Back-Barrier Sediment Dynamics: A Major Control on Modeling Sediment Properties, Cyclicity and Depositional Profiles - Examples from the Arid Coastline of Qatar*

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Abstract

Building geological models based on modern analogue data relies on combining process-based observations with geospatial information. This paper describes the evolution of back-barrier sediments along the eastern coastline of Qatar to illustrate key processes that control deposition and diagenesis as they are captured in geological models.

Qatar barrier beaches have formed from coastal headlands with an oblique orientation to prevailing winds. Ridges have built 5-10 kilometers southeastward, by lateral accretion with minor washover. Landward of beach complexes are broad back-barrier areas with a range of surface sediment types ranging from evaporitic sabkha to open marine, subtidal lagoons.

Radiocarbon age dating indicates coastal sediments began forming approximately 8,000 years before present, at the end of a period of rapid sea-level rise (1m/100 years). The rapid rise to 2-4 meters above present day formed a distinctive, 30-50 centimeter thick, basal transgressive lag composed of open marine, cardiid bivalves and mollusk hardground.

An initial, **Lagoon Phase** is marked by open marine circulation in back-barrier areas. Burrowed, thin-shelled bivalve sands generally fine upward to sea grass muds. Punctuated drops in sea level to present day have led to seaward stepping beach complexes.

A second, **Inlet Phase** is marked by restricted tidal flow. Generally concentric facies patterns result, proceeding from sabkha, stromatolite, mangrove, tidal flat and tidal channel facies. Confined exchange of tidal waters results in reworking of older beaches, distributing sand into sheets. Lateral migration of tidal channels produces a distinctive erosional unconformity mid back-barrier infilling cycle. Back-barrier erosion through sheet wash and confined channel flow redistributes linear sand bodies into sheets and creates a marker unconformity.

As barriers become continuous, tidal flow to back-barrier areas is closed off in a final, **Evaporite Phase**. Restricted flow and water depths lead to formation of a thin, muddy cap above the grainy intertidal and channel facies. Salt and gypsum flats form around the margins and deflation areas.

The model described here applies to wave-dominated, arid coastlines, lacking continental runoff. Although mud prone in final phases, tidal exchange and channeling create sand-prone facies throughout most of the back barrier depositional history.

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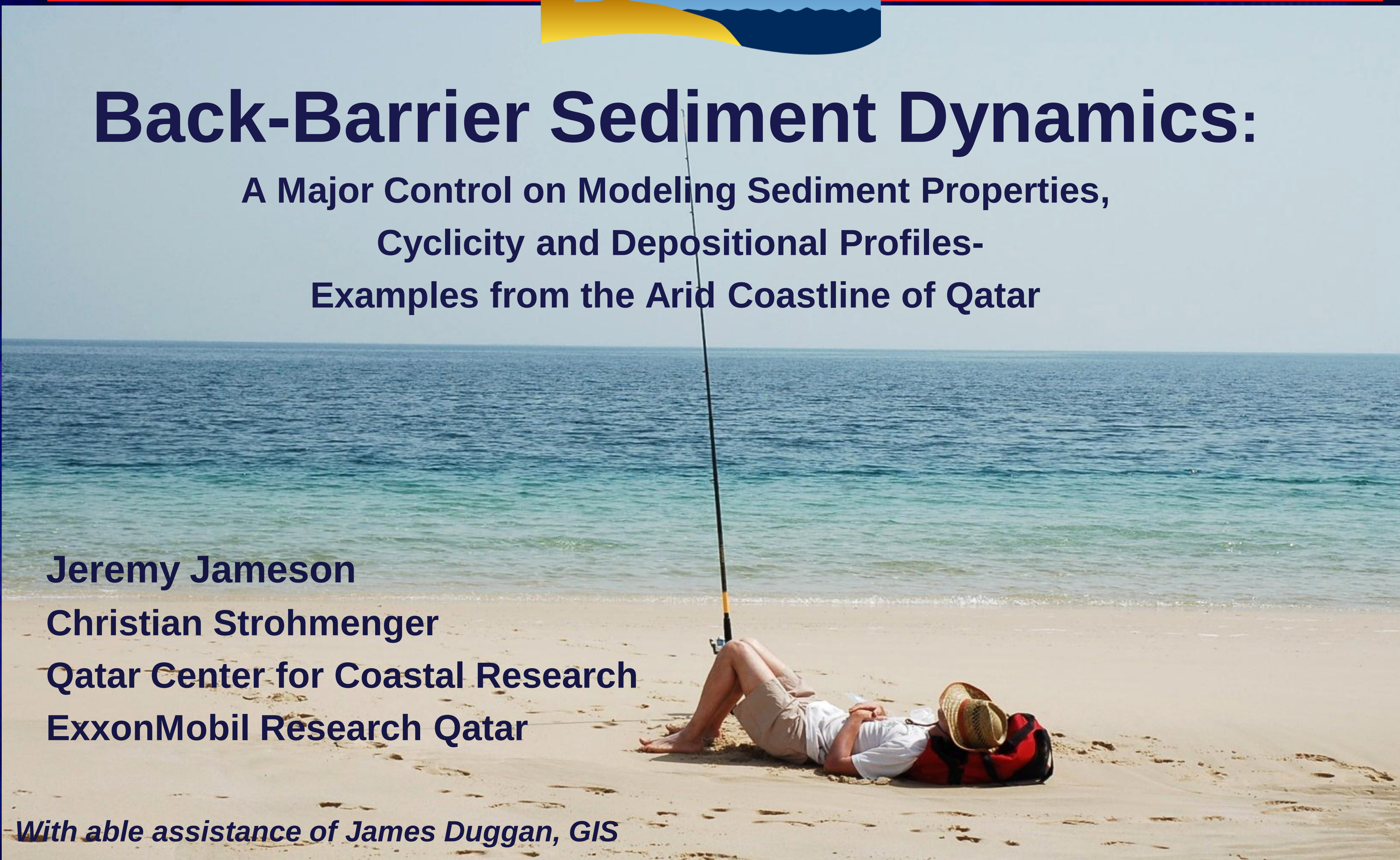

Back-Barrier Sediment Dynamics:

A Major Control on Modeling Sediment Properties, Cyclicity and Depositional Profiles- Examples from the Arid Coastline of Qatar

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Summary

1. Back barrier environments are characterized by a punctuated dis-equilibrium between erosion, deposition, evaporite precipitation and sea level changes

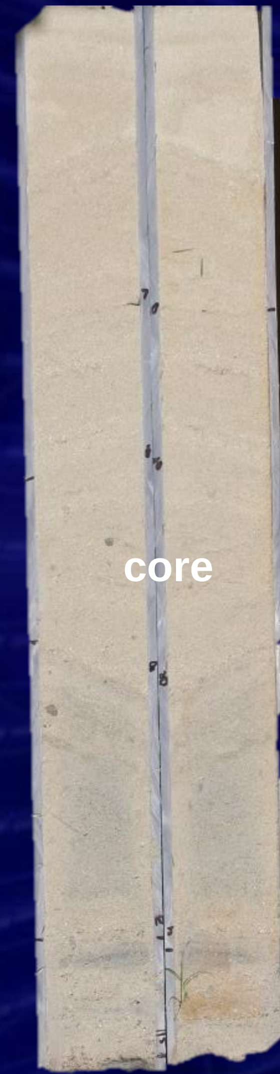
2. Back barrier sediments show a cyclic, ordered depositional history

3. Holocene coastal sediments are 5-10 m thick; occurring on scale that would be captured in a geological model

4. Back-barrier tidal drainage and flooding redistribute sands
   - Re-shape linear beach ridges in sheet sands
   - Back barrier environments are sand prone

Database

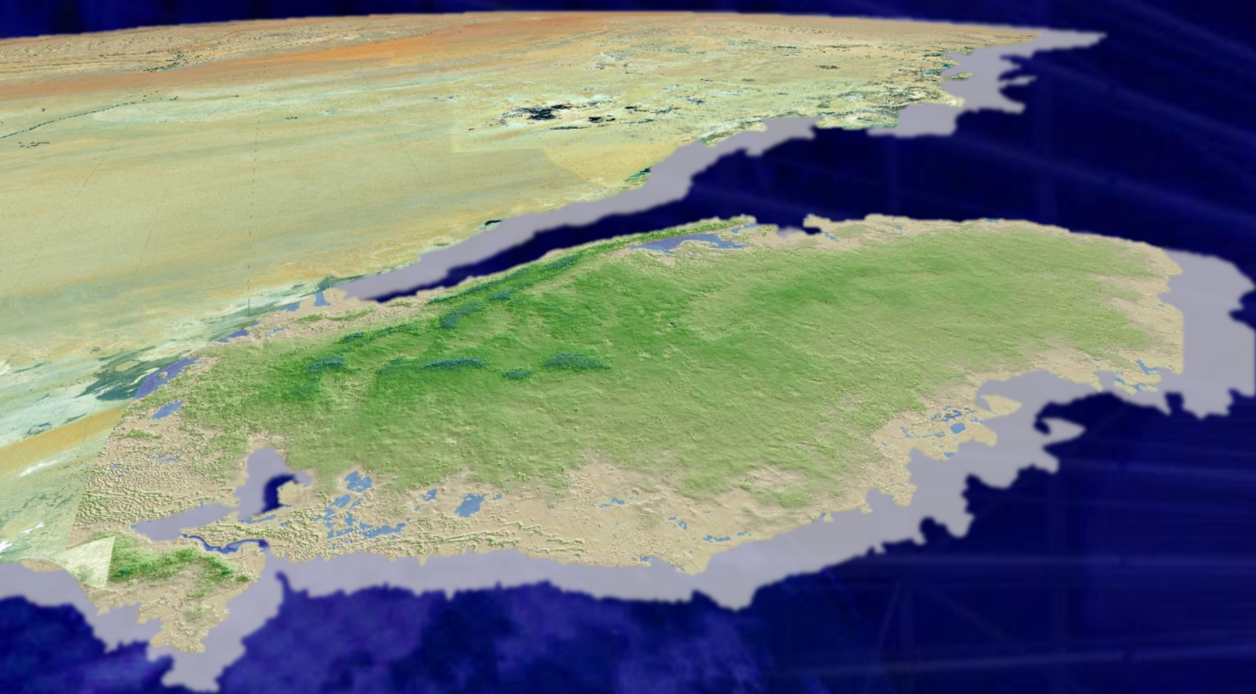
1. Comparison of depositional history 5 back barrier areas
2. Countrywide and offshore satellite imagery, digital elevation models
3. 12 Years field mapping- 1:10,000 scale in focal areas ArcGIS
4. 150 Radiocarbon age dates
5. Mapping most major industrial sites in country
6. 300 thin sections; over 1000 hand samples
7. Cores 60 industrial wells
8. Cores 20 research wells (1-12 m)

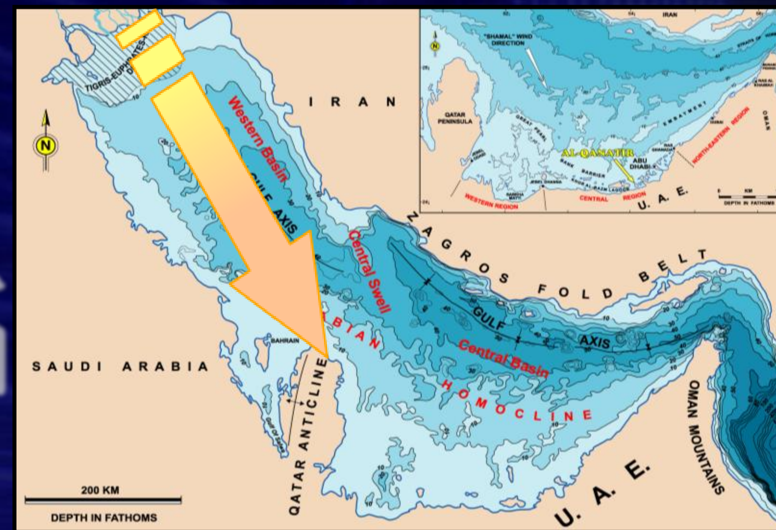


Map of North Dukhan sabkha

ExxonMobil

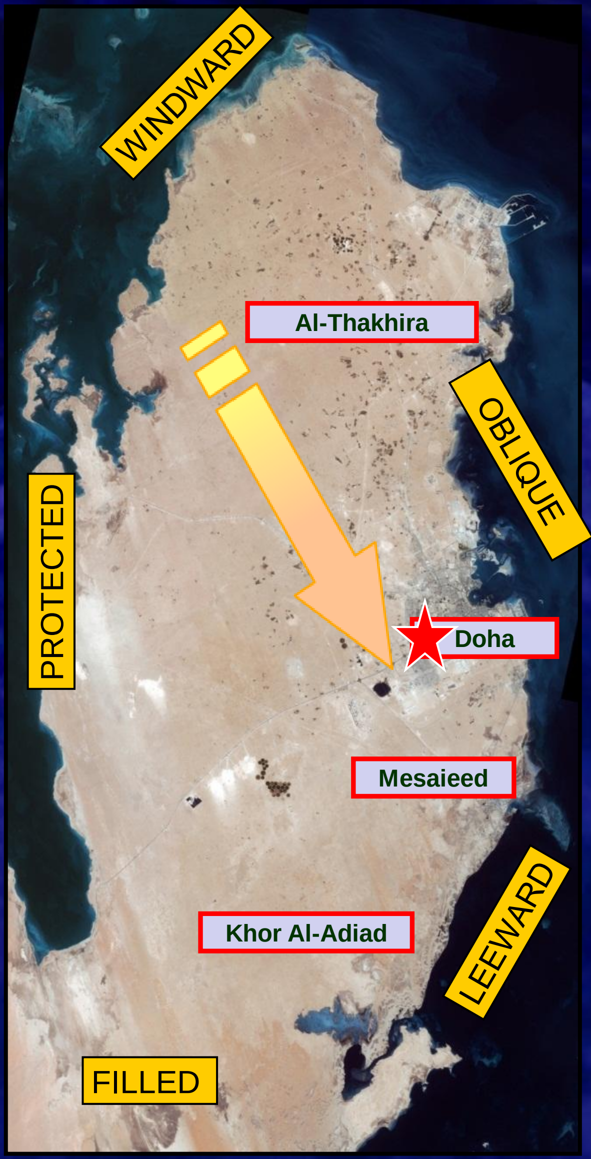
Qatar Location: 25 degrees N





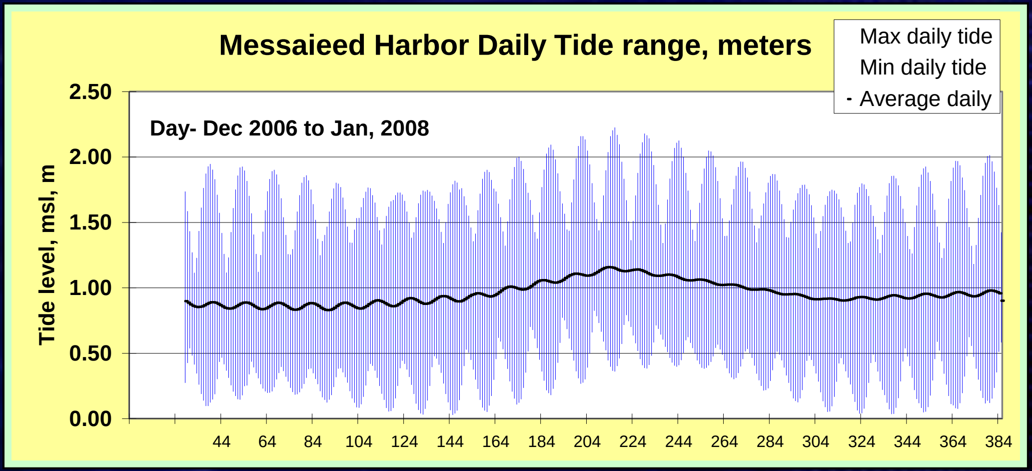
- Prominent peninsula extends into Arabian Gulf
- Southern margin of Arabian homocline
- Not like Bahamas :
    - Arid to hyper arid climate
    - No Hurricanes
    - Rare calcareous green algae-mud producers

Hydrographic Setting of Qatar



Factors affecting coastal deposition

1. Strong prevailing winds
    - Drive marine circulation
    - Create 4 coastal profiles
    - Drive sediment from land into sea
2. Tides- micro tidal
3. Antecedent topography- very low relief coastal plain
4. Hot, arid climate- no vegetation, evaporite-prone
5. Sea level history



Sea Level History

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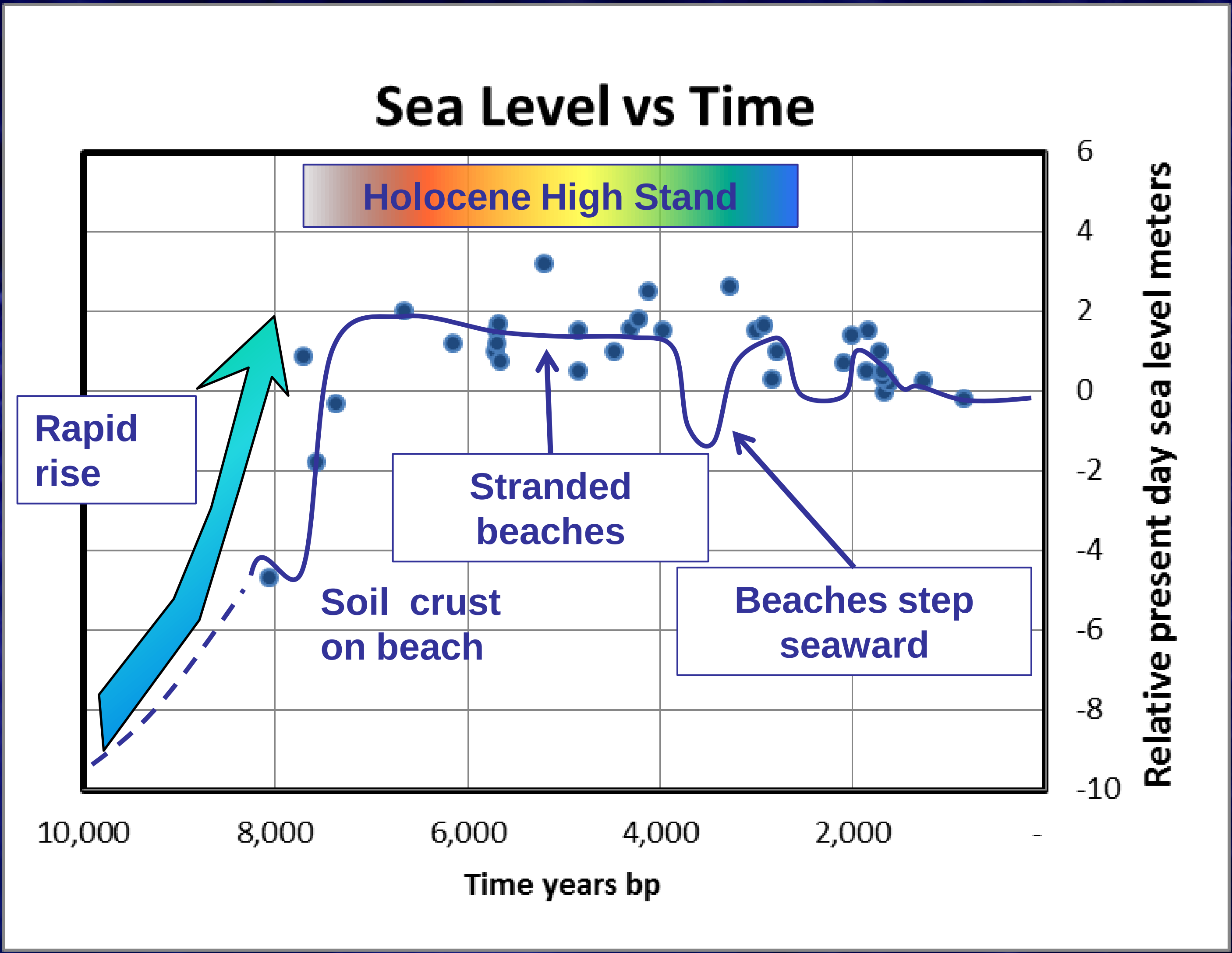
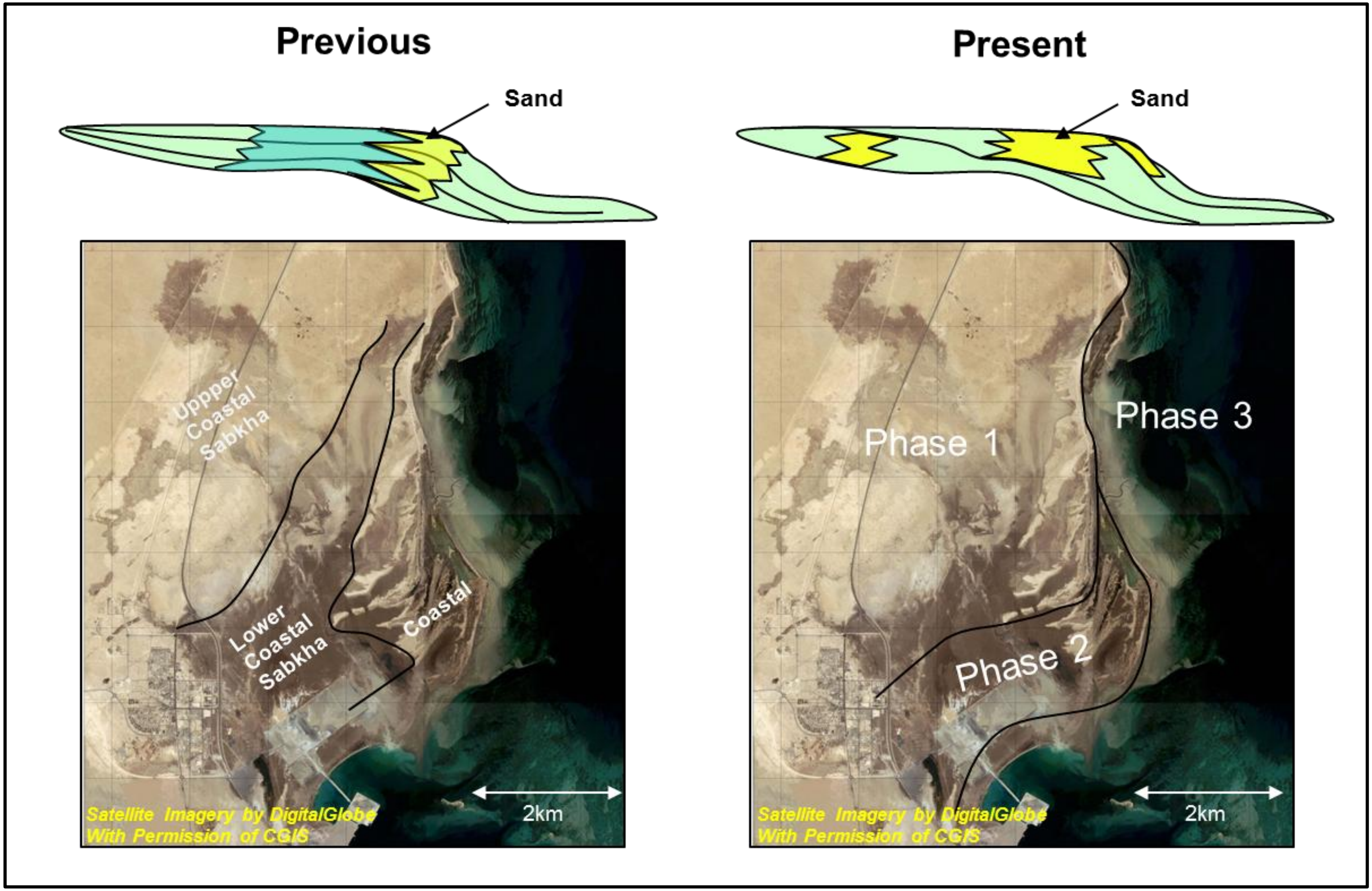


مركز قطر للأبحاث الساحلية
Qatar Center for Coastal Research

Main Events

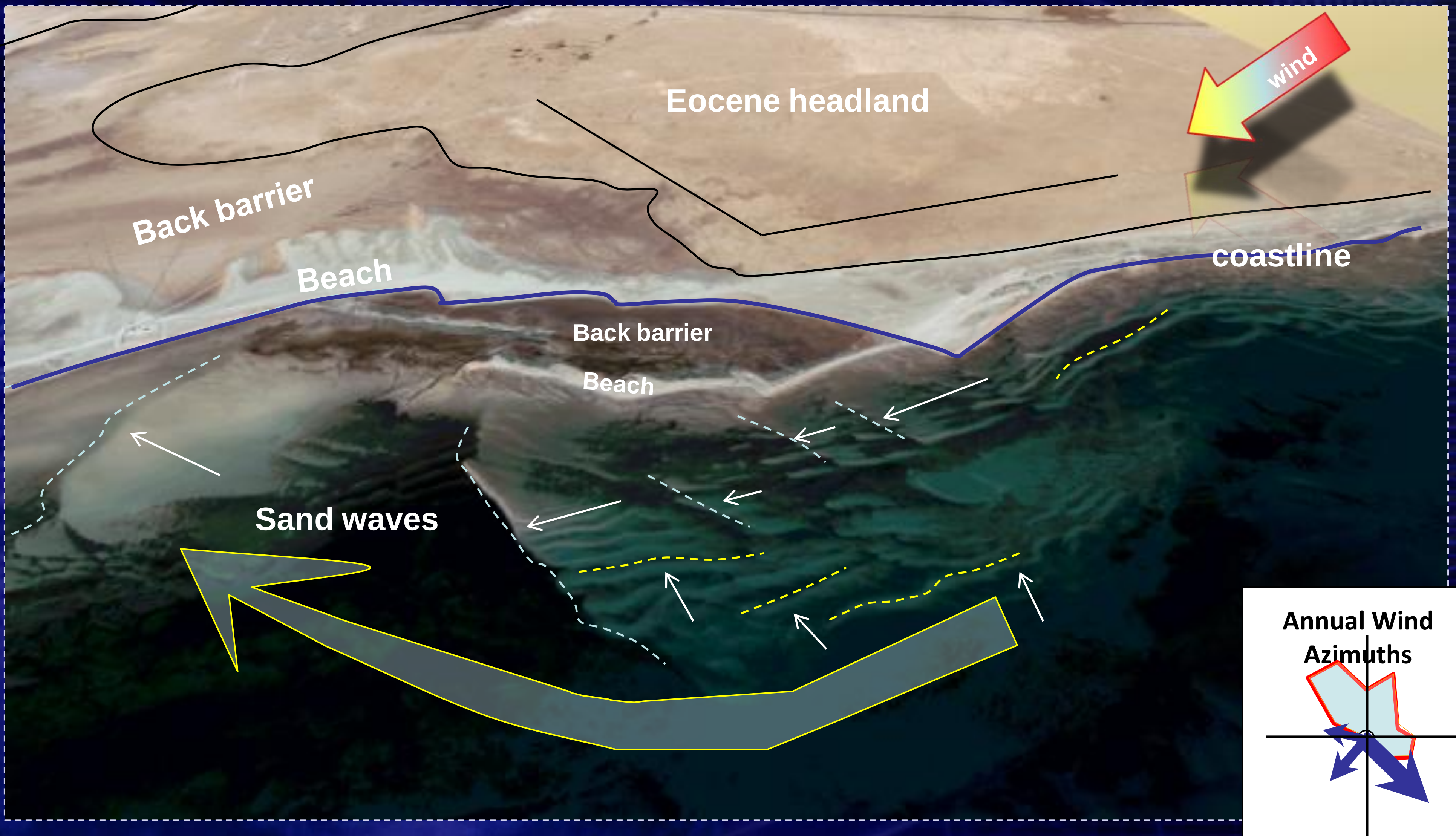
- 10 – 8 ka Rapid rise 1m / 100 years
- Holocene High stand- +2 m above present
- Seaward Facies offsets

Impact of Sea Level on Barrier Evolution



Comparison of Sand Distribution

Origin of Back Barrier: Long Shore Drift

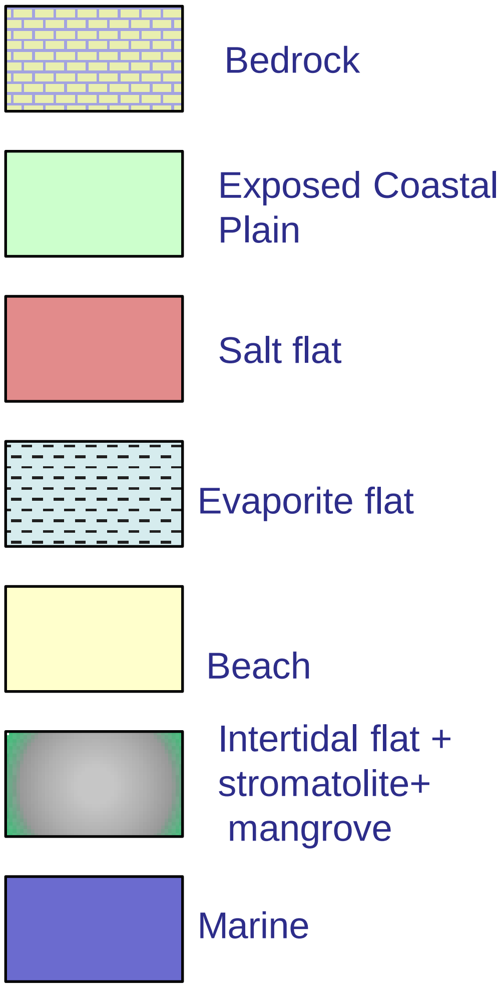


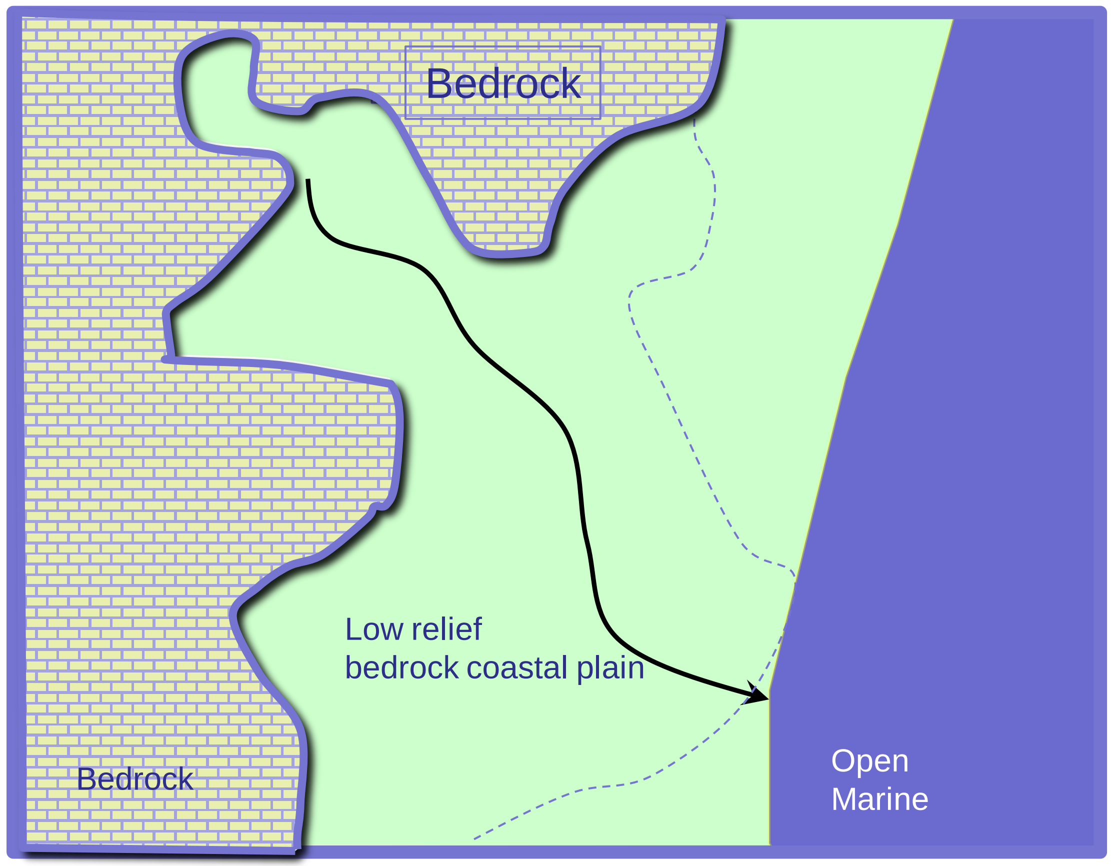
2005-2009 Based on data from Windfinder.com

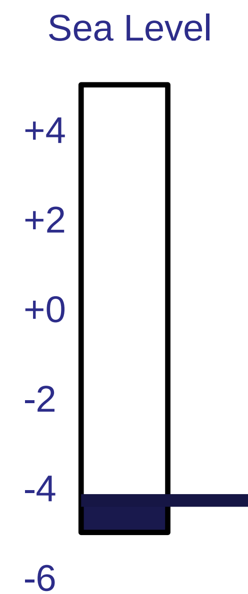
Back Barrier Evolution

9000 ypb

- Low sea level
- Pleistocene fluvial drainages



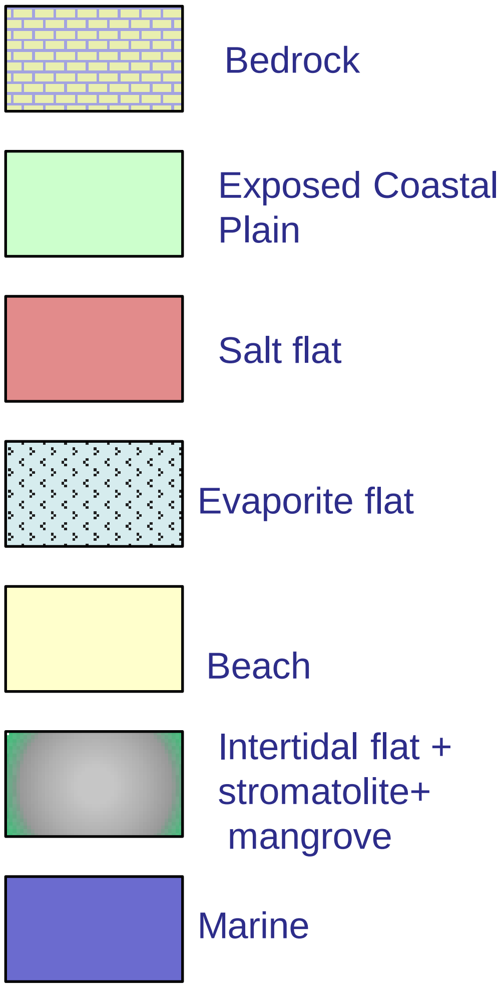


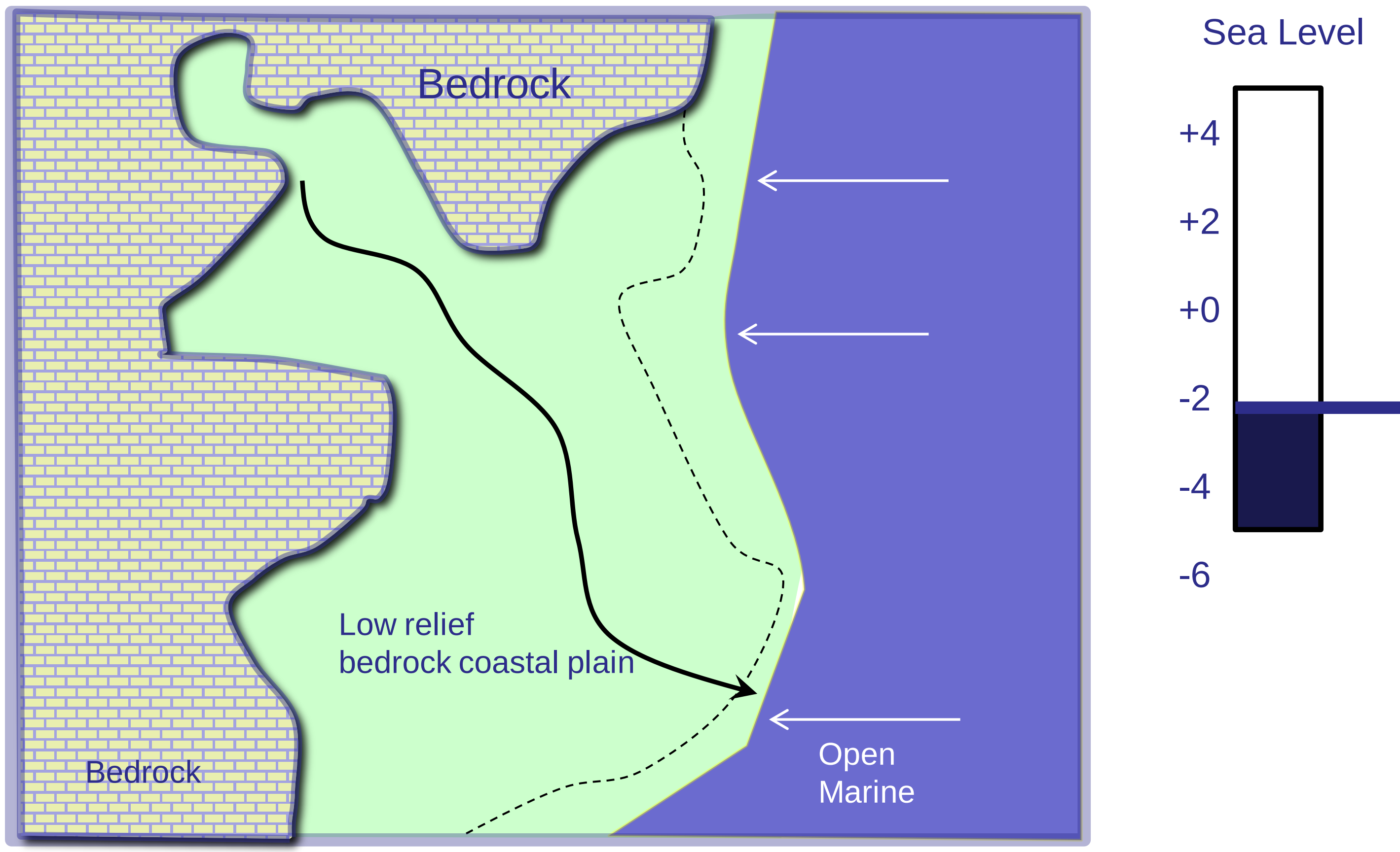


Back Barrier Evolution

8000 ypb

- Rapid rise





Back Barrier Evolution

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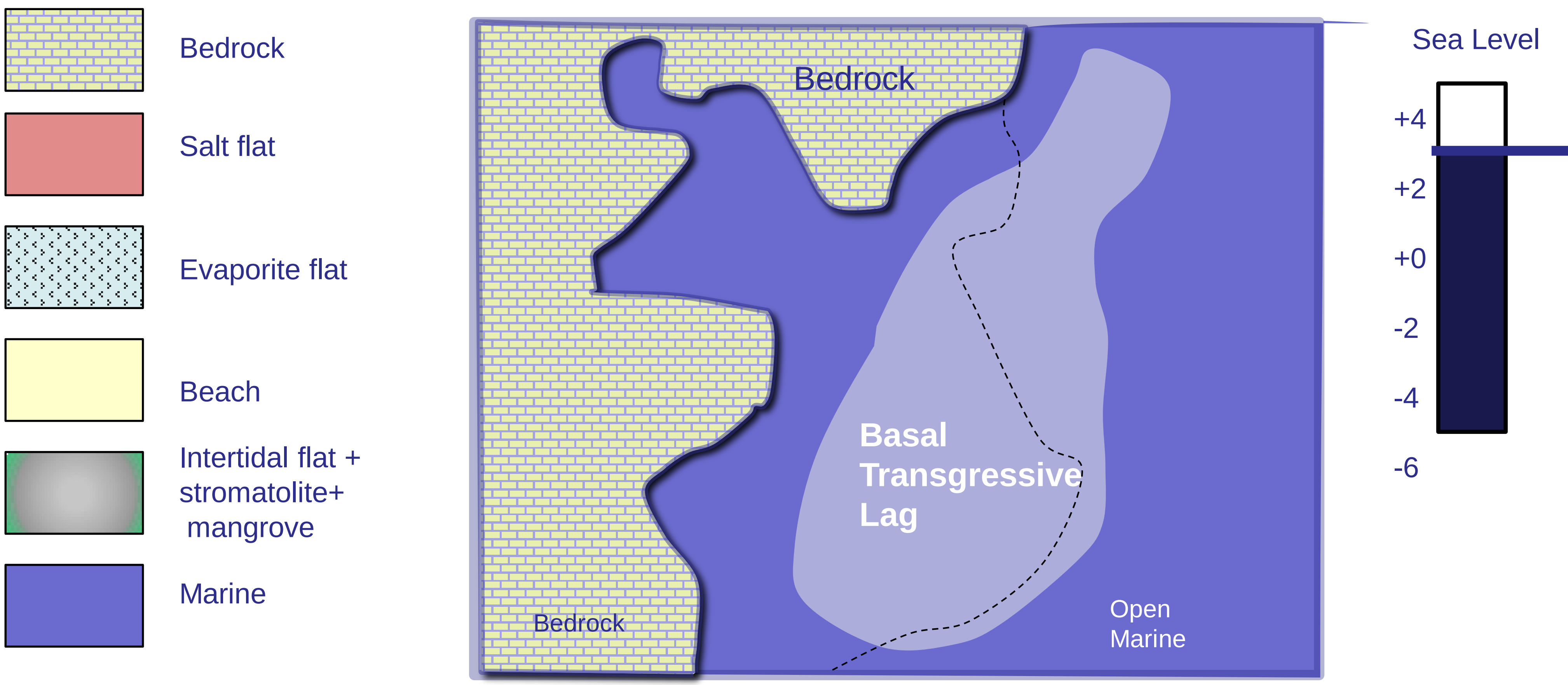
7000 ypb

- Rapid rise to +2-3 m
- Basal transgressive lag forms



Back Barrier Evolution

6000 ypb

- Land attached beaches appear
- Evaporite deposition in embayments

Bedrock

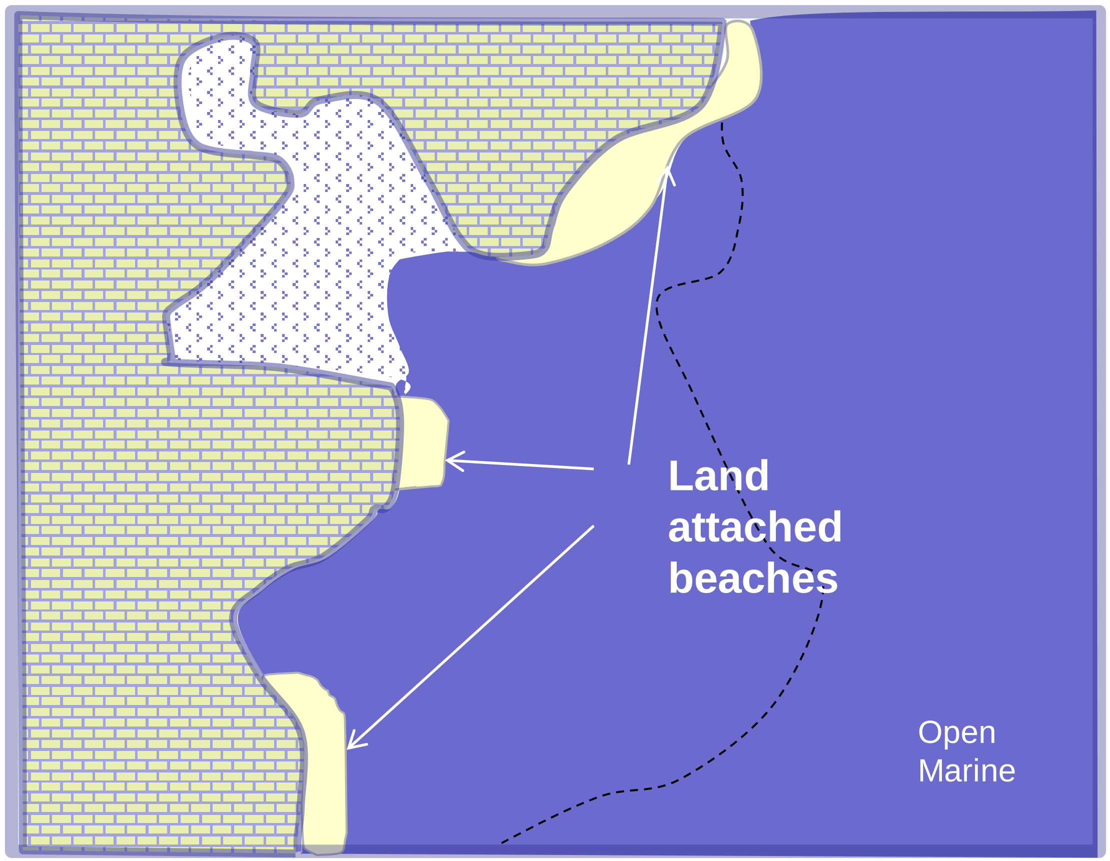
Salt flat

Evaporite flat

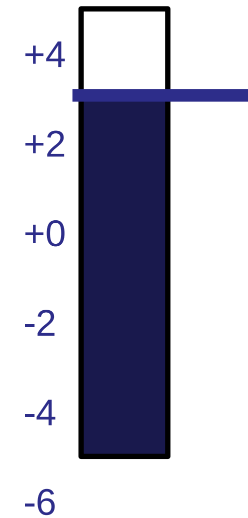
Beach

Intertidal flat + stromatolite+ mangrove

Marine



Sea Level



Back Barrier Evolution

4000 ypb

- Barriers form due to long shore drift
- Open, unconfined circulation behind barriers
- Symmetrical filling

Bedrock

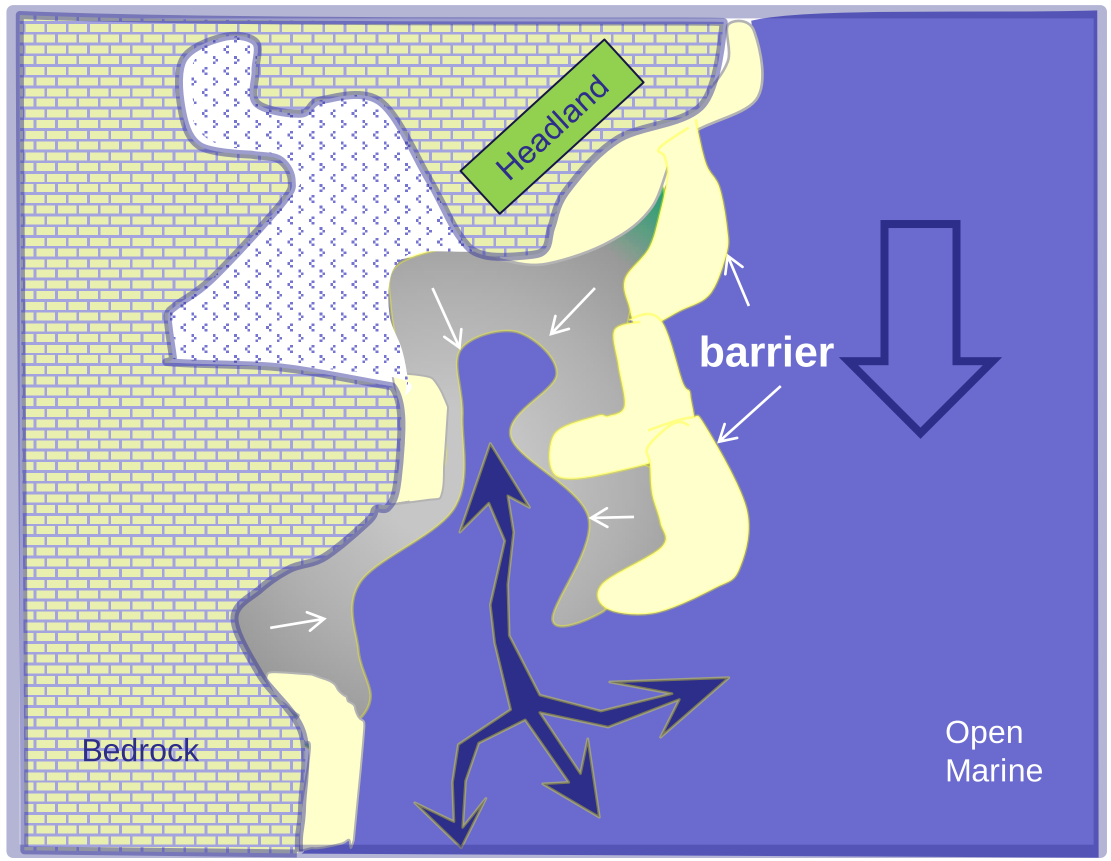
Salt flat

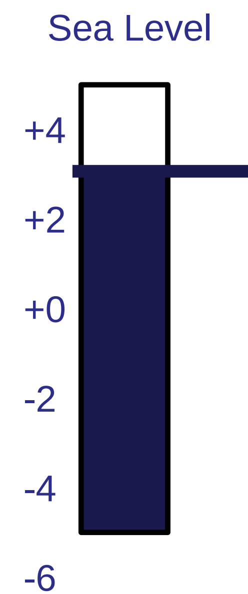
Evaporite flat

Beach

Intertidal + stromatolite+ mangrove

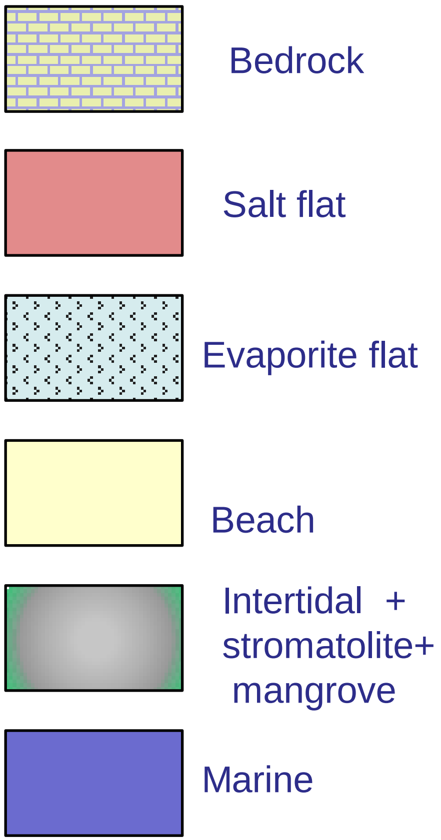
Marine

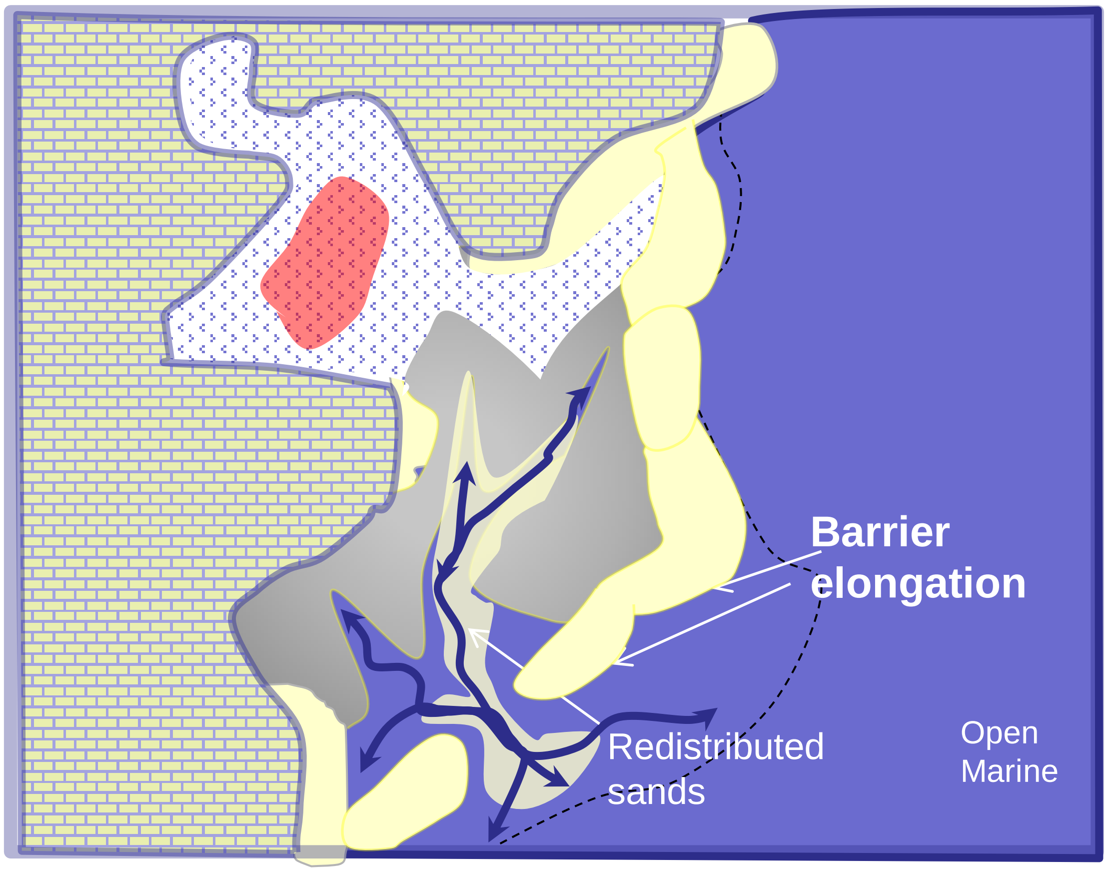


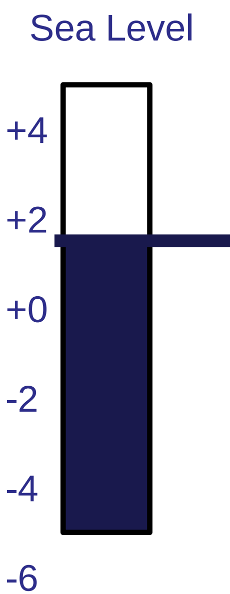


Back Barrier Evolution

- Barriers close lagoon
- Channel meander belts in back barrier
- Evaporites expand

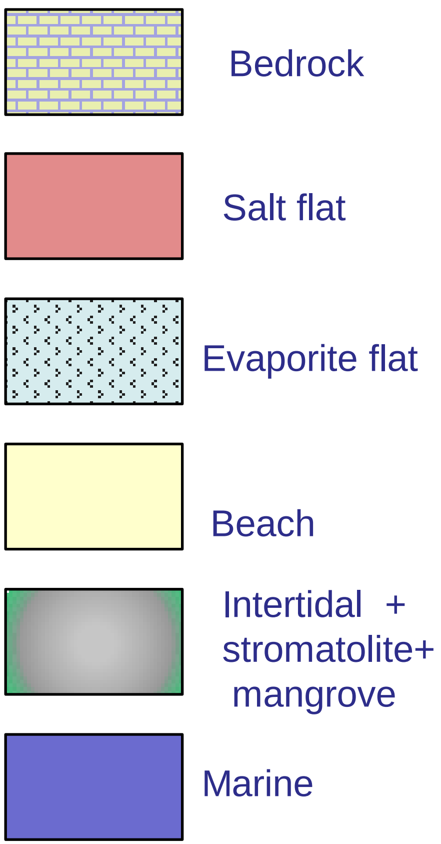


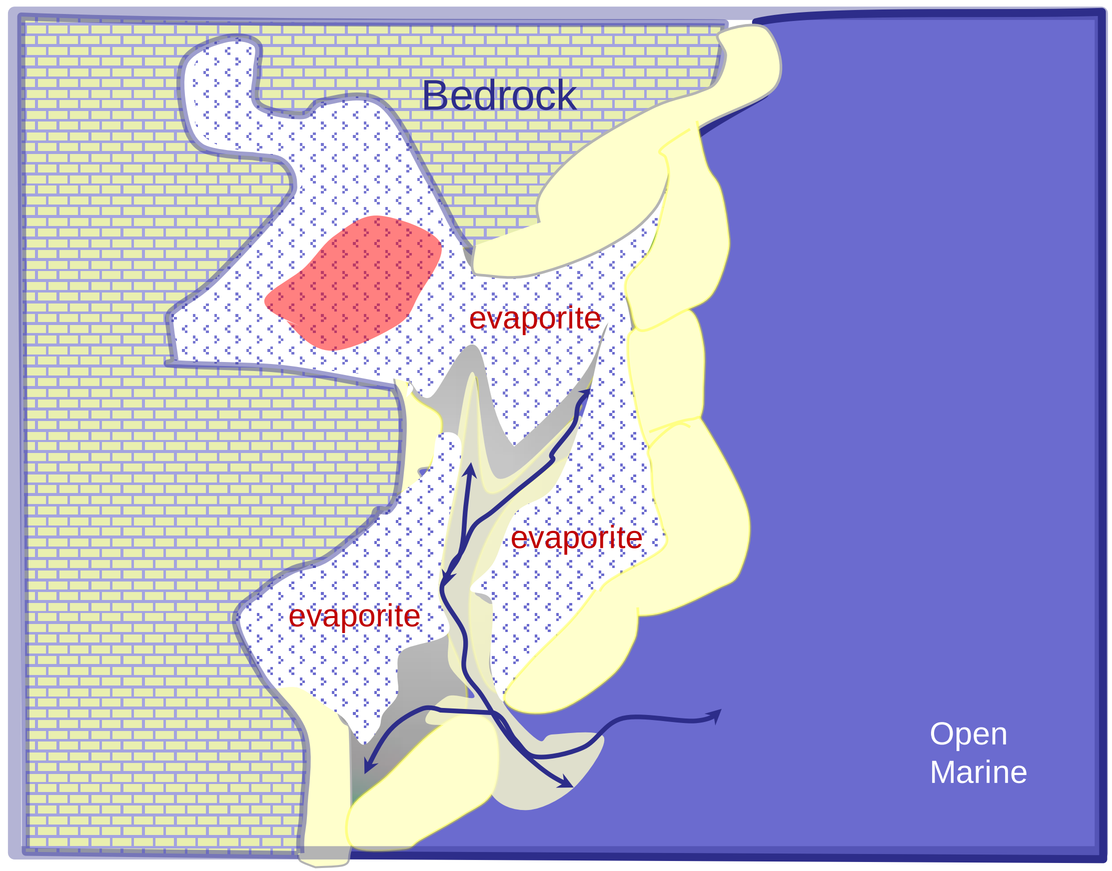


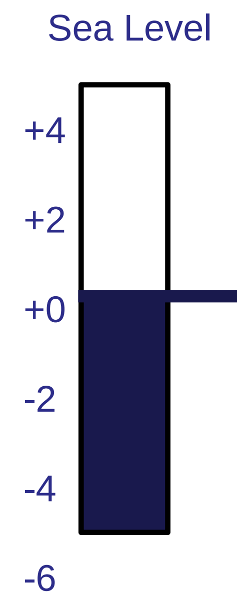


Back Barrier Evolution

- Back Barrier closed
- Seasonal flooding
- Evaporites form



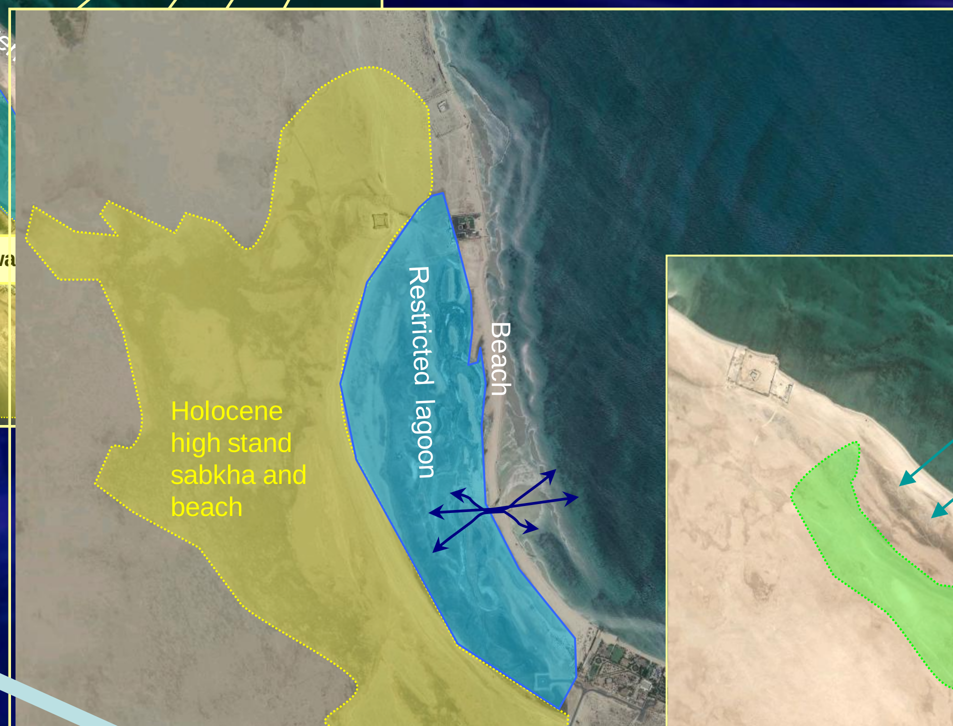




Back Barrier evolution- oblique coast

Refraction tips on spit

Open Lagoon

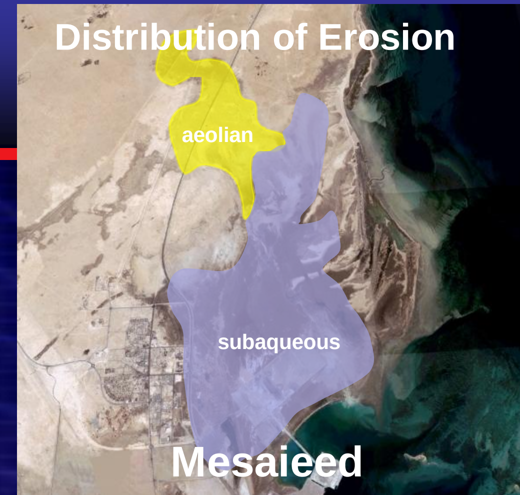


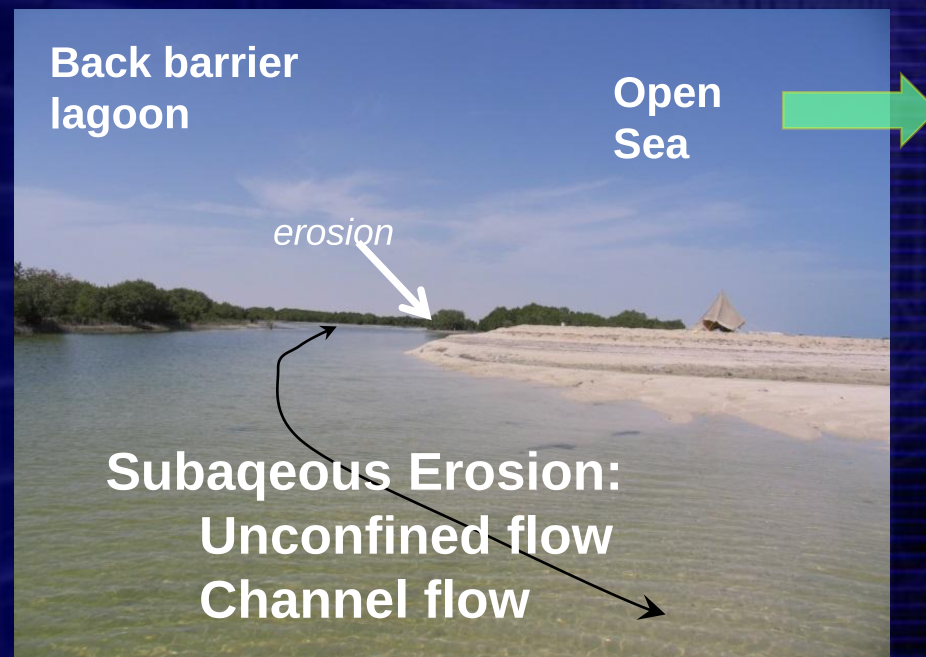
Restricted Lagoon

Inlet phase

Evaporitic Back Barrier

Two styles of Back Barrier Erosion





Holocene High Stand- inland areas deflate from Stokes-type erosion 6200 ypb surface sediments

Back barrier eroded by tidal channel

Erosional bedforms

Giant sand wave in Back Barrier Lagoon - 300 m x 30 m x 3m

Back barrier eroded by tidal channel

Back barrier erosion

Ground view of sheet wash reworked from beach ridges in back barrier

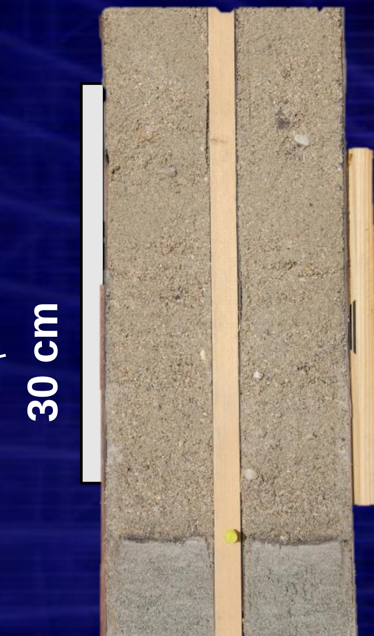
Close up of open marine skeletal gravel in sheet wash, Edge of shovel for scale

Back Barrier Evolution- oblique coast

Meters	Thickness m	Sediment	Circulation
1 2	Evaporite Phase	Gypsum crusts , stromatolites, mangrove rooted muds	Episodic flooding
	Inlet Phase	Mixed skeletal sands with muddy layers	Restricted marine communication
		Coarse; poorly sorted mixed skeletal sands; often trough cross bedded or graded	Tidal exchange with marine-deltas and sand waves form
4	Lagoon Phase	Diverse skeletal sands pass up to lam/burrowed sand, dominated by *Tellina;* sea grass layers;	Unconfined flow between marine and back barrier
6	Transgressive lag	Limestone, coarse Cardiid bivalve gravel with pebbles	Rapid sea level rise

Barrier Closed

Channel Access To lagoon

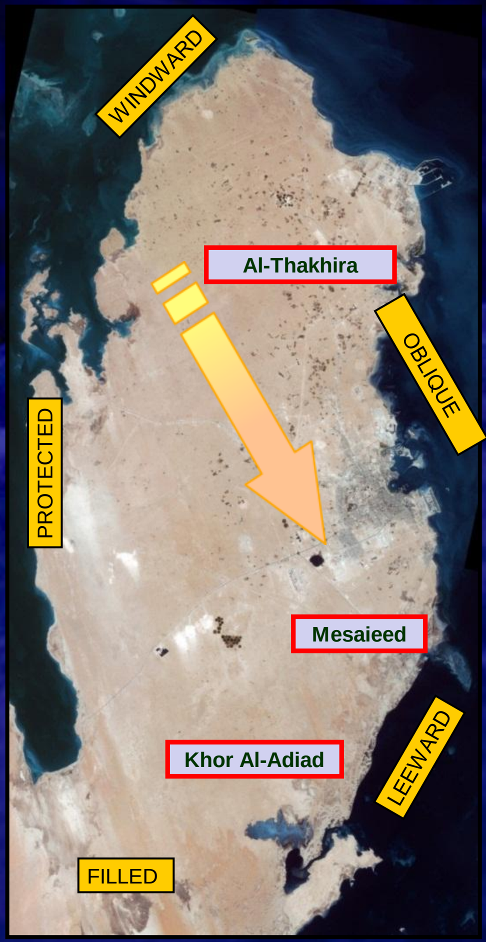


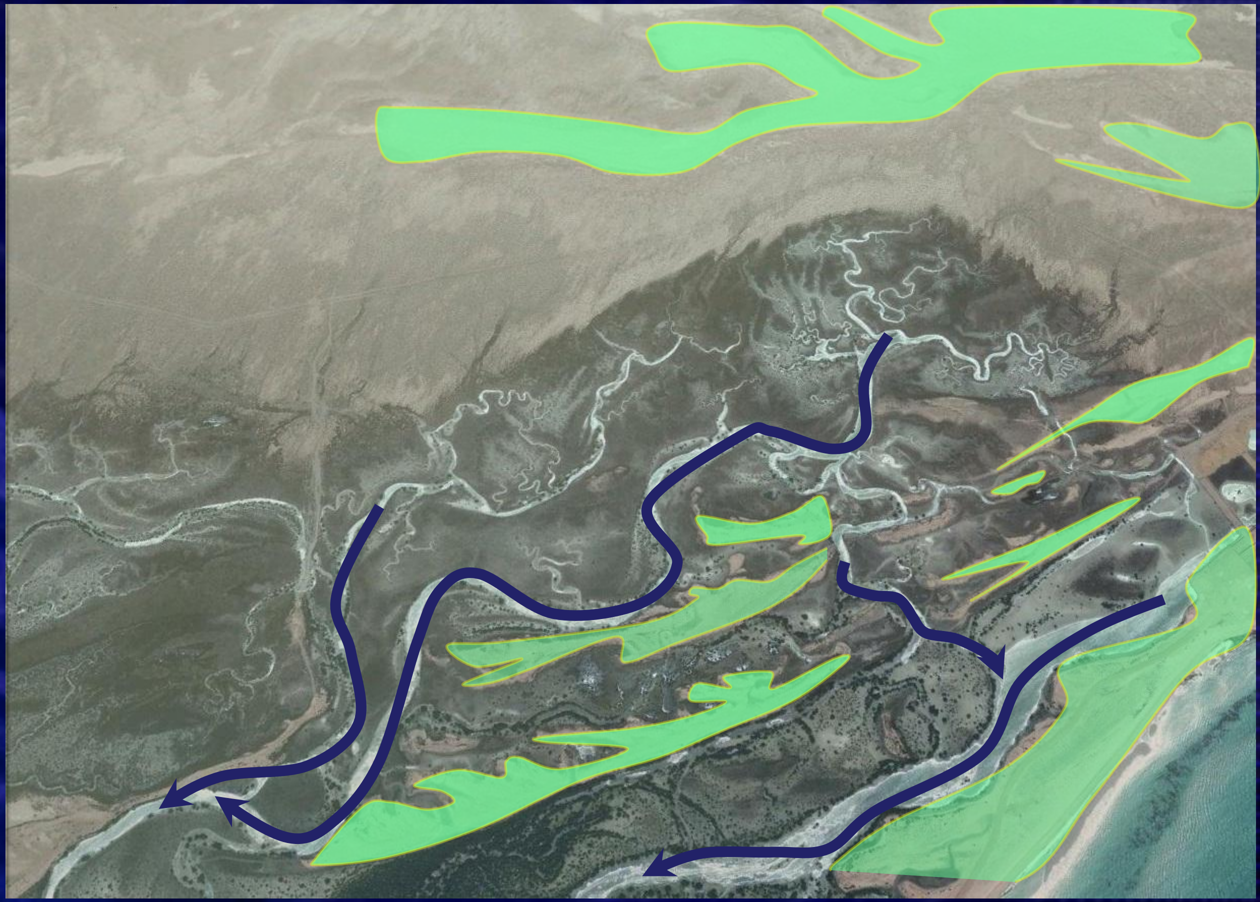
Basal Lag

Open, unconfined flow To lagoon

Rapid Rise

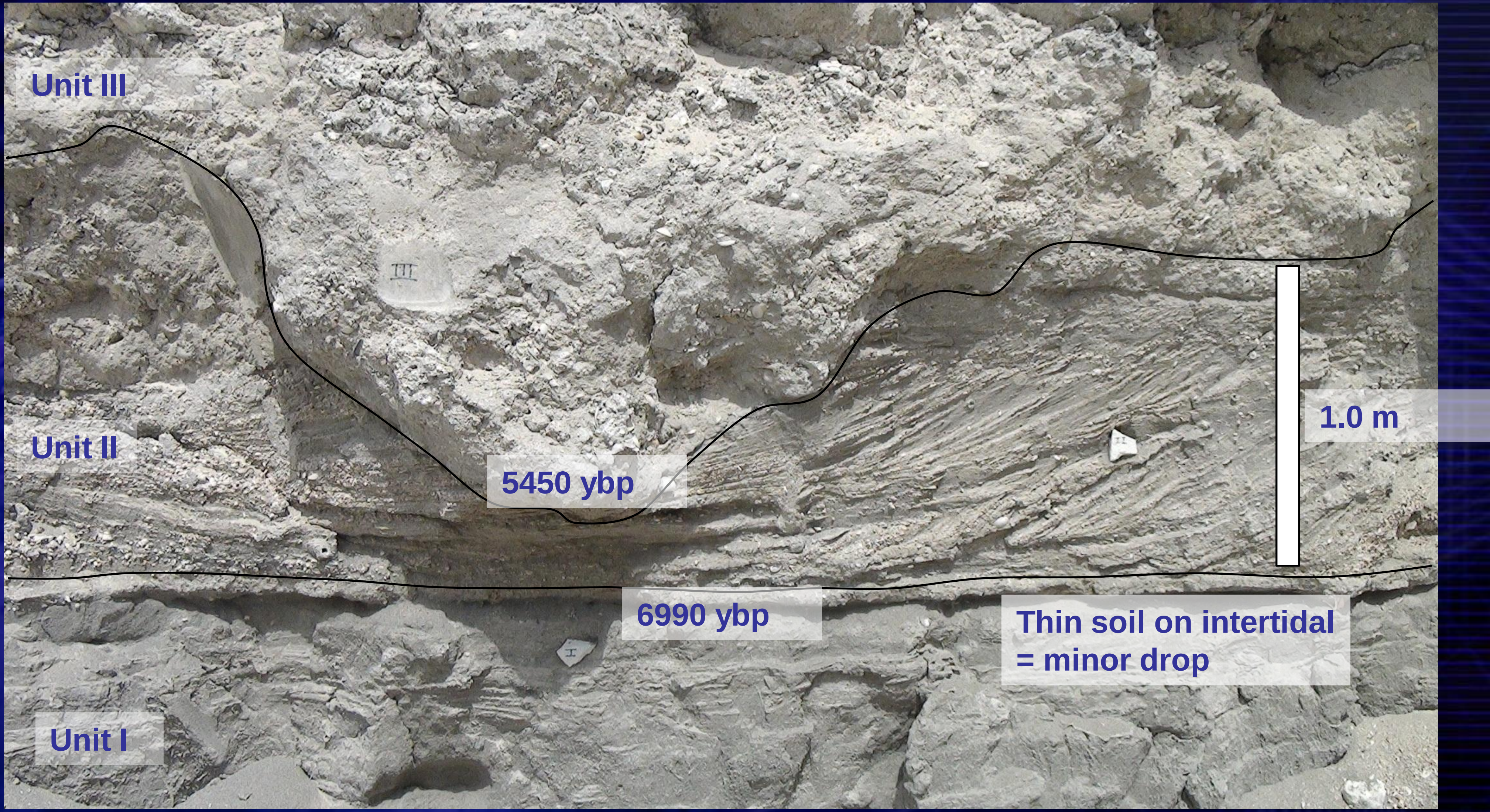
Back barrier erosion





Perspective view of channel phase of back barrier infill. 1 km wide meander belt is reworking 2000-3000 year old beach ridges

Back Barrier Channeling- Doha example



Illustrations of Back Barrier Filling

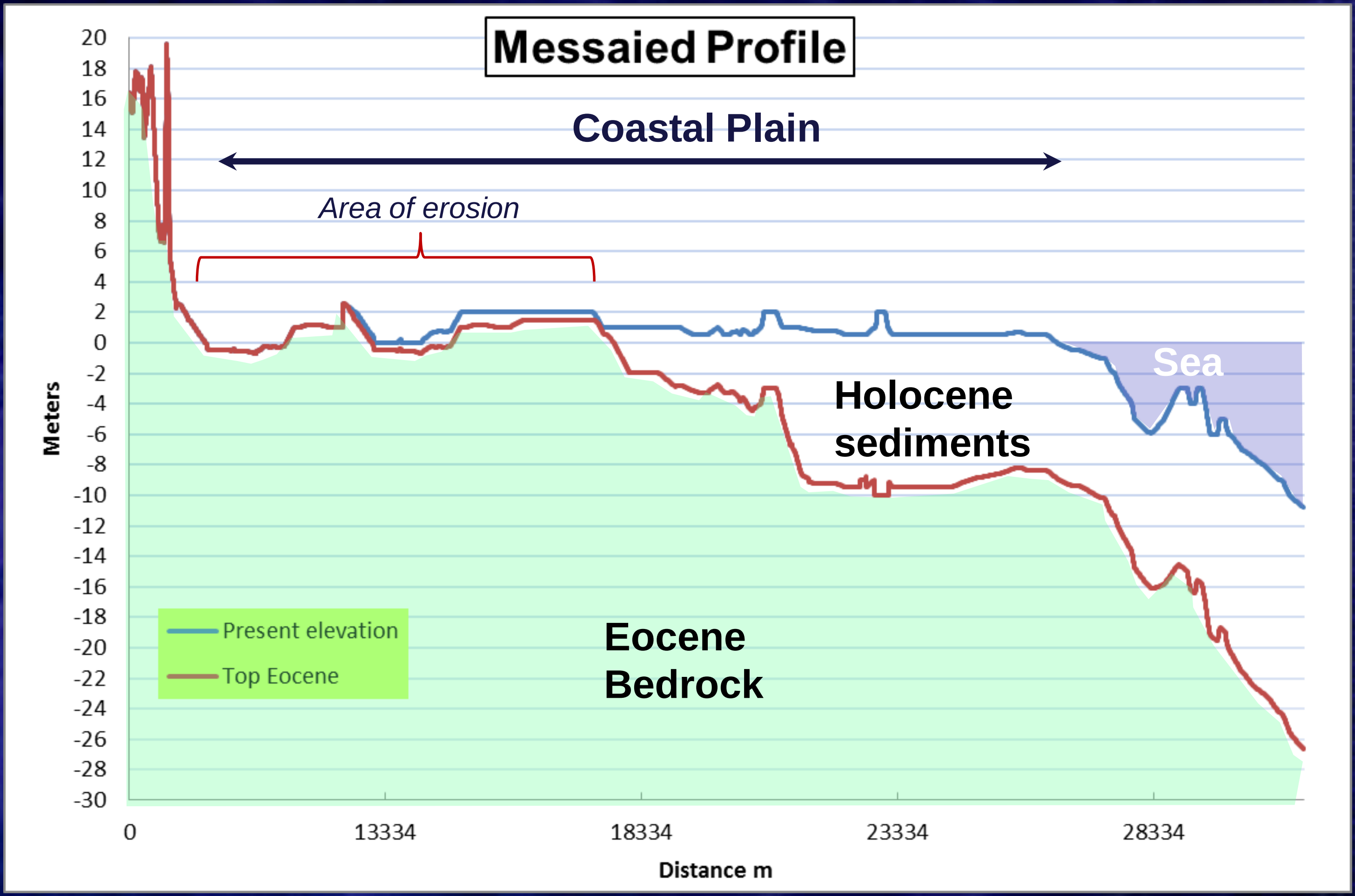
Unconfined sheet flow low angle cross stratification

Ebb oriented sand waves

Evaporite Phase

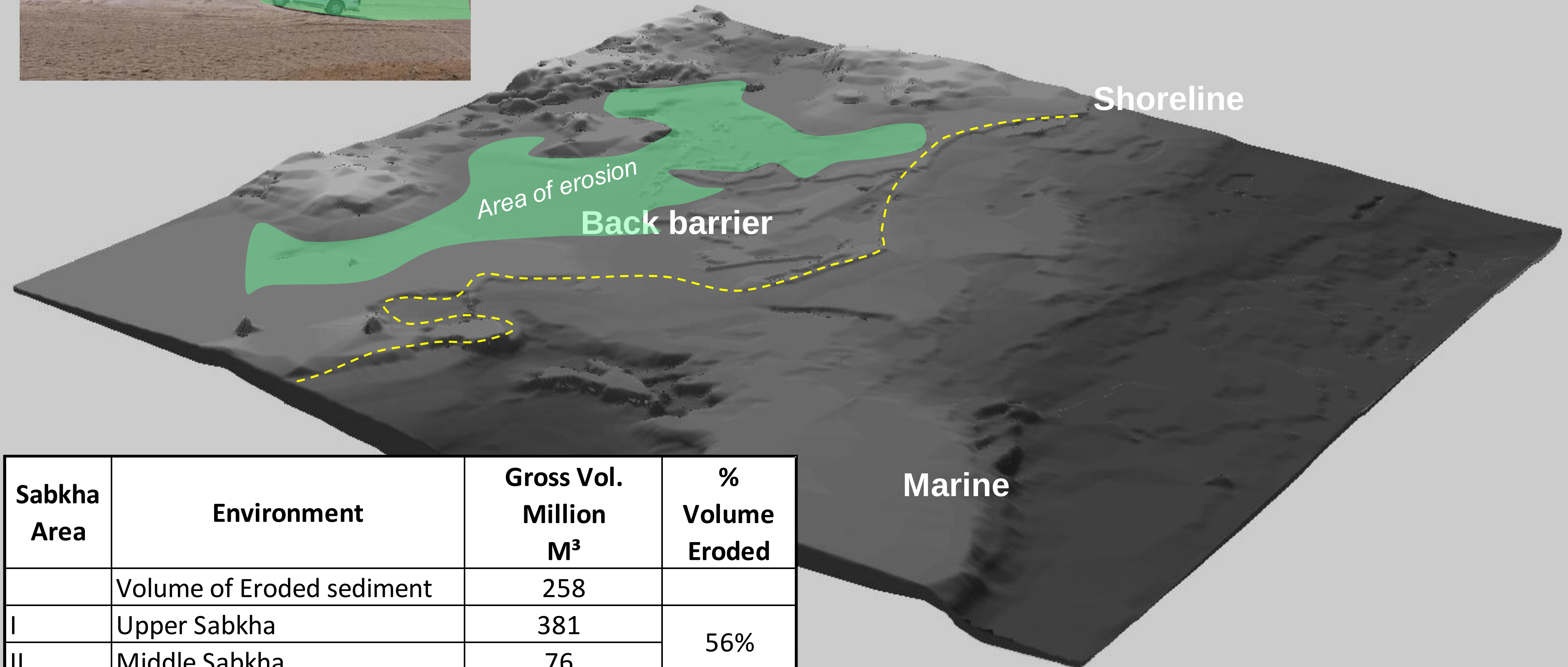
Final phase sedimentation marked by extensive gypsum precipitation as crusts and intra-stratal crystal growth

Quantifying back barrier erosion



Calculation of Eroded Volumes

Calculation of eroded volume based on restored thickness in upper sabkha



Sabkha Area	Environment	Gross Vol. Million M³	% Volume Eroded
	Volume of Eroded sediment	258	
I	Upper Sabkha	381	56%
II	Middle Sabkha	76	
III	Lower Sabkha and Coastal	203	
IV	Offshore	2,015	
	Total	*2,675*	

Approximately 50% upper sabkha has been eroded in roughly 6000 years

Al Thakhira Core- 3 to 6.5 meters

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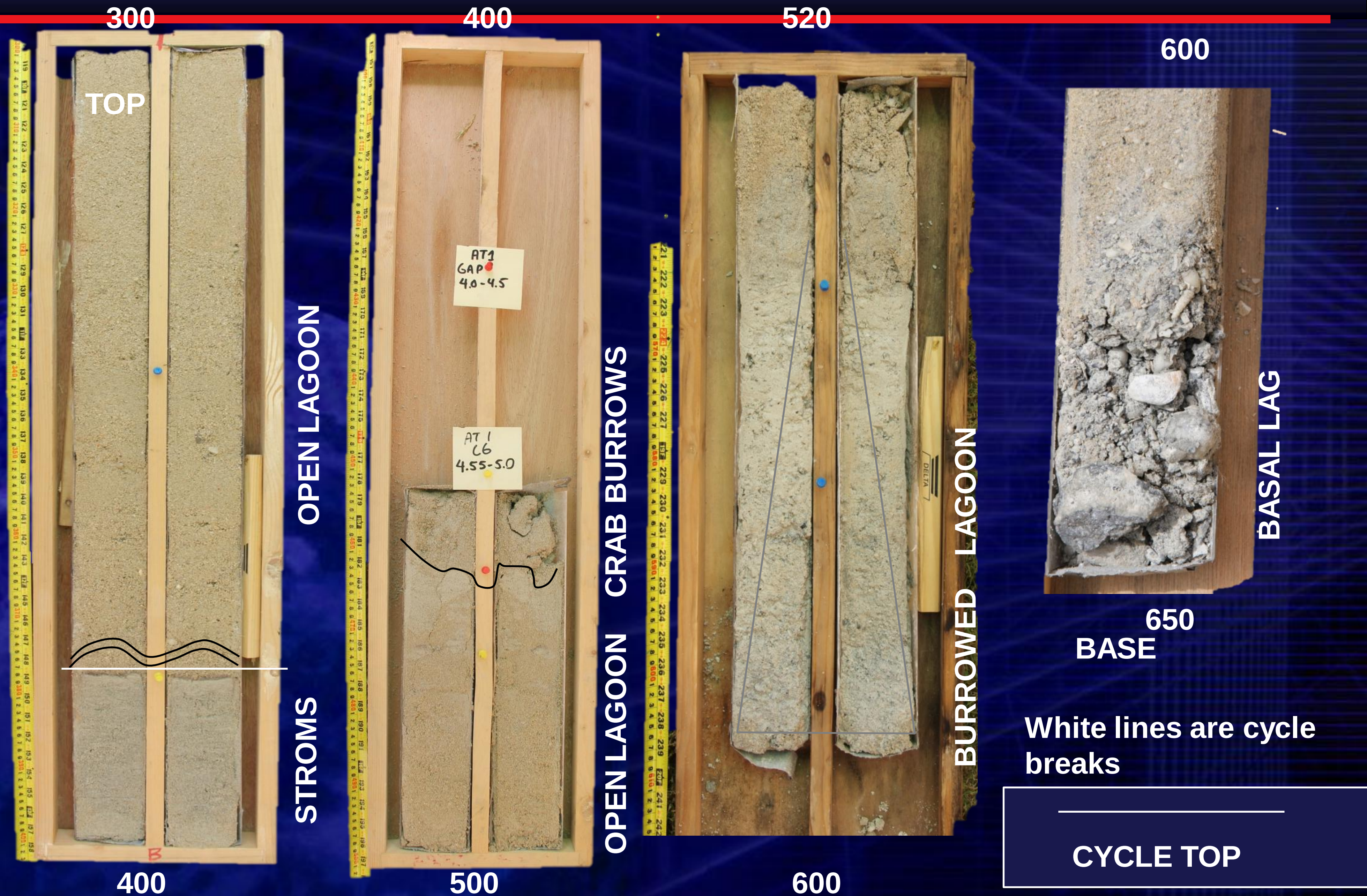

Al Thakhira Core- 0 to 3 meters

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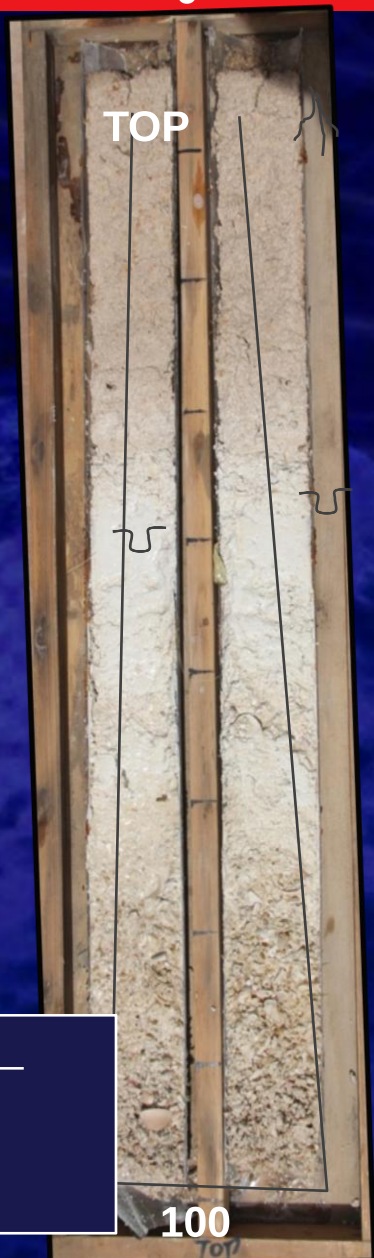
0

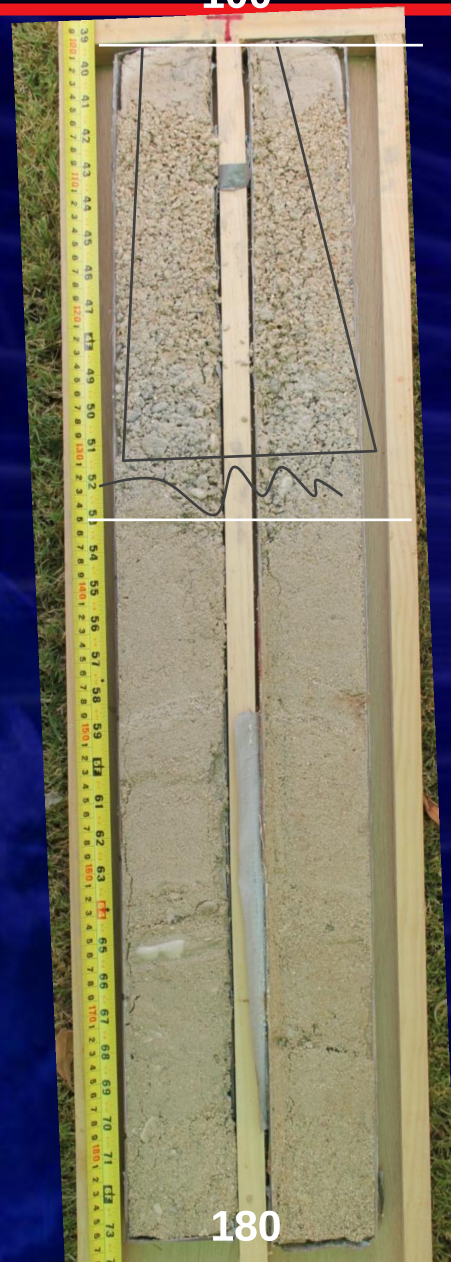


100

FINES UP TO STROMATOLITES

CHANNEL

100



180

MEANDRINE CHANNEL

OPEN LAGOON

180

300

INLET CHANNEL

OPEN LAGOON

BASE

White lines are cycle breaks

CYCLE TOP

Summary

- Redistribution of sand is a significant process- infilling back barrier areas with sediments derived from beaches
- Back barrier areas show ordered cyclicity on a scale that could be captured in geological models
- Phases
  1. Open lagoon
  2. Inlet Channel
  3. Evaporitic

Dark cover of stromatolites & mangroves in 50 years