<140°C) and where uplift above sea level does not occur, so that pore spaces of the sediment are continuosly filled with water.

Early diagenetic patterns correlate with environment of deposition and sediment composition.

Early and Burial Diagenesis

Burial diagenesis (late diagenesis)

.

refers to deep burial

Later diagenetic patterns cross facies boundaries and depend on regional fluid migration patterns.

Effectively predicting sedimentary rock quality depends on predicting diagenetic history as a product of depositional environments, sediment composition, and fluid migration patterns

Diagenetic water in deep burial

- During deep burial, pore waters are modified further by reactions with clay minerals, dissolution of unstable grains, precipitation of authigenic minerals and mixing with waters from other sources.
- Burial diagenesis operates over millions of years and affects sediments to depths of around 10,000 m, where temperatures are in the region of 100°-200°C. Beyond this, processes of burial metamorphism take over. In general, pore waters in deeply-buried sediments are saline, neutral and alkaline.

Diagenetic zones

diagenetic zones defined by subsurface temperatures. Depending on geothermal gradient, depths to these zones can vary. The table below summarizes major diagenetic processes and their impact on pore geometry.

Zone	Temperature	Major diagenetic processes	
		Preserves or enhances porosity	**Destroys porosity**
Shallow	<80°C or 176°F (<5,00 to 10,00 ft)	▪ Grain coatings (inhibit later overgrowths) ▪ Nonpervasive carbonate cements that can be dissolved later	▪ Clay infiltration ▪ Carbonate or silica cement (in some cases irreversible) ▪ Authigenic kaolinite ▪ Compaction of ductile grains
Intermediate	80-140°C or 176–284°F	▪ Carbonate cement dissolved ▪ Feldspar grains dissolved	▪ Kaolinite, chlorite, and illite precipitate as a result of feldspar dissolution ▪ Ferroan carbonate and quartz cement
Deep	> 140°C or 284°F	▪ Feldspar, carbonate, and sulfate minerals dissolved	▪ Quartz cement (most destructive) ▪ Kaolinite precipitation ▪ Illite, chlorite form as products of feldspar dissolution ▪ Pyrite precipitation

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Porosity variability

Most sediments deposited under normal surface conditions have **primary porosities of on the order of 30% to 70%.**
The lower values are more typical of coarser, sandy sediments, and the higher initial porosities are more typical of finer- grained, clay-rich sediments.

Porosity in conglomerates and sandstones is largely a matter of pore spaces among the framework grains, as modified by later cementation together with certain other diagenetic changes (more on those later).

In muds the initial porosity is commonly higher, although permeability is low

Porosity variability

Porosity in carbonate rocks varies widely, depending upon sediment type:
the porosity of well-sorted carbonate sands is in the same general range as that of the corresponding siliciclastic sands, whereas reef carbonates commonly have much higher initial porosities