# PALEOENVIRONMENTAL INTERPRETATION OF EVAPORITIC FACIES

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# Outline

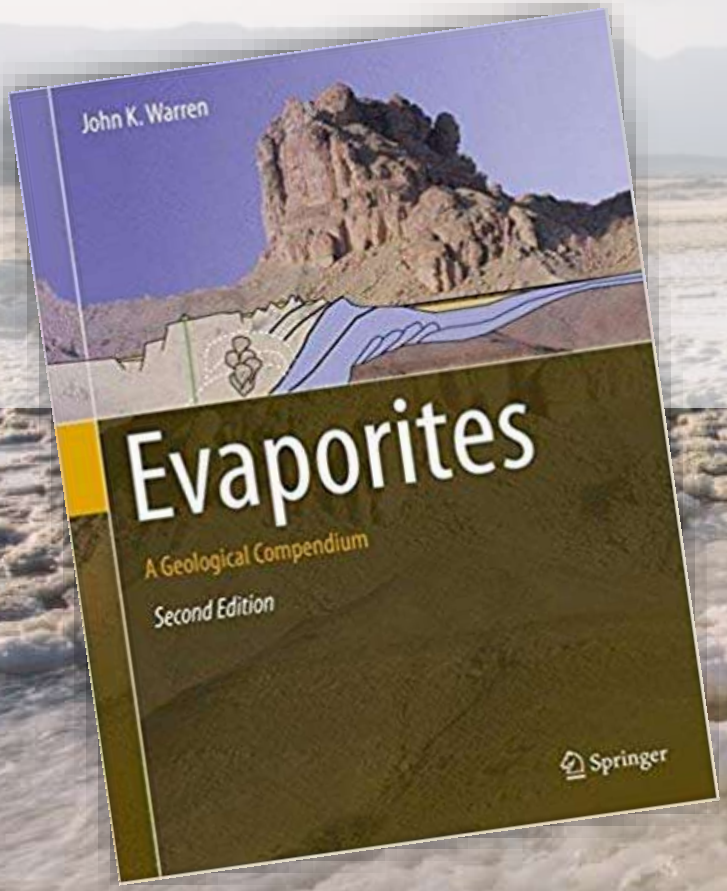
1. Definition of evaporites

2. Evaporitic minerals and brine chemistry

3. Modern evaporites

4. Ancient evaporites (gypsum) and associated sediments (shales)
   *Facies and depositional environment*

# Evaporites: a definition



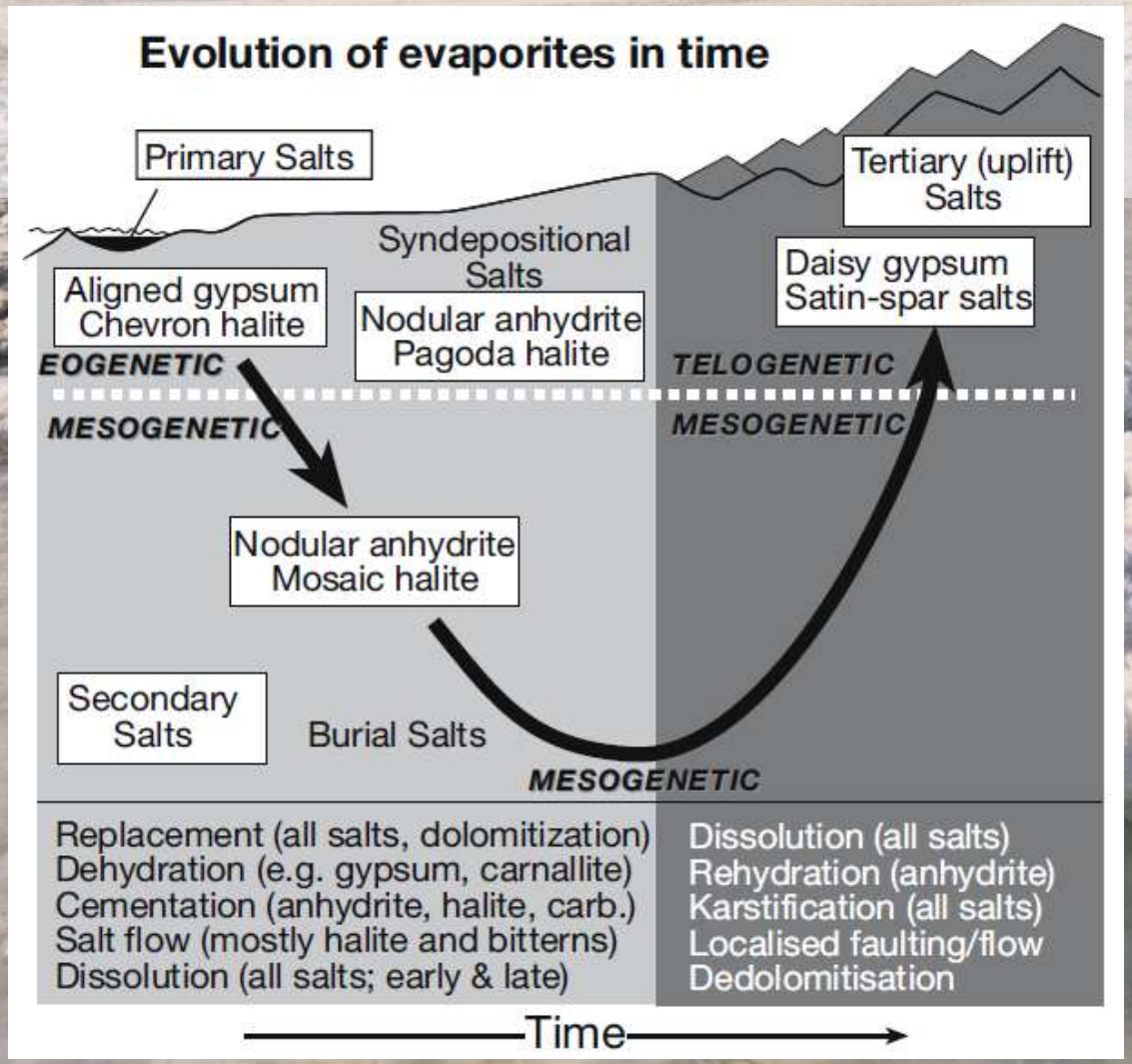

*A salt rock that was originally precipitated from a saturated surface or nearsurface brine concentrated by solar evaporation." (Warren, 2006)*

*Salt deposits: salt rocks formed by other processes than evaporation*

# Evaporites: a definition

***Primary evaporites***: Texture and lithology are a direct evidence of the hydrology of the basin at time of precipitation/accumulation.

***Secondary evaporites***: during burial and exhumation.



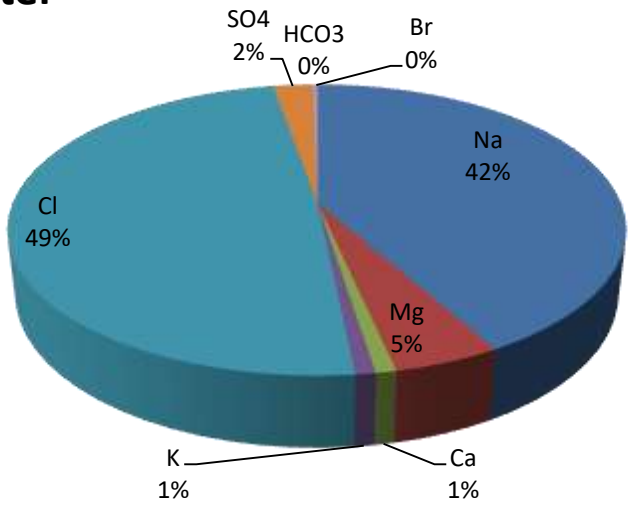
# Brine chemistry and evaporitic minerals

The mineralogy of evaporites strongly depends from the type and the chemistry of their mother brines (seawater, continenta, hydrothermal, or a mixture of them)

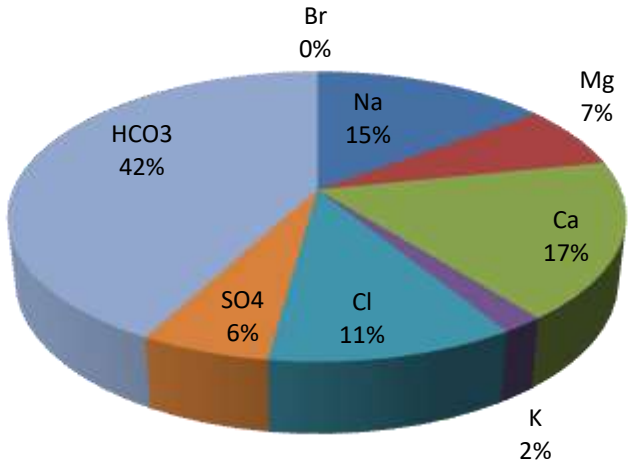
**Modified from Warren, 2006**

| Locality | Salinity (‰) | Na | Mg | Ca | K | Cl | $SO_4$ | $HCO_3$ | Br |
|---|---|---|---|---|---|---|---|---|---|
| Seawater (average) | 35 | 468 | 53 | 10 | 10 | 546 | 28 | 2 | 1 |
| River water (average) | 0.11 | 0.31 | 0.15 | 0.37 | 0.04 | 0.23 | 0.12 | 0.89 | - |

## Seawater




## River




**Marine**

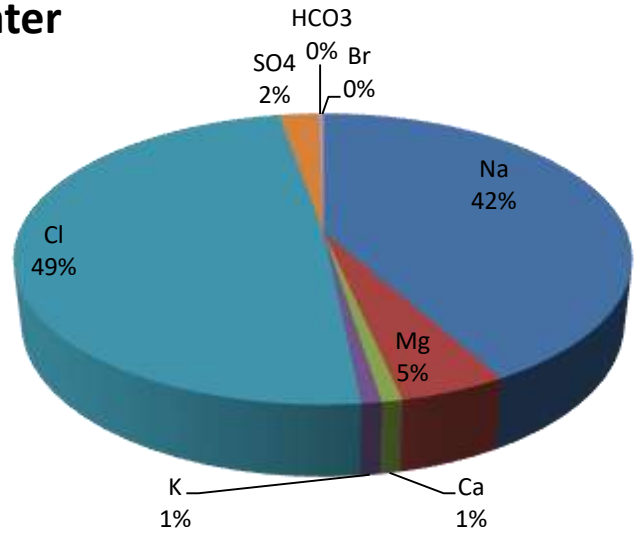
**Continental**

Types of evaporites

# Main evaporitic minerals

1) Evaporitic alkaline carbonates (aragonite, dolomite, low-Mg calcite, and high-Mg calcite)
2) Evaporite salts (gypsum, anhydrite, halite, sylvite, kainite, carnallite)

**Seawater**

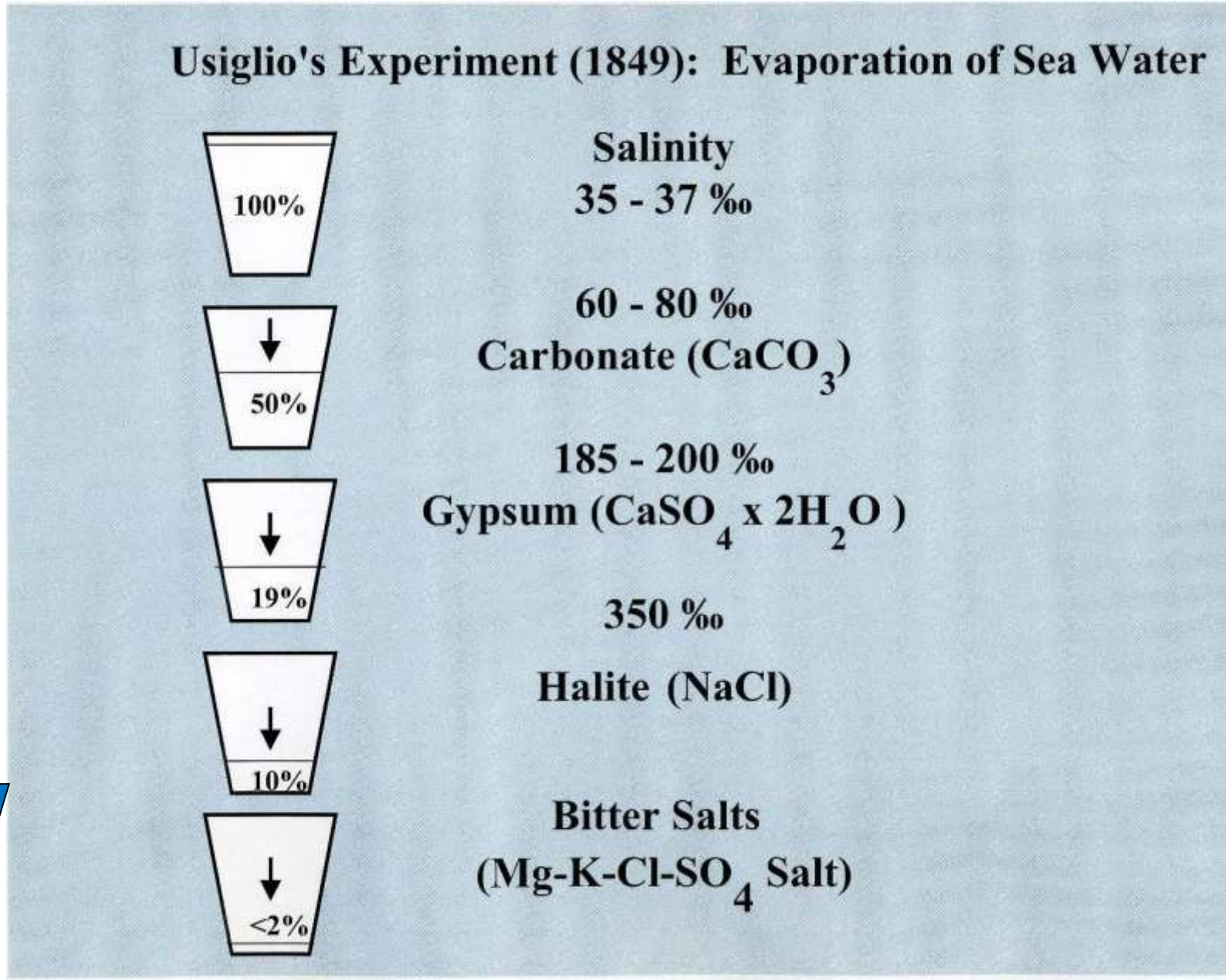



**Marine**

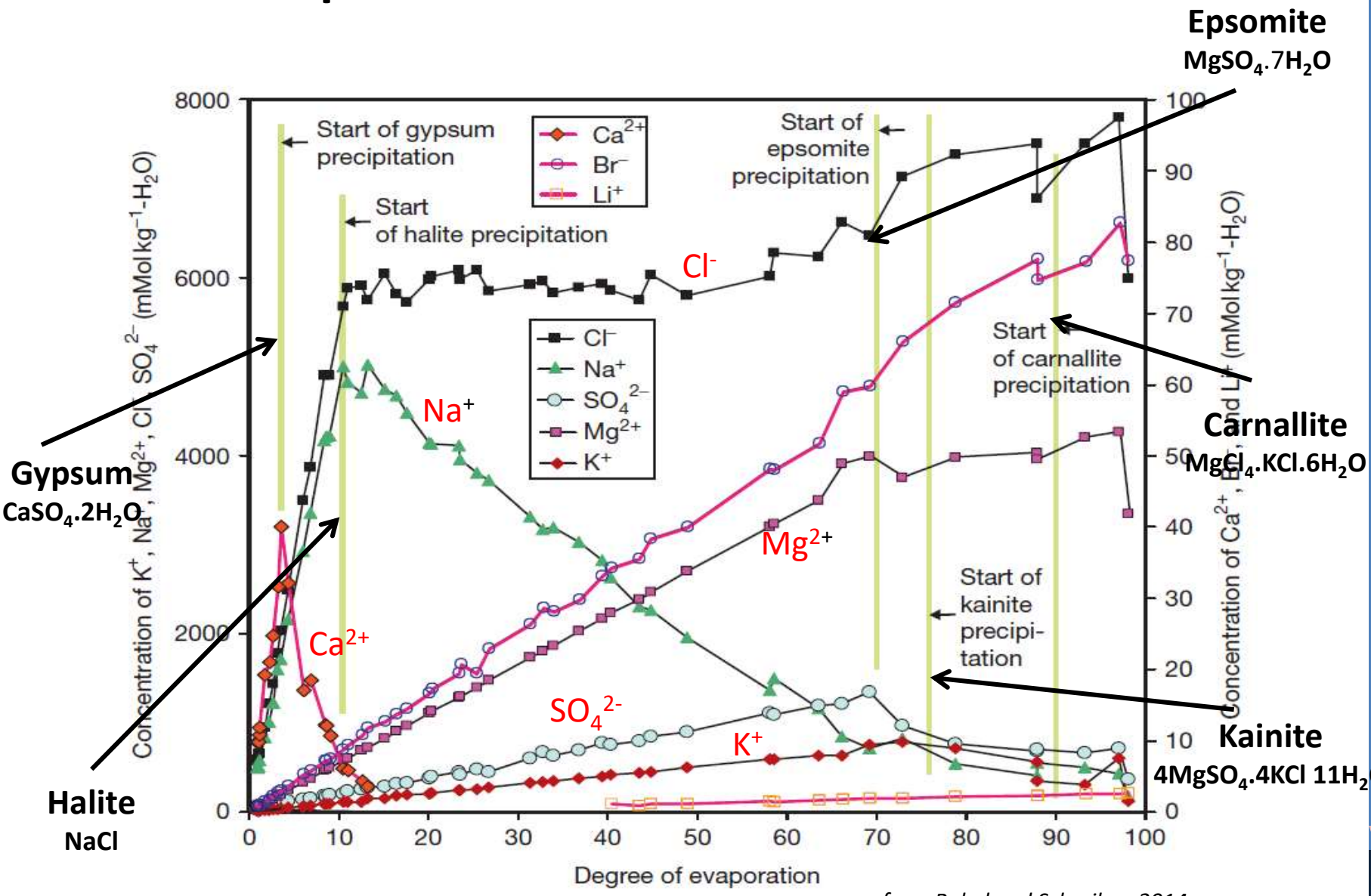
| Mineral | Formula | Mineral | Formula |
|---|---|---|---|
| Anhydrite | $CaSO_4$ | Leonhardtite | $MgSO_4.4H_2O$ |
| Antarcticite | $CaCl_2.6H_2O$ | Leonite | $MgSO_4.K_2SO_4.4H_2O$ |
| Aphthitalite (glaserite) | $K_2SO_4.(Na,K)SO_4$ | Loewite | $2MgSO_4.2Na_2SO4.5H_2O$ |
| ★ Aragonite ** | $CaCO_3$ | ★ Mg-calcite ** | $(Mg,Ca)CO_3$ |
| Bassanite | $CaSO_4.1/2H_2O$ | Magnesite** | $MgCO_3$ |
| Bischofite | $MgCl_2.6H_2O$ | Meyerhoffite | $Ca_2B_6O_{11}.7H_2O$ |
| Bloedite (astrakanite) | $Na_2SO_4.MgSO_4.4H_2O$ | Mirabilite | $Na_2SO_4.10H_2O$ |
| Borax (tincal) | $Na_2B_4O_7.10H_2O$ | Nahcolite | $NaHCO_3$ |
| Boracite | $Mg_3B_7O_{13}.Cl$ | Natron | $Na_2CO_3.10H_2O$ |
| Burkeite | $Na_2CO_3.2Na_2SO_4$ | Nitratite (soda nitre) | $NaNO_3$ |
| ★ Calcite** | $CaCO_3$ | Nitre (salt petre) | $KNO_3$ |
| Carnallite | $MgCl_2.KCl.6H_2O$ | Pentahydrite | $MgSO_4.5H_2O$ |
| Colemanite | $Ca_2B_6O_{11}.5H_2O$ | Pirssonite | $CaCO_3.Na_2CO_3.2H_2O$ |
| Darapskite | $NaSO_4.NaNO_3.H_2O$ | Polyhalite | $2CaSO_4.MgSO_4.K_2SO_4.H_2O$ |
| ★ Dolomite** | $Ca_{1-x}Mg_{1-x}(CO_3)_2$ | Proberite | $NaCaB_5O_9.5H_2O$ |
| Epsomite | $MgSO_4.7H_2O$ | Priceite (pandermite) | $CaB_4O_7.7H_2O$ |
| Ferronatrite | $3NaSO_4.Fe_2(SO_4)_3.6H_2O$ | Rinneite | $FeCl_2.NaCl.3KCl$ |
| Gaylussite | $CaCO_3.Na_2CO_3.5H_2O$ | Sanderite | $MgSO_4.2H_2O$ |
| Glauberite | $CaSO_4.Na_2SO_4$ | Schoenite (picromerite) | $MgSO_4.K_2SO_4.6H_2O$ |
| ★ Gypsum | $CaSO_4.2H_2O$ | Shortite | $2CaCO_3.Na_2CO_3$ |
| ★ Halite | $NaCl$ | Sylvite | $KCl$ |
| Hanksite | $9Na_2SO_4.2Na_2CO_3.KCl$ | Syngenite | $CaSO_4.K_2SO_4.H_2O$ |
| Hexahydrite | $MgSO_4.6H_2O$ | Tachyhydrite | $CaCl_2.2MgCl_2.12H_2O$ |
| Howlite | $H_5Ca_2SiB_5O_{14}$ | Thernadite | $Na_2SO_4$ |
| Ikaite** | $CaCO_3.6H_2O$ | Thermonatrite | $NaCO_3.H_2O$ |
| Inyoite | $Ca_2B_6O_{11}.13H_2O$ | Tincalconite | $Na_2B_4O_7.5H_2O$ |
| ★ Kainite | $4MgSO_4.4KCl.11H_2O$ | Trona | $NaHCO_3.Na_2CO_3$ |
| Kernite | $Na_2B_4O_7.4H_2O$ | Tychite | $2MgCO_3.2NaCO_3.Na_2SO_4$ |
| Kieserite | $MgSO_4.H_2O$ | Ulexite | $NaCaB_5O_9.5H_2O$ |
| Langbeinite | $2MgSO_4.K_2SO_4$ | Vanthoffite | $MgSO_4.3Na_2SO_4$ |

Evaporitic minerals

# Marine evaporites



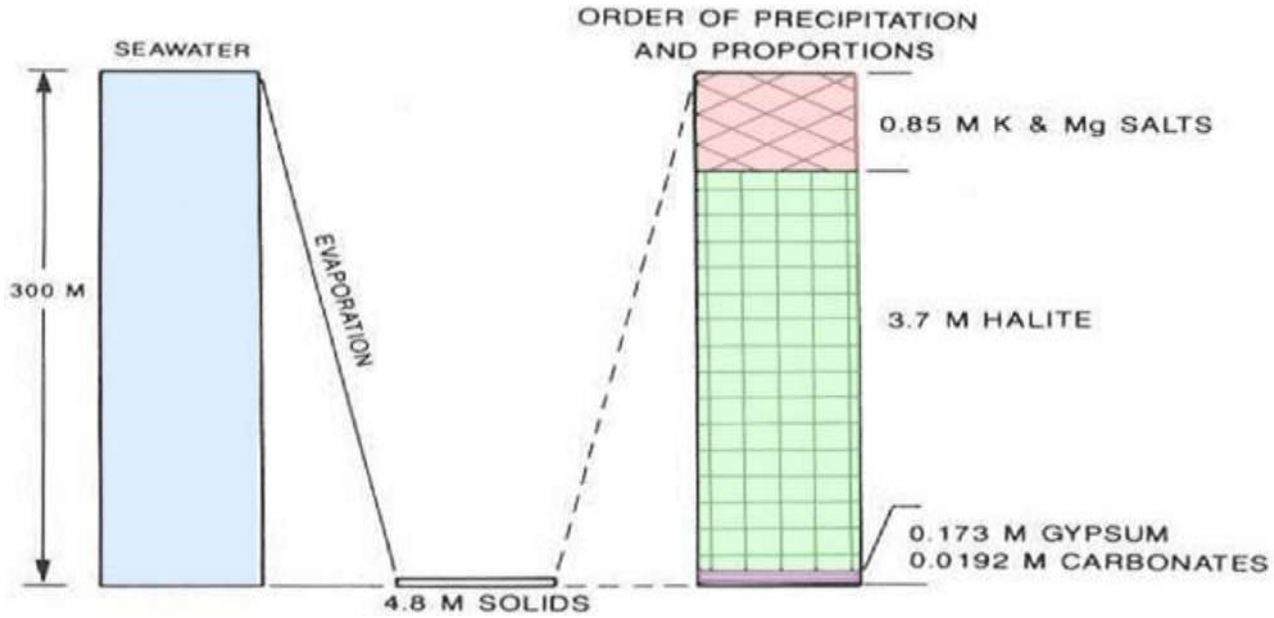
# Marine evaporites




*from Babel and Schreiber, 2014*

Marine evaporites

# Marine evaporites: rate of deposition




| SEDIMENT TYPE | ENVIRONMENT | RATE OF DEPOSITION |
|---|---|---|
| **Sulphates and carbonates** | Sabkha (supratidal) | 1m/1000yrs + progradation 1km/1000yrs |
| **Sulphates** | Shallow subaqueous | **1-40 m/1000 yrs** |
| **Sulphates** | Deep subaqueous | **1-2 m /1000 yrs** |
| **Halite** | Shallow subaqueous | **10-100 m/1000 yrs** |
| **Halite** | Deep subaqueous | **1-10 m /1000 yrs** |
| **Reefal carbonates** | Shallow water | 1-3 m/ 1000 yrs |
| **Non-reefal carbonates** | Shelf | 1-3 cm/ 1000 yrs |
| **Pelagic carbonates** | Deep sea | 0.05-0.1 cm/ 1000 yrs |

# Modern evaporites

- *Observations of modern evaporites form the core of our understanding of evaporite deposition in the geological past!*

- *Mostly shallow water (salt works) and subaerial (sabhka) environments. No modern analogues for (inferred) deep water settings*

# Modern salt works

*Trapani (Sicily)*

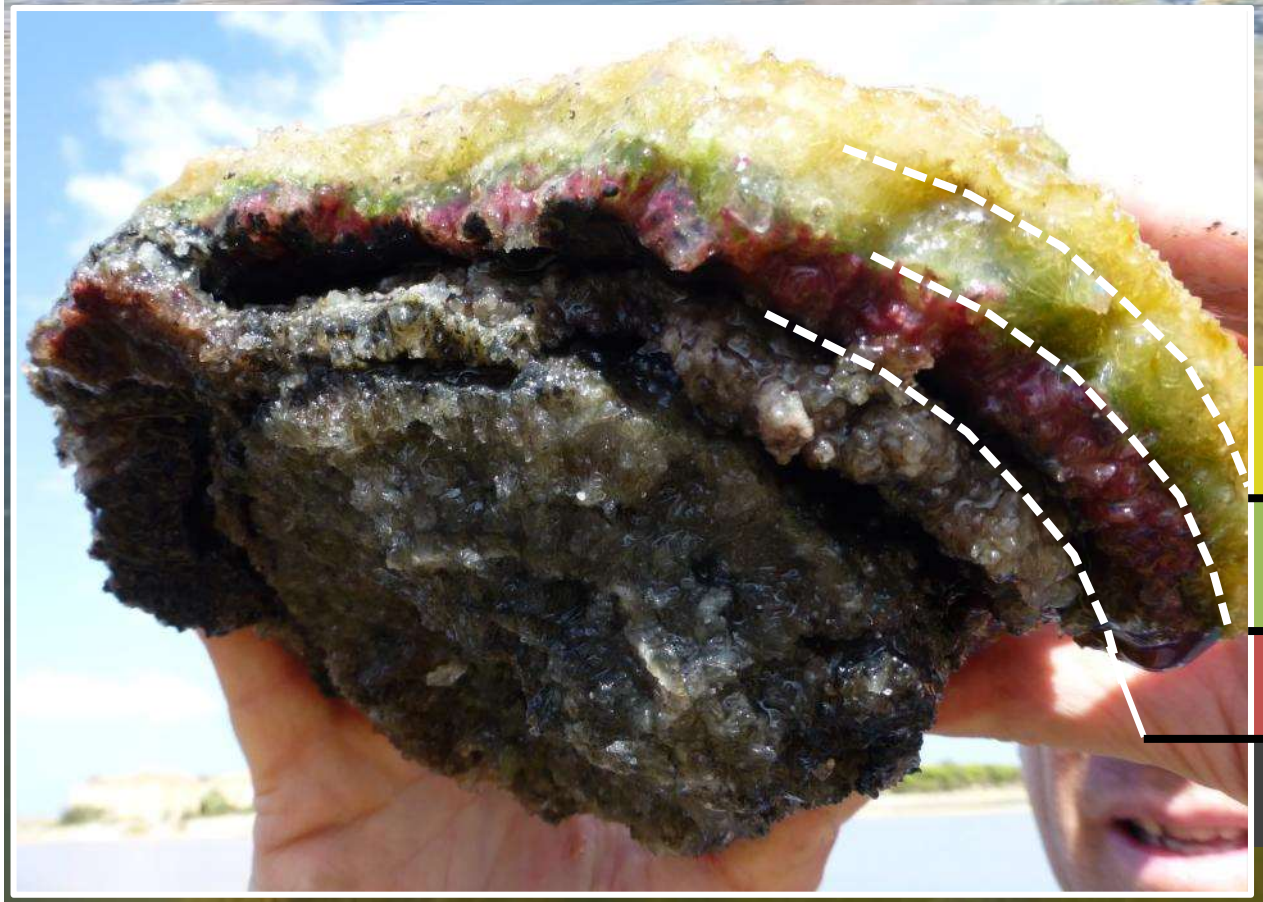
*Gypsum "crystallizer" pond*

*Salinity > 110 ‰*

# Micro-organisms in modern gypsum

*Modern saltworks*

*Gypsum layering*






Oren, 2009

# Modern salt works

*Trapani (Sicily)*

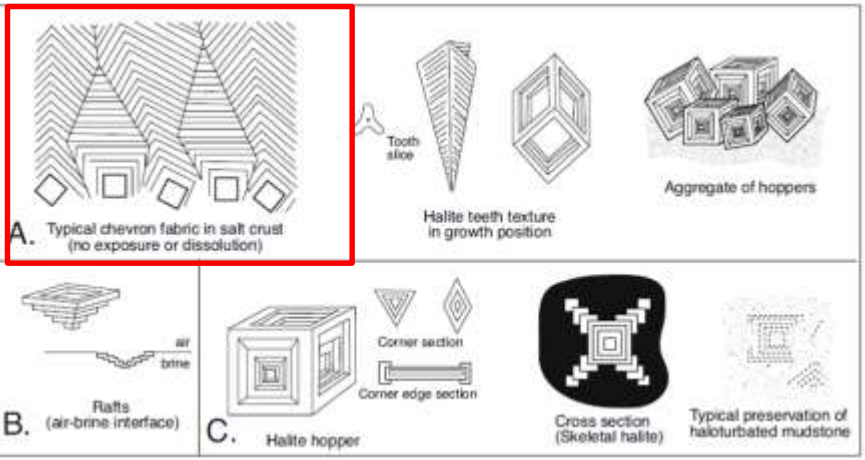
*From Warren, 2006*

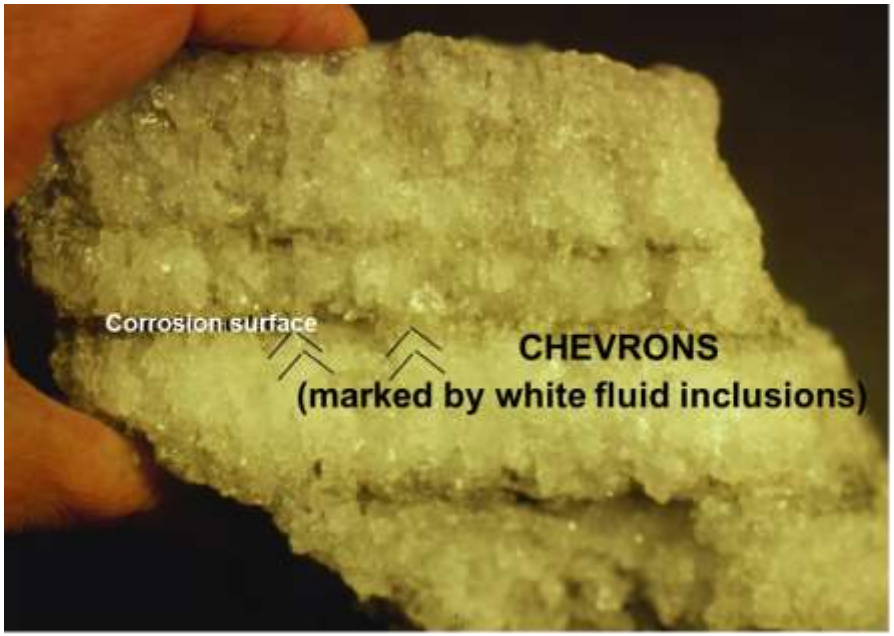
*Halite "crystallizer" pond*

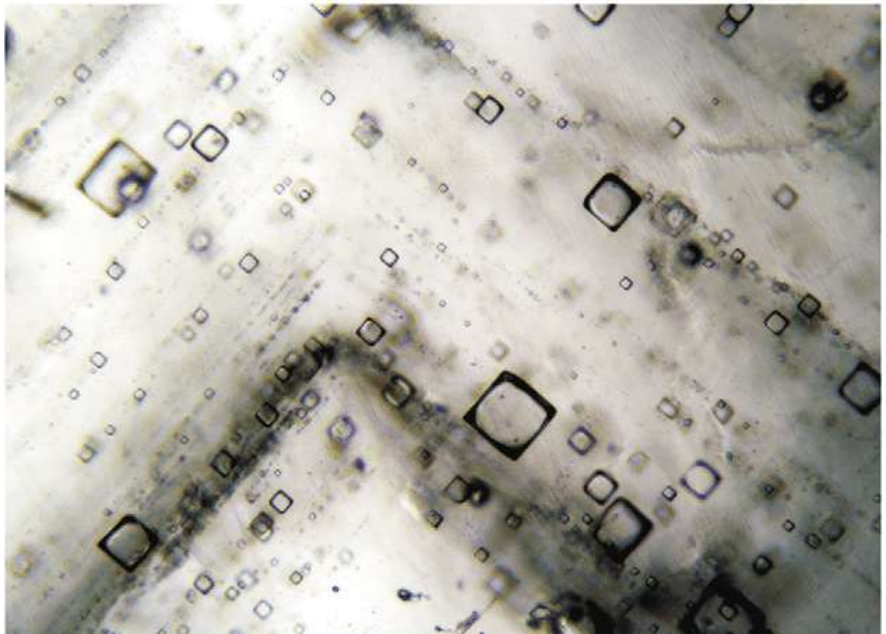
*Salinity > 350 ‰*

# *Halite chevrons*

*Babel and Schreiber, 2014*

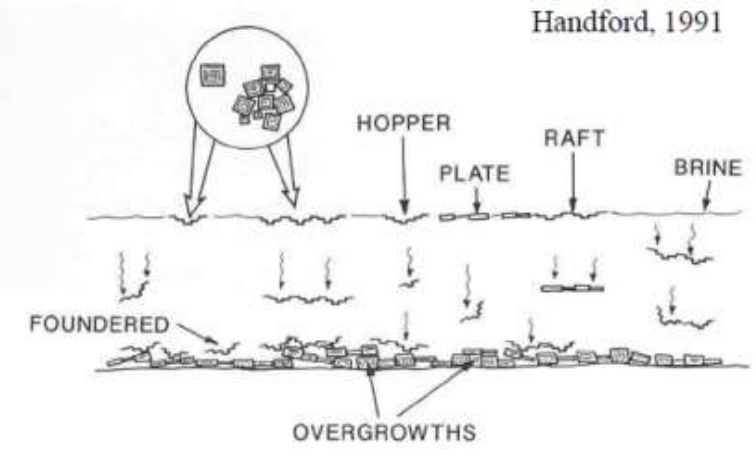


Modern evaporites

# *Halite rafts*

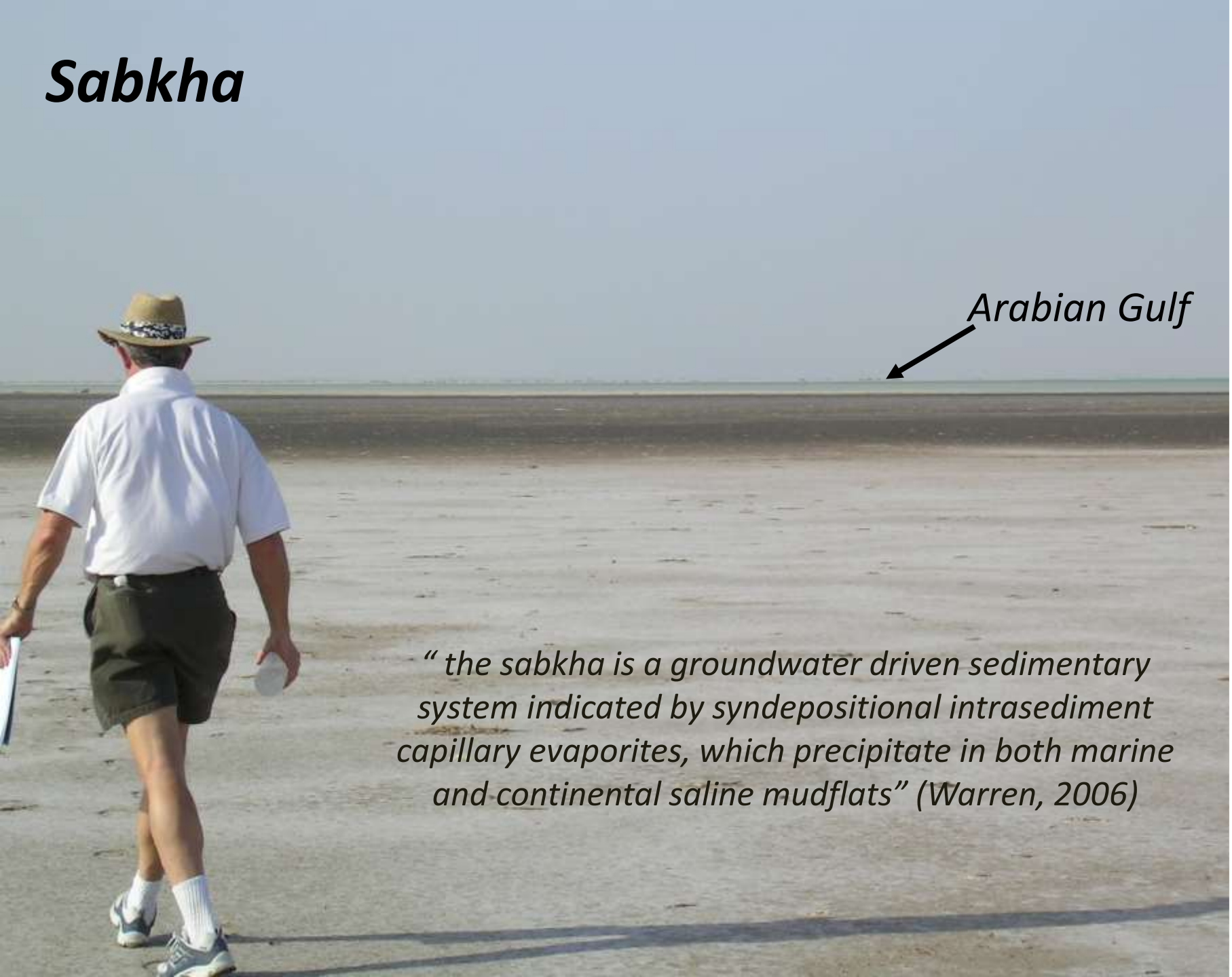




Filippi et al. 2011

# Deep water halite (Ded Sea)

# *Sabkha*



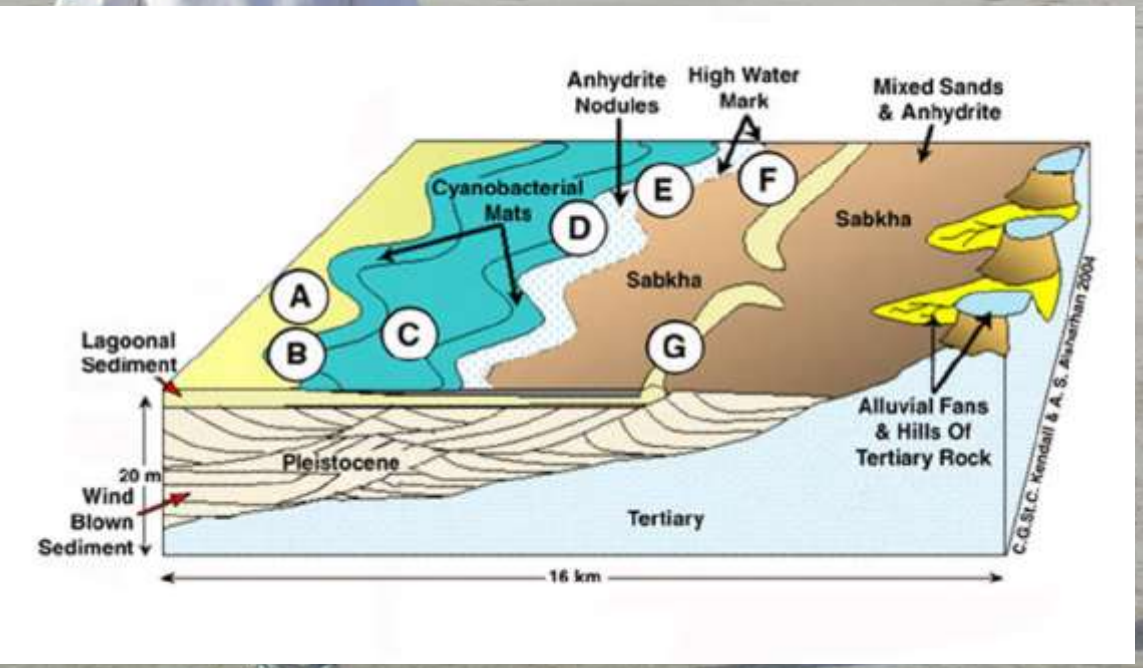

*" the sabkha is a groundwater driven sedimentary system indicated by syndepositional intrasediment capillary evaporites, which precipitate in both marine and continental saline mudflats" (Warren, 2006)*

# *Sabkha*

*Arabian Gulf*

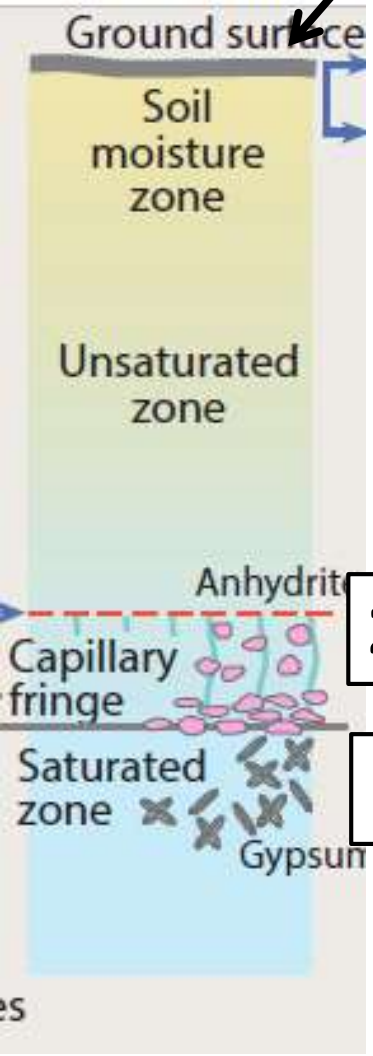
*cyanobacterial mat*

*sabkha*




Primary evaporites

# *Sabkha*




*From Warren, 2017*


Cyanobacterial mat

Anydrite



Displacive gypsum

*www.kenig-ogl.org*

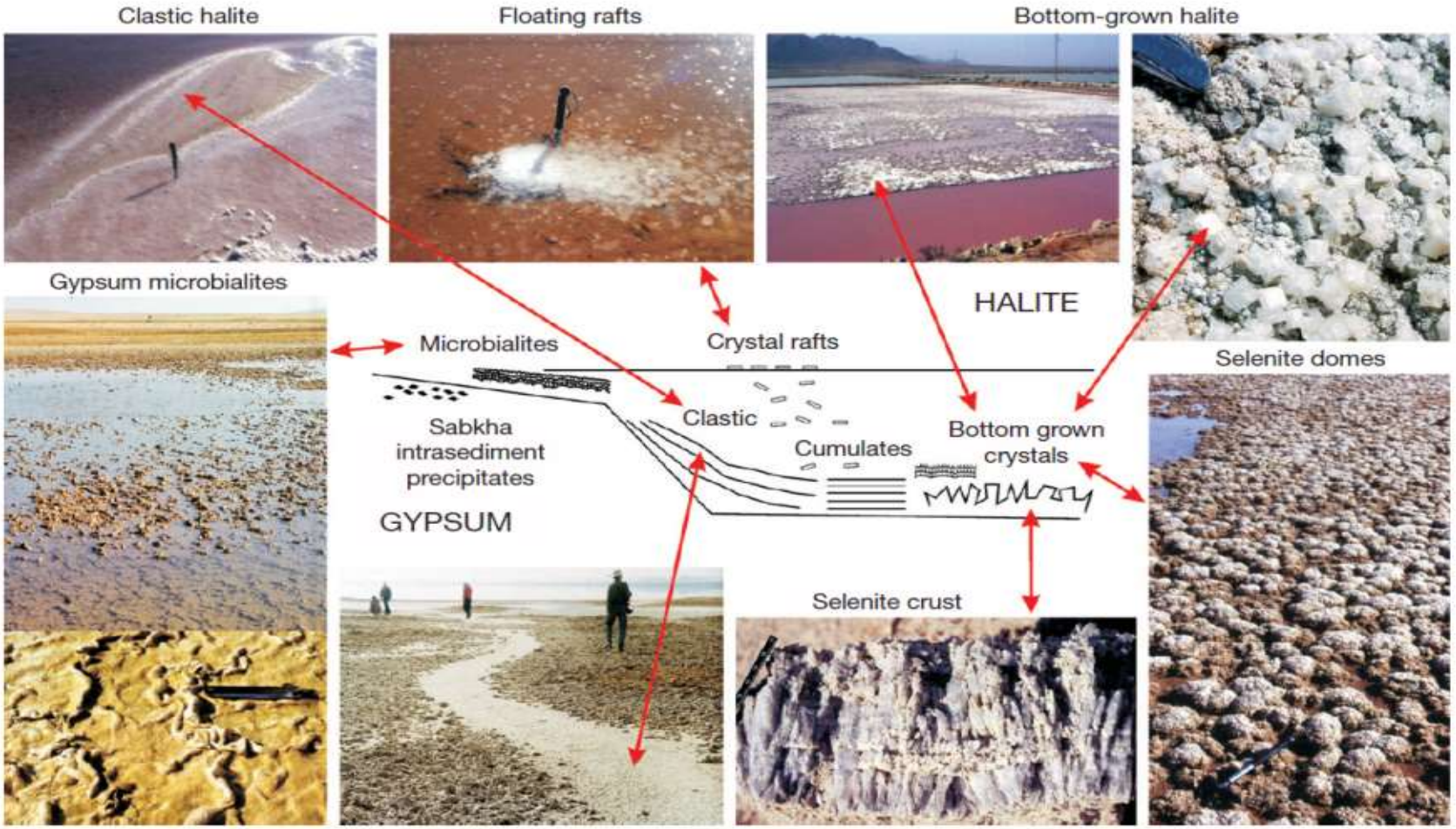
Modern evaporites

## *Where evaporite form?*

- at the brine/air interface
- within the brine column, particularly at the pycnocline
- on the floor of the evaporite basin
- in brine-soaked sediments (Sabkas)

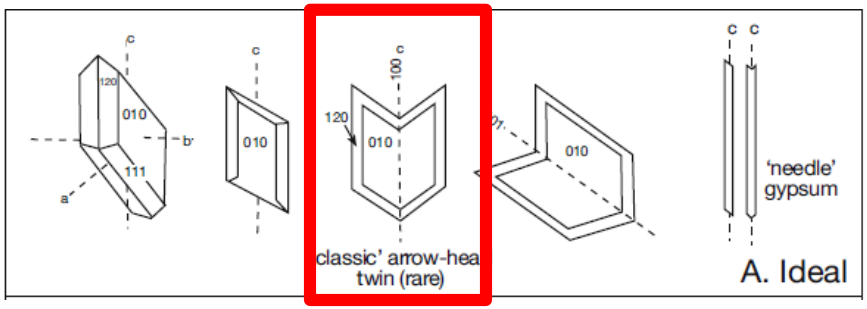
} ***Cumulate deposits***

→ ***Bottom grown crystals***




*from Babel and Schreiber, 2014*

# *Bottom grown gypsum*



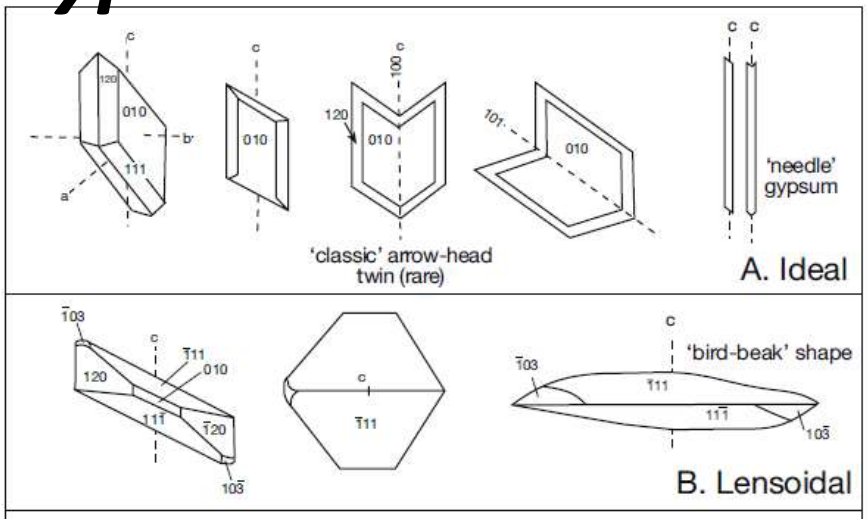

# Mottura's Rule

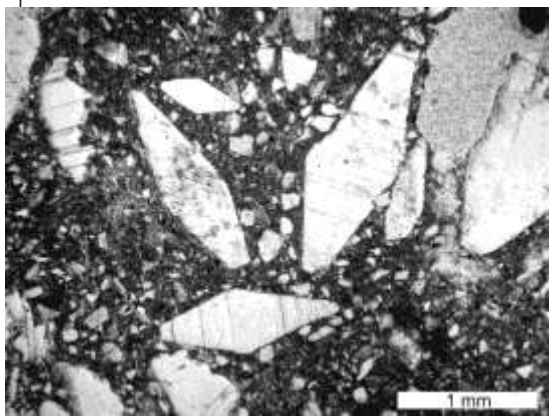
(arrow-head, swallow's tail)


**Eraclea Minoa, Sicily**

Modern evaporites

# *Gypsum* - lenticular



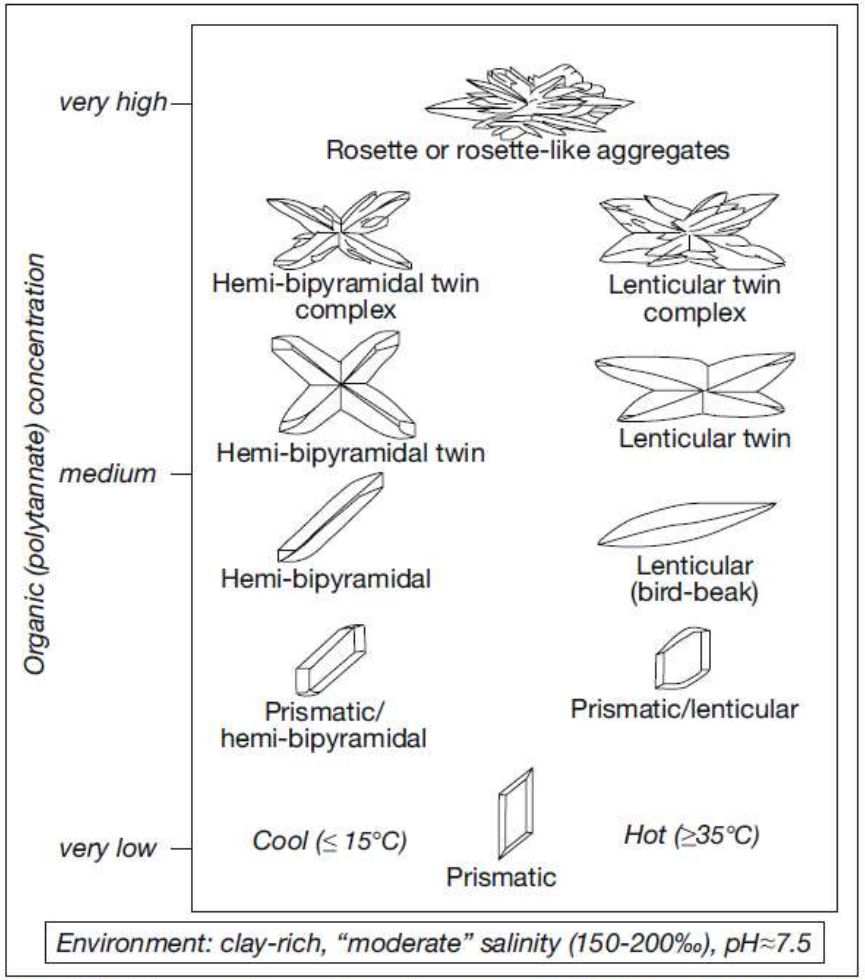




Figure 1.17. Laboratory based changes in gypsum growing in a muddy (bentonite) sediment matrix at moderate salinity and neutral pH in environments characterized by increasing temperatures and dissolved polytannate concentrations. Polytannate is considered to be an analog for terrestrial humic material. c-axis vertical in all examples (after Cody and Cody, 1988).

*From Warren, 2006*

Modern evaporites

# Models of marine evaporite formation

**Marine marginal basin**

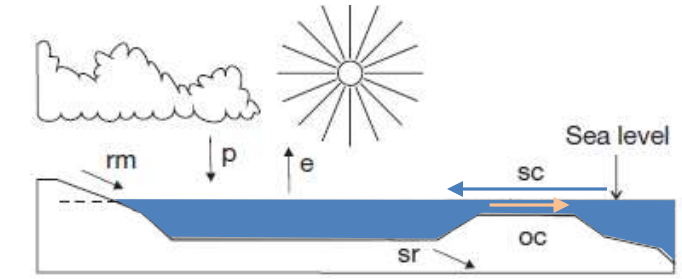
***Crucial element***

Negative hydrological budget

***Key factors:***

- Marginal position
- Seal or topographic barrier
- Restriction with episodically re-connection with the sea/ocean
- Climate control (aridity promoting evaporation)

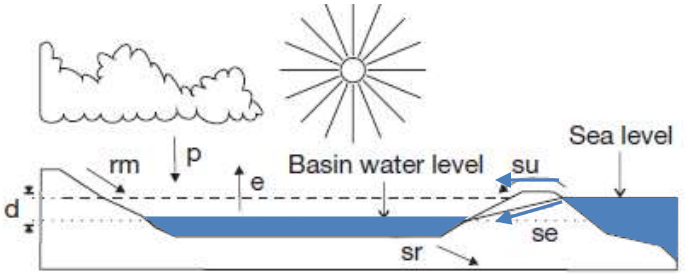
**Lagon basin**




sc - Surface inflow current
oc - Bottom outflow current
sr - Seepage reflux
rm - Run-off meteoric water
p - Precipitation
e - Evaporation

(a)

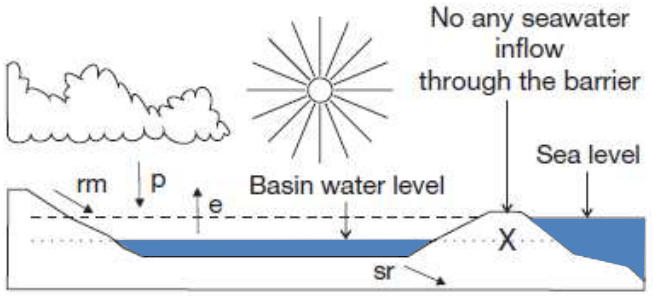
**Salina basin**




se - Seepage influx
su - Surface inflow
sr - Seepage reflux
rm - Run-off meteoric water
d - Range of evaporite drawdown
p - Precipitation
e - Evaporation

(b)

**Salina lake**



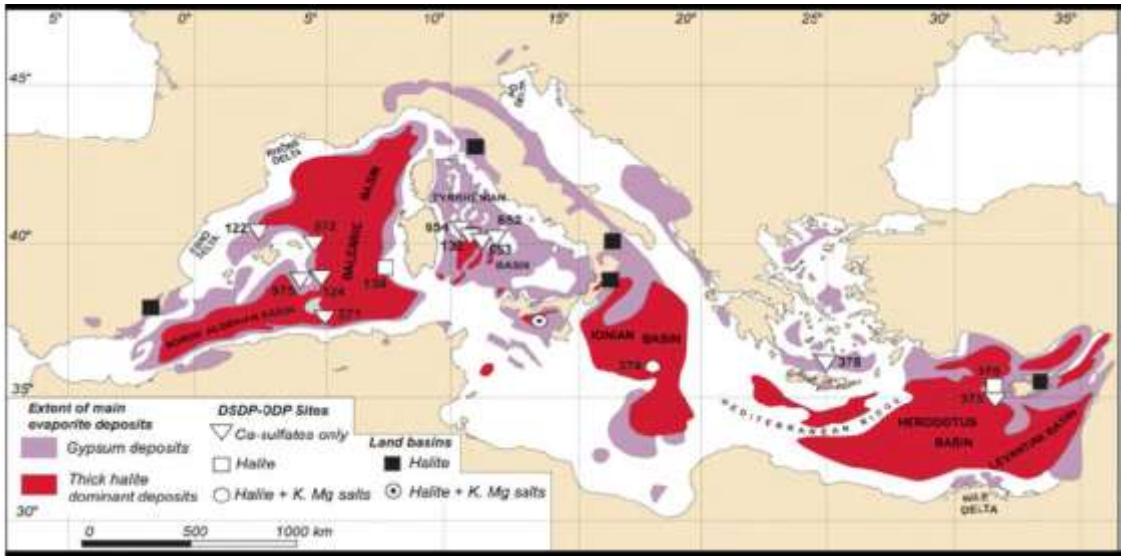

rm - Surface run-off
sr - Seepage reflux
p - Precipitation
e - Evaporation

(c)

*from Babel and Schreiber, 2014*

Modern evaporites

# Ancient evaporites (MSC)




*Rouchy and Caruso 2006*

Interpretation of ancient marine evaporite deposits is difficult!

- No (few) clues to estimate water depth
- No modern analogues for very large and (relatively) deep basins (Salt giants)

This is particularly true for the wide array of Messinian evaporites facies (mostly gypsum and halite) of the Mediterranean!

# Gypsum

## Bottom-grown gypsum

- Massive selenite
- Banded selenite
- Branching selenite («Supercones»)

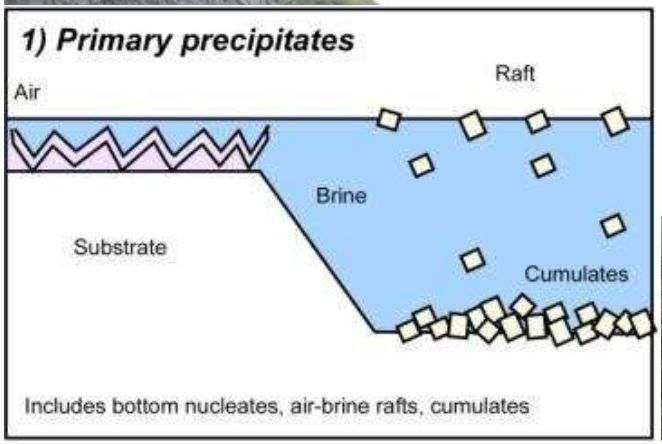
## Gypsum cumulate

- Laminar gypsum

## Clastic gypsum

# Massive selenite

Vena del Gesso



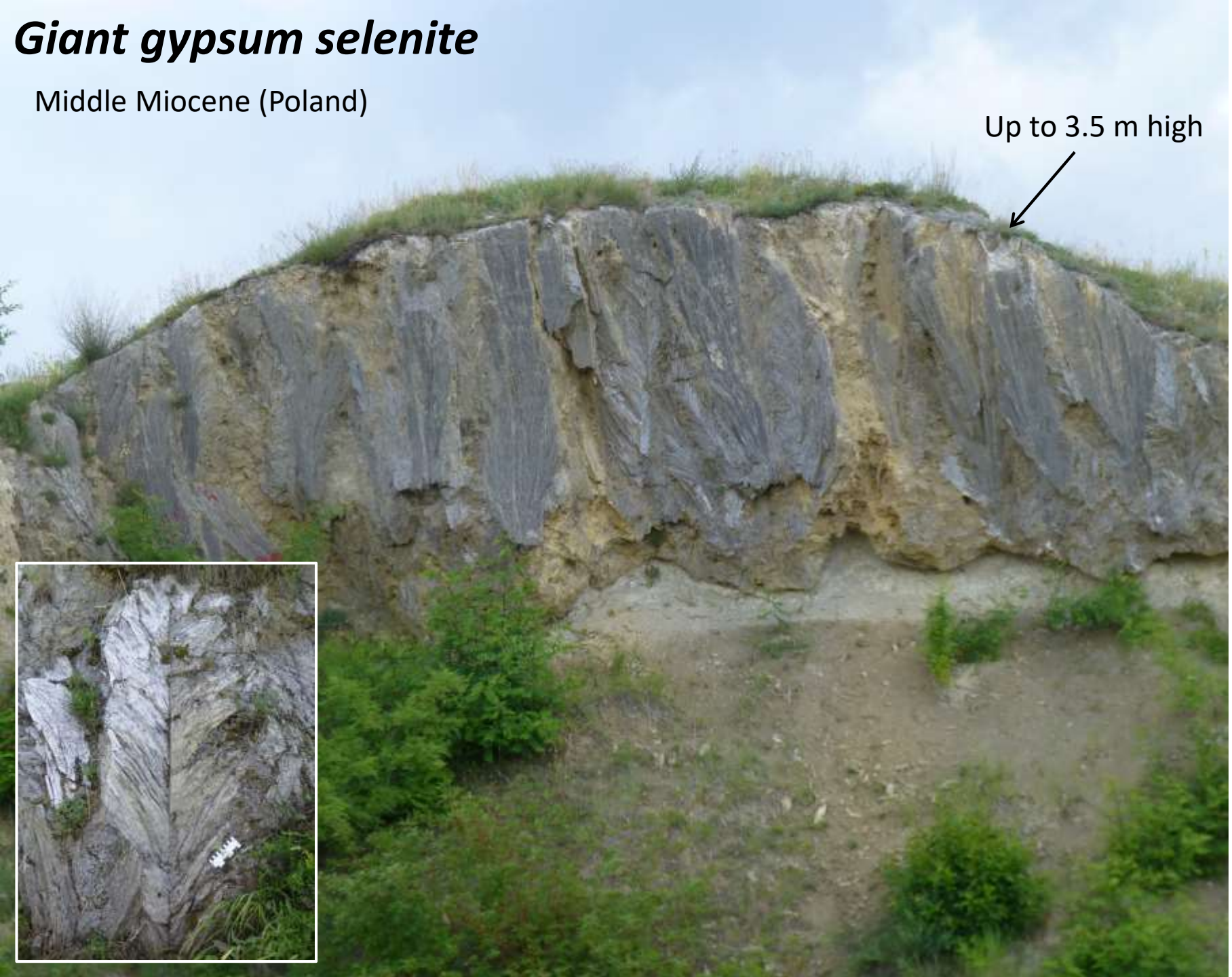




Ancient evaporites

# *Giant gypsum selenite*

Middle Miocene (Poland)



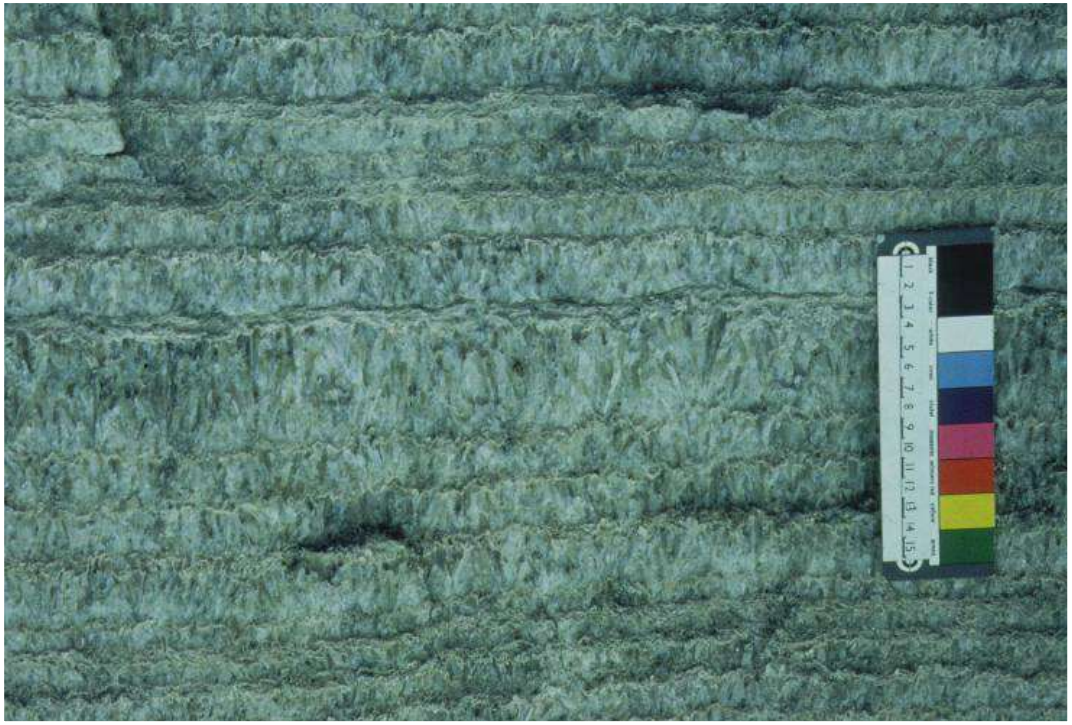
Upper Gypsum, Monte Palco (Sicily)

# Nucleation cones

Sorbas

Cuevas de Sorbas

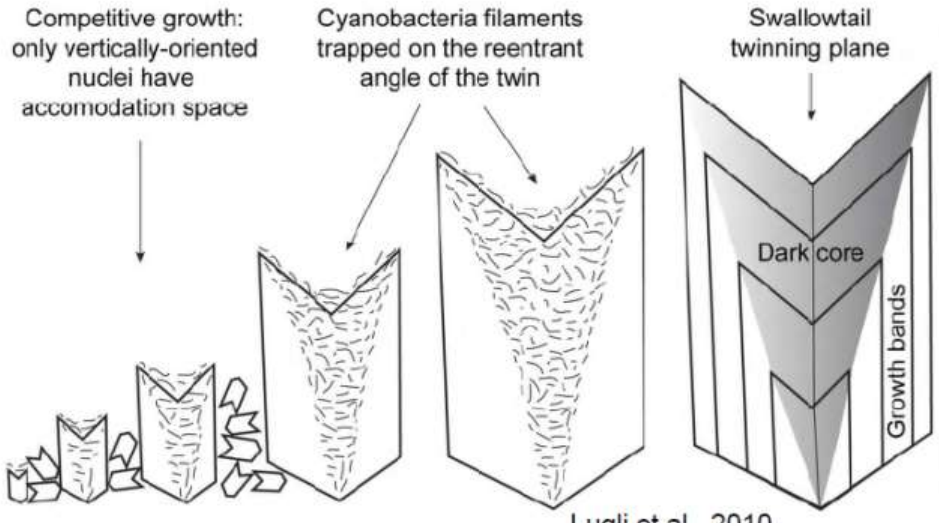
# Banded selenite

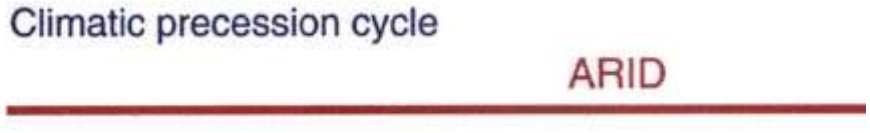


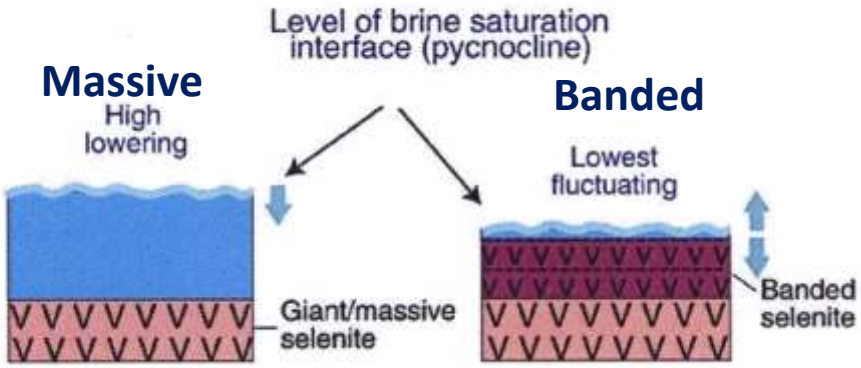
Vena del Gesso

Piedmont Basin

# Vertical growth of crystals in massive and banded selenite



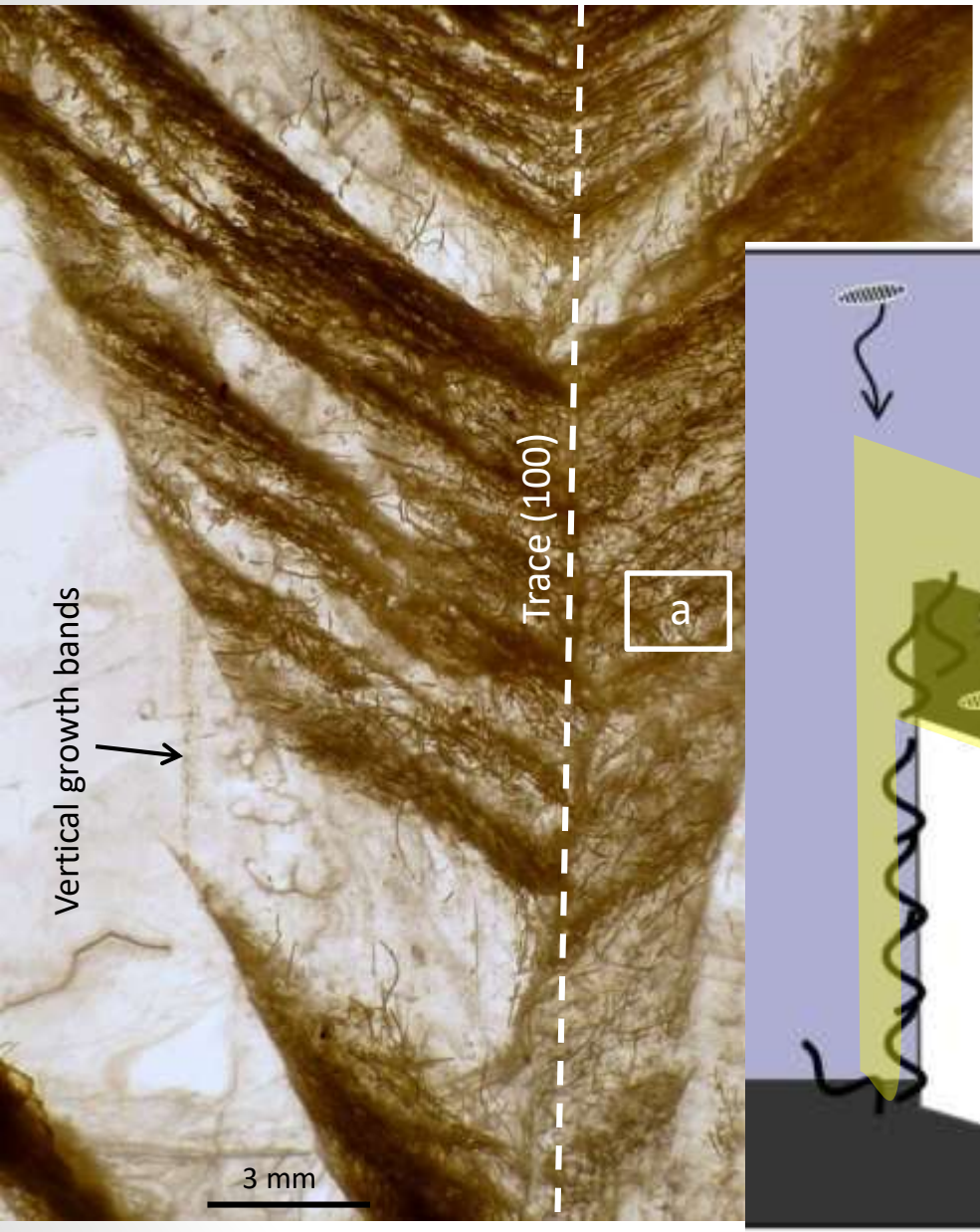



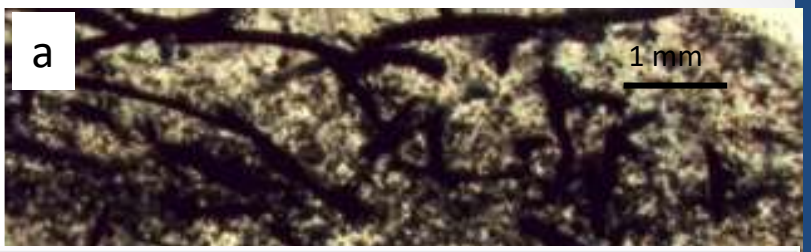



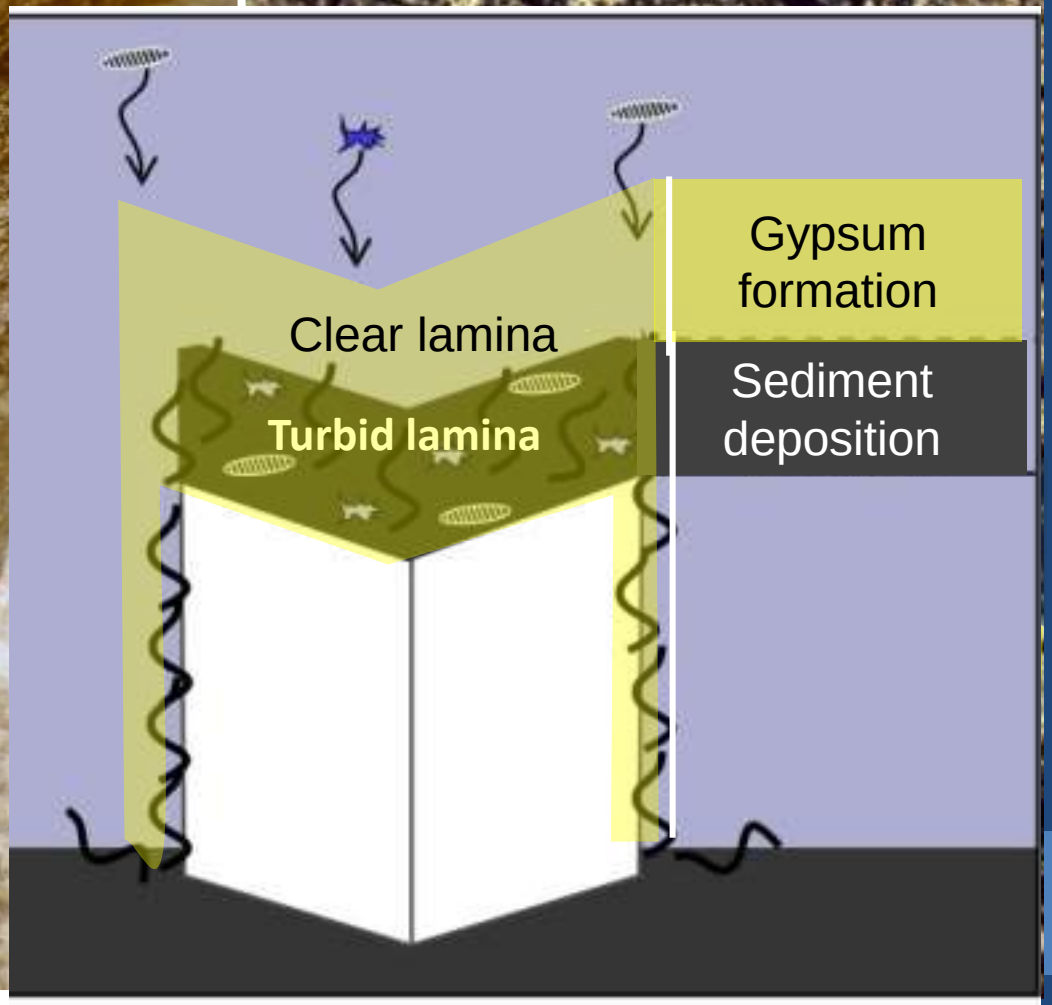

Lugli et al., 2010

Ancient evaporites

# Microbiological content of massive and banded selenite

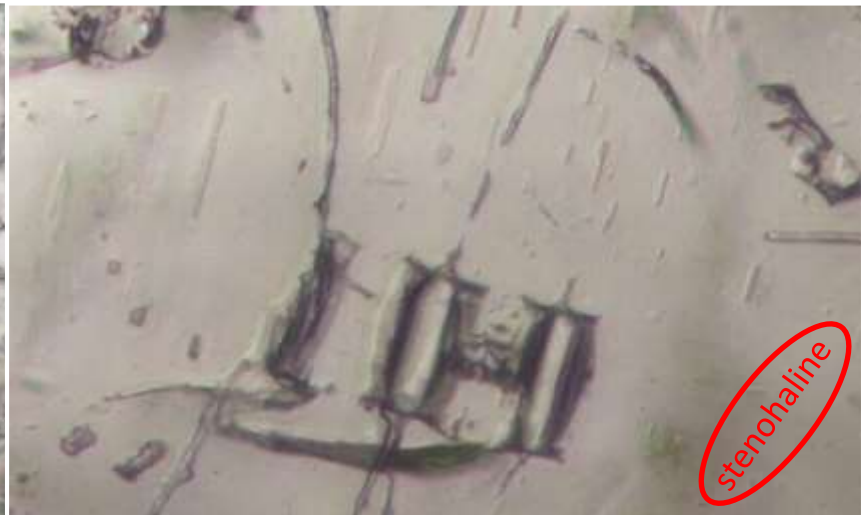


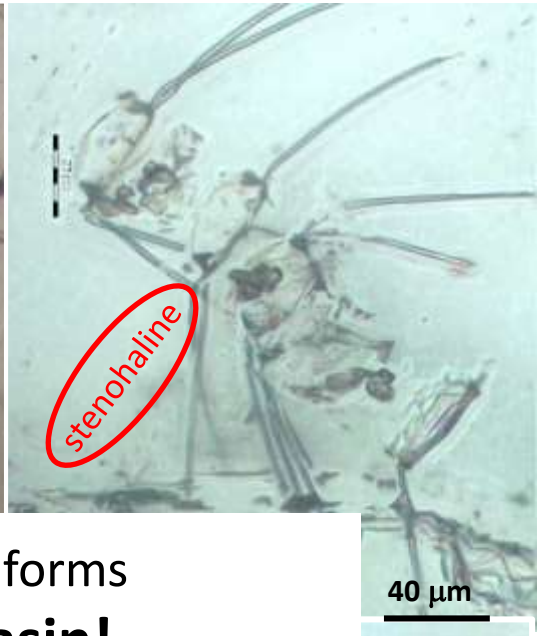




Ancient evaporites

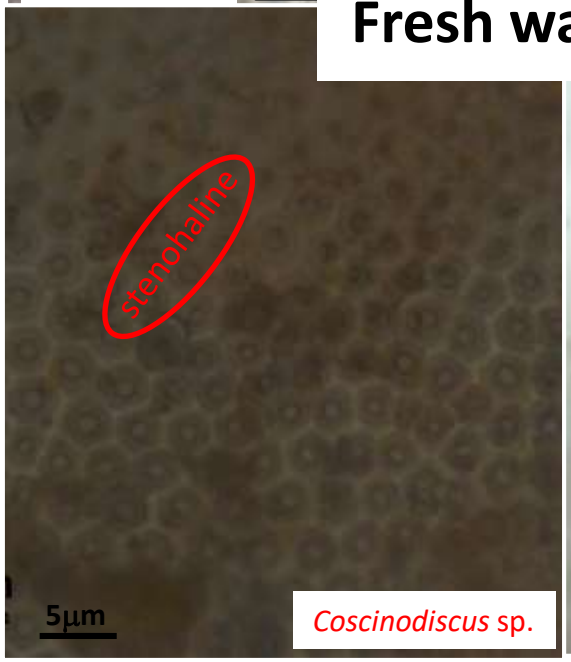
# Planktic components (only in the reentrant angle)

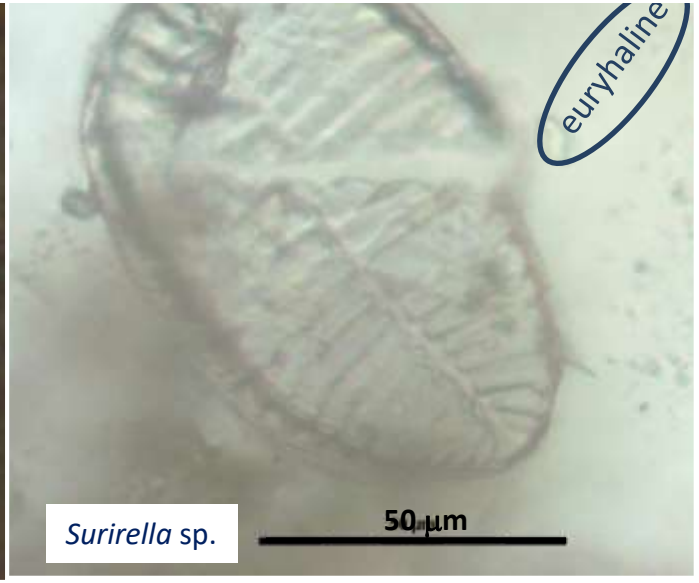




Mixing of steno- and euryhaline forms

**Fresh water inflows in a marine basin!**



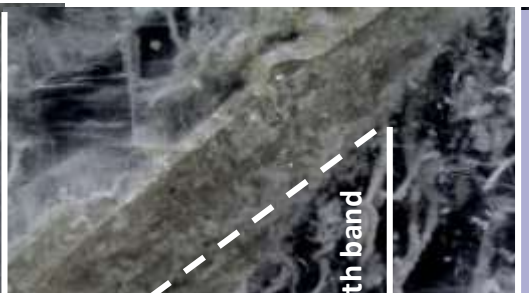



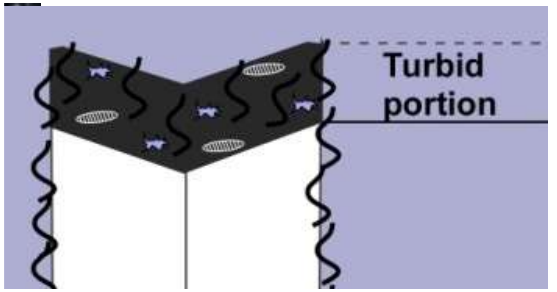


Ancient evaporites

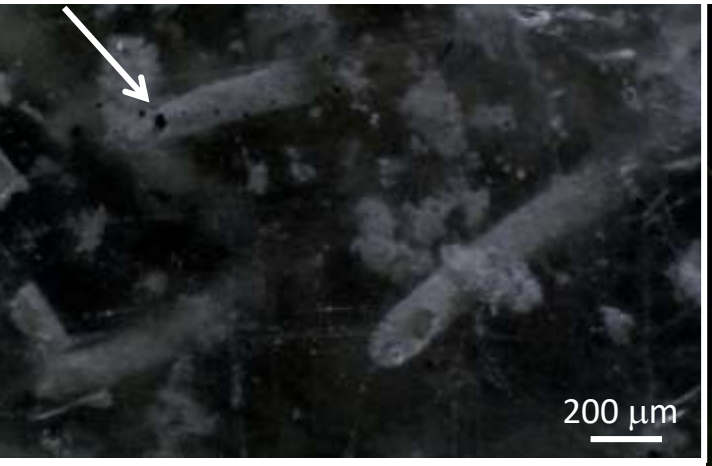
Benthic components (in the reentrant angle and along the vertical growth bands)

## Filamentous microfossils

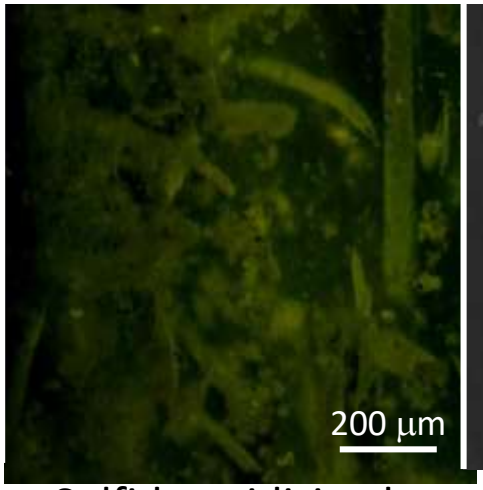



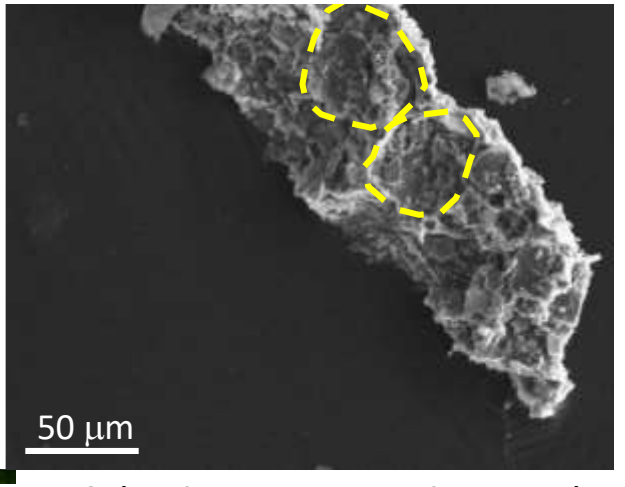




- ✓ Microbial sulfur cycling was an active process in the gypsum forming brines
- ✓ Deposition not necessarily in the photic zone



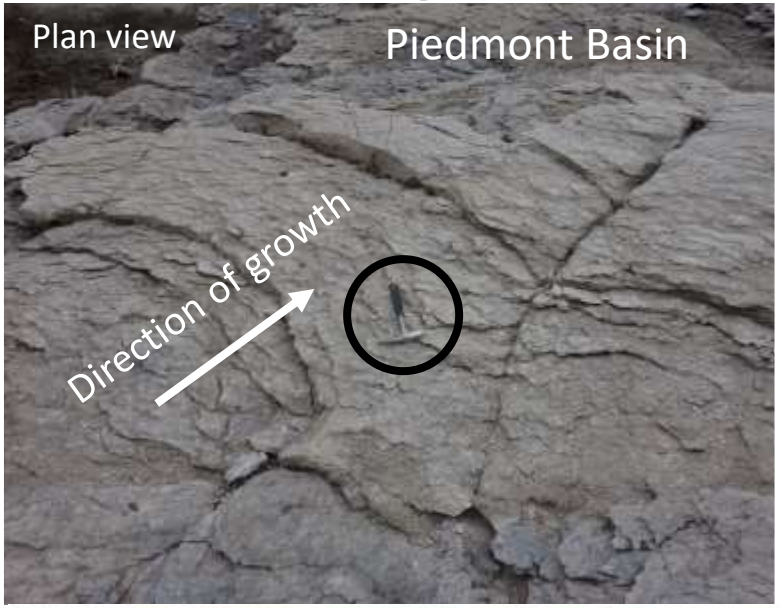

Cyanobacteria ?(Panieri et al., 2010)




Sulfide-oxidizing bacteria? (Dela Pierre et al., 2015)

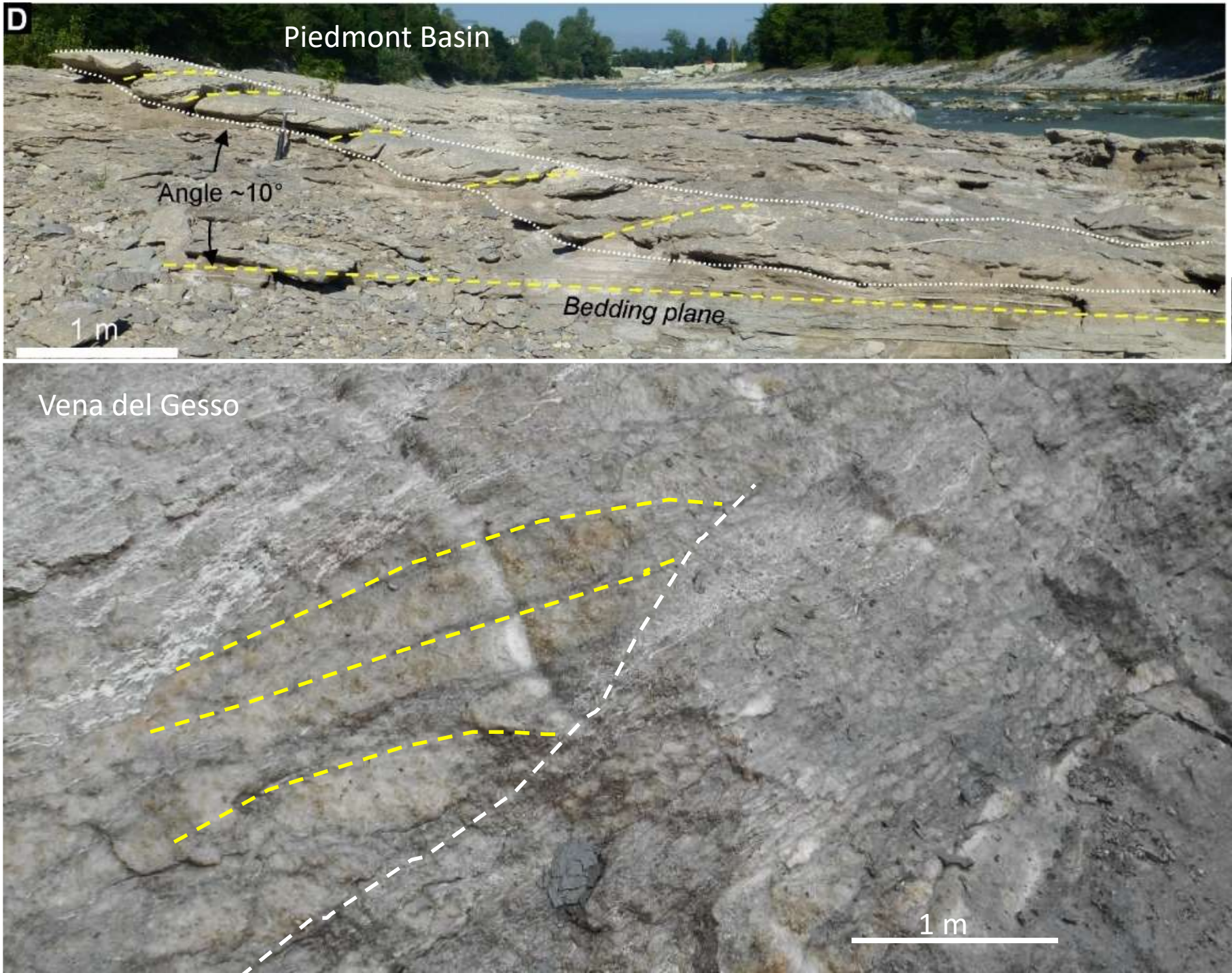
# Branching selenite



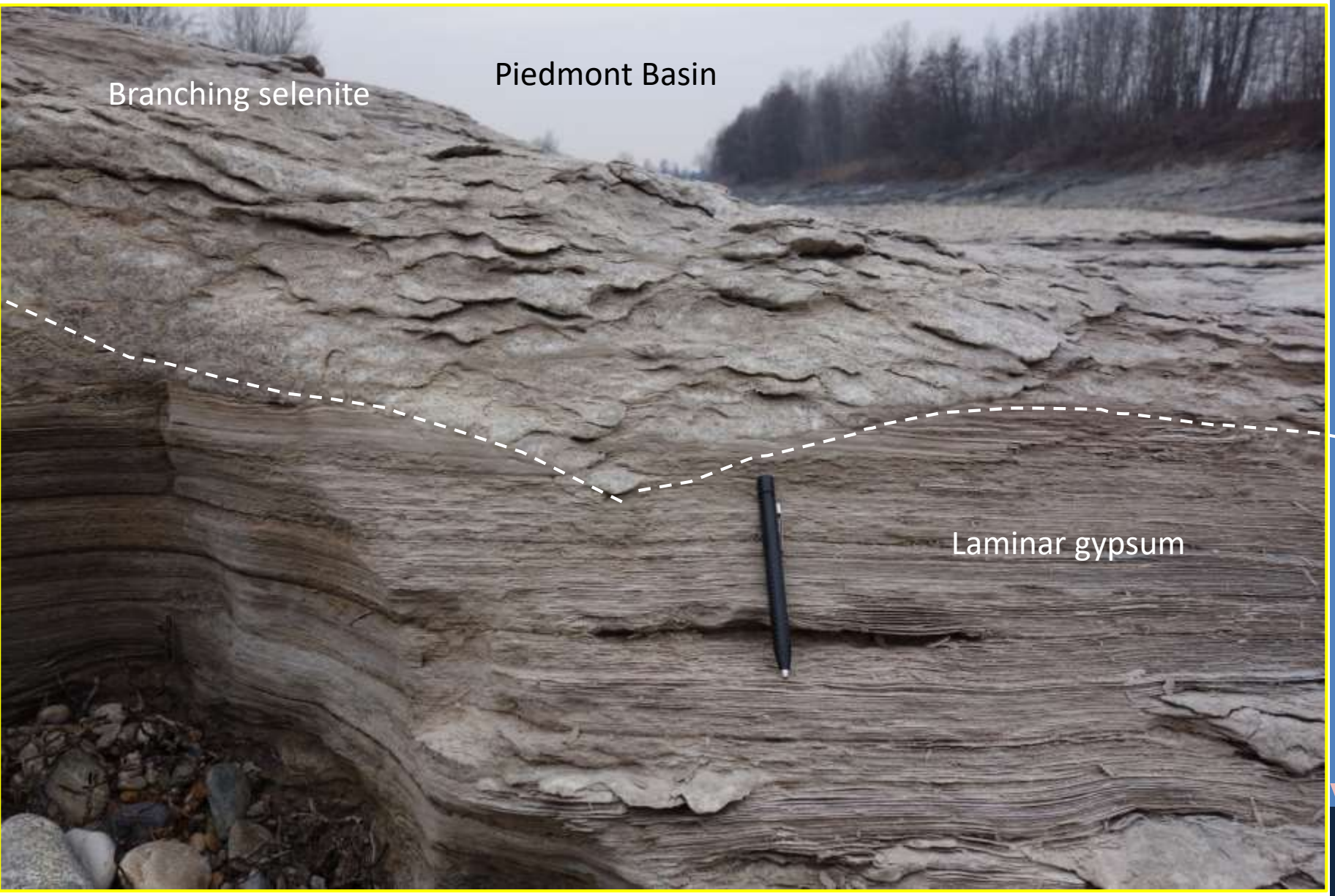




Ancient evaporites




Ancient evaporites



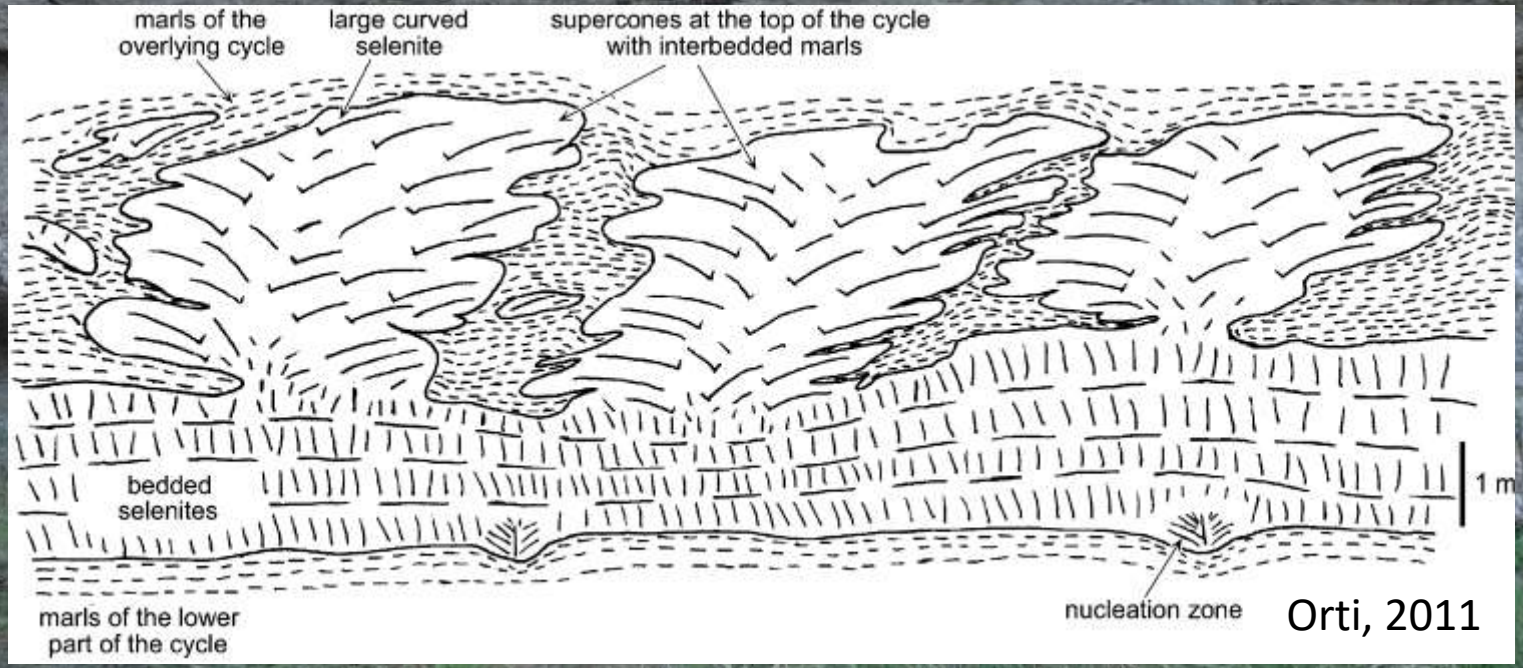

# Ancient evaporites

marls

m

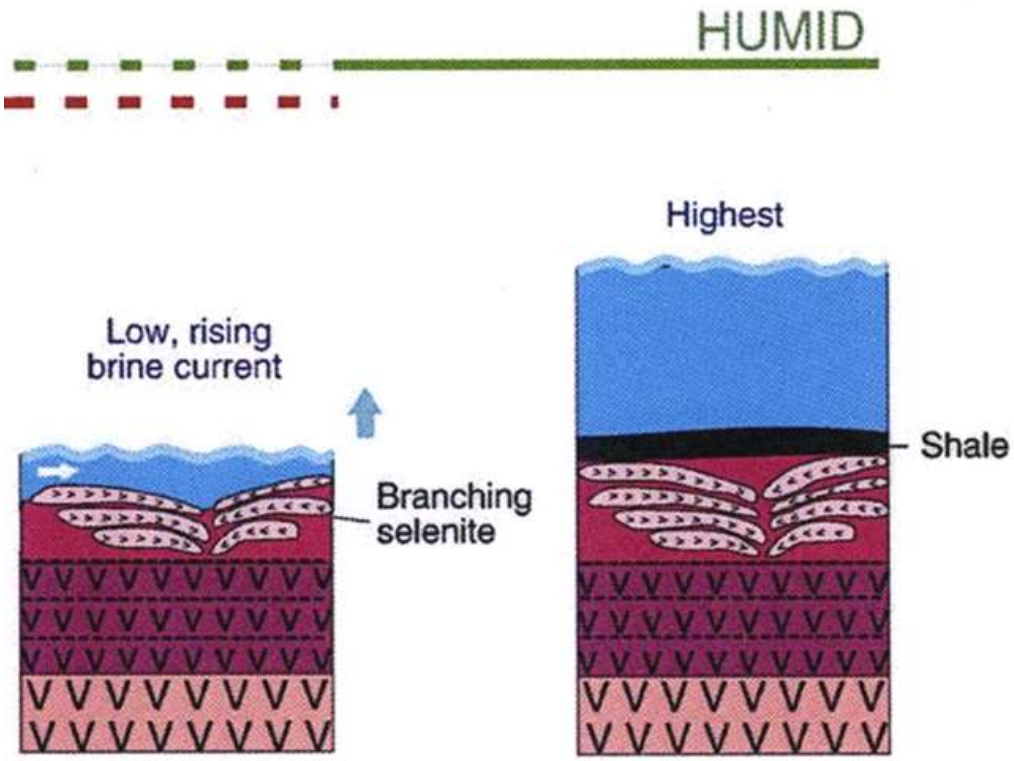
m

Banded



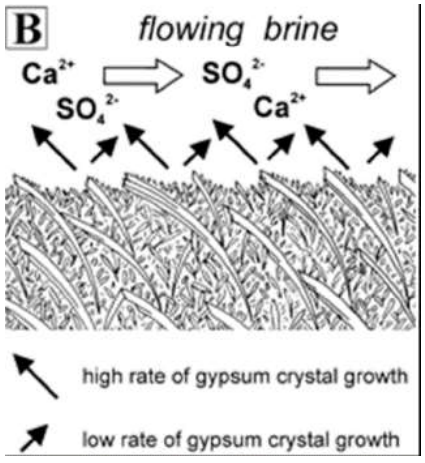

Orti, 2011

# Braching selenite: interpretation




Brine flows favouring the horizontal growth of the crystals, and a depressed pycnocline the force the strcture to grow laterally.

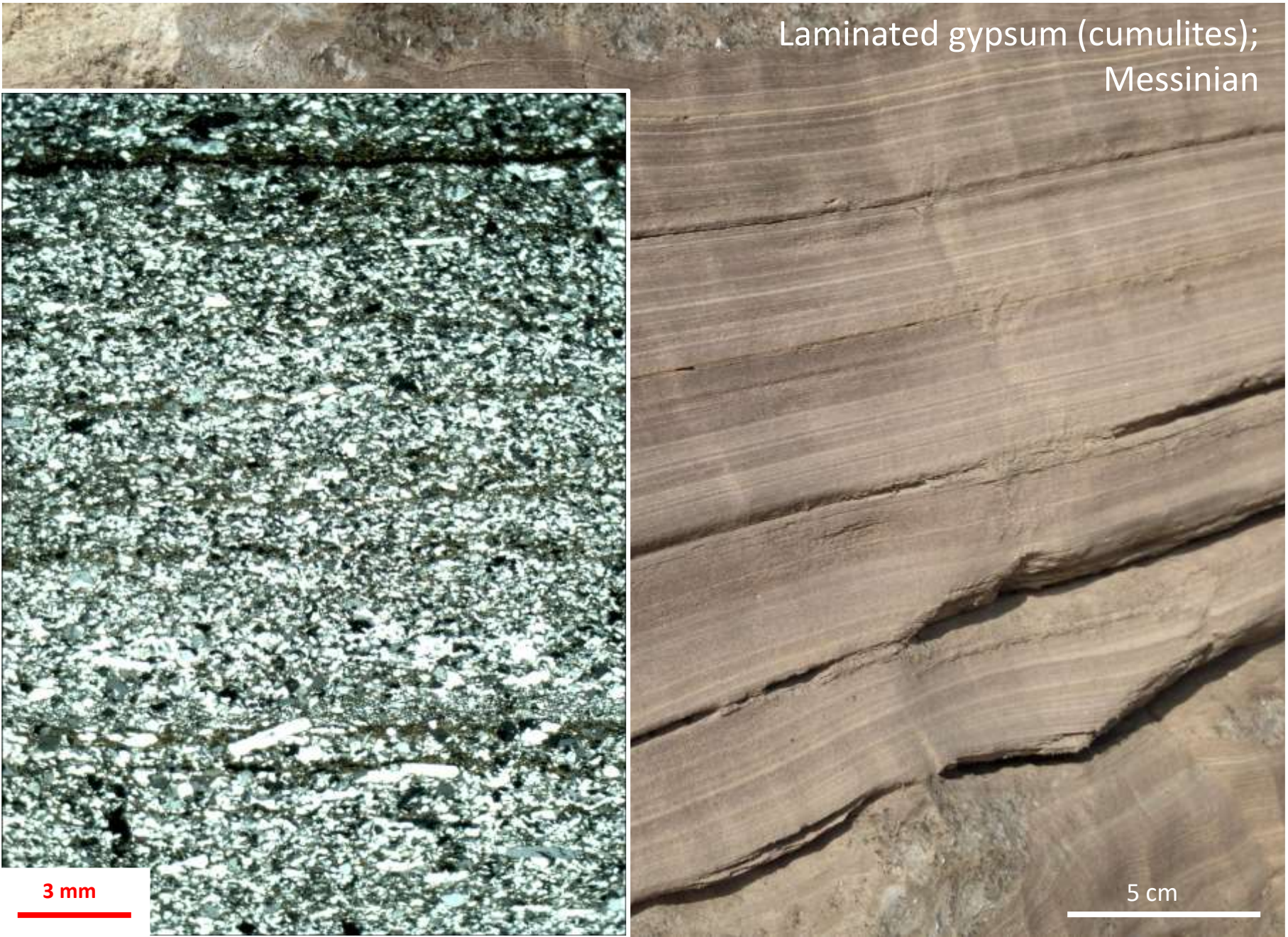
*Lugli et al., 2010*



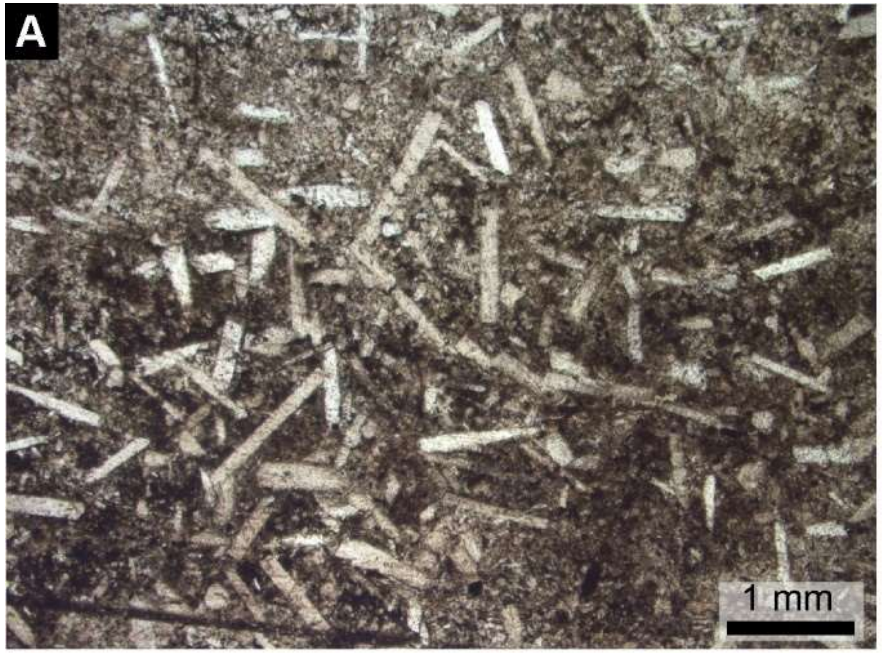

Brine currents, with preferential growth of the crystals upstream, i.e towards the ions

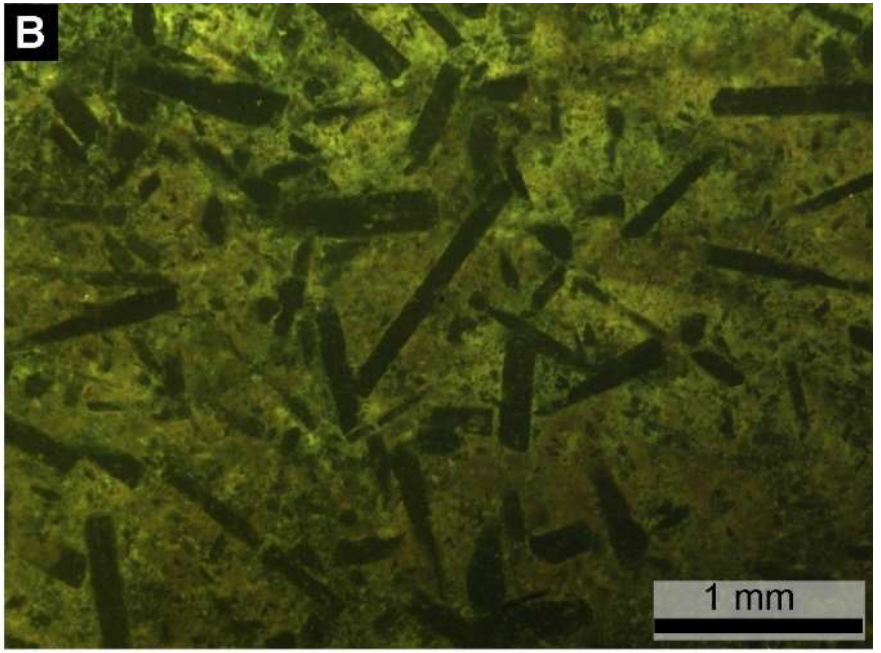
*Babel, 2002*

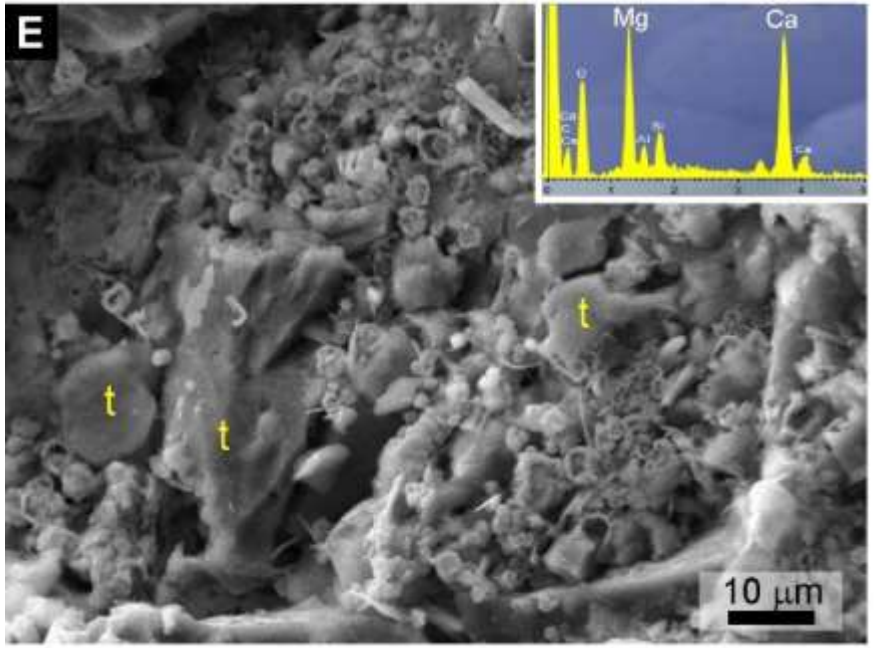
# Laminar gypsum (“Balatino”)

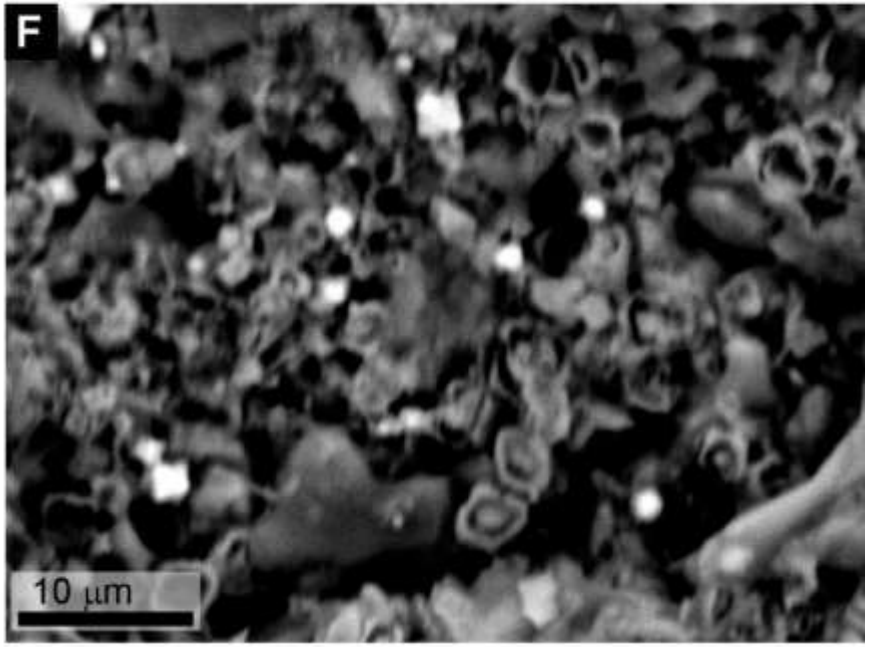


# Laminar gypsum (“Balatino”)

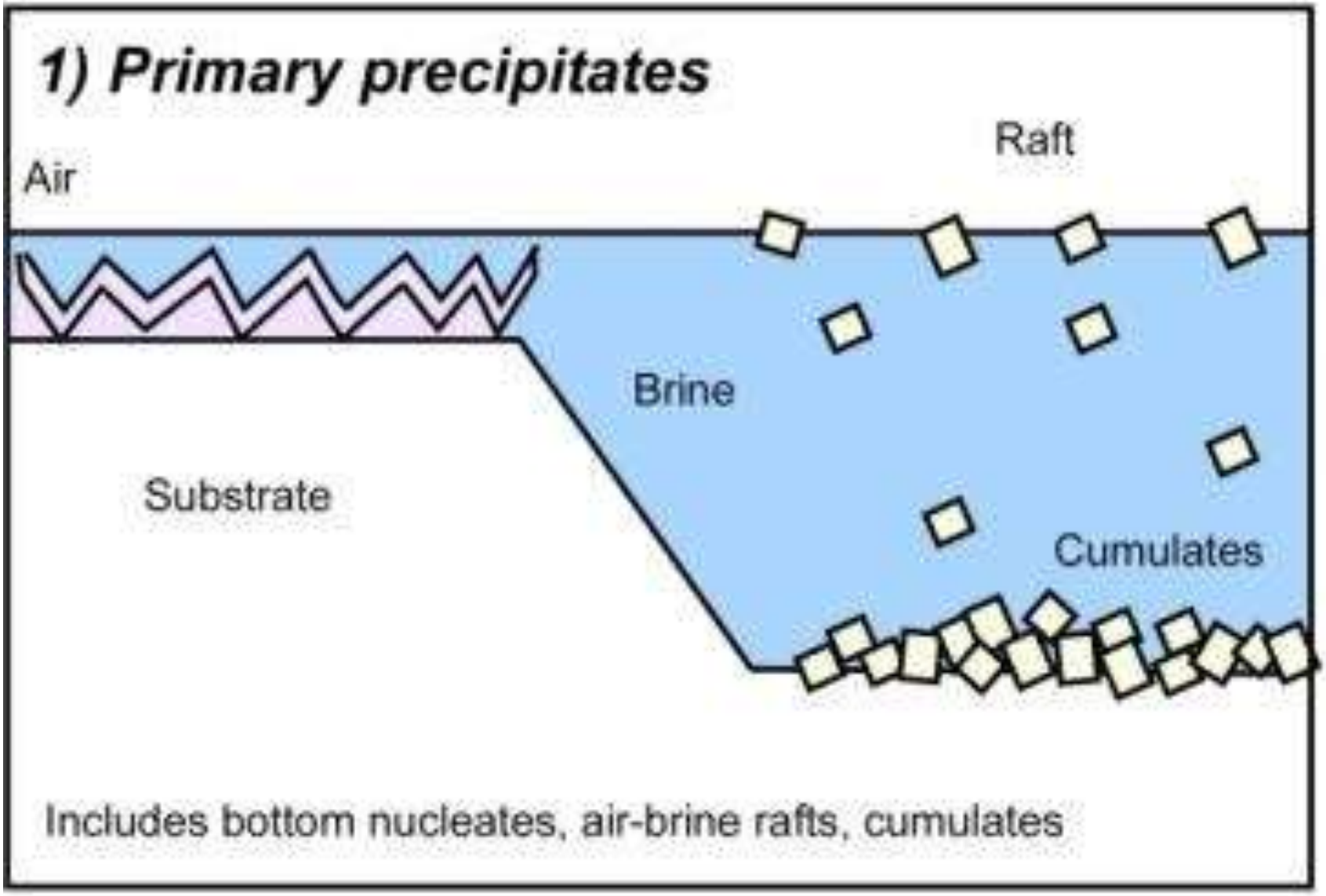


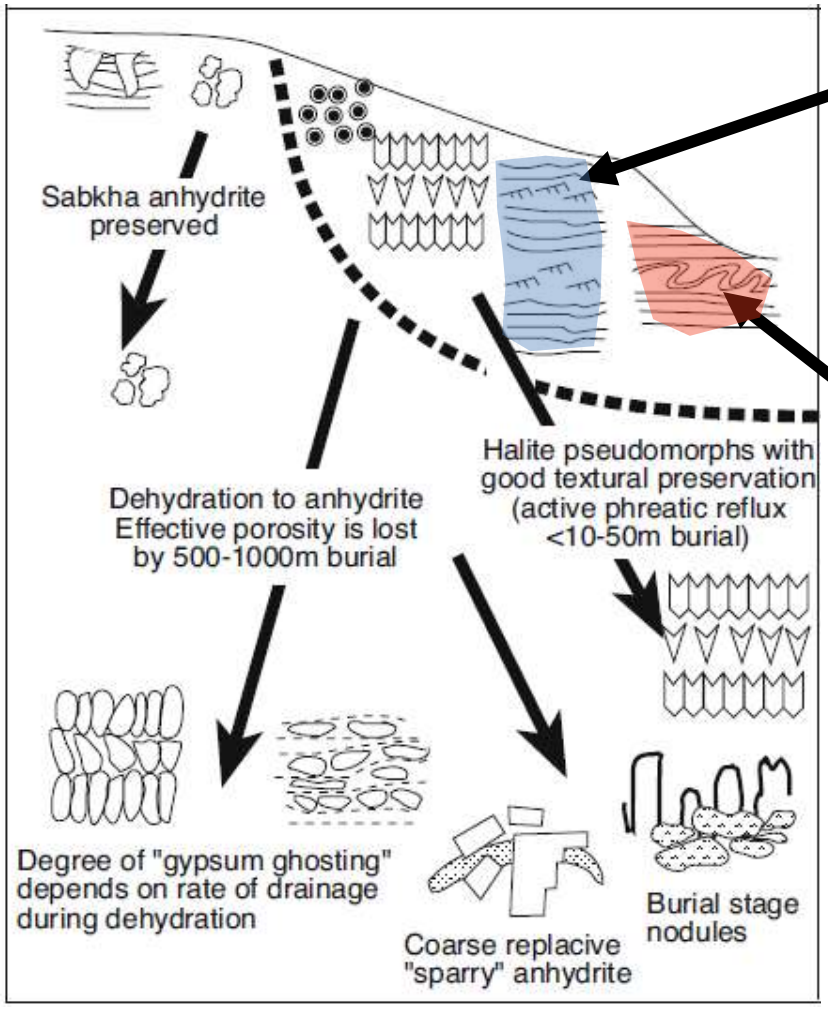




Ancient evaporites


1) Primary precipitates
Air
Raft
Brine
Substrate
Cumulates
Includes bottom nucleates, air-brine rafts, cumulates

# CLASTIC GYPSUM: SHALLOW & DEEP WATER



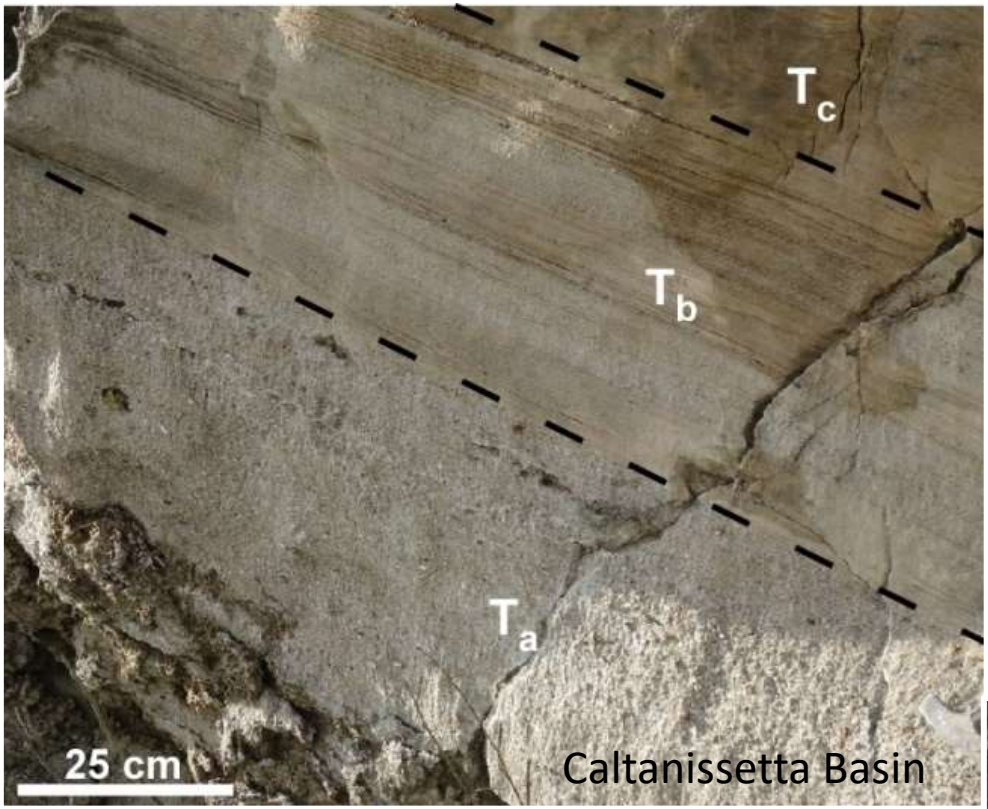

Shallow water: clastic sedimentary strctures (Cross bedding, ripples ecc..)

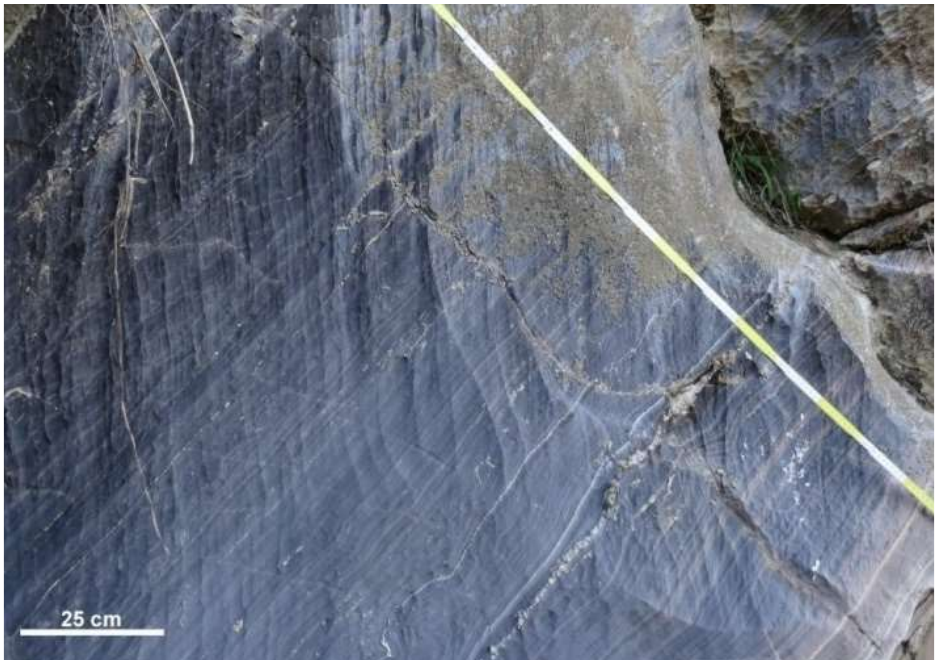
Deep water: Mass flows, Turbidites, Slumps and Slides

Warren, 2006

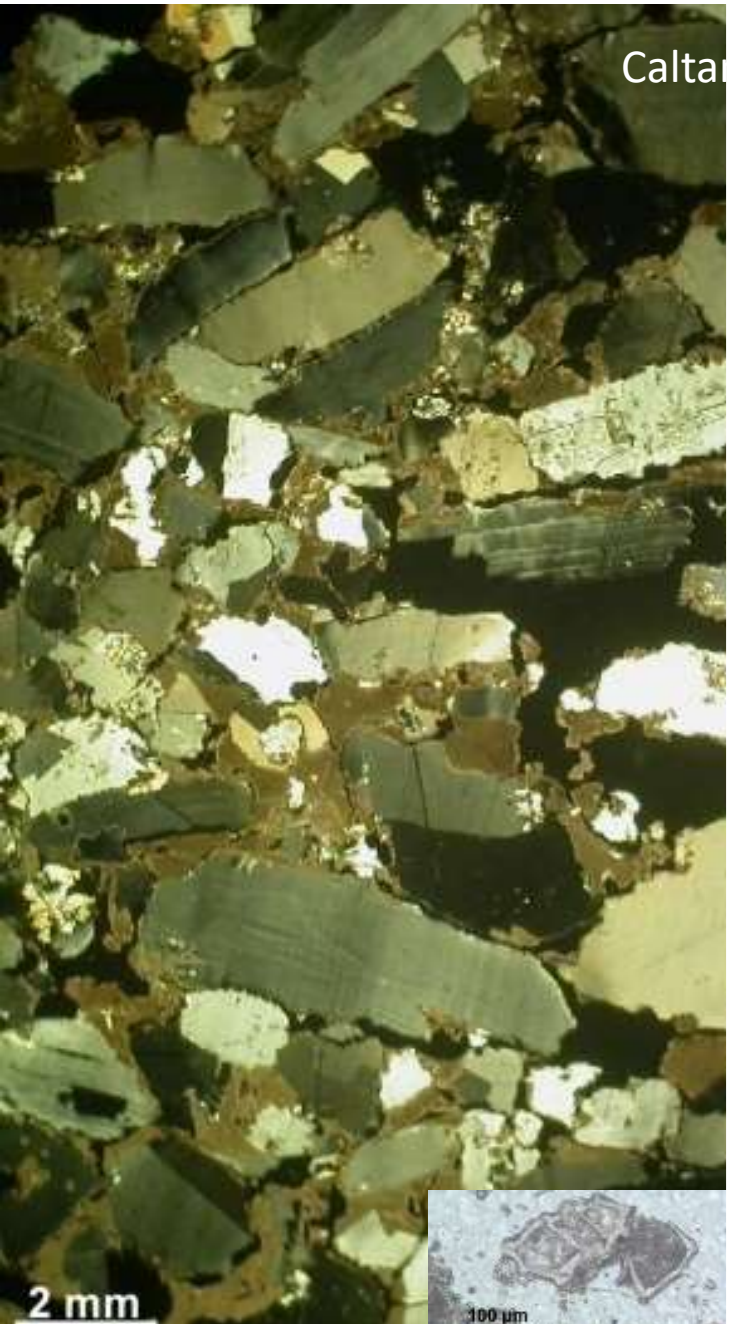
# Clastic evaporites (shallow water)

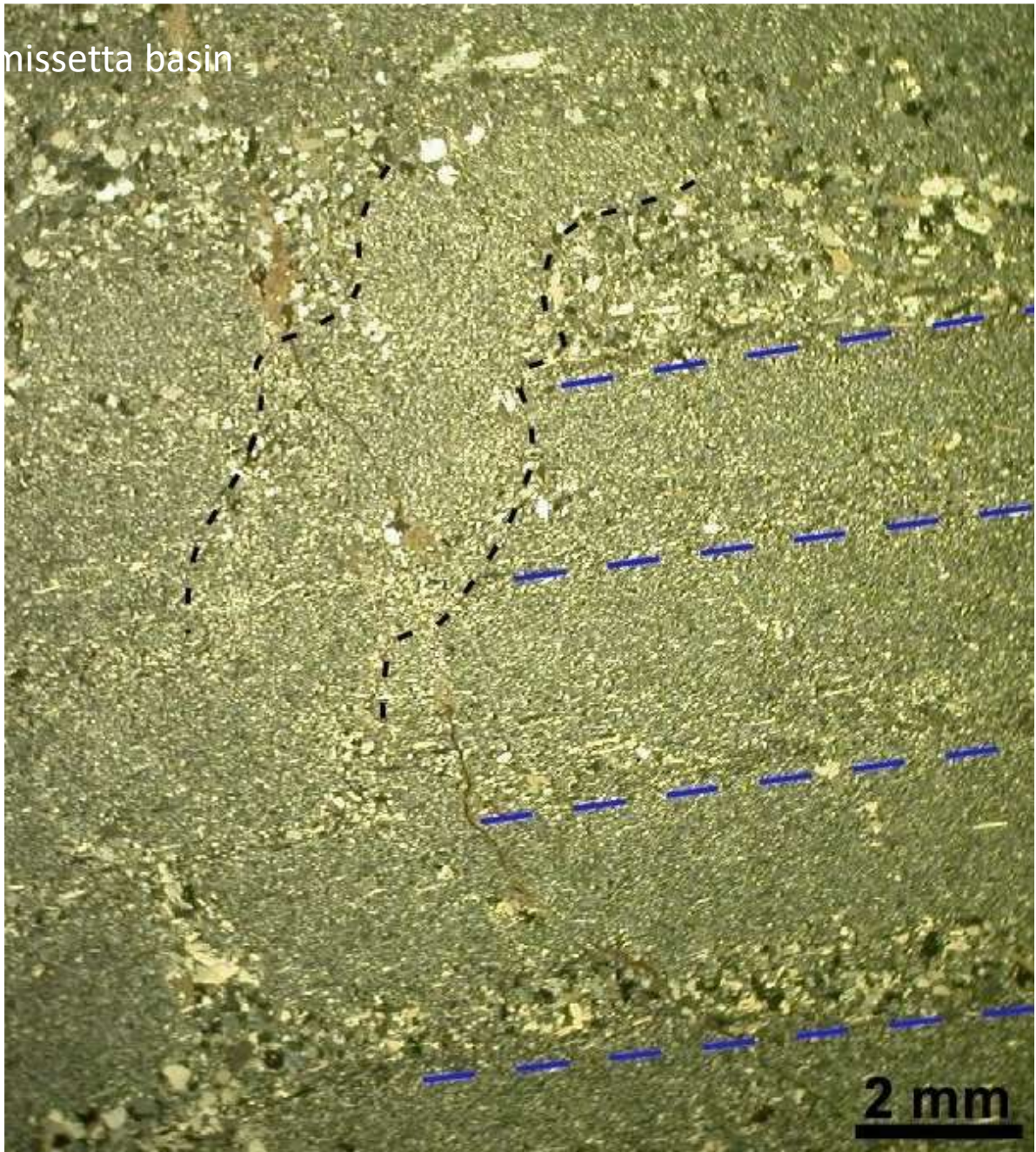

# Clastic evaporites (“deep” water)



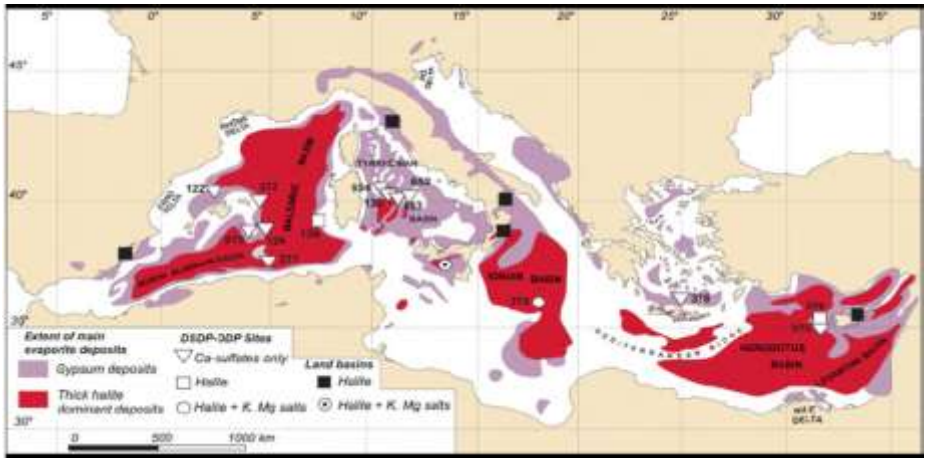



# Clastic evaporites

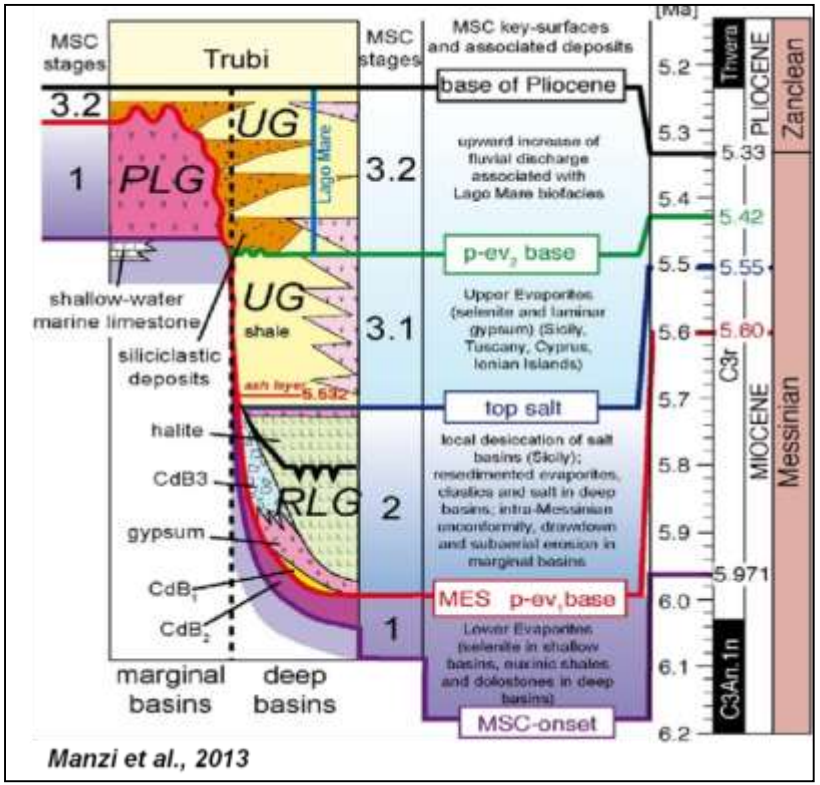


# Ancient evaporites (MSC)




Rouchy and Caruso 2006

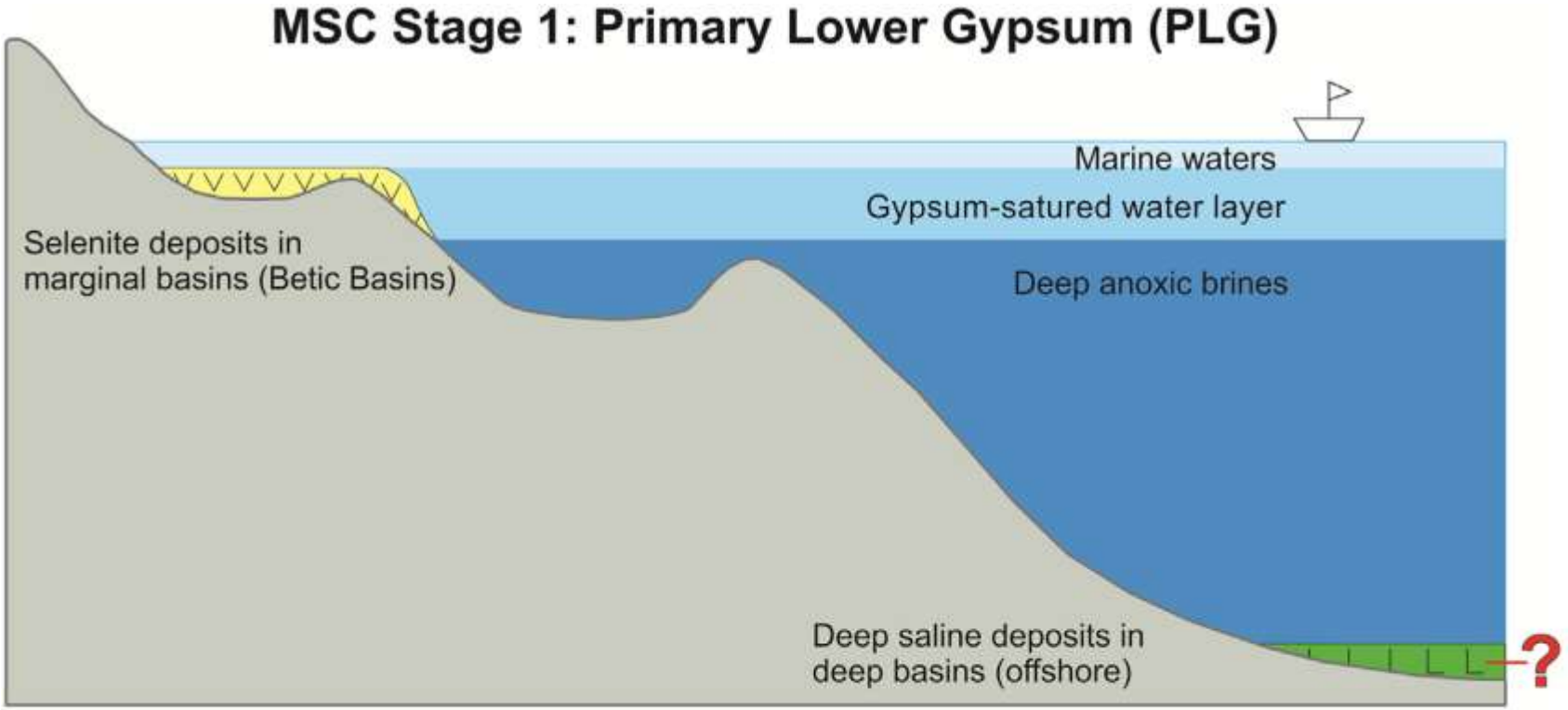



Interpretation of ancient marine evaporite deposits is difficult!

- No (few) clues to estimate water depth
- No modern analogues for very large and (relatively) deep basins (Salt giants)

This is partularly true for the wide array of Messinian evaporite facies (mostly gypsum and halite) of the Mediterranean!

# MSC gypsum deposits: the PLG unit (and lateral equivalents)

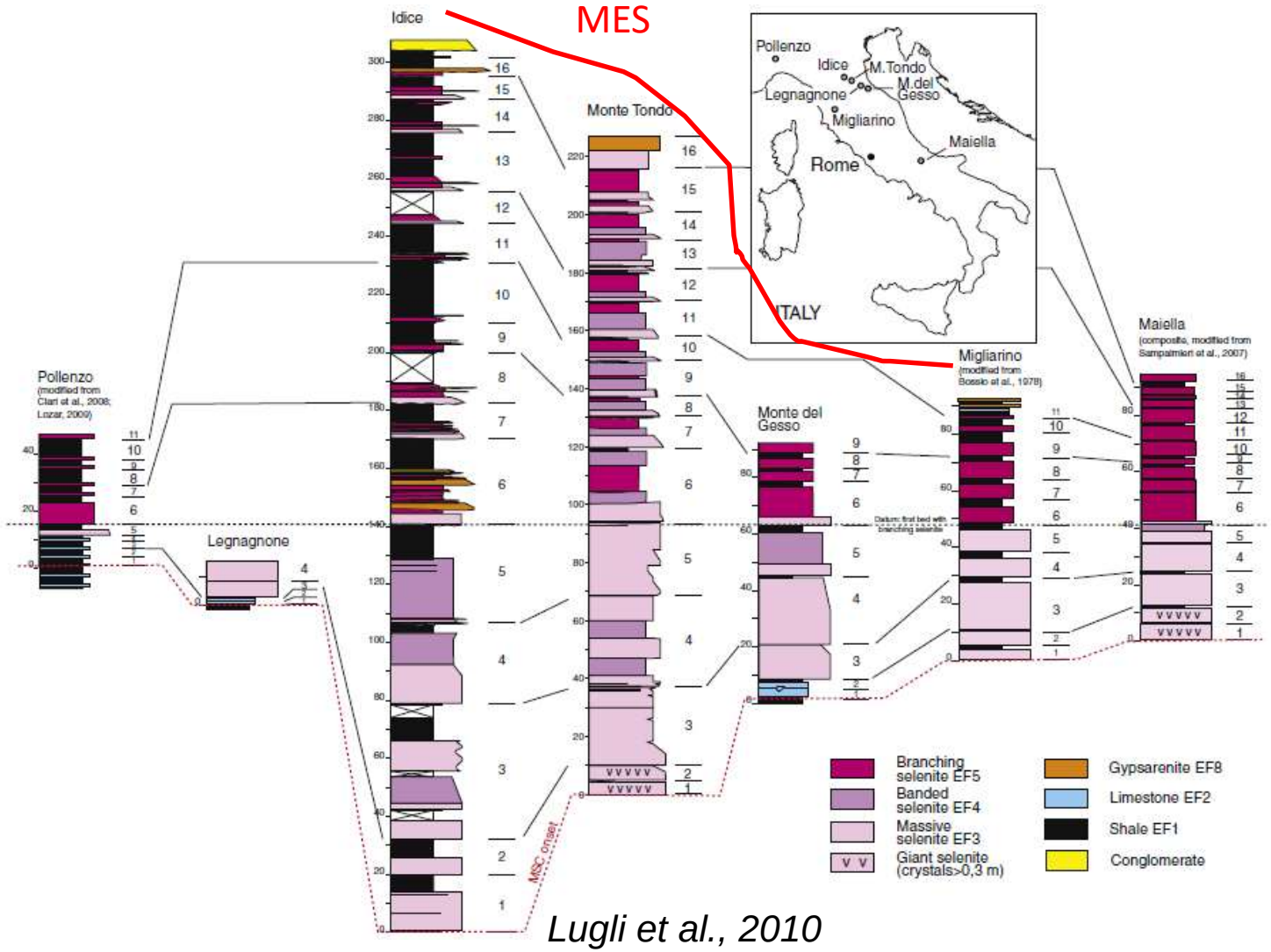



Garcia Veigas et al., 2018

Primary gypsum (bottom grown and laminar) in peripheral marginal basins within a gypsum saturated layer.

In intermediate to deep basinal areas, no gypsum but organic-rich shales and possibly halite (Melijson et al., 2019)

# PRIMARY LOWER GYPSUM UNIT (PLG) (5.97-5.60 Ma)




*Lugli et al., 2010*

# Messinian Lower Gypsum deposits

Thickness: 200 m

In < 300 kyr

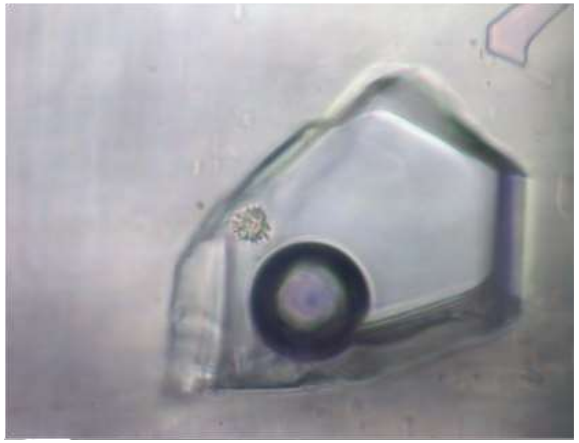
*Vena del gesso (Apennines, Italy)*


Vena del gesso (Apennines, Italy)

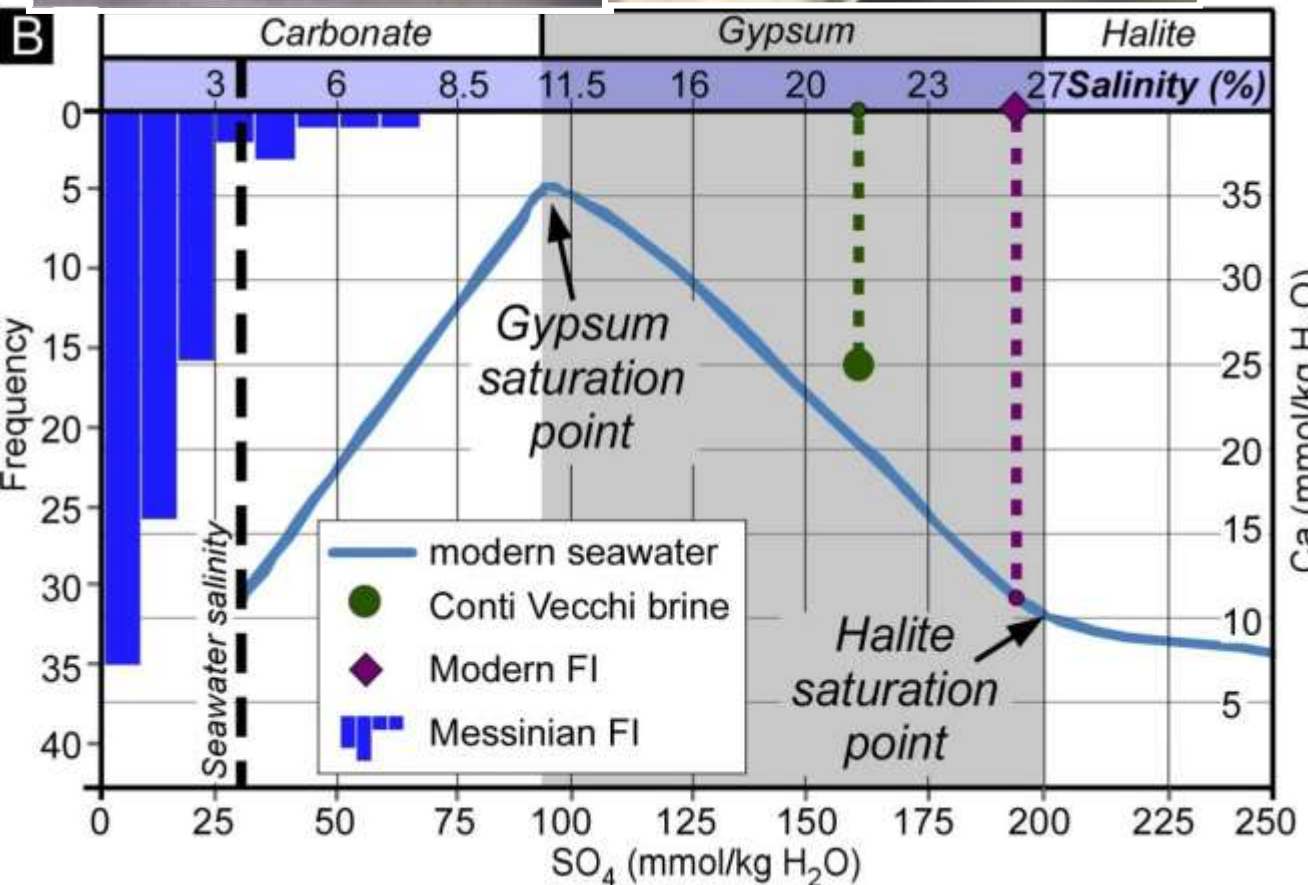
Vena del Gesso

*Brisighella quarry (Northern Apennines)*

# Salinity of the parent brines of massive selenite

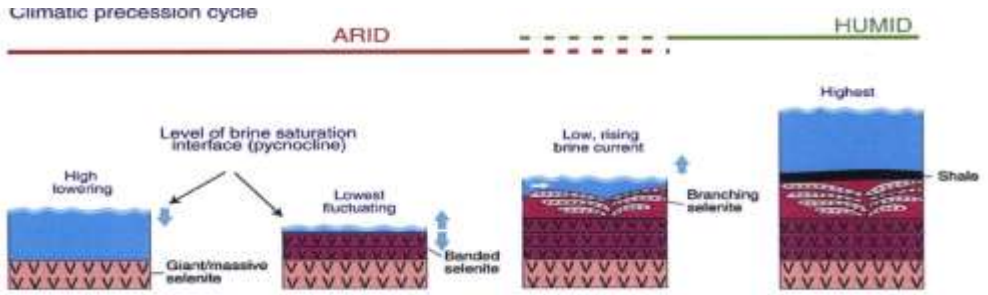


Lower salinity than not evaporated sewater (below the gyspum saturation point)

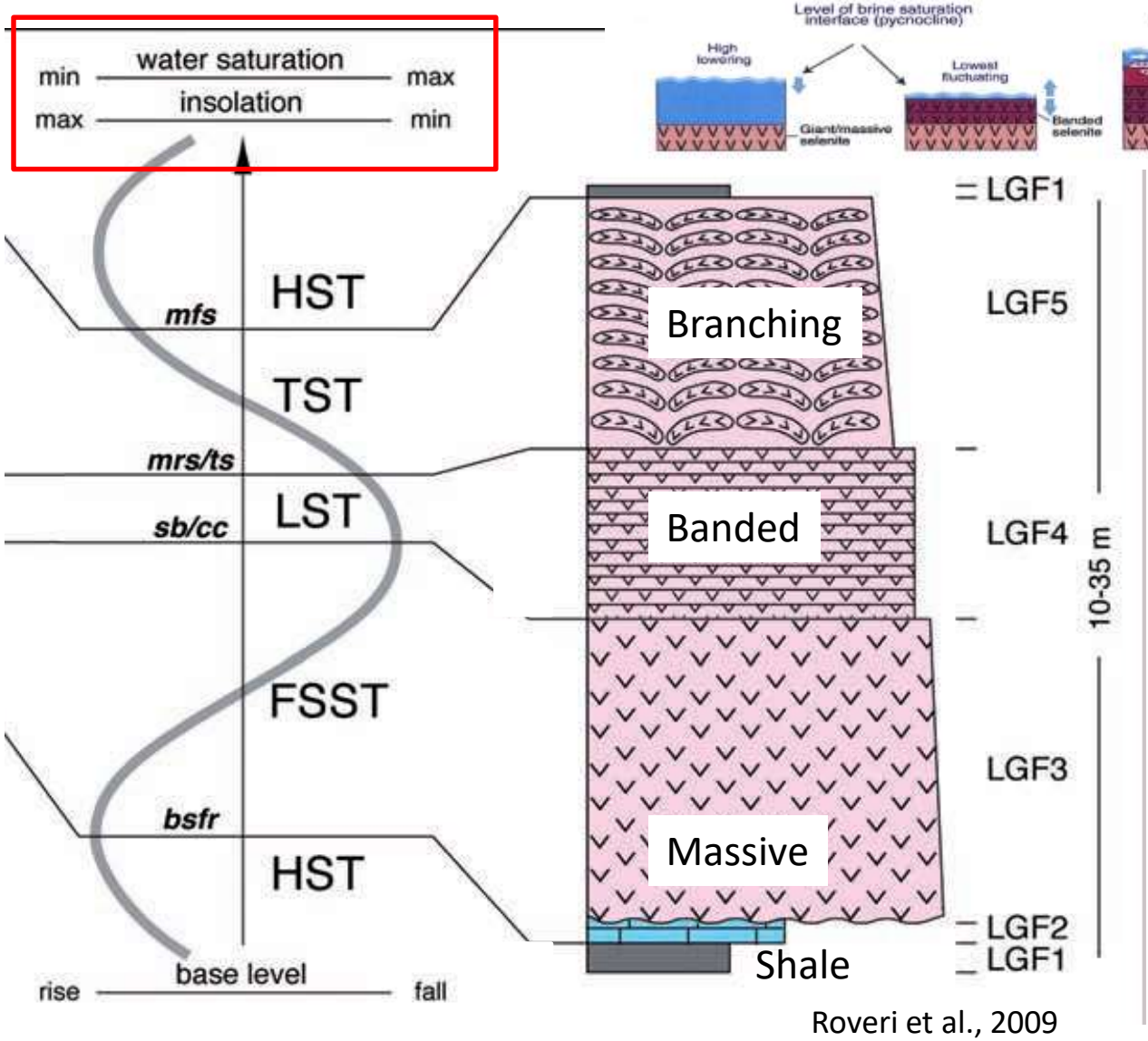


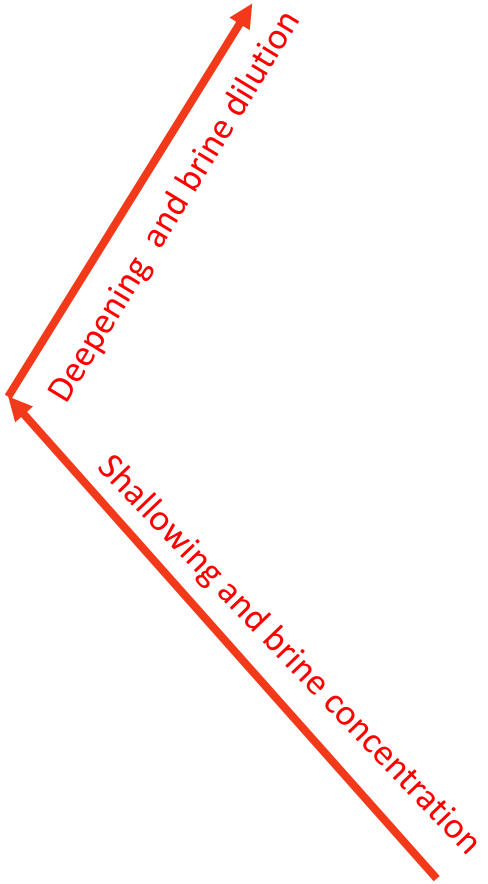

Natalicchio et al., 2014

# Ideal facies cycle in the PLG unit (Vena del Gesso)

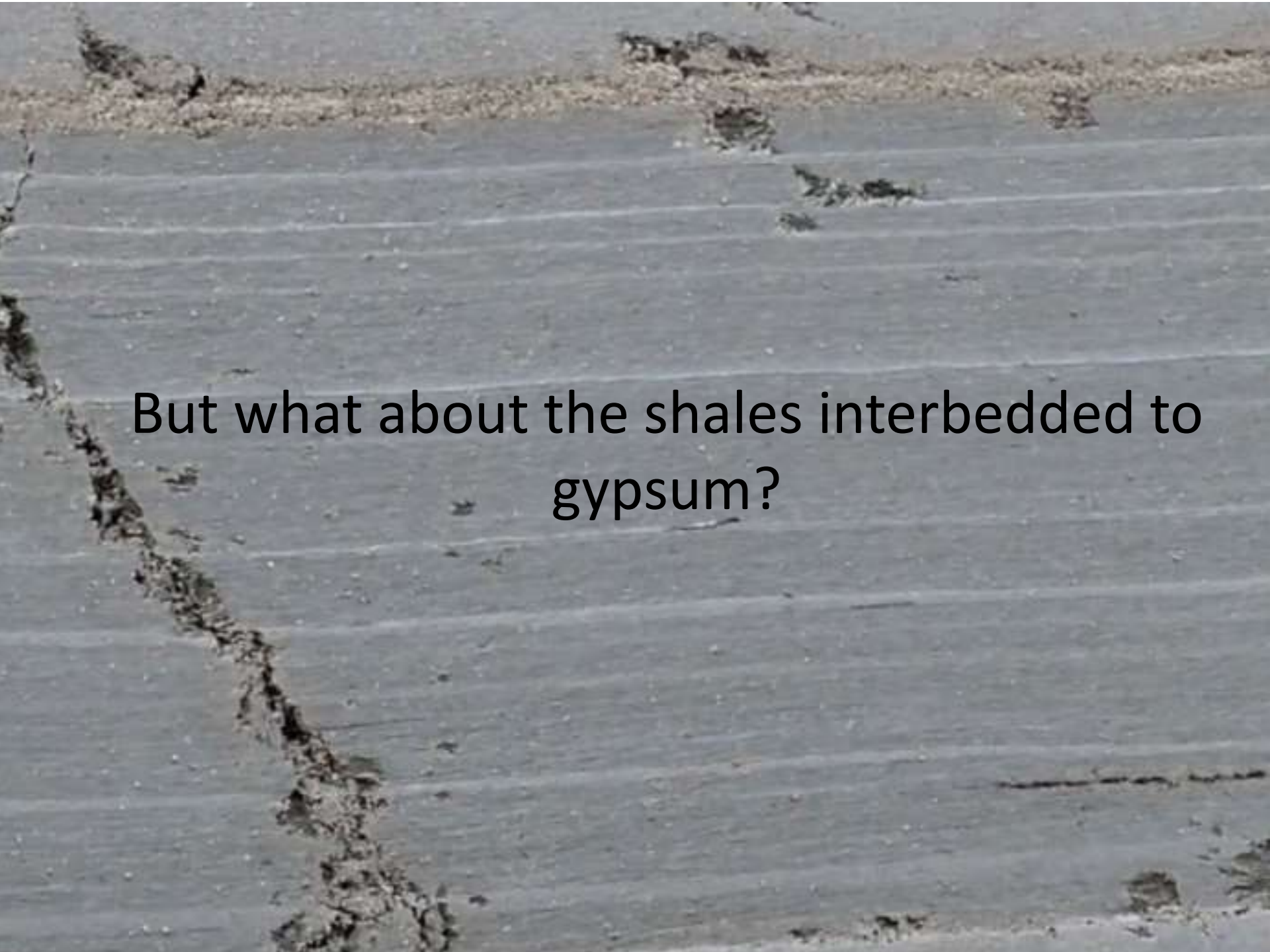



Lugli et al., 2010

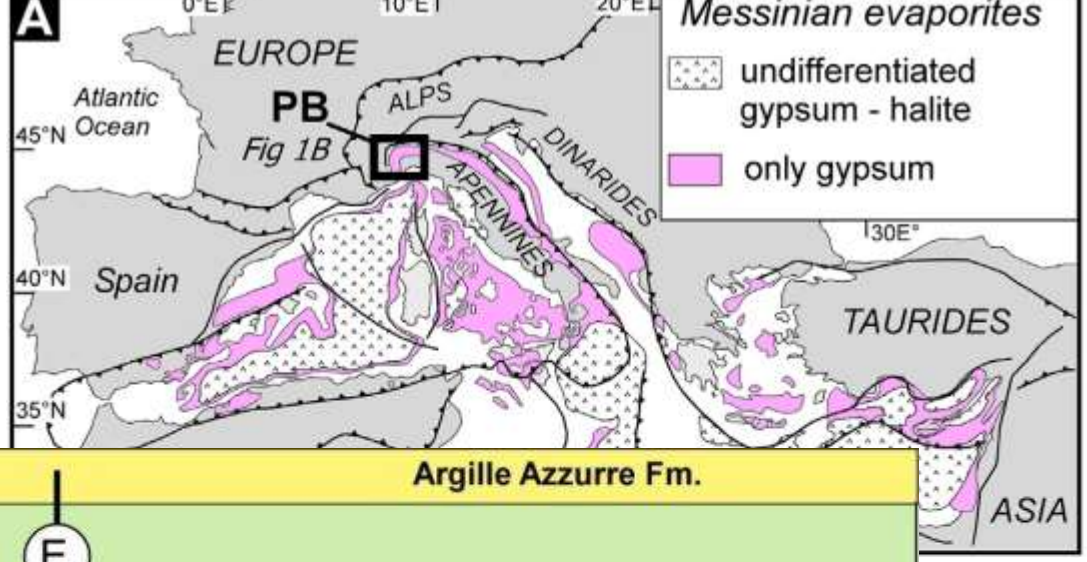


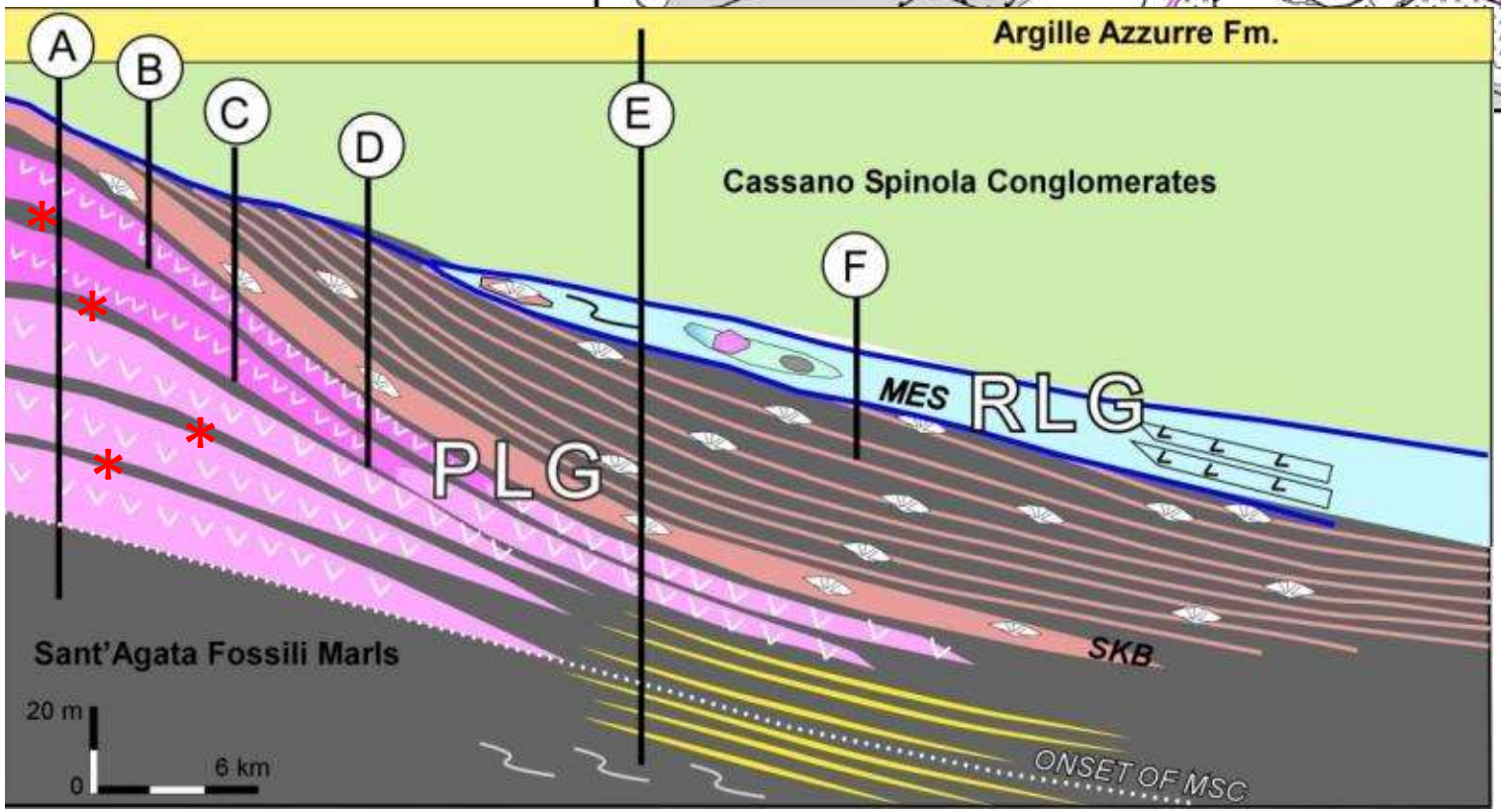




Roveri et al., 2009


But what about the shales interbedded to gypsum?

# Piedmont Basin




Gypsum (PLG5)

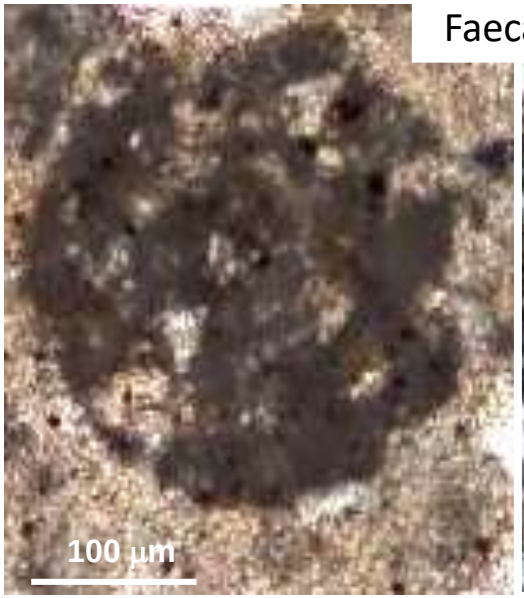

PRIMARY LOWER GYSPUM UNIT
10 cm

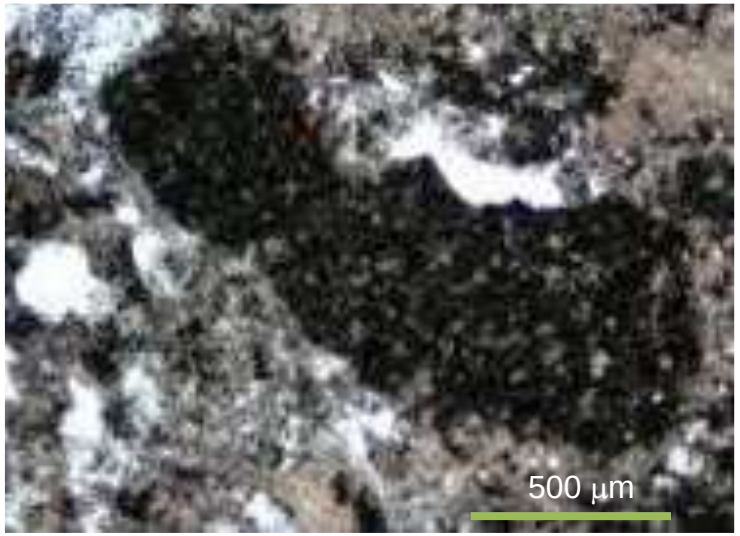

22
2cm
Filament layer

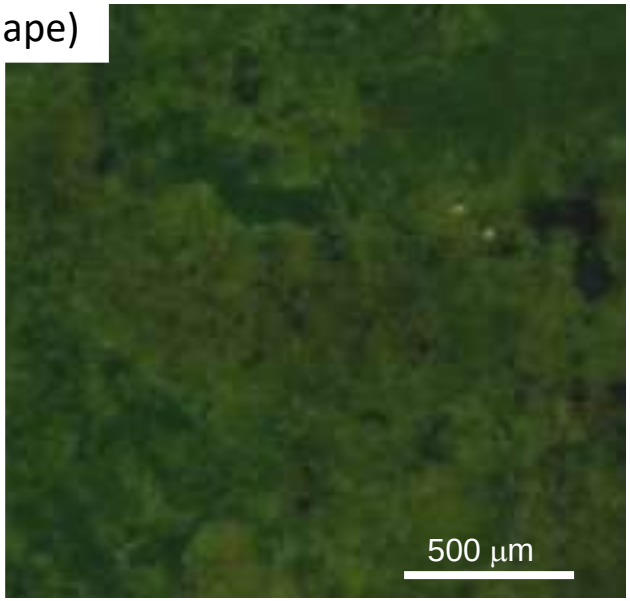

1 cm
Peloidal layer

# Peloidal layers

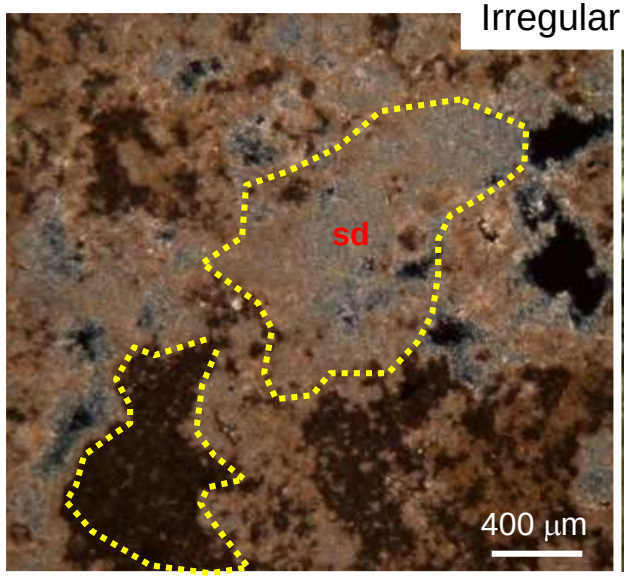
Faecal pellets (sharp boundaries and regular shape)

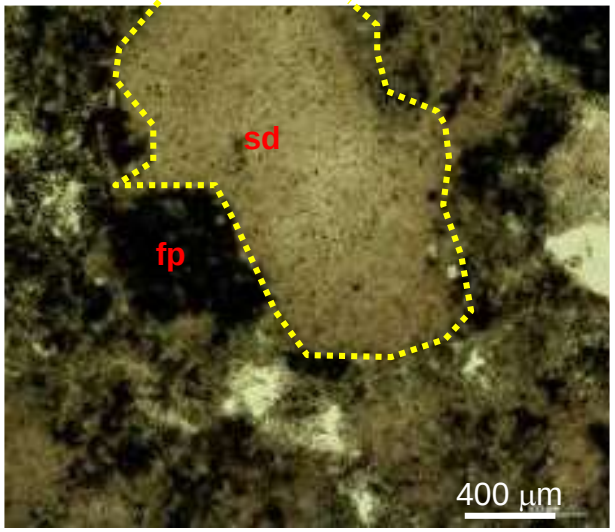


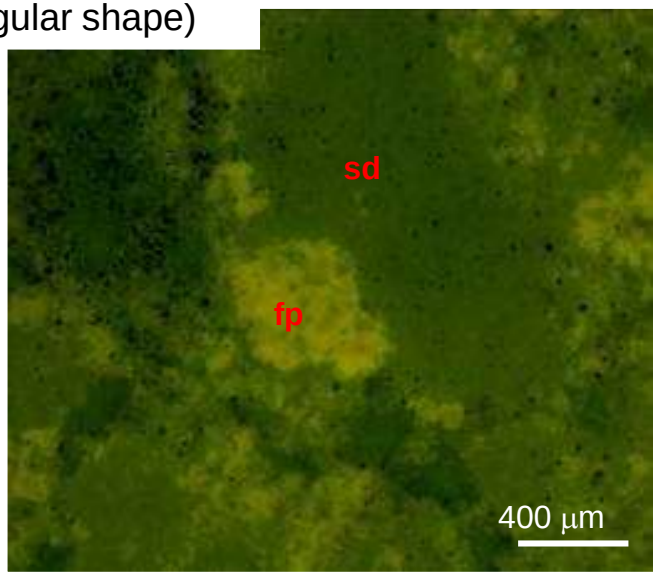



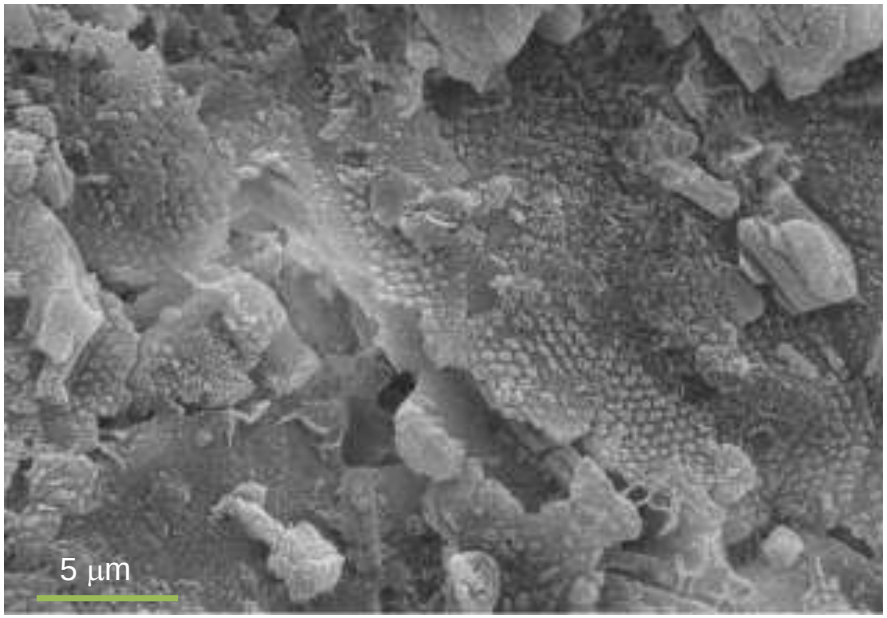

Irregular aggregates (diffuse boundaries, irregular shape)

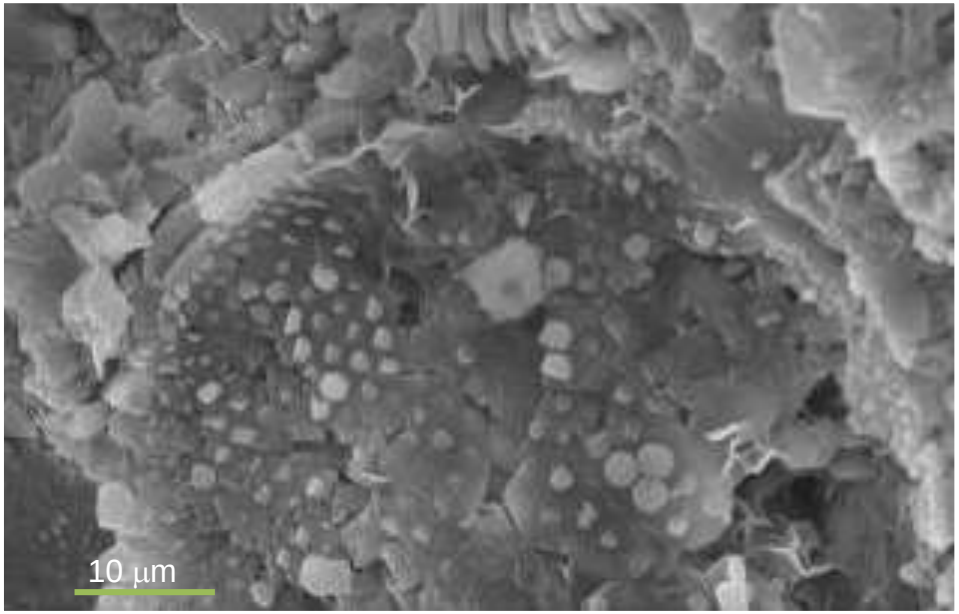


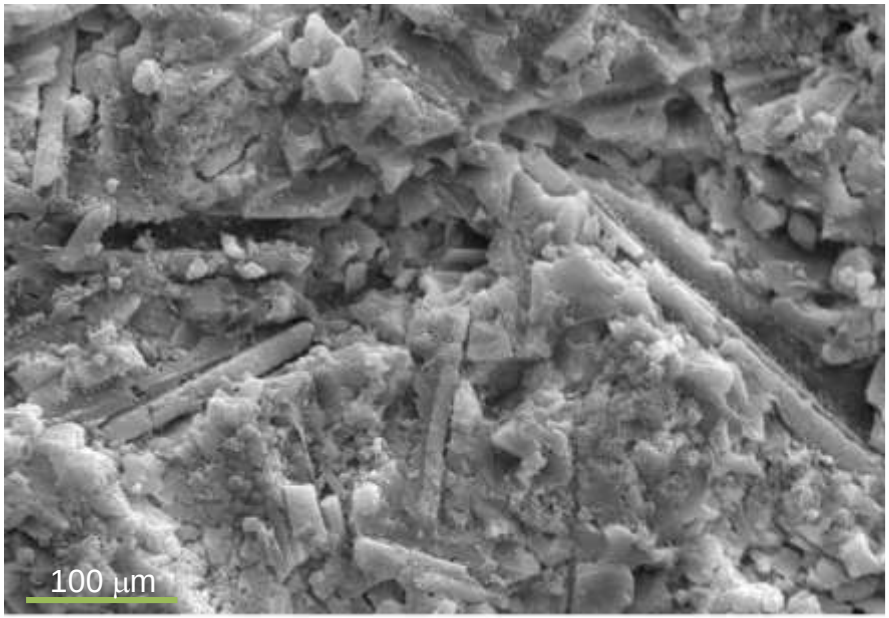



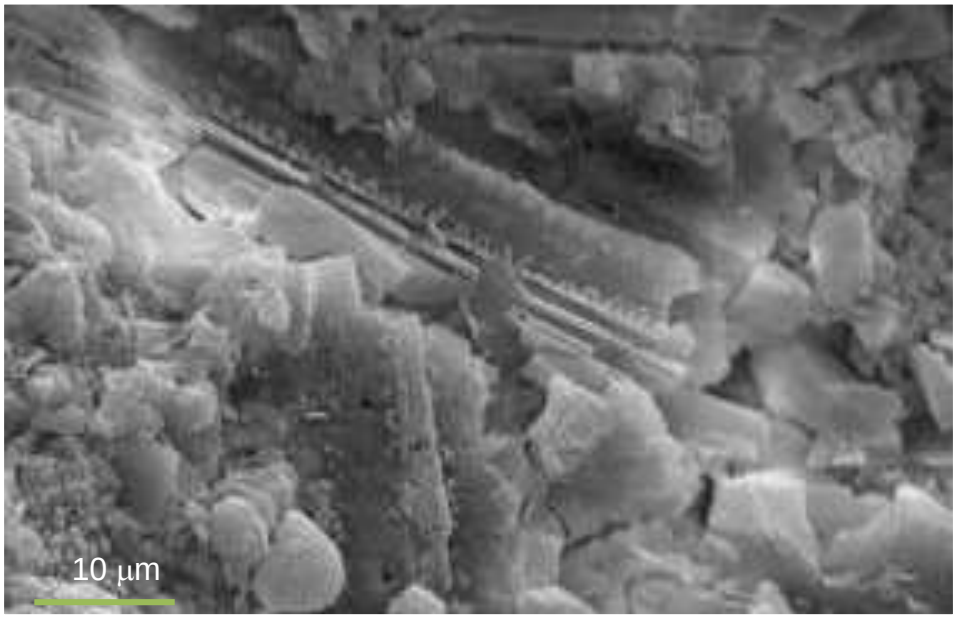



Ghost of diatoms within the aggregates.The skeleton is often dissolved and replicated by dolomite crystals



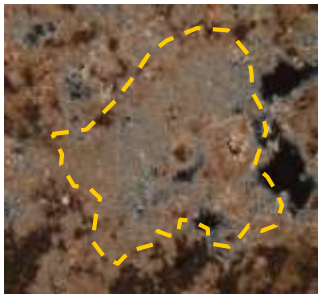



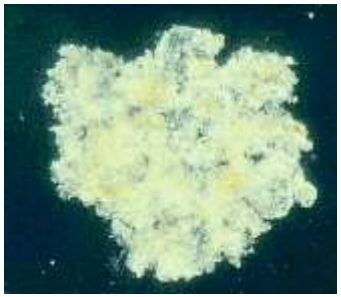



# Peloidal layers

**Irregular aggregates = marine snow** ⟷ **Faecal pellets**



**Messinian aggregate**



**Present-day marine snow**

**Present day faecal pellets**

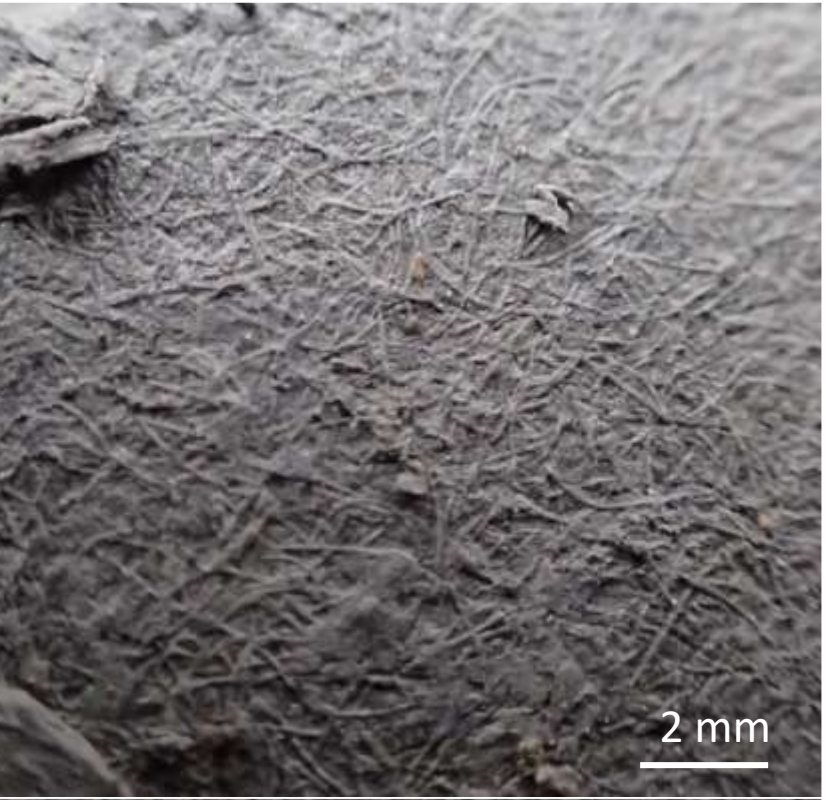
**Messinian peloids**

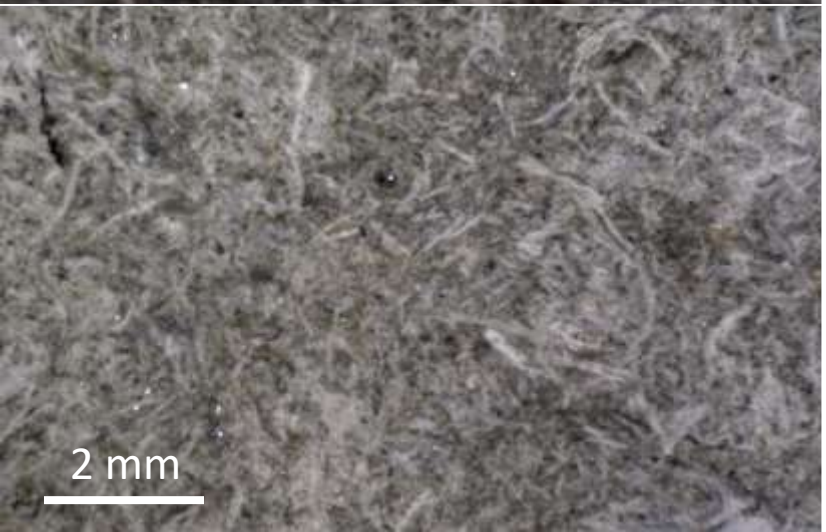
**PRESERVATION OF FLOCCULENT LAYERS**

✓Episodes of high organic productivity in the upper water column

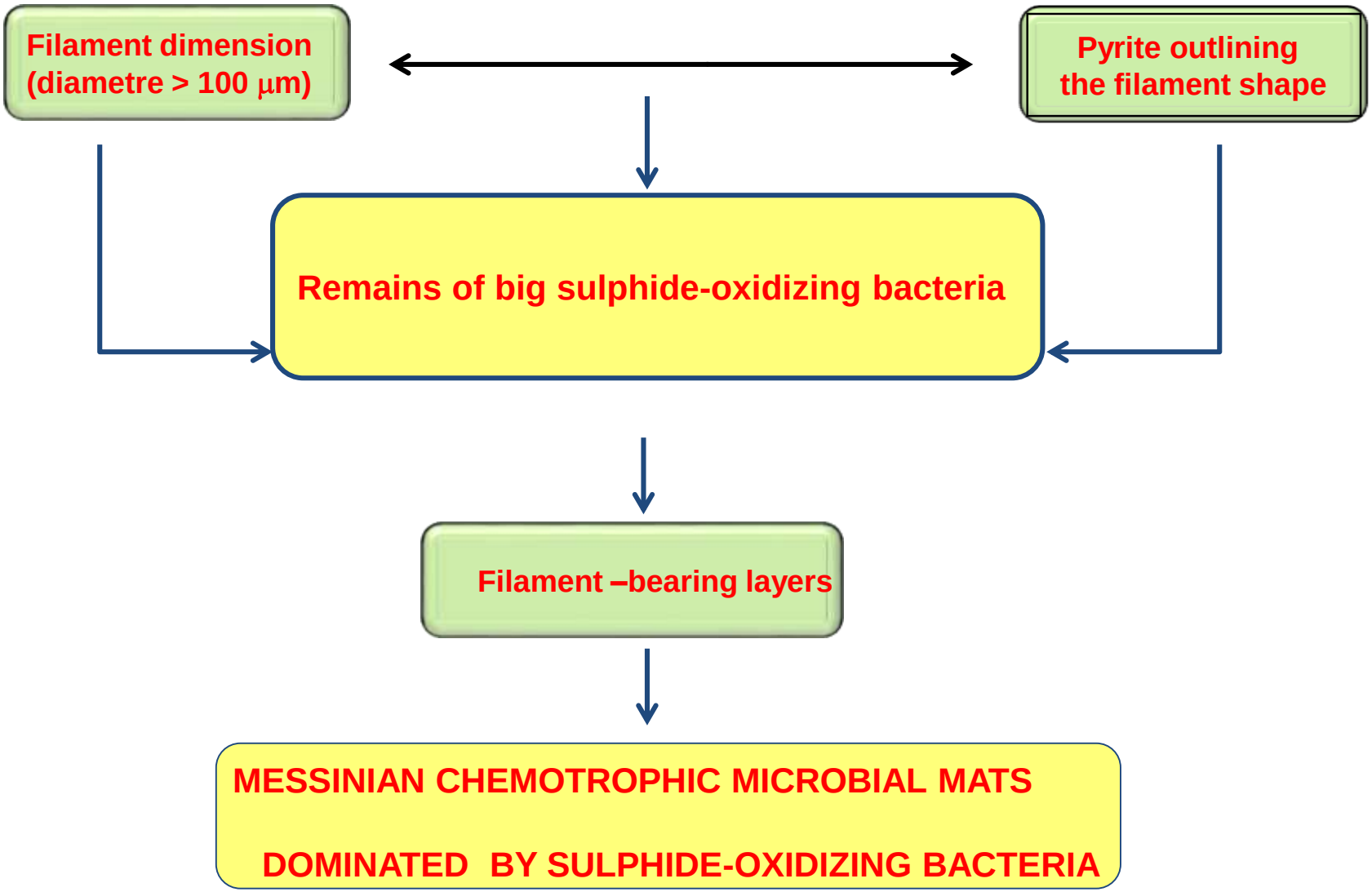
✓High rate of sulphate reduction and production of hydrogen sulphide

# Filament-bearing layers

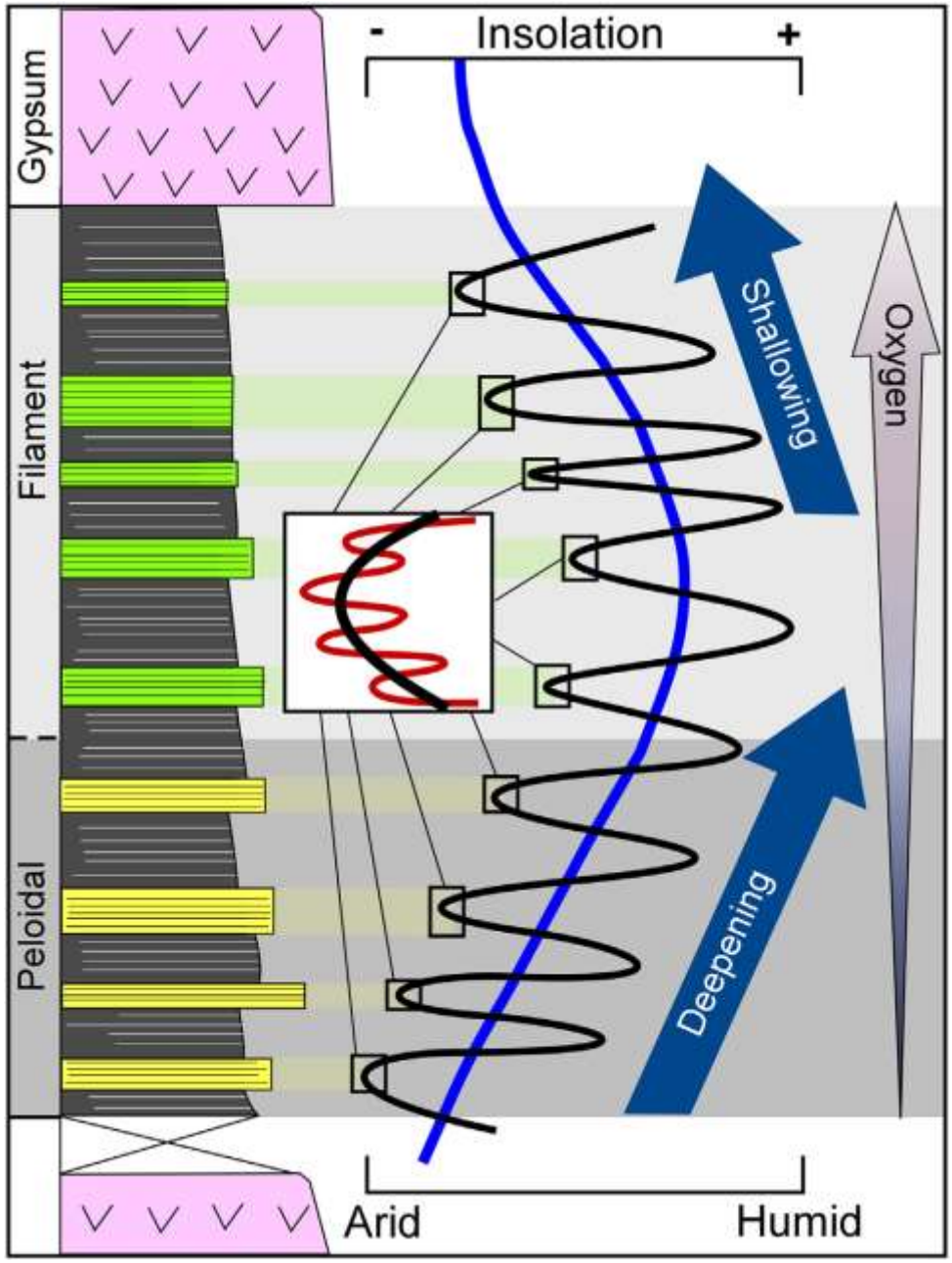


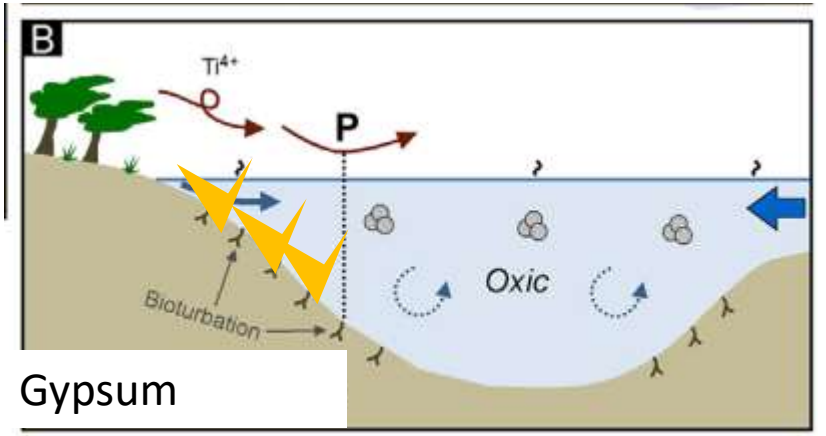




# Interpretation

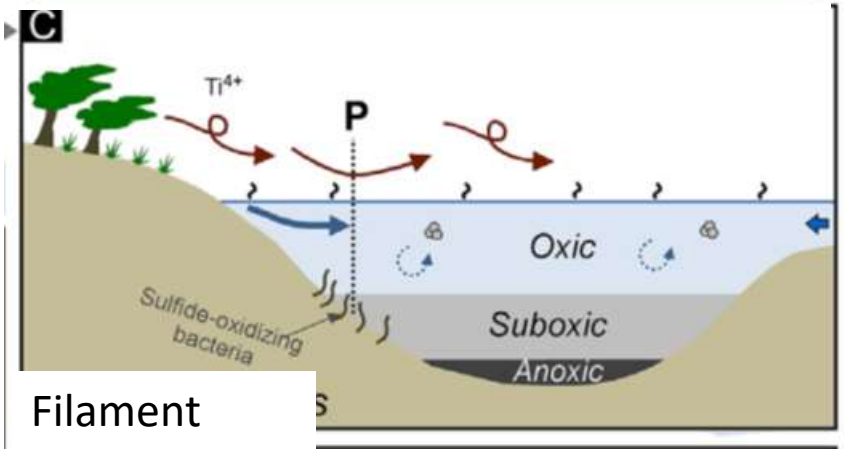


# Ideal facies cycle in the shales

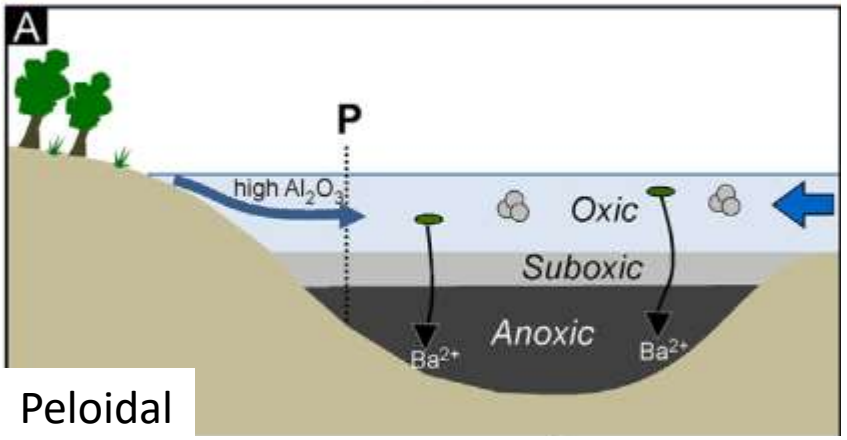



Gypsum

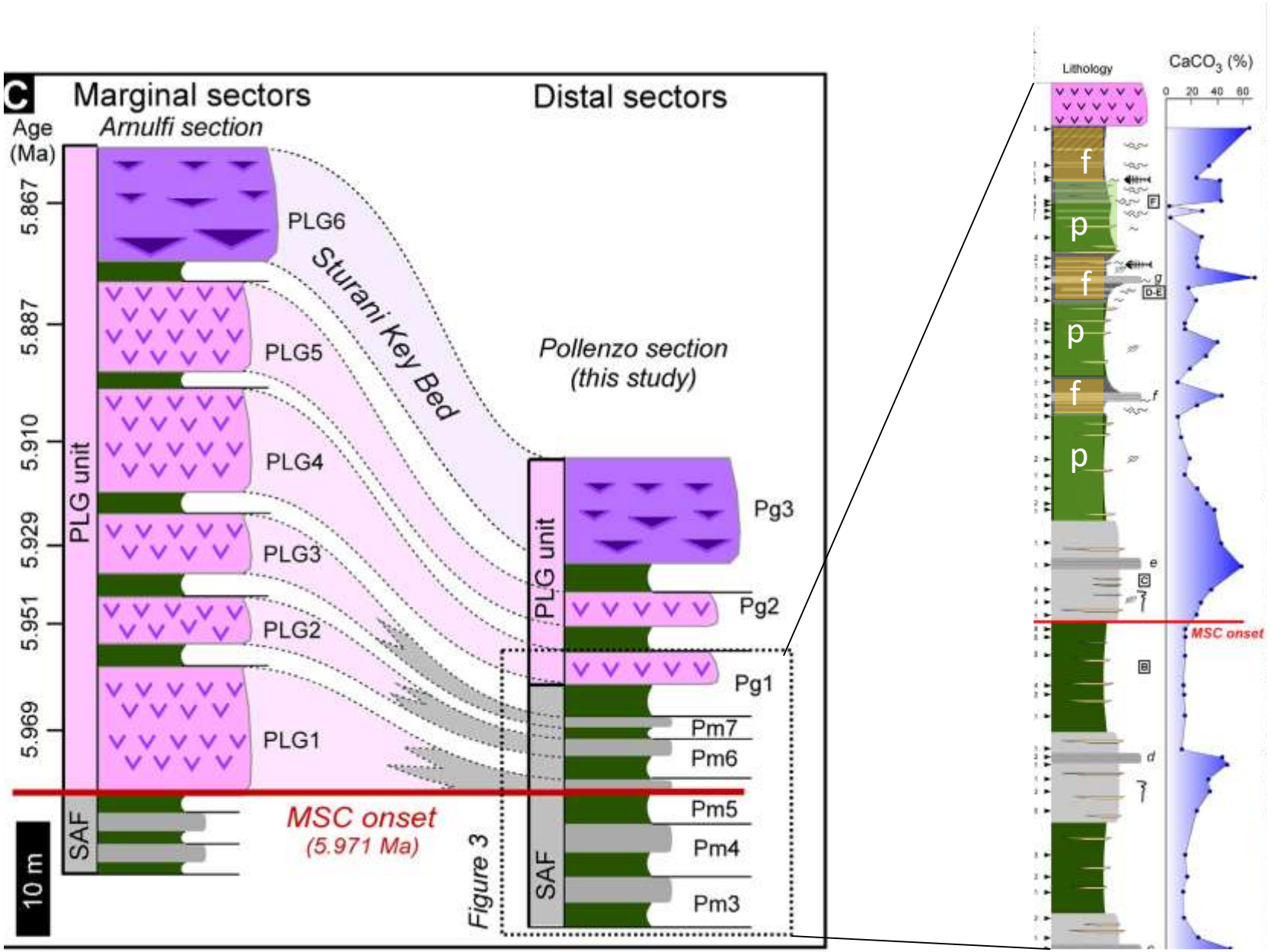



Filament




Peloidal

Similar stacking pattern in the deep water equivalents of marginal gypsum (Pollenzo section)




But now, let' move to organic geochemistry…..


Grazie per l’attenzione!