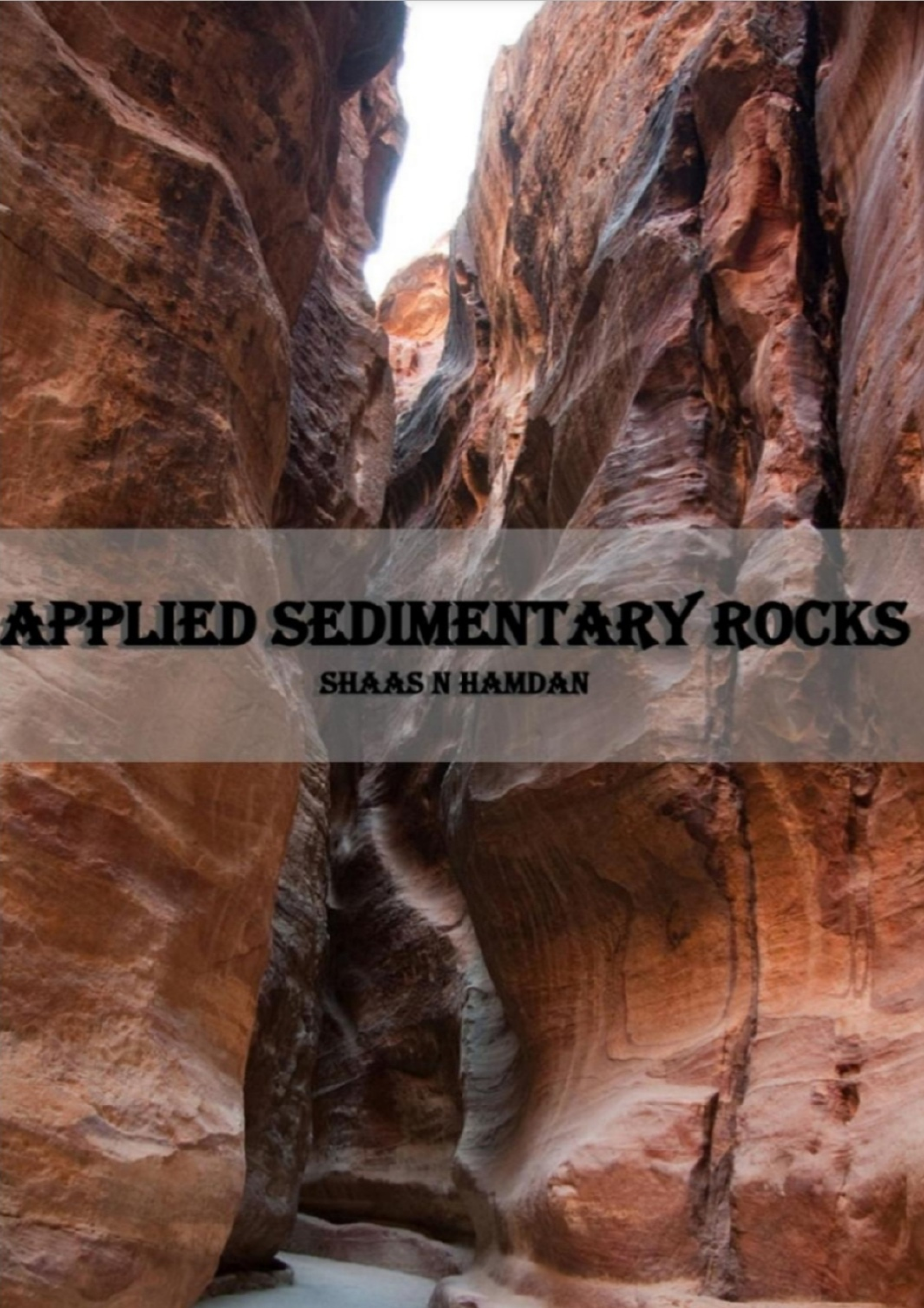


APPLIED SEDIMENTARY ROCKS

SHAAS N HAMDAN

GRAIN SIZE ANALYSIS

φ size	mm size	Raw wt. [gm]	Individual wt%	Cumulative wt%
-4 — -3	16 -8	0.000		
-3 — -2	8 -4	0.380		
-2 — -1	4 -2	0.060		
-1 — 0	2 -1	1.660		
0 — 1	1 – 0.5	38.44		
1 — 2	0.5 -0.25	39.40		
2 — 3	0.25 -0.125	11.62		
3 — 4	0.125 -0.0625	4.900		
4 — 5	0.0625-0.03125	2.880		
5 — 6	0.03125-0.015625	0.000		

1. Using graphical method of grain size analysis determine Mode, Mean, Median, Sorting, Skewness, & kurtosis

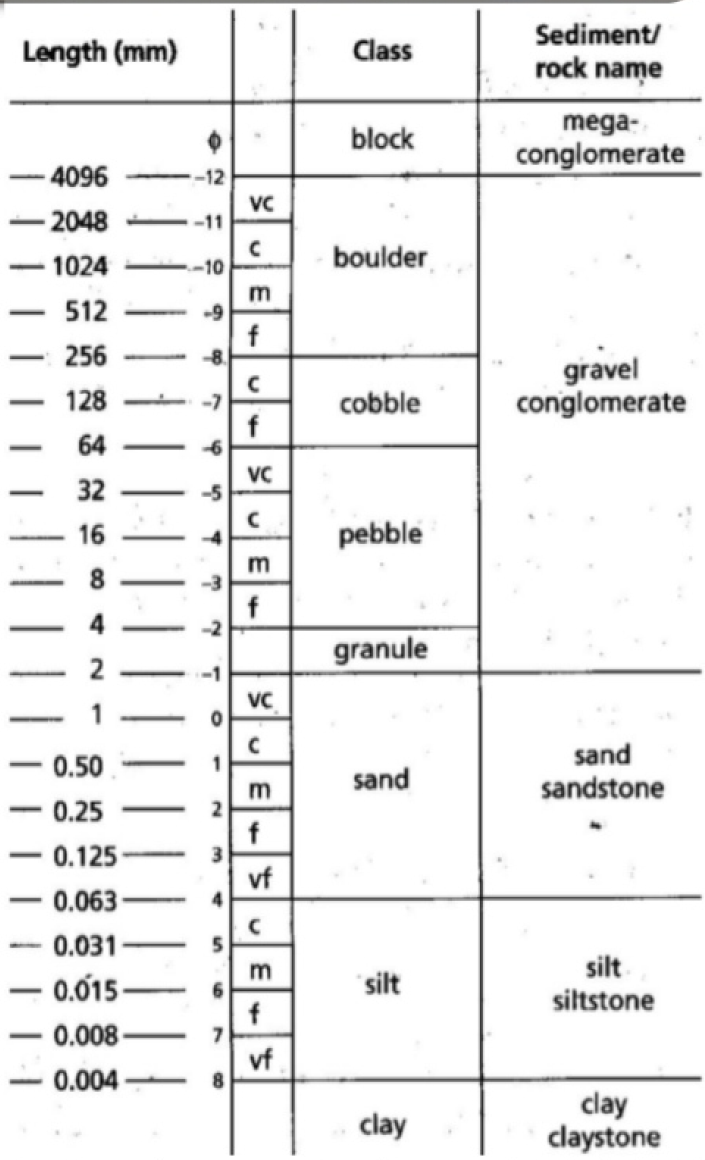
Mean (M)	$M = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$
Median (Md)	$Md = \Phi_{50}$
Sorting (σ)	$\sigma_\Phi = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_5}{6.6}$
Skewness (SK)	$Sk = \frac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_5 + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_5)}$
Kurtosis	$KG = \frac{\Phi_{95} - \Phi_5}{2.44(\Phi_{75} - \Phi_{25})}$
Mode	$Mo = \frac{\Phi_{max} + \Phi_{min}}{2} of \max wt$
Individual wt%	$wt_{1_x}\% = \frac{Raw\ wt_x\ [g]}{\Sigma raw\ wt\ [g]}$
Comu. wt%	$wt_x\% = wt_{1x} + \Sigma wt_{1(<x)}$

2. Describe the verbal terms of these grain size parameters (use the following tables)

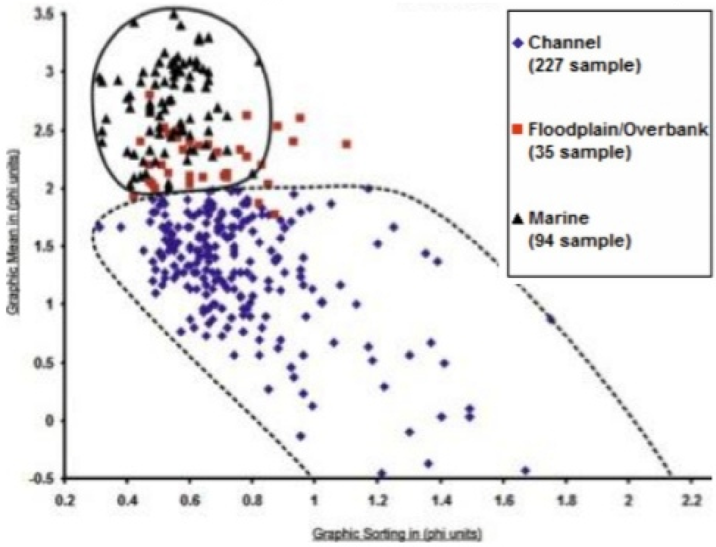
Grain size [Φ]	Terms for sorting
<0.35	Very well sorted
0.35 – 0.50	Well sorted
0.50 – 0.71	Moderately well sorted
0.71 – 1.00	Moderately sorted
1.00 – 2.00	Poorly sorted
>2.00	Very poorly sorted

Sk	Terms for skewness
<-0.3	Strongly coarse-skewed
-0.10 – -0.30	Coarse-skewed
+0.10 – -0.10	Near-symmetrical
+0.30 – +0.10	Fine-skewed
>+0.30	Strongly fine-skewed

- -ve skewed: If the distribution has a coarse 'tail' (there is an excess of coarse material)
- +ve skewed: if the sediment has a fine 'tail'
- No skew: If the distribution is symmetrical



3. Using the mean-sorting diagram of Amireh (2015) determine the depositional environment of the sample



1st step : calculate individual & cumulative wt%

- **Individual wt% (wt_1%)**

$$wt_{1_x}\% = \frac{Raw\ wt_x\ [g]}{\Sigma raw\ wt\ [g]}$$

0.380g/99.34g = 0.382%

0.060g/99.34g = 0.060%

. . .

. . .

2.880g/99.34g = 2.899%

- **Cumulative wt%**

$$wt_x\% = wt_{1x} + \Sigma wt_{1(<x)}$$

0.382% + 0 = 0.382%

0.060% + (0.382%) = 0.442%

1.671% + (0.442) = 2.113%

. . .

. . .

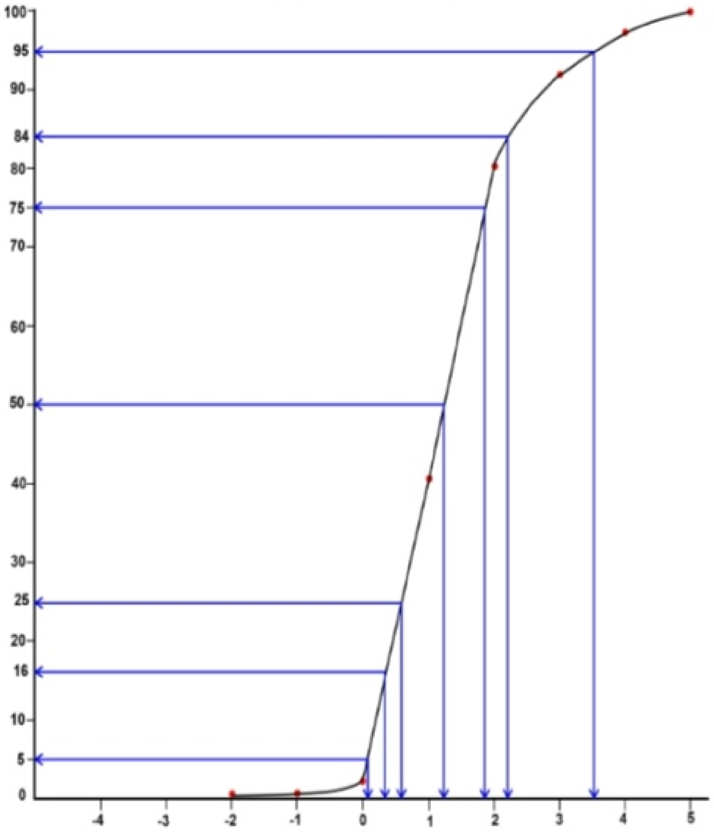
2.899% + (97.11%) = 100.0%

ϕ size	mm size	Raw wt. [gm]	Individual wt%	Cumulative wt%
-4 — -3	16 -8	–	–	–
-3 — -2	8 -4	0.380g	0.382%	0.382%
-2 — -1	4 -2	0.060g	0.060%	0.442%
-1 — 0	2 -1	1.660g	1.671%	2.113%
0 — 1	1 – 0.5	38.44g	38.70%	40.81%
1 — 2	0.5 -0.25	39.40g	39.66%	80.47%
2 — 3	0.25 -0.125	11.62g	11.70%	92.17%
3 — 4	0.125 -0.0625	4.900g	4.933%	97.11%
4 — 5	0.0625-0.03125	2.880g	2.899%	100.0%
5 — 6	0.03125-0.015625	–	–	–
Total		99.34g	100.0%	

2nd step : plot the cumulative frequency curve

X-axis → Grain Size (Φ-unit)

Y-axis → Cumulative wt%



3rd step : Calculate parameters & Describe verbal terms

$\Phi_5 = 0.06$, $\Phi_{16} = 0.32$, $\Phi_{25} = 0.6$, $\Phi_{50} = 1.25$

$\Phi_{75} = 1.86$, $\Phi_{84} = 2.18$, $\Phi_{95} = 3.55$

- **Mode**

$$M = \frac{\Phi_{max} + \Phi_{min}}{2}_{max\ wt} = \frac{2+1}{2}_{39.4g} = 1.5\Phi$$

- **Mean**

$$M = \frac{\Phi_{16}+\Phi_{50}+\Phi_{84}}{3} = \frac{0.32+1.25+2.18}{3} = 1.25\Phi$$

- **Median** = Φ_{50} = 1.25Φ

- **Sorting**

$$\sigma_\Phi = \frac{\Phi_{84}+\Phi_{16}}{4} + \frac{\Phi_{95}-\Phi_5}{6.6}$$

$$= \frac{0.32\Phi + 2.18\Phi}{4} + \frac{3.55\Phi - 0.06\Phi}{6.6} = 1.17\Phi$$

- **Skewness**

$$Sk = \frac{\Phi_{16}+\Phi_{84}-2\Phi_{50}}{2(\Phi_{84}-\Phi_{16})} + \frac{\Phi_5+\Phi_{95}-2\Phi_{50}}{2(\Phi_{95}-\Phi_5)}$$

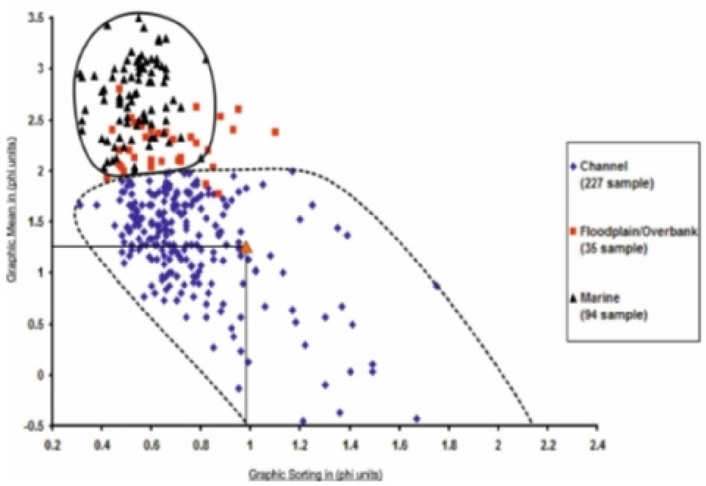
$$= \frac{0.32+2.18-2x1.25}{2(2.18-0.32)} + \frac{0.06+3.55-2x1.25}{2(3.55-0.06)} = 0.16$$

- **Kurtosis**

$$KG = \frac{\Phi_{95}-\Phi_5}{2.44(\Phi_{75}-\Phi_{25})} = \frac{3.55-0.06}{2.44(1.86-0.6)} = 1.14$$

Parameters	Value	Verbal terms
Mean (M)	1.25Φ	Medium Sand
Median (Md)	1.25Φ	Medium Sand
Mode	1.50Φ	Medium Sand
Sorting (σ)	1.17Φ	Poorly sorted
Skewness (SK)	0.16Φ	Fine-skewed
Kurtosis	1.14Φ	————

4th step : determine the depositional environment

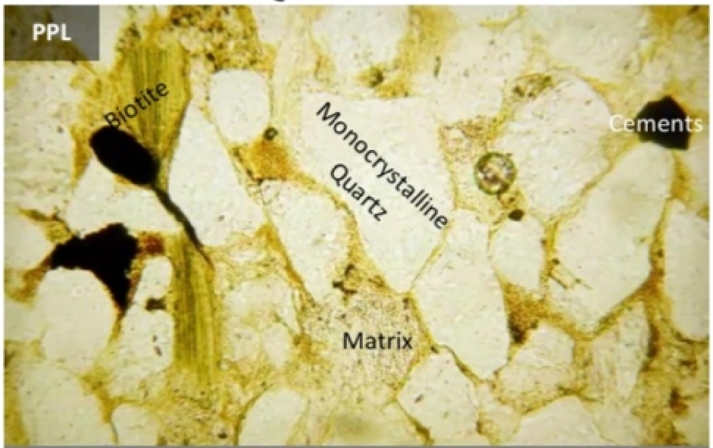


The dispositional environment is Channel

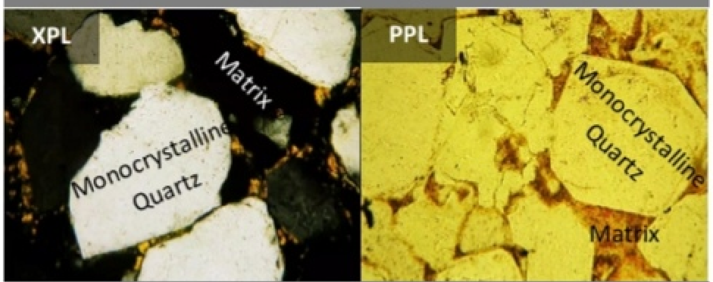
Sandstones Mineral Composition

- The clastic texture consists of:
  1. **Framework components**: clasts, grains, or particles (include quartz, feldspar, & rock fragments)
  2. **Matrix**: grains < silt (<0.63mm) between the clasts
  3. **Cement**: filling pore spaces between grains & matrix
  4. **Pore spaces:** empty (not filled by cement or matrix)

الفرق بين ال cement وال matrix هو اننا نستطيع تميز ال cement لانها تتميز بخصائص بصرية محددة ولكن لا نستطيع تميز ال matrix



Sand-sized grains: Quartz (light or colorless) + biotite
تشكل هذه البلورات ال framework لانها متصلة مع بعضها البعض
Matrix : (<63µm) yellow لا يمكن تمييز خصائصها
Cements : black grains



البلورات الصفراء هي كوارتز وتم تمييزها بواسطة ال shape (polyhedral) والذي ينتج بسبب ال overgrowth
ال overgrowth هو جزء من البلورة يحيط بجزء اخر (يسمى core) ويفصل بينهما خط (يسمى dust line) والذي تبلور ببيئة مختلفة عن ال core
لا يوجد cement لان المادة الصغيرة بين البلورات لا يمكن تمييز خصائصها البصرية وبالتالي هي matrix

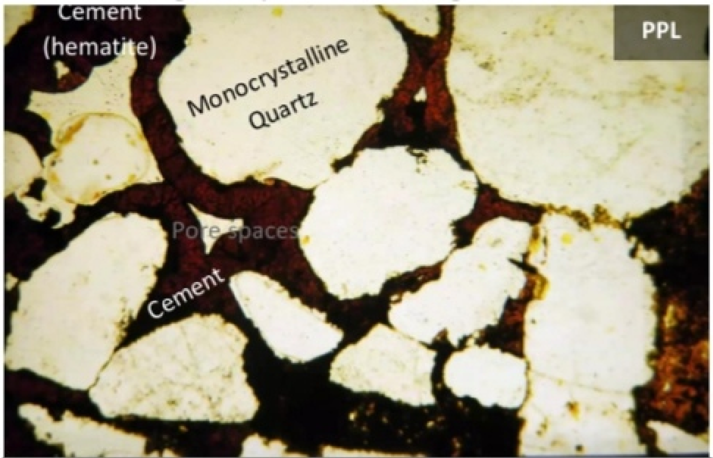
Quartz [Qz, SiO_2]

- The most common detrital mineral in all sandstones
- No sandstone without Qz, because Qz most stable silicate light mineral under sedimentary conditions
- **Monocrystalline Qz**: consists of single crystal بلورة واحدة
- **Polycrystalline Qz:** each grain consists of ≥ 2 crystals
- **Non-undulose Qz:** having a straight or unit extinction under cross polarized light تطفئ كل البلورة عند التدوير
- **Undulose**: having wavy or undulose extinction تطفئ من طرف البلورة للطرف الاخر مرورا بالوسط اثناء الدوران
- Qz characterized by presence of some inclusions such as needles of sillaminite, vacuoles of fluids or minute crystals (tourmaline, mica or rutile)
- **Qz parent rock:** plutonic rocks, acid gneisses, schist, & in some cases from pre-existing sandstones

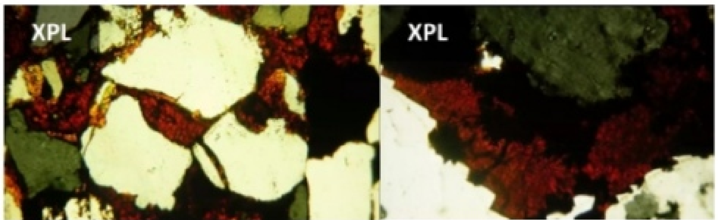
Properties of Qz that can be employed to infer its source rock

Sources	Quartz properties
Volcanic rock	Non-undulose Monocrystalline no inclusions & euhedral crystals
Hydrothermal vein	Have fluid-filled vacuoles
Metamorphic rocks	Poly., Elongate, preferred orientation
Plutonic rocks	Large with Undulose extinction
Older Sandstone	Non-undulose mono., overgrowth

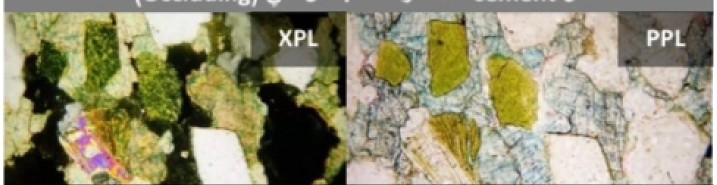
- Non-undulose monocrystalline is the most common in most sandstones due to its higher stability during weathering, transportation, & diagenesis



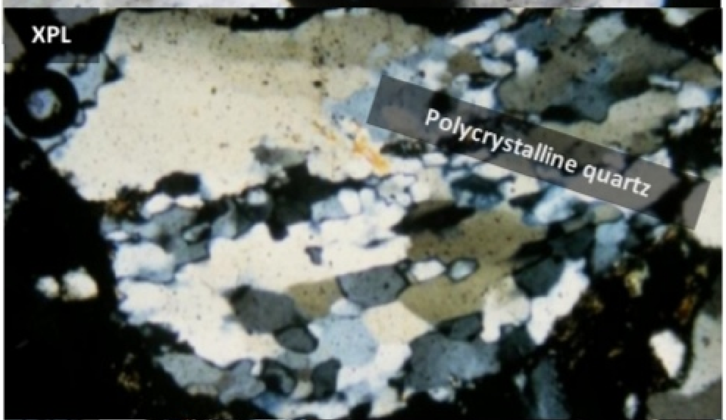
Cement : red or brown which filled pore spaces (hematite)
هو cement لان خصائصه البصرية واضحية ويمكن معرفة انه اكسيد الحديد
الاماكن الموجودة بين السمنت هي فراغات لم تملأ ونستطيع التأكد من ذلك بادخال الضوء المستقطب حيث يصبح لونها اسود (isotropic) ولونها مثل الكوارتز color less لانها مملوءة بالصمغ الذي تحضر به ال thin section



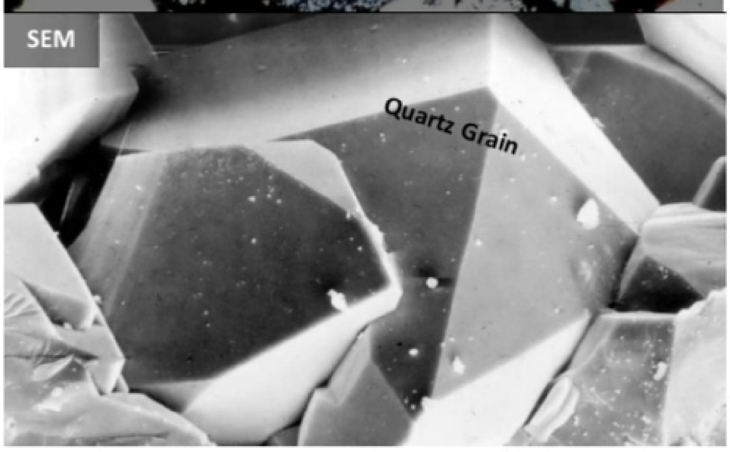
ال cement ملأ الفراغات بشكل كلي (Occluding)

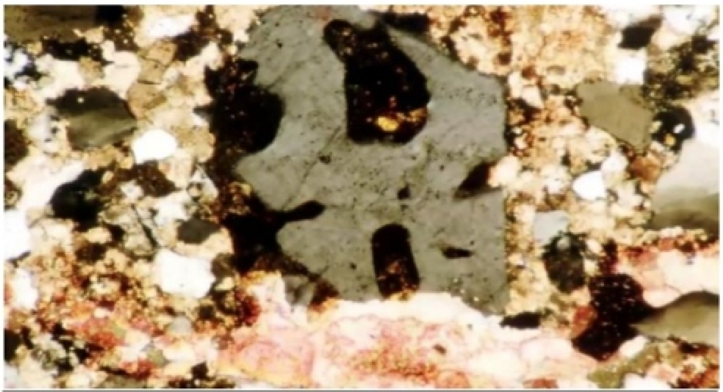


Quartz + Glauconite (green) + Muscovite (replacement by Glauconite in part "alteration")
Cements: Fe-dolomite "ankerite" (cleavage, & high order IC)

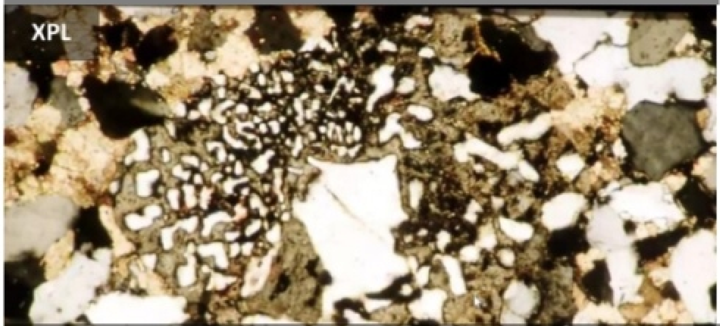


Polycrystalline quartz
هذه ال variety من الكوارتز هي ال chert

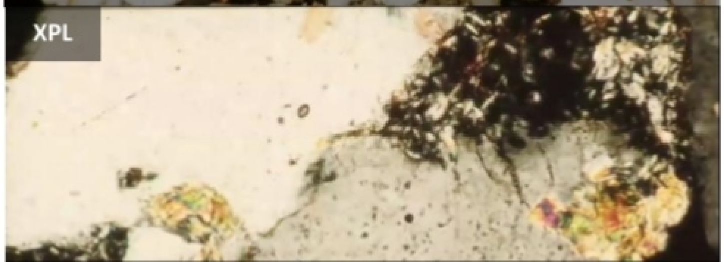




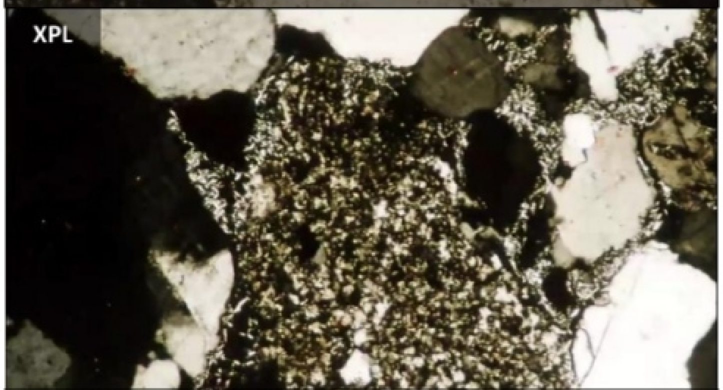
المادة البنية بالكوارتز corosion inpemaent وتدل على volcanic origin
Dolomite cements (colorless), Calcite cement (red, by staining)
Both has high order IC



Quartz & feldspar intergrowth (graphic) → plutonic origin

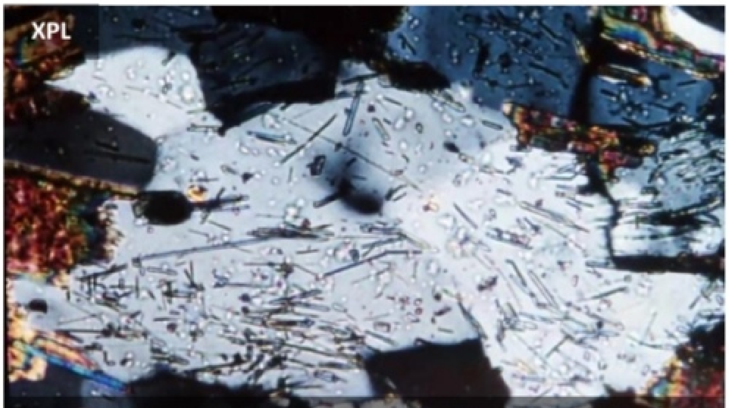


Quartz (muscovite inclusion) →plutonic origin

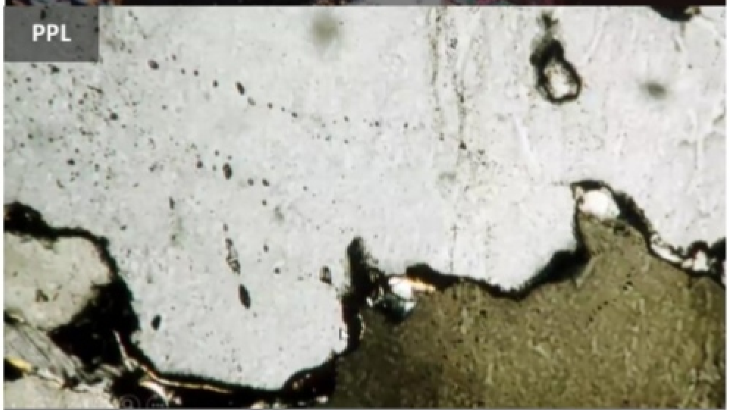


Polycrystalline + monocrystaline (non-andolose)
Matrix : illite indicate Recrystalization (Recrystalized matrix)

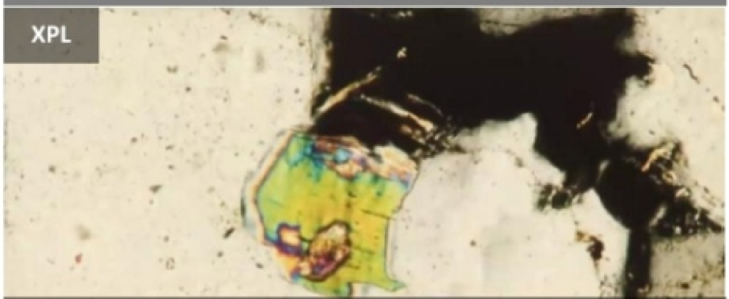
Phenocryst quartz with inclusions →plutonic origin



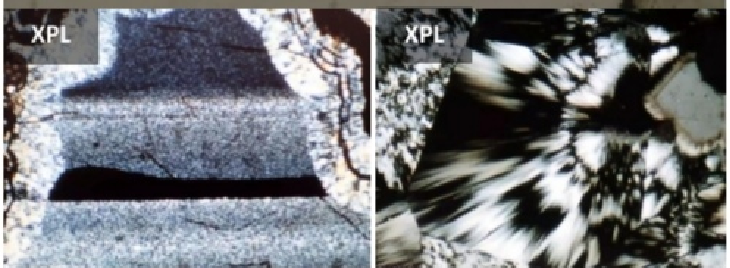
Quartz with inclusions → metamorphic origin



الكوارتز يوجد به sutured contact حدث بسبب ال dissolution والذي يدل
على high burial depth
يدفن الكوارتز اولا فيحدث له buried contact بسبب الضغط من الصخور
اعلاه وعند حدوث P-solution تتغير الي sutures
Contact types : bonds, concave-convex, & Sutured



Inclusion of muscovite in quartz grain & inclusion of zircon in muscovite (Inclusion inside another one → plutonic origin)

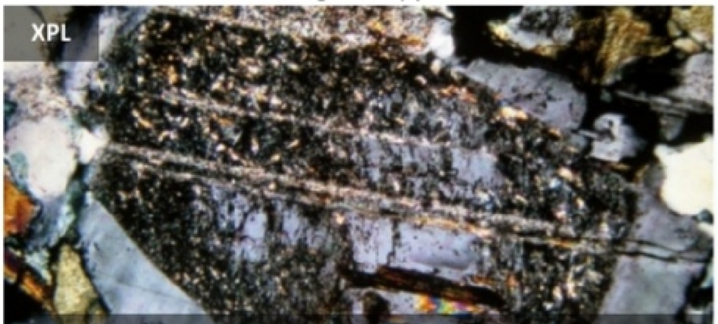


(Right) cryptocrystalline quartz surrounded by chalcedony, (Left) chalcedony: variety characterized by Zebra-extinction

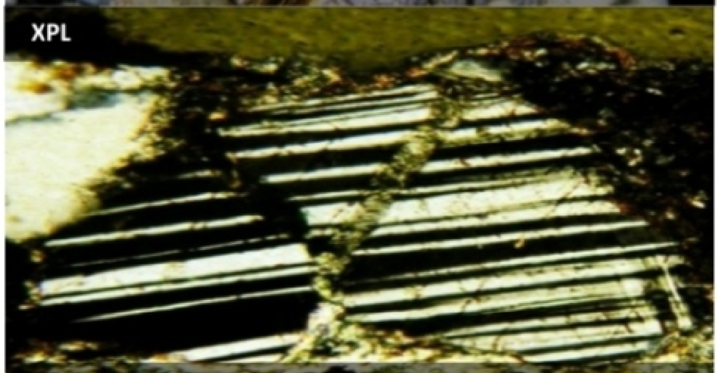
نميز بين ال core وال overgrowth باستخدام Cathodoluminescence
الاختلاف باللون بسبب اختلاف درجات الحرارة في بيئات الترسيب المختلفة

Feldspars [Fs, $(Na,K)AlSi_3O_8$, $CaAl_2Si_2O_8$]

- Less common in sandstones than quartz
- The reason for lower concentration than quartz:
  1. lower chemical stability to chemical weathering
  2. lower resistance against mechanical abrasion due to well-developed cleavage
- **Feldspar grains Vs quartz grains in thin sections**
  1. **Twining**: Cross-hatch twining of microcline, & Carlsbad twining of orthoclase
  2. **Cleavage**: in Fs, chemical alteration products concentred along cleavage planes
  3. **Appearance**: chemical weathering of Fs imparts a turbid color, cloudy, or dusty appearance, whereas Qz are clear lacking this appearance



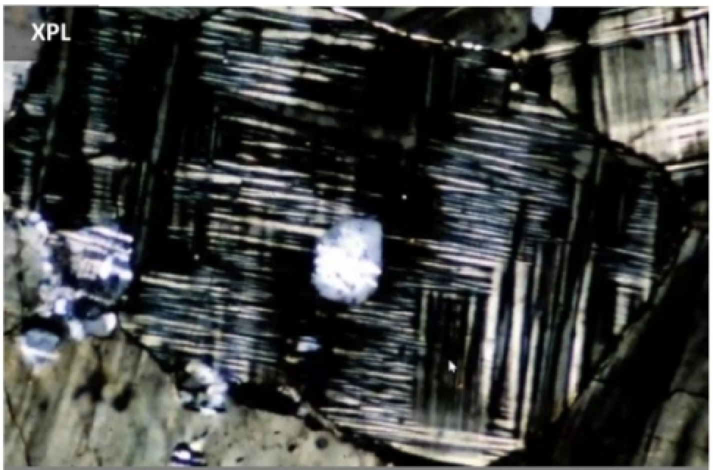
Orthoclase grain characterized by overgrowth
The overgrowth lacks weathering or alteration products affect detrital core, & the cleavage suffering from strong alteration



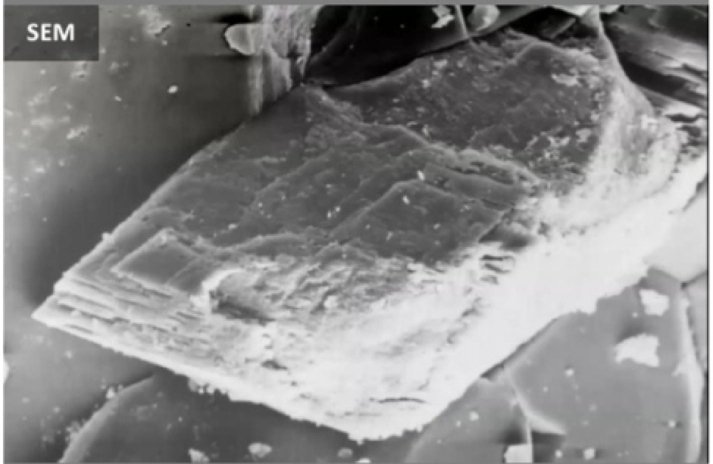
Plagioclase grain characterized by multiple twining

Sanadine (characterized by simple twinning)

Sanadine (characterized by polysynthetic twinning & zoning)

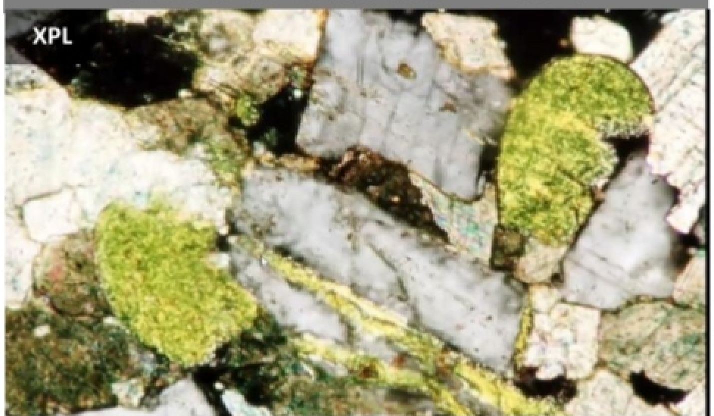


Orthoclase (characterized by cross-Hatching twinning)

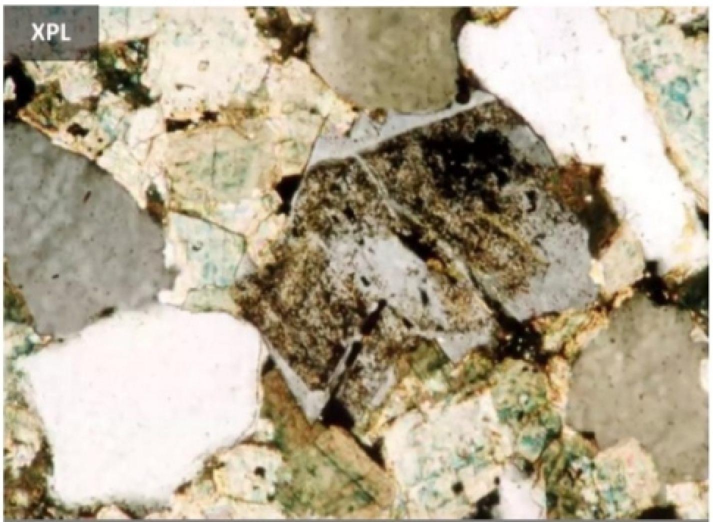


Plagioclase by SEM (LAMINAE over LAMINAE)

فيلدسبار حدث له dissolution ودخل به carbonate



Feldspar with twinning & 1 set of cleavage perpendicular to the grain boundary (2set), gloconite crystallize along cleavage plane



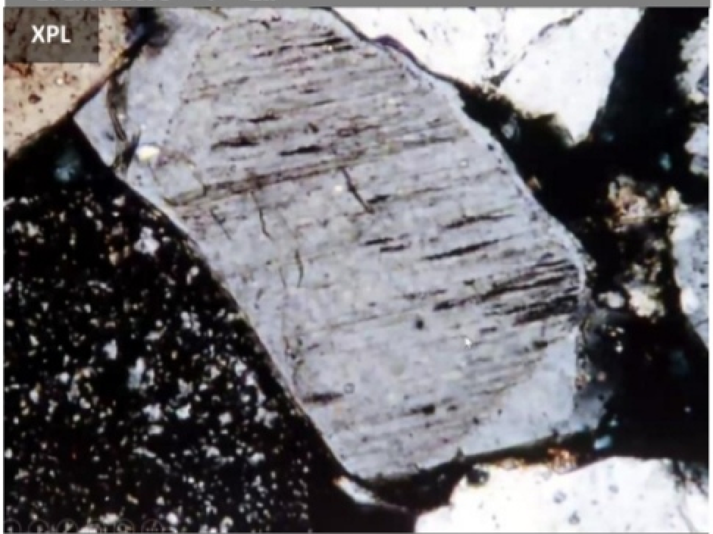
Feldspar with very sharp overgrowth

تشير ال overgrowth الى انه لا يمكن ان تكون الزاوية الحادة ل detrital
grains لذا فأن ال overgrowth تكون خلال ال diagenesis بعد الدفن
ببيئة بعيدة عن التجوية, والبلورة في الوسط (core) هي detrital لانها
rounded & include weathering product

فيلدسبار حدث له internal dissolution واللون الاخضر هو صبغة حتى
نتعرف على ال pore spaces

* Type of pore spaces:

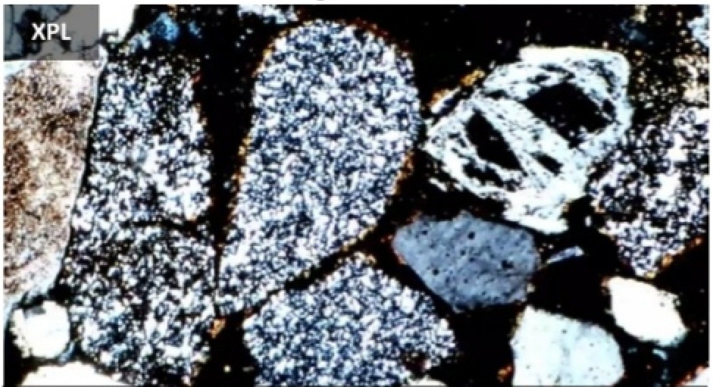
1. Intrapore داخل البلورة
2. Extrapore بين الحبات



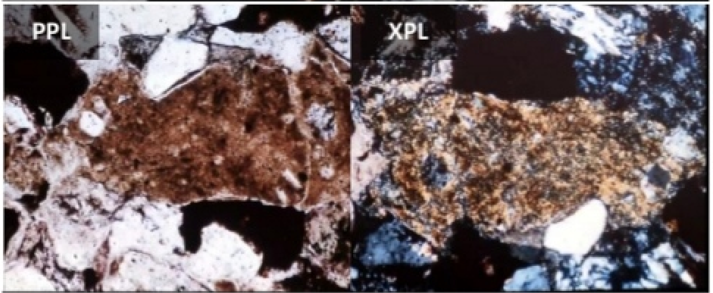
Feldspar core with weathering product along cleavage plane, & dust line divided the core from overgrowth

Rock Fragments [lithic fragments]

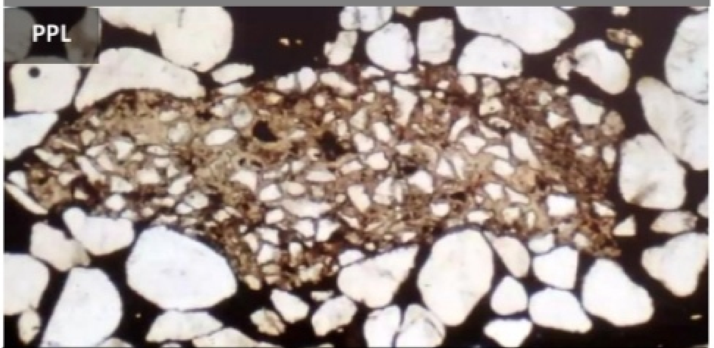
- more abundant in conglomerate than sandstones



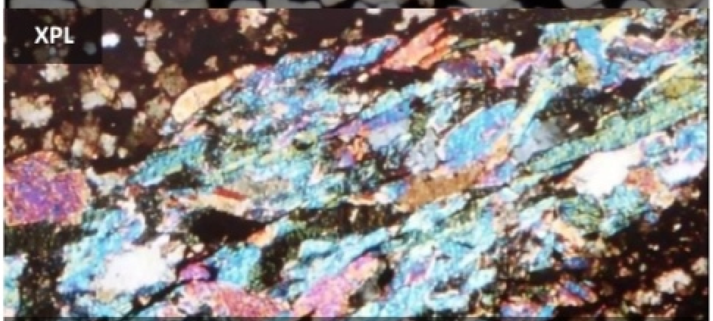
ال chert يمكن اعتباره grains او rock fragments بحسب الدارس



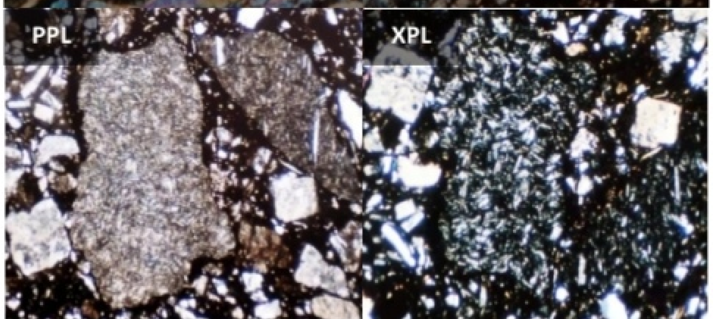
Mudstone rock fragment
تتفتت تحت الضغط، وهي ليست matrix لان لها boundary
في XPL بدأنا نرى IC for clay minerals ما يدل انها mud



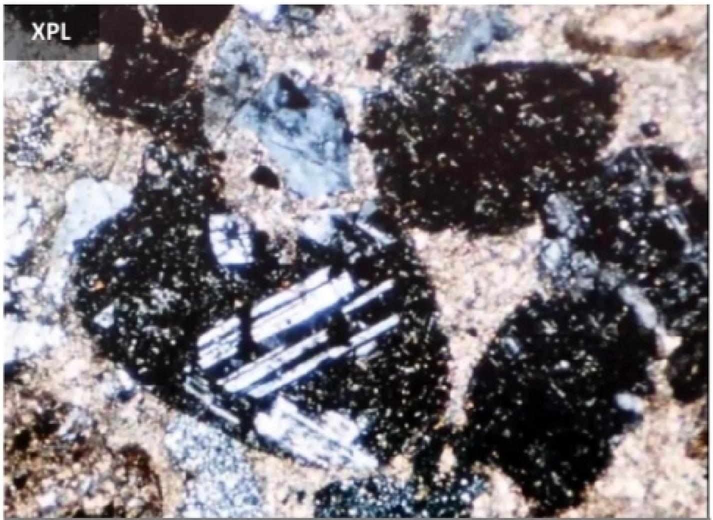
Siltstone rock fragment



Metamorphic rock fragment(orientation of muscovite)



Basaltic rock fragments

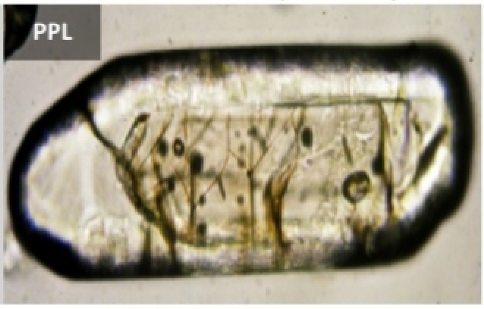


Basaltic rock fragments (plagioclase laths in a host of augite crystal "ophitic texture")

Other Components

- **Detrital micas**: ***biotite, muscovite, & rarely chlorite***
  - Form flakes & arranged parallel to bedding plane
  - muscovite is more common than biotite (unstable)
  - If biotite is present, it mainly altered into Fe-oxide, chlorite, or clay mineral (illite or kaolinite)
- **Carbonate fragments:** shells, fossils, ooids, & intraclasts
- **Galuconite & phosphatic grains**
- **Heavy minerals (HM):** with a concentration < 1%, from separation from the light minerals (Qz & Fs)
  - ***Zircon, Tourmaline, & Rutile*** (stable to ultrastable)
  - ***Apatite, Garnet, Epidote, Sillimanite*** (metastable)
  - **Olivine, Pyroxene, & Hornblende** (Unstable)

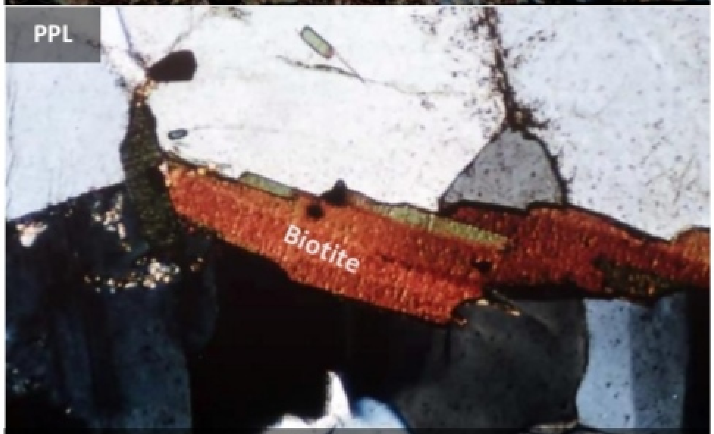
Zircon: very high relief, high IC, inclusions, the borders of the grain are heavily abraded



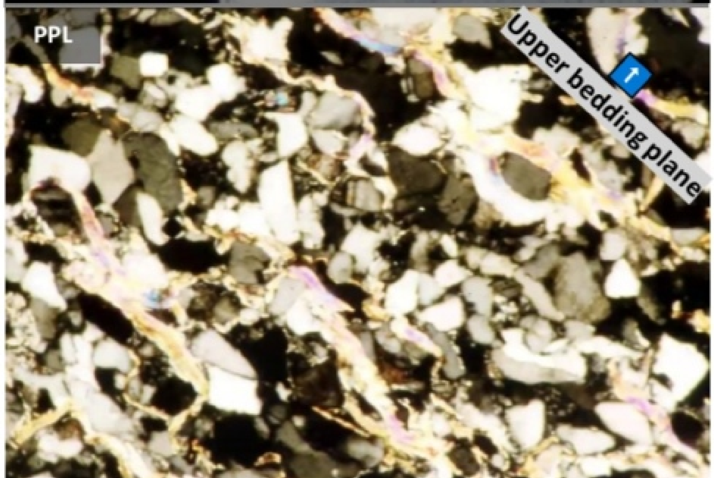
Tourmaline: strong relief, high order IC, & strong pleochroism

Rutile: red, very strong relief & IC, masked by the original color of the mineral

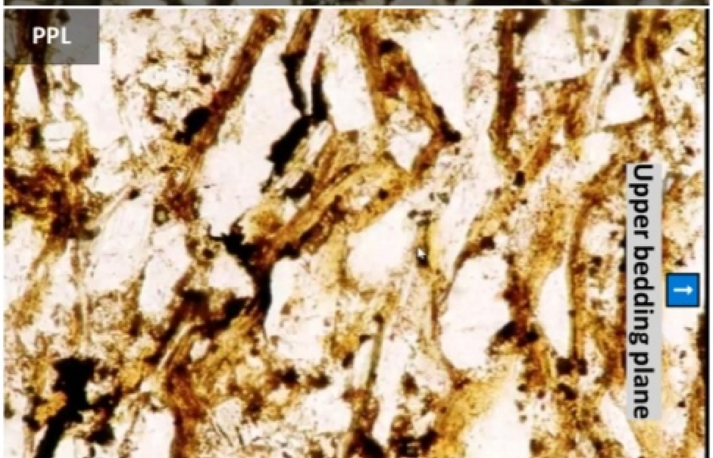
Muscovite: 2nd order IC & colorless (PPL), cleavage 1set



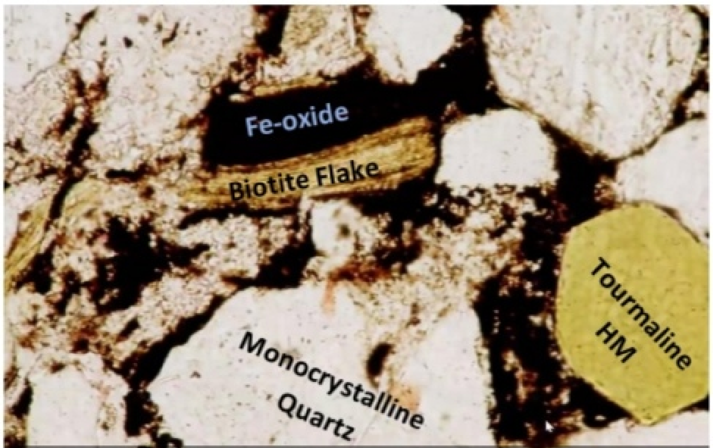
Biotite (masking of IC, 1set of cleavage)



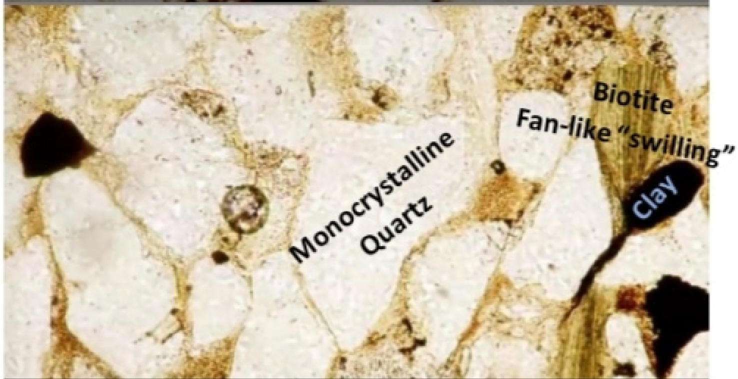
Muscovite arranged parallel to load pressure



Biotite (pleochroism, 1 set of cleavage)



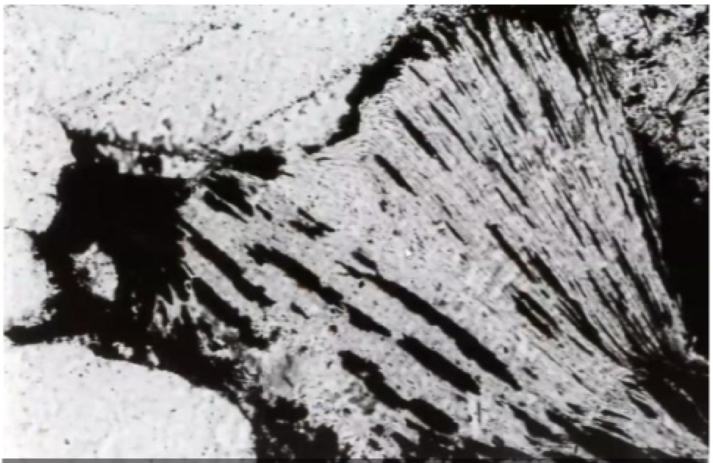
Biotite may altered into Fe-oxide along cleavage plane



Biotite swilling during weathering & Diagenesis & altered into clay minerals such as Kaolonite

Biotite with muscovite

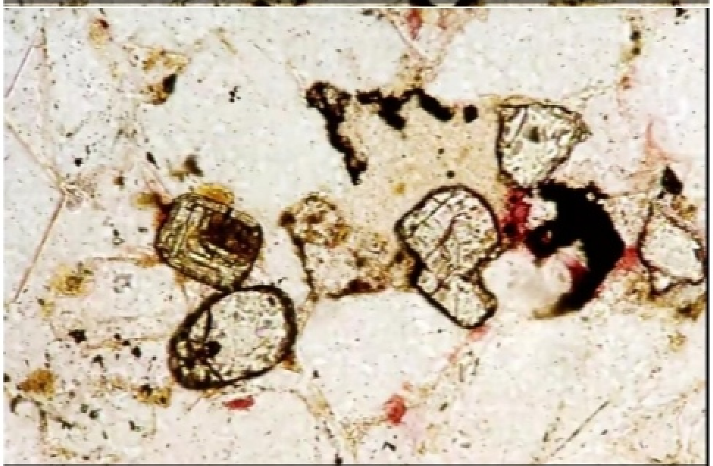
Biotite may altered into Fe-oxide along cleavage plane



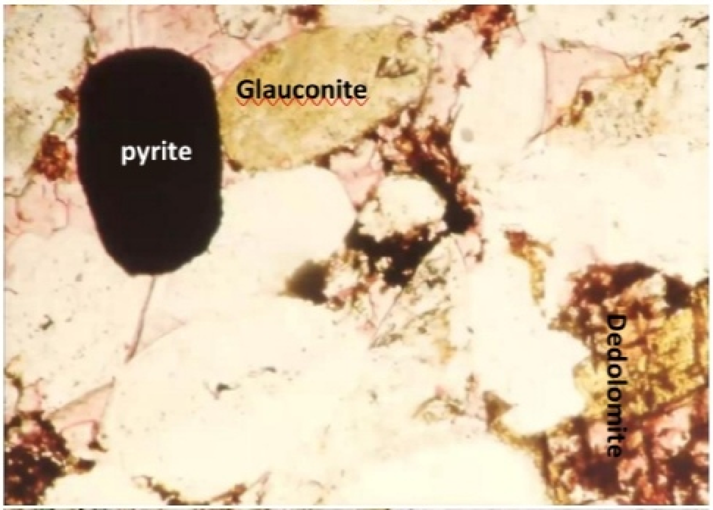
Cleavage of Biotite & replacement into Fe-oxide

Phosphatic grain (internal structure: prismatic structure parallel to lamellae)

Phosphate (simi-isotropic, الوان تداخل قليلة)



Heavy minerals (very high relief)



السن انكسر ثم دخل calcite وملأ الفراغ

Marine Environment

Diagenesis of Clastic Sedimentary Rocks

- **Diagenesis**: all physical & chemical processes that affect the sediments from sedimentation until the on set of low grade metamorphism
- **Factors that Control diagenesis**: Provenance, Burial Depth, Depositional Environment, Tectonism & Thermal Activities, Uplift & Subaerial Weathering

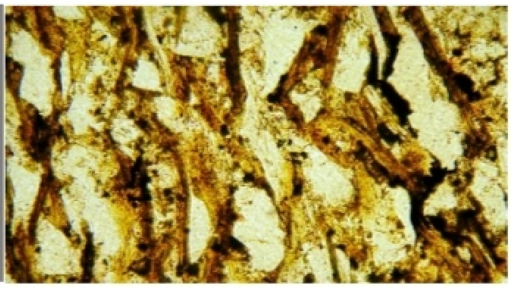
Physical or Mechanical Diagenesis

- Results from the weight of overlying sediments & starts by mechanical compaction followed by pressure solution due to increasing burial depth

At a low burden depth (early compaction)

- elongate (or plate) grains (e.g. mica flake) respond to P by orientation of their long axis (maximum surface-area) parallel to bedding planes
- Point contacts are still visible

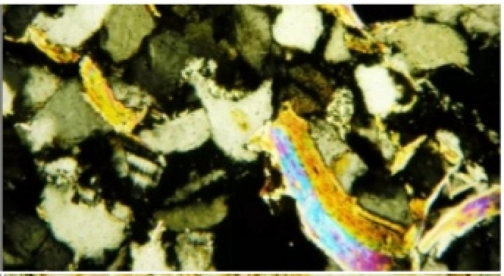
Quartz, & flaky micas (biotite & muscovite grains which arranged parallel to bedding plane)



By increasing burial depth (pseudoplastic deformation)

- **ductile grains** (mica flakes) respond by *pseudoplastic deformation* (pseudoplastic bending for ductile grains)
- **brittle grains** fracturing

Pseudoplastic bending for ductile grains
Biotit (masking to IC) & Muscovite (2nd order)

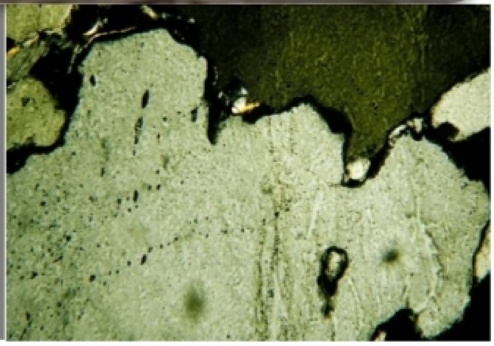


Phosphatic & Qz grains, with dolomite cement
phosphate grain fractured due to increasing burial depth because it has a brittle behavior (green dolomite → high Fe)

Increasing burial depth (1000-1500, Pressure Solution)

- Qz at point contacts subjected to high effective P, causes preferential solution (Qz characterized by ***concavo-convex & sutured contacts***)

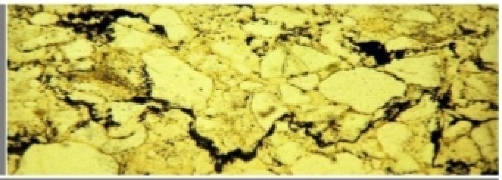
2 quartz grains suffering from P-solution & characterized by sutured contact
Bond contact formed after burial depth & as increase depth become concave-convex & finally suture



By subsequent increase of burial depth (Microsylolites)

- **Microsylolites**: zigzag cross-cut quartz grains, marked by concentration of insoluble material that resulted from P-solution & migrated along them

Microstylolite in Qz
Devolved after suture contact & represents greater burial depth

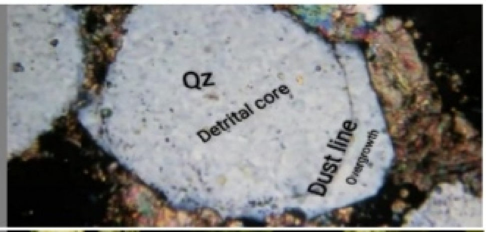


Summary
machenical diagenesis depending on burial depth, as burial depth increases: compaction → pseudoplastic deformation of ductile grains & fractured of brittle grains → P-Solution (Bond → concave-convex → suture → Microsylolites)

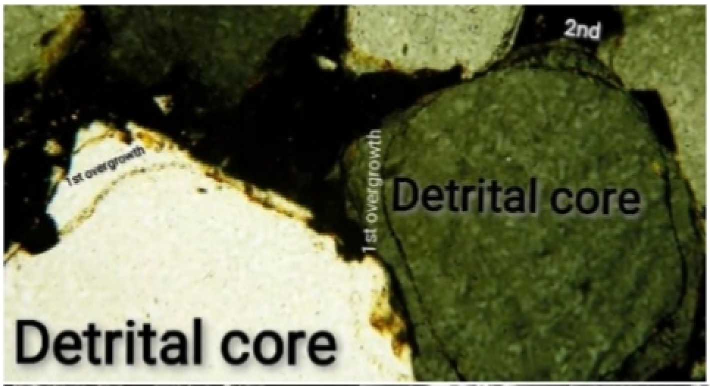
Chemical diagenesis

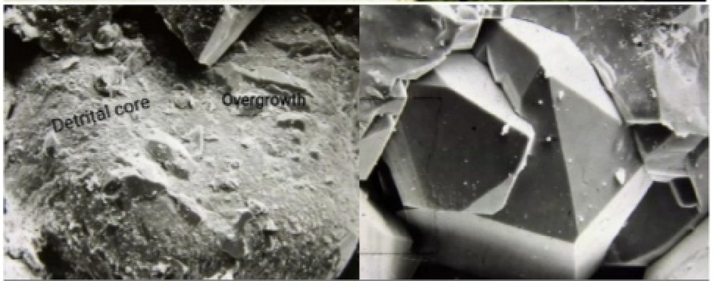
- **Silica cement**: precipitated around the quartz grains in form of a ***quartz overgrowt***
  - **Qz overgrowth:** optical continuity with detrital core
  - Qz overgrowth characterized by presence of a ***dust line*** which is a coat of Fe-oxides or clay minerals
  - If there is no dust line, it is difficult to distinguish between the quartz overgrowth and the core & a ***cothodoluminescence*** study is required
  - **Sentaxial overgrowth**: has the same chemical composition (& optical properties) as detrital core
  - **Epitaxial overgrowth:** has the different chemical composition (optical properties) from detrital core

Sentaxial Overgrowth has a distinctive crystal phases
لانه لم يحدث له عمليات تجوية وتعرية وترسب في عمليات ال diagenesis



تلتحم ال ل للبلورات المختلفة مع بعضها البعض لتنتج mosaic texture

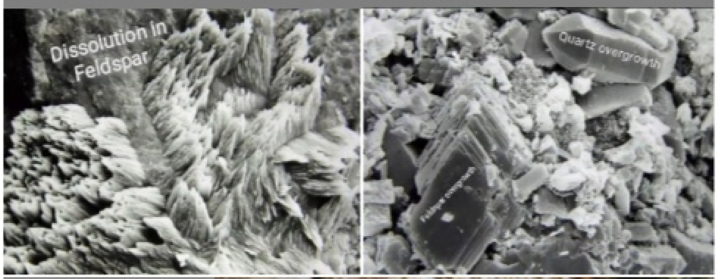




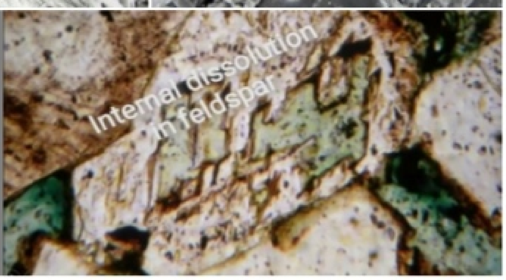
بقايا ال pore spaces هي التي اعطت المجال لنمو ال overgrowth

- **Feldspar authigenesis** occurs in some sandstones in form of **feldspar overgrowth** around detrital core
  - ➢ Overgrowth is clear & have sharp crystal phases

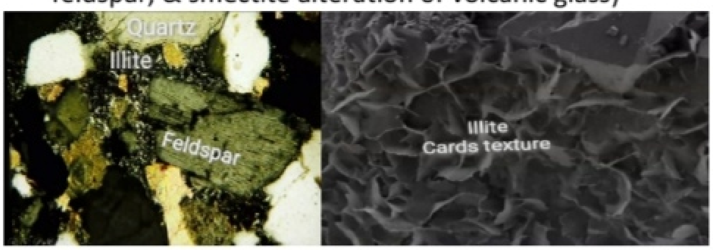
Overgrowth isn't optical continuity with detrital core (epitaxial)

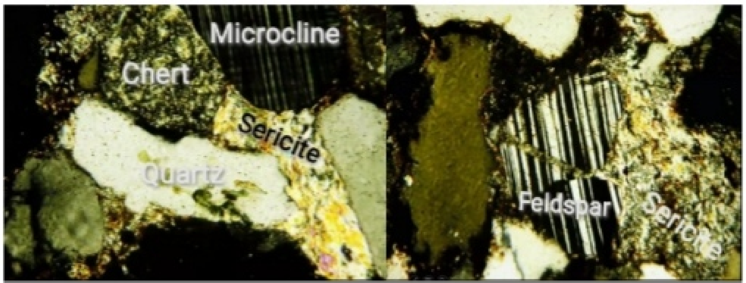


Feldspar with internal dissolution in development of intrapore space
اللون الاخضر هو صبغة وضعت على المادة اللاصقة اثناء تحضير ال thinsection

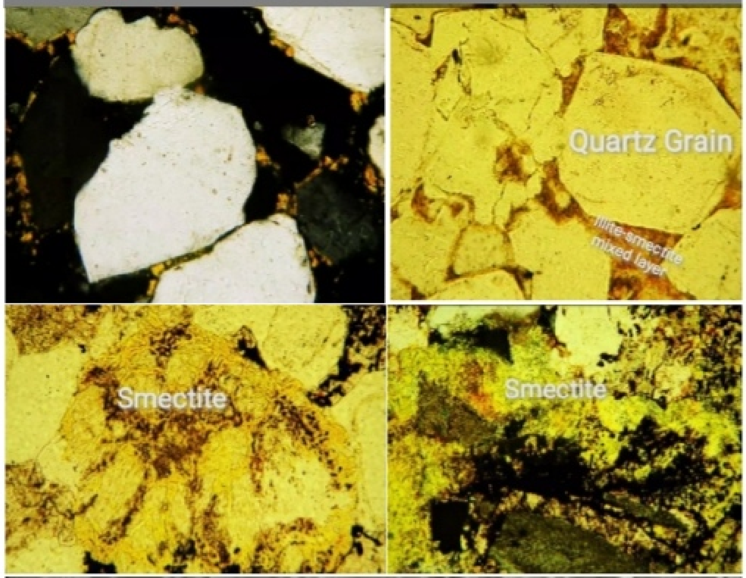


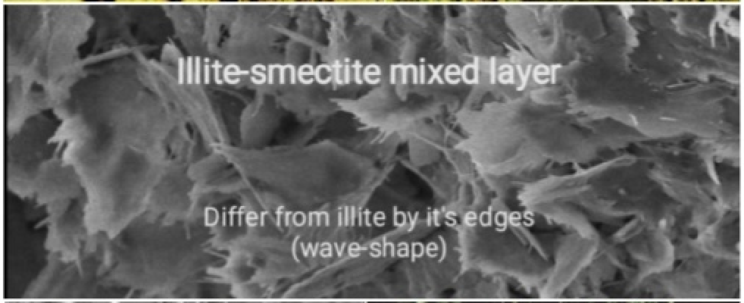
- **Clay mineral** occur as pore-filling cement or caly rims around detrital grains produced by replacement or alteration of detrital minerals (e.g. kaolinite replacing feldspar, & smectite alteration of volcanic glass)

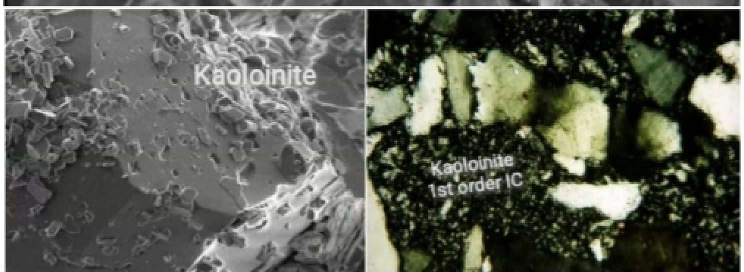




Illite altered or metamorphized into sericite due to burial depth

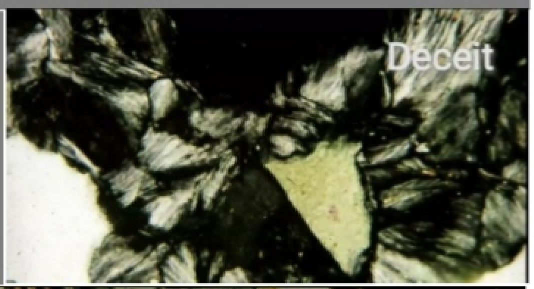


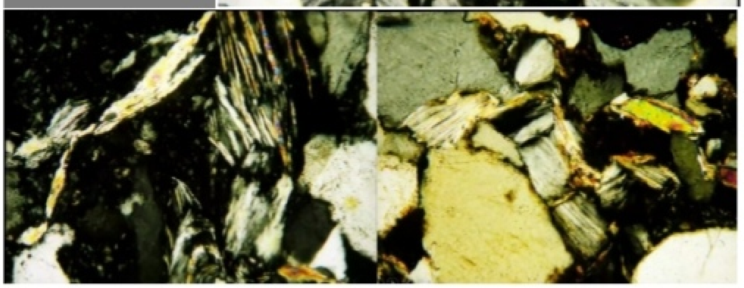


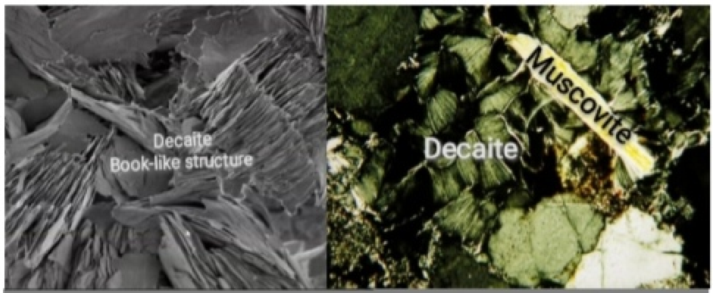


Kaoloinite (work-like) 1st order IC under XPL, & Colorless under PPL

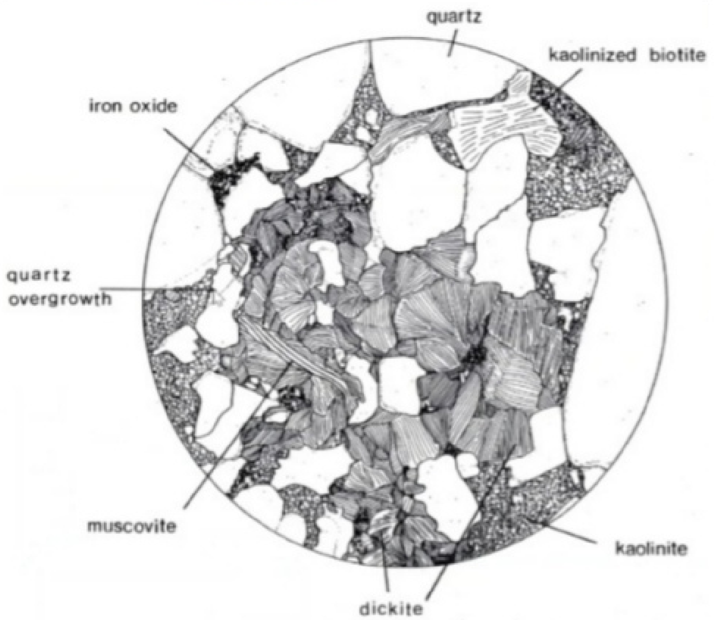
Optically decaite same as Kaolonite but larger in size & characterized by Rotational arrangement
Decaite formed by dissolution of Qz



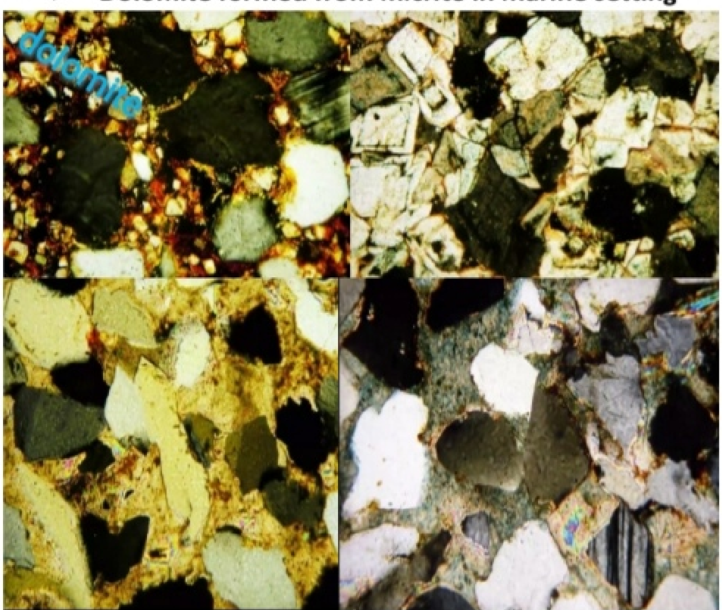




Decaite directly precipitate in pore spaces or replaced (altered) from phylosilicate such as muscovite

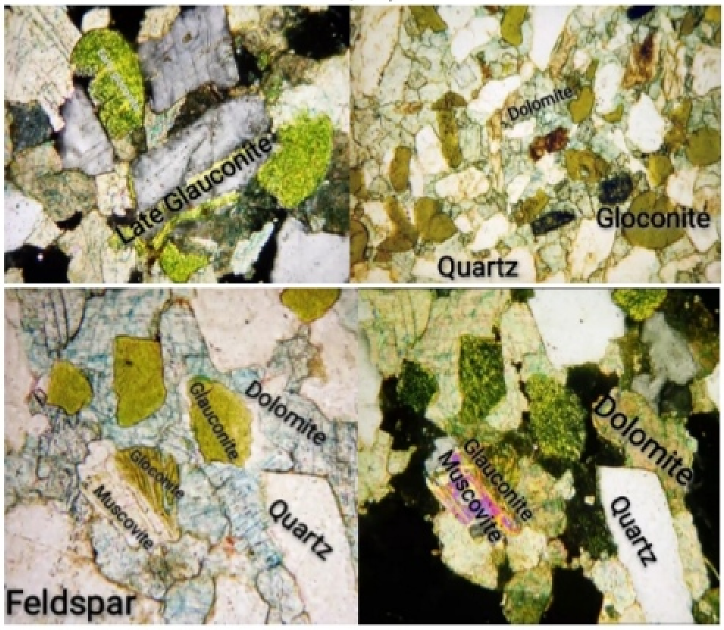


- **Carbonate cementation** calcite or dolomite
  - **Calcite**: poikilotopic cement, consists of large patches of calcite crystals engulfing sand grains
  - **drusy calcite** equant calcite crystals that fill the pore spaces & show an increase in crystal size towards the center of the original cavity
  - **Dolomite** pore-filling microcrystalline rhombs to coarse anhedral mosaics & large poikilotopic
  - **Fe-dolomite (Fe-rich)**: under reducing conditions
  - **Dolomite formed from micrite in marine setting**

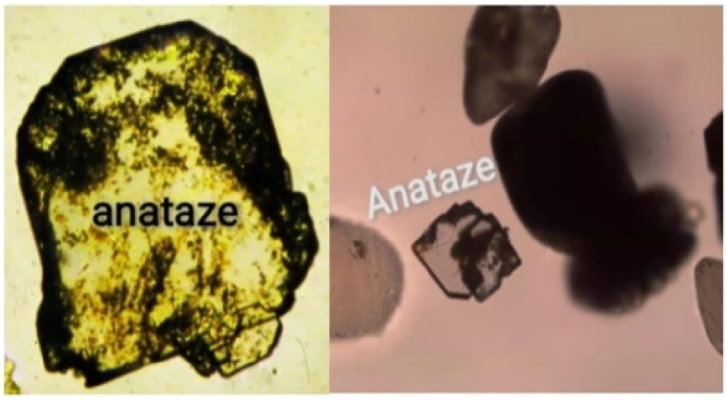


Poikilotopic: is a many quartz & feldspar crystals in a large dolomite crystal

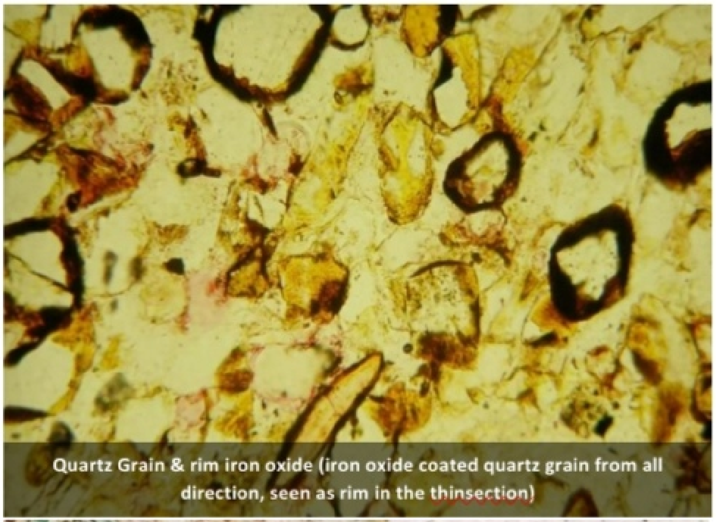
- **Glauconite:** formed during 2 stages
  1. **Sensedimantary stage:** is an Early diagenetic processes (precipitated during precipitation)
  2. **Glocotanization**: late, replacement another mineral



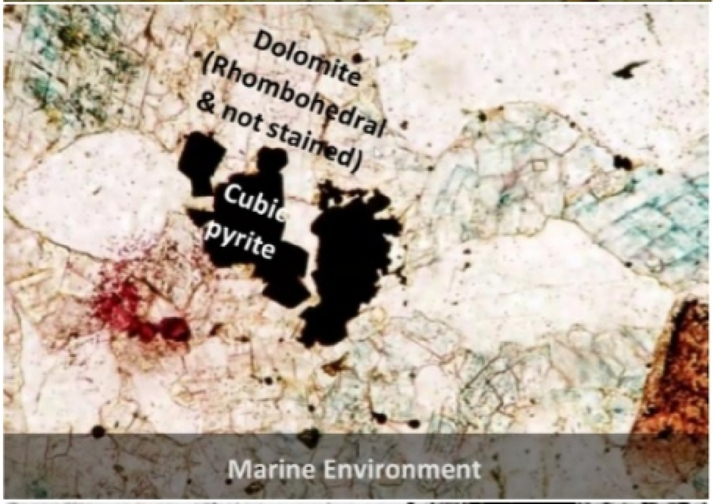
- **Anataze**



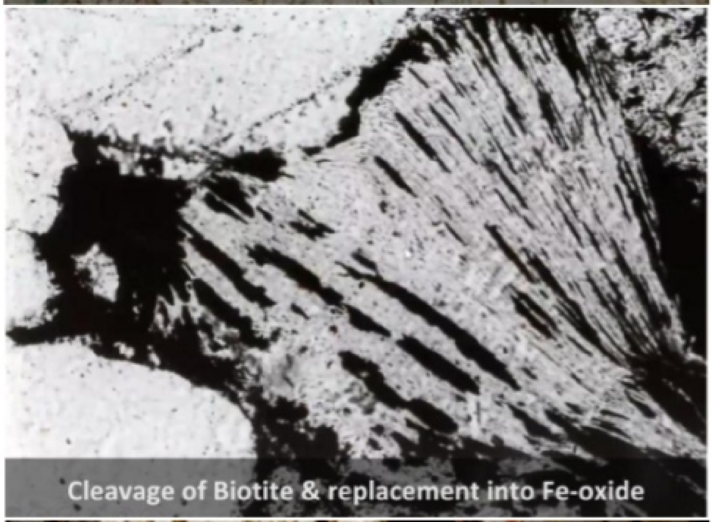
- **Fe-oxide:** red color (hematite)**,** Occurs as pore lining or filling, & rim coating detrital grains, stain authigenic clay minerals & feldspar grains along fractures or cleavage
  - Hematite replaces variably biotite flakes along cleavage planes, ranging from scattered spots or lamellae to complete replacement of flake, which is identified as a former detrital biotite flake on base of a fan- or flake-like shape
  - **Hematite "optical"**: red; translucent; & filling pore space, dark brown; opaque; as rim cement
  - Source of Fe-oxides cements:
  1. ***detrital origin (amorphous Fe-compounds)*** via humid tropical weathering, transported & deposite, & then converted (aged) to hematite
  2. ***yellow-brown coats on detrital sand grains*** through chemical weathering & converted into hematite after deposition (ageing)
  3. ***pure diagenetic*** from intrastratal solution of detrital ferromagnesian silicates, If the diagenetic environment is oxidizing the Fe precipitated as hematite or hydrated Fe-oxide precursor (converts to hematite on ageing)



Quartz Grain & rim iron oxide (iron oxide coated quartz grain from all direction, seen as rim in the thinsection)



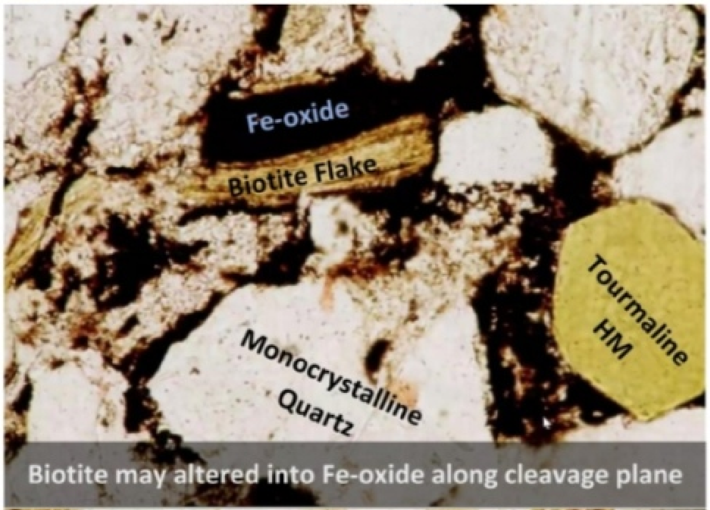
Marine Environment



Cleavage of Biotite & replacement into Fe-oxide

Biotite with muscovite

Biotite may altered into Fe-oxide along cleavage plane



Biotite may altered into Fe-oxide along cleavage plane

Biotite swilling during weathering & Diagenesis & altered into clay minerals such as Kaolonite

- Diagenesis of Jordanian sandstone succession from the Lower Cambrian to the Upper Cretaceous is influenced by depositional environment, burial depth & uplift
  - ➢ Most common diagenitic processes Qz-overgrowth, kaolinite authigenesis, & Fe-oxide cementation, & these processes are depositional environment & burial depth ***irrelevant***
  - ➢ Marine sandstones exhibit authigenesis of feldspar, glauconite, dolonite, smectite or illite-smectite mixed Byer, & pyrite
  - ➢ Burial depth controlled Qz P-Solution & subsequent microstylolite development, alteration of ilite into sericite, dickite formation, & tourmaline, Corrosion
  - ➢ uplift governed Fe-oxide cementation

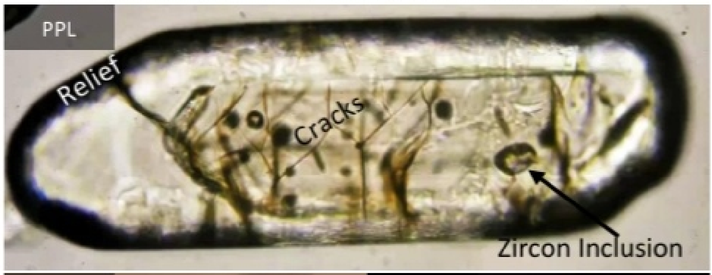
Heavy Minerals

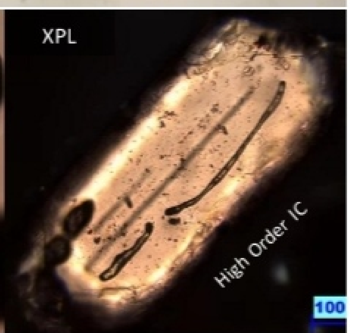
ULTRASTABLE

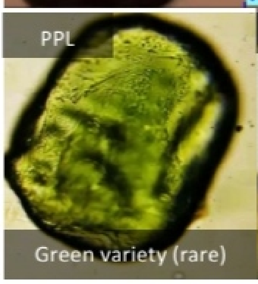
- All heavy minerals characterized by high relief due to high refractive index relative to epoxy
- Found in all sandstones as accessory minerals (<1%Vol)
- Separated from another minerals in sandstones using heavy liquid because all have specific gravity > 2.9, will quartz & feldspar around 2.5

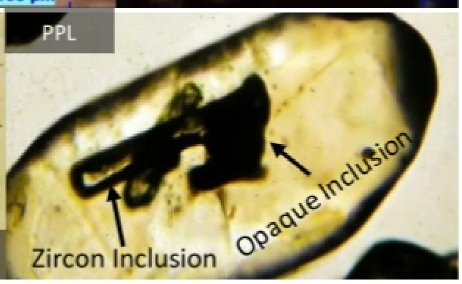
ZIRCON

- Most stable heavy mineral, found in all sandstones due to high resistance to machanical & chemical weathering during transportation
- **Optically:**
  1. ***Very High Relief***: due to high Refractive index, higher than all heavy minerals
  2. ***Color:*** **(PPL)** Colorless (most common), or Green (rare), **(XPL)** Very High Order IC
  3. ***Lack of pleochroism*** (لا يتغير لونه عند تدوير السيتيج)
  4. ***Rounding grains (Lack of edges):*** due to long distance of transportation
  5. ***Presence of Cracks:*** due to decay of radioactive elements in the zircon grains
  6. ***Inclusion:*** small-zircon crystals, or opaque



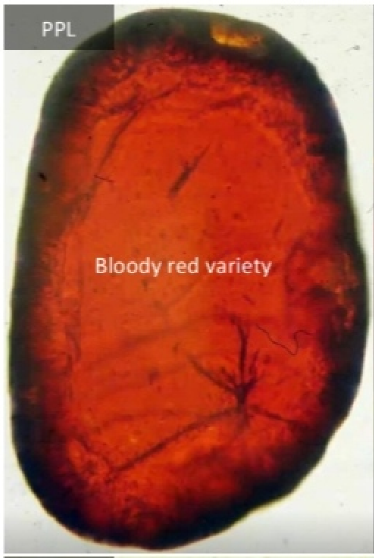


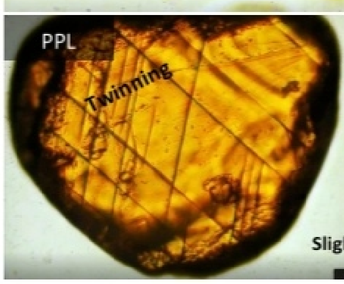


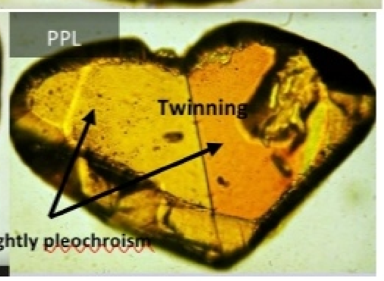


RUTILE (Ti-Oxide)

- **Optically:**
  1. **Slightly pleochroism**
  2. **High relief (less than zircon)**
  3. **Presence of inclusions**
  4. **Color: (PPL)** Bloody red (most common), golden or yellow variety, **(XPL)** masks IC
  5. **Shape: Twinning, Rounded, may take hart-shape**



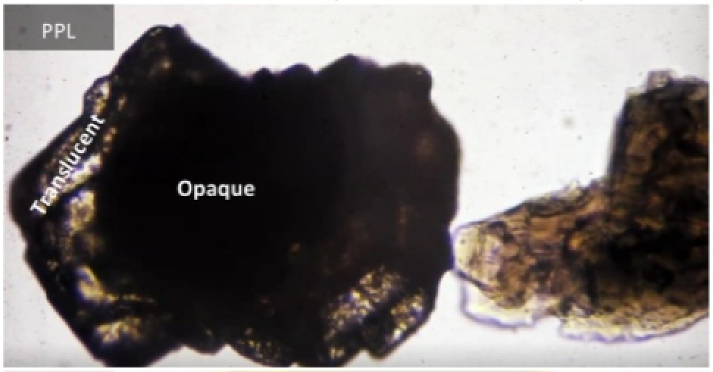


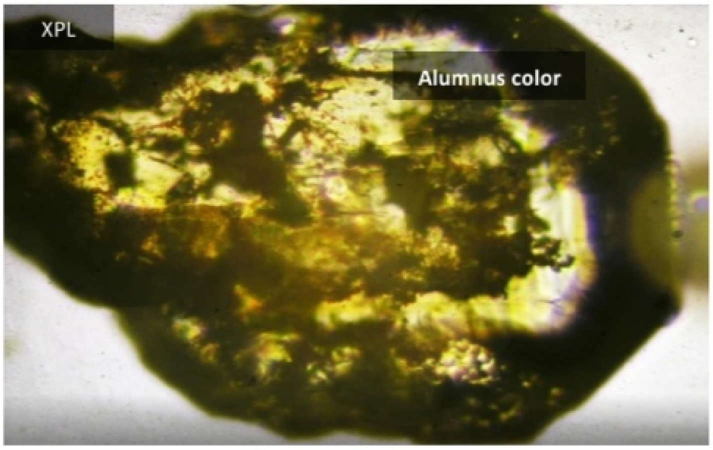


- This planes are twinning planes, not cleavage planes because these grains are rounded (transported long distance), ao if this planes are cleavage this grains must be breaking down into smaller minerals along cleavage plane, another evidence arises from pleochroism

ANATASE (Ti-Oxide)

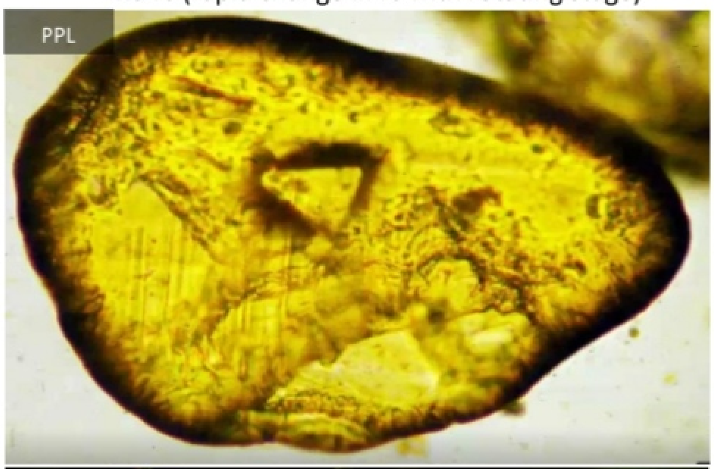
- **Optically**
  1. Slightly Transparent to Translucent at the edges (colorless), & opaque in the center (black, or brown)
  2. **Very High Relief** (high refractive index)
  3. **XPL:** 1st order blue (called Alumanuse IC)

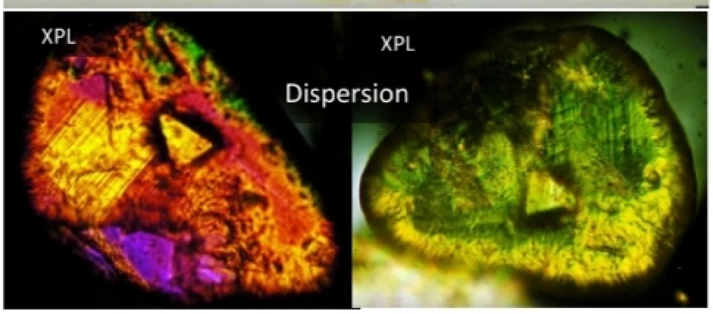




Prookite (Ti-Oxide)

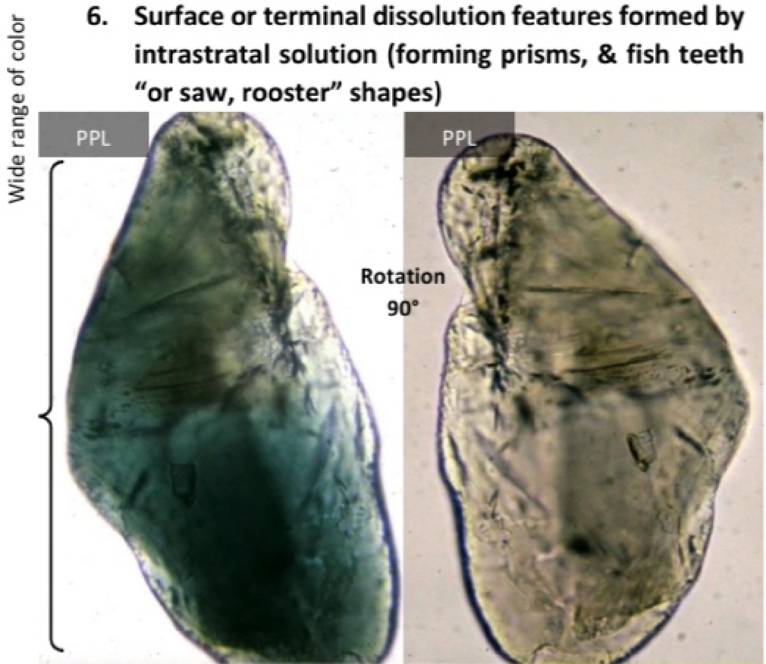
- **Optically**
  1. **High relief**
  2. **Color: (PPL)** yellow, **(XPL)** Dispersion between 1st & 2nd IC (rapid change in IC with rotating stage)

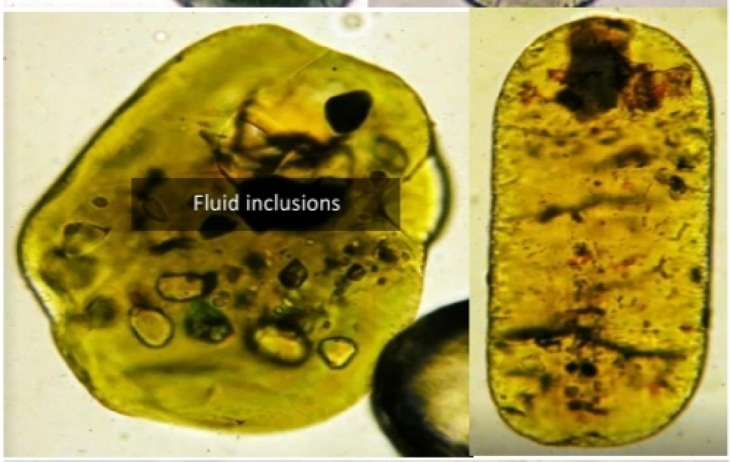


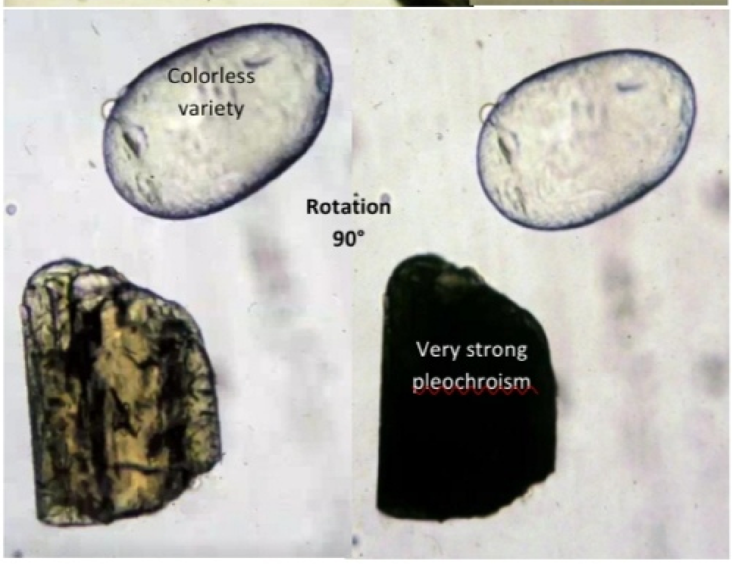


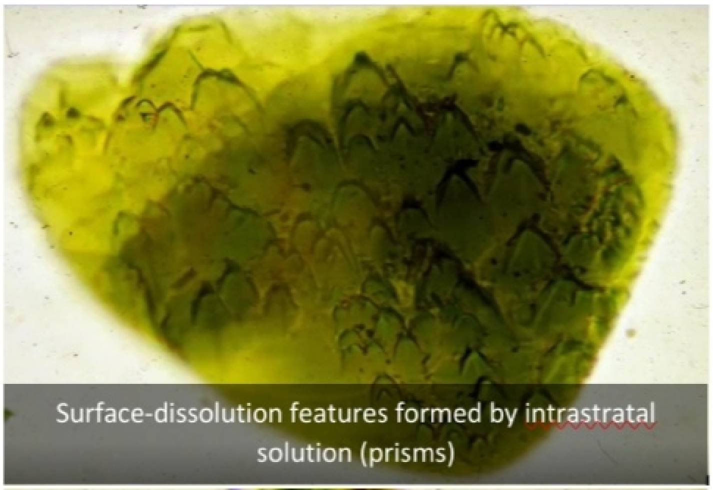
TOURMALINE

- **Optically**
  1. **Color: (PPL)** wid range of color in the same grain, or colorless (rare), **(XPL)** high ordar IC (the colorless variety distinguished from apatite by IC)
  2. **Very strong pleochroism under poth PPL & XPL**
  3. **High relief (less then zircon & rutile)**
  4. **Presence of inclusions such as fluid inclusions**
  5. **Rounded:**by sedimentation cycles or transportation
  6. **Surface or terminal dissolution features formed by intrastratal solution (forming prisms, & fish teeth "or saw, rooster" shapes)**

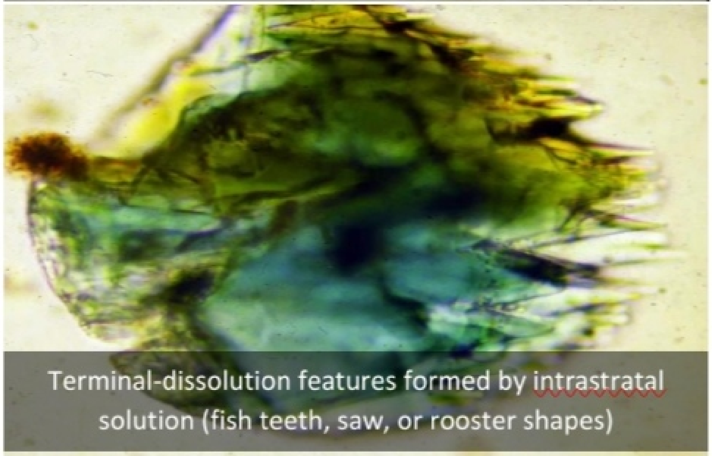








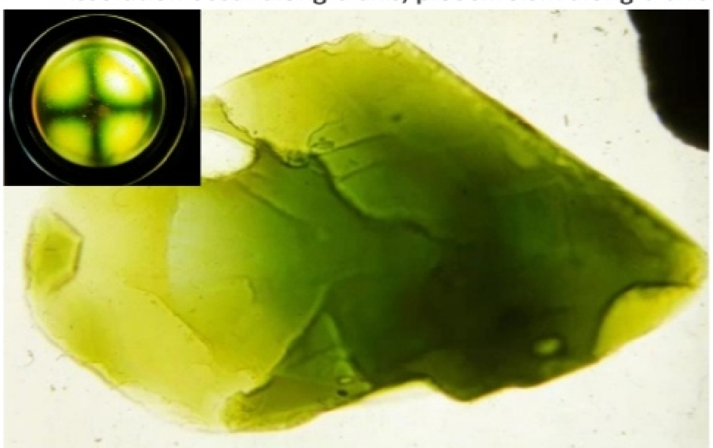
Surface-dissolution features formed by intrastratal solution (prisms)



Terminal-dissolution features formed by intrastratal solution (fish teeth, saw, or rooster shapes)

Terminal-dissolution features formed by intrastratal solution (fish teeth, saw, or rooster shapes)

- Dissolution occur along C-axis, pleochroism along C-axis

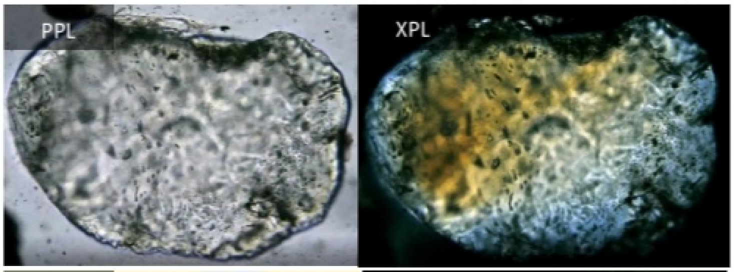


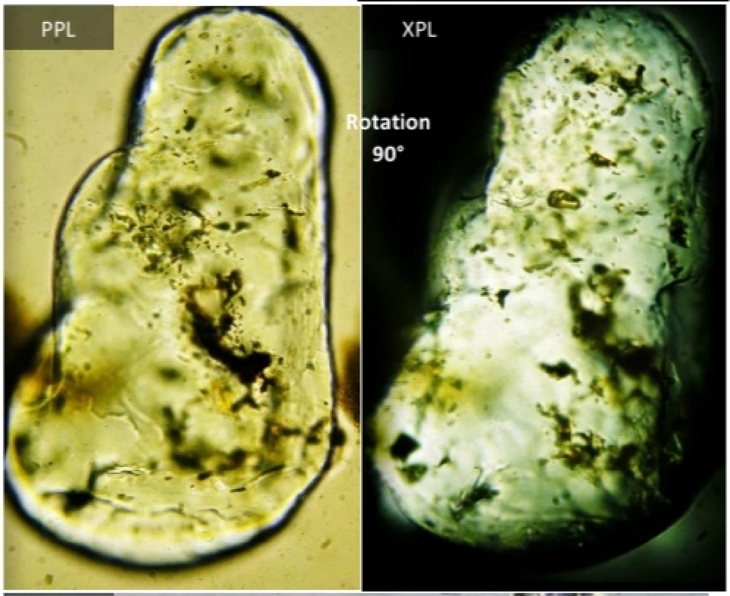
This grain is tourmaline because optical figure show that, this grain is uniaxial grain, not hornblende because hornblende is biaxial

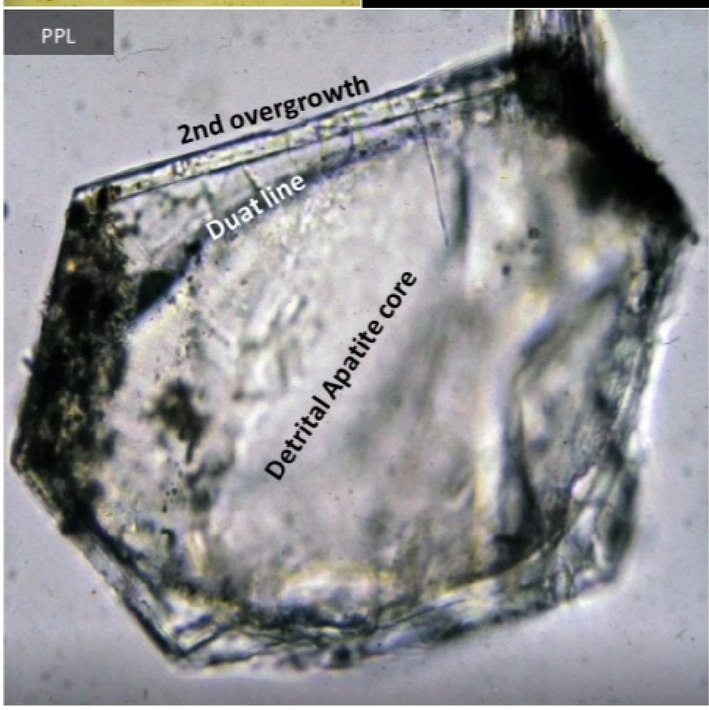
METASTABLE

APATITE

- **Optically**
  1. **High relief:** has higher refractive index than epoxy
  2. **Presence of inclusions, dissolution feature, or apatite overgrowth (due to diagenesis)**
  3. **Rounded:** sedimentation cycles of transportation
  4. **Color: (PPL)** colorless, **(XPL)** 1st gray to 2nd orange



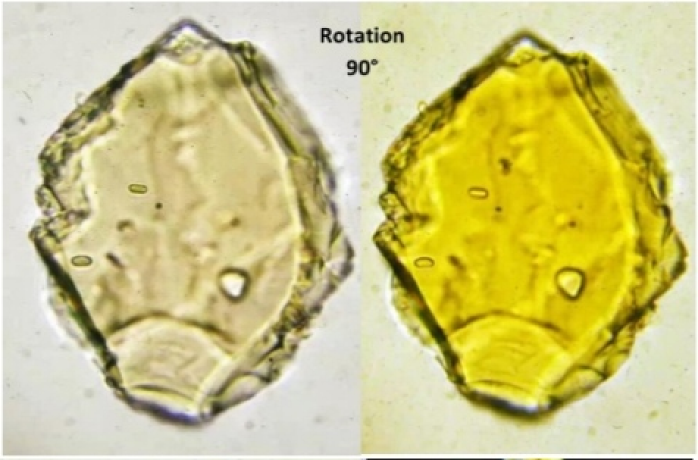


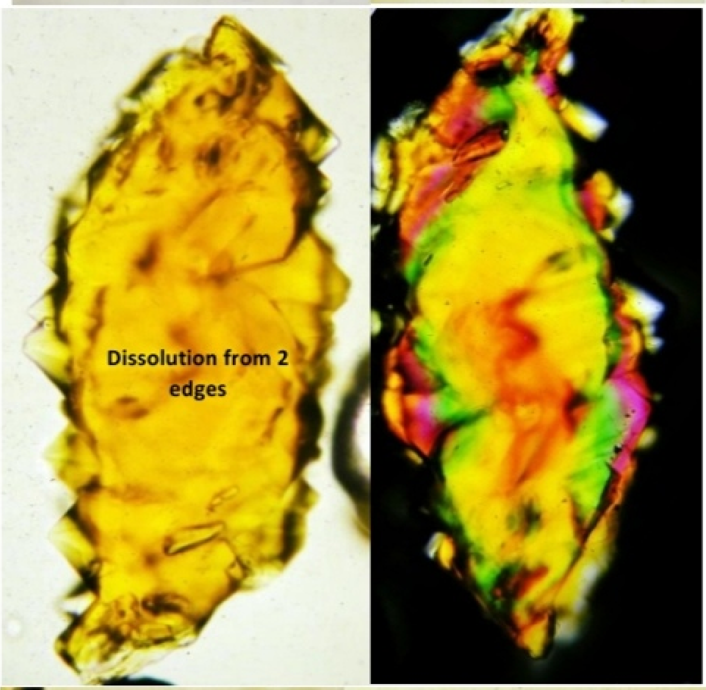


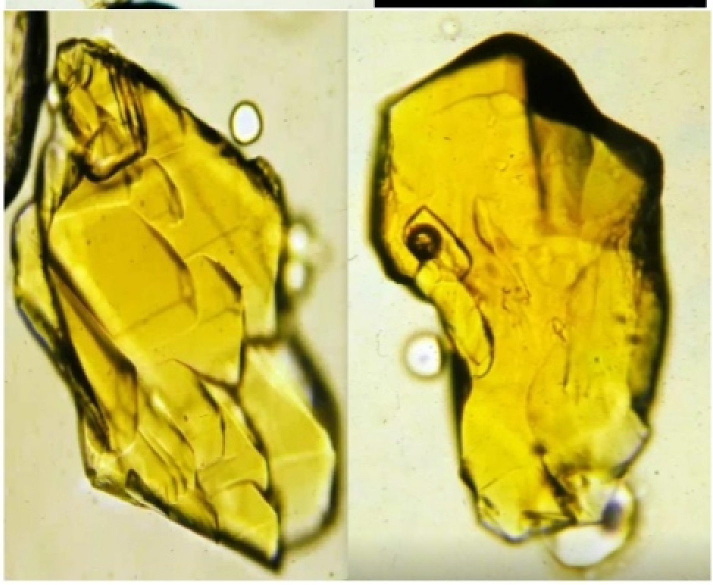
There're 2 stages of overgrowth (not 2 cycles because the first one are very angular, if there's another sedimentation cycle this edges must be rounded)

STAUROLITE

- **Optically**
  1. **Pleochroism, & high relief**
  2. **Angular grains due to interstartal solutions**
  3. **Presence of inclusions, & overgrowth**
  4. **Color: (PPL) colorless, yellow, or yellowish-orange, (XPL) 3rd order interference color**
  5. **Terminal surface or terminal dissolution of 2 edges**

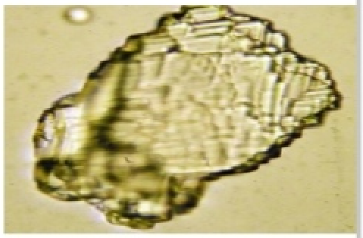






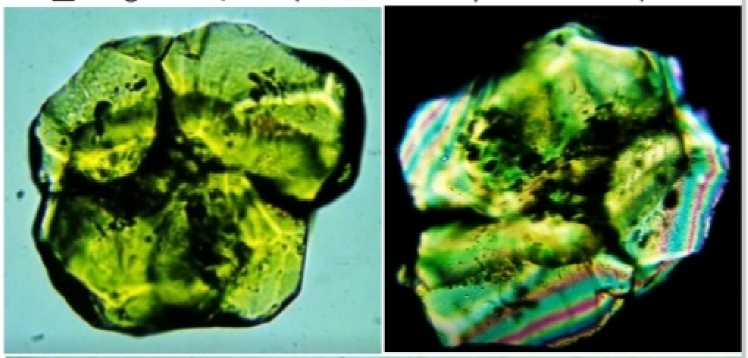
GARNET

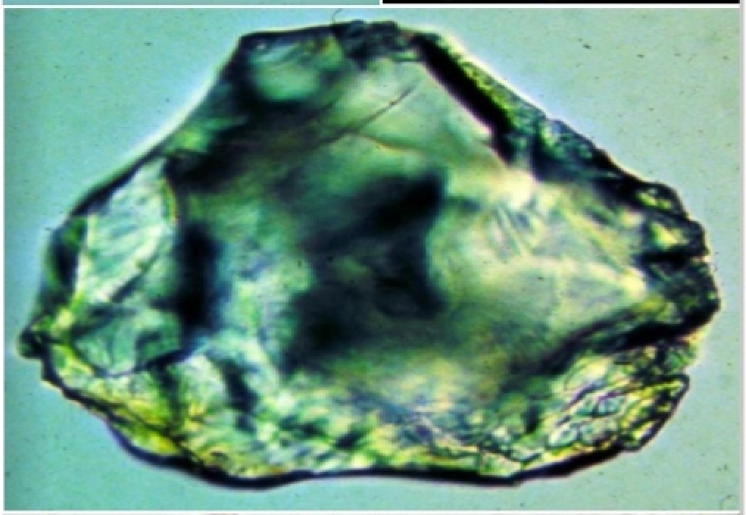
- **Optically**: Colorless, With surface or terminal dissolution, extinction under XPL (isotropic)

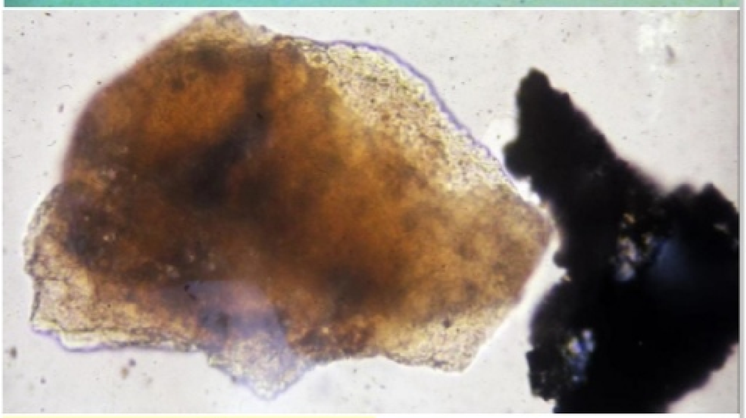


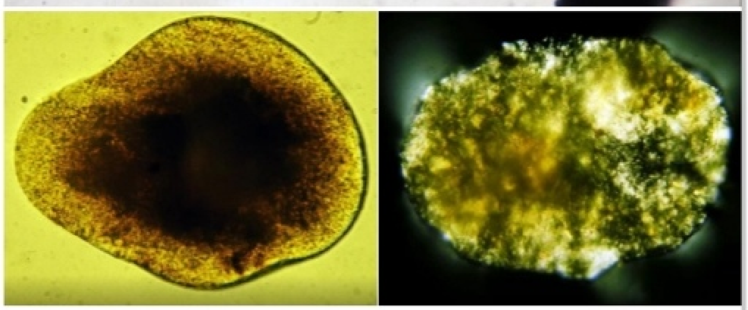
EPIDOTE

- **Optically**:
  1. <u>Yellowsh-Green (Stachia), Colorless (Zeozite), Orange (by senziratization during diagenesis)</u>
  2. High relief, & IC (2nd to 3rd & up to 4th order)

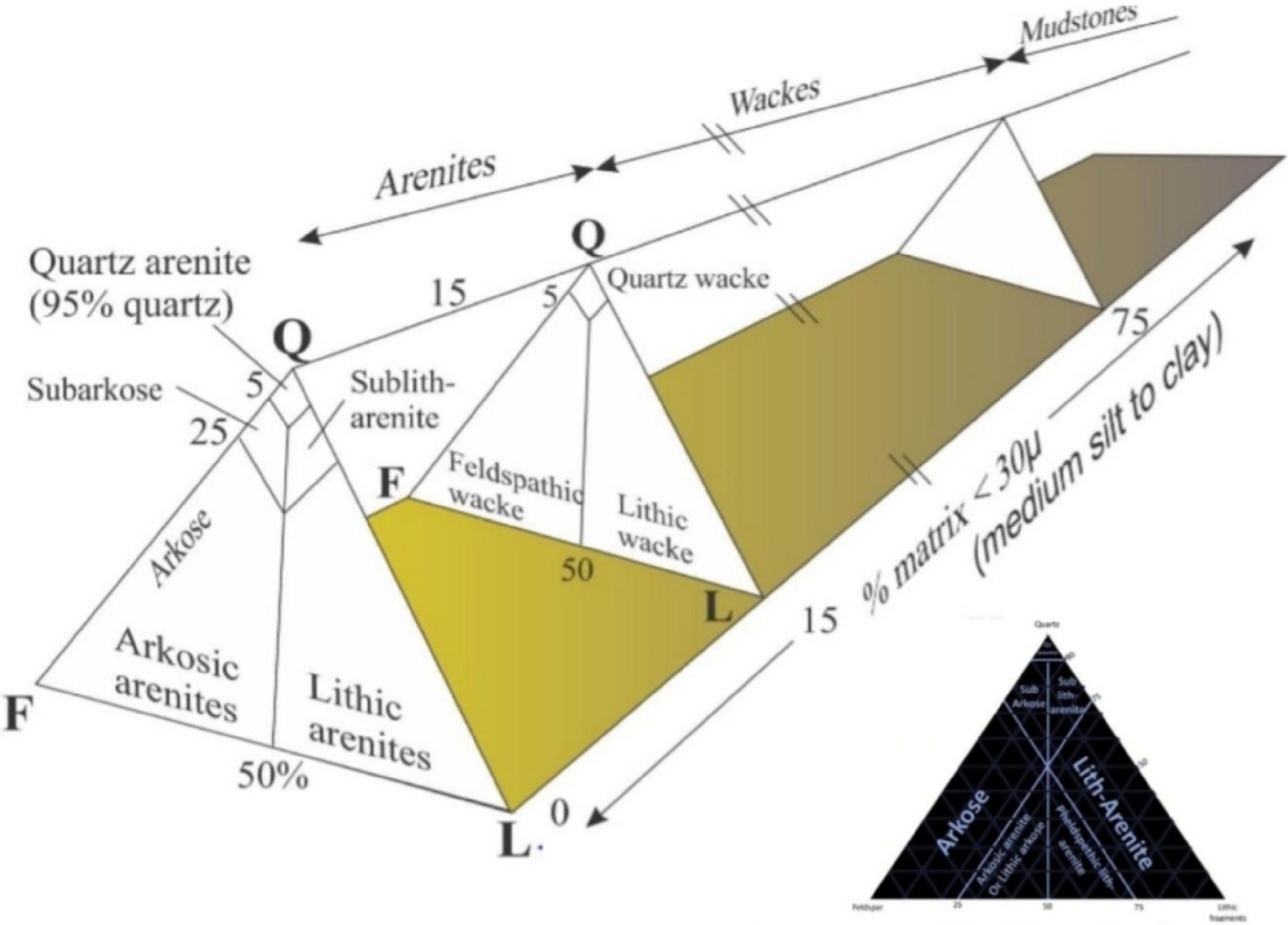








Clastic Sedimentary Rock Classifications



Framework Grains									Cements					
Qz			Fs		Fr			Mt	Qz	Car		Fe	Cl	PS
NU	U	P	K	Pl	V	M	S		Ov	Cal	Dol	He		

Prefix: **NU**: Non-undulose, **U**:Undulose, **P**: Polycrystalline, **K**: K-feldspar, **Pl**: Plagioclase, **V**: Volcanic, **M**: Metamorphic, **S**: sedimentary, **Mt**: Matrix, **Qz**: Quartz, **Ov**: Overgrowth, **Cal**: Calcite, **Dol**: Dolomite, **He**: Hematite, **Cl**: Clay Minerals, **PS**: Pore Spaces, **Fs**: Feldspar, **Fr**: Rock Fragments, **Car**: Carbonates, **Fe**: Fe-Oxides

1. نحسب مجموع ال grains (S), مجموع ال grains باستثناء pore spaces (X) ومجموع ال Framework Grains (Y)

$$Y = \Sigma Qz + \Sigma Fs + \Sigma Fr$$
$$X = S - PS$$

2. نحسب ال Matrix% بقسمة ال Ma على مجموع ال grains

$$Mt\% = \frac{Mt}{X} x100\%$$

3. نحسب ال Modal Qz, Modal Fs, Modal Fragments

$$Modal\ (Grains) = \frac{\Sigma Grains}{Y} x100\%$$

4. نحسب ال Porosity

$$Porosity = \frac{PS}{S} x100\%$$

Framework Grains									Cements					
Qz			Fs		Fr			Mt	Qz	Car		Fe	Cl	PS
NU	U	P	K	Pl	V	M	S		Ov	Cal	Dol	He		
159	45	15	40	10	7	4	-	30	20	18	5	25	7	15

S = 400

Y = 280

X = 385

$$Mt\% = \frac{30}{385} x100\% = 7.8\% \rightarrow Arenite$$

$$Modal\ Qz = \frac{159 + 45 + 15}{280} x100\% \rightarrow 78\%$$

$$Modal\ Fs = \frac{40 + 10}{280} x100\% \rightarrow 18\%$$

$$Modal\ Fr = \frac{7 + 4}{280} x100\% \rightarrow 4.0\%$$

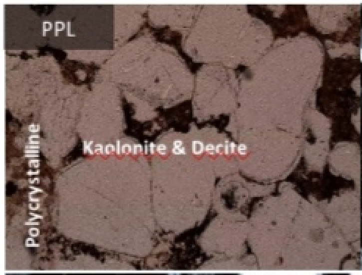
$$4.0\% Fr + 18\% Fs + 78\% Qz = 100\% \rightarrow Subarkose$$

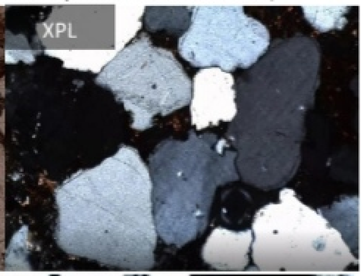
The classification of this rock : Calcite-cemented,Hematitic-Subarkosic-Arinite Sandstone

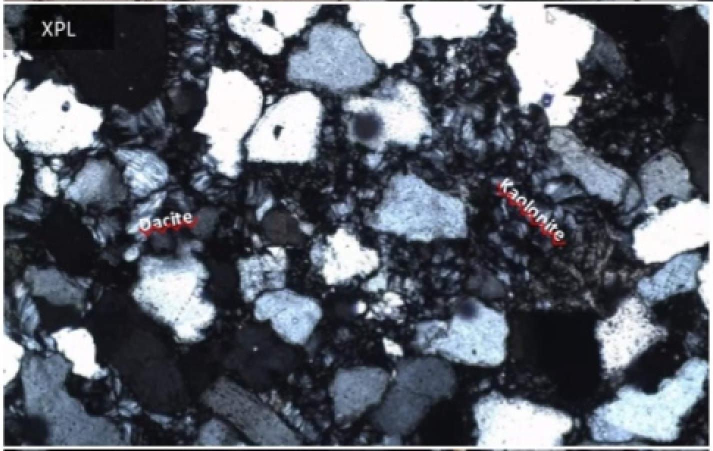
- من الصور قم بعد كل الحبات الموجودة ثم اقسم عدد ال Fs على Qz وحدد كمية ال Matrix وستحصل على اسم الصخر

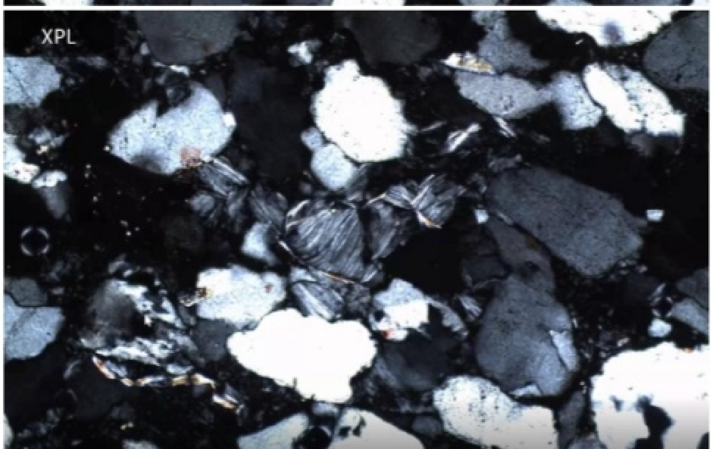
ARENITE SANDSTONES

- **Composition:** Mostly Undulose & Non-Undulose Monocrystalline Quartz & Polycrystalline Quartz
- **Cements:** Quartz Overgrowth, Clay Minerals such as Kaolonite, & Decite (Formed by alteration of mica flakes along cleavage planes) or Fe-oxide (Hematite)
- **Characterized by** sutured contact, Concave-Convex, or Microstirolite contacts (due to pressure solution)

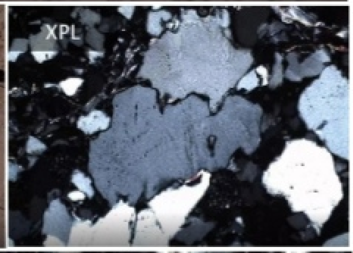


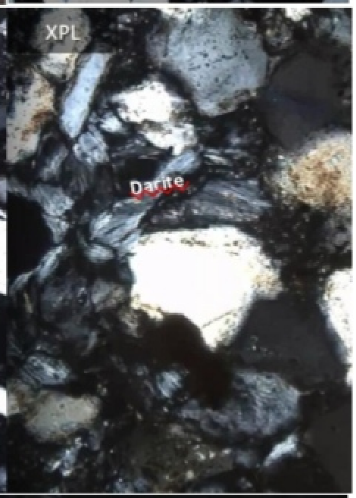


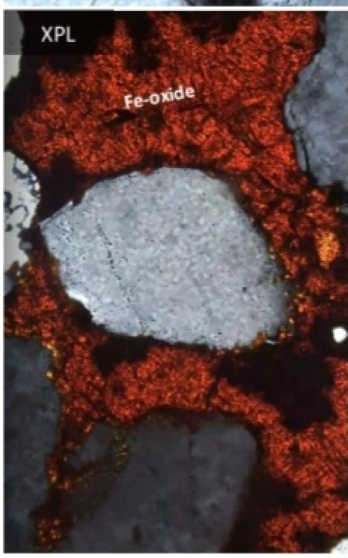


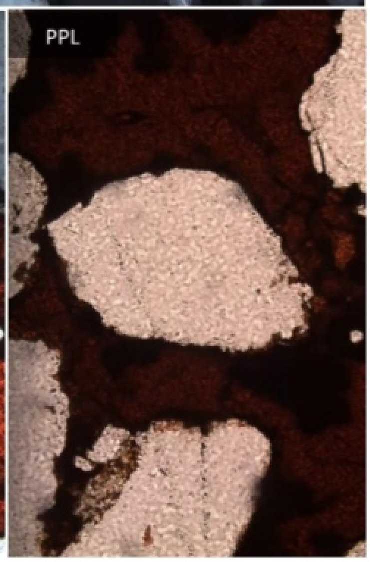


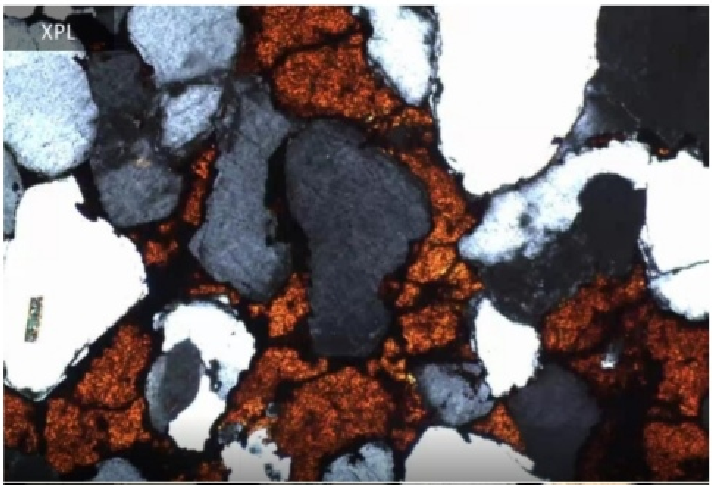
Dacite replaces muscovite flakes along cleavage plane



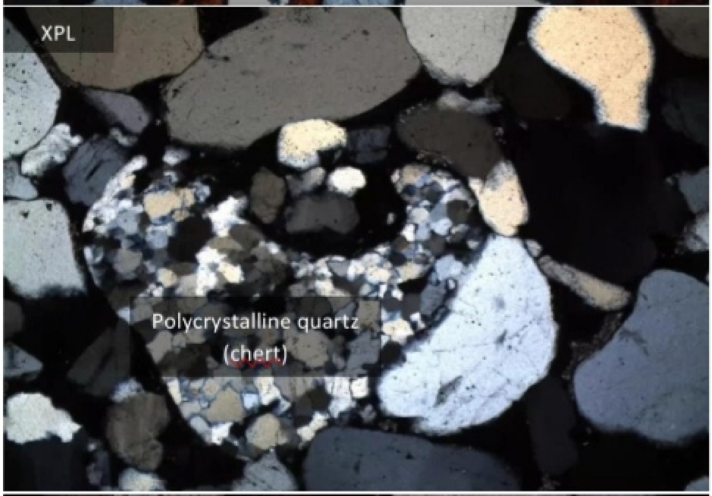


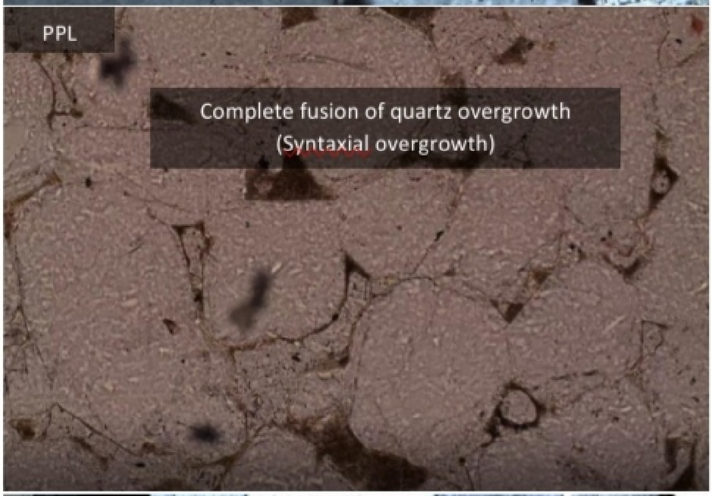


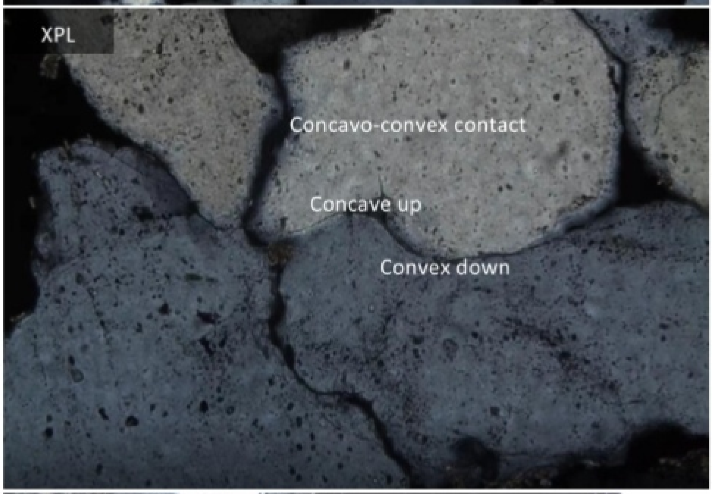


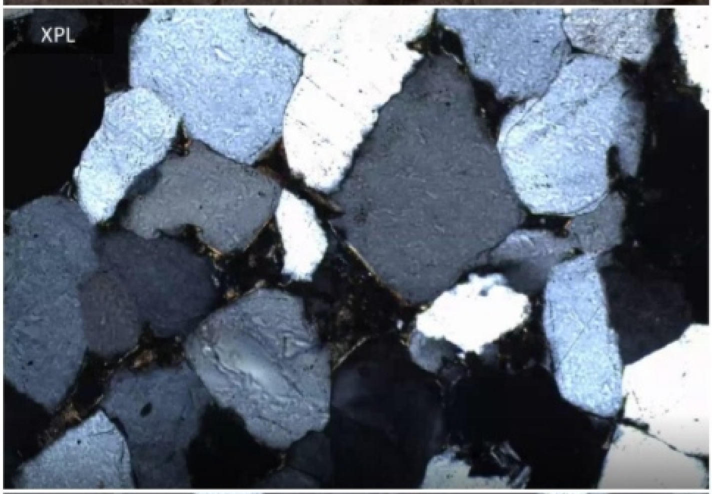

XPL

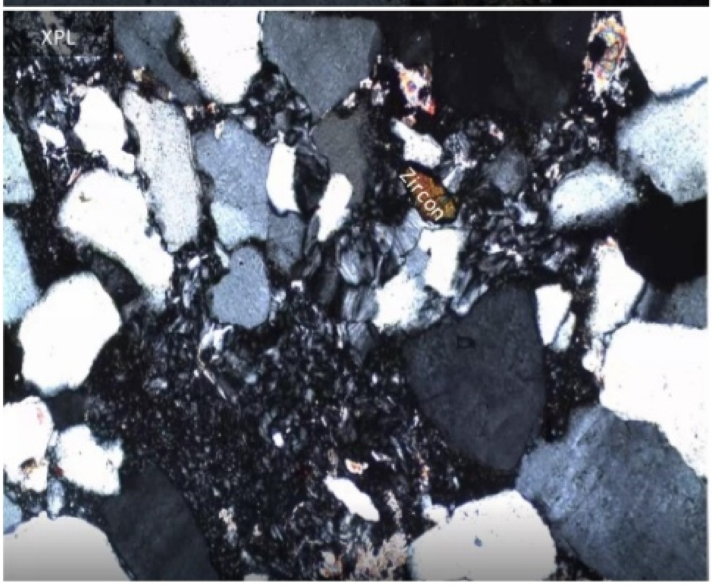

XPL
Biotite altered along cleavage plane

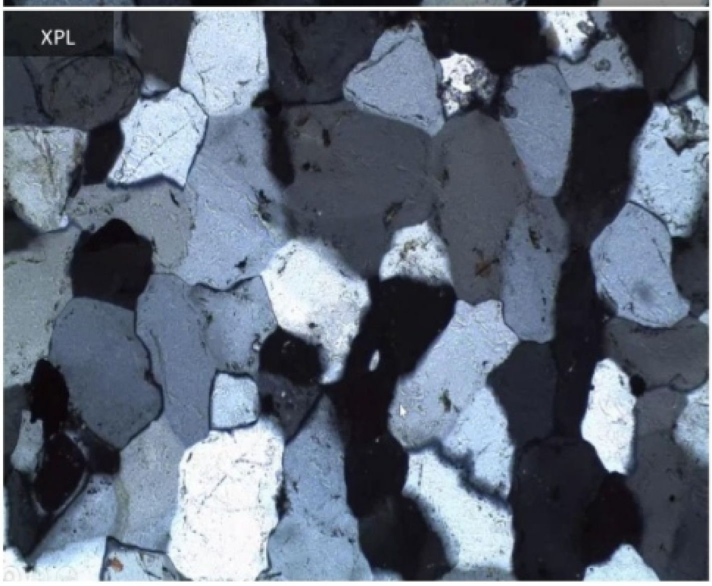

XPL
Polycrystalline quartz (chert)


PPL
Complete fusion of quartz overgrowth (Syntaxial overgrowth)

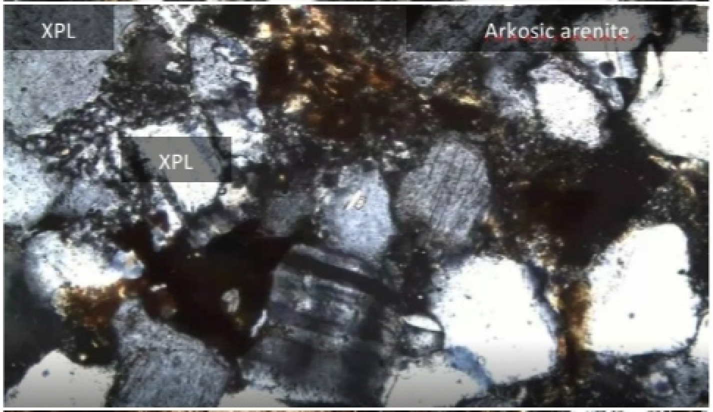

XPL
Concavo-convex contact
Concave up
Convex down

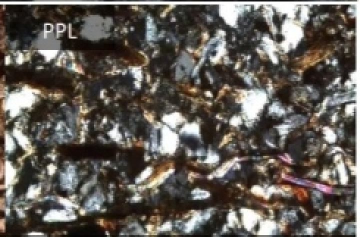

XPL


XPL
Zircon

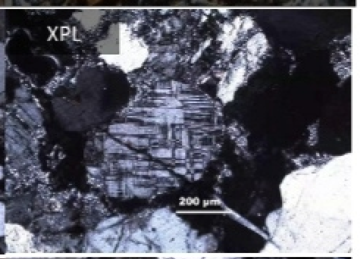

XPL

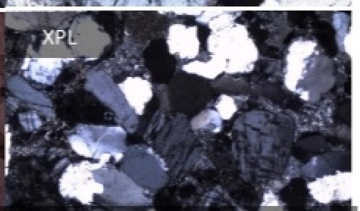
ARKOSIC SANDSTONES



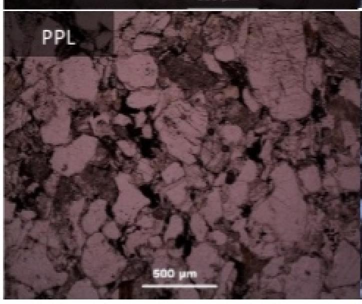


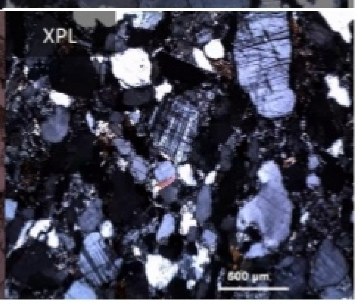
Mica flakes oriented parallel to bedding plane or perpendicular to load of overlying sediments due to physical diagenesis (compaction)

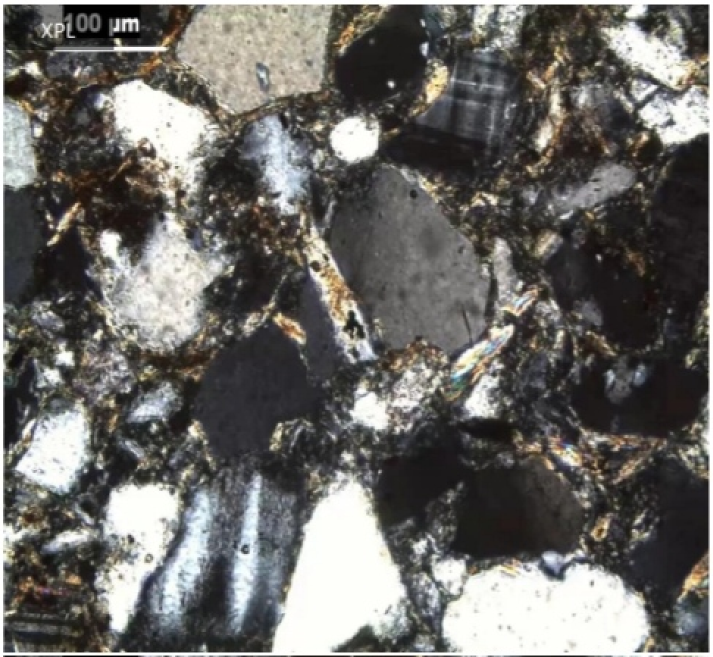


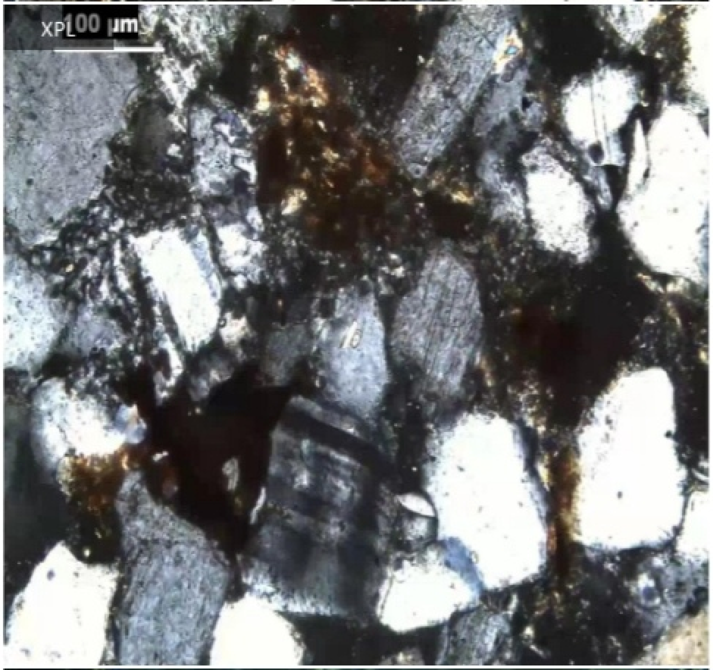


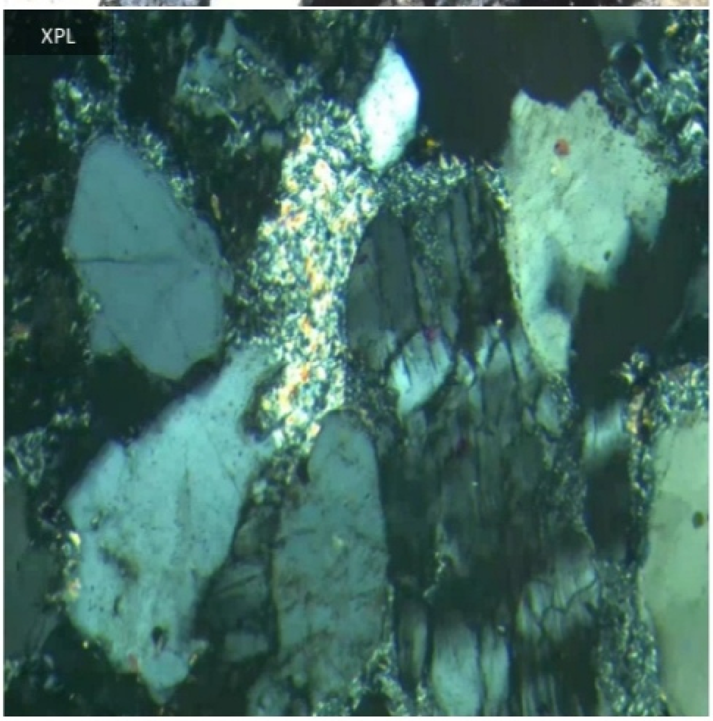
Feldspar overgrowth represent marine environments







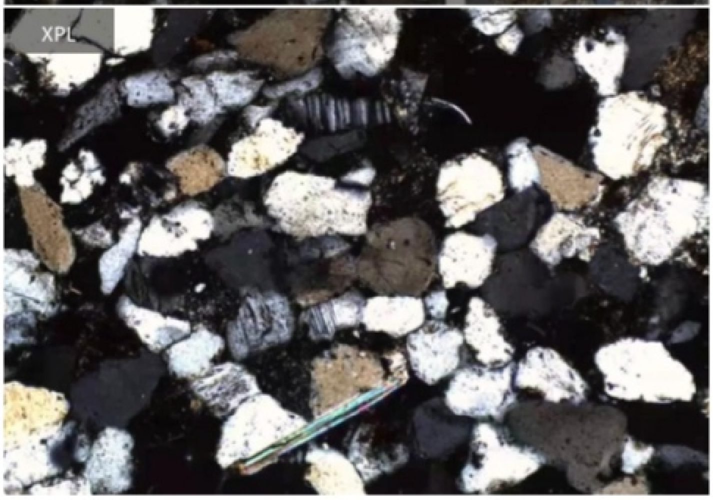


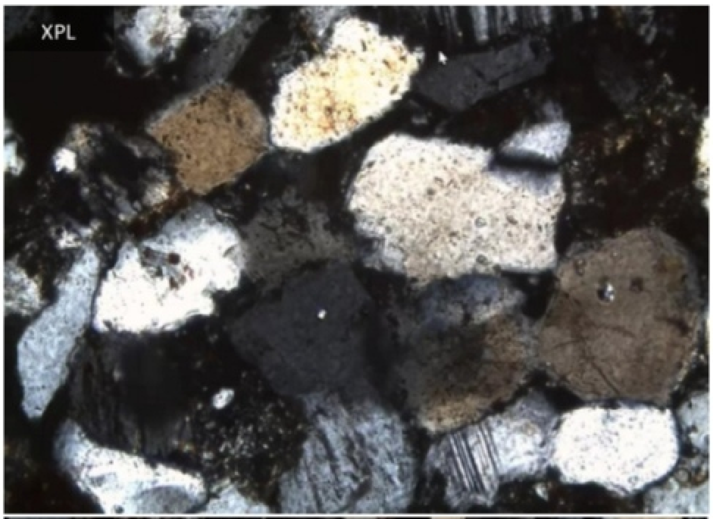


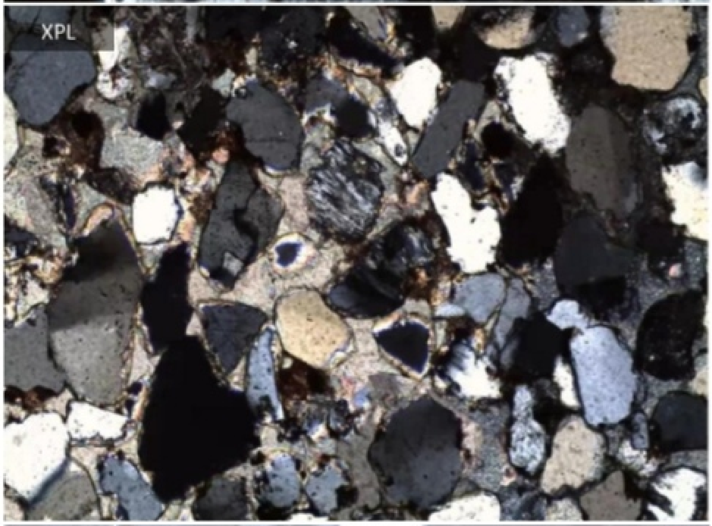
SUBARKOSIC SANDSTONE

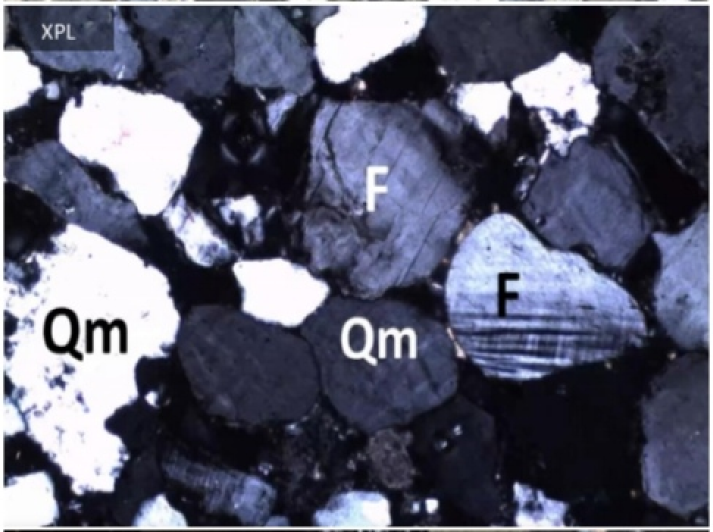
Grains with High Order interference colors are heavy minerals

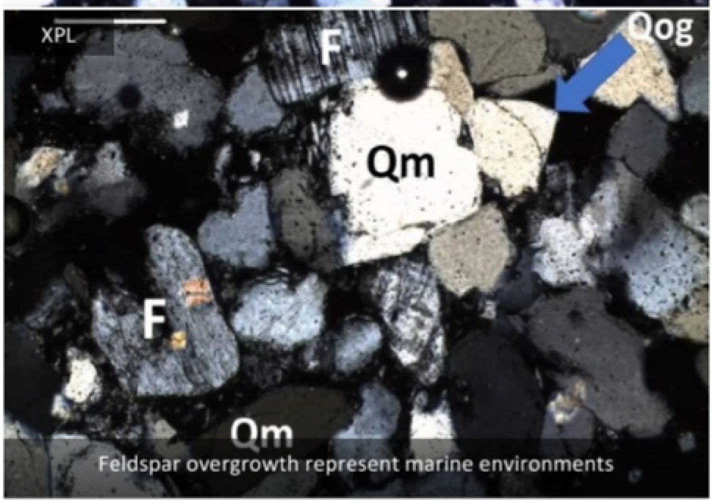
Cements are dolomite or calcite (high order IC)







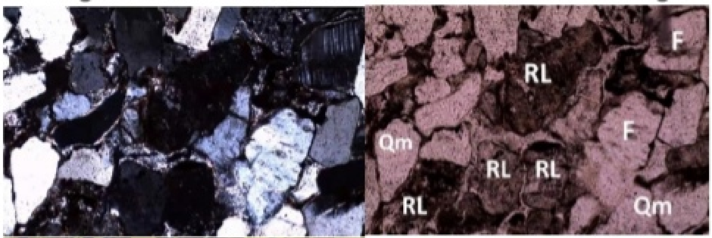


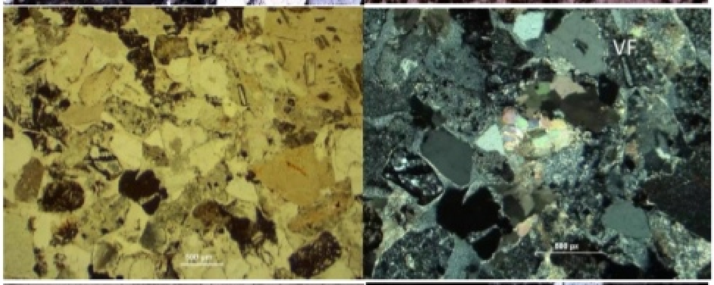


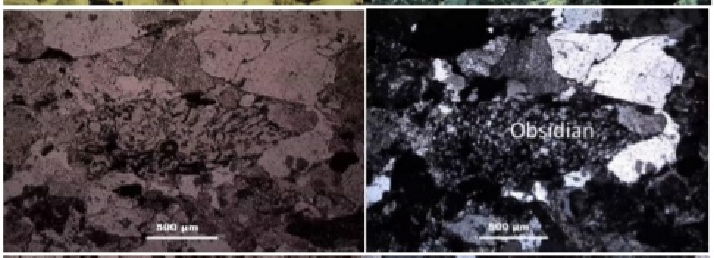
Feldspar overgrowth represent marine environments

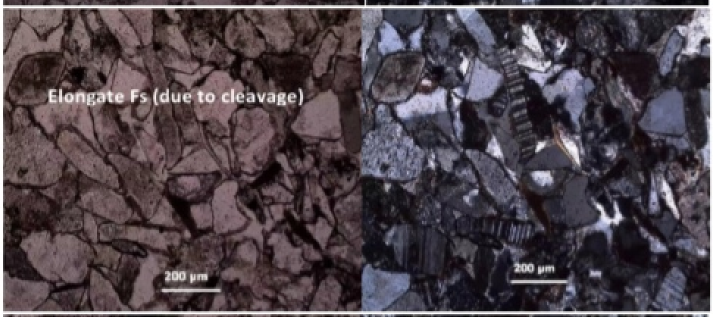
LITHIC SANDSTONES

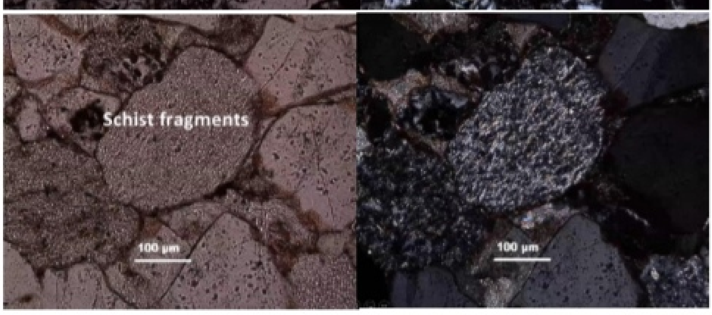
- Lithic fragments with parallel arranged micas or with polycrystalline quartz have a metamorphic origin
- Rock fragments with feldspar laths have basaltic origin
- Lithic fragments with silt-sized quartz grains have a sedimentary origin (siltstones)
- Lithic fragments with obsidian have volcanic origin
- Fagments with mica or biotite flakes have mafic origin

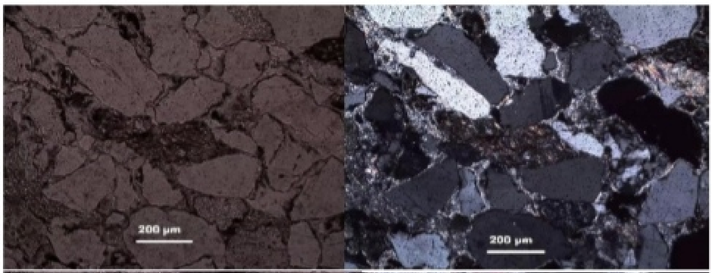


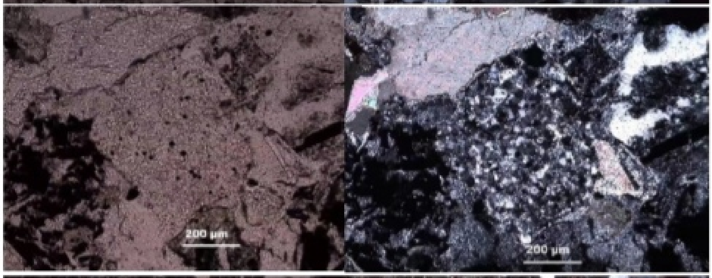


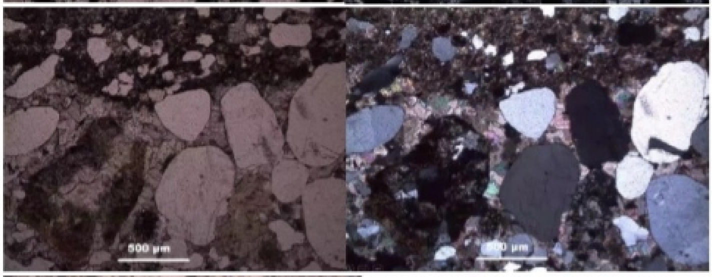


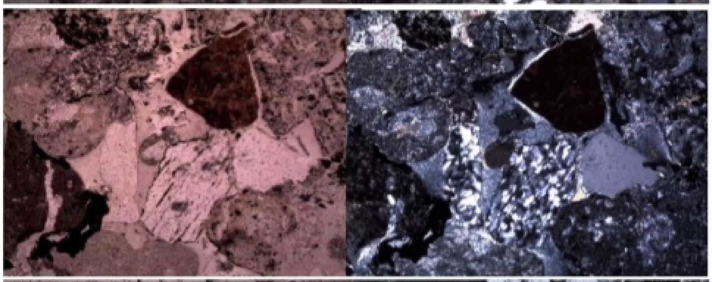


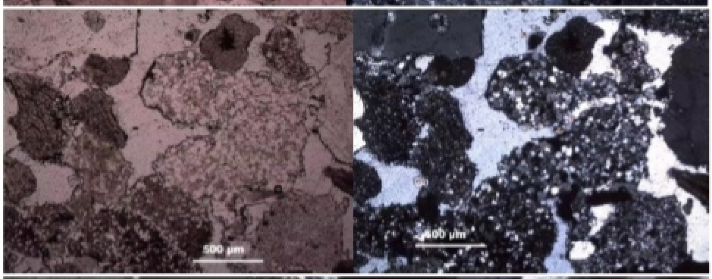


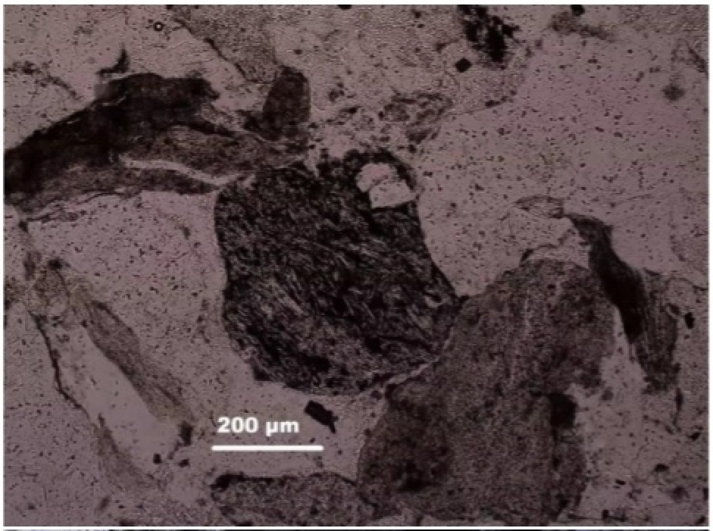


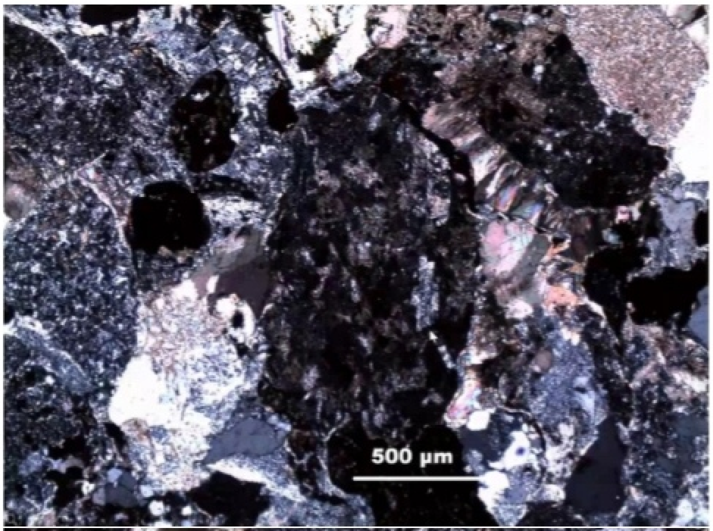


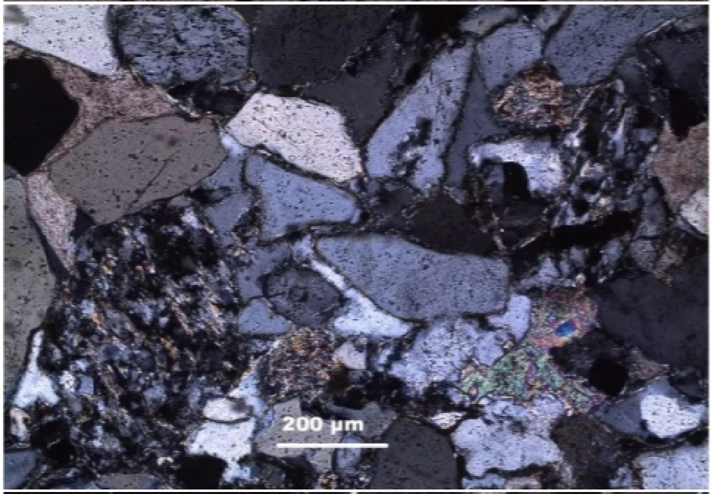


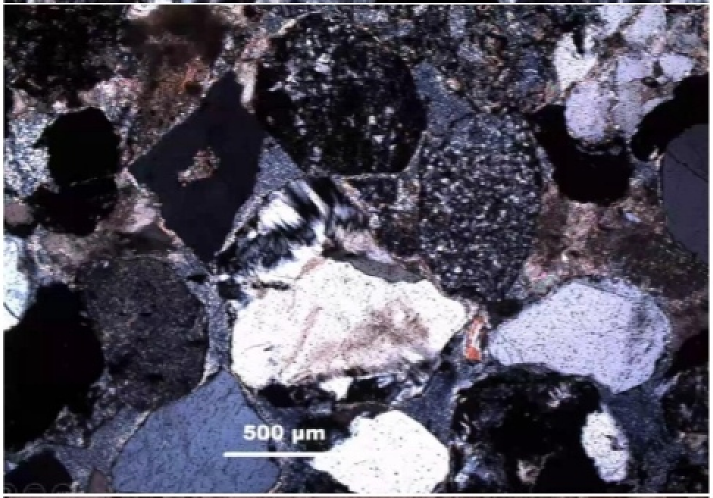




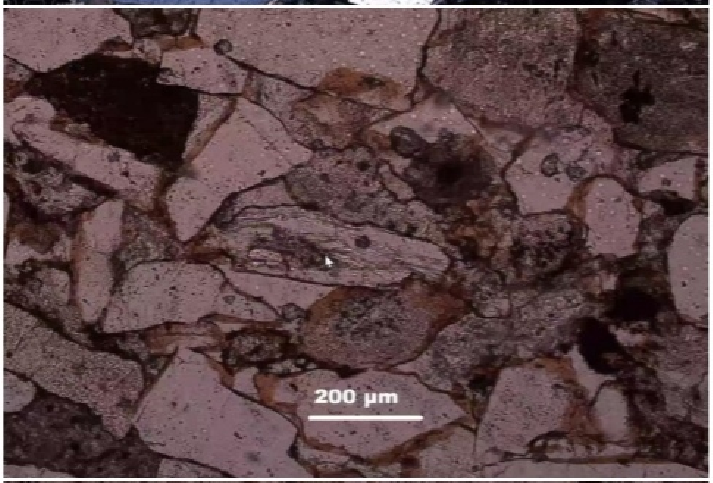

200 µm

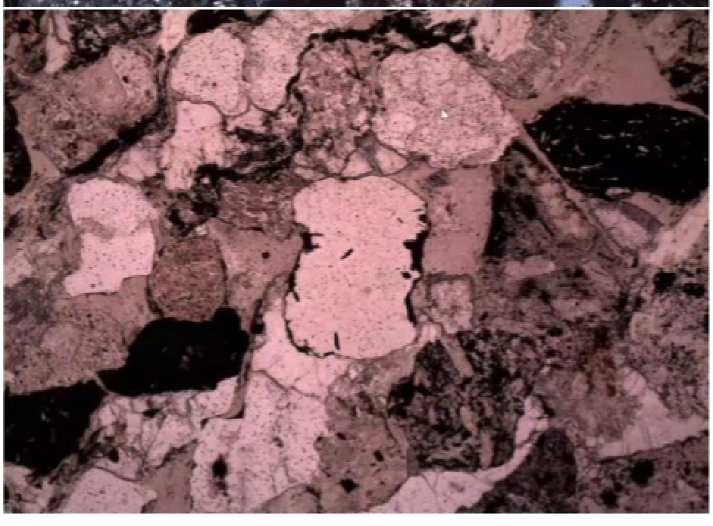

500 µm

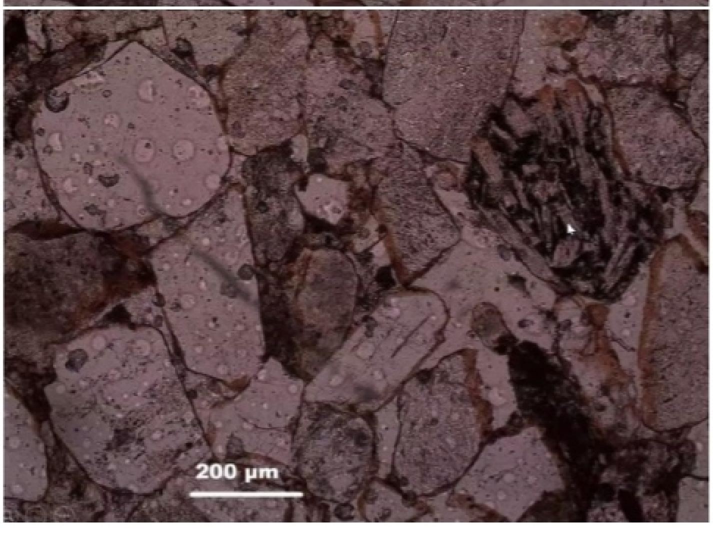

200 µm


500 µm


500 µm


200 µm




200 µm

Carbonates

- Form 10-15 % of the sedimentary rocks
- Limestones are more abundant than dolostones
- Carbonate rocks are normally free of impurities, & contains < 5% clays & fine-grained quartz
- Limestones are recognized in the field by its relative softness & by reactivity with diluted HCl

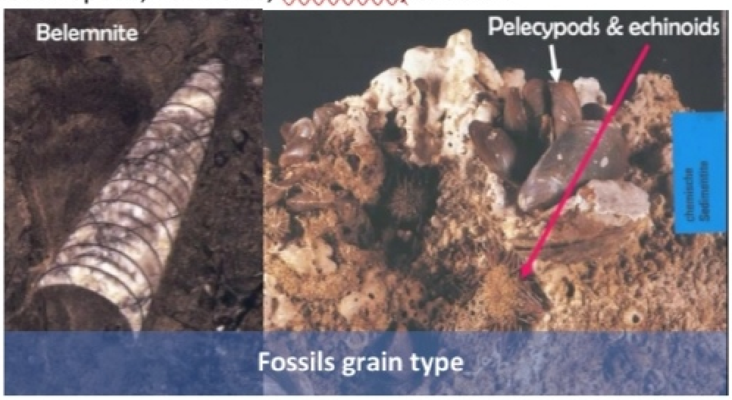
$$CaCO_3 + 2HCl \rightarrow Ca^{2+} + 2Cl^{-} + CO_2 + H_2O$$

- Dolostone reacts visibly with HCl when powdered
- Dolostones commonly weather to dull brownish material due to the presence of some iron
- The textures of limestone are quite variable due to the complex origins of these rocks
  - Form textures of detrital rock, chemical precipitate, & characteristic of growth habits of organisms
- Formed ***biochemically***, or ***diagenesis*** (recrystallization, compaction, & cementation at ≥ 200°C)
- Mineralogy
  - **Calcite** $CaCO_3$ (Rhombohedral)
    Low-Mg (<4Mg, stable), & High-Mg (>4%)
  - **Aragonite** $CaCO_3$ (Orthorhombic)
  - **Dolomite** $CaMg(CO_3)_2$

Grains (allochemical, allochem)

- gravel-, sand-, & coarse silt-size carbonate particles >30 microns that form the framework in mechanically deposited limestone
- 4 grain type: Fossils, ooids, peloids, & limeclasts

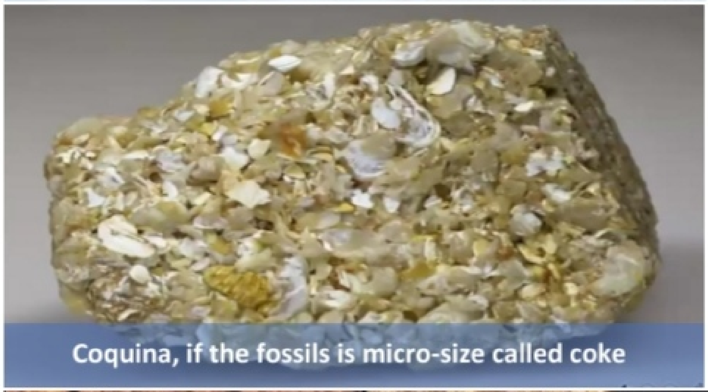
Fossils or skeletal grains: include pelecypods, brachiopods, Gastropods, Echinoids, Ostracods, & Corals



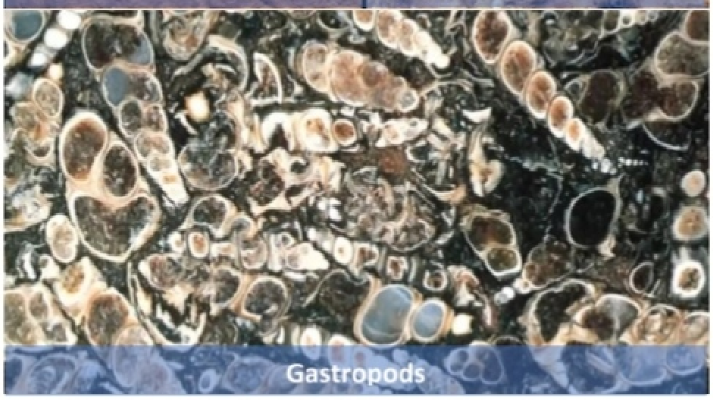
Fossils grain type

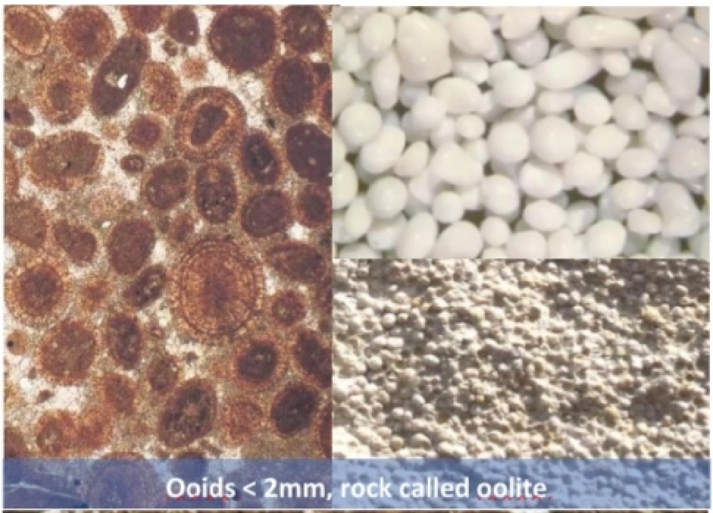
- **Ooids (<2mm)**: Spherical, polycrystalline carbonate grains of sand size, have a concentric or radial structure
  - have quartz or carbonate fragments as nuclei
  - Oolitic limestone form in agitated shallow marine waters & commonly have cross beds
- **Pisoliths** have organic origin, & differ from ooids by grain size (larger than ooids)


Bioclasts, fossils grain size

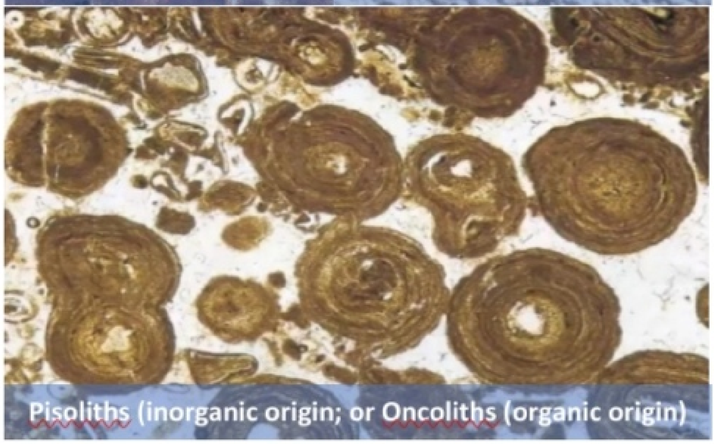

Coquina, if the fossils is micro-size called coke

Fossiliferous limestone


Gastropods

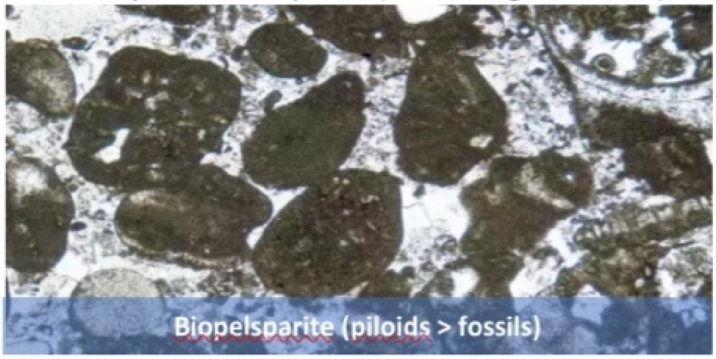


Ooids < 2mm, rock called oolite



Pisoliths (inorganic origin; or Oncoliths (organic origin)

- **Peloids** sand-sized of microcrystalline calcite that lacks any of internal structure, elliptical to spherical in shape
  - ➢ Represent fecal pellets (contain organic matter)

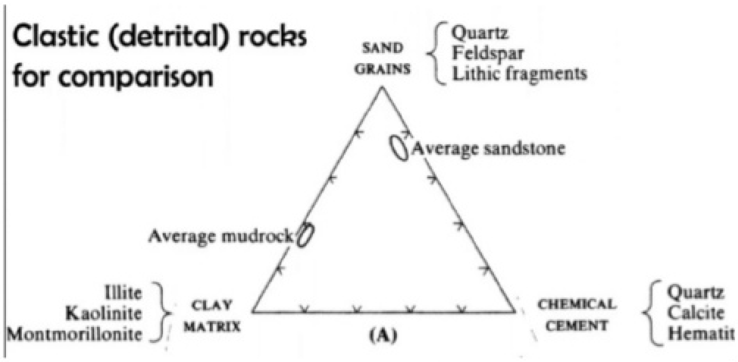


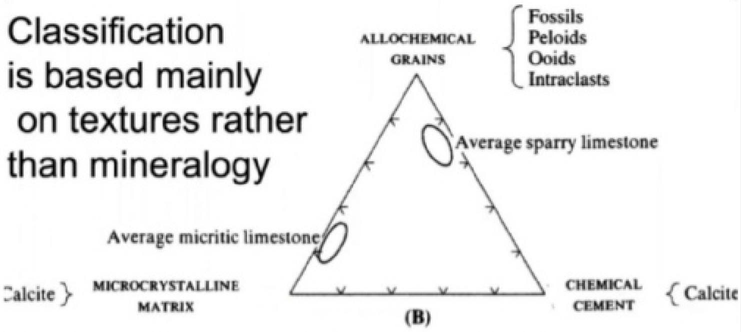
Biopelsparite (piloids > fossils)

- **Limeclasts:** Fragments of earlier formed limestone or partially lithified carbonate sediment
  - ➢ 2 types of limeclasts: ***intraclasts & Extraclasts***, Most are **intraclasts** (pieces of penecontemporaneous partially lithified carbonate sediment from within the basin of deposition)

Limestone Classification

- **The matrix in limestones**
  1. **mud (micrite):** Ca-carbonate mud (1-5µm), binds allochemical grains, & represents low energy env.
  2. **Microspar** 5-15 µm, recrystallization of micrite
  3. **Sparry** calcite cement > 20 microns
- **Insoluble residues**: chert, clay, detrital quartz
  - ➢ shells of radiolarian & diatom (consist of silica)
  - ➢ The silica is present in the form of nodular form parallel to limestone bedding planes





Original components not bound together during deposition				Original components were bound together during deposition . . . as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are 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*

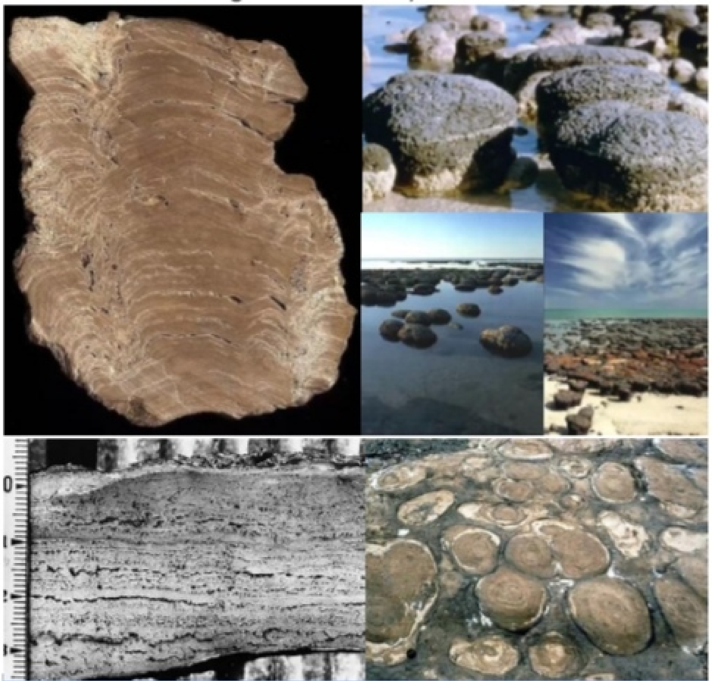
Principal grains in limestone	Limestone types: Cemented by sparite	Limestone types: With a micrite matrix
Skeletal grains (bioclasts)	Biosparite	Biomicrite
Ooids	Oosparite	Oomicrite
Peloids	Pelsparite	Pelmicrite
Intraclasts	Intrasparite	Intramicrite
Limestone formed in situ	Biolithite	Fenestral limestone-dismicrite

TABLE 16-1 Names and compositions of various limestones

Composition of limestone: Allochems	Orthochems	Folk name	Dunham name
70% Pelecypods 30% Ooids	Sparry cement	Oolitic pelecypod biosparite	Oolitic pelecypod grainstone
80% Ooids 5% Fossil fragments 15% Glauconite	Sparry cement	Glauconitic oosparite[a]	Glauconitic oolitic grainstone
60% Peloids 30% Fossil fragments 10% Intraclasts	Microcrystalline carbonate matrix	Fossiliferous pelmicrite	Fossiliferous peloidal wackestone or packstone
70% Intraclasts (gravel size) 25% Trilobites 5% Peloids	Sparry cement	Trilobite intrasparudite[b]	Intraclastic grainstone
40% Crinoid fragments 40% Brachiopods 20% Clay minerals	Microcrystalline carbonate matrix	Clayey crinoid-brachiopod biomicrite	Crinoid-brachiopod wackestone or packstone

Structure

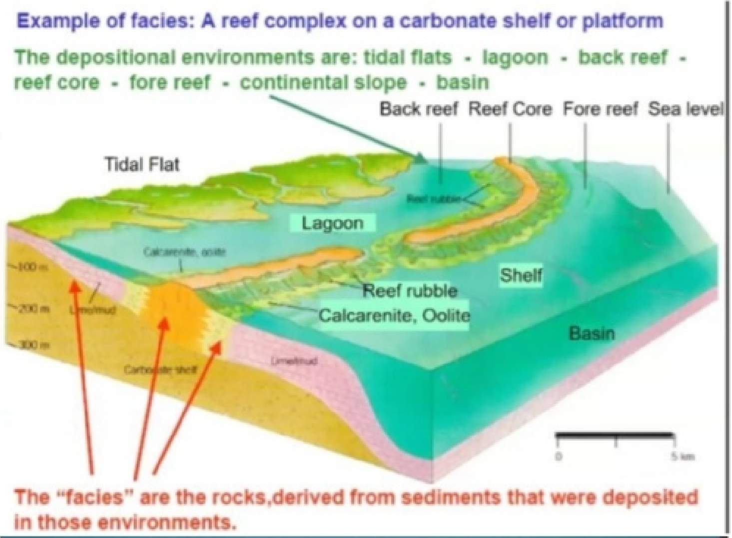
- All structures of sandstones that generated by currents can forme in limestones: e.g. cross bedding,imbrication
- **Geopetal sructuires** The shells of organisms aiter their death settie down with concave side pointing downwar, this used to determine up direction of the beds
- **Lamination**: organic or inorganic, & the most important type are produced by soft- bodied, filamentous blue green algae that grow as mats (mats are swept over by wave fine carbonate mud becomes attached to these mats. Producing stromatolites)

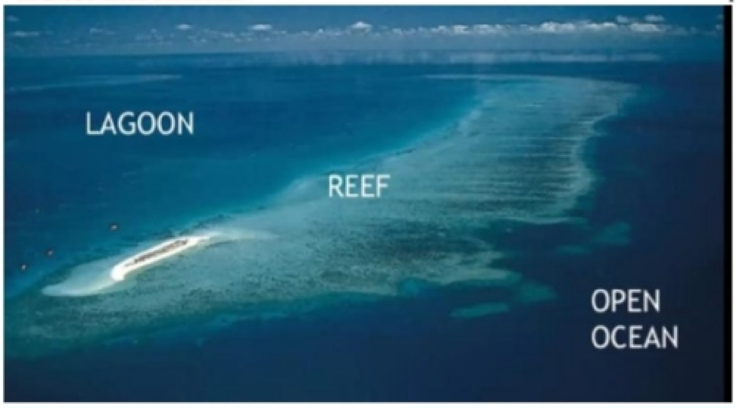


Stromatolites, limestones formed by cyanobacteria
Very important as a Water & oil tank duo to vesicles

- **Micrtic Mud Mounds**: Circular to oval dome-shaped accumulations of microcrystalline calcite
  - ➢ Thicknesses up to 100’s m & diameters up to 1km
  - ➢ They can form shallow & deep environments
  - ➢ Reef formed from accumulation of mud mounds
- **Organic reefy** Carbonate buildups of local origin that are laterally restricted
  - ➢ Reefs originate almost entirely in low latitudes in shallow marine waters
  - ➢ The carbonate sediments are produced by a variety of frame-building organisms: corals, sponges, algae, bryozoas, rudist pelecypods

Distribution of reefs



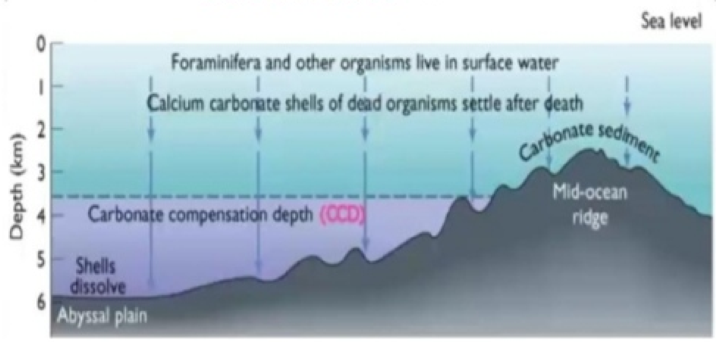


Atoll Reef (circular), above oceanic mountains

Calcium Carbonate Depositional sites

- Warm T necessary to cause supersaturation of waters with respect to $CaCO_3$ (abundance & growth of calcareous-shelled organism)
- Calcareous-shelled organism are mostly marine & need light, constant salinity, clear & warm waters, Water must be very shallow & far from large rivers which cause a drop in salinity
- Modern reef-building organisms (corals) contain blue-green algae which needs light to thrive
- Carbonates Compensation level (CCL) where calcium carbonate breaking down deeper in equatorial regions because carbonate formation is larger in warmer water
  - ➢ CCL pelagic carbonate, 4km in open ocean (photic)
  - ➢ Under CCL, T decreases so solubility of $CaCO_3$ increases to produce H_2CO_3 which controlling the solubility of limestone (unstable in acidic env.)
  - ➢ pH on the surface (7.9 - 8.1) & as the concentration of H_2CO_3 increases pH became (7.8) limestone at this pH disintegrates (limestone fense : pH = 7.8)

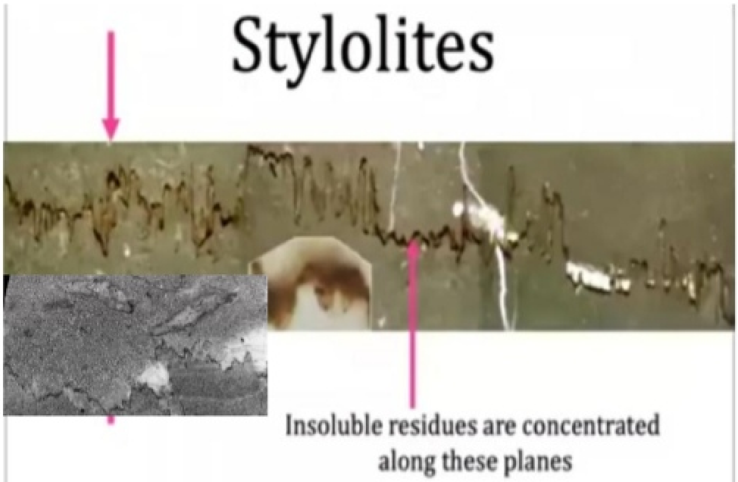
- The limestone can be formed over the bridge because it's a high area & under CCL it melts & chert is more stable (cryptocrystalline quartz)
- chert is formed as a result of the sink of the shells to the oceanic floor, which build their shells from Qz or $CaCO_3$, whose shells are built from Qz (e.g. idolaria & diatomes) forms pelagic silica (chert, melts 8.5pH)
- Carbonate secreting planktonics didn't evolve until Jurassic, microbiomicrite of pre-Jurassic didn't exist



- **Lacustrine Carbonate:** lake deposits & commonly associated with other evaporites
  - During late spring & early summer surface waters of lakes turn white as T increase, removal of CO_2 from surface waters is at maximum as a result of active photosynthesis by microscopic plant "***charophyte***"

8.8 IAP & Diagenesis

- **Diagenesis**: all process that contributes to solidification of sediments into a sedimentary rock include cementation, compaction, Lithification
  - start after deposition of skeletal carbonates
  - **Cementation** by production of hardground on the shelf carbonates or beach rocks (Meteoric water cementation)
  - Mechanical compaction & Chemical cementation (including P solution)



Stylolites limestone: structure formed by P solution due to
1. Deposition of a new layer of limestones
2. Tectonic Compression: limestone dissolution

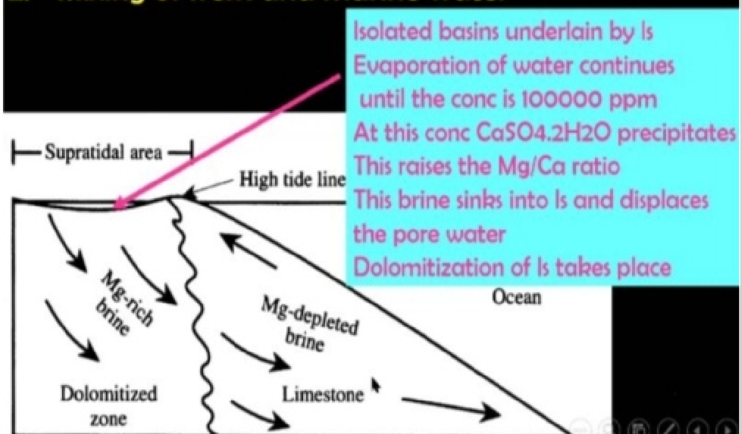
Dolostones

- **Dolostones** impure carbonate rock formed by one or 2 mechanisms (Evaporative reflux or mixing of a fresh & marine water)

Dolostones (composed of dolomite)
Is a chemically rocks forms by dolomitization (change a limestone into a dolomite) in arid climates

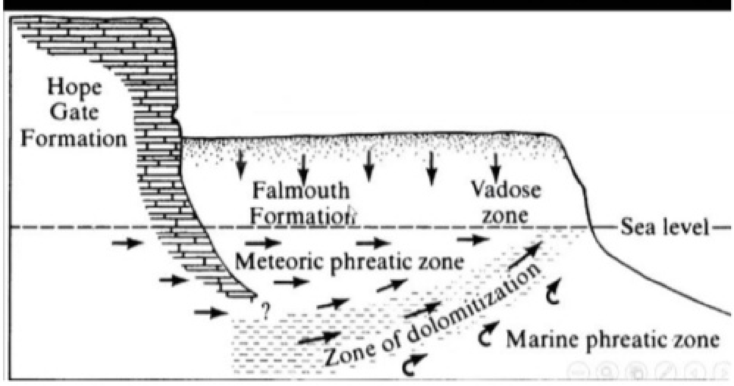
Dolostones thinsection
We can distinguish dolomites from calcites in thinsection by staining (staining of calcite)

- Dolomites form by either one of two mechanisms:
1. Evaporative reflux;
2. Mixing of fresh and marine water

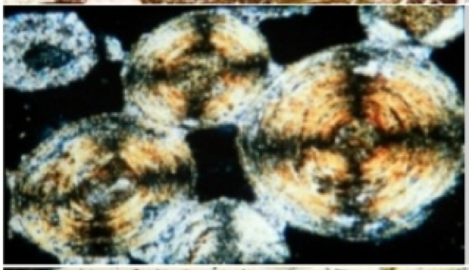


Mixing model : fresh meteoric water with sea water = brackish water

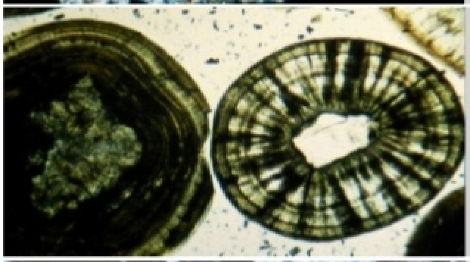
Mg in seawater ~ 1290 ppm



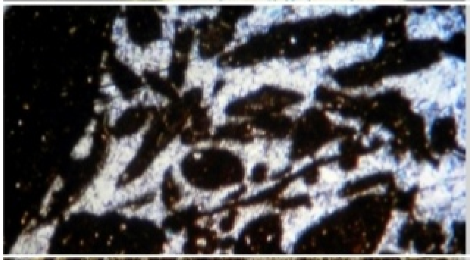
Pisoids having regular, well-defined concentric layering, of inorganic origin



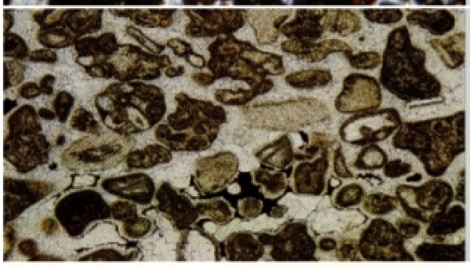
Ooids aragonitic have a tangential arrangement of crystals which yield pseudo-uniaxial cross section



coarse, & radiating Ooids of bladed to fibrous aragonite interspersed tangential, radial texture appears to be disruptive & secondary



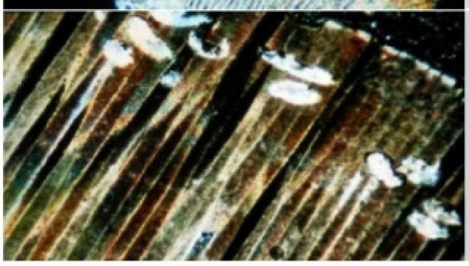
Peloids (lower right & left) consisting of cryptocrystalline calcite (micrite) & devoid of any internal structure



Aggregate botryoidal form of aggregates, similar to grapestones

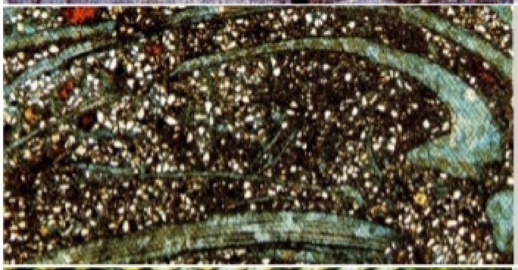
brachiopod shell surrounded by micrite

Crossed-lamellar (aragonitic texture) in mollusks, from a gastropod

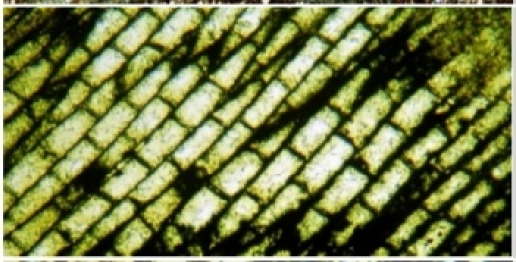


Inoceramus shell with distinctive prismatic structure break up into individual prisms which constitute important fraction of some sediments. boring in hell wall

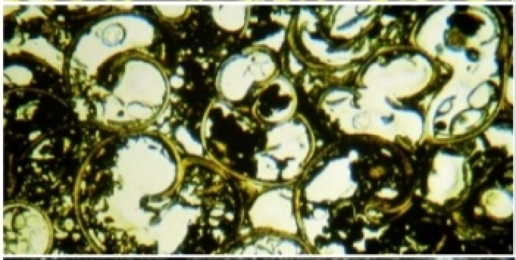
The importance of micrite envelops in preserving molluscan fragments during diagenesis



bivalves shell & calcitization
The shells consist of a blue-Fe sparite & lines cutting across crystal boundary indicate original foliated structure of shell

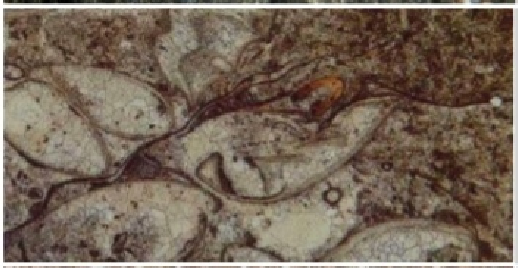


The well preserved cellular prismatic outer layer of the shell. These rudists are the major contributors to Cretaceous reefs & bioherms



Sorted gastropod limestone
The variety of shapes produced by different angles of section these aragonitic & have crossed-lamellar structure

Longitudinal high-spiral gastropod
aragonite inverted to calcite with loss of internal detail, yet internal & external outline faithfully preserved by micrite

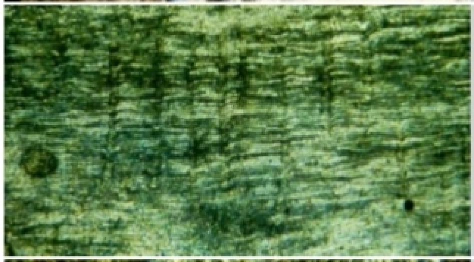


Impunctate brachiopods with the large pedicle valve & smaller brachial valve complete

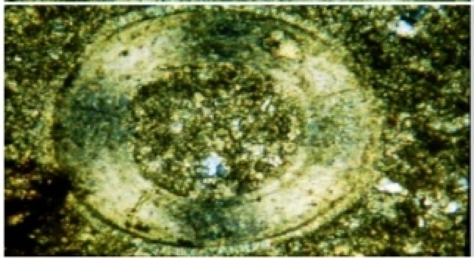
A brachiopod fragment with its outer prismatic layer preserved. The brachiopod is impunctate having no punctae

Broken brachiopod
consist of 2 valves, & micrite envelope Fibrous structure & the fine tubes at right angles to the wall (endopunctae) sparis blue stained due to high Fe

punctate brachiopod clearly defined pores (punctae), penetrate shell & filled with micrite micrite-coated echinoderm & bryozoan

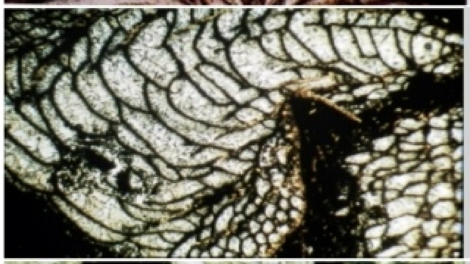


pseudopunctate brachiopod shell fibrous with small plication that run vertically via shell. pseudopunctae that not represent actual openings or pores in the shell

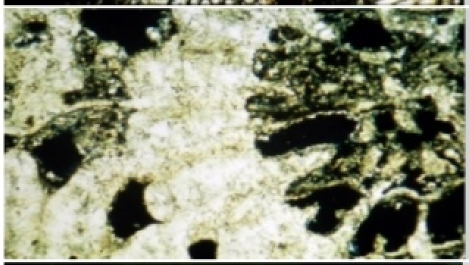


Brachiopod spine Fibrous structure yielding pseudo-uniaxial cross, central canal, & outer wall

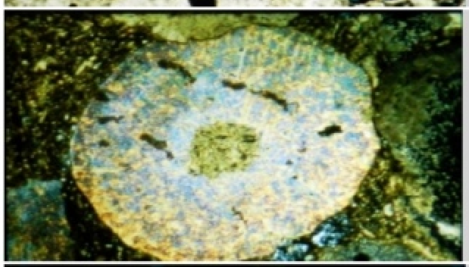
Rugose coral (Lithostrotion) Showing internal plates (septa, tabulae, & dissepiments)



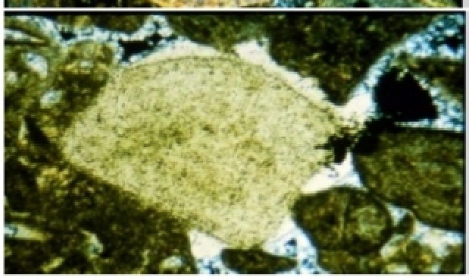
Rugose coral in oblique cut Large corallites, radiating septa, & dissepiments



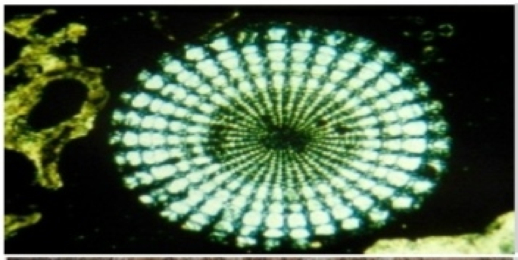
Scleractinian coral Show original septa (central dark line) & partial filling of living chambers, Considerable recrystallization has occurred



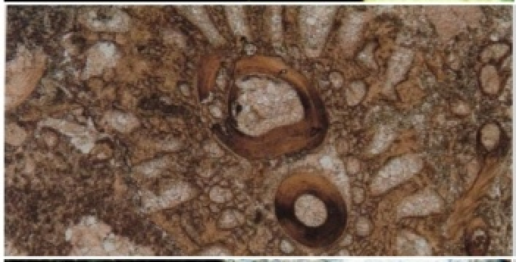
Large crinoid ossicle typical characteristic of echinoderm grains, single crystal extinction, Circular shape & central canal are common in many crinoidal



Large echinoderm fragment single- extinction & uniform granular microstructure (small pores filled with dirt), Early calcite overgrowth, & later silica cement



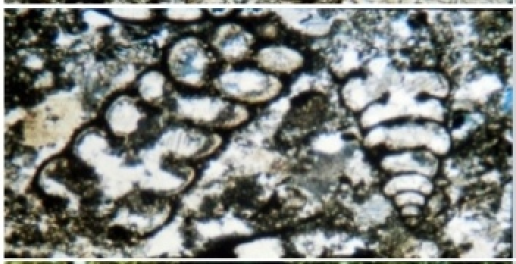
Echinoderm spine show single-crystal structure & very characteristic lacy pattern rather common to find echinoidal spines in limestones



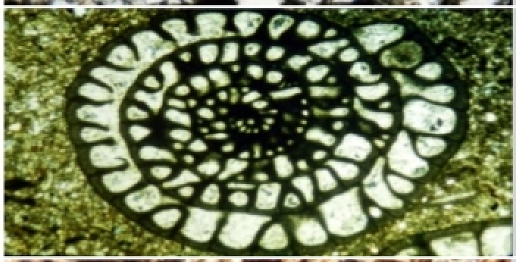
Broyozoa encrusting 2 brachiopod spines, concentrically-laminated grains Thick calcite wall of bryozoan & pores (*zoooecia*) filled with calcite

A large bryozoan frond with regular circular to elongate holes (zooecia) & fibrous wall structure

A large bryozoan frond showing typical shape & structure

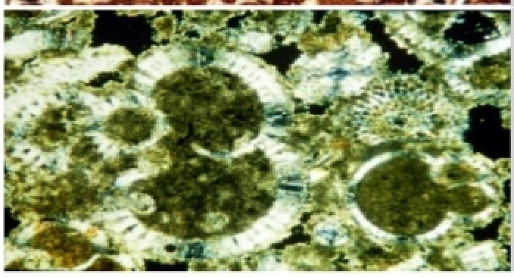


Sections through uniserial & biserial foraminifera Micritized wall structures & chamber shapes



Fusulinid Foraminifera Chamber shapes & radial wall structure

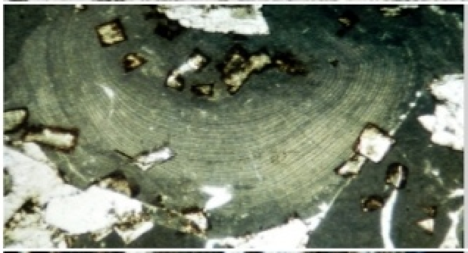
A limestone composed largely of miliolid Foraminifera



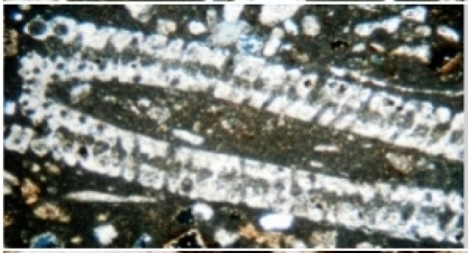
planktonic Foraminifera well-preserved porous radial wall structure & micrite filling of chambers

Calcareous red algae, Lithothamnion in longitudinal section (showing seasonal growth zones)

Very well-preserved red alga, possibly Lithophyllum. The cellular structure, branching form, & good preservation characterizes this type of algae



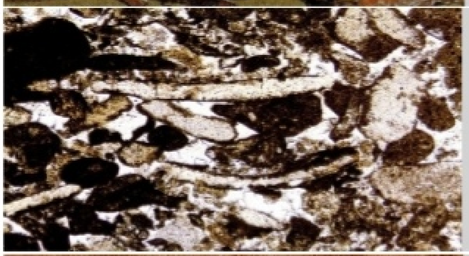
Large red algal with typical laminated & cellular structures. Cut by rhombs of dolomite (often selectively because of original high Mg content)



Large green-algal (Dasycladacean) with oblique cut through central cavity & radiating porous tubes

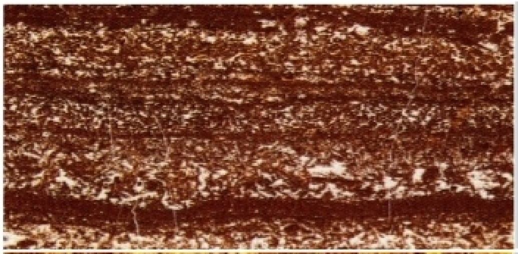
Dasyclad algae

A sediment made up largely of segments of the codiacean algae. rock highly porous, impregnated (the brownish gray background)

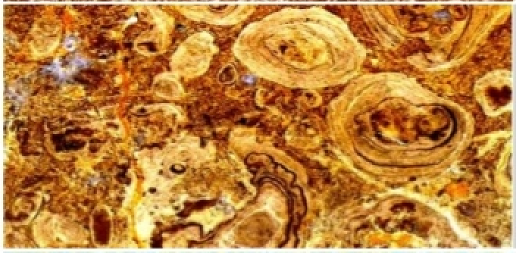


Micrite envelops Developed on brachiopod shells (the foliated structure) & echinoderm fragments (the speckled plates)

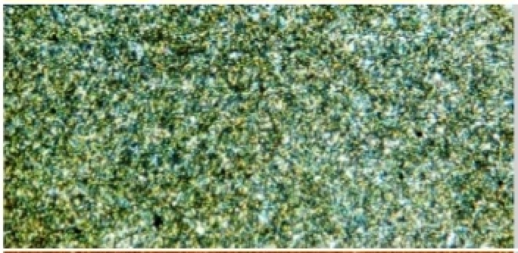
Stromatolite Layering is irregular & picked out by color differences, & laminae may form flat or crinkly structure, or build up into columns or domes



Stromatolite appearing The laminations consist of alternating thin micriteic layers & layers containing a mixture of micrite & sparite

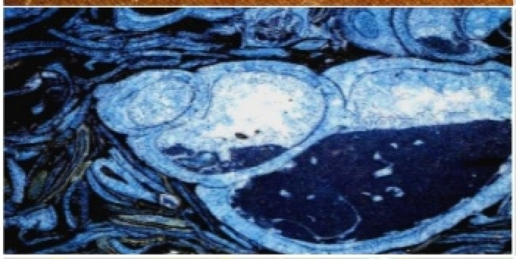


Polished rock surface showing oncoids The bluish areas are sparry calcite

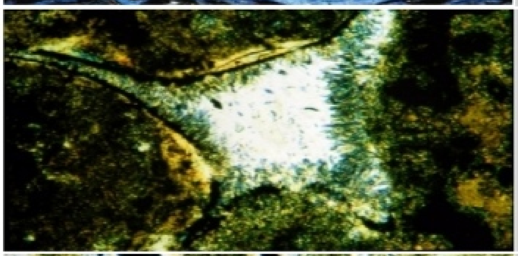


Micrite (rather lithified carbonate mud)

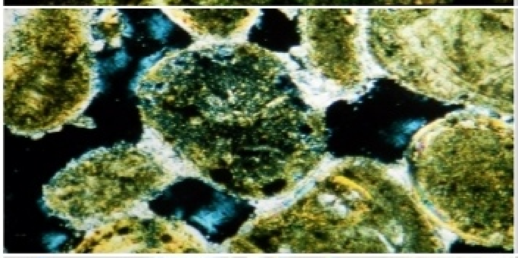
Micrite with < 10% allochems (forminifera & calcite casts of radiolarian) in Dunham mudstone



Geopetal structure within a gastropod The primary pore in the gastropod was filled with sediment, then ferroan calcite filled the remaining pore space

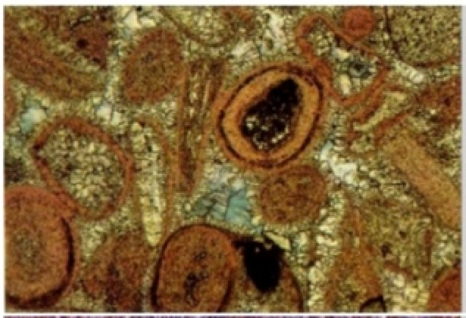


Fibrous aragonite-needle cement holding oolitic Fringe smoothly follows outline of voids & isn't concentrated near grain junctions

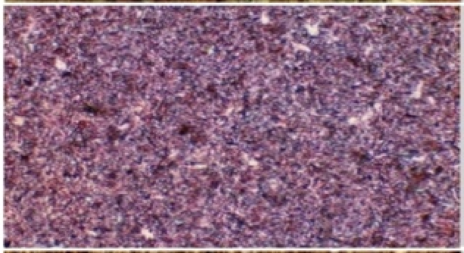


vadose cement Cement found grain contacts, no complete cavity linings

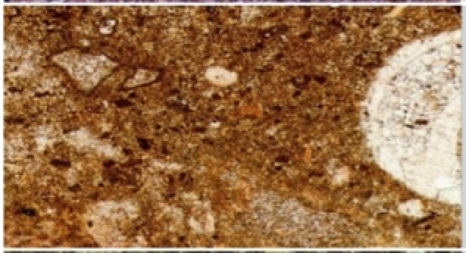
Coarse fibrous calcite crystals showing radially oriented fan-shaped clusters interspersed with thin rinds of gypsum



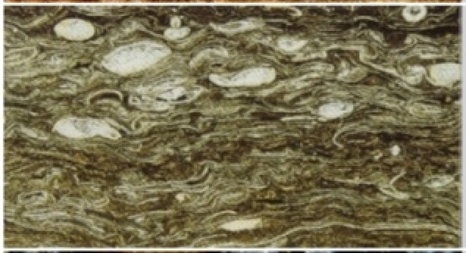
2 cement: the first appears as a rim of equal thickness (isopachous) exhibiting radial fibrous fabric, & the second is a pore fill of equant sparite blue stained (Fe-calcite) precipitated by meteoric water



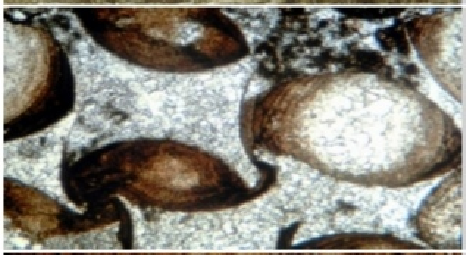
A limestone composed almost entirely of calcite grains of microspar size



limestone with fine pseudospar matrix cloudy & contrasts with coarse clear mosaic replacing the wall & infilling chamber of mollusk, (originally micrite)



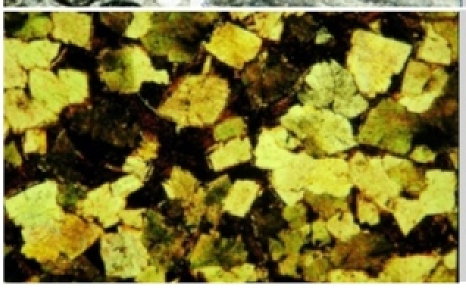
bioclastic sediment, consisting of 2-valved ostracods & single ostracod valves & long thin bivalve fragments



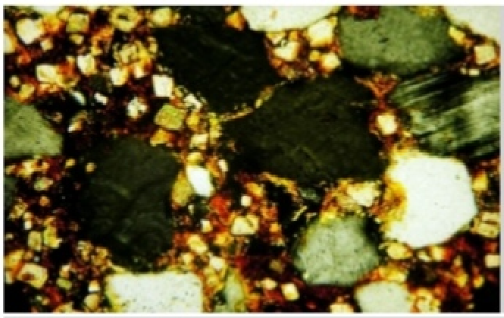
Deformed ooids Strong compression will shear off outer concentric coatings of the ooids & produces shapes often difficult to identify as ooids

Limestone that has undergone grains P-solution leading to fine saw-tooth appearance characteristic of styloiltes

stylolitization Large brachiopod shell & numerous echinoderm fragments have mutually dissolved & interpenetrated each other

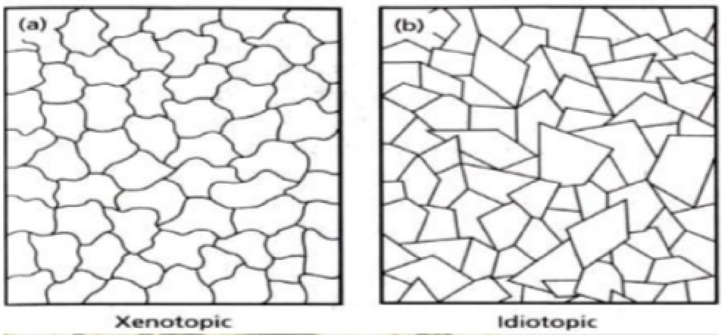


Dolomite rock (dolostone) consisting entirely of rhombs



Dolomite rhombs replacing a micritic matrix between framework Qz & Fs in a sandstone Micritic of reddish color not dolomitized & remaining between particles

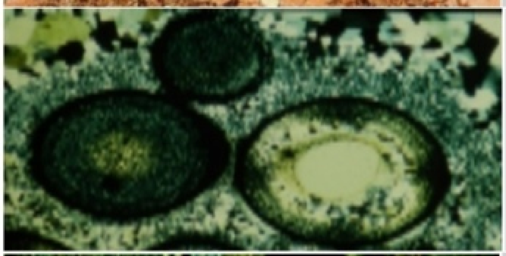
Dolomite Textures	
Xenotopic	Anhedral crystals with curved to serrated & irregular crystal boundary
Idiotopic	Euhedral rhombic crystals



Dolomite crystals are commonly zoned, the inner part is more cloudy (from fluid inclusions or calcite relics) & the outer part is clear

Poikilotopic dolomite engulfing several Qz & Fs in an arkosic arenite sandstone The dolomite is stained turquoise due to Fe-content

Dedolomite consisting of calcite spar that exhibits rhombs outlined by Fe-oxide & rich in inclusions indicative of former dolomite rhombs

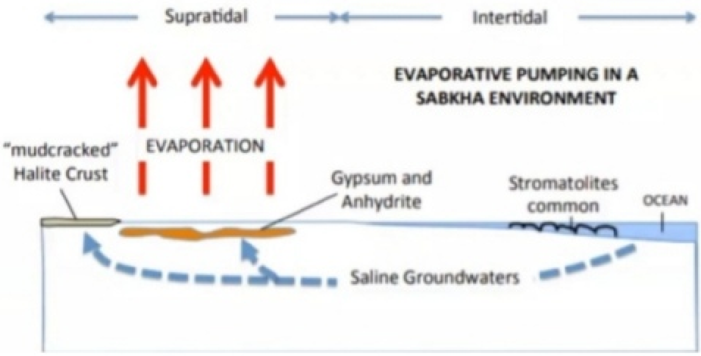


Silica replacement of carbonate (oolitic) sediment Qz overgrowths on nuclei of ooids, chert replacement of ooids

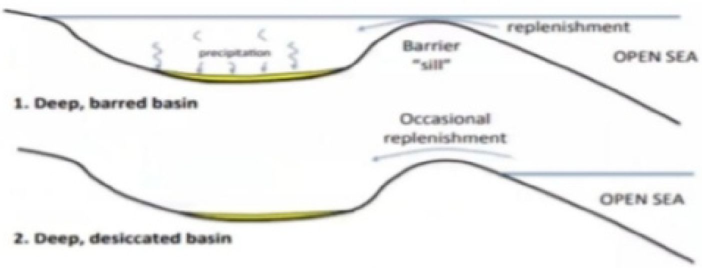
Chalcedonic Qz in a calcareous sponge The well-developed radiating bundles of chalcedony fibers cut by growth banding, & the growth interference between chalcedony bundles

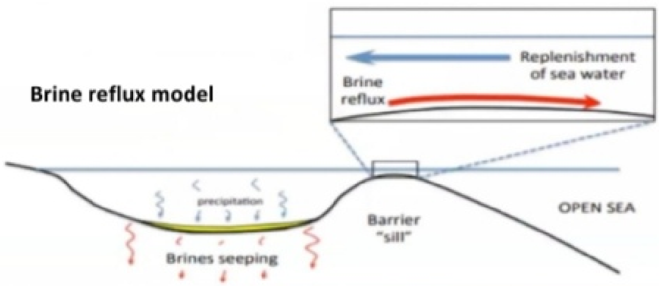
Evaporites

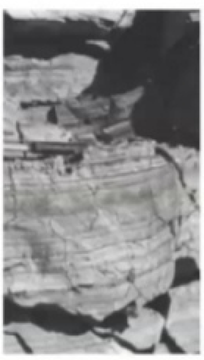
- **Sabkha** Supratidal environments along arid coastlines build out 'prograde' OVER intertidal sediments giving them a unique sequence of facies in sedimentary logs.
  - ➢ Supratidal Intertidal Gypsum precipitated directly into sediments (also dolomitization), Gypsum has nodules, chicken-wire, or enterolithic textures
  - ➢ May get anhydrite precipitating further landward rather than gypsum



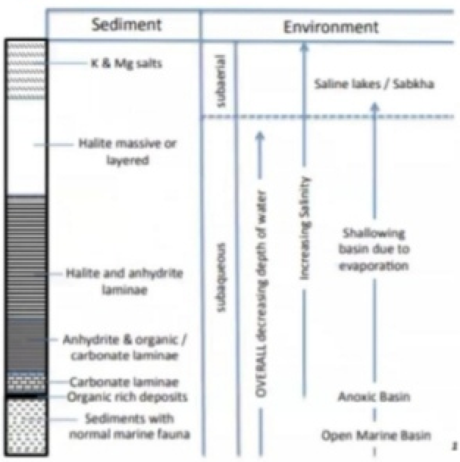
- **Deep Basins**: Most important source of evaporite
  1. **Deep basins barred by a barrier**: fault,CO_3bank,reef
  2. **Deep basins with occasional access to sea**

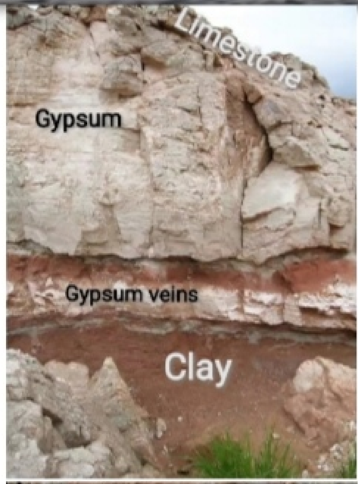


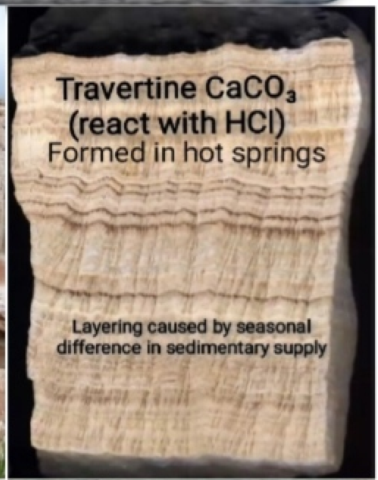


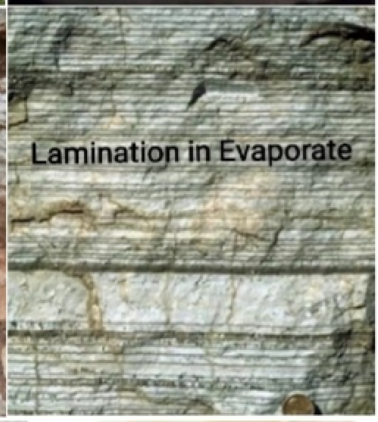


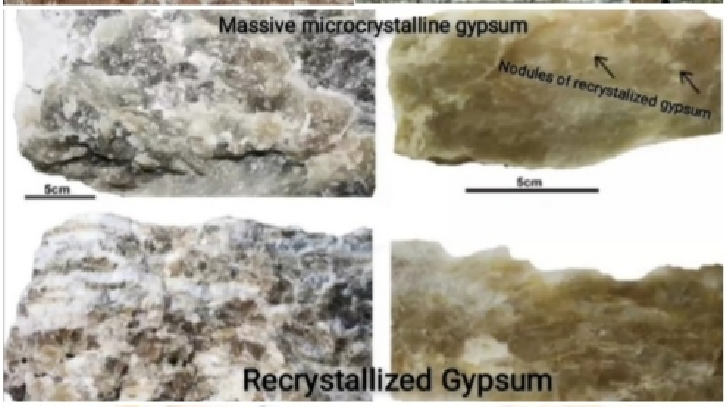
Laminated Evaporites

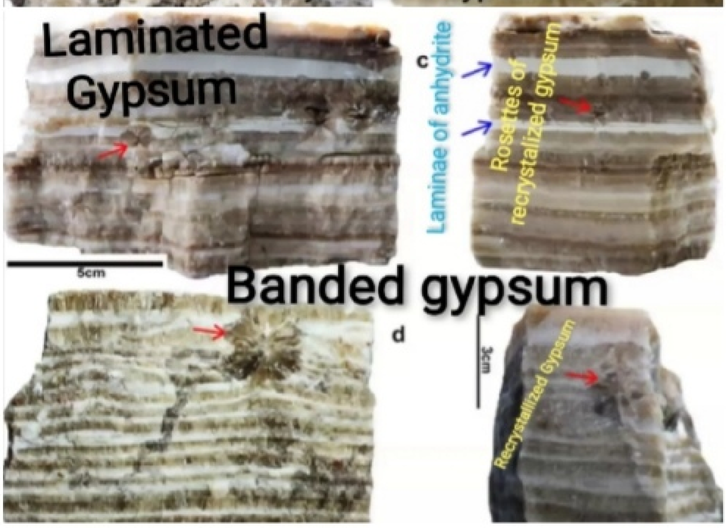


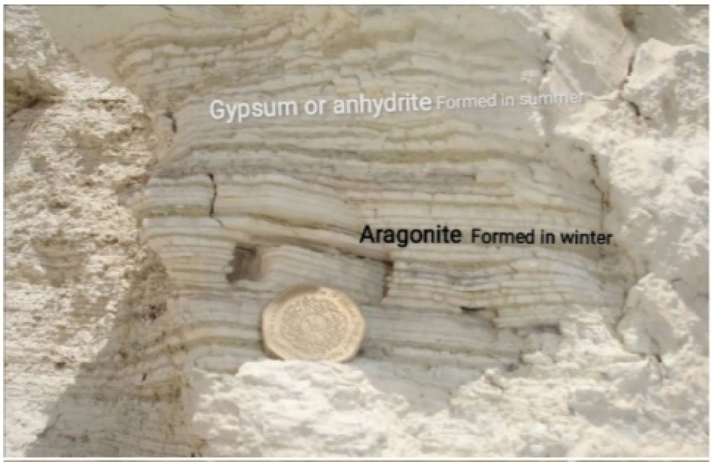


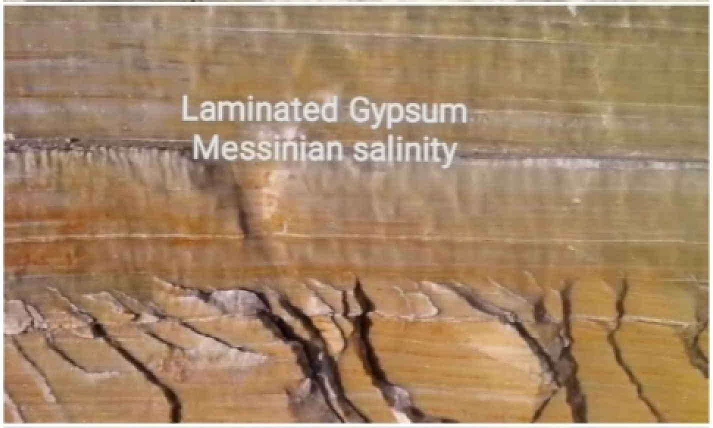


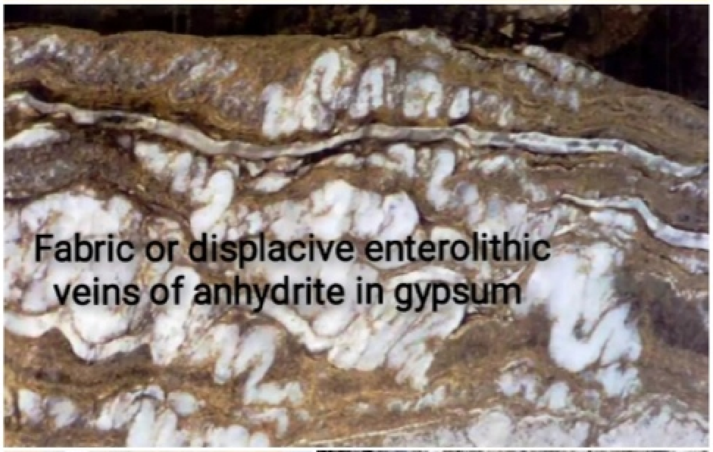






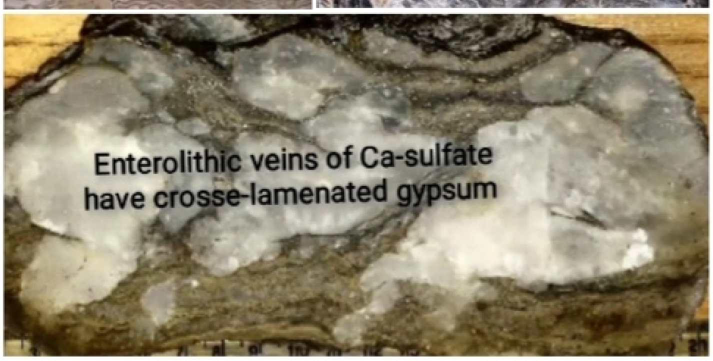

Gypsum or anhydrite Formed in summer
Aragonite Formed in winter

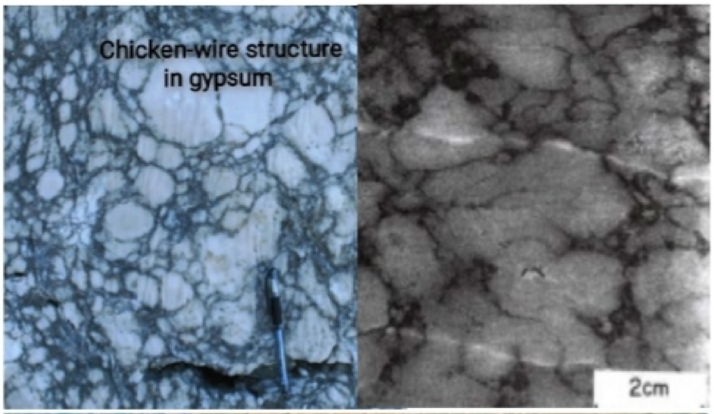

Laminated Gypsum
Messinian salinity

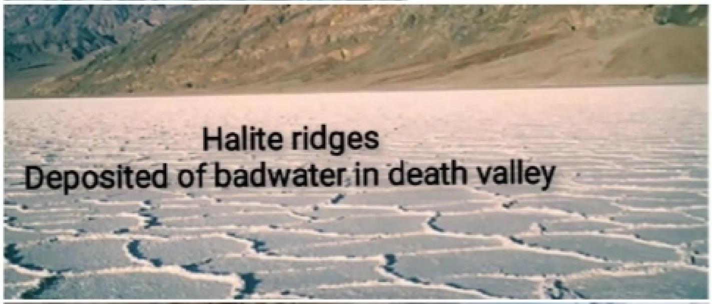

Fabric or displacive enterolithic
veins of anhydrite in gypsum


Laminated evaporate


Twinned messinian
selenite crystals


Enterolithic veins of Ca-sulfate
have crosse-lamenated gypsum


Chicken-wire structure
in gypsum
2cm


Halite ridges
Deposited of badwater in death valley


Tepee halite in dead sea

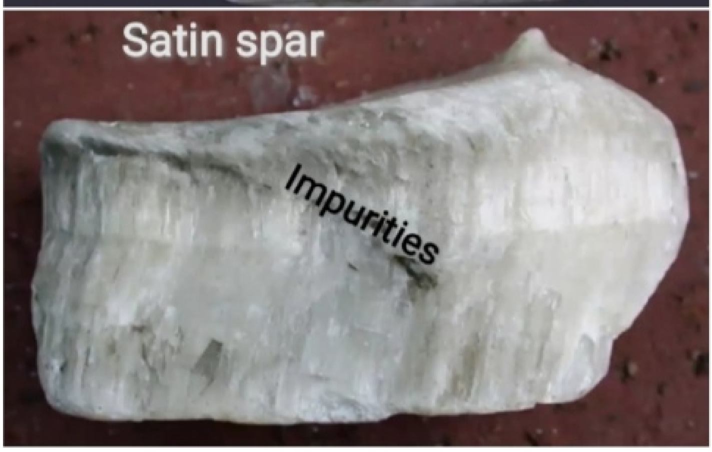

Selenite (clear gypsum)
H = 2 & 1 nice cleavage


Selenite
Good cleavage parallel to ground surface
& 3 poor givin skewed angular look


Selenite
Brownish color due to impurities


Selenite
Impurities

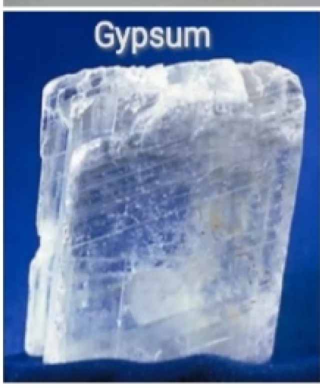

Satin spar (fibrous gypsum)


Satin spar
Impurities


Massive or earthy gypsum


Selenite
Impurities

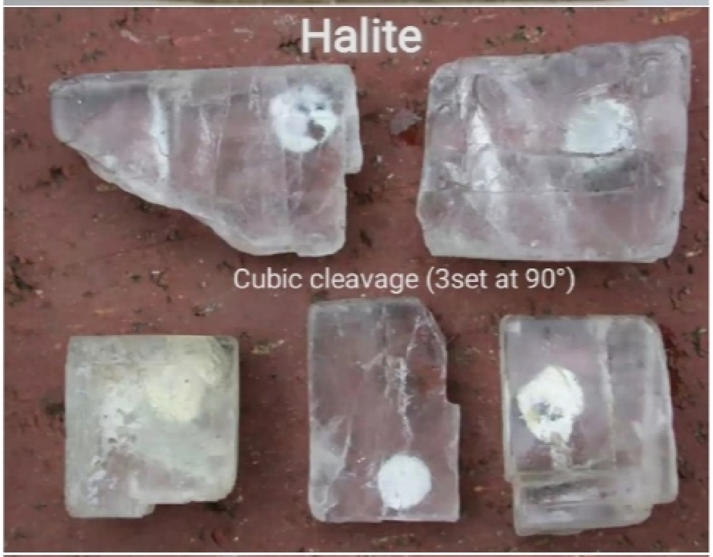

Anhydrite


Gypsum


Anhydrite


Massive anhydrite
Sedimentary layering & sugary appearance


Fine anhydrite
Confused with lithographic limestone


Halite
Cubic cleavage (3set at 90°)


Rock salt
Different colors due to impurities

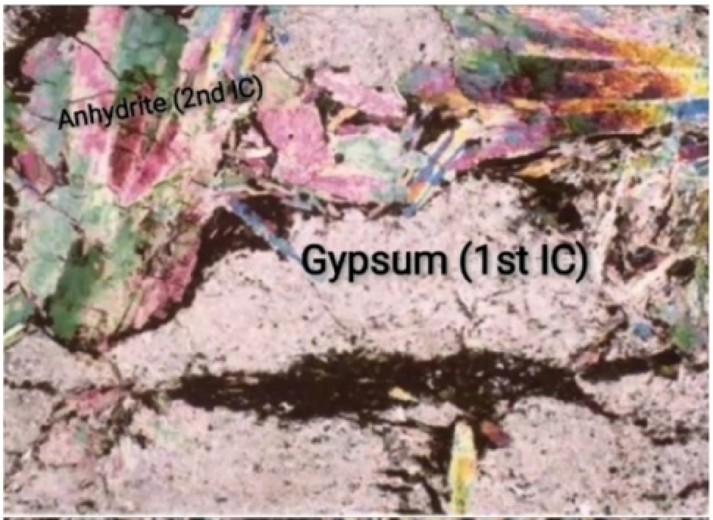

Rock salt (halite)

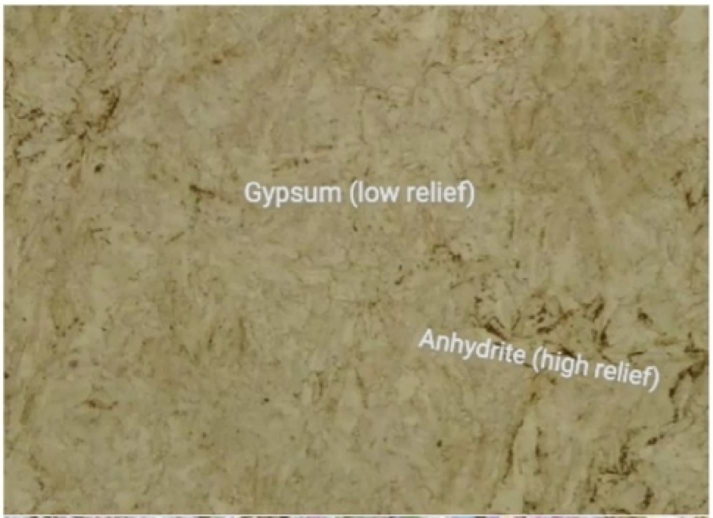

Blocks of Halite

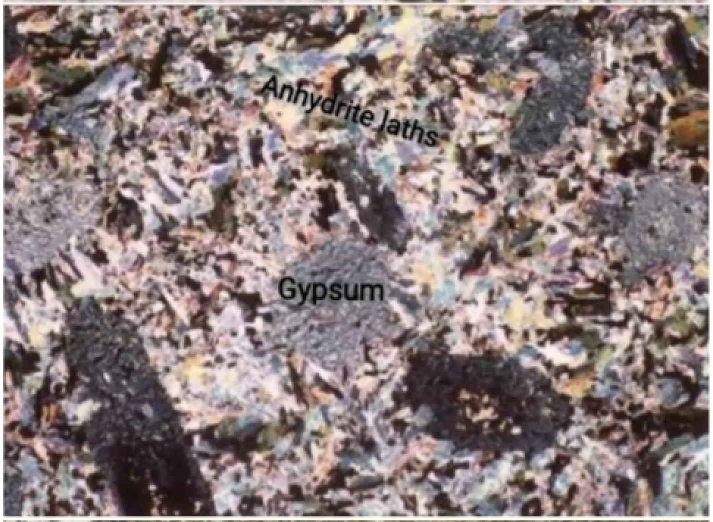

Halite


Halite with impurities


Halite
Cubic
crystal
habit

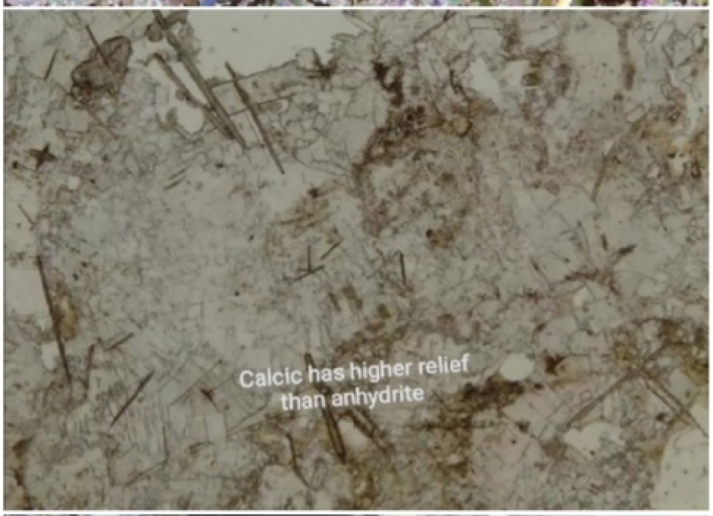

Anhydrite (2nd IC)
Gypsum (1st IC)

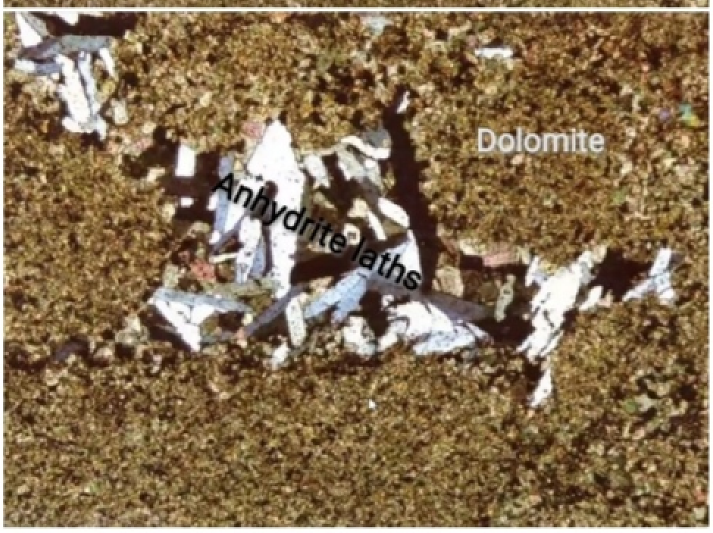

Gypsum (low relief)
Anhydrite (high relief)


Anhydrite laths
Gypsum

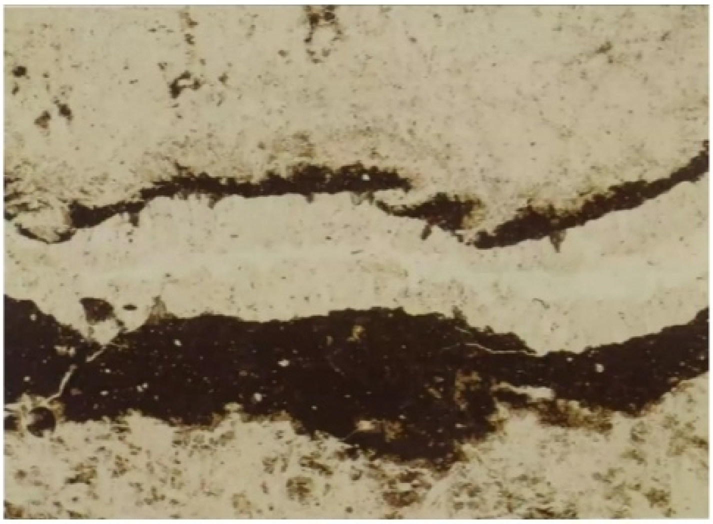

Anhydrite

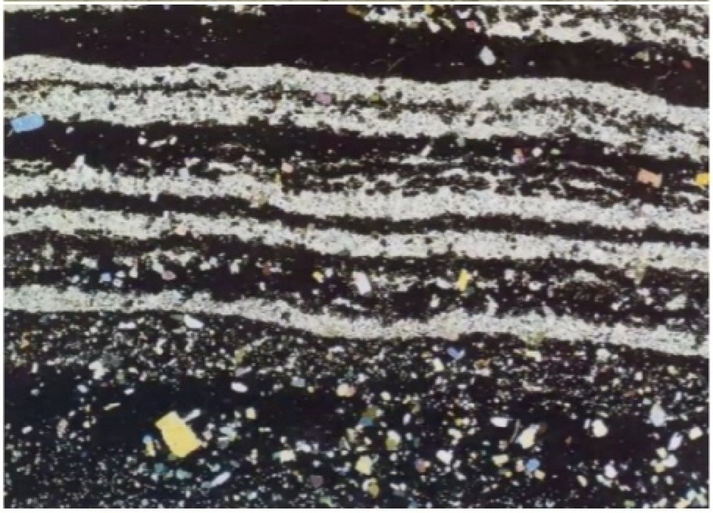

Dolomite
Anhydrite laths

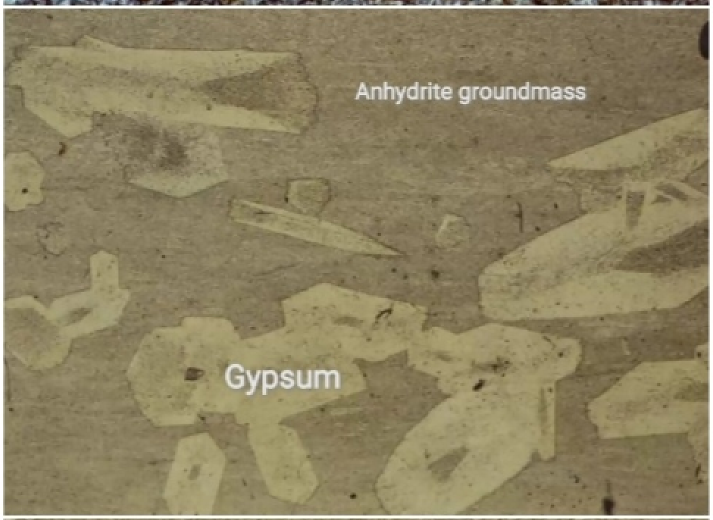

Calcic has higher relief
than anhydrite

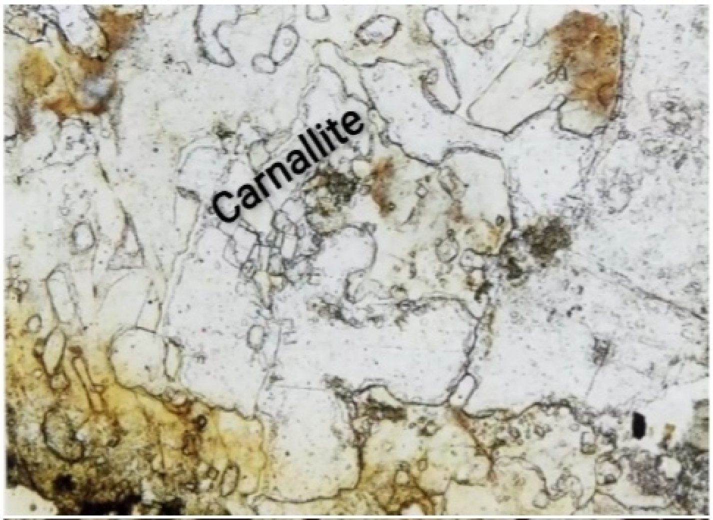

Dolomite
Anhydrite laths

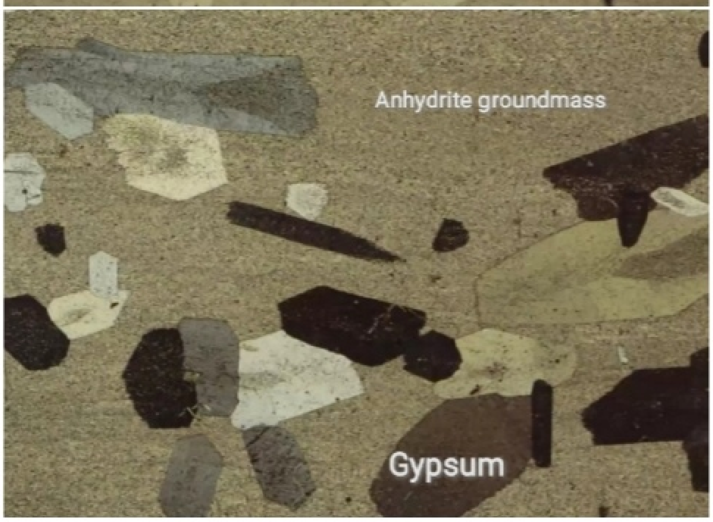

Anhydrite in carbonate

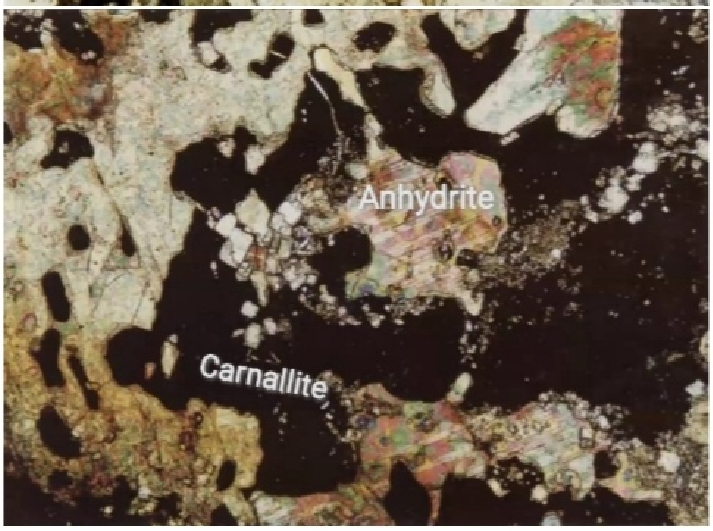


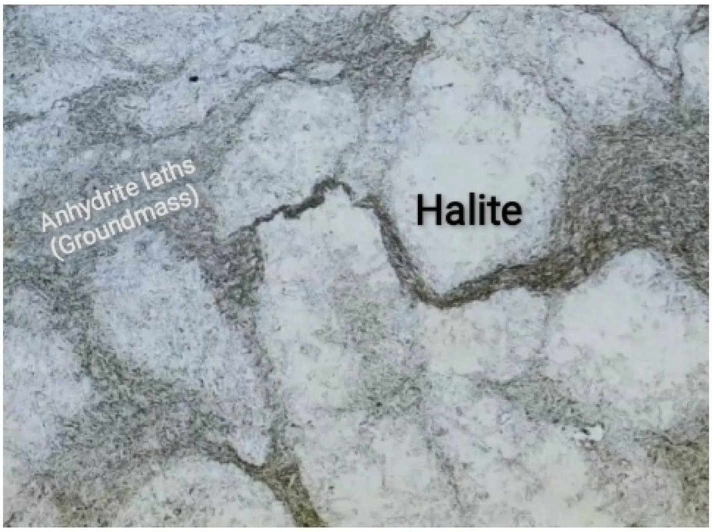



Anhydrite groundmass
Gypsum

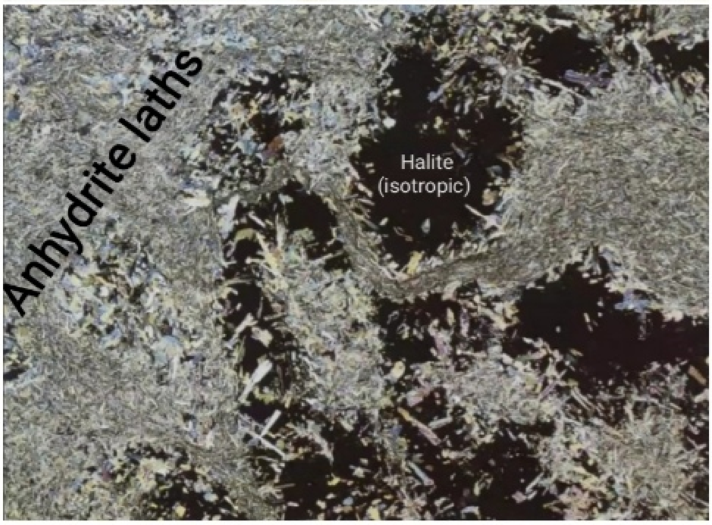

Carnallite


Anhydrite groundmass
Gypsum

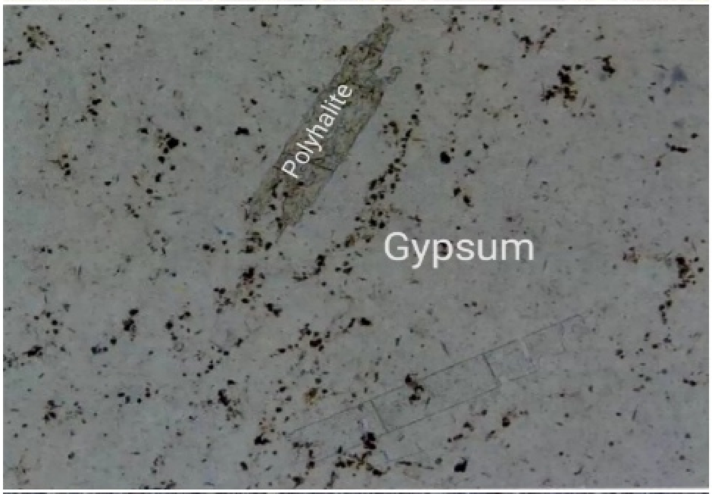

Anhydrite
Carnallite

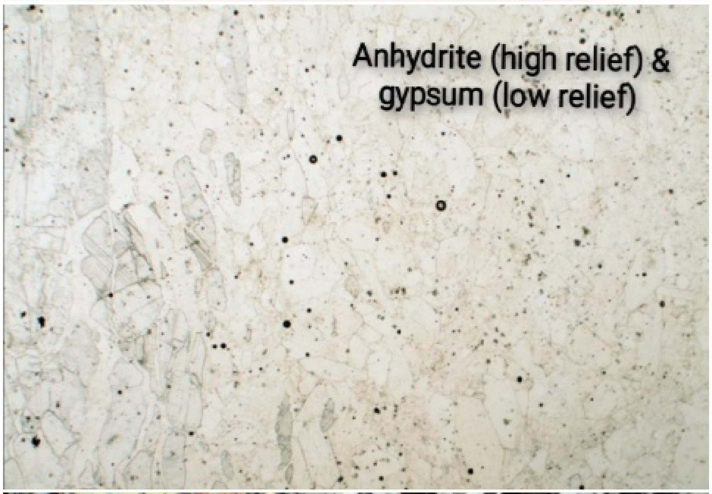

Anhydrite laths
(Groundmass)
Halite

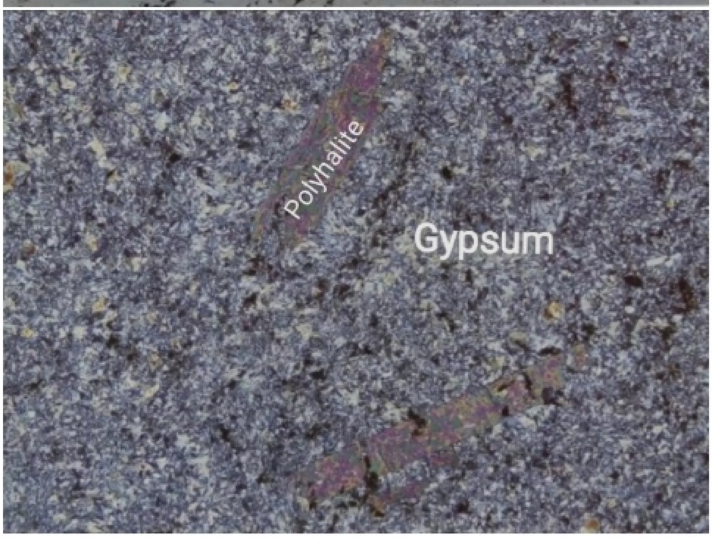

Polyhalite & Halite


Anhydrite laths
Halite
(isotropic)


Polyhalite


Polyhalite
Gypsum

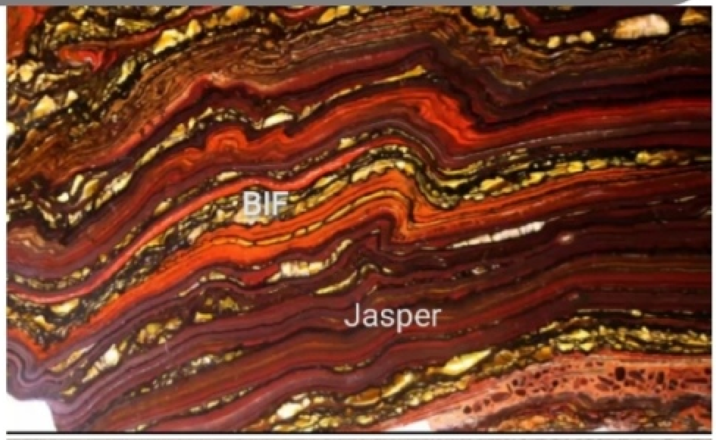

Anhydrite (high relief) &
gypsum (low relief)

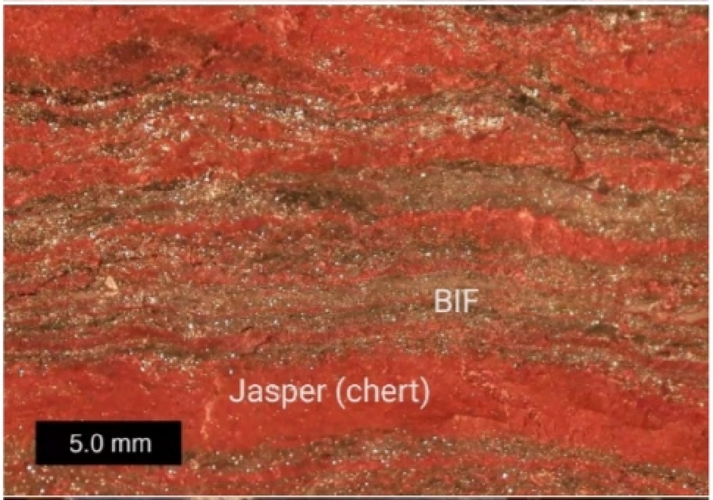

Polyhalite
Gypsum

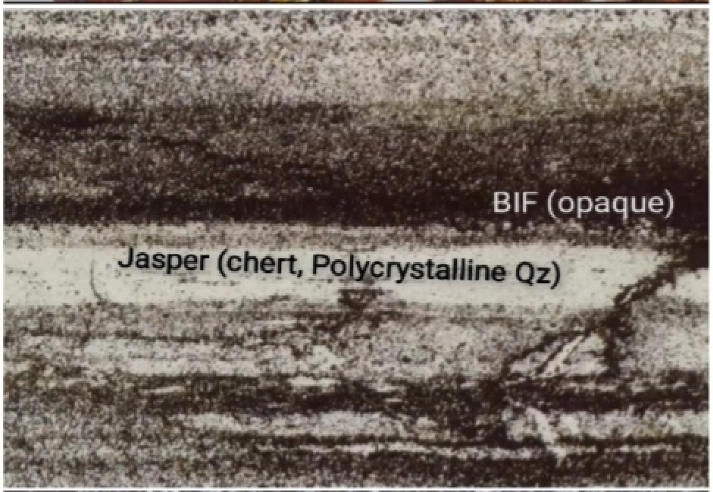

Anhydrite (high IC)
gypsum (1st order gray)

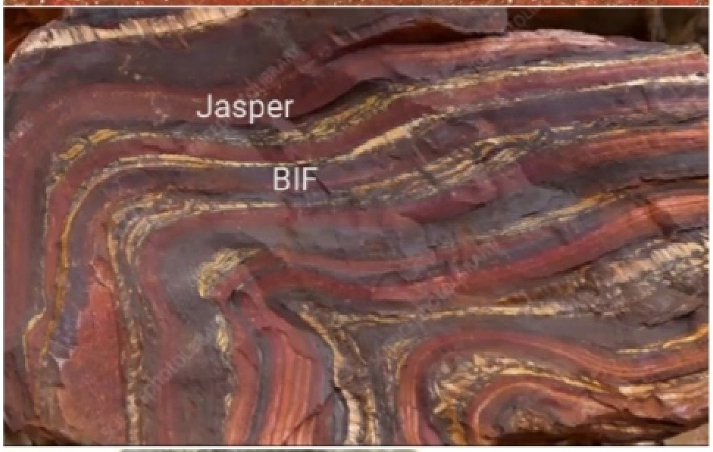
Ironstones

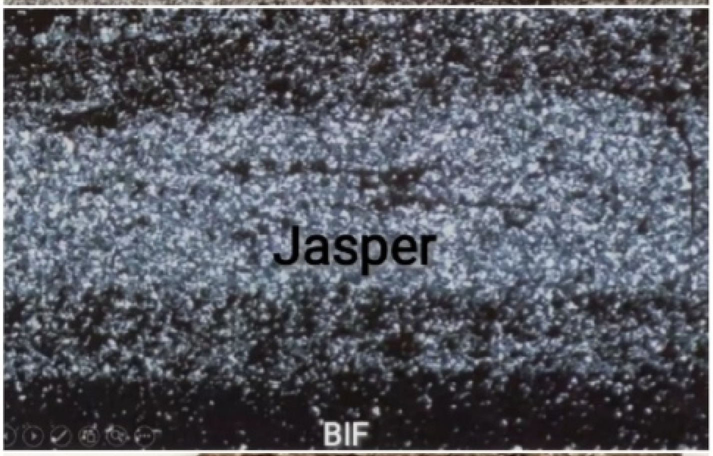

Bounded iron formation (gray)
Jasper (red)

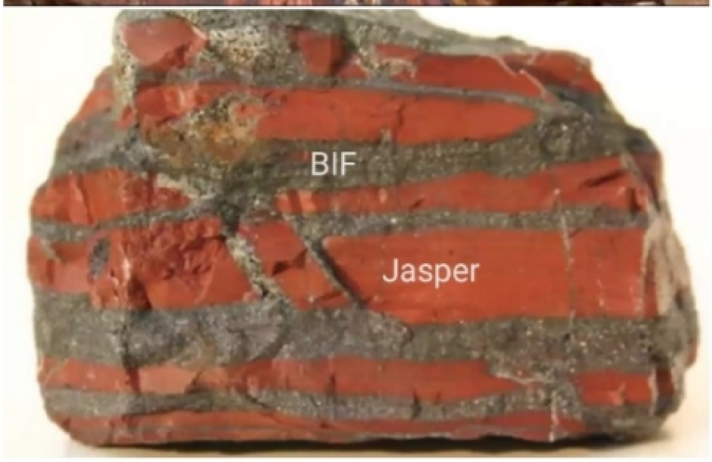

BIF
Jasper


BIF
Jasper (chert)
5.0 mm

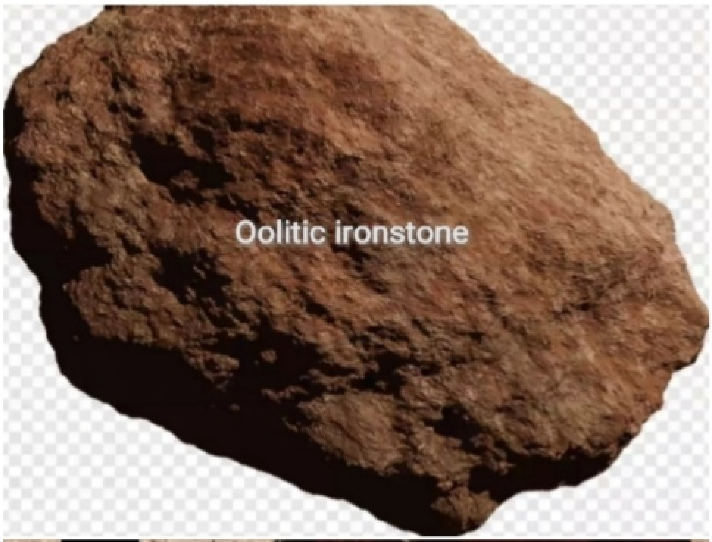

BIF (opaque)
Jasper (chert, Polycrystalline Qz)

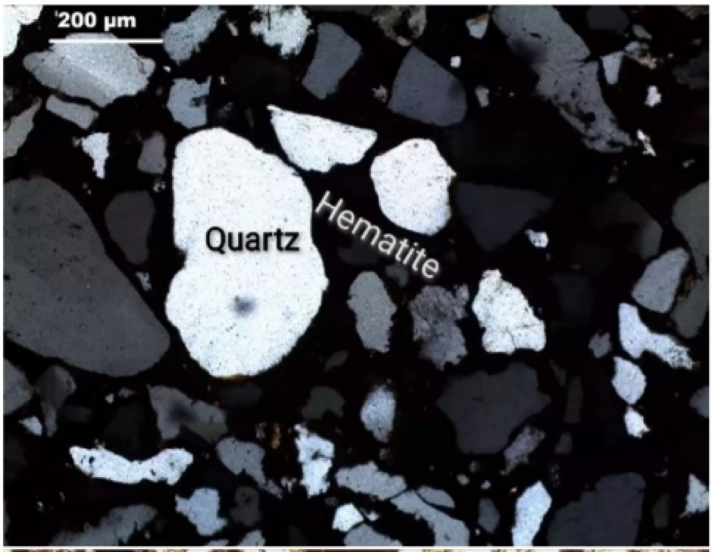

Jasper
BIF

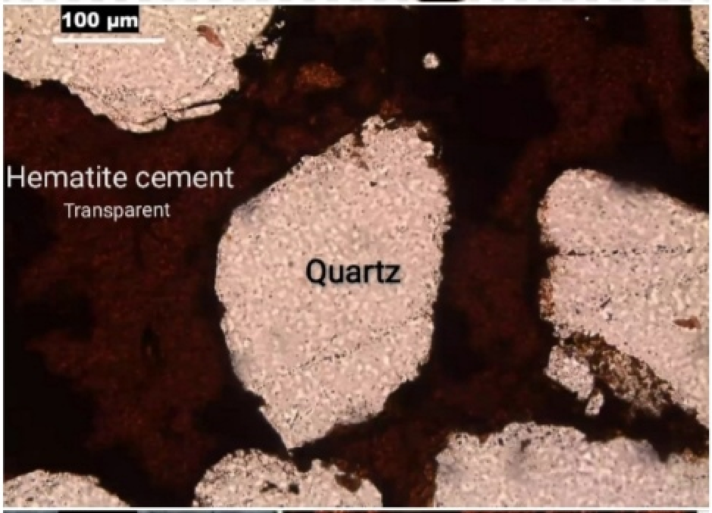

Jasper
BIF

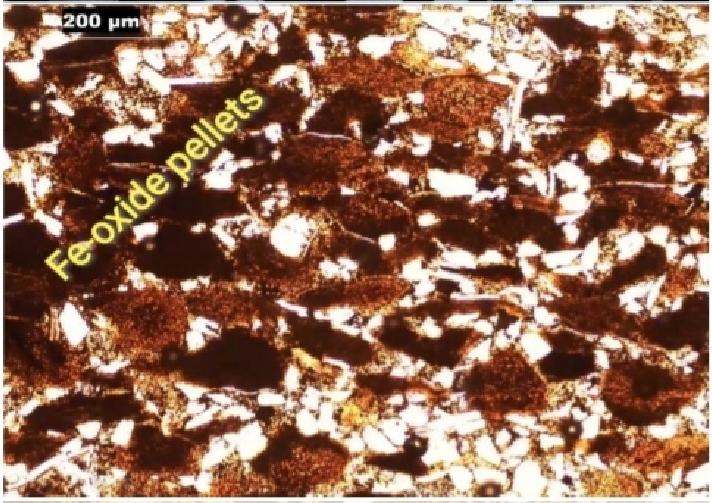

BIF
Jasper

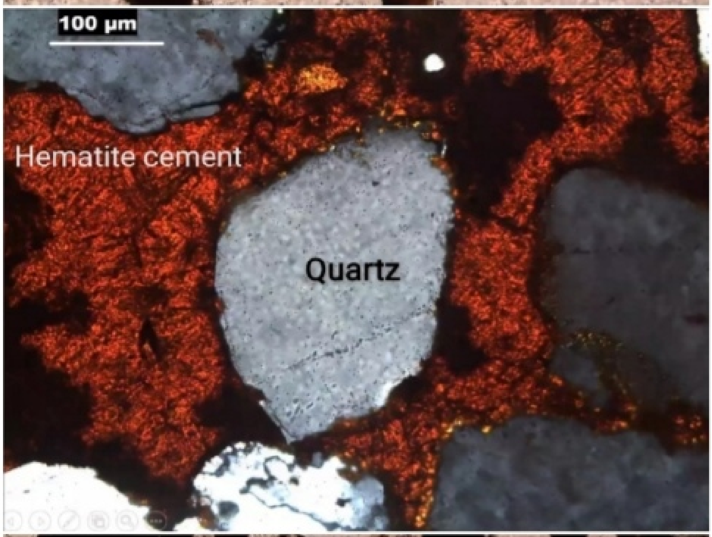

Oolitic ironstone


Oolitic ironstone

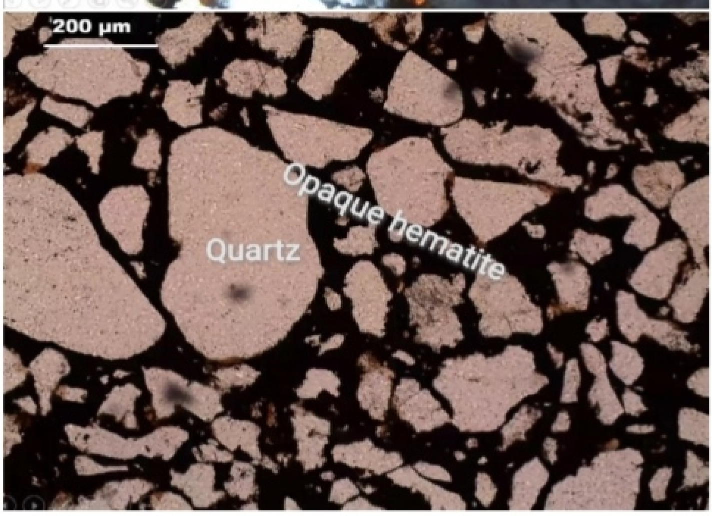

200 µm
Quartz
Hematite

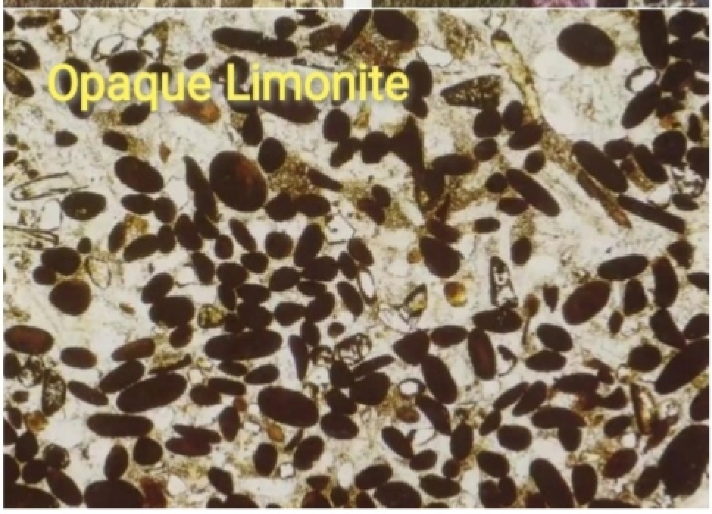

100 µm
Hematite cement
Transparent
Quartz

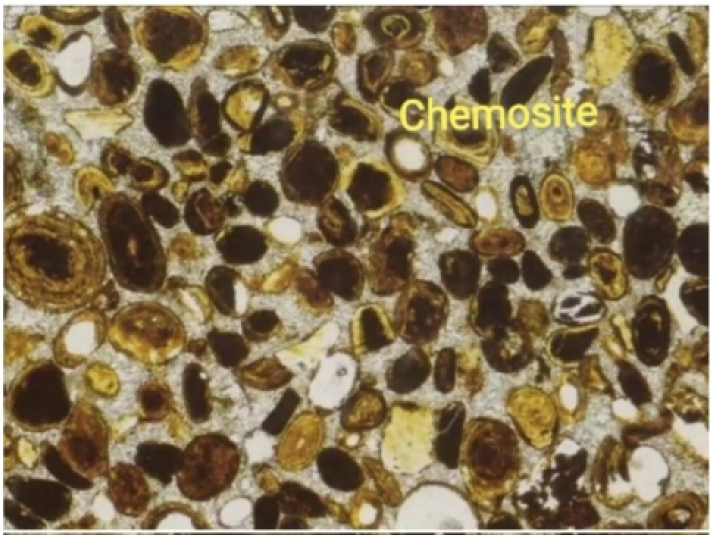

200 µm
Fe-oxide pellets

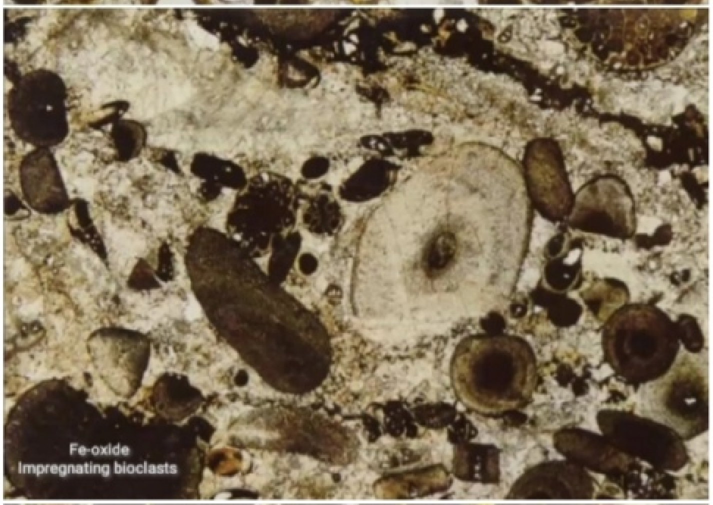

100 µm
Hematite cement
Quartz

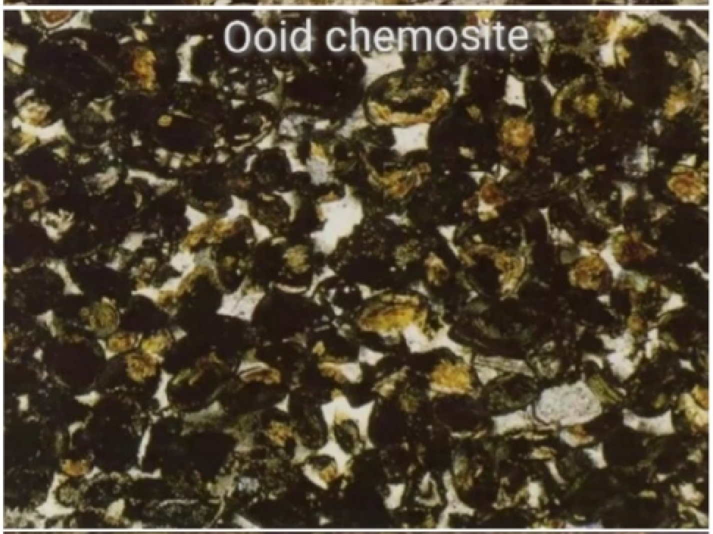

Hematitic Fe-oxide
impregnating bioclasts
Hematitic Fe-oxide
impregnating bioclasts


200 µm
Quartz
Opaque hematite

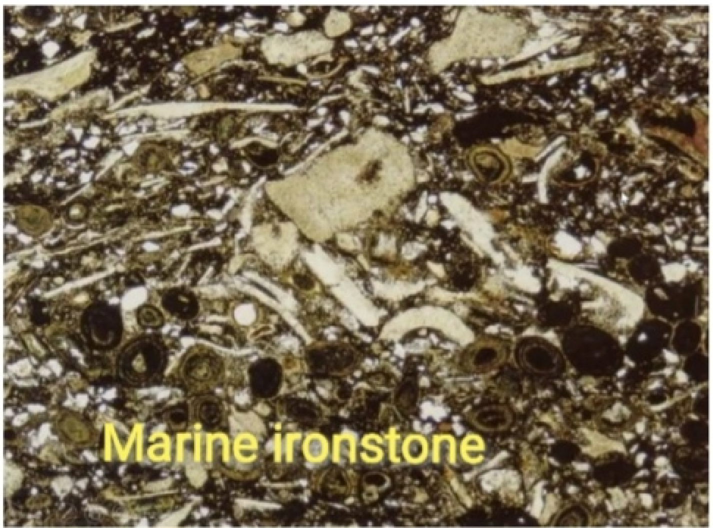

Opaque Limonite

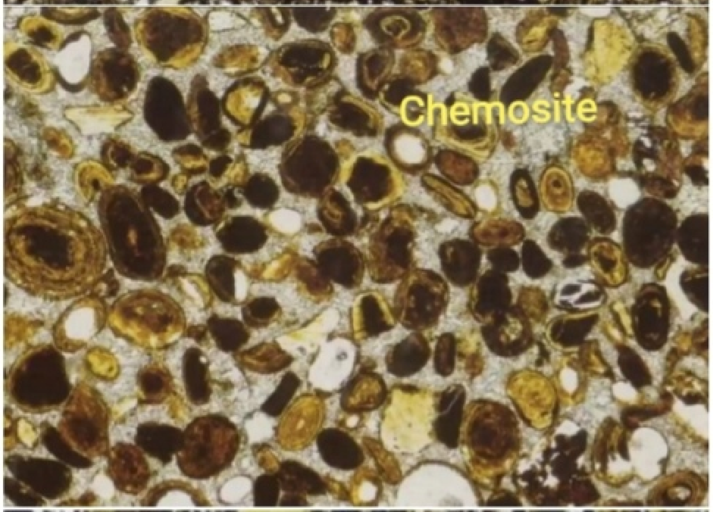

Chemosite


Fe-oxide
Impregnating bioclasts


Ooid chemosite

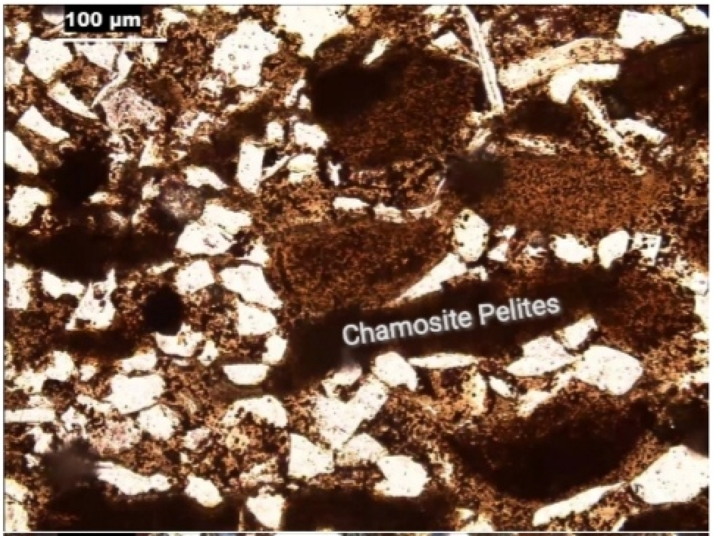

Soft squashed chemosite

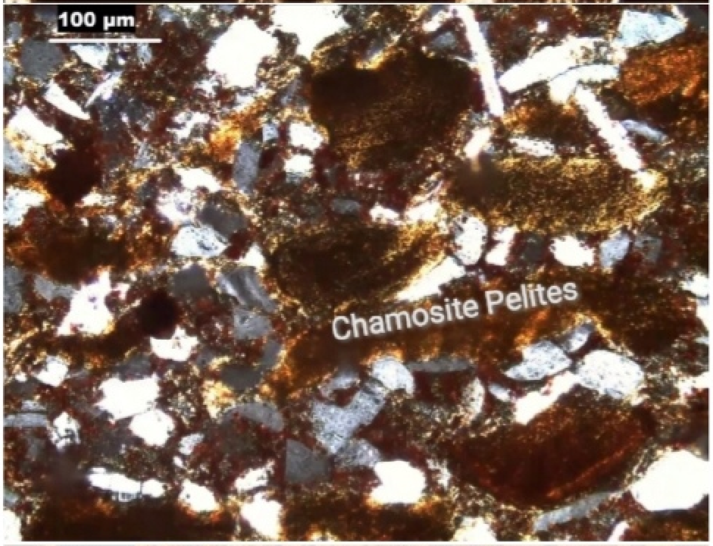

Marine ironstone


Chemosite


Ironstone Glauconite

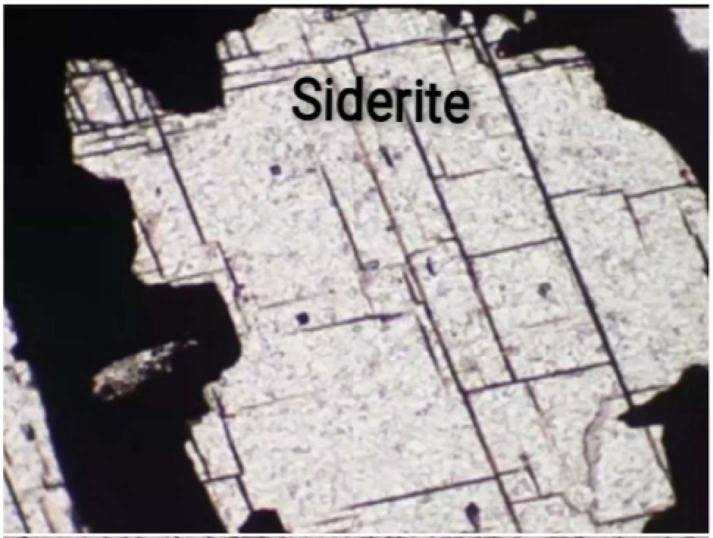

Chamosite - berthierine

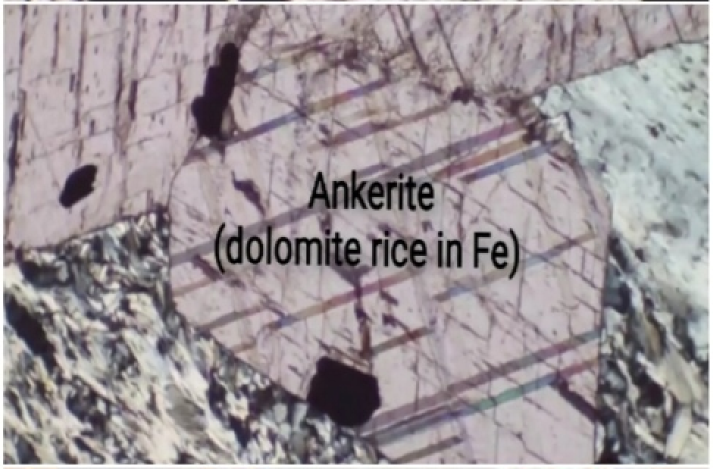

100 µm
Chamosite Pelites

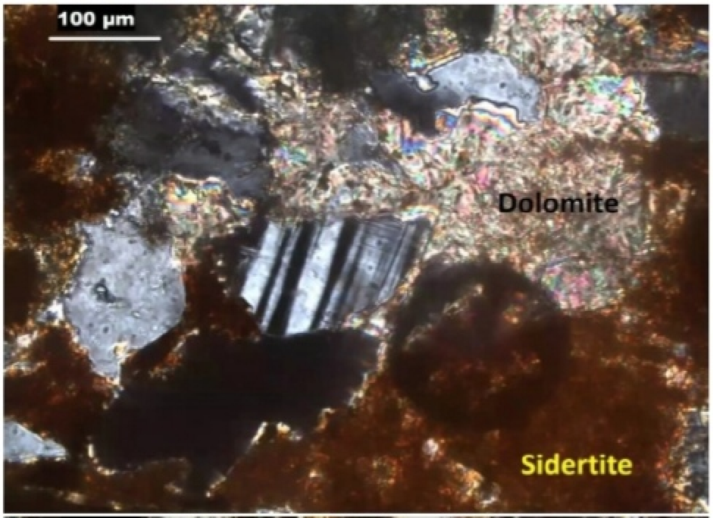

100 µm
Chamosite Pelites


100 µm
Oval flattened
hematite-chamosite ooide


50 µm
Oval flattened
hematite-chamosite ooids

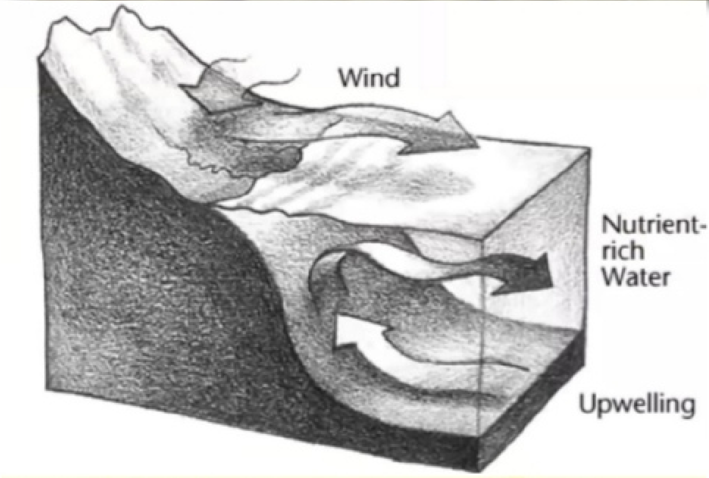

Siderite

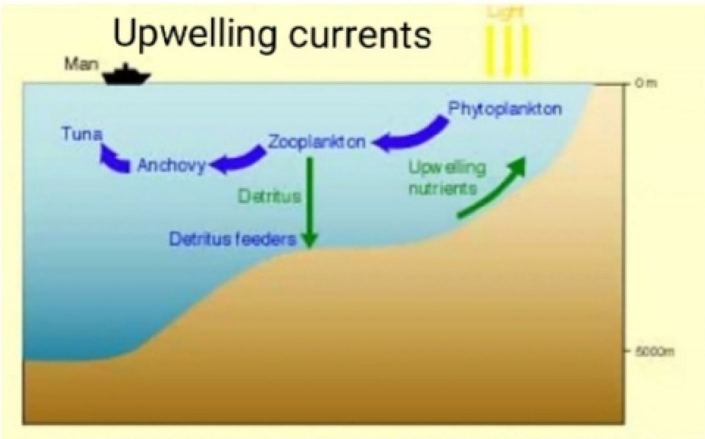

Ankerite
(dolomite rice in Fe)

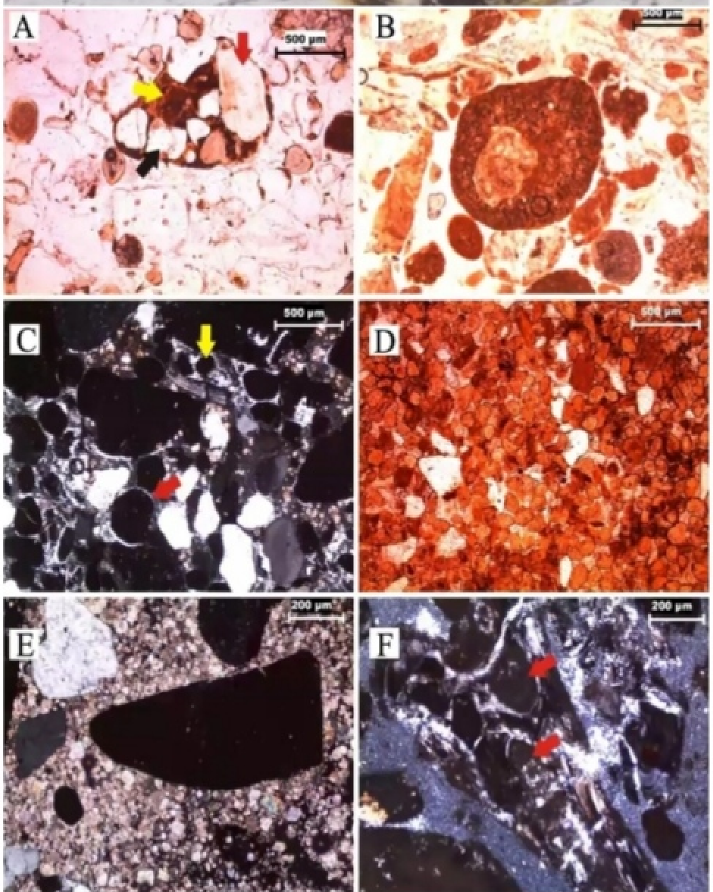

100 µm
Dolomite
Sidertite


100 µm
Siderite (translucent)
Hematite (opaque)

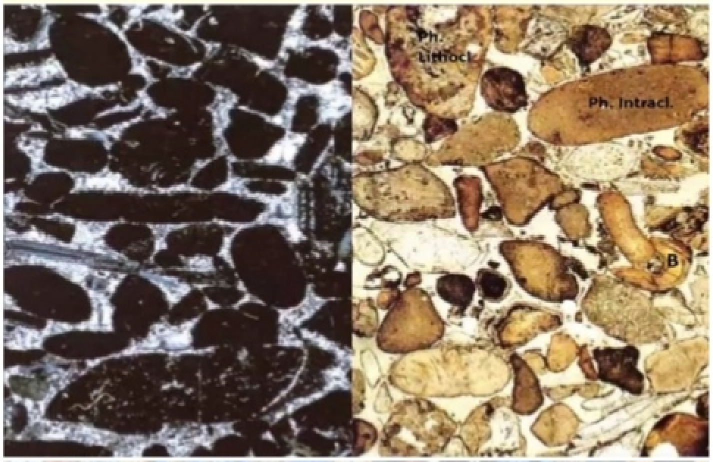
Phosphates

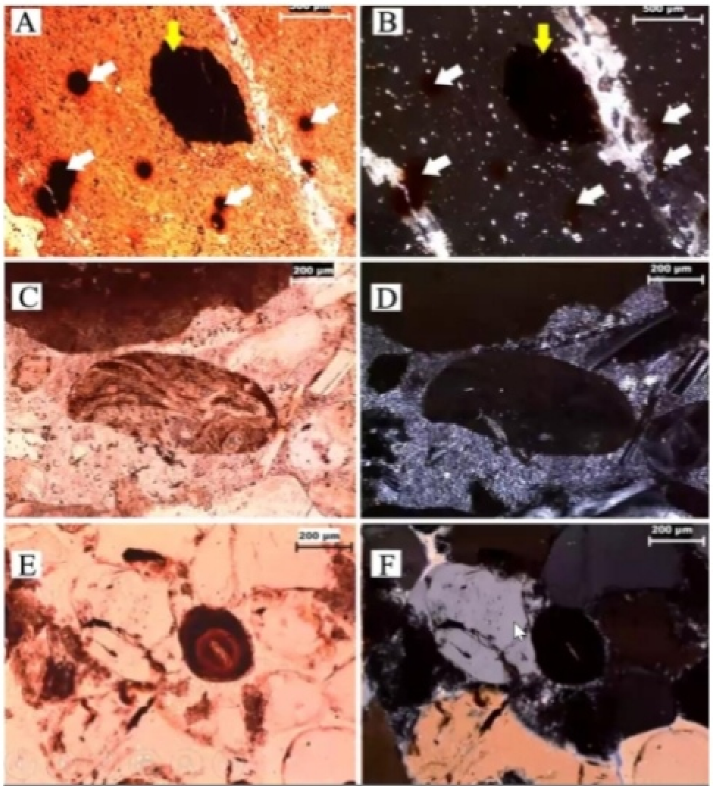




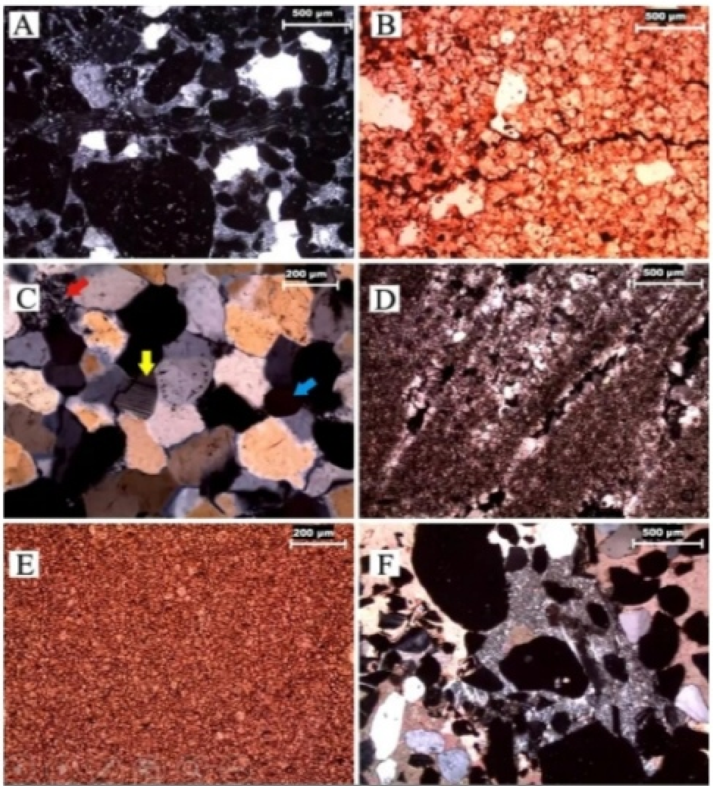


(A) phosphatic lithoclast with angular Qz (black arrow), small piece of bone (red) & phosphatic clast (yellow)
(B) 2 generations phosphatized intraclast, entire clast derived from preexisting phosphatized hardground, during transporting & reworking processes it is enveloped by younger phosphatic material
(C) bimodality in size of Phosphatic peloids; the smaller particles might be faecal in origin (coprolite)
(D) small & similar size Peloids are phosphatized pellet
(E) large isotropic tooth (1mm in diameter)
(F) phosphatic materials which filled the internal tissues of large bone fragments

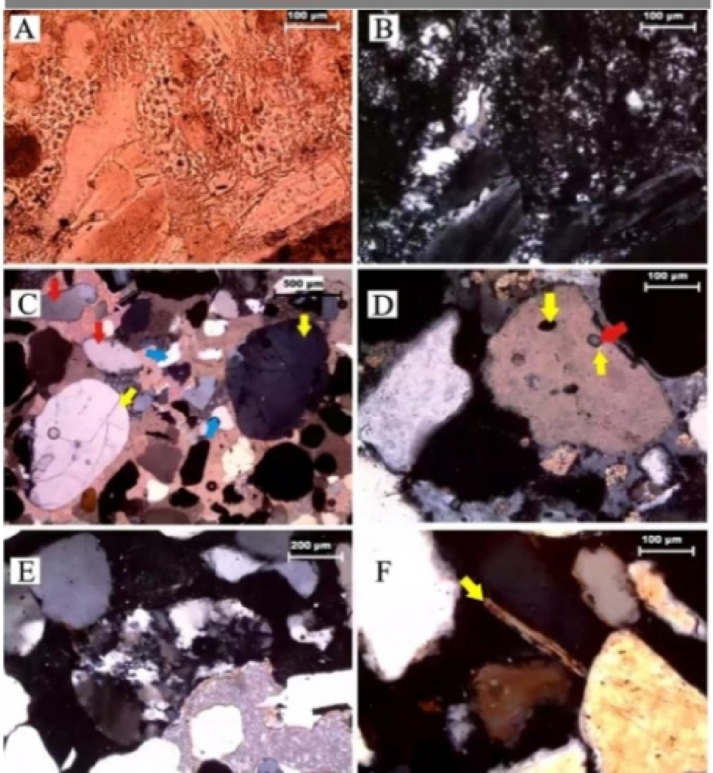




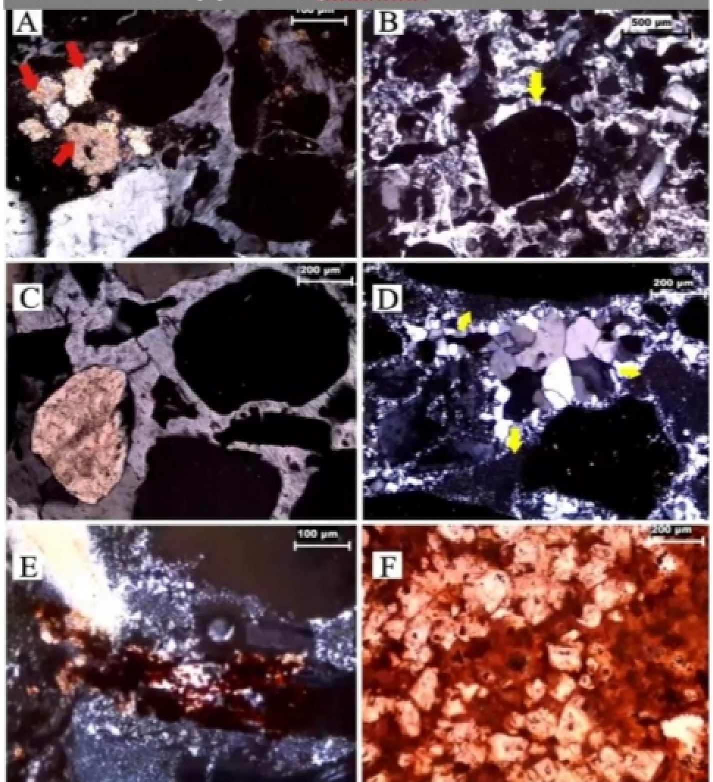
(A) phosphatized micrite consists of irregular patches of organic matter (yellow arrow) & patches of Fe-oxide
(B) phosphatized micrite
(C) phosphatized shell
(D) phosphatized shell floating in cryptocrystalline Oz
(E) Phosphatized oolite
(F) Phosphatized oolites surrounded by silica cement



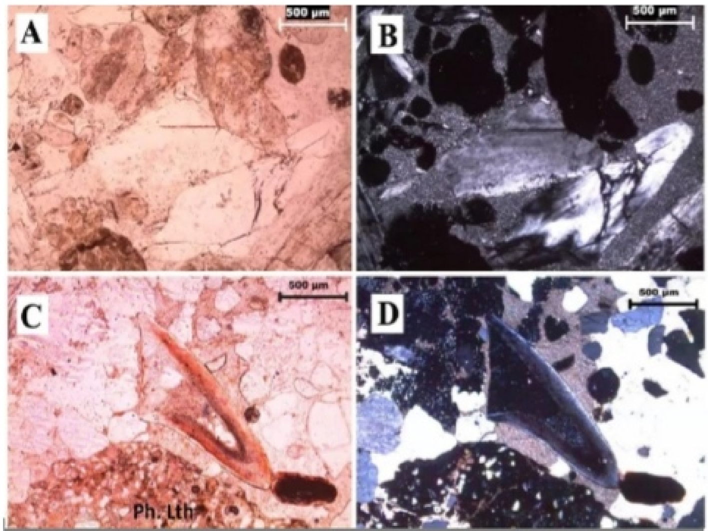
(A) due to compaction bending bone around more rigid quartz grains & phosphate clasts is seen
(B) µ-stylolite structure (Fe-oxide solutions pathways)
(C) Oz syntaxial overgrowth, rutile, & Feldspar grain
(D) mulloscs shells in micritic ground
(E) Mosaicing dolomite
(F) calcite poikilitic cement



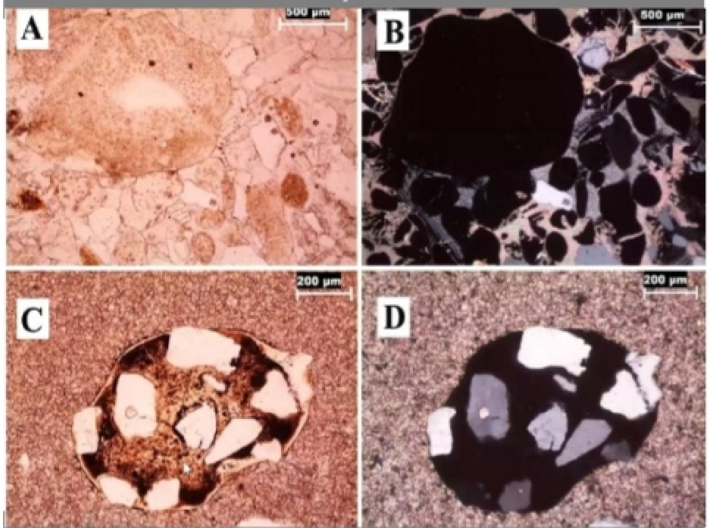
(A + B) phosphatized algae
(C) monocrystalline Oz cemented by calcite
(D) The abraded Oz includes heavy minerals (yellow arrows) & fluid inclusions (red arrow)
(E) Polycrystalline Oz with sutured boundaries
(F) Micaceous flake embedded in monocrystalline Oz



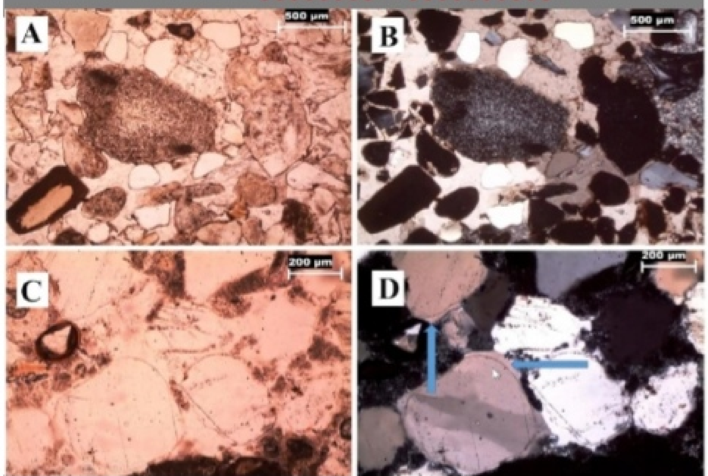
(A) gypsum replaced dolomite
(B) isopachous gypsum cement phosphatic clast
(C) poikilitic texture of gypsum cement
(D)Yellow arrows assign micrite patches
(E) Iron oxides replaced piece of bone partially
(F) Organic matter replaced dolomite



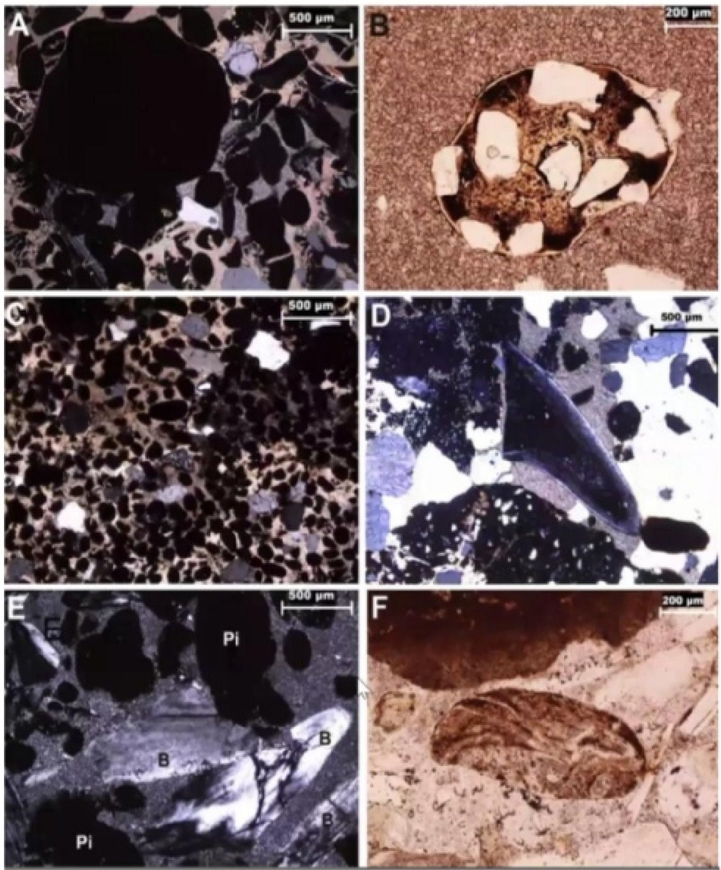
(A, B) Phosphatic bones (semi-isotropic), 2 phosphatic lithoclast (isotropic) characterized by irregular shape, & smaller phosphatic litho/intraclasts
(C, D): tooth (semi- isotropic), phosphatic lithoclasts consisting of silt-sized quartz grains set in phosphatic muddy matrix



(A, B) Phosphate- Intracalsts & bone fragments cemented by saprry calcite
(C, D) Phosphate- lithoclast in microsparry dolomite

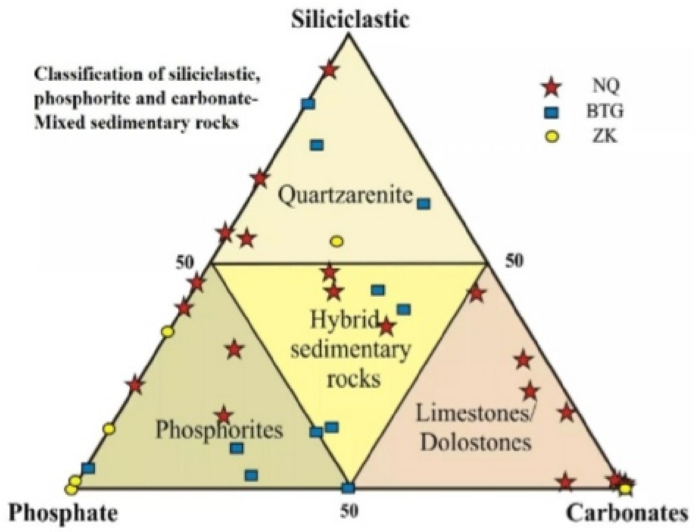


(A, B) 2 large lithoclasts that are angular to subangular (silicified, & phosphatic) with smaller phosphatic intraclasts & detrital quartz grains
(C, D) Detrital monocrystalline quartz grains exhibiting syntaxial quartz overgrowth



(A) P-intraclasts: structureless, shapeless, badly sorted
(B) Phosphate intraclast including angular Qz grains.
(C) Phosphate peloids in calcite poikilotopic cement
(D) Large isotropic (1st grey) tooth, 1mm in diameter
(E) Bone fragments (B) & phosphate intraclasts (Pi). The bones show 1st order grey

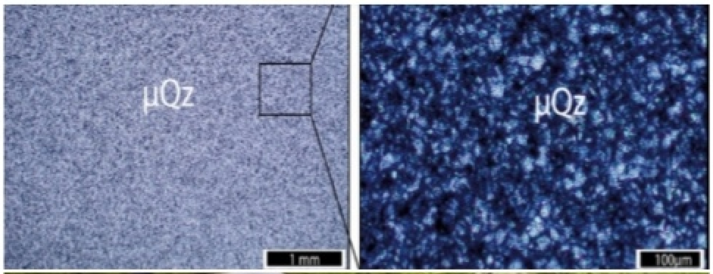
Jordan phosphates



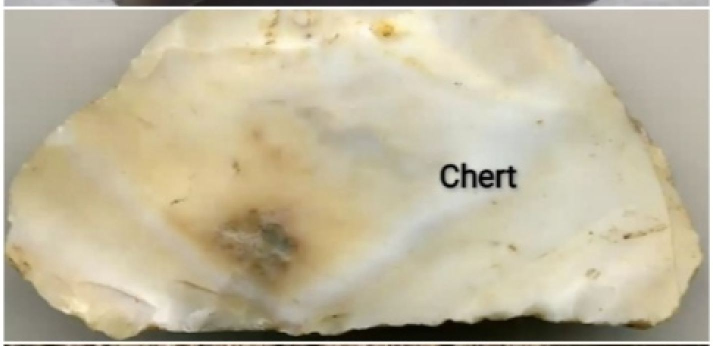
No.	Silic.	Phos.	Car.	Rock name
NQ9	39.4	60.1	0.50	Arenaceous phosphate grainstone
NQ10	22.6	77.4	0.00	Siliceous phosphate grainstone
NQ16	44.7	55.3	0.00	Arenaceous phosphate packstone
NQ18	30.0	55.3	14.7	Dolomitic Siliceous P-Packstone
NQ19	15.3	64.9	19.8	Arenaceous Dolomitic P-Packstone
BTG11	11.8	48.2	36.1	Arenaceous calcareous Phosphate Packstone
BTG12	13.4	46.4	40.2	
BTG15	8.90	66.0	25.2	
BTG16	4.30	95.7	0.00	Phosphate packstone
BTG18				Siliceous calcareous

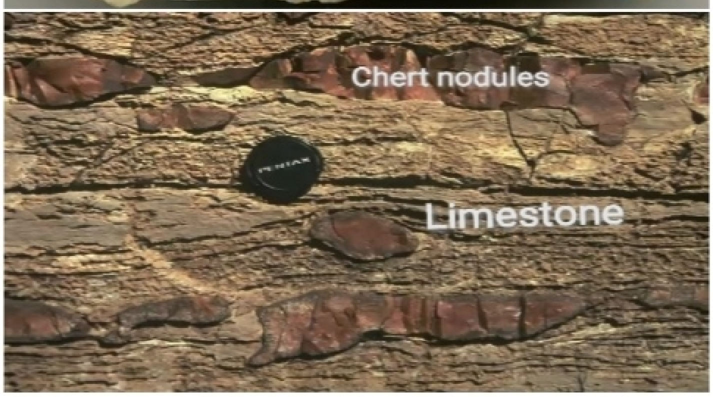
Chert

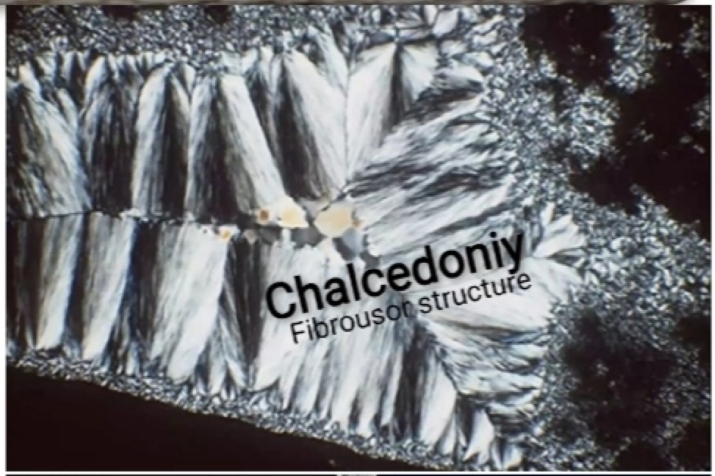

Massive chert

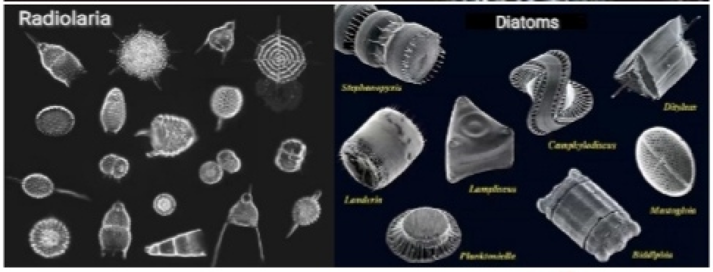

μQz
μQz
1 mm
100μm


Flint
Conchoidal fructure
Dark color due to organic origin


Chert


Chert nodules
Limestone


Chalcedoniy
Fibrousor structure

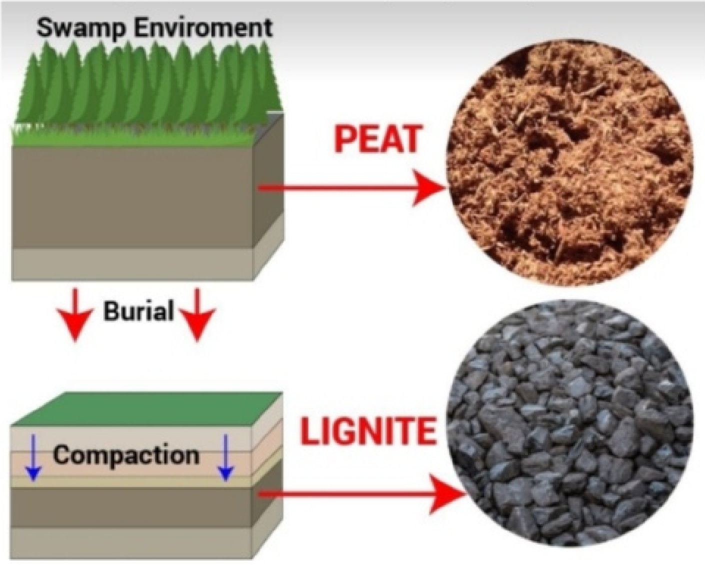

Radiolaria
Diatoms


Jasper
Red color is due to presence of Fe-oxides

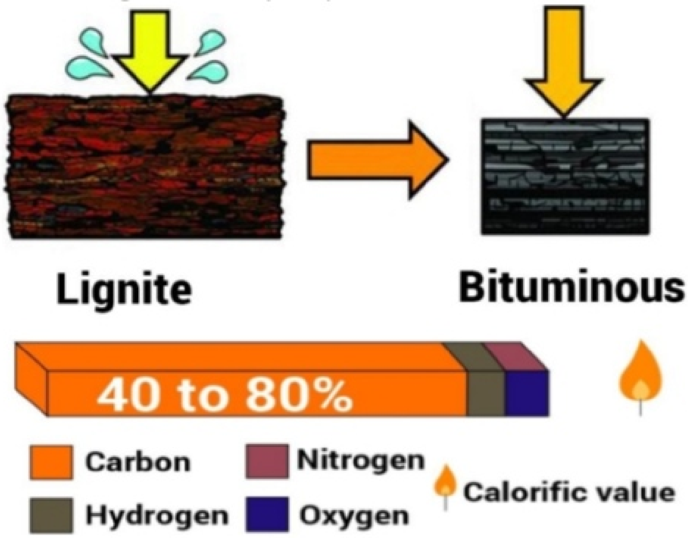

Agate

Coal

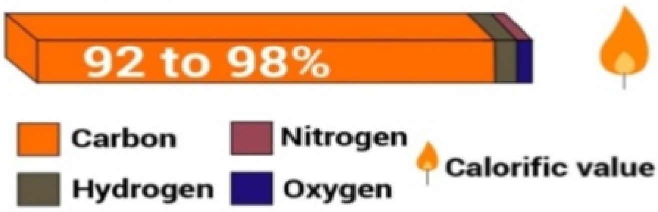
- **Formationof coals involved 4 stages:** peat, Lignite, bituminous, & Finally Anthracite
- **Peat & lignite are poor in quality (less heat capacity) due to lesser amount of carbon in them**
  - ➢ Lignite has more heat capacity than peat



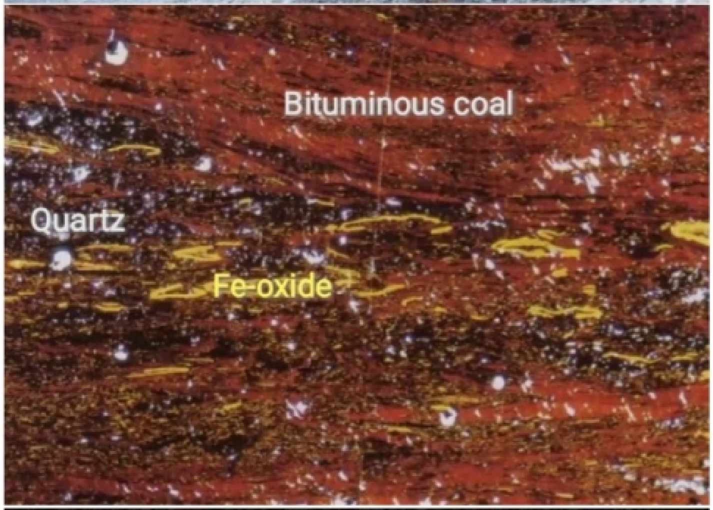
- Lignite transfer into bituminous in the 3rd stage
  - ➢ Bituminous: soft & black
  - ➢ Higher heat capacity than other coals



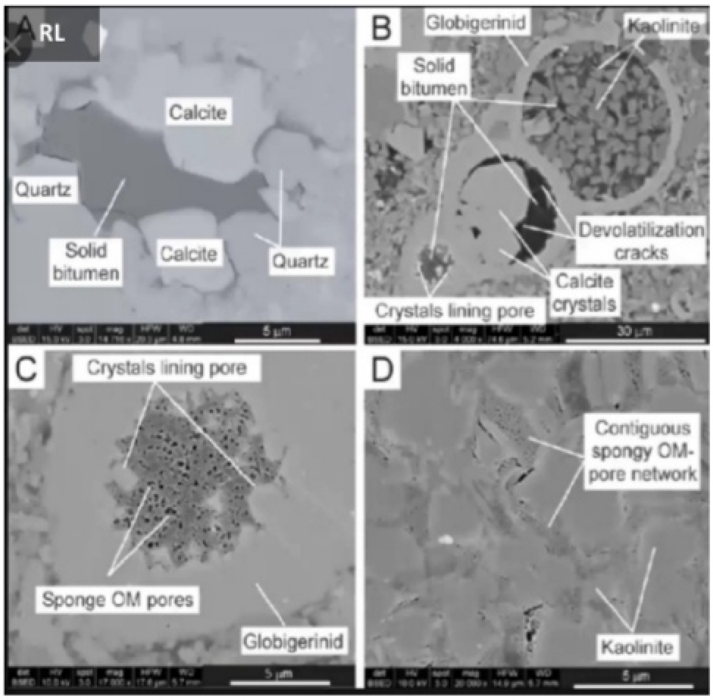
- At the last stage of coals formation we get Anthracite
  - ➢ Anthracite is a metamorphic coal has shiny luster & very hard, due to it's strongest chemical bonds cannot used as fuel

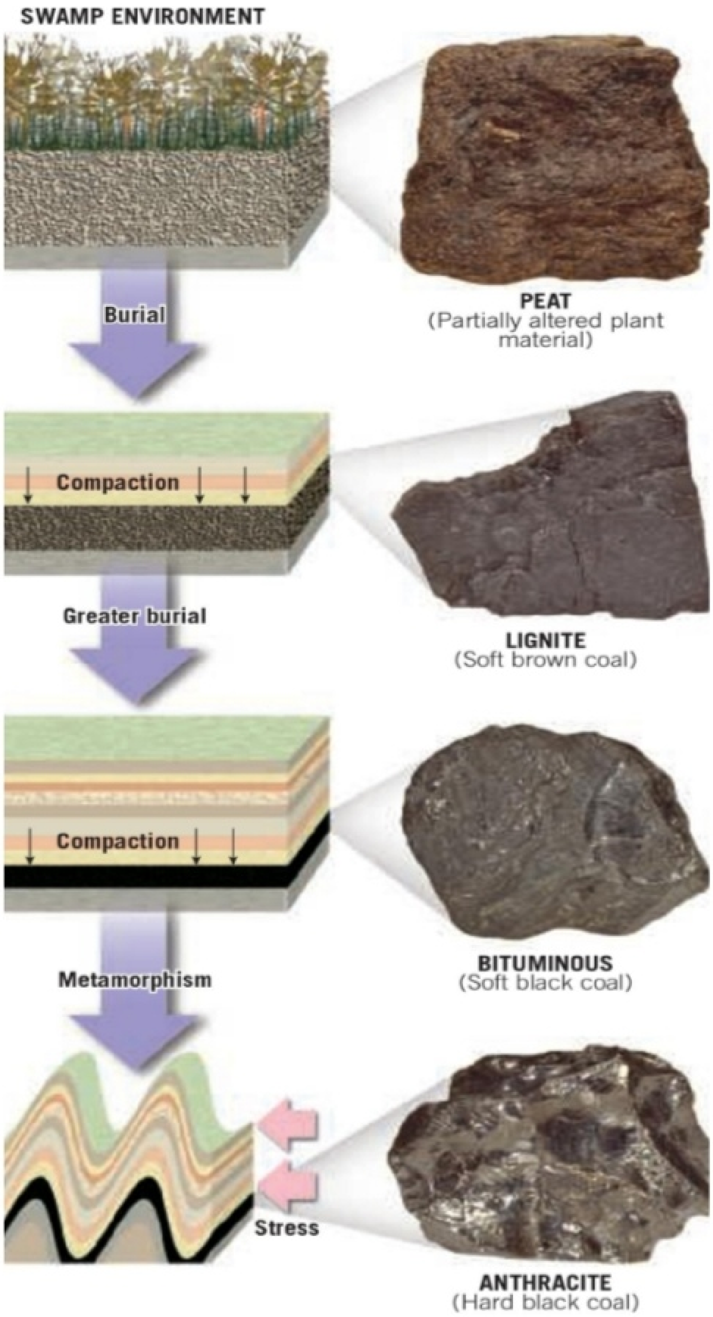



Bituminous bed
Sandstone bed


Bituminous coal
Quartz
Fe-oxide


Anthracite


A
RL
Calcite
Quartz
Solid bitumen
Calcite
Quartz
B
Globigerinid
Kaolinite
Solid bitumen
Devolatilization cracks
Calcite crystals
Crystals lining pore
C
Crystals lining pore
Sponge OM pores
Globigerinid
D
Contiguous spongy OM-pore network
Kaolinite


SWAMP ENVIRONMENT
Burial
PEAT
(Partially altered plant material)
Compaction
Greater burial
LIGNITE
(Soft brown coal)
Compaction
Metamorphism
BITUMINOUS
(Soft black coal)
Stress
ANTHRACITE
(Hard black coal)