Textural Types of Evaporites in Holocene Sabkhas of Qatar and Their Geological Significance*

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Abstract

The growth habits and distribution of evaporite minerals in sabkhas of Qatar provide insights in their origins and models for the interpretation of ancient evaporites. The Holocene forms a 3–10 km wide coastal plain around the peninsula of Qatar. Rates of evaporation exceed precipitation by a factor of 1000 for six or more months of the year. In such an arid climate, bodies of standing water and evaporation in the capillary fringe promote rapid formation of evaporites. Evaporite minerals are common throughout the 3–10 meters of the Holocene. Gypsum dominates (8–20%), followed by halite (6–10%), with minor anhydrite, calcite, dolomite and probably attapulgite. The most obvious textural differences occur between subaqueous mineral phases deposited in standing water, those formed in the capillary fringe, and precipitates near the water table. Subaqueous crystals are clear, devoid of much sediment, relatively large (mm-cm sized), laminated and may show compressional ridges (tepees) at the surface. Gypsum forms vertically oriented, 'fish-tail' twins in vertical arrays. Halite occurs as hoppers and vertical prisms. Halite is an indicator of a marine water source. Thick subaqueous deposits only occur where there has been a marine source. Layers of crystals nucleated along chemical contacts in the water column and fish-tail twin habits are diagnostic. Evaporites formed in the capillary fringe are typically displacive, incorporate sediment, finely crystalline or poikilotopic, showing variable degree of crystallographic ordering. Micritic coatings are common. Halite is a common pore-filling, often leaving molds. Capillary fringe evaporites habits and morphology reflect seasonal changes in water chemistry. Evaporites formed at the water table are poikilotopic and may/may not be euhedral. This style of predominantly gypsum cementation has not been documented previously. Desert rose twins are the most well know water table morphology. Layers may extend over kilometers, reducing interparticle pore space by 20–30%. Crystals grow by interparticle cementation with little/no replacement. All styles of evaporite cementation are driven by extreme aridity of the climate. Millimeter sized crystals can grow in a few months, a geological instant. Limiting factors on growth rates of evaporites are seasonal water chemistry fluctuations and in some cases, limited supply of marine waters. Surface evaporites in Holocene export plumes into underlying bedrock.

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Outline

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- Summary
- Database
- Geological setting and climate of Qatar
- Distribution of evaporites
- Evaporite mineralogy
- Textural and genetic types of evaporites
- Dynamics of evaporite growth
  - the Evaporite Factory
- Dolomite and halite
- Impact reservoir quality

Summary

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- **Mineralogy** - Gypsum, followed by halite and anhydrite. Dolomite and palygorskite (attapulgite) are widespread, occurring in trace amounts

- **Origins** Evaporites accumulate in two end-member settings:
  - Subaqueous- precipitated from standing water
    Time range- Perennial lakes- 1-2 ka
    Sabkha depressions- seasonal flooding/drying
  - Within sediments- interparticle pore filling, formed by precipitation from water films in capillary zone or from a solution in a phreatic zone

- **Dynamics-** Geologically/economically significant amounts of evaporites can form in a few thousand years
  1. Significant sediment pore volume reduction
  2. The evaporite factory- comparable to the carbonate factory
  3. Capillary evaporation generates brine plumes that can modify older, underlying and adjacent sediments

Database

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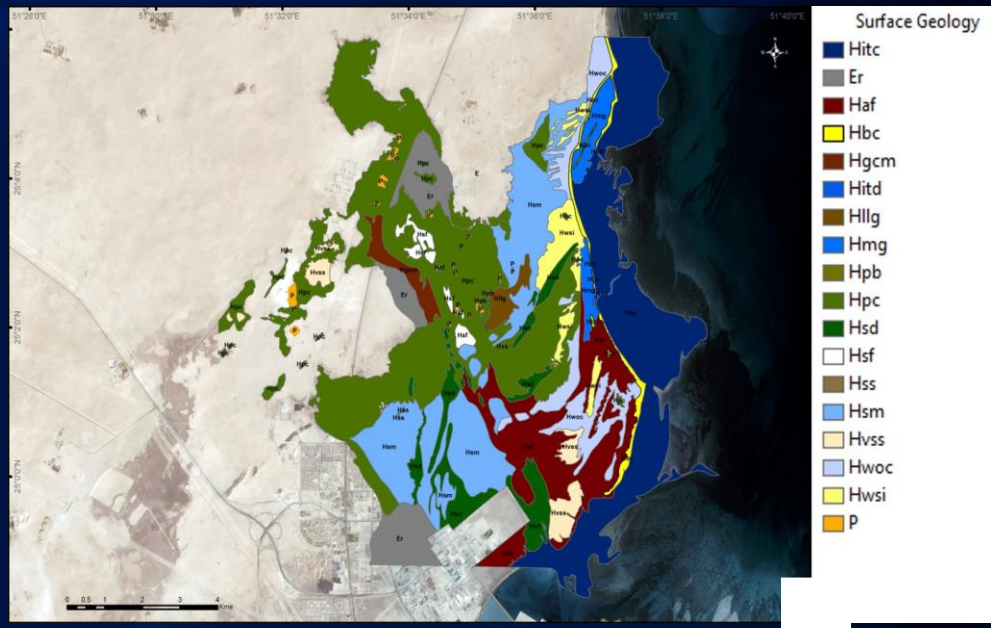
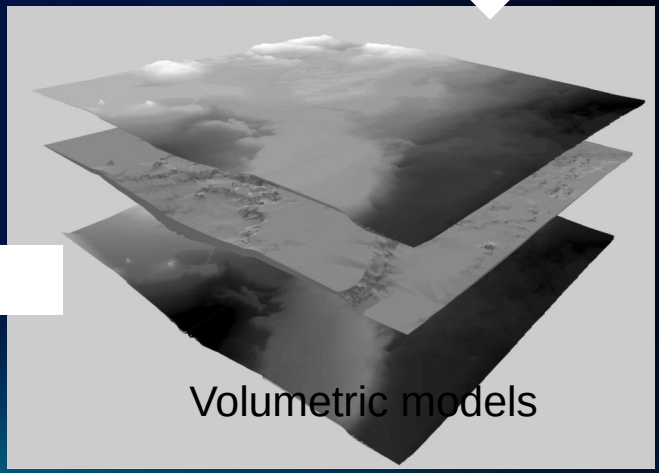
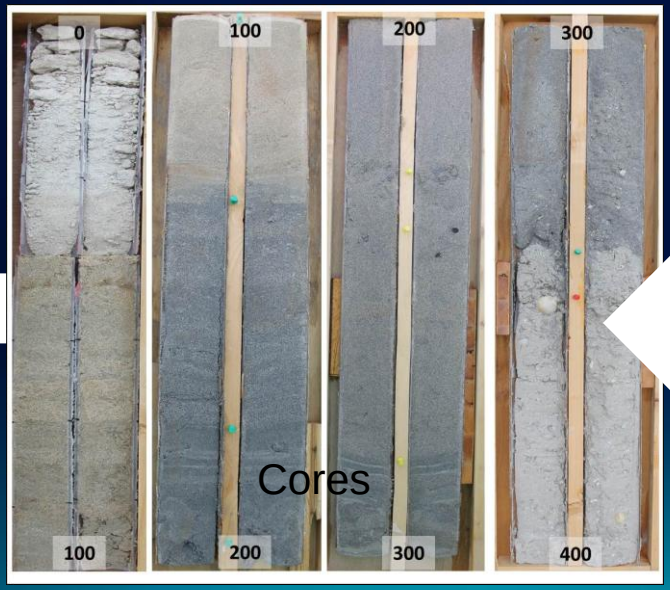
1. 15 year study of Holocene of Qatar
2. 1:30,000 mapping focal areas
3. Countrywide ArcGIS
4. Volumetric models for 2 locations
5. PhD Studies- Didi Ooi Sher Mei
6. ~ 60 water chemistry samples- elevations- water property data
7. >200 Radiocarbon age dates
8. Mapping many major industrial sites in country
9. 300 thin sections; over 1000 hand samples
10. Cores 60 industrial wells
11. Cores 20 research wells (1-12 m)



Detailed maps



Volumetric models



Cores

Analyses

Database- Access to industrial sites and data

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Dry excavation:
3 km offshore
3 m water depth
-11 m excavation

Unique data=new observations

Onshore excavation pumped dry below water table

Qatar Geological Setting

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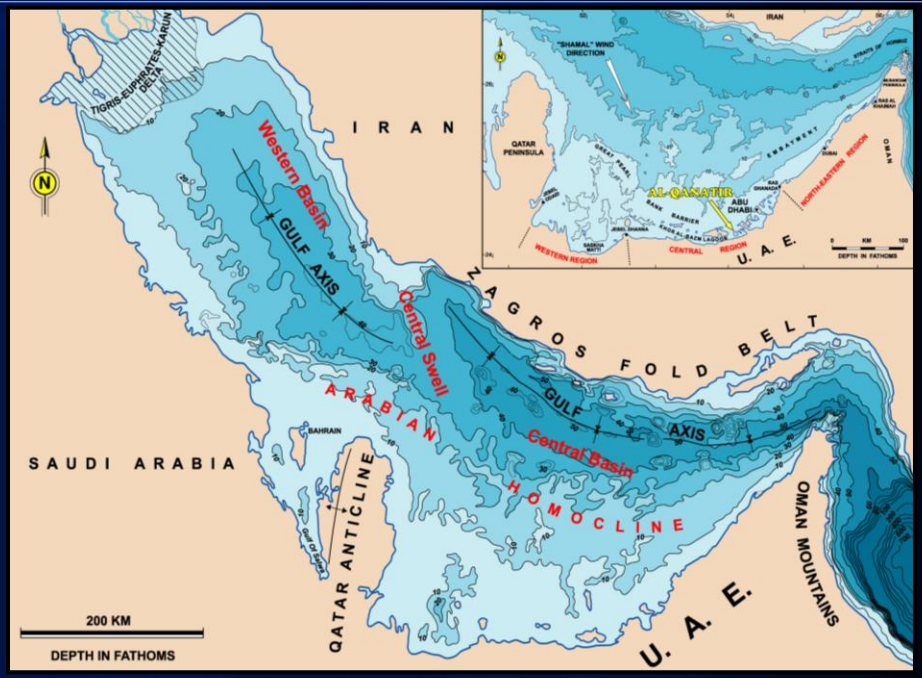
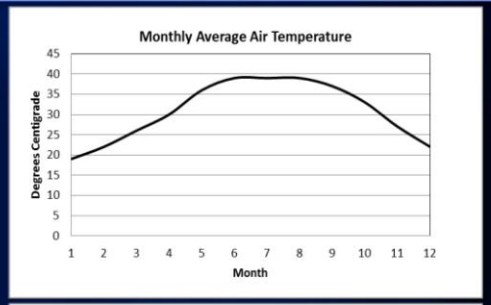
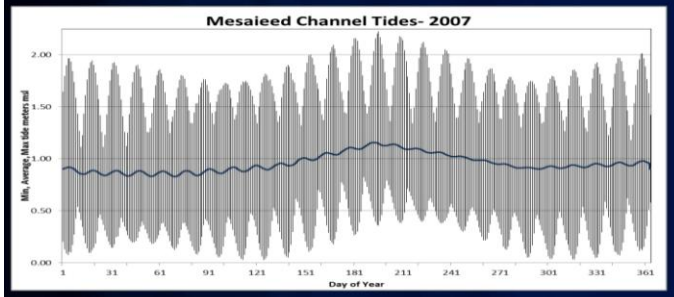


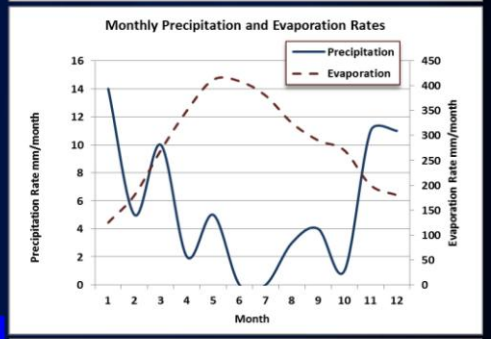
- Prominent peninsula extends into Arabian Gulf
- Southern margin of Arabian homocline
- Weather and circulation comes from NW
- Unusual setting; arid climate, surrounded by water

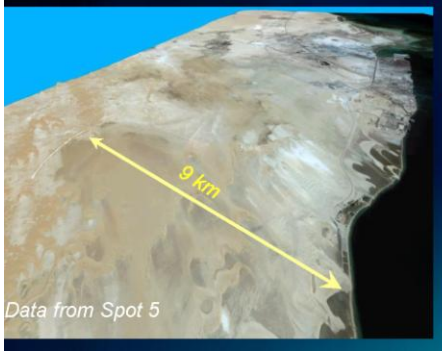
Climate- drives evaporation AAPG 2015

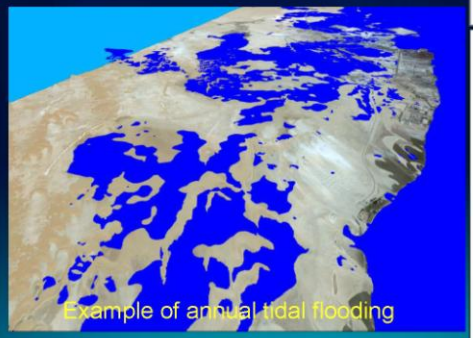
1. High air and water temperatures
2. Long dry season- evaporation exceeds precipitation for 9 months
3. Steady winds draw water to surface
4. Tides flood inland 4-6 km, in mid year- fill vadose zone each year; source of solutes

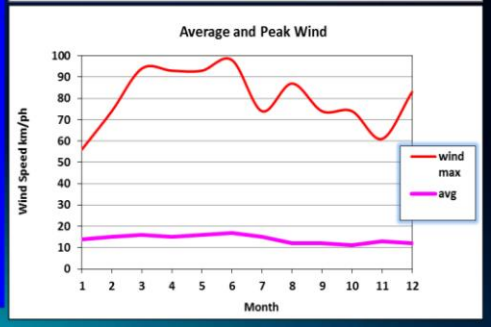




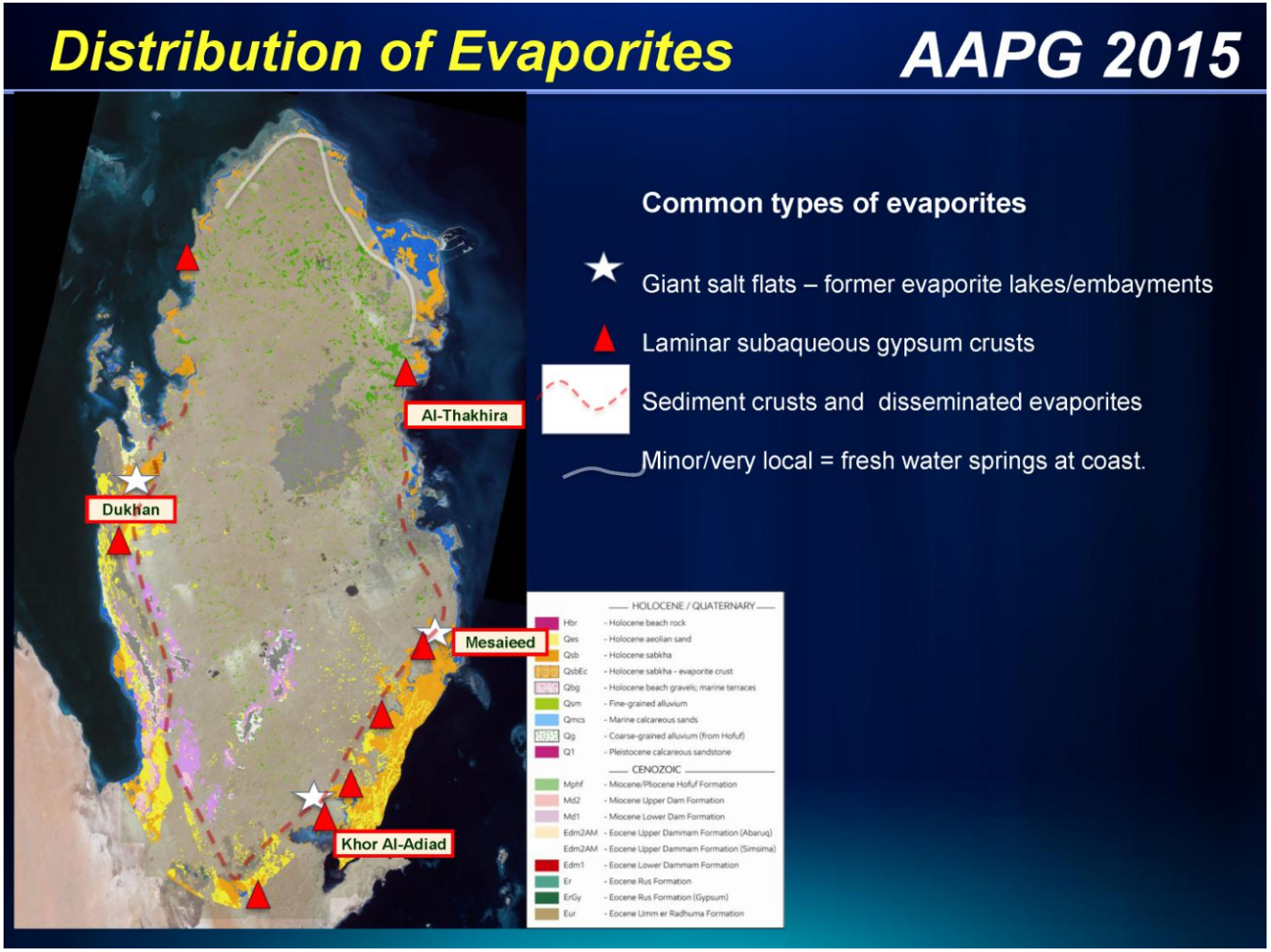








Presenter's notes: Shown here, three plots of yearly average climate for a 10-year period. Air temperatures > 30° C seven months/year. Same period, rainfall drops off and evaporation exceeds precipitation by a factor of 500-1000 seven months/year. Always a gentle 10-15 mph breeze. Two other factors are important in evaporite formation: very low relief coastal plain and seasonal tidal flooding.



Presenter's notes: Shown here surface geological map orange and yellow polygons are difference Holocene sediments. Within these areas, evaporites occur as giant salt flats (stars) ~ 5 km^2. Triangles denote laminar subaqueous gypsum crusts. Erosional remnants cover similar areas. Dashed line shows where evaporites occur in sediments. Solid white line shows where they are absent- this coincides with areas where fresh water springs occurred at coast.

Evaporite Mineralogy

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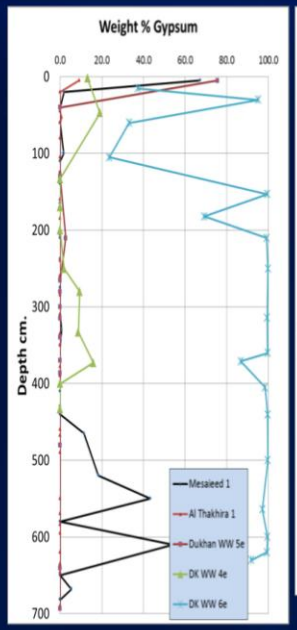
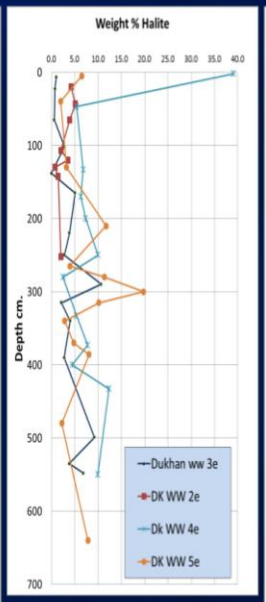
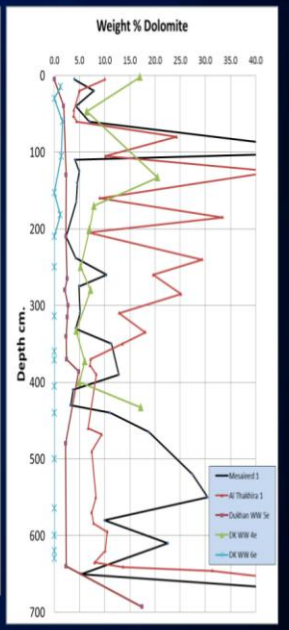
		Arithmetic Average	Minimum	Maximum
Clastic	Quartz	33.2	0.0	92.4
	K Feldspar	2.8	0.0	12.2
	Plagioclase	3.3	0.0	18.3
	Clastic Sum	***39.2***	***0.0***	***94.4***
Carbonate	Calcite	11.2	0.0	82.7
	Dolomite	8.6	0.0	90.2
	Mg-calcite	4.3	0.0	38.4
	Aragonite	10.5	0.0	86.5
	Magnesite	0.1	0.0	16.7
Evaporite	Halite	8.0	0.0	99.3
	Gypsum	16.0	0.0	99.8
	Bassanite	0.4	0.0	26.7
	Anhydrite	2.1	0.0	94.0
	Celestine	0.0	0.0	4.0
Clay	*Total Clay*	***1.0***	***0.0***	***15.1***
	Palygorskite	4.4	0.0	9.9
	Illite	0.9	0.0	6.1
	Kaolinite	0.3	0.0	2.0
	Chlorite	0.4	0.0	3.0

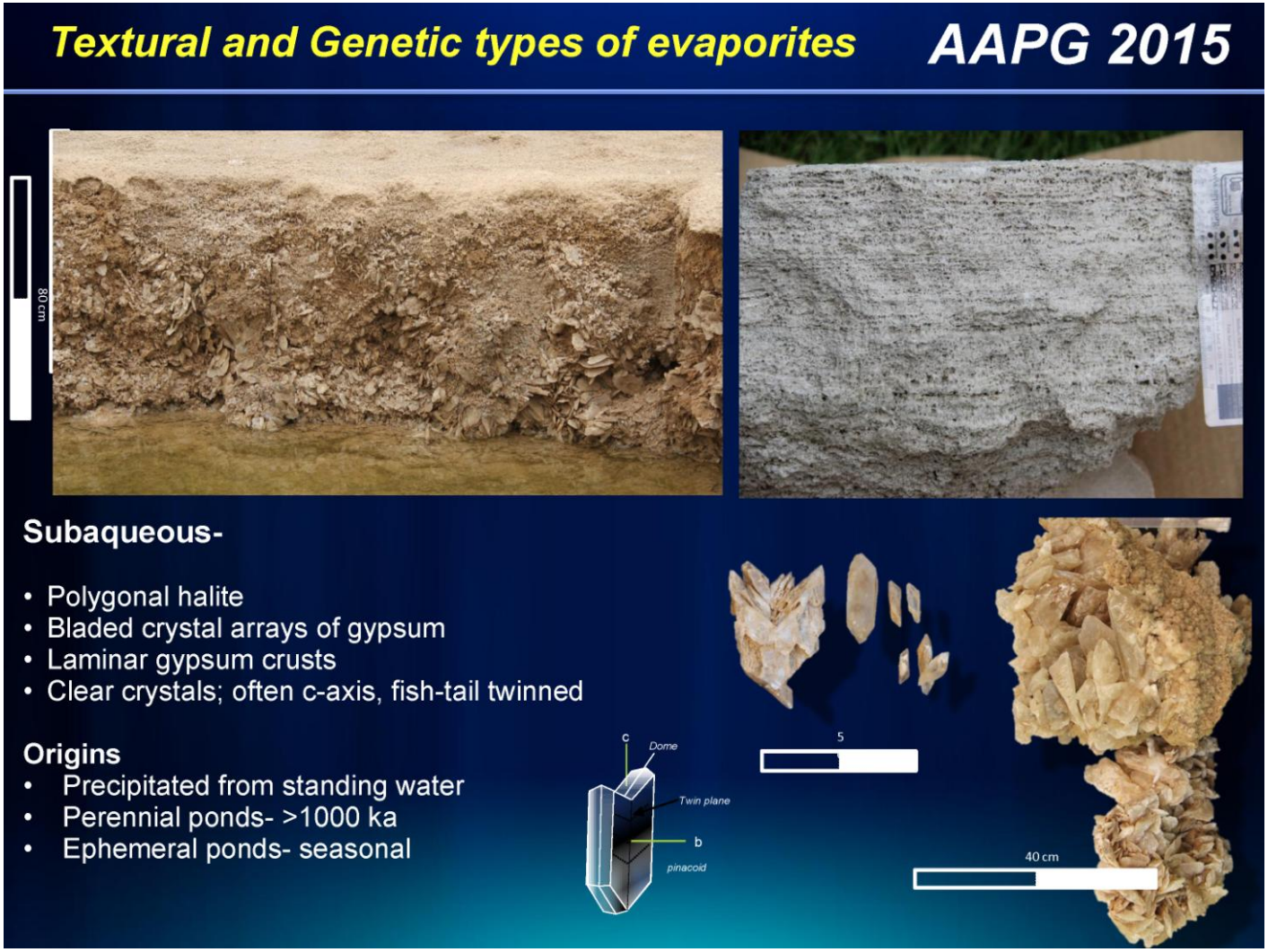




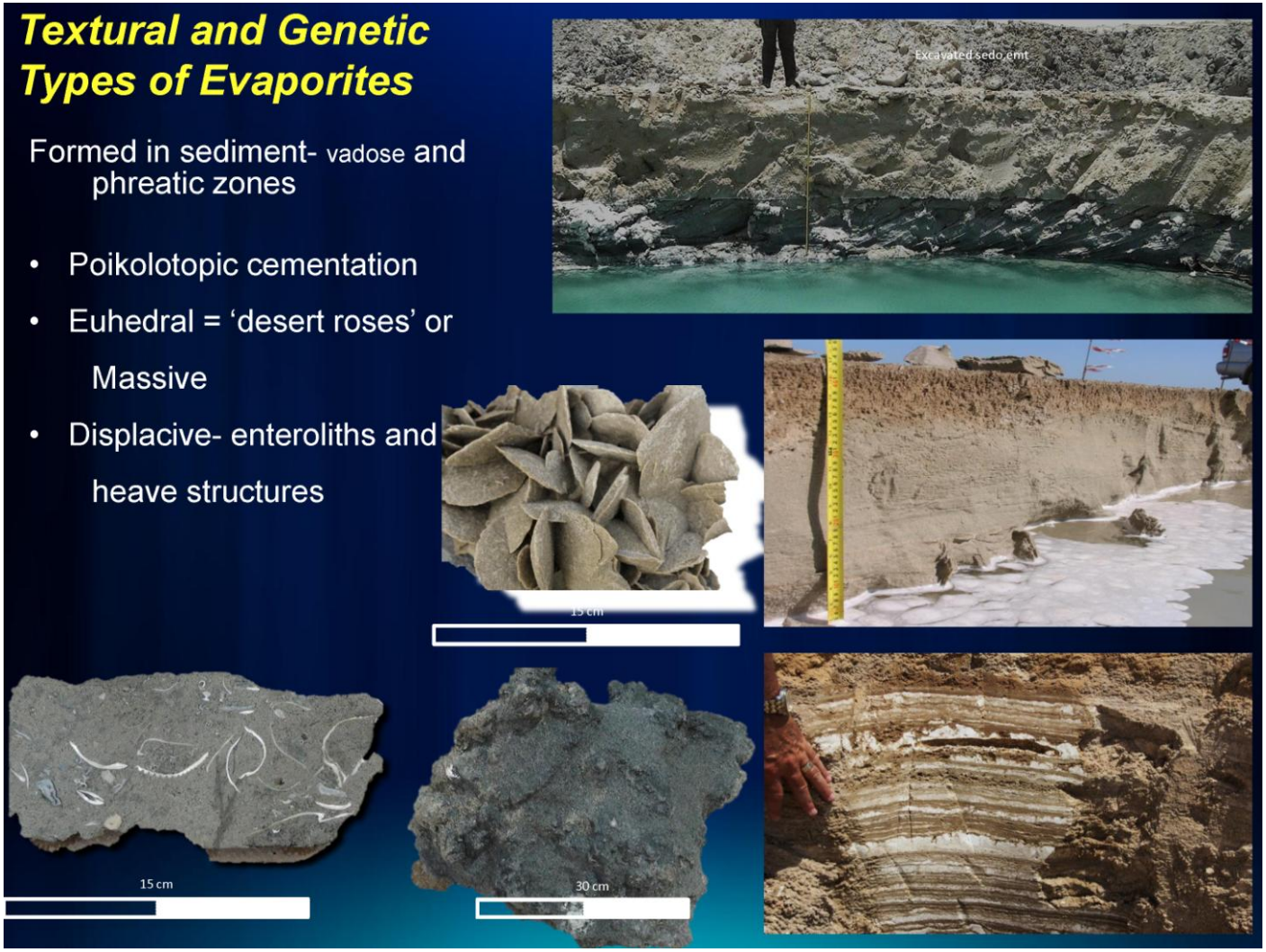


- Variable mixture of carbonate and clastic sediments; minor clays
- ~ 10% gypsum is present throughout; higher % in surface crusts and evaporite lakes
- 5-10% halite is present throughout; higher in crusts
- Dolomite- variable; occurs as detrital grains and authigenic grain coatings.

Presenter's notes: Table on left shows average composition of sabkha sediments based on 200 xrds
Variable admixture clastic and carbonate sands- dolomite sand and for that matter dolomite dust is very common.- atmospheric dust is 26% dolomite. Shown on right are profiles from wells – from surface to 7 m.



Presenter's notes: Next is a description of textural types of gypsum. First are those formed by direct precipitation from standing water. Crystals are clear and free of inclusions-elongate or bladed. C axis fishtail twins are common. Radial arrays as you see here, of laminar crusts.
Remnants of ponds.



Presenter's notes: At the other end, gypsum precipitated in sediment. Styles of cementation vary with whether precipitation occurred in vadose or phreatic zone and with water salinity. Gypsum roses occur near water- example in situ roses, massive cementation, cementation along cross lamina. Anhydrite enteroliths- vadose feature of pore waters at salt saturation. Styles of evaporite cementation are unique to modes of formation.

The Evaporite Factory

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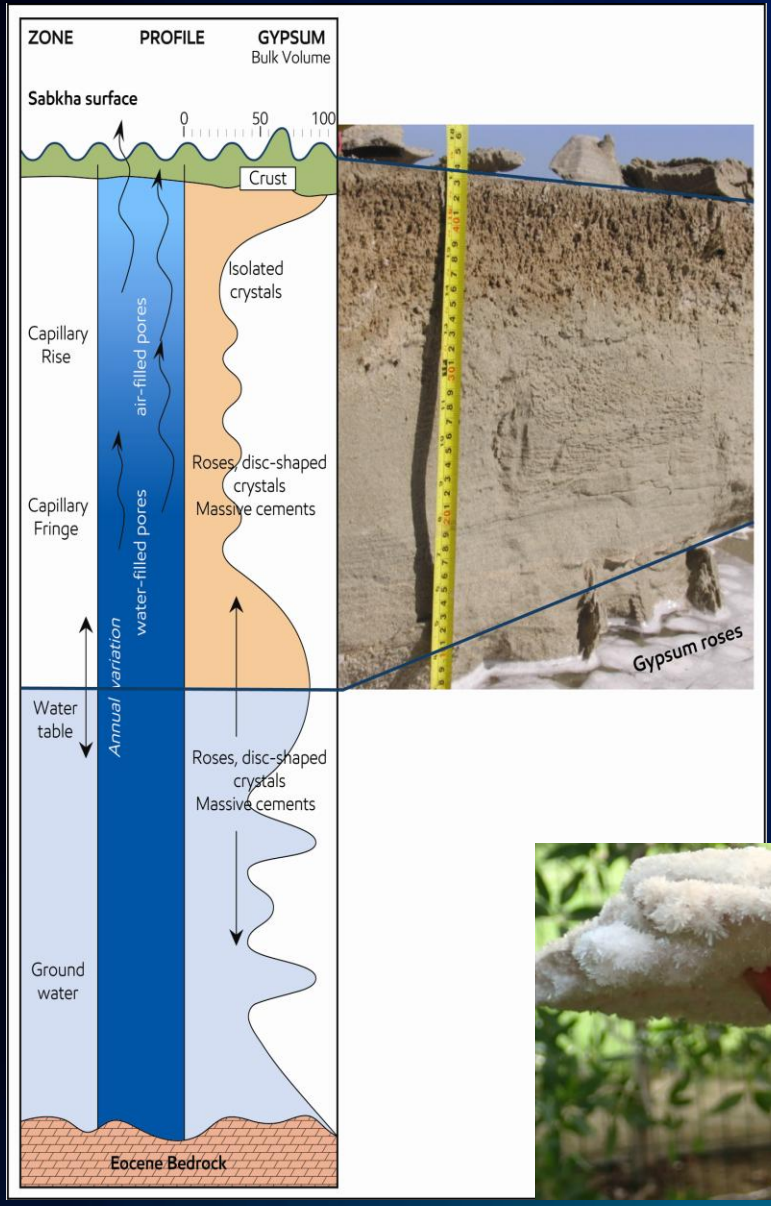

Model

- High rates of evaporation from either surface ponds or groundwater close to the surface create brines that cement the Holocene and underlying or adjacent sediments
- Both marine and meteoric water sources
- Massive halite is only found in settings with a marine source
- Dynamic process
    1. High evaporation rates
    2. Large capillary forces: affinity for water, small grain size, very high surface areas
    3. 1 cubic meter of sand= 1.25 x 10^9 grains
       4.9 x 10^4 km^2 area

Example of a gypsum crust formed in a single season

Mesaieed example of an evaporite factory

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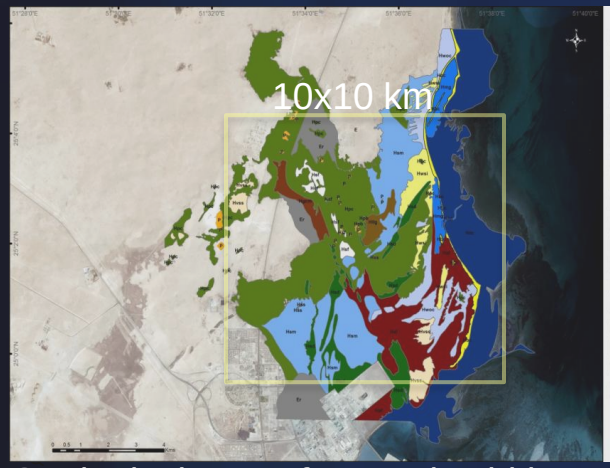
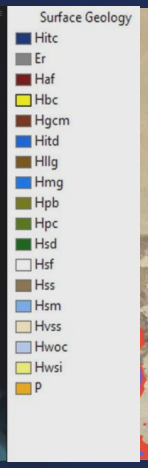
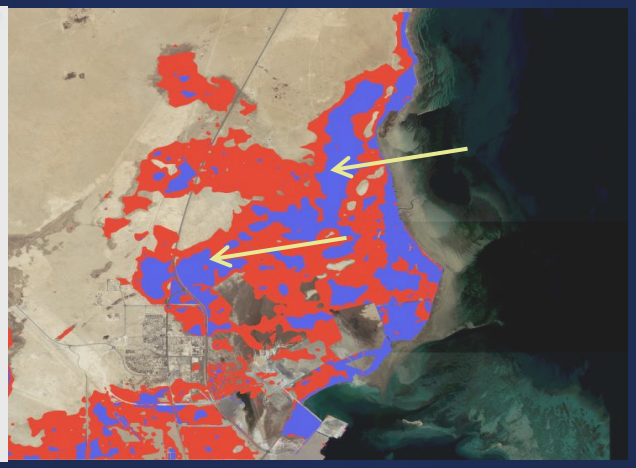
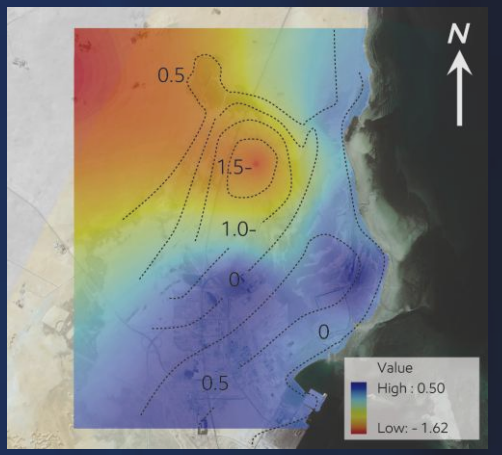




Geological map of coastal sabkha



Surface elevation map showing back Barrier depressions



Water table drawndown 1.5 m by evaporation

- High rates of evaporation in topographic lows behind barrier draw down water table 1.5 meters
- These areas are inland of marine flooding
- Show extensive gypsum precipitation at surface and within sediment

Mesaieed example of an evaporite factory

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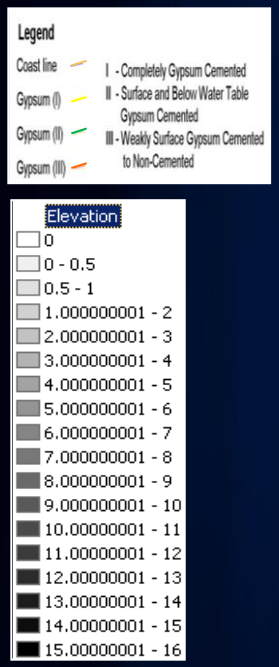
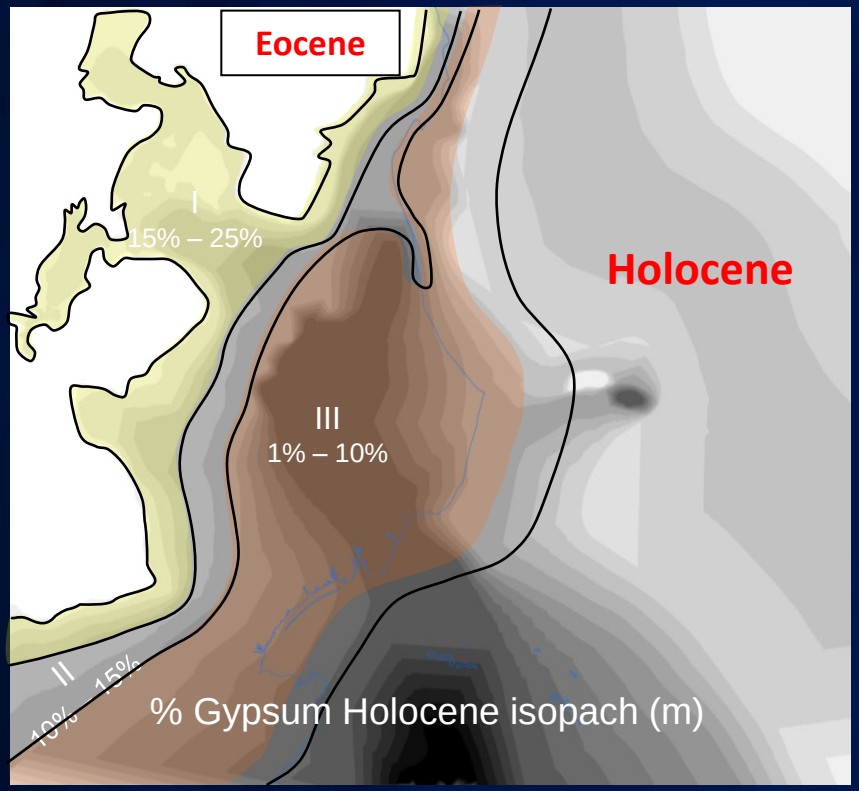
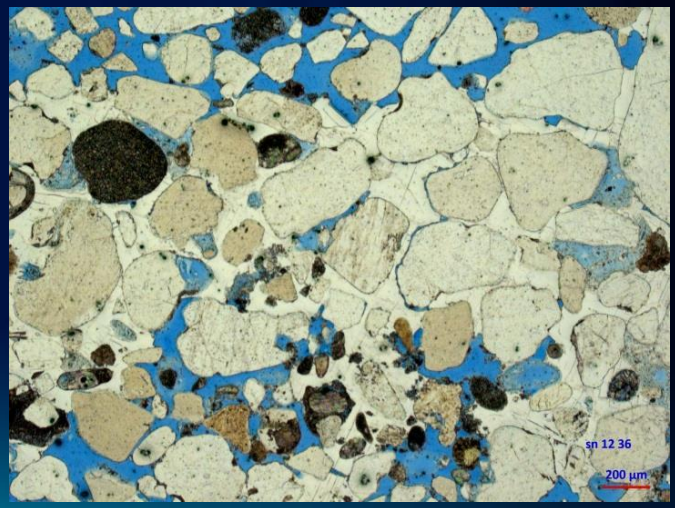




- Significant pore volume reduction by interparticle gypsum cementation
- 20-30 % pore volume reduction is typical in onshore parts of coastal plain
- Water chemistry- coincides with areas of elevated salinity, depleted Ca and S04

Mesaieed								Approximate	Approximate	
Area	Environment	Area	Gross Vol.	% Gypsum		Volume Gypsum		Pore Volume	Pore Volume	
		Million	Million	Low	High	Million M³		Million	Loss by Gypsum	
		M²	M³			Low	High	M³	Low	High
I	Upper Sabkha	84.62	380.64	15%	25%	57.10	95.16	171.29	33%	56%
II	Middle Sabkha	16.08	76.50	10%	15%	7.65	11.47	34.42	22%	33%
III	Lower Sabkha and Coastal	62.29	203.49	1%	10%	2.03	20.35	91.57	2%	22%
IV	Offshore	163.64	2,014.64	0%	0%	-	-	906.59	0%	0%
	Total	*326.63*	*2,675.28*							



Pore filling gypsum

Dolomite and Halite- minor but significant

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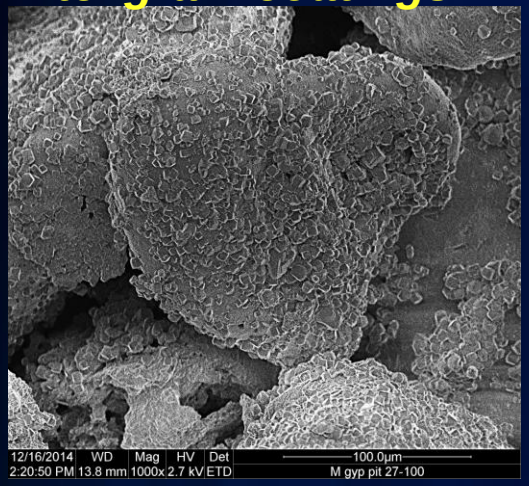
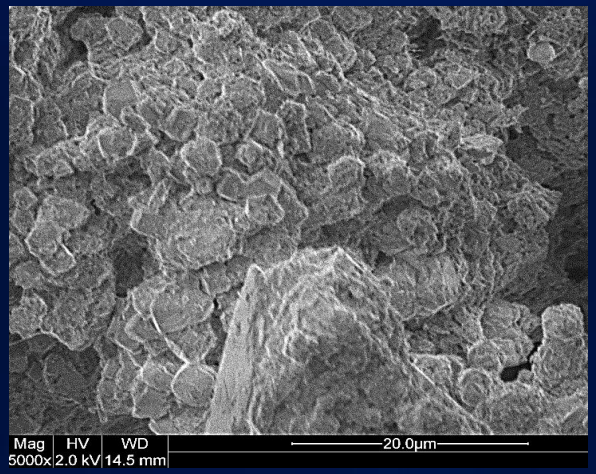
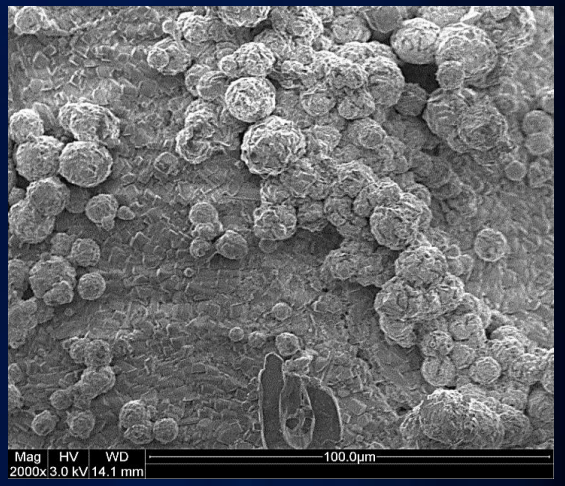
Dolomite grain coatings

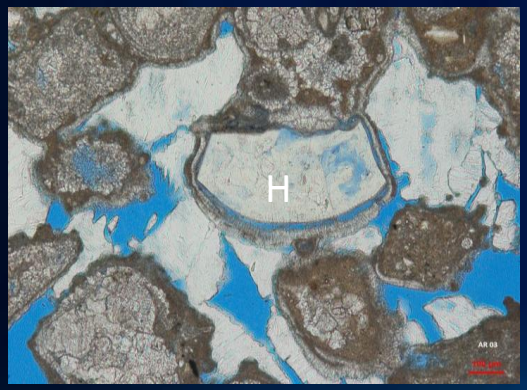


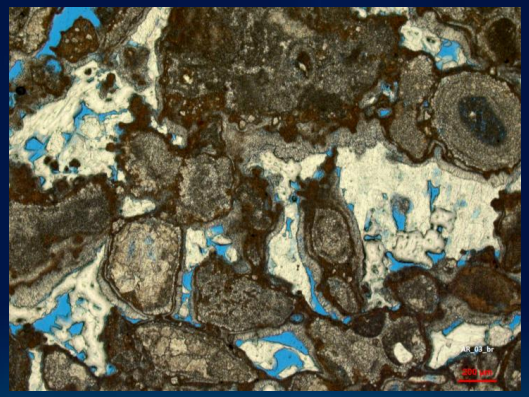


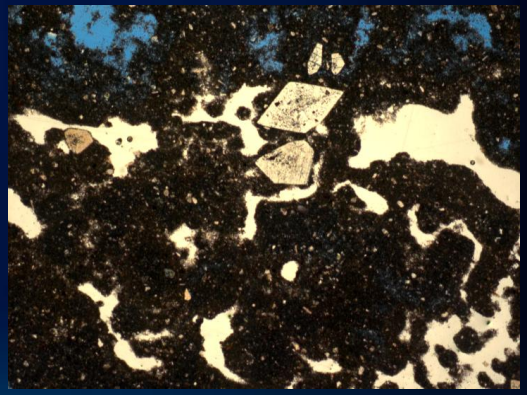


- Distribution complicated by detrital and atmospheric dolomite
- Trace amounts are common as non-microbial grain coatings

Halite







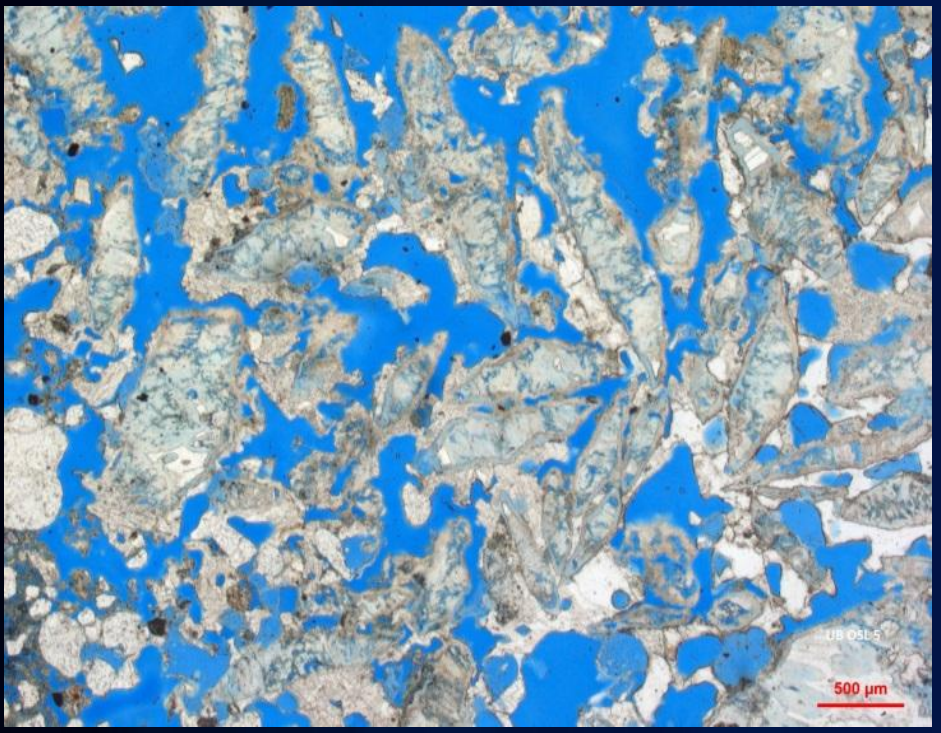
- Widespread, early pore filling in coastal areas
- Halopores- create significant, irregular pores in coastal and pedogenic carbonates

Summary

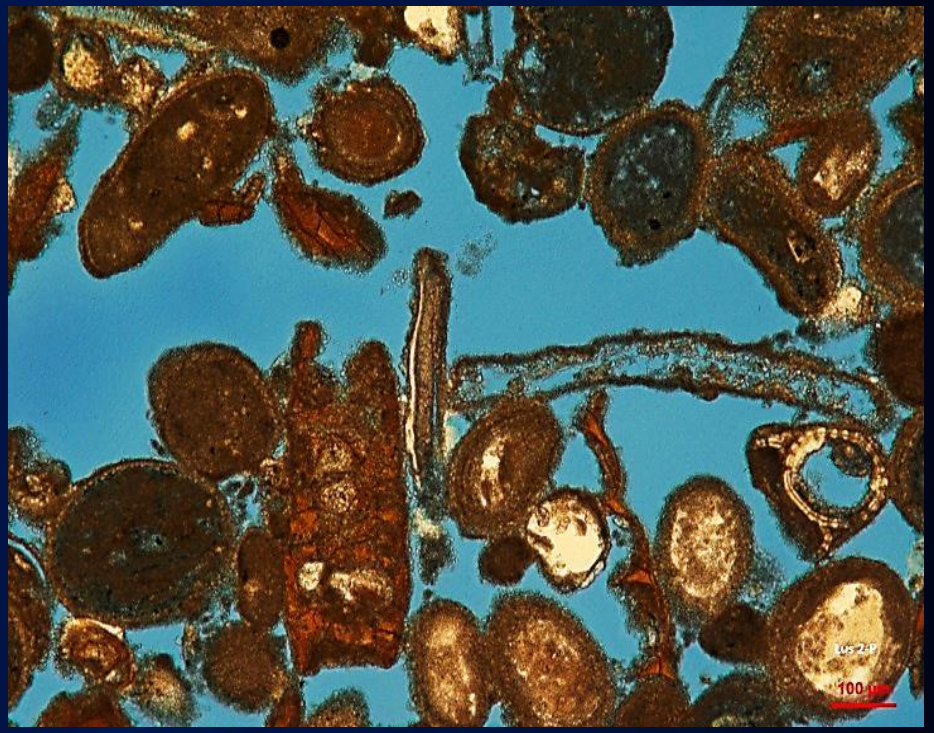
- **Mineralogy** - Gypsum, halite and minor anhydrite are common throughout Holocene sabkha sediments

- **Origins** Evaporites accumulate in two, end-member settings:
  - Subaqueous- precipitated from standing water
    Time range- Perennial lakes- 1-2 ka
    Sabkha depressions- seasonal flooding/drying
  - Subaerial- within a sediment- in capillary zone

- **Dynamics-** Geologically/economically significant amounts of evaporites can form in a few thousand years
  1. Significant sediment pore volume reduction
  2. The evaporite factory- comparable to the carbonate factory
  3. Capillary evaporation generates brine plumes that can modify older, underlying and adjacent sediments



In gypsum



In a carbonate