Carbonate Diagenesis

- Terms and structures
- Carbonates
  - Non-tropical
  - Terrestrial
- Cements
- Dolomitization

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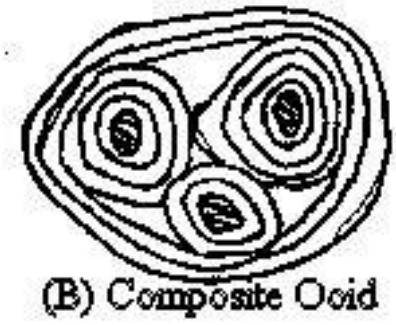
Some Carbonate Fabrics /Terms:

Coated Grains (cortoids): grains lined with a fine micrite envelope (can be biogenic or abiogenic)

Grapestones: Cemented clusters of allochems (type of lithoclast if non-algal origin)

~ Coated Grain



~ Grapestone

Some Carbonate Fabrics /Terms:

Fenestral (Bird's Eye) Pores: cavities left by trapped gas bubbles, commonly associated with organic-rich, lagoonal muds and laminites (commonly filled with cement in rocks)

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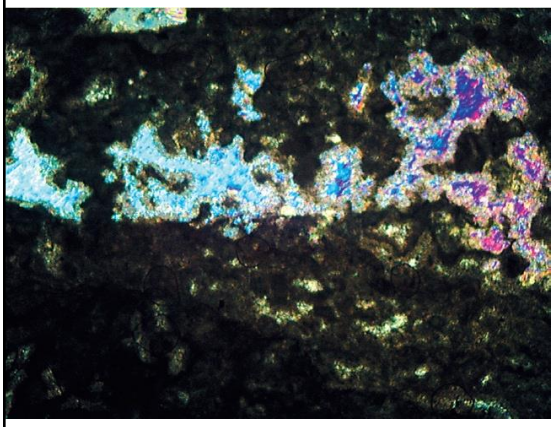
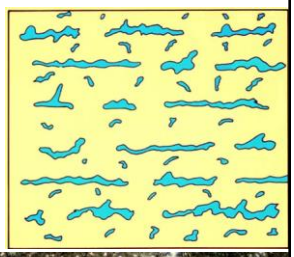
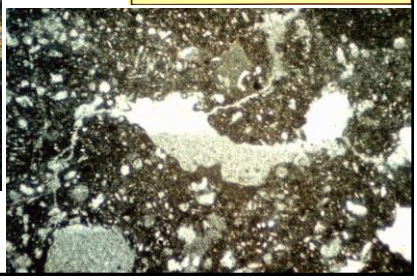




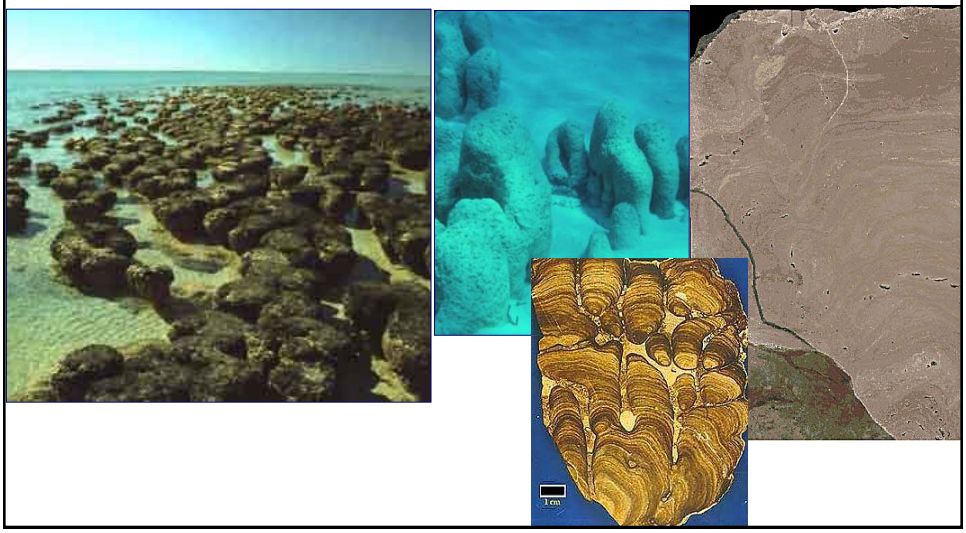


Some Carbonate Fabrics /Terms:

Cryptalgal laminite: Irregular, thinly bedded mud-rich units produced by sediments sticking to ‘slimy’ algal mats (tidal flats, stromatolites)

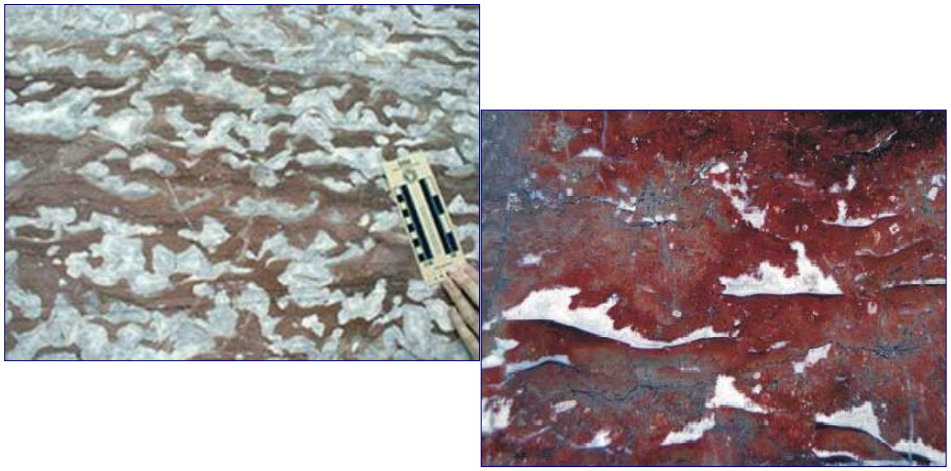
Some Carbonate Fabrics /Terms:

Stromatolites: Concentrically laminated algal accumulations (typically dome-shaped, upward growth forms)



Some Carbonate Fabrics /Terms:

Stromatactis: Calcite spar-filled cavities in generally muddy matrix (believed to be related to organic material-sponges / microbes?)



Some Carbonate Fabrics /Terms:

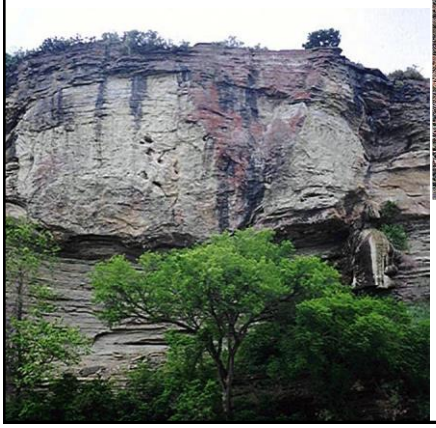
Teepee structures: Small anticlinal structures that form in response to mineral precipitation, typically associated with evaporative conditions (like a sabkha or tidal flat)

Some Carbonate Fabrics /Terms:

Geopetal Fabric: Features that indicate depositional way-up (such as partially crystal lined cavities, with sediment drape on bottom)

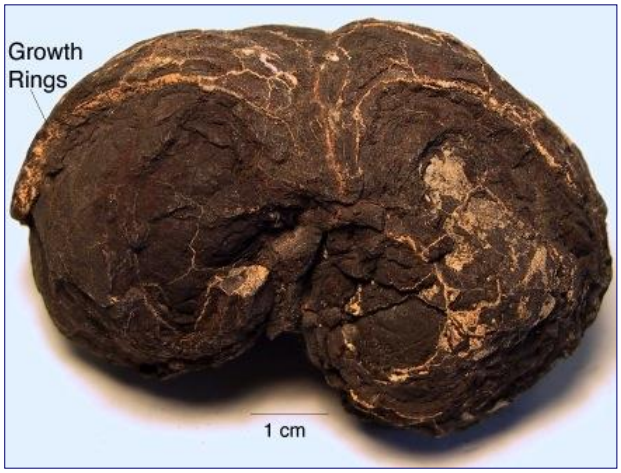
Some Carbonate Fabrics /Terms:

Bioherm: Accumulation of organisms that built up a mound upon death (not necessarily a rigid framework cemented *in situ* during life)



Some Carbonate Fabrics /Terms:

Nodules: Intrabasinal chert (commonly) or other minerals that are concentrated along bedding planes (migration paths, typically made up of dissolved silica)



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Some Carbonate Fabrics /Terms:

Concretions: Generally round masses of resistant rock formed as cement precipitated around a core material (commonly organic)

A Kimmeridge Clay nodule with ichthyosaur bones. Apparent upper side, as on the beach. West of Osmington Mills. *Ian West (c) 2003.*

Some Carbonate Fabrics /Terms:

Marl: Argillaceous (clay mineral-rich) lime mudstone ~50:50 of each.

Closely related to shelf and deep-sea chalk

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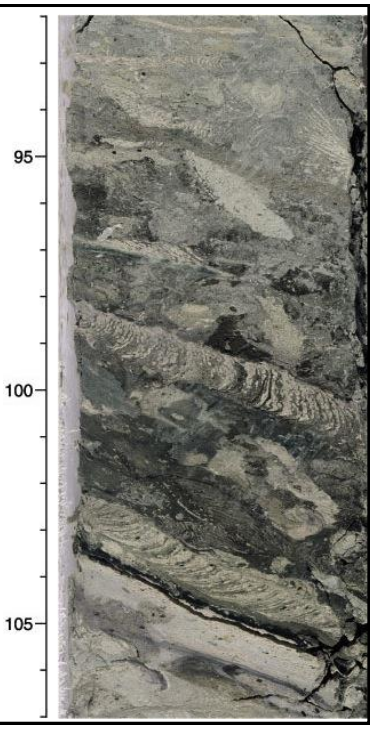
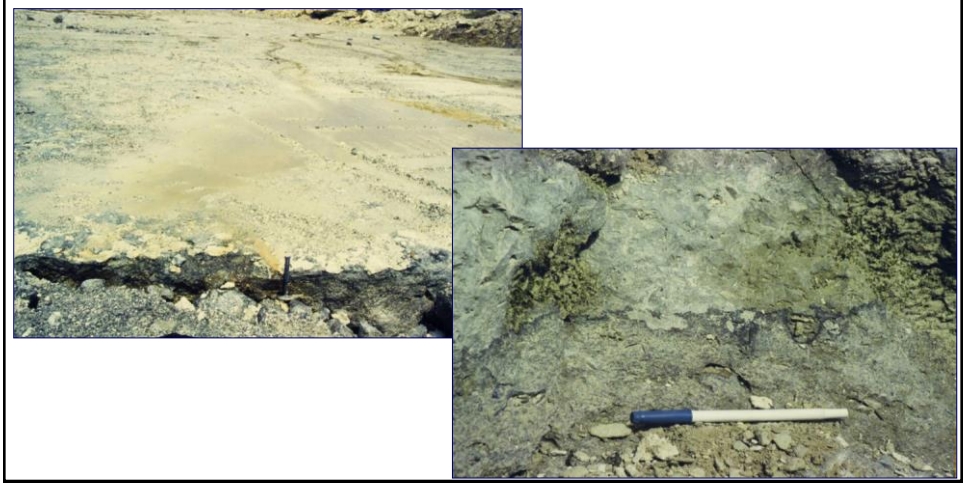


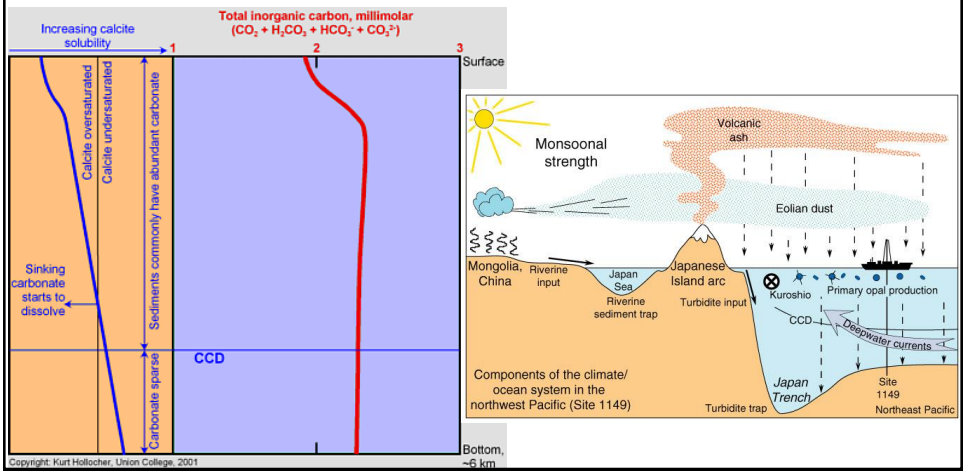
Some Carbonate Fabrics /Terms:

Hardground: hard, lithified layers (typically 1-3 cm thick) that generally develop during extended periods of non-deposition—typically bored and encrusted



Some Carbonate Fabrics /Terms:

CCD: Carbonate Compensation Depth—depth at which carbonate material becomes soluble; deeper in higher temperatures, commonly ~5 km water depth



Some Carbonate Fabrics /Terms:

Bedding, Stratification: argillaceous, thin bedded limestones of shelf

Some Carbonate Fabrics /Terms:

Bedding, Stratification: normal grading and HCS with bioclastic lag of a storm bed (tempestite), probably on shelf

Some Carbonate Fabrics /Terms:

Bedding, Stratification: trough cross-stratification of allochems (*e.g.*, ooids), by nearshore, wave-forced currents or tides (*e.g.*, shoals)

Carbonates

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Non-Tropical Carbonates

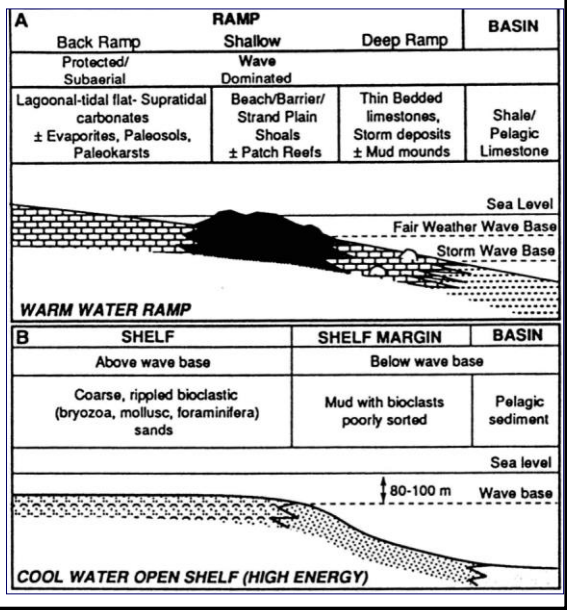
- Common, but much lower accumulation rates

- Many heterotrophs (*vs*. phototrophs)

- Commonly dominated by **echinoderms, bryozoa, foraminifera, mollusks**

- **Framework builders much less common** (typically grain rich)

- Facies heavily influenced



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- Facies heavily influenced by wave base

Terrestrial Carbonates

Much less common

Lacustrine (Green River Fm)

-generally micrite rich

-Oolites if conditions right

-Charophytes common (calcifying encrusting green algae—dasyclasdacean)

-Seasonal 'whitings' as temperature increases and CO_2 levels drop (from algal growth)

-Algal laminites and stromatolites locally common

Terrestrial Carbonates

Soil profiles

Caliche—soil carbonate

- Generally white micritic material

- Associated with roots or water table (zones of fluid migration)

- B-horizons of soil profiles

- More common in arid climates (or seasonal)

- Capable of significantly modifying flow properties*

- Sparry veins, pisolites, rhizoliths, nodules

Terrestrial Carbonates

Soil profiles

Caliche—soil carbonate

- Sparry veins, pisolites, rhizoliths, nodules

Rhizoliths in sst. Pleistocene, Sardinia, Italy

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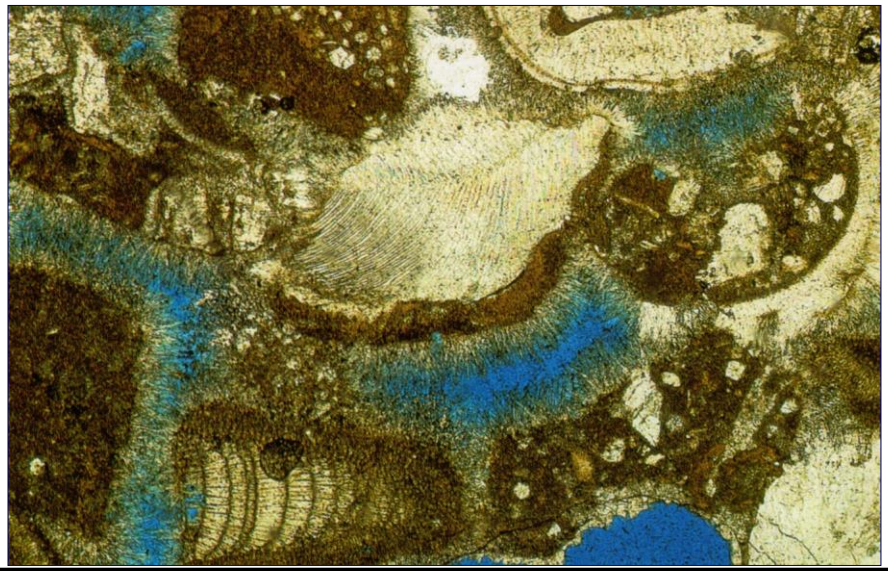
Carbonate Cements

- Marine Aragonite (modern)



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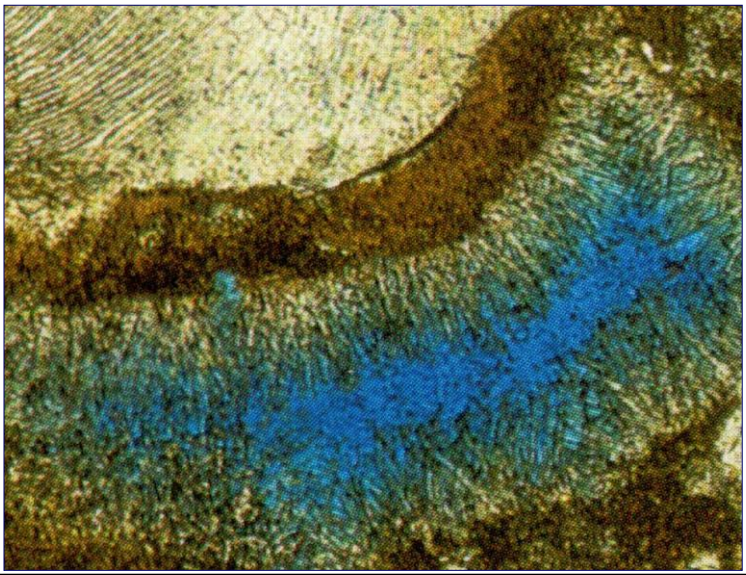

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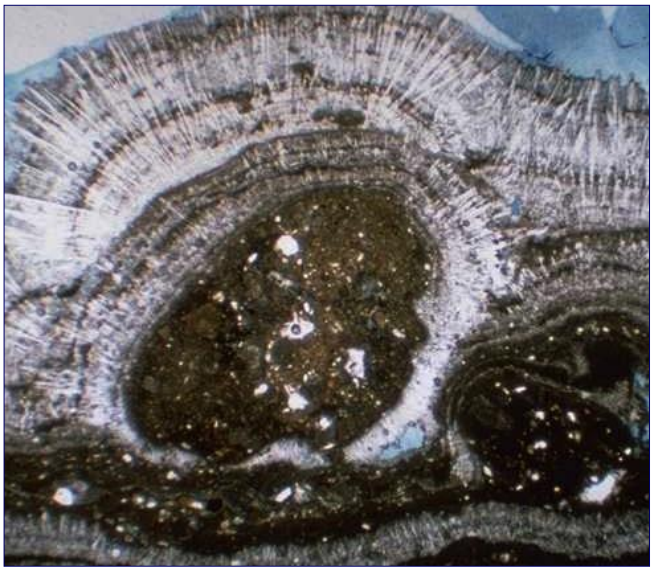
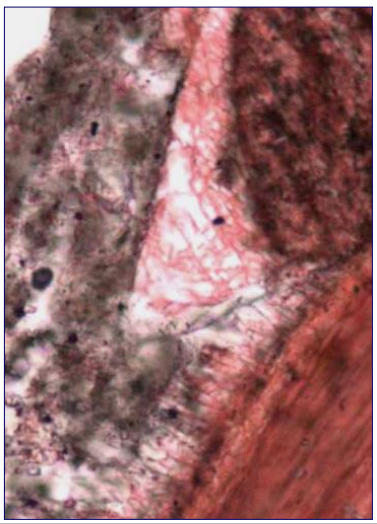
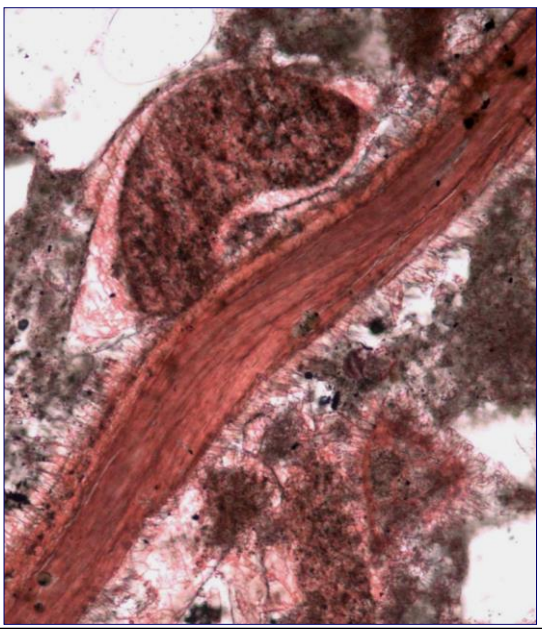


Carbonate Cements

Fibrous calcite rims

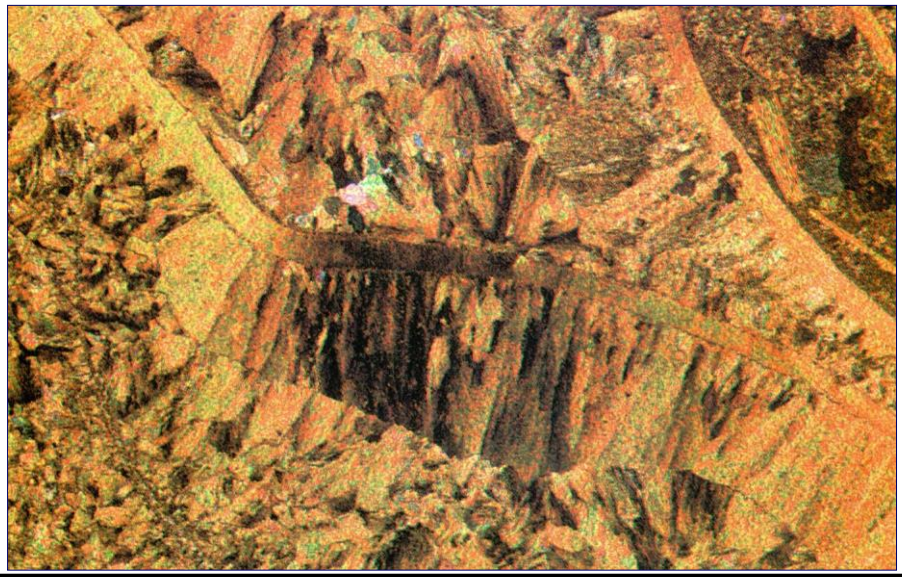
Overgrowths





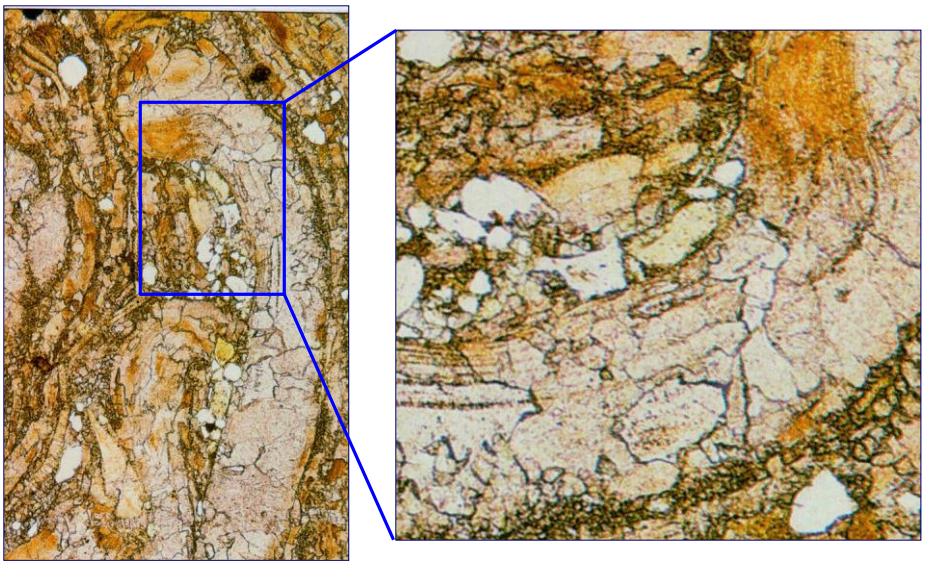
Carbonate Cements

Cements - Radiaxial Fibrous Calcite



Carbonate Cements

Neomorphic calcite (fossil microstructure preserved)

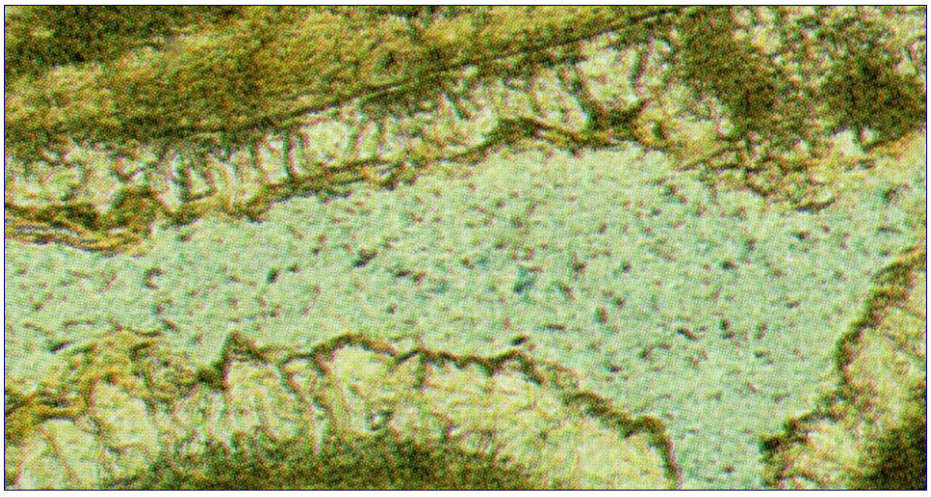


Carbonate Cements

Cements - Isopachous Rims: uniform thickness

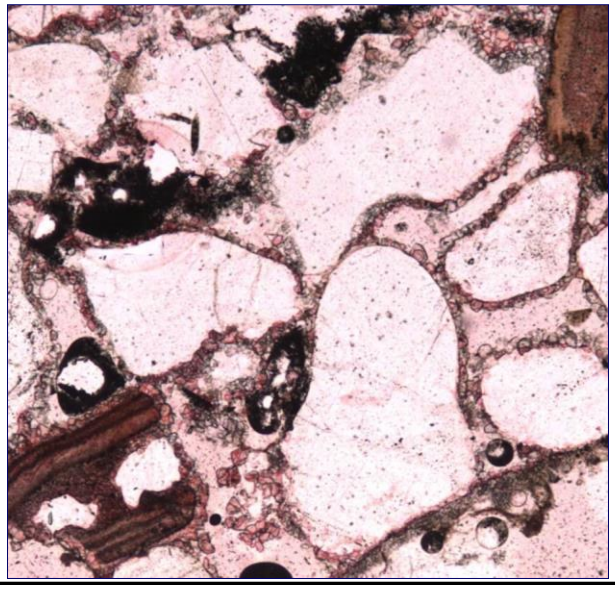
Carbonate Cements

Cements - Isopachous Rims



Carbonate Cements

Cements - Isopachous Rims



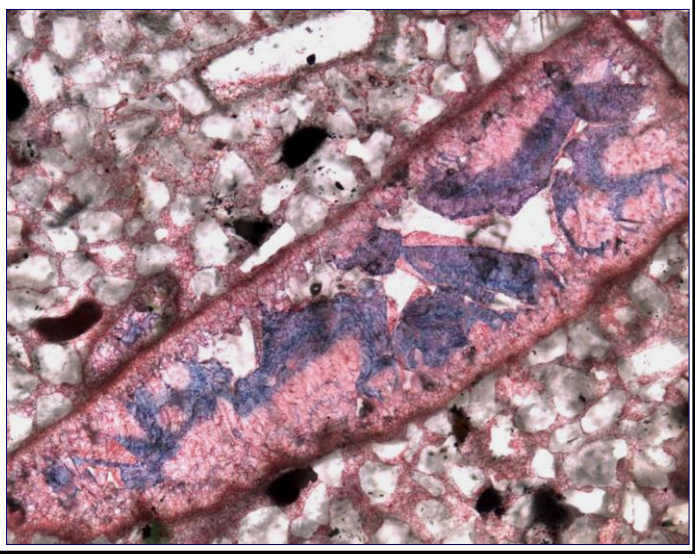
Carbonate Cements

Zoned (mosaic) calcite (stained with Dickson's solution)

- pink = calcite
- blue = Ferroan calcite

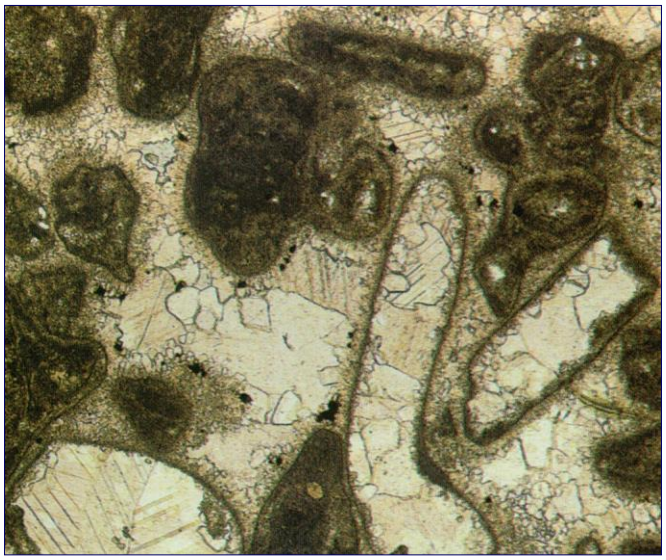
Fine Equant

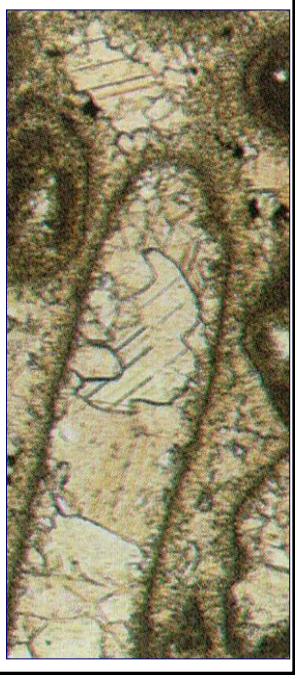
Coarse Mosaic



Carbonate Cements

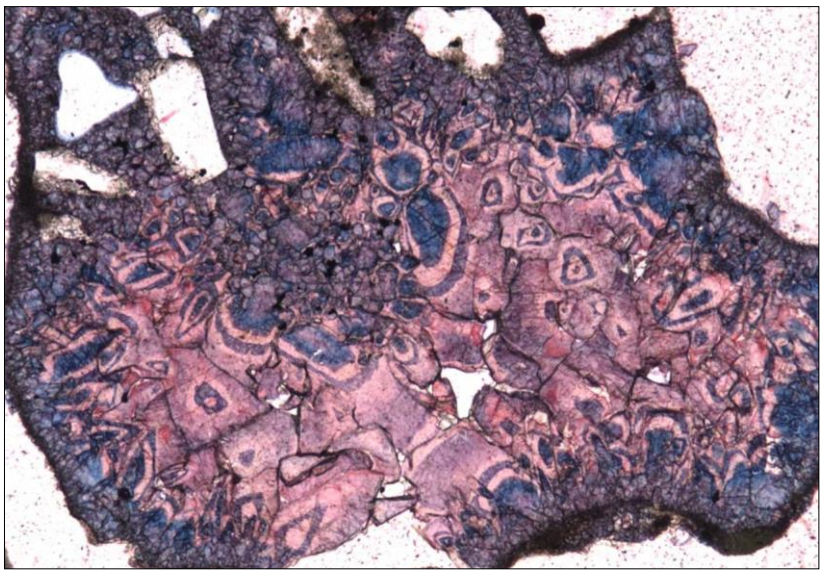
Cements - Mosaic





Carbonate Cements

Cements - Mosaic

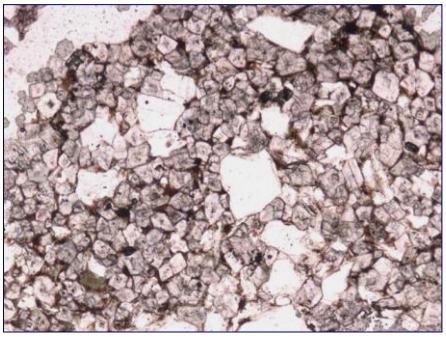


Carbonate Cements

Cements - Dolomite

-Early, v. fine
(commonly laminated)

-Late, coarse, euhedral, fabric replacive

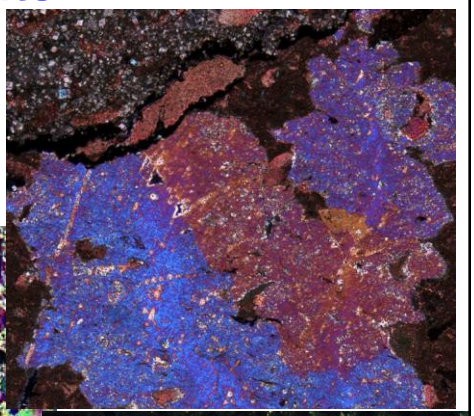


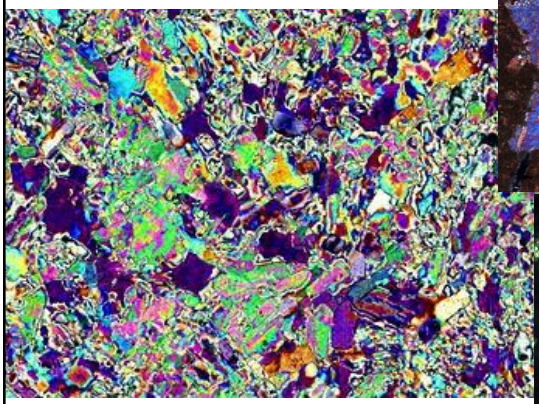
- ID from calcite by rhombs, less twinning, and higher relief (or *via* staining)

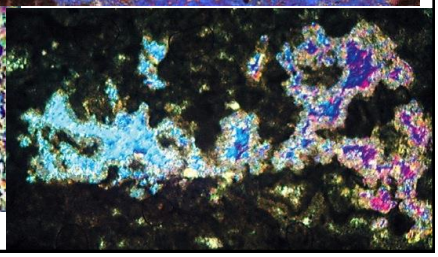
Carbonate Cements

Cements - Anhydrite

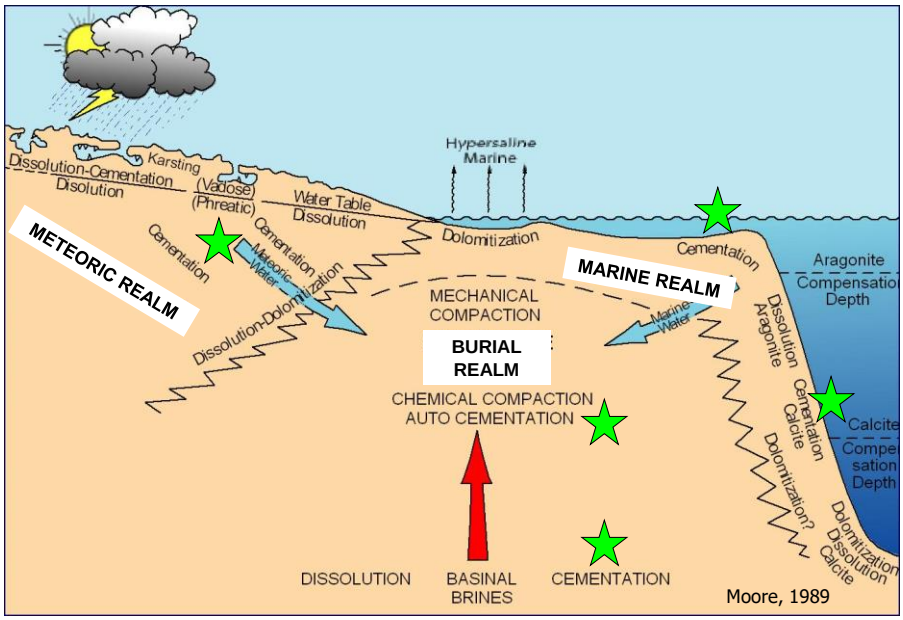
- Fine or coarse crystals
- Generally fabric replacive
- Extensive pore occlusion







Cementation



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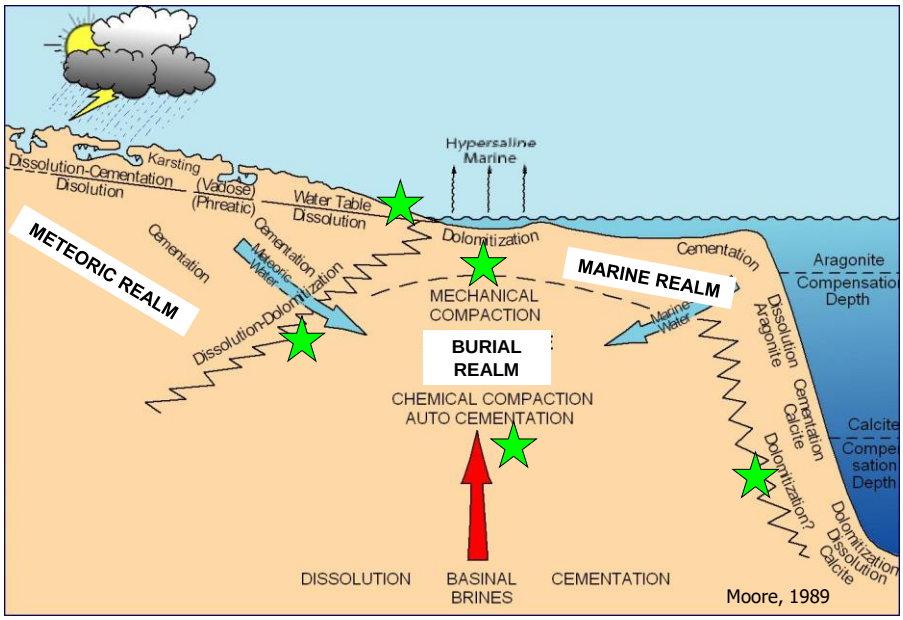
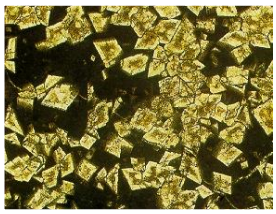
Dolomitization

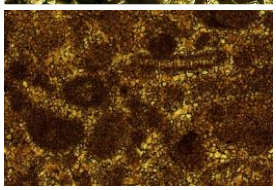


Dolomitization

$Mg^{2+} + 2CaCO_3 \longleftrightarrow MgCa(CO_3)_2 + Ca^{2+}$



REPLACEMENT
Fabric Destructive



REPLACEMENT
Fabric Preserving

OVER DOLOMITIZATION

Diagenetic Environments
- Seawater
- Hypersaline Brines - Reflux
- NOT MIXING ZONE
- Burial

Reservoir Quality
- Permeability enhancement depends on replacive crystal size
- Significant enhancement in muddy facies
- "Over dolomitization" reduces permeability
- Resistive to compaction cf. limestones
- Prone to fracturing

Reservoir Examples
- Ghawar, Jurassic, S. Arabia
- Leduc, Devonian, W. Canada

Dolomitization

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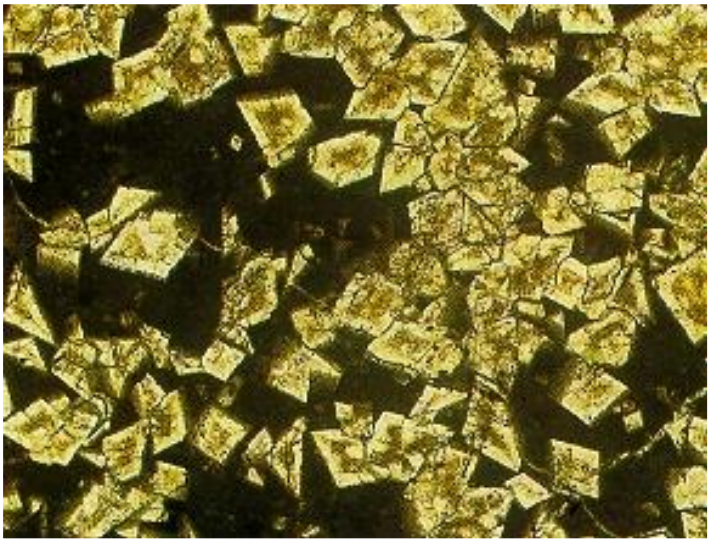
REPLACEMENT
Fabric Destructive



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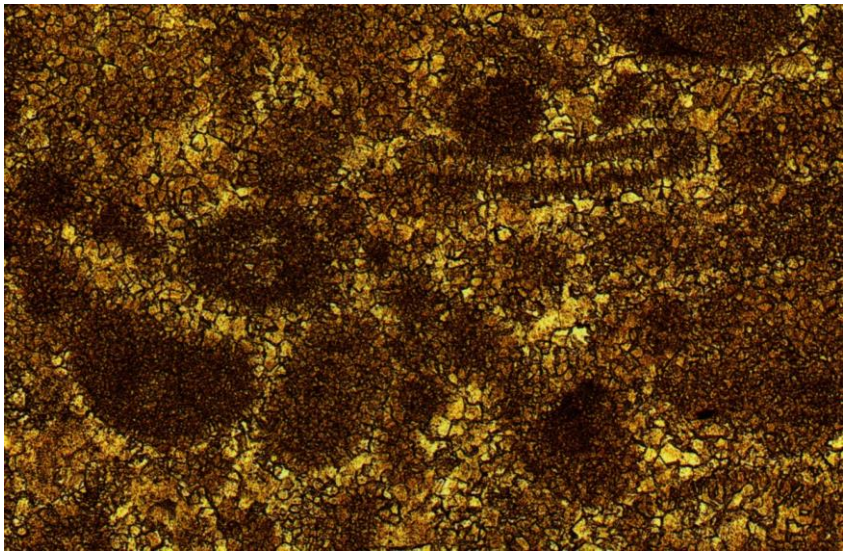

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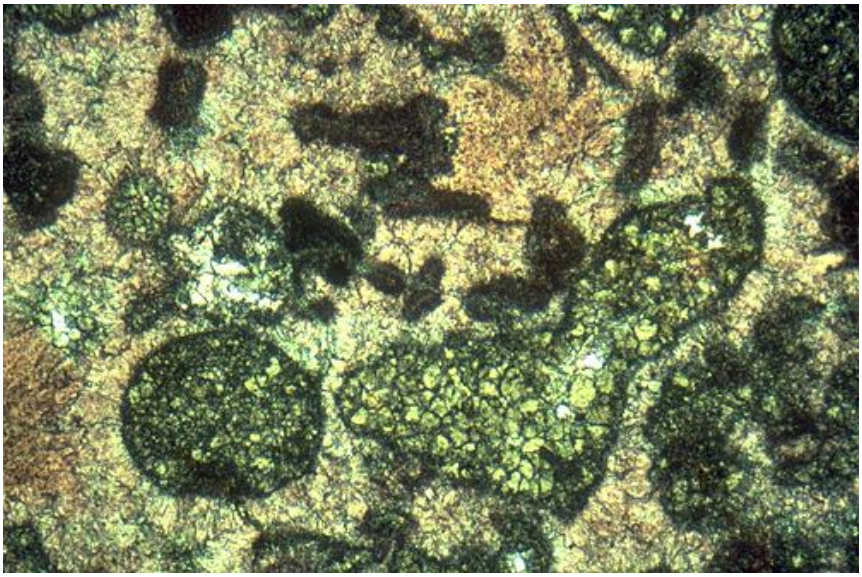

Dolomitization

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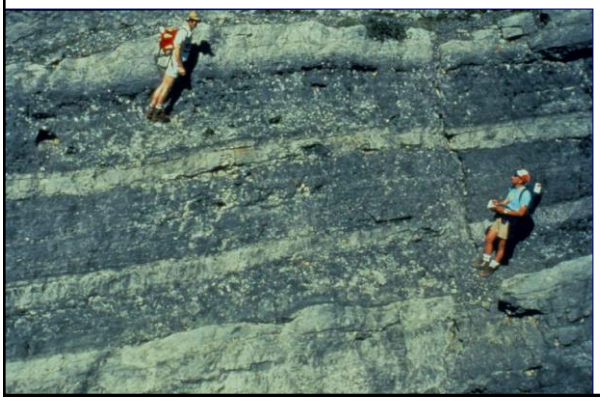
OVER DOLOMITIZATION

Dolostone: rocks that comprise > 50% dolomite

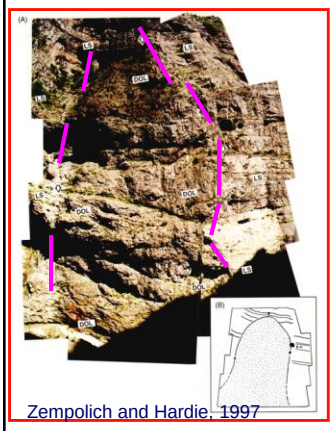
- Mg ions replace Ca ions in crystal lattice: $CaMg(CO_3)_2$
- Common euhedral crystals with higher relief
- Commonly disrupts and replaces primary carbonate fabrics
- Less reactive to acid (nearly inert to cold 10% HCl)
- More stable under burial conditions
- Yellowish-buff colour in outcrop common (Mg^{2+} substituted for by Fe^{2+})



Early dolomitization (evaporative peritidal settings)

Many current workers use dolostone and dolomite synonymously!

Diagenetic Process: Dolomitization



Zempolich and Hardie, 1997

$2(CaCO_3) + Mg^{2+} \rightarrow CaMg(CO3)_2 + Ca^{2+}$

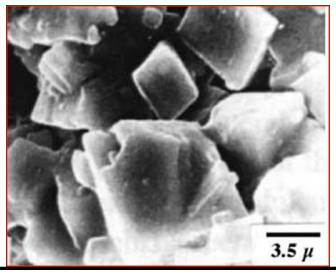
Most by replacement - direct precipitation rare

Requires a source of Mg^{2+} ions - a 3-5 x increase (and removal of Ca^{2+})

Requires an efficient flow mechanism

Must overcome substantial kinetic barriers

Diverse range of models, environments, fluids



DOES NOT ALWAYS INCREASE POROSITY

Variable effect on rocks

More resistive to compaction (*vs*. limestone)

Need to remove ~50% Ca ions from limestone and enrich fluids in Mg to precipitate dolomite. Where does this occur??

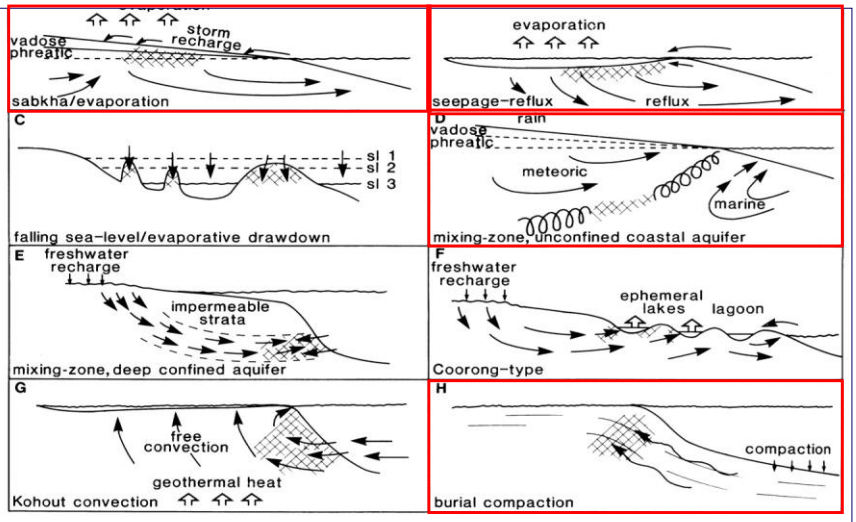


Fig. 8.1 *Models of dolomitization, illustrating the variety of mechanisms for moving dolomitizing fluids through the sediments. In part after Land (1985). Also see Fig. 8.31 for seawater dolomitization models.*

Dolomitization Models

Tidal Flat Evaporation

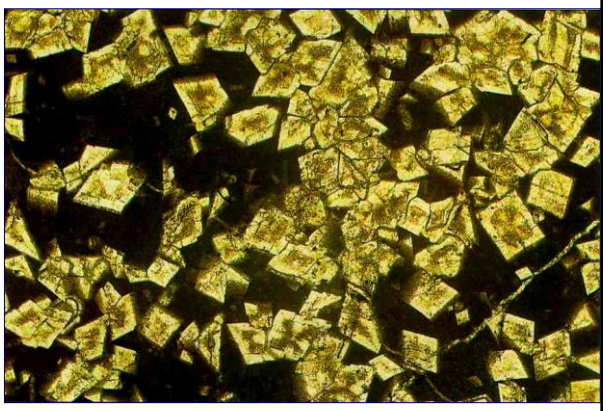
Mixing Zone (Dorag)

Seepage Reflux

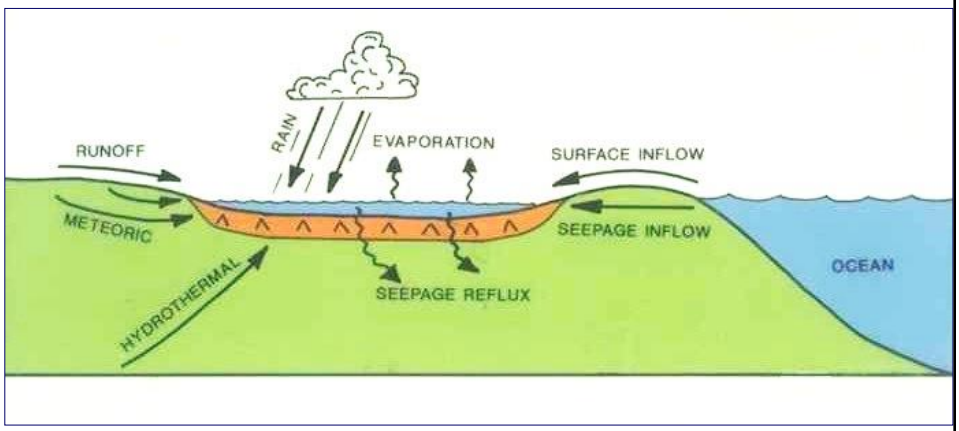
Seawater Pumping

Burial

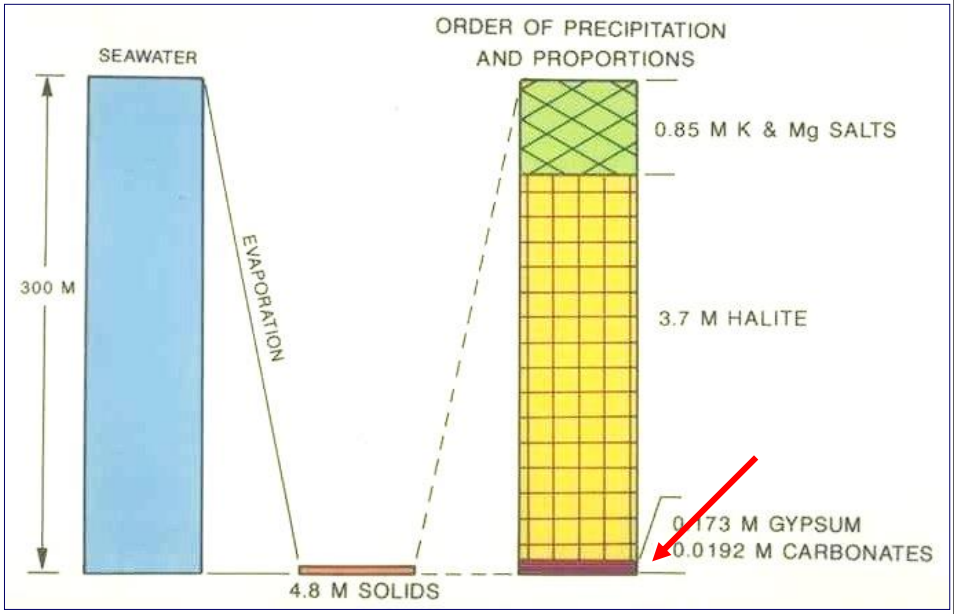
Hydrothermal



Dolomitization Models



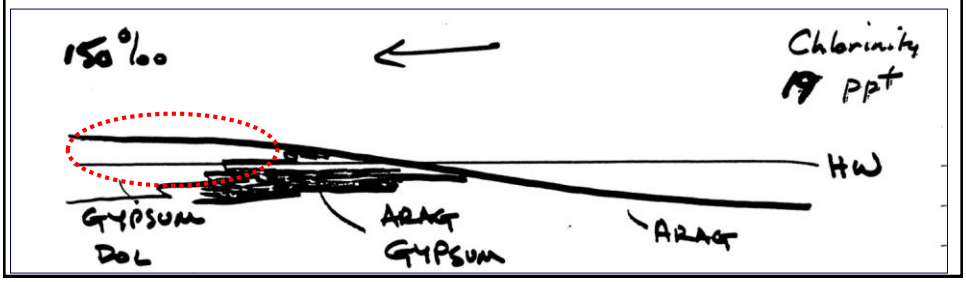
Dolomitization Models



Dolomitization Models

Sabkha / Tidal Flat Evaporation

- Very early stage (Eogenesis) ~ syndepositional
- Arid, highly evaporative climates
- Poorly ordered crystal lattice
- Very fine crystalline dolomite
- Commonly well stratified (forms laminites)
- Isotopes heavy (^{13}C +^{18}O range from 2-4‰)



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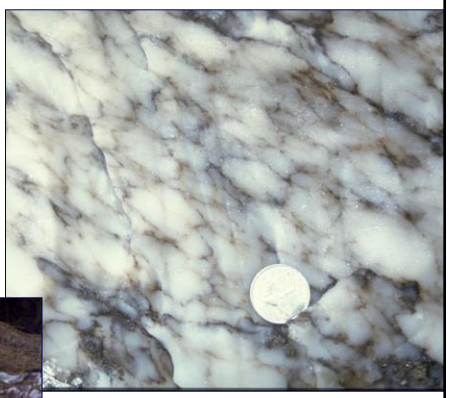
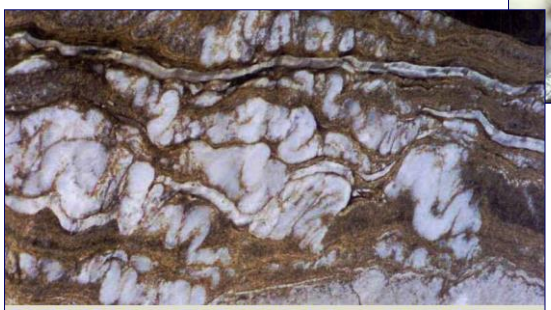




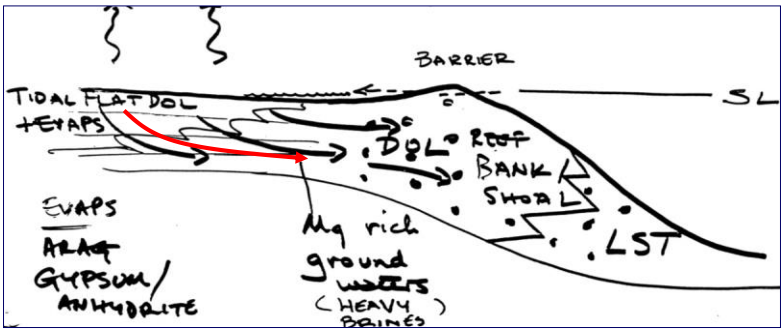
Early fabric of displacive enterolithic veins now preserved in late, secondary, (post-anhydrite) porphyrotopic gypsum. Soft Cockle Mb, Purbeck Formation, Worbarrow Tout . Ian West (c) 2005

- Commonly well stratified (forms laminites)
- Isotopes heavy (^{13}C +^{18}O range from 2-4‰)

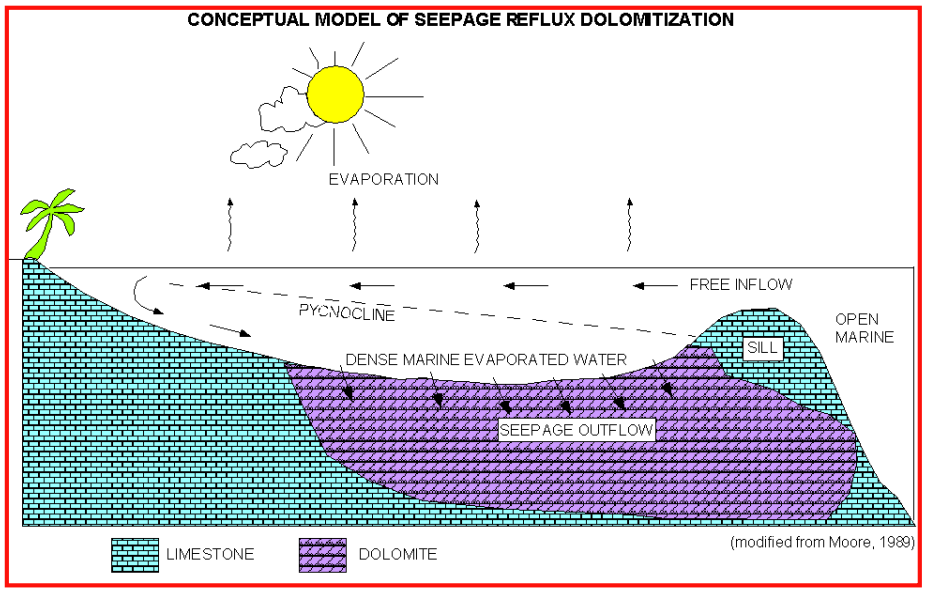
Dolomitization Models

Seepage (Evaporative) Reflux

- Protected lagoons with high evaporation
- Brines develop to levels allowing gypsum precipitation (~100,000 ppm Cl)!
- Ca stripped out of solution to precipitate gypsum, increasing Mg:Ca ratios
- Mg-rich brines are very dense and seep into underlying strata on flow path to the ocean



Dolomitization - Near-Surface, Tabular

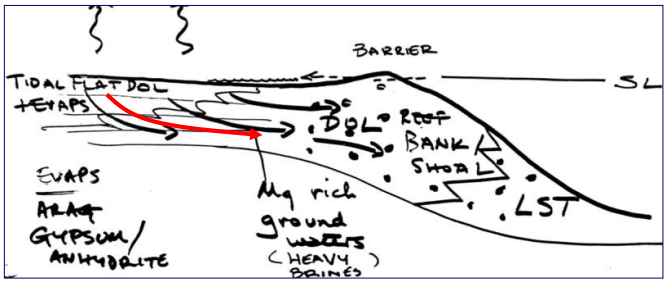


Dolomitization Models

Seepage (Evaporative) Reflux

- Dolomite replaces aragonite and calcite (mud first) along this flow path
- Dolostones of this type are associated with evaporites (mainly gypsum/anhydrite) and supratidal/peritidal facies
- Mg recharged by storm surge into restrictive 'ponds'

~80% of dolomites associated with peritidal conditions (early diagenetic replacement) - nearly syndepositional!



Dolomitization Models

Evaporative Related

- Close association between evaporites and dolostones
- Look for features that support peritidal or coastal margin deposition! (*e.g.*, vadose cementation, desiccation cracks, teepee structures, salt growth, beach rock, fenestral pores, stromatolites, evaporite cement, algal-coated grains, etc.).

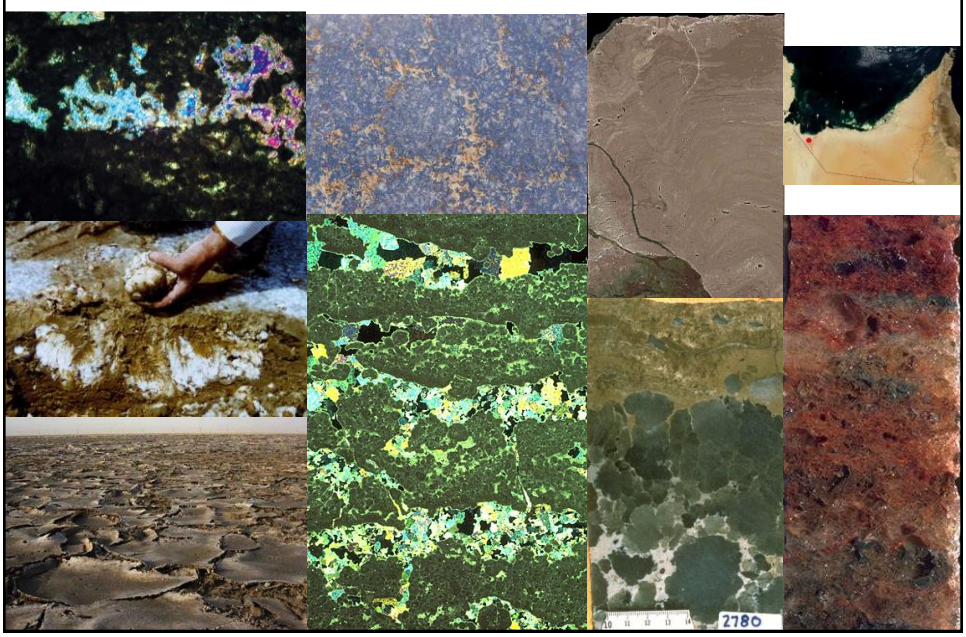
- Reflux dolomitization requires subequal proportions of evaporites (*e.g.*, gypsum to anhydrite) and dolostone!

Dolomitization Models

Evaporative Related

Dolomitization Models

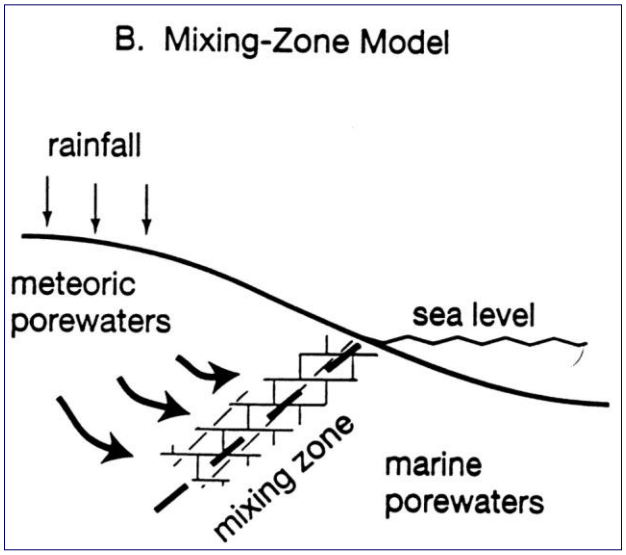
Evaporative Related



Dolomitization Models

Mixing Zone (Dorag type)

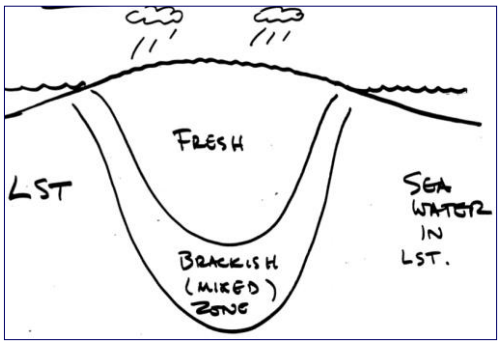
- Forms below water table, under brackish-water conditions
- Below /near coastlines
- Very shallow burial (>100 m)
- Constant flux of fresh- and salt-water facilitates ion exchange along interface

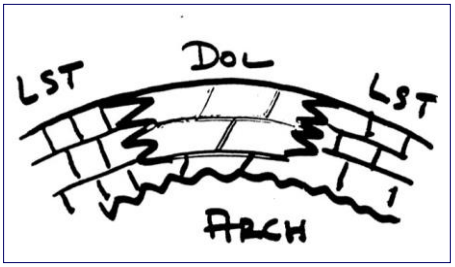


Dolomitization Models

Mixing Zone (Dorag type)

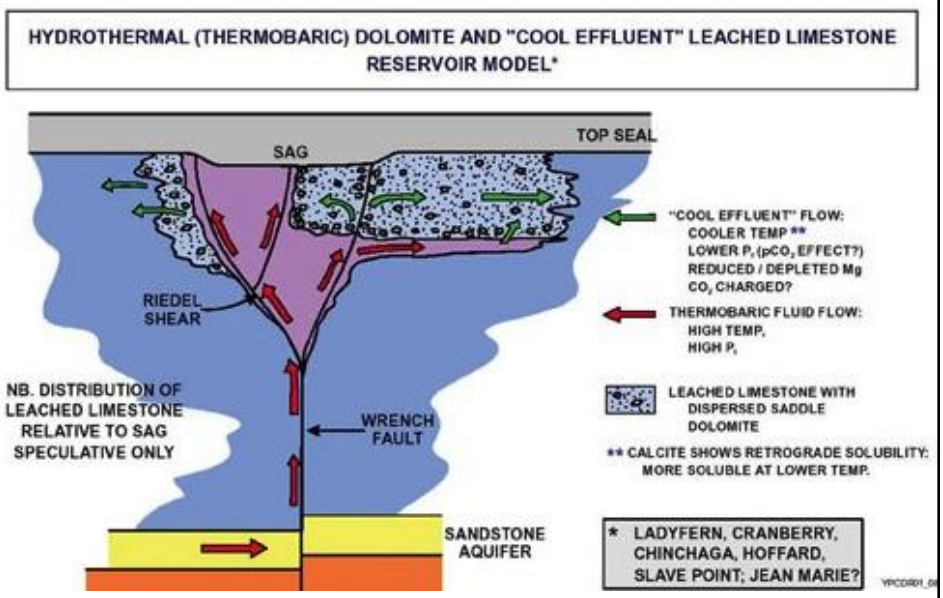
- Develop lens of dolostone, unrelated to environment of deposition of the replaced limestone
- Distribution controlled by aquifers / paleogeography
- Strongly dependent on relative sea-level (position of the mixing zone partly controlled by sea-level)
- Rarely observed in the field





Dolomitization Models

Hydrothermal (thermobaric)



Dolomitization Models

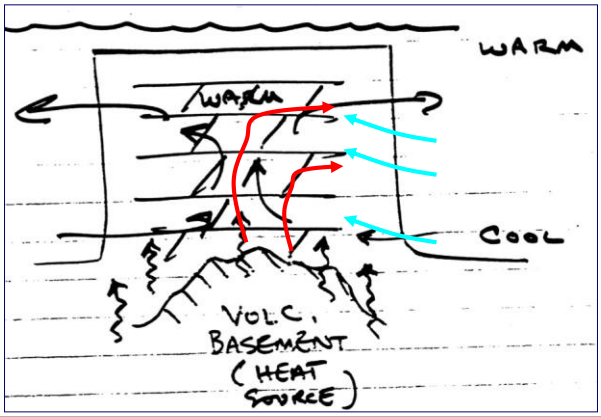
Burial (Hydrothermal)

- Much coarser crystals but are made up of anhedral crystals
- Always Fabric Displacive
- Elevated temperatures facilitate stripping of Mg from water molecules (don't need elevated Mg:Ca ratios)
- Need source of Mg and mechanism to remove Ca ions
- Enriched burial fluids migrate *via* flow pathways
- Common stable pore type at depth in Alberta reservoirs

Dolomitization Models

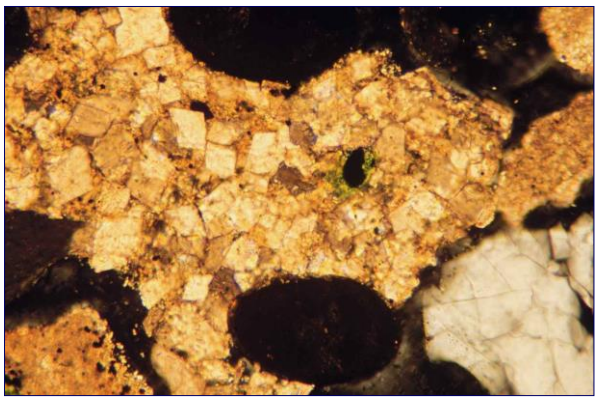
Convection Zone

- Thermal convection of water mass in the deep ocean (2-4 km water)
- Thermal anomaly (*e.g.*, seamount) warms formation waters, which cools as it nears the ocean surface
- Difficult to prove (could originate from sea-level changes)



Distribution Summary

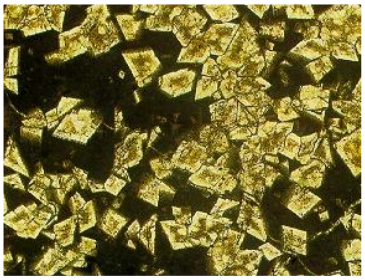
- If early, commonly related to eustatic processes and position of the water table (especially peritidal and shelf margin)
- Both Facies/Allochem (fabric) specific and Non-specific
- Burial alteration commonly concentrated along faults and fractures (fluid conduits)



Secular Variations in Dolomitization

OBSERVATIONS

- dolostones common in the Paleozoic and PreCambrian
- no simple relationship with other global phenomena



WHY ?

- dolomite is a function of time
- different environmental conditions
  - higher temperature
  - higher pCO_2
  - higher Mg/Ca ratio
  - lower SO_4^{2-} in sea water