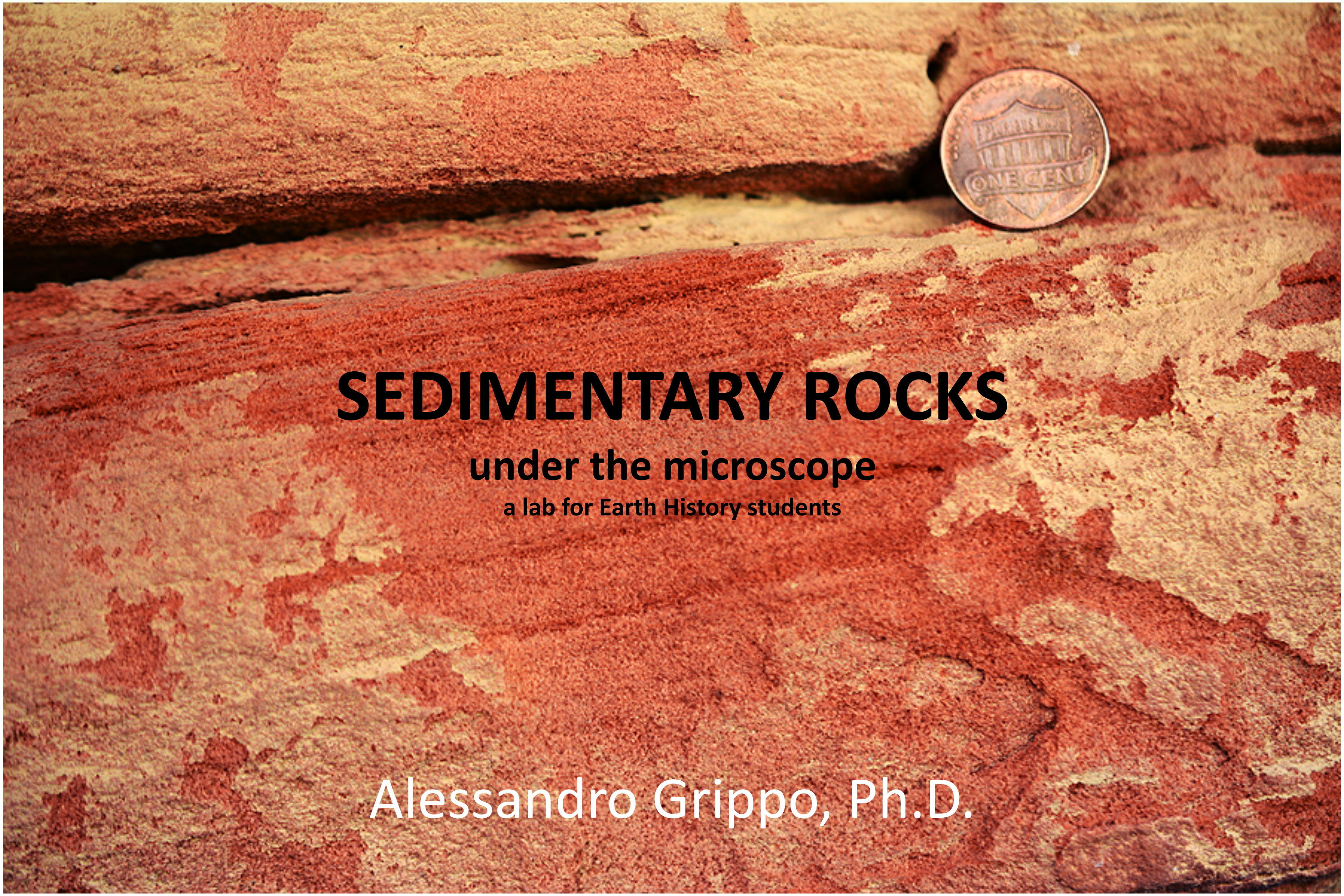


SEDIMENTARY ROCKS

under the microscope

a lab for Earth History students

Alessandro Grippo, Ph.D.

A detail of the cross-bedded sand laminae that are part of an ancient sand dune deposit
Jurassic Navajo Sandstone
Zion National Park, Utah, U.S.A.

Summary

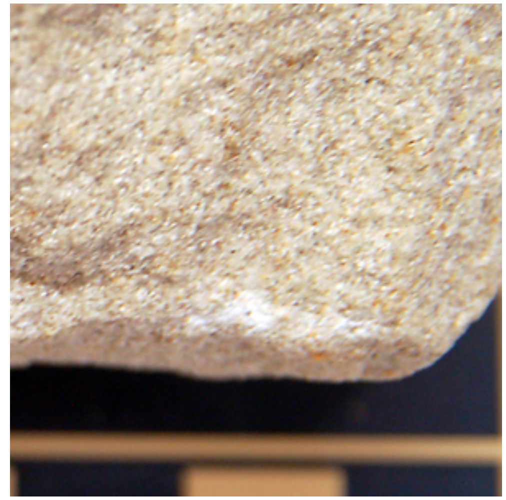
- From sediment to sedimentary rock
  - Mechanical and chemical weathering
  - Gravel, sand, silt, clay, ions in solution
  - Erosion, transportation, deposition
  - Rounding, sorting, compositional maturity
  - Lithification: burial, compaction, cementation

Summary: sedimentary rocks

- Sedimentary rocks
  - Clastic, or detrital sedimentary rocks
    - Cemented fragments of other rocks (the only category of rocks that is NOT formed by crystals)
  - Chemical sedimentary rocks
    - Mineral crystals that grow in, or thanks to a solution
  - Organic sedimentary rocks
    - Formed by preserved remains of organic matter
      - Coal C

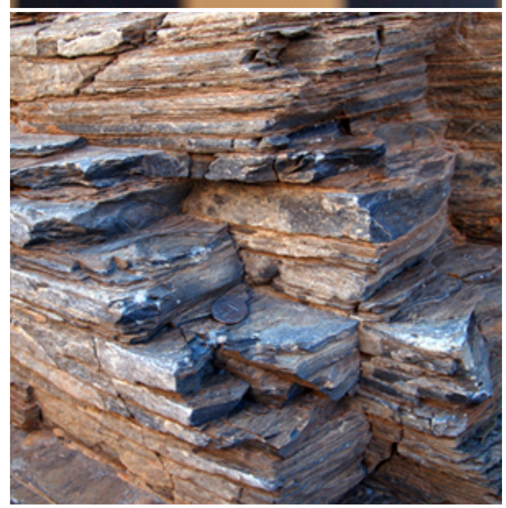
Clastic Sedimentary Rocks

- From gravel
  - Breccia
  - Conglomerate
- From sand
  - **Sandstone**
    - Quartz sandstone, lithic sandstone (arkose sandstone), graywacke sandstone
- From silt
  - Siltstone
- From clay
  - Mudstone
  - Claystone
  - **Shale**



Quartz Sandstone

sample from SMC rock collection



Shale

Mosaic Canyon
Death Valley National Park,
California, U.S.A.

Chemical Sedimentary Rocks

- Phosphates

- Ironstones
  - Hematite Fe_2O_3
  - Limonite $Fe_2O_3*nH_2O$, Magnetite Fe_3O_4, Banded Iron Formations

- Evaporites
  - Gypsum $CaSO_4* 2H_2O$
  - Anhydrite $CaSO_4$
  - Halite (Rock Salt) NaCl

- Carbonates
  - **Limestones** $CaCO_3$
  - Dolostones $(CaMg)[CO_3]_2$

- Cherts SiO_2

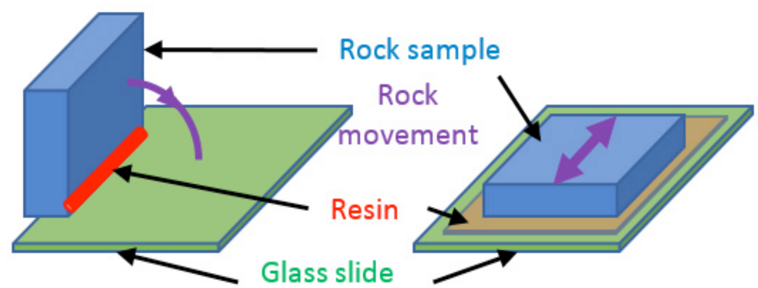
Oncolitic **limestone**, Chambless Formation
Cadiz, California

Basic information

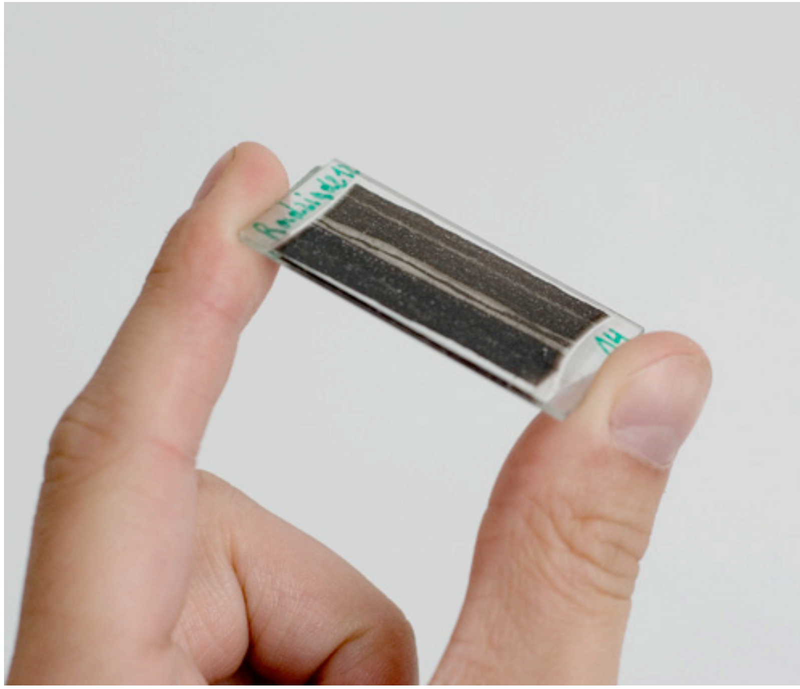
- Shales, sandstones, and limestones are the most common sedimentary rocks
- Shales constituent grains are invisible even to the naked eye
- Sandstone and limestone components can be so small that it is often difficult to identify their mineral components
- Identification is easier when we examine:
  - Thin sections
  - Acetate peels

Thin sections

- Thin sections are laboratory preparation of rocks for use with a polarizing petrographic microscope
- A thin sliver of rock is cut from the sample with a diamond saw and ground optically flat
- It is then mounted on a glass slide and then ground smooth using progressively finer abrasive grit until the sample is only 30 µm thick



Above: cutting the rock sample. Below: attaching it to a glass slide



The size of a thin section

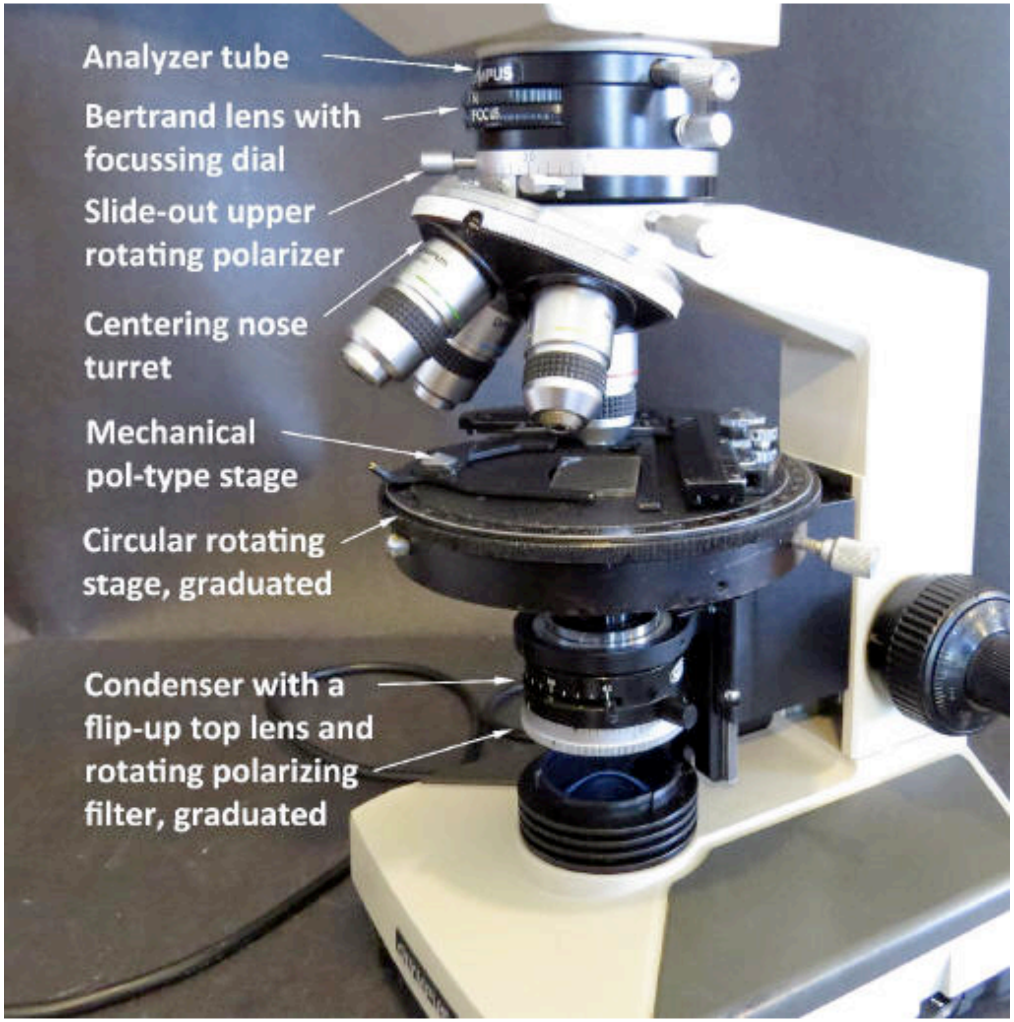
© http://www.thin-section-preparation.com/

Examples of thin sections

Above: http://www.precimat.com
Below: http://rocksmineralscollections.com

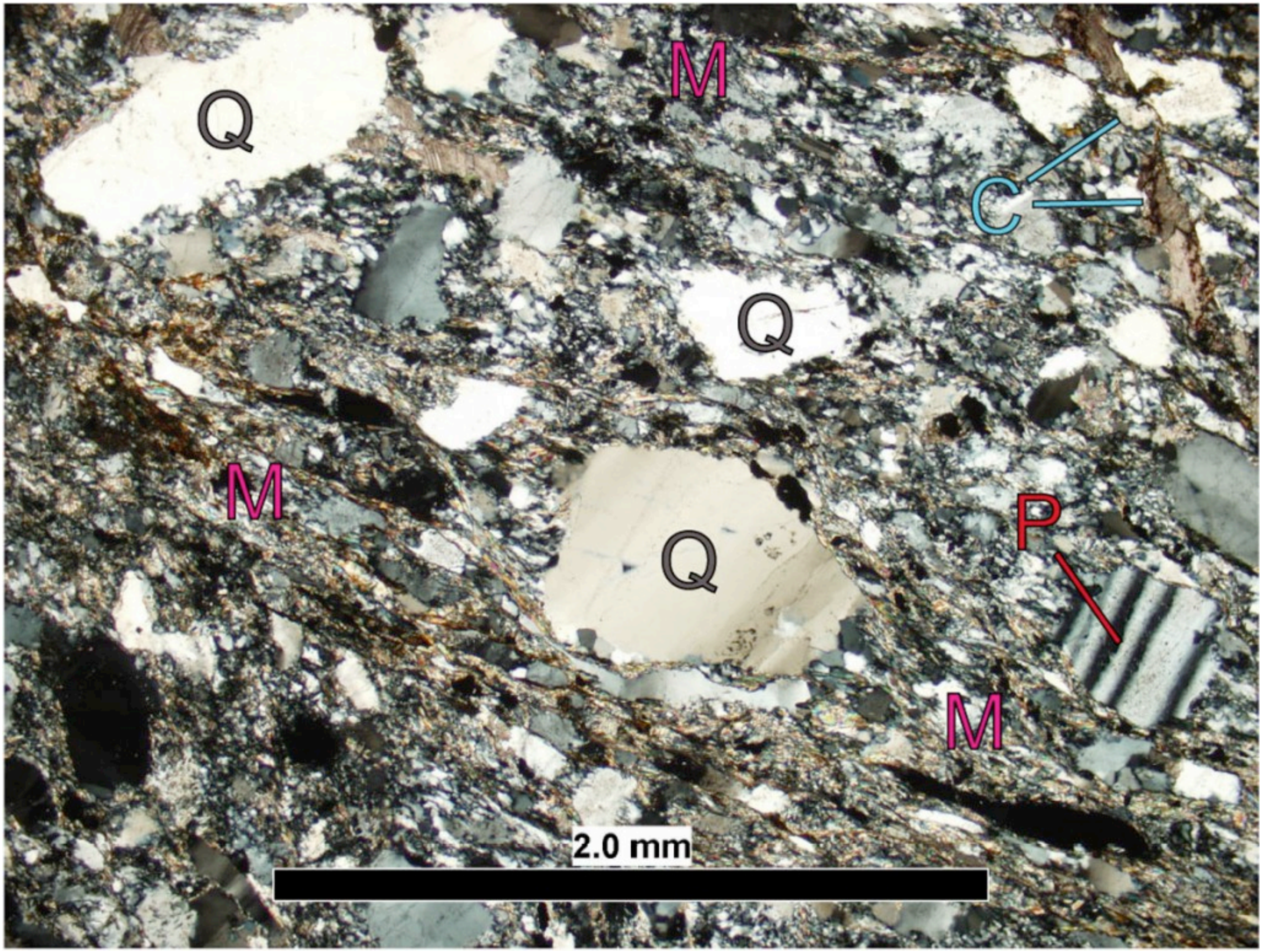
What do we do now with a thin section?

- At 30 µm of thickness most minerals are transparent to visible light
- Minerals are more distinctly seen under a polarized microscope (crossed polarizers)
- While identification requires experience, the textural relationships of the grains are easy to identify



The components of a polarizing microscope

Studying mineral components in rocks under the polarizing microscopes



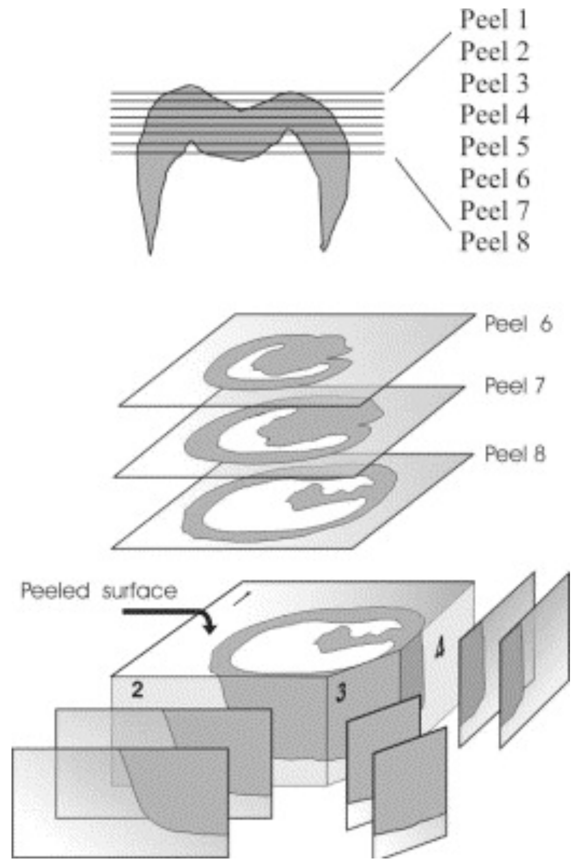
Micaceous meta-sandstone. Clasts of quartz (Q) and plagioclase (P) in matrix (M) of fine-grained muscovite and quartz. Calcite vein (C) cuts sample. Cross polarized light.

Acetate peels

- Sometimes making thin sections is impractical
- An acetate peel is made by wetting the polished surface of a rock chip (or a core) with acetone $(CH_3)_2CO$. Acetone It is a colorless, volatile, flammable liquid,
- Acetone film is placed on the polished wet surface
- Acetone softens the film, which then records an accurate impression of the texture of the rock
- Acetate peels are widely used for the study of texture of carbonates (limestone an dolostones) and non-porous sandstones

Making acetate peels

©meganhendrickson (on Twitter @meghendrickson)



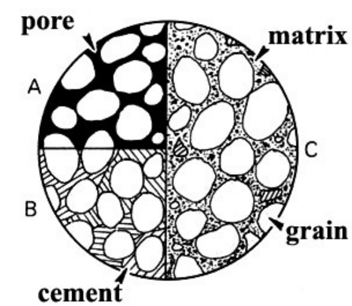
Making acetate peels allows you to obtain several films at different levels and different positions from the same sample

From Füsun et al. (2005), **Acetate peel technique: a rapid way of preparing sequential surface replicas of dental hard tissues for microscopic examination**
At https://doi.org/10.1016/j.archoralbio.2004.06.009

- In the end, whether we use thin sections or acetate peels, we obtain a thin, transparent medium that is, or has an image of, a rock
- Shales are formed by clay particles, which are invisible under a microscope (you will need a SEM)
- While all rocks can be studied, we are particularly concerned with sandstones and limestones

Textures of sandstones

- The possible textural components of a sandstone are:



  - **Grains**
    - Between 2 and 1/16 mm
    - Rounded or angular
    - Sorted or unsorted
    - Any composition, but usually quartz, feldspars, or lithic fragments (that is, fragments of any kind of rock)
  - **Matrix**
    - Anything smaller than a grain of sound that is found in the spaces (pores) between the sand grains themselves (silt and clay)
  - **Cement**
    - A chemical precipitate that "glues" the grains one to the other (so that we do not have a sand anymore, but a sandstone)
    - Could be any composition, but the most common are calcite $CaCO_3$, silica SiO_2, hematite Fe_2O_3

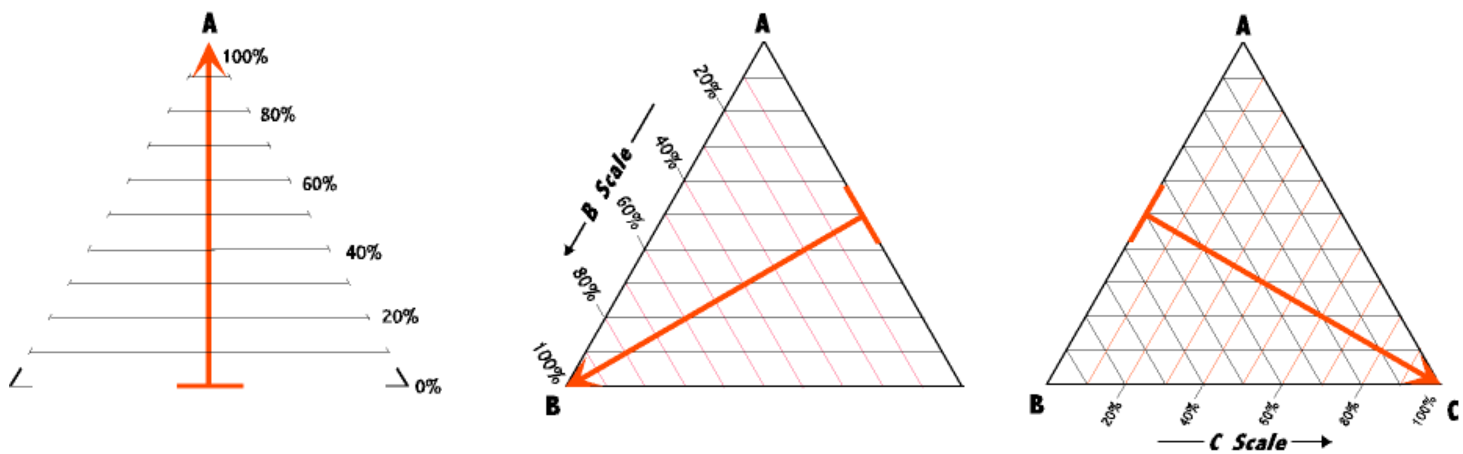
- In order to classify sandstones we use **ternary diagrams**

- Ternary diagrams consist of triangles that show the relative percentages of three major components

- They can be used for several components but in our case we will work with quartz, feldspars, and lithic fragments

How do I read a ternary diagram?

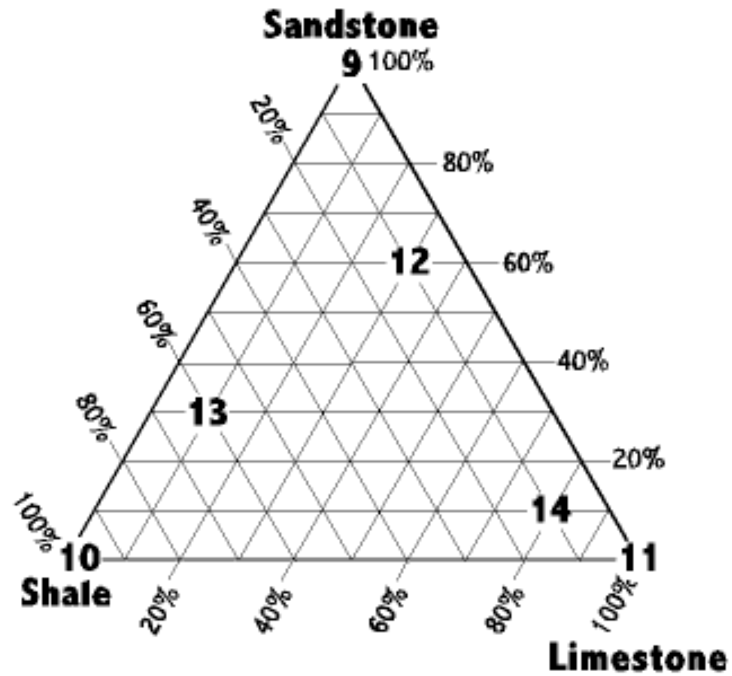
- I look at components A, B, C individually
- 100% of that component is plotted at the corner with the same name
- 0% is found on the opposite side



All these figures (and next page) come from a http://csmgeo.csm.jmu.edu/geollab/Fichter/SedRx/readternary.html
Please refer to that web site if you want to know more

examples

- 9. **100**% Sandstone | **0**% Shale | **0**% Limestone = 100% ***Sandstone***.
- 10. **0**% Sandstone | **100**% Shale | **0**% Limestone = 100% ***Shale***.
- 11. **0**% Sandstone | **0**% Shale | **100**% Limestone = 100% ***Limestone***.
- 12. **60**% Sandstone | **10**% Shale | **30**% Limestone = 100% ***Shaley, limey sandstone***.
- 13. **30**% Sandstone | **60**% Shale | **10**% Limestone = 100% ***Limey, sandy, shale***.
- 14. **10**% Sandstone | **10**% Shale | **80**% Limestone = 100% A ***limestone*** of some kind, depending on how the sandstone and shale are nudged.



- When sandstones are examined, the textural and compositional maturity change from immature to submature to mature sandstone
- This change is marked by a gradual increase in rounding and sorting (and consequent decrease in matrix)

Immature Sandstones

- Contain in general little or no cement
- Are kept together by matrix (clay minerals)
- Sand grain are not in contact with each other
- If the matrix (clay minerals and micas such as biotite, muscovite, chlorite) can recrystallize and grow into larger minerals, it can become very durable, making the sandstone very resistant

- Lithic sandstones
- Arkose sandstones
- Graywacke sandstones

Submature sandstones

– Held together by a combination of matrix, cement, and **pressure solution**

– Pressure solution occurs when the constituent grains are pressed together so strongly that chemical reactions (solution) occur at grain boundaries

– At the contact, grains dissolve, thus cementing the rock together

Mature sandstones

- Held together either by cement or pressure solution (no matrix!)
- If grains are not closely packed, cement is present
- If grains are closely packed, pressure solution is possible

- Quartz sandstone

Figure 3.5 Textures of sandstones as seen in thin section under the microscope. Rock names are given at left and top, degrees of textural maturity at bottom. Sometimes the rock names are not used and a sandstone is identified simply as immature, submature, or mature. Typically, an **arkose** is derived from weathered granite. **Graywacke** is derived from a variety of rocks, including volcanic rocks, slate, and schist. Most of these rocks have mineral components (or the rock fragments themselves) that are dark in color and thus impart a dark color to graywacke. Both arkose and graywacke contain angular and poorly sorted grains, but graywacke generally has more fine-grained matrix than an arkose. *Submature sandstones* typically have only a small amount of matrix and consist of subrounded and moderately sorted grains, some of which may be dark in color. The grains in a *mature quartz sandstone* are typically subrounded to rounded. The sorting of grains is moderate to good, and few, if any, dark grains are present. Grains in a mature quartz sandstone are commonly held together by cement.

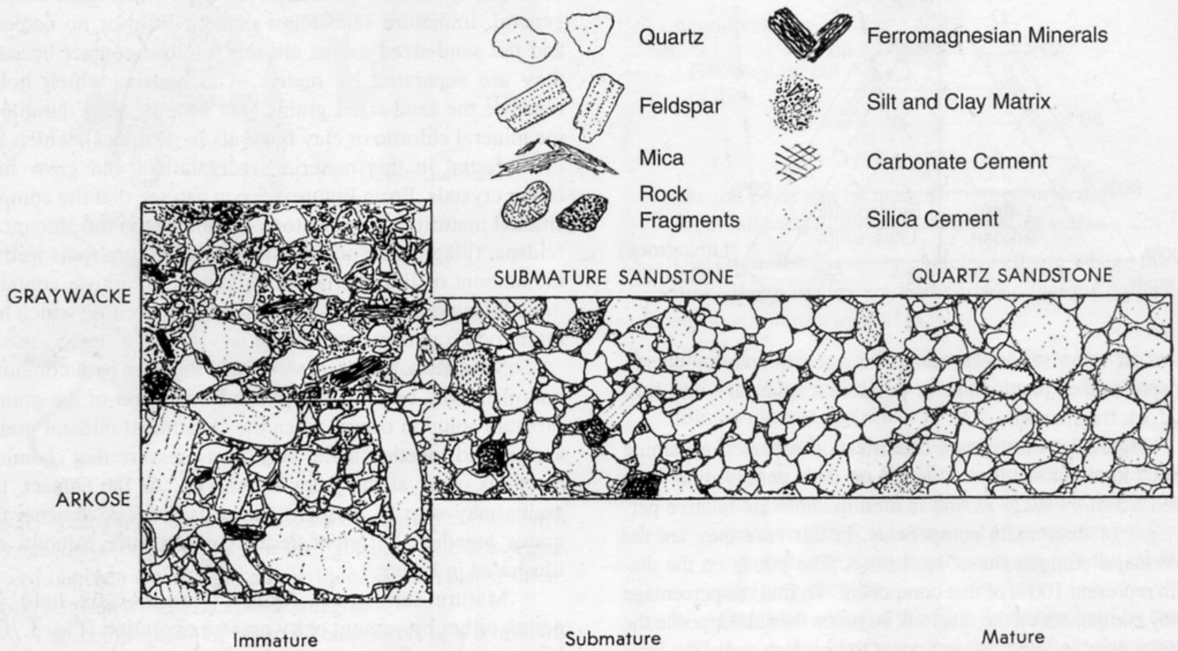
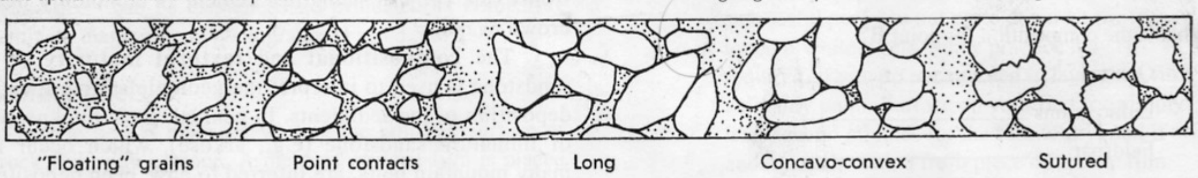


Figure 3.6 Types of contacts between grains in sandstone. As sandstone is buried to successively greater depths, grains in contact are pressed together, and one or the other grain dissolves at the contact. This is called pressure solution. Abundant matrix prevents pressure solution by keeping grains apart. The transition from point contacts to sutured contacts represents an increasing degree of pressure solution between grains.



What information do we get?

- Compositional and textural maturity of a sandstone are used to determine the geologic setting for the deposition of sediments

- Great amounts of immature sandstones (arkoses, lithic sandstones) which occur in mountain belts, are inferred to have been deposited rapidly on subsiding areas
- The rate of accumulation was too rapid for the grains to be rounded and the matrix to be winnowed out

- Great amounts of mature sandstones are inferred to have accumulated slowly on more stable parts of the crust
- There was enough time (and length of transportation) for the sediment grains to become highly rounded and sorted

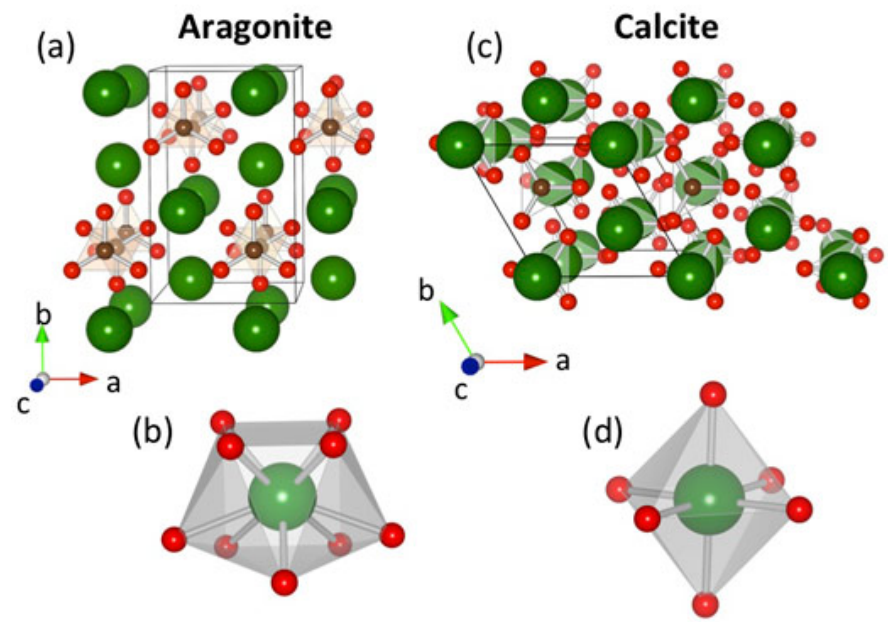
Texture of Carbonate Rocks

- Carbonate rocks include all rocks formed by carbonate minerals

- By far, the most common carbonate rocks are:
  - Limestone $CaCO_3$
    - Mostly calcite
    - Sometimes aragonite
  - Dolostone $(CaMg)[CO_3]_2$
    - Dolomite

Carbonate review:

- Magnesium and its role in the formation of calcite
- **Calcite vs. aragonite**
  - Polymorphs!
  - Why do some organisms prefer aragonite to calcite?
  - What is the role of plate tectonics in the establishment of "calcite seas" vs. aragonite seas"?



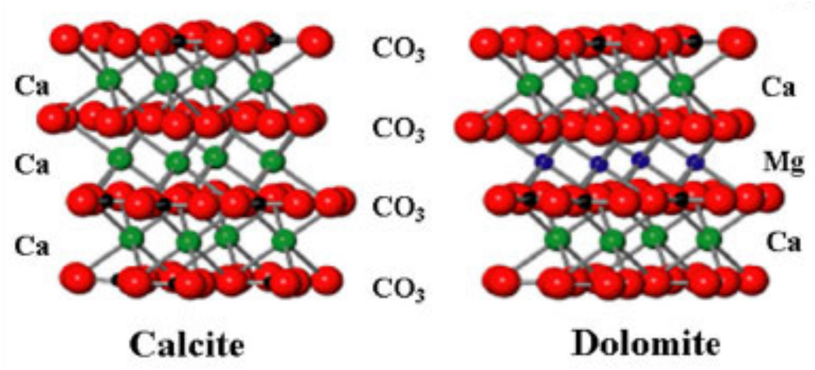
Schematic crystal structure of the $CaCO_3$ polymorphs aragonite and calcite

From: https://www.researchgate.net/figure/Schematic-crystal-structure-of-the-CaCO-3-polymorphs-aragonite-and-calcite-Aragonite-a_fig1_305654328

Carbonate review

- Calcite vs. dolomite
  - Where does magnesium go?

- Relative abundance of limestones and dolostones
  - Today: dolostones are rare
  - Geological record: dolostones almost as common as limestones in shallow-water deposits



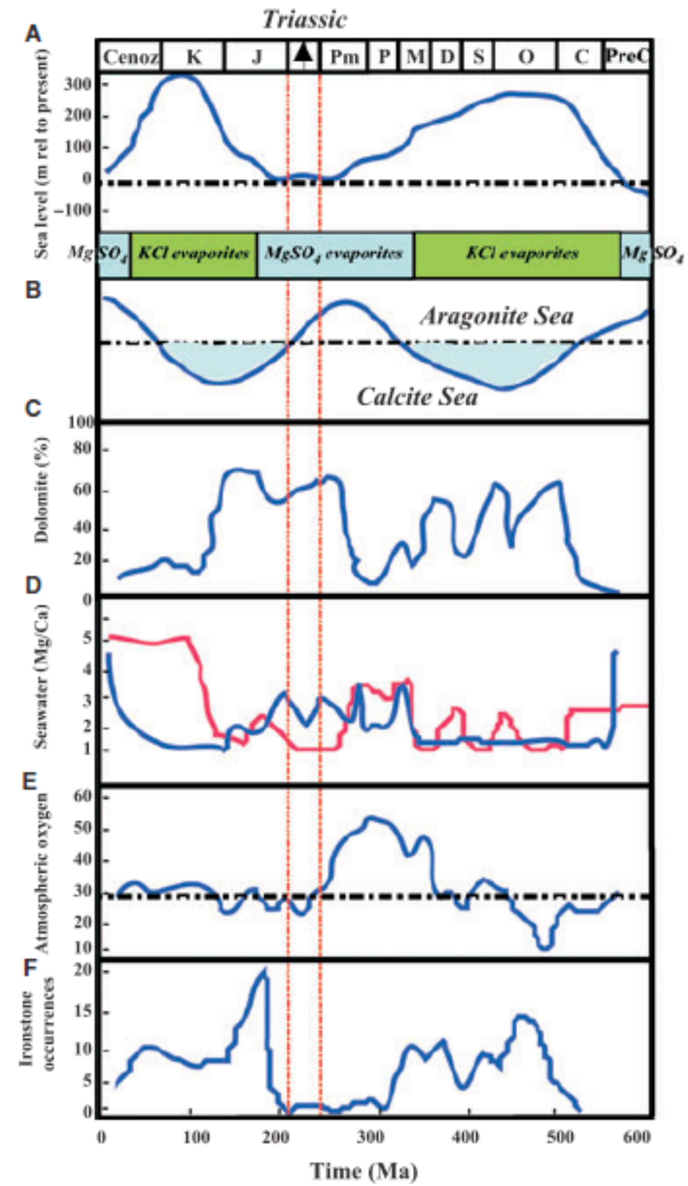
3-D structure of calcite and dolomite

Both crystals consist of alternating sheets of carbonate ions but in calcite carbonate sheets can only alternate with calcium ions. In calcite, magnesium can disturb the calcium sheets, originating impurities. In dolomite instead, magnesium forms its own separated, alternating sheets.

Modified from http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-50532013000200018

Carbonate review

- Most dolomite is not a primary precipitate but forms as a slow alteration of original calcite
- Ocean conditions that favor dolomite replacement for calcite are;
  - High salinity
  - High pH
  - Low Ca2+/Mg2+ ratio
  - High temperature



Relative variation of dolomite (and other parameters) over geologic time

The Dolomites of Italy

Tre Cime (Three Peaks) di Lavaredo
Dolomiti region of Belluno and Bolzano, Italy

Dolomites as rocks were first investigated and described in northern Italy by the French geologist Deodat de Dolomieu. The mineral (dolomite), the rock (dolostone), and this whole geological region (Dolomiti) are named after him.

Texture of Carbonate Rocks

- Carbonate rocks can be classified based on
  - Individual grains (allochemical grains)
    - Components of the carbonate framework
    - Bioclasts, ooids, fecal pellets, intraclasts
  - Cement
    - **Sparite** (clear crystalline carbonate precipitated between grains, or formed by recrystallization of carbonate grains)
  - Matrix
    - **Micrite** (fine-grained carbonate mud deposited together with the grains and recrystallized during lithification)

Allochemical grains

- **Bioclasts**
  - Microbialites (mostly stromatolites)
  - Broken and whole skeletal parts of organisms
    - Sheaths, shells, tests, spicules
- **Ooids** (pisoids if larger than 2mm)
  - Coated grains
- **Pellets** (and peloids)
  - Sand-sized grains of microcrystalline carbonate, expelled as fecal materials by marine organisms
  - Peloids look like pellets but they form by spontaneous precipitation of Mg-calcite and diagenetic alteration of other grains
- **Intraclasts** (and aggregate grains)
  - Limestones that have already turned into rocks can be broken down (by storms, earthquakes, etc.) and fragments (clasts) remain in the environment of deposition (intra-)
  - Aggregate grains are grains of all kinds bound together by biofilms or encrusting organisms, or cemented by aragonite or calcite

Sparite

- A crystalline, easily cleavable, light colored mineral (spar), in this case calcite, (**sparite**)

- Consists of coarse calcite crystals that act as a cement in limestones

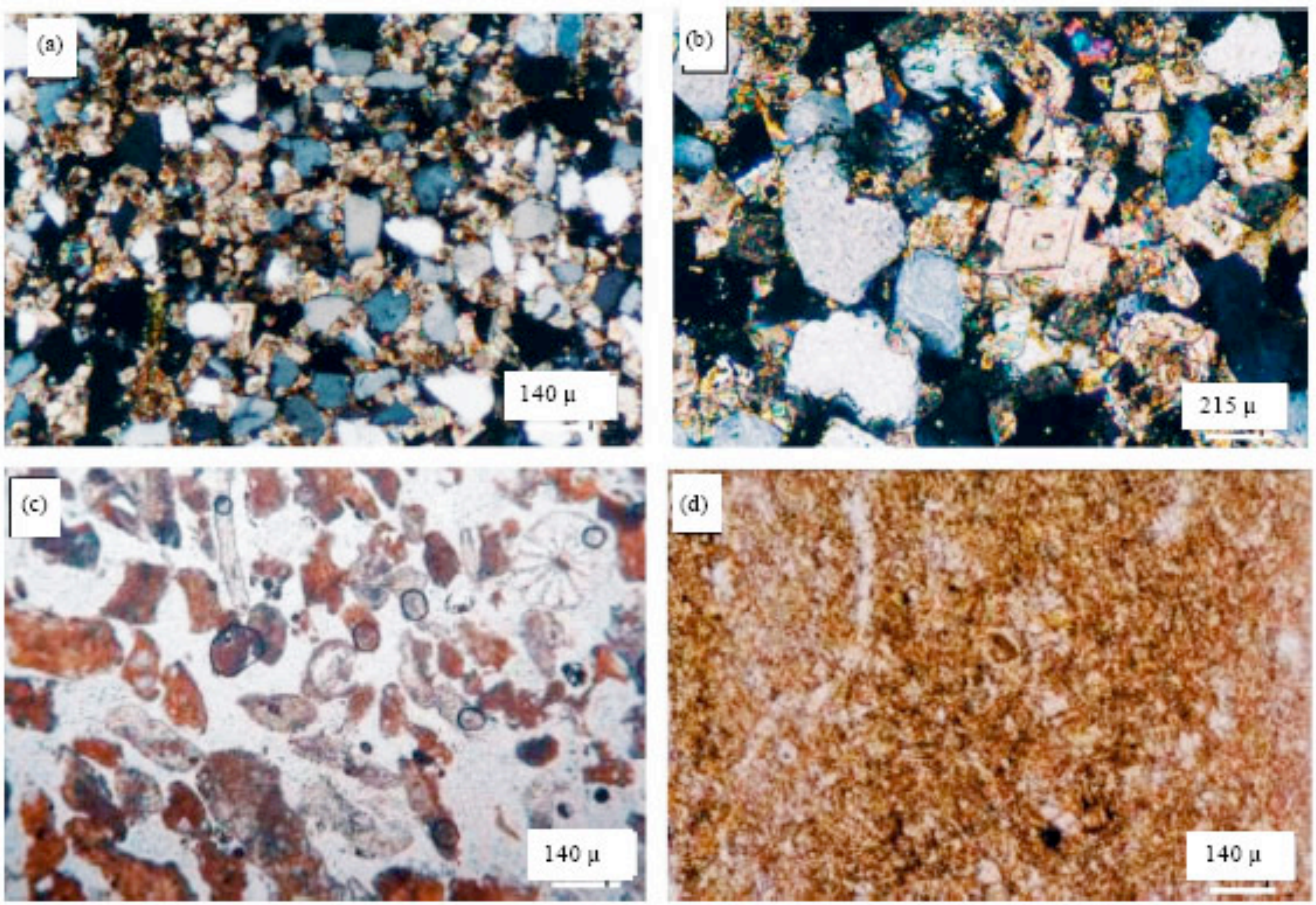
Micrite

- Micro-calcite, or **micrite**, consists of crystalline calcite or aragonite with size range between 1µm and 4 µm

- Can also be described as **lime mud**

- There are two types of micrite:
  - Allomicrite (a sediment)
  - Automicrite (an in-place chemical precipitate)

A few carbonates in thin section



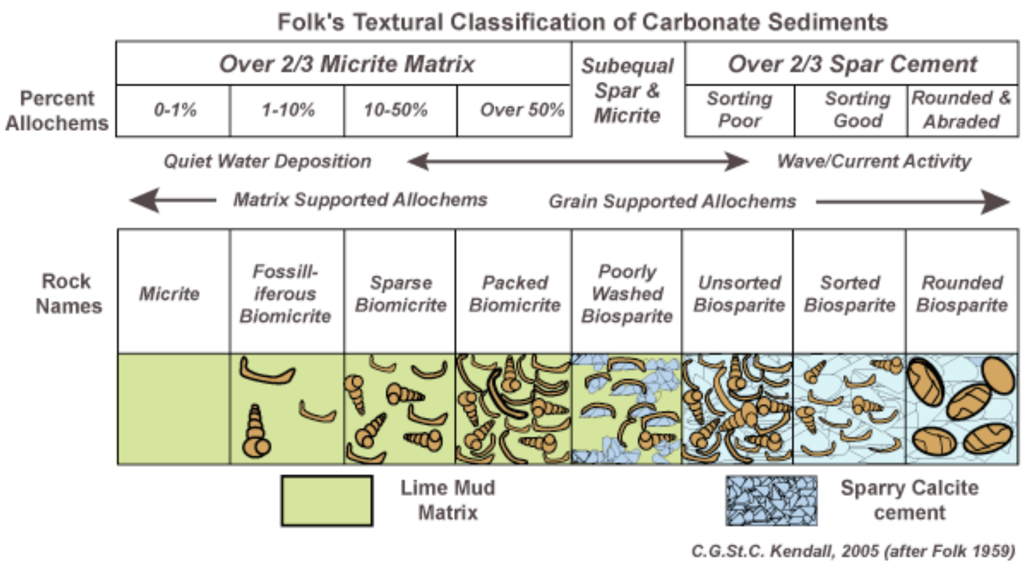
Limestone samples:
(a) Dolomitiic sandstone (b) Sandy dolostone (c) Biosparite (d) Lime- mudstone

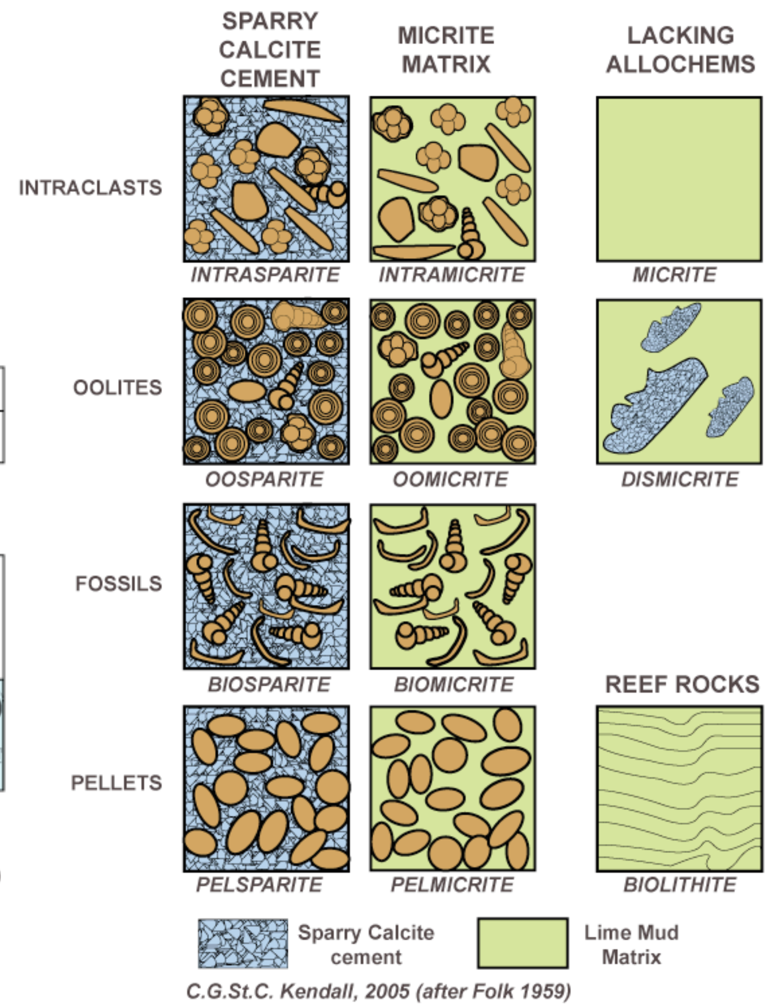
From https://scialert.net/fulltext/?doi=jas.2011.2513.2524

How do we classify carbonates?

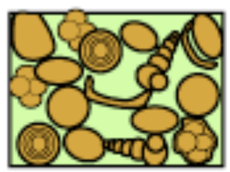
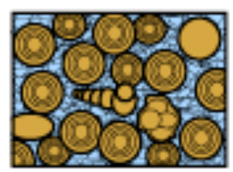
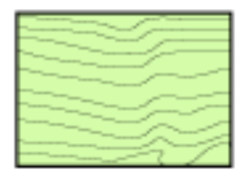
- We need methods that are concise and rigorous
- Two methods are normally used:
  - Folk’s classification
    - Based on the type of allochems, and whether or not they are surrounded by micrite matrix or carbonate cement (sparite)
  - Dunham’s classification
    - Based on the nature of the supporting framework between particles

Folk's carbonate classification





Dunham's carbonate classification

Original components not bound together at deposition				Original components bound together at deposition. Intergrown skeletal material, lamination contrary to gravity, or cavities floored by sediment, roofed over by organic material but too large to be interstices
Contains mud (particles of clay and fine silt size)			Lacks Mud	
Mud-supported		Grain-supported		
Less than 10% Grains	More than 10% Grains			
Mudstone	Wackestone	Packstone	Grainstone	Boundstone
				

C. G. St. C. Kendall, 2005 (after Dunham, 1962, AAPG Memoir 1)

The end