

# **The Giant Oil Field Evaporite Association: A Function of the Wilson Cycle, Climate, Basin Position and Sea Level\***

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Please refer to companion article, “World Source Rock Potential through Geological Time: A Function of Basin Restriction, Nutrient Level, Sedimentation Rate, and Sea-Level Rise,” [Search and Discovery Article #40472 \(2009\)](#).

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## **Abstract**

Over 50% of world's most easily accessible hydrocarbon reserves are trapped in carbonates; over 60% of these beneath evaporite seals. The seals are distinct widespread stratigraphic markers capping evaporite successions that accumulated during Wilsonian plate-motion cycles of extension and compression. Hydrocarbon-prone succession architecture is driven by base-level change during deposition; juxtaposing source, reservoir, and seals, and favoring hydrocarbon exploration and exploitation in Arabian Gulf, Central Asia, Atlantic, and the Cordilleran and Appalachian Mountains.

Critical to these settings are high rates of organic production, accumulation and preservation, a response to widespread enveloping continental plates windward of rain-shadowed lee shores of restricted anoxic and saline basins behind structural and/or depositional barriers. Internal drainage and/or limited access to open-ocean waters are products of linear belts of uplifted crust marginal to depressed crust, often below sea level, and so favoring evaporites and organic matter preservation. The upper bounding surface of updip, supratidal sabkha evaporite cycles is found in regressive coastlines, matching sea-level positions of late highstand system tracts while surfaces of downdip restricted playas and basin evaporites matches the sea-level position of lowstand system tracts.

Common updip shallow water carbonate platform play elements include sabkhas, salinas, and mudflats with nearshore and tidal-flat reservoirs sealed by lateral and top seal sabkha facies, and offshore bar and shoal complexes capped by tight peritidal carbonates. Examples include Central Basin Platform Permian San Andres, Arabian shelf Permian Khuff, and Devonian Dolomitized Wabamun ramp. Downdip carbonate-platform play elements include subaqueous salterns with platform-margin buildups; isolated buildups on

platform; and nearshore/tidal-flat plays. Examples include Eastern Arabian Basin Arab D and Eastern Siberian Basin Lower Cambrian Osa grainstone play.

Common basins play elements from shallow and/or deep basins include platform margin buildups, isolated buildups, and allochthonous mass-gravity deposits. With no structure, platform-margin buildups often lack top and lateral seal probability, but Iranian and Iraqi Asmari and Main Limestone plays have structure and potential. Smaller isolated buildups are the most successful play and include the Paradox Basin porous algal buildups, Western Canadian Middle Devonian Keg River play, and Michigan Basin Niagaran plays.

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# **'The Giant Oil Field Evaporite Association'**

## **a function of the**

# **Wilson Cycle, Climate, Basin Position & Sea Level**

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# Acknowledgments

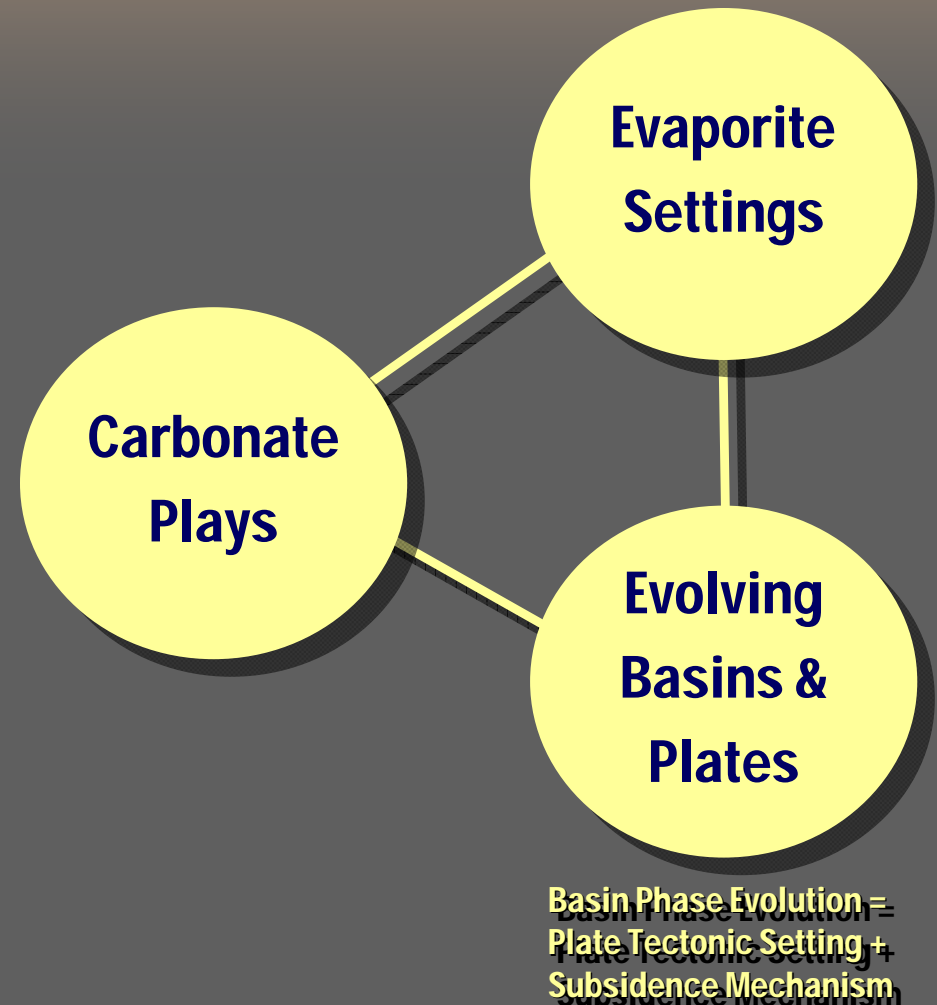
**We extend our thanks & appreciation to:**

- **University of South Carolina**
- **ExxonMobil**
- **MEGE**

**for making the study reported in this  
presentation possible**

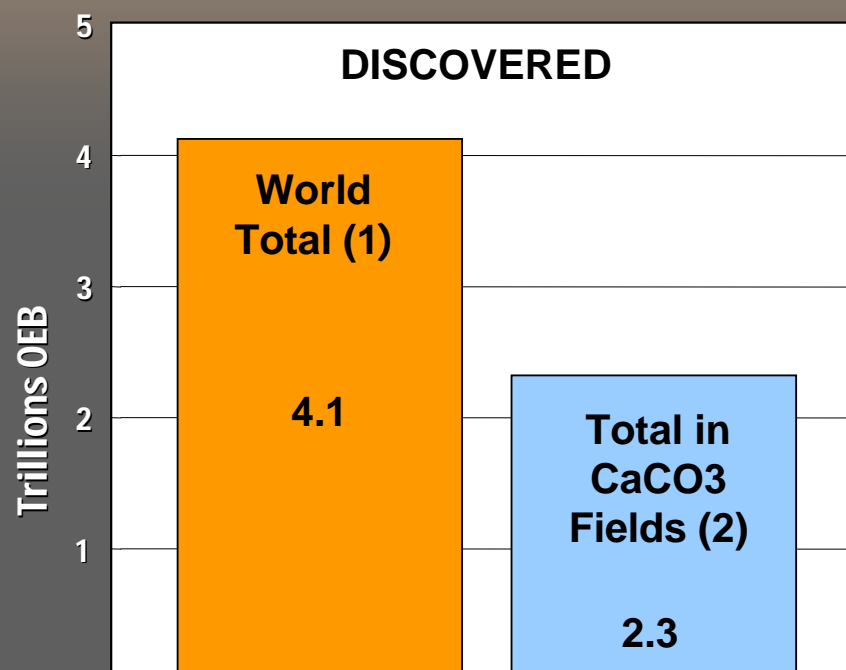
# Presentation Outline

- Carbonate/Evaporite Hydrocarbon Reserves
- Tie between Carbonate/Evaporite Settings
  - Climate
  - Basin Phase (extension, compression, or barred)
  - Sea Level
- Carbonate/Evaporite Play Geometries
- Summary & Conclusions

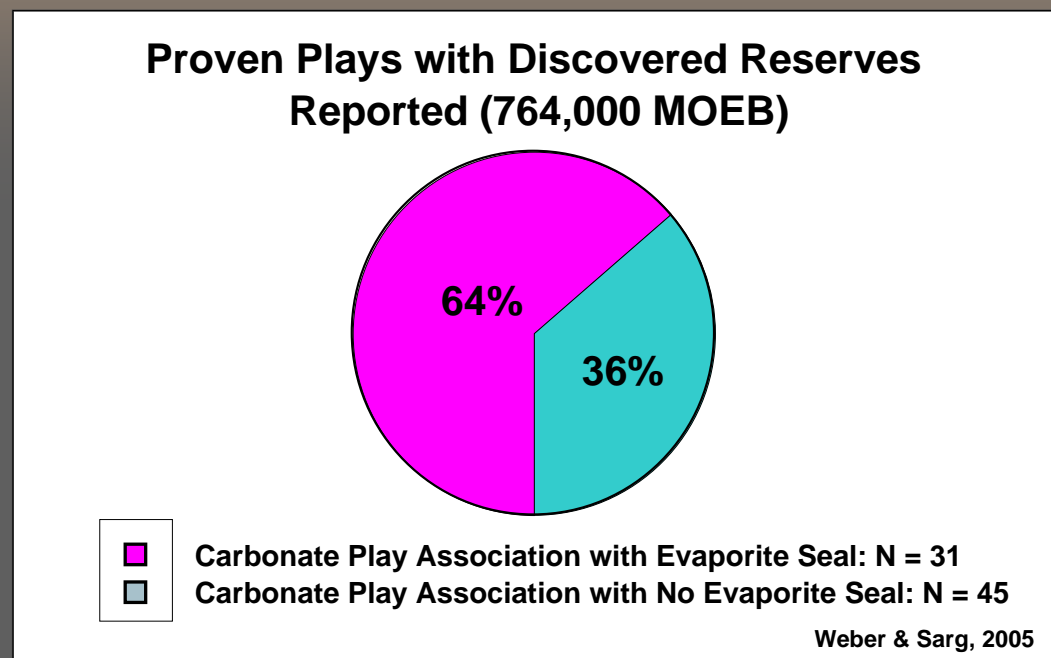


Talk based on Proven Plays from Commercial Databases (e.g., C & C Reservoirs, IHS Energy, USGS Assessments)

# Significance of Carbonates & Evaporites

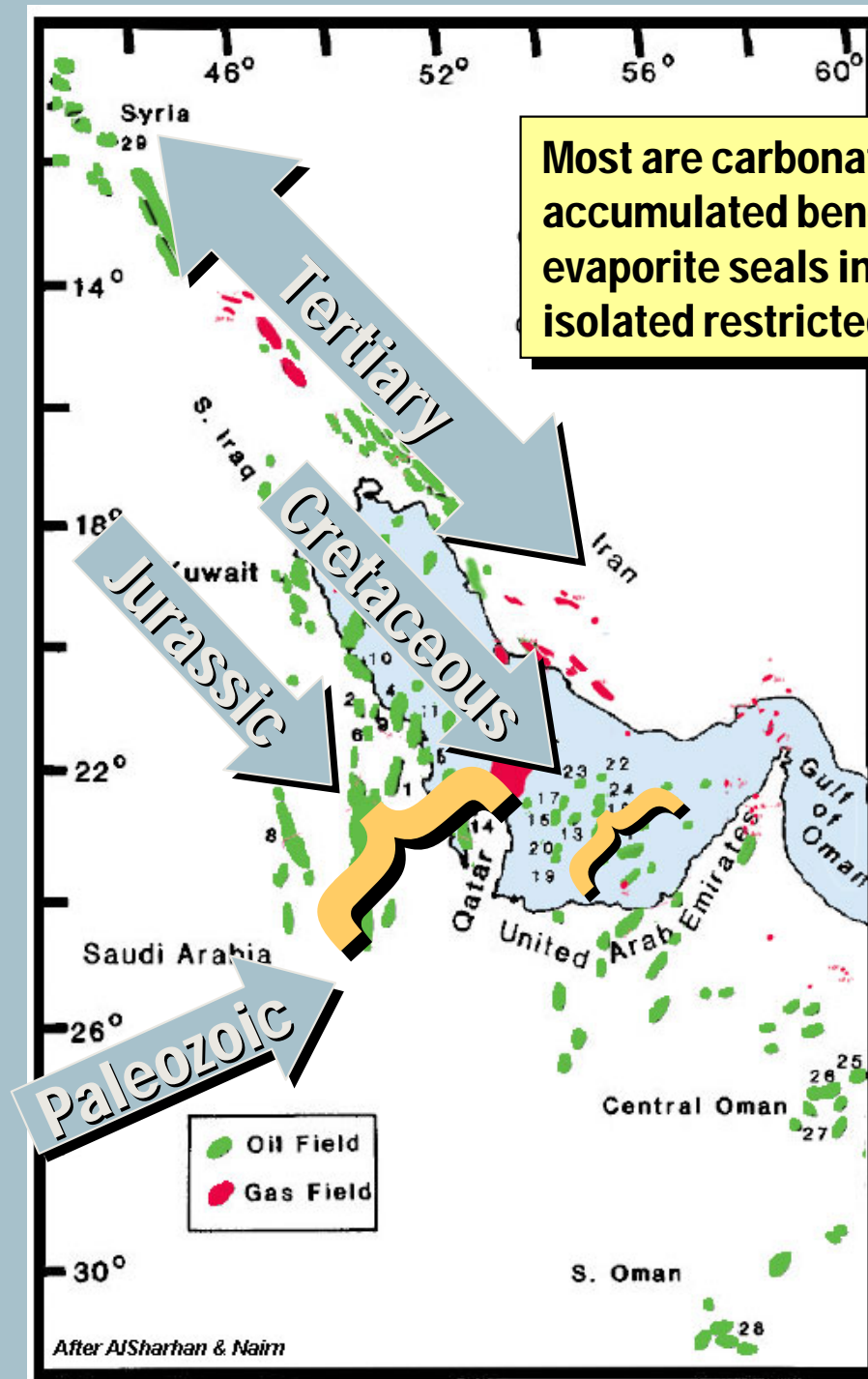


- (1) USGS World Assessment (2000)
- (2) Mobil CATT Study (1999)



- Database captured 33% of total discovered reserves in carbonates
- 41% of plays exhibit an evaporite seal
- 64% of discovered reserves trapped under an evaporite seal
- So evaporites are important?

# Location of Oil & Gas Fields of Arabian Gulf - Reservoirs are Younger to East





# Evaporites - Tectonic Phase, & Source, Reservoir, & Seal, & Sea Level

- Major carbonate/evaporite successions accumulated in the **arid tropics** adjacent to continental plate margins at start of **extensional** & end of **compressional** Wilsonian phases of plate motion & to **lee of** structural & depositional **barriers** on trailing margins
- These phases juxtaposed **source, reservoir, & seal**, favoring hydrocarbon exploration & exploitation
- **Geometries** of hydrocarbon prone carbonate/evaporite successions are determined by position of **base level change**

Evidence comes from plate motion cycles of Arabian Gulf, Central Asia, Atlantic, Cordilleran & Appalachian Mountains

isolated linear  
belt of interior  
drainage

restricted  
entrances  
to sea

Northern Atlantic

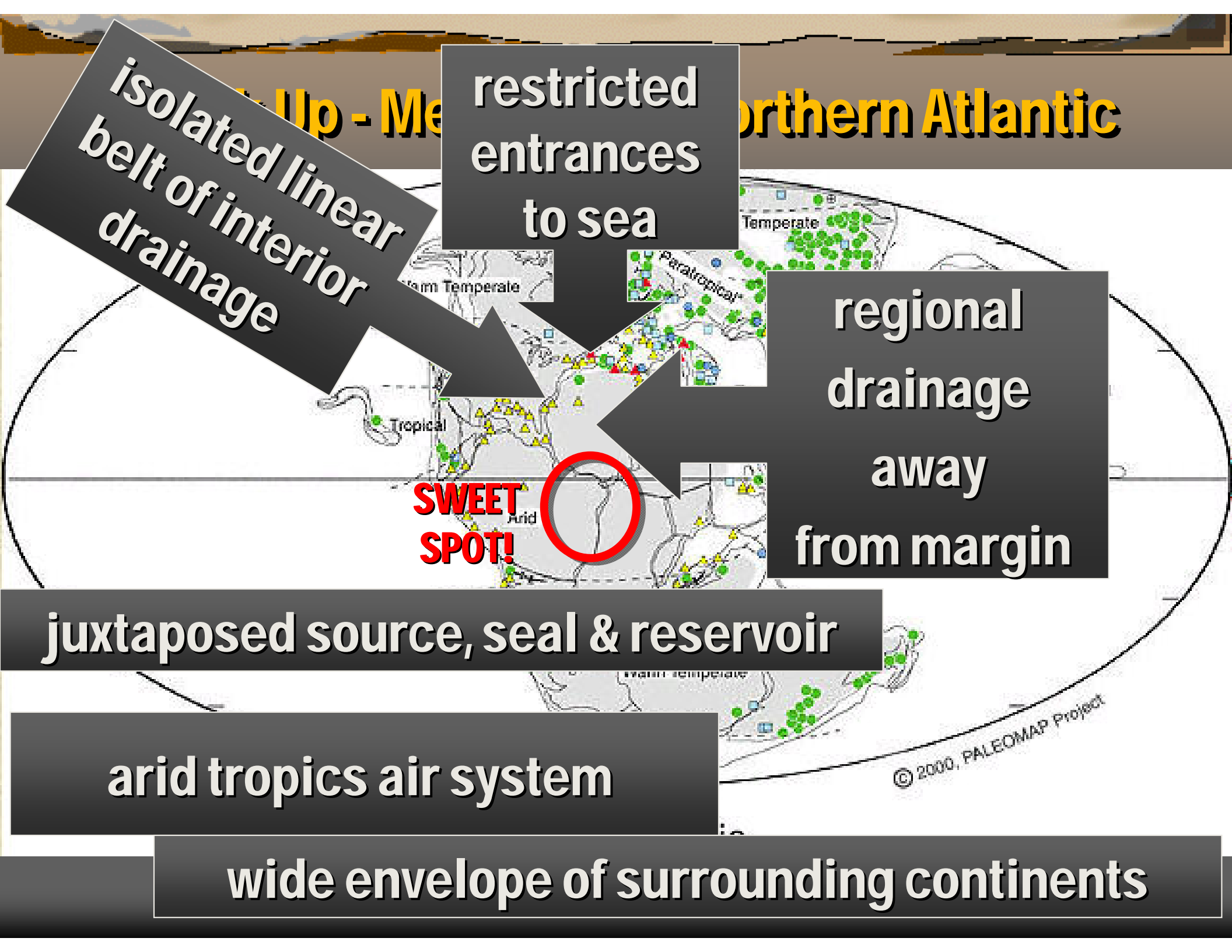
regional  
drainage  
away  
from margin

**SWEET  
SPOT!**

juxtaposed source, seal & reservoir

arid tropics air system

wide envelope of surrounding continents



# Break Up Margins & Evaporites

- **Mesozoic of northern Gulf of Mexico**
- **Mesozoic of North & South Atlantic margins**
- **Mesozoic of Yemen rift belt**
- **Mesozoic & Tertiary of Eritrea**
- **East African Rift**
- **Dead Sea**

**Collision**

**vaporites**

regional  
drainage  
into basin

restricted  
entrance  
to sea

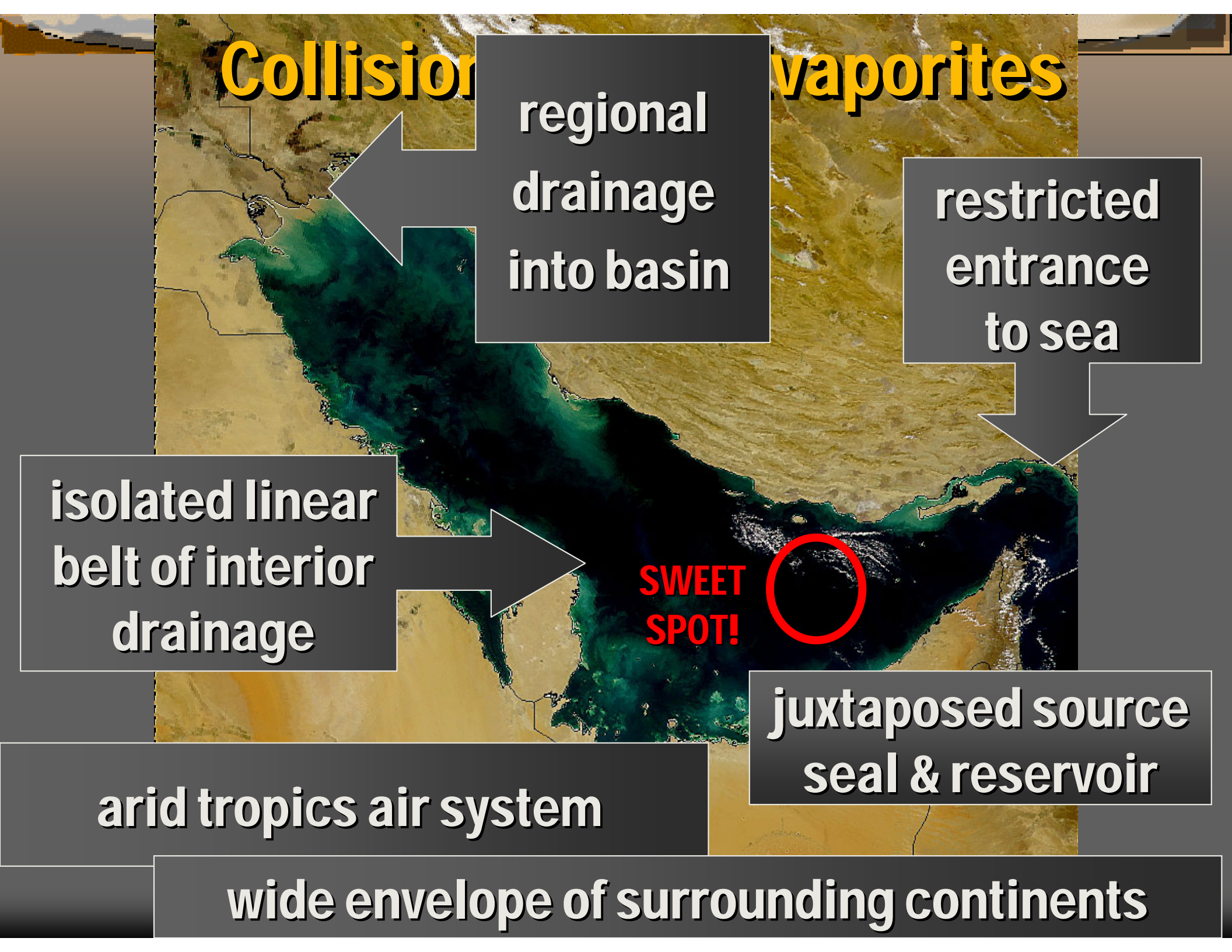
isolated linear  
belt of interior  
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**SWEET  
SPOT!**

juxtaposed source  
seal & reservoir

arid tropics air system

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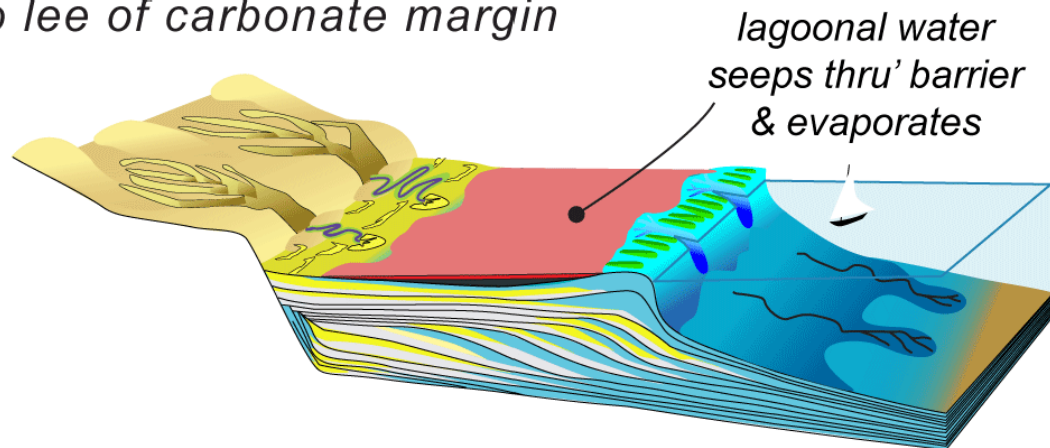
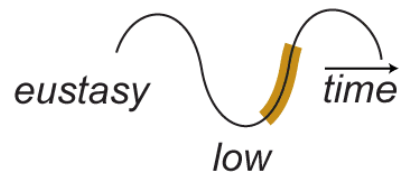
# Collision Margin & Evaporites

- **Current Arabian Gulf & underlying Late Mesozoic to Tertiary**
- **Silurian of Michigan Basin & Western New York State**
- **Devonian of Western Canada & NW USA**
- **Permian of New Mexico & West Texas**
- **Permian of Zechstein Basin**
- **Mesozoic to Tertiary of southern South America**
- **Tertiary of Mediterranean**
- **Mesozoic & Tertiary in final phases of Tethys Sea**

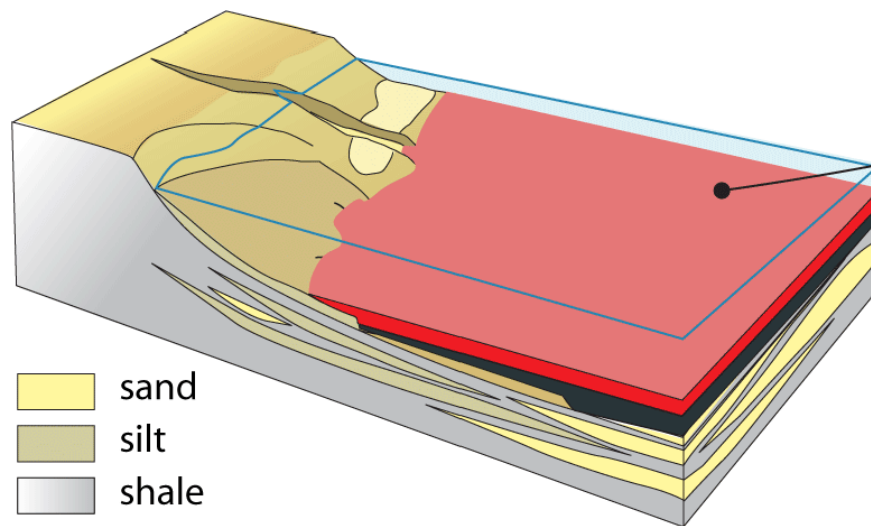
# Restricted Basin Evaporites

*restricted shallow shelf to lee of carbonate margin*

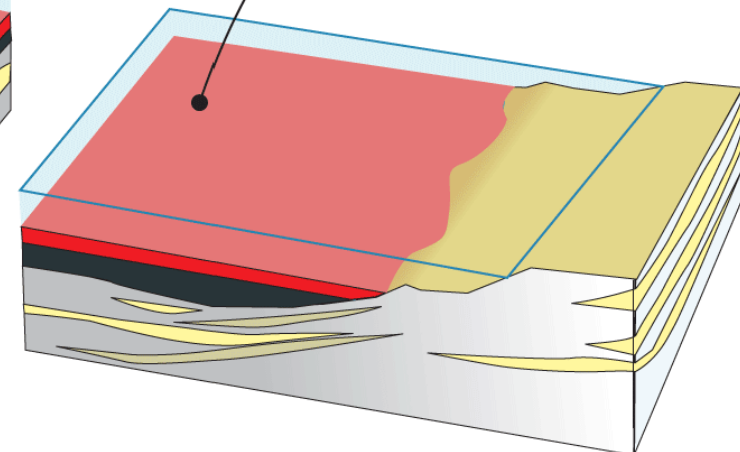
*transgression lowers  
sediment input  
& evaporite accumulation  
dominates*









*restricted deep water rifted basin*



*evaporation causes  
evaporite precipitation*



-  sand
-  silt
-  shale
-  organic rich shale &/or marl
-  carbonate
-  evaporite

Christopher Kendall, 2009

# Example of Barred Basin Mesozoic - Arabian Gulf

Late Jurassic  
Volgian (150 Ma)

restricted  
entrance  
to sea

juxtaposed source  
seal & reservoir

upper Jurassic  
Saudi Arabia  
Kuwait, Iran  
& UAE

**SWEET  
SPOT!**

structural &  
depositional  
barrier over  
Hercynian  
horst blocks

arid tropical air system

(Rees et al. 2000)

wide shadow from adjacent continents

**Restricted  
Basins  
Isolated by  
Build Up  
Barriers  
Organic Rich  
Fill  
Arabian Gulf  
Jurassic**

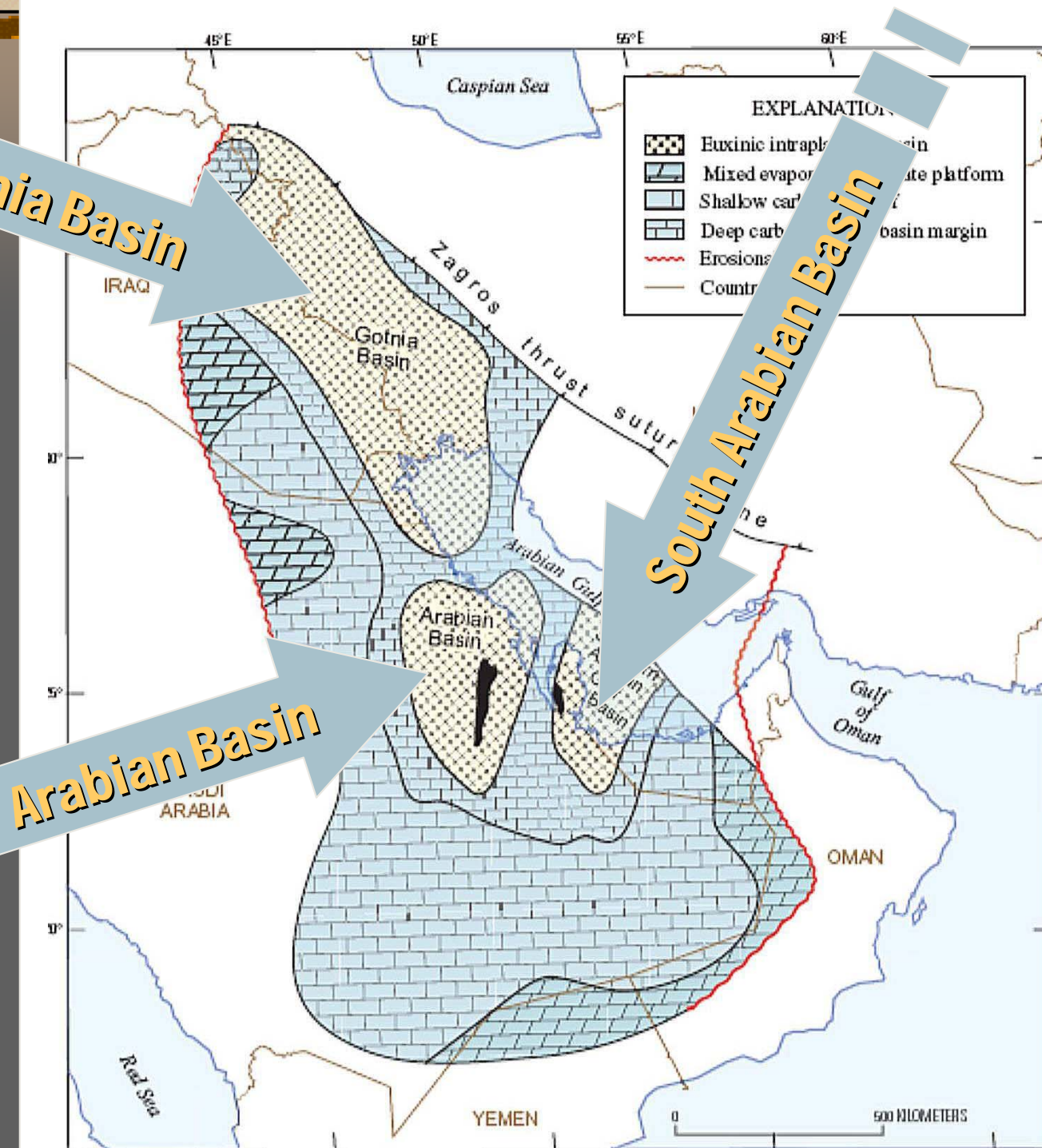


Figure 13. Gotnia, Arabian, and Southern Arabian Gulf Basins in which Jurassic hydrocarbon source rocks accumulated (modified from Asharhan and Kendall, 1986). Sawtooth on upthrown block of Zagros thrust suture zone.

*After Fox & Albrandt, 2002*



# **Structural & Depositional Barrier Evaporites**

- **Late Paleozoic to Early Mesozoic beneath Arabian Gulf**
- **Cretaceous Ferry Lake Anhydrite of Florida**

**Evaporites trapped by structural & depositional barrier**

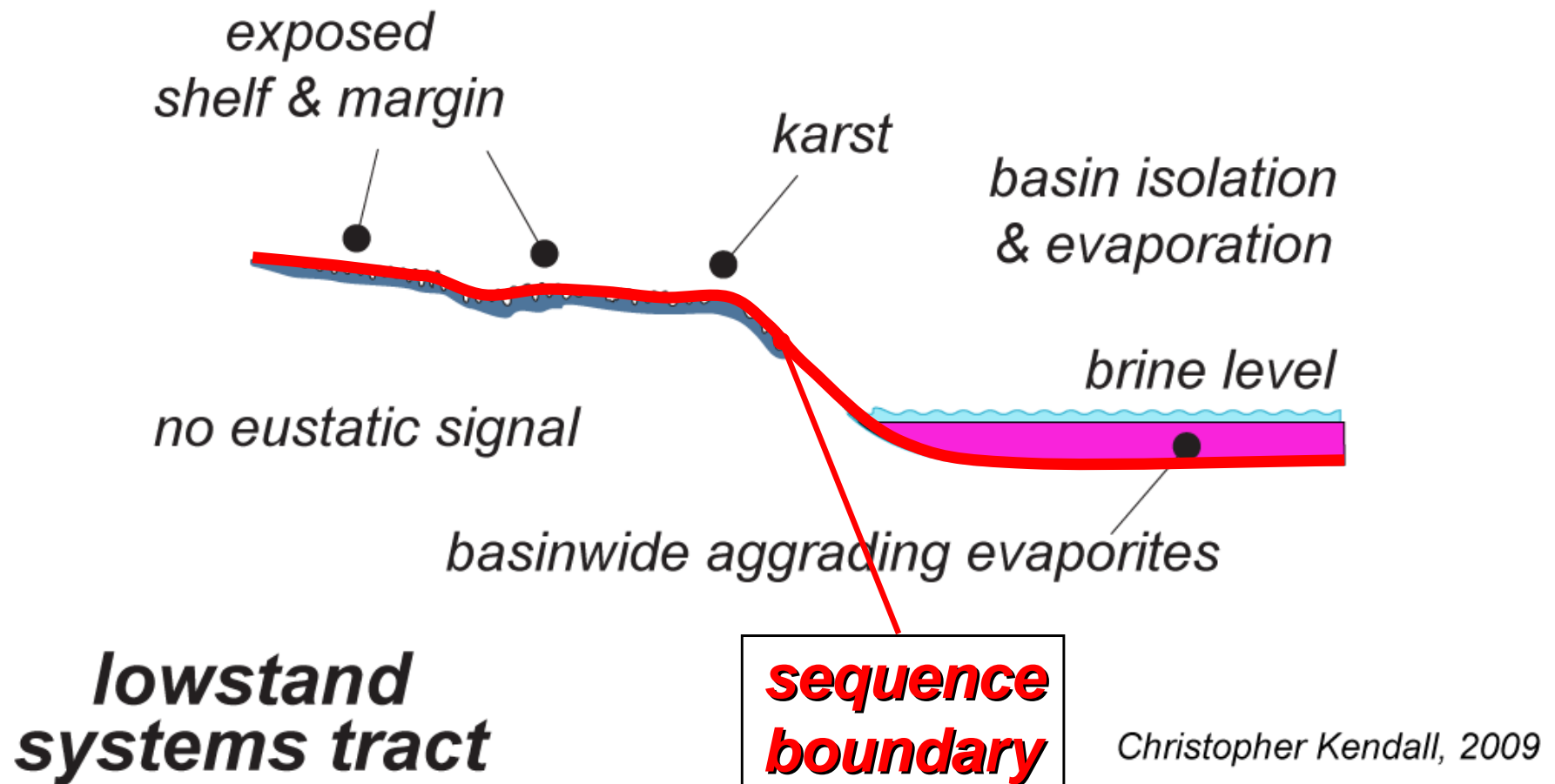
**Punctuated by limited access to sea & repeated arid climatic events**

# Carbonate/Evaporites Plays & Sequence Stratigraphy

- **Downdip restricted playas, salinas & basin evaporites (upper surface coincides with sea level position of the lowstand (LST) & following transgressive (TST) system tracts**
- **Updip supratidal sabkha evaporite cycles (upper bounding surface preserved in regressive coastlines matching sea level position of late high stand (HST) system tract**

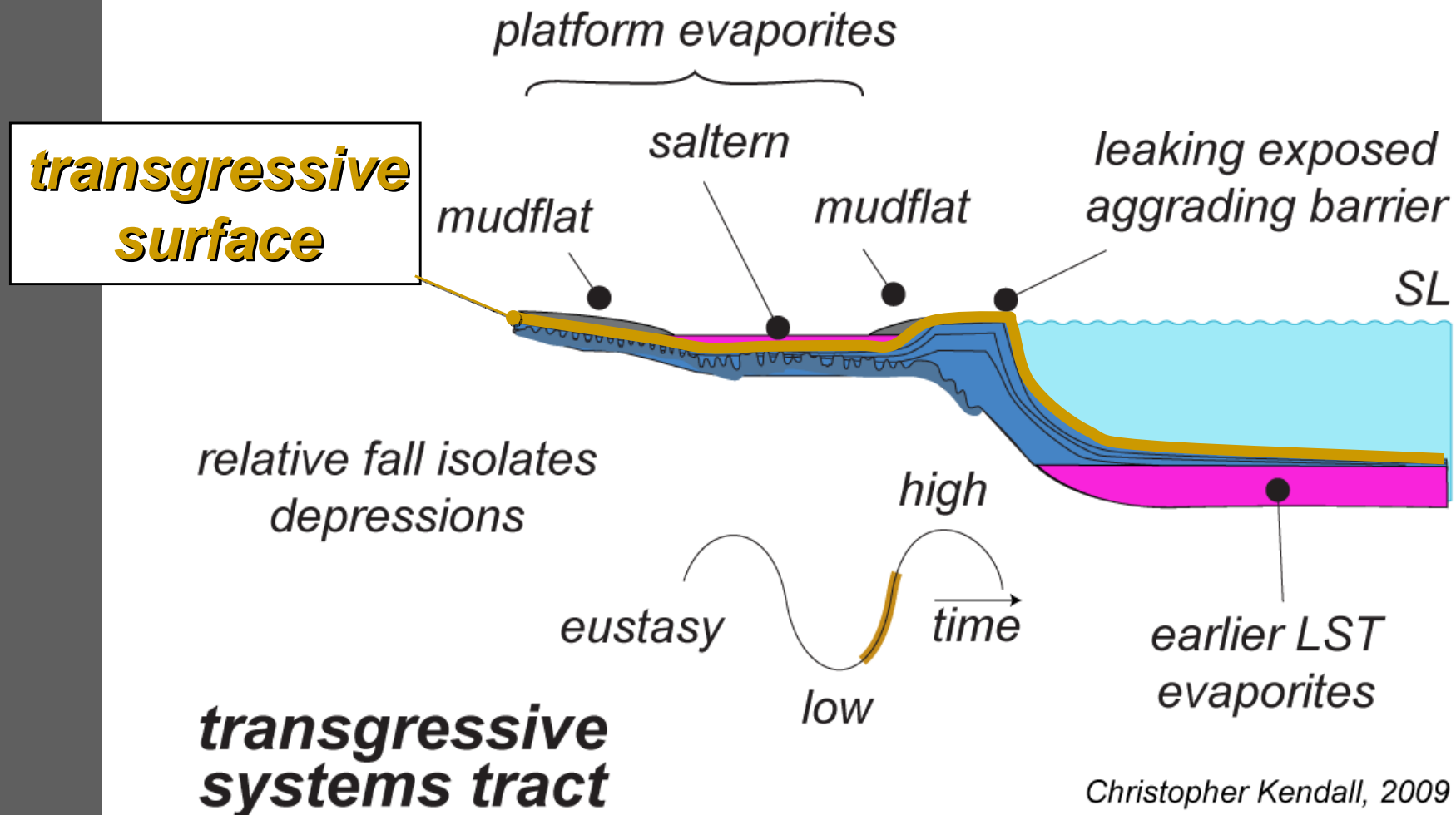
# Low Stand Evaporite Signals

*arid carbonates/evaporites with deep basin, saltern, &/or flanking mudflat settings*



# Transgressive Evaporite Signals

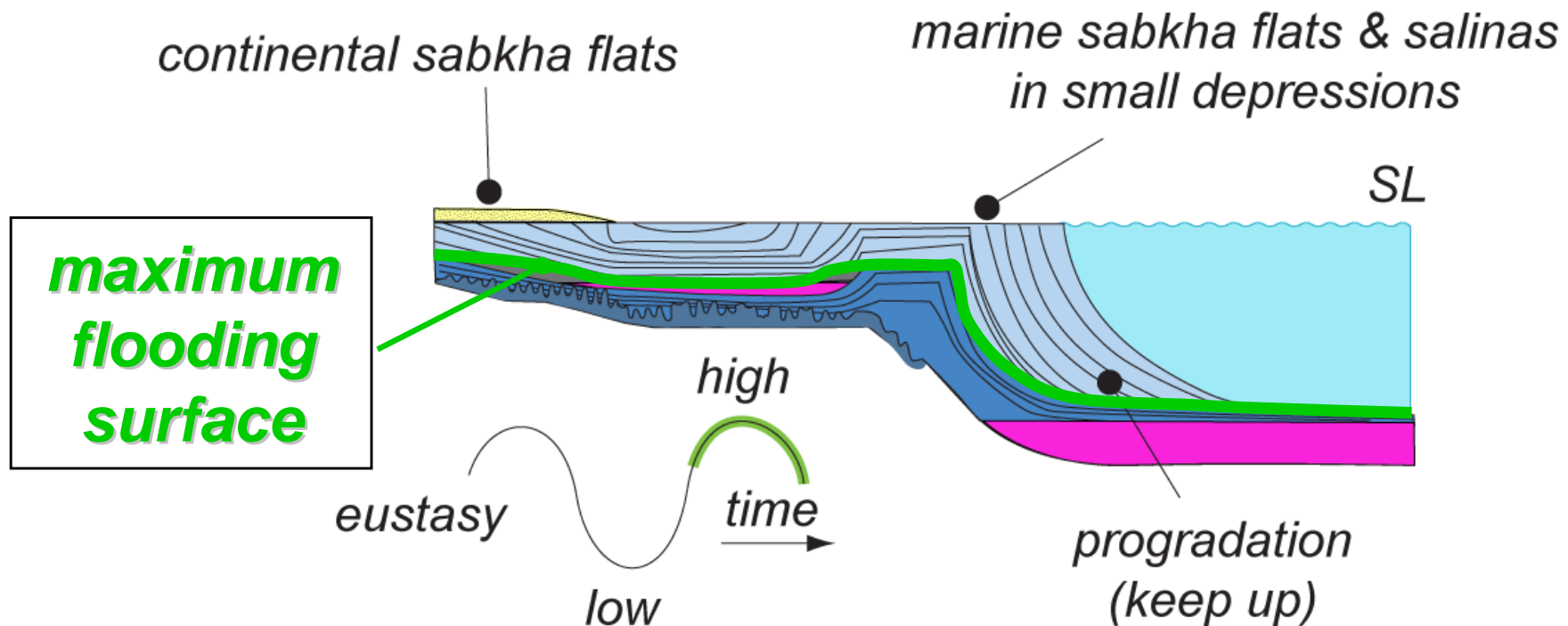
*arid carbonates/evaporites saltern  
with flanking mudflat settings*



Christopher Kendall, 2009

# High Stand Evaporite Signals

*arid carbonates/evaporites dominated  
by ephemeral coastal sabkhas*



**highstand  
systems tract**

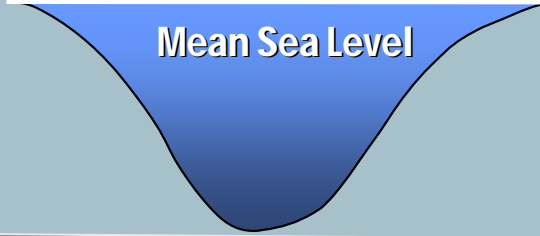
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# Major Evaporite Settings

## Basin-Center Evaporites

Shallow to Deep Basin

Mean Sea Level



## Platform Evaporites

Subaqueous Saltern

Sabkha, Salina, Mudflat

## Continental Evaporites

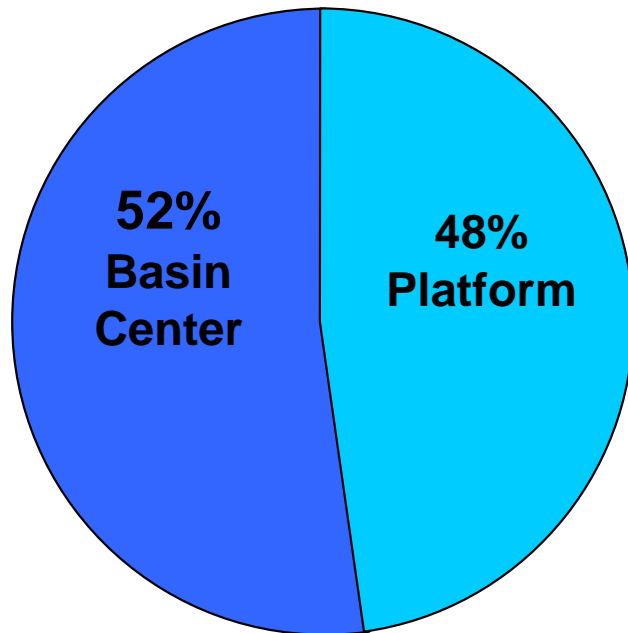


### Discovered Reserves for Proven Carbonate Plays

Total = 490,000 MOEB

### Discovered Reserves for Proven Evaporite Plays

Total = 485,884 MOEB



- Basin-Center (Commonly product of **LST** & **TST**)
  - Thick evaporites deposited across whole basin (> 50 m thick evaporite intervals)
  - **Shallow** to **deep** water evaporites occur in many different settings (**shelf**, slope, basin)
- Platform (Commonly product of **LST** & **TST**)
  - < 50 m thick evaporite intervals, commonly < 5 m thick evaporite beds inter-bedded with thin to thick carbonate intervals
  - Shallow water (**Saltern**) & subaerial (**Sabkha**, **Salina**, **Mudflat**) evaporites landward of barrier or sill
  - Open marine sediments deposited seaward of sill
- Continental (Playa Lakes) (not discussed here)

# Evaporite Setting Plays & Basin Phase Evolution

N = 9 Plays

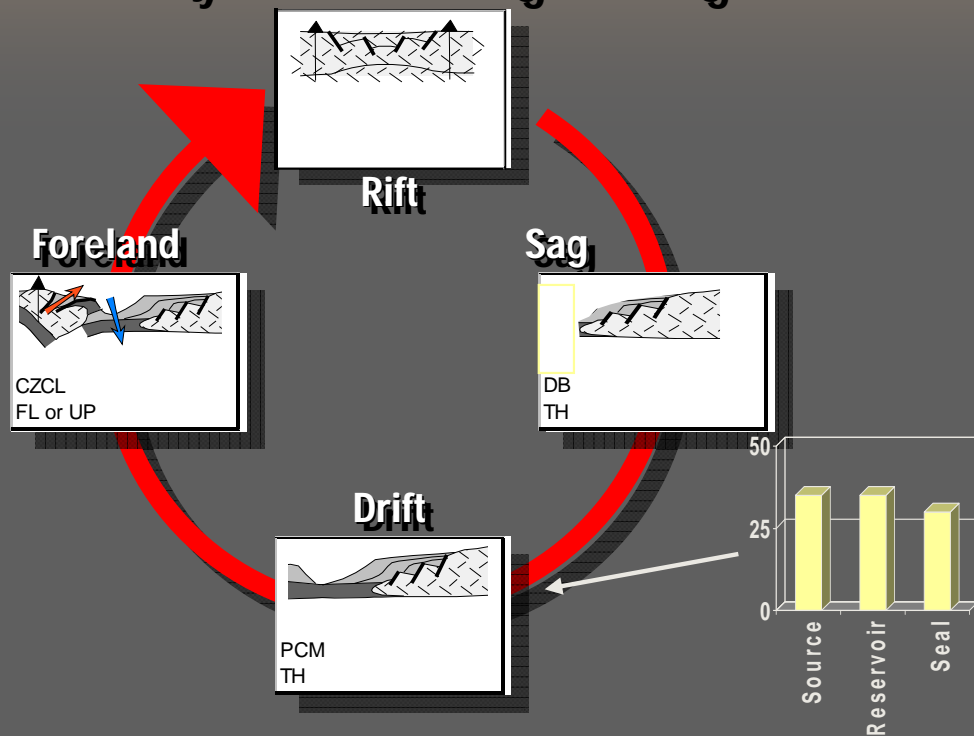
## TECTONIC PHASE FOR PLATFORM-SUBAQUEOUS SALTEN EVAPORITE SETTINGS

		Rift	Sag	Drift	Foreland
Passive Margin	Post-Seal				
	Seal	Peten Arabian Platform Timan-Pechora Angara-Lena Gulf Basin			
	Reservoir				
	Source				
Continental Interior	Post-Seal				
	Seal				
	Reservoir				
	Source				
Back-Arc	Post-Seal				
	Seal				
	Reservoir				
	Source				

Dominant Occurrence

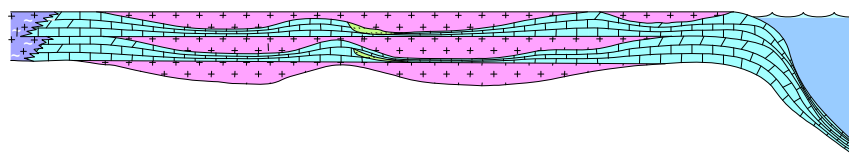
Minor Occurrence

## Play Elements & Tectonic Evolution Pathway for Passive Margin Settings



## Plays Occur in Passive Margin Settings

- 25% of Plays Do Not Evolve to Foreland Phase
- Stratigraphic Traps are Important
- Source, Reservoir, Seal Likely in Drift Phase
- >90% Source Rocks Carbonate in Origin
- Source Rocks in Close Proximity to Reservoir





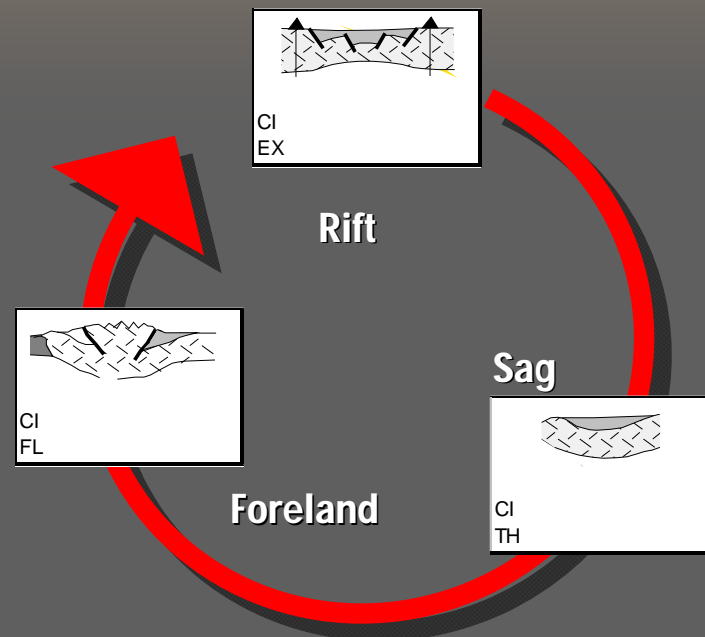
# Evaporite Play Settings & Basin Phase Evolution

N = 13 Plays

## TECTONIC PHASE FOR BASIN CENTER-SHALLOW MARINE SHALLOW BASIN EVAPORITE SETTINGS

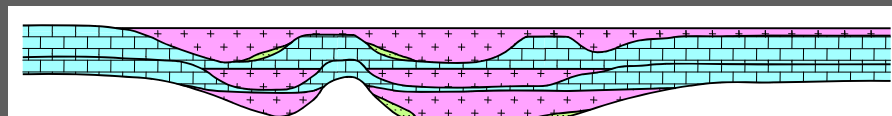
		Rift	Sag	Drift	Foreland
Passive Margin	Post-Seal				
	Seal		Zagros Fold Belt		
	Reservoir				
	Source				
Continental Interior	Post-Seal			Gulf Suez Michigan Oman Salt European Permian Williston Dnepr/Donets Pripyat Paradox	
	Seal				
	Reservoir				
	Source				
Back-Arc	Post-Seal				
	Seal			Amu Darya Western Canada	
	Reservoir				
	Source				

## Play Elements & Tectonic Evolution Pathway for Continental Interior Settings



### Plays in Continental Interior Settings

- 40% of Plays Do Not Evolve to Foreland Phase
- Stratigraphic Traps Important
- Source, Reservoir, Seal Possible in ALL Phases
- >90% Source Rocks Carbonate in Origin
- Source Rocks in Close Proximity to Reservoir



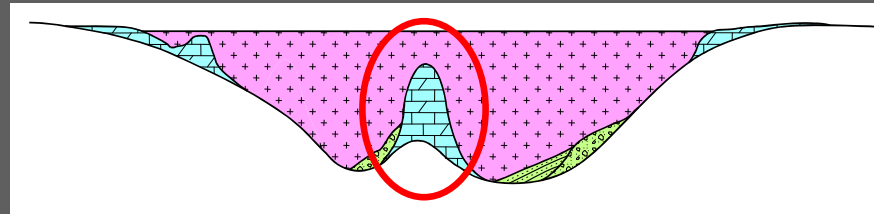
Dominant Occurrence

Minor Occurrence

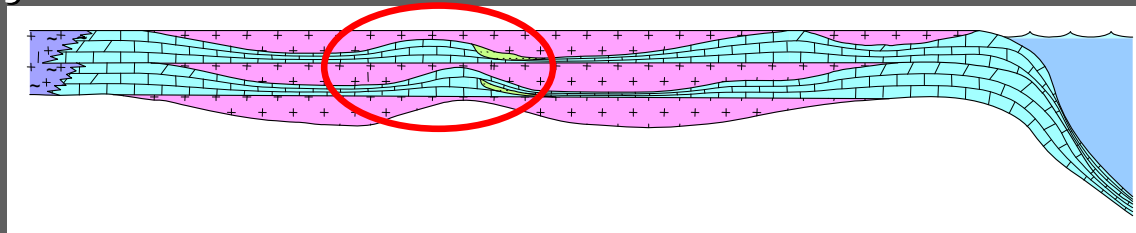


# Summary & Conclusions

- One can predict Carbonate Play Opportunities in Evaporite Basins from an understanding of Basin Phase Evolution and Evaporite Setting
- The opportunities occur in:
  - Land Detached Isolated Platforms in Basin-Center Evaporite Settings in Arc-Related and Passive Margin Settings that Evolve to the Foreland Basin Phase



- Isolated buildups in Platform Evaporite Settings in Passive Margin Settings That May or May Not Evolve to the Foreland Basin Phase



- The Exploration potential of Carbonate Plays in Evaporite Basin is good. However where the “prospects” are located is the ever evolving objectives tied to access to prospective acreage and a drilling program!

# Conclusions

**Now let's  
find oil!**



Kendall, Weber & Alsharhan "*Evaporite Plays*"

# **Arid Climates Common to Earth History**

**Evidence comes from:**

- **Evaporites of Mesozoic to Tertiary of Middle East; Paleozoic & Mesozoic the USA, Europe & Middle East**
- **Eolian sediments of Late Paleozoic & Mesozoic section of Western USA, Permo-Triassic of Western Europe & Middle East, Precambrian of India & NW Africa**

**All these evaporite basins have oil reserves**

# Current Reserves for Middle East

	Crude Oil(BB)	Natural Gas (TCF)
•Saudi Arabia	263.5 bbls	204.5 Tcf
•Iraq	112.0 bbls	109.0 Tcf
•UAE	97.8 bbls	212.0 Tcf
•Kuwait	96.5 bbls	52.7 Tcf
•Iran	89.7 bbls	812.3 Tcf
•Oman	5.3 bbls	28.4 Tcf
•Yemen	4.0 bbls	16.9 Tcf
•Qatar	3.7 bbls	300.0 Tcf
•Syria	2.5 bbls	8.5 Tcf
•Bahrain	0.1 bbls	3.9 Tcf

Most in carbonate  
plays beneath  
evaporite seals

# Late Paleozoic - Arabian Gulf

Restricted  
Entrance  
To Sea

Juxtaposed Source  
Seal & Reservoir

Structural &  
Depositional  
Barrier over  
Hercynian  
Horst Blocks

Permian Khuff  
Saudi Arabia  
Oman & UAE

**SWEET  
SPOT!**

Arid Tropical Air System

Wide Shadow from Adjacent Continents

Wordian

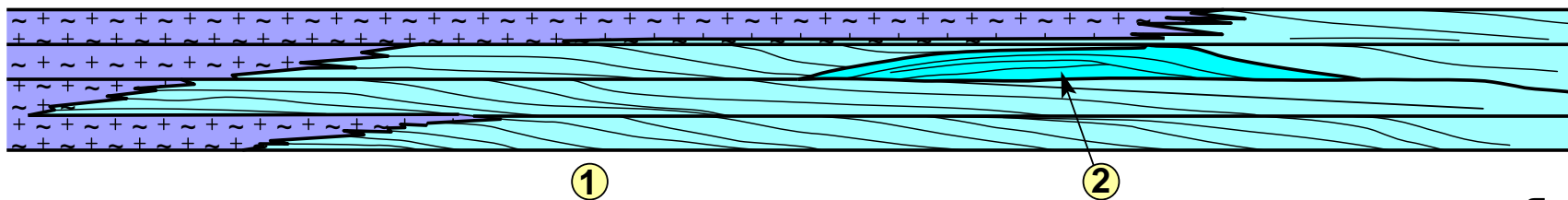
00M)  
M)  
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# DEEP MARINE DEEP BASIN



# Platform Evaporite Plays (PMM)

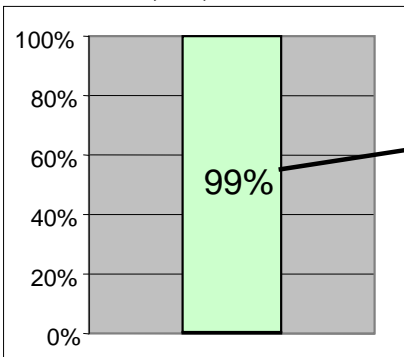
## PLATFORM - MARINE MARGINAL (SABHKA, SALINA, MUDFLATS)



 EVAPORITE & TIGHT CARBONATES

 CARBONATE

N = 7; 31,205 MOEB



### POSSIBLE CARBONATE PLAYS

1. NEARSHORE/TIDAL FLAT
2. OFFSHORE BAR/SOAL COMPLEX

### Basin Examples:

Caspian Middle  
Tarim  
W. Canada Plains  
Neuquen  
Caucasus North  
Midland Basin  
Central Basin Platform

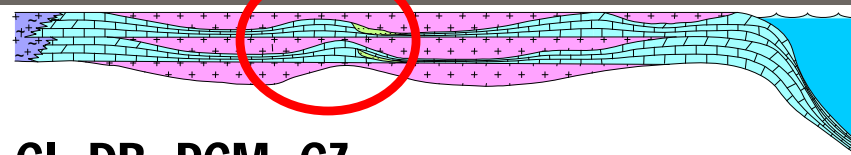
Weber & Sarg, 2005



# Proven Plays & Known Opportunities

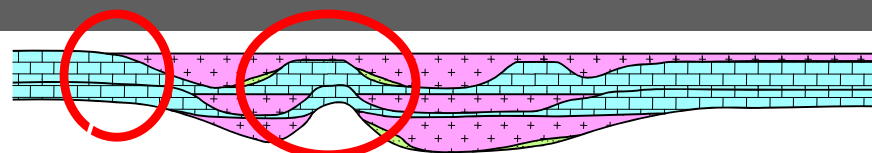
	EVOLUTION TYPE	EXTENSION	THERMAL (SAG)	THERMAL (PASSIVE MARGIN)	CONVERGENCE
PASSIVE MARGIN	CI_DB	CI EX	DB TH		
	CI_DB_PCM	CI EX	DB TH	PCM TH	
	CI_DB_PCM_CZ	CI EX	DB TH	PCM TH	CZCL FL or UP
CONTINENTAL INTERIOR	CI	CI EX			
	CI_CI	CI EX	CI TH		
	CI_CI_CZ	CI EX	CI TH		CI FL or UP
BACK-ARC	BA	CZBA EX			
	BA_BA	CZBA EX	CZBA TH		
	BA_BA_CZ	CZBA EX	CZBA TH		CZBA FL or UP

**PSS**



**CI\_DB\_PCM\_CZ**

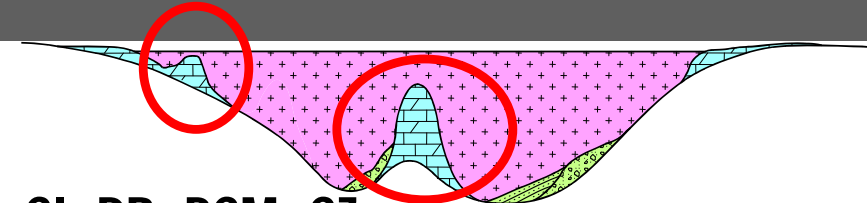
**BSMSB**



**CI\_CI\_CZ**

**CI\_CI**

**BDMDB**



**CI\_DB\_PCM\_CZ**

**BA\_BA\_CZ**



# Conclusions Hydrocarbon Potential

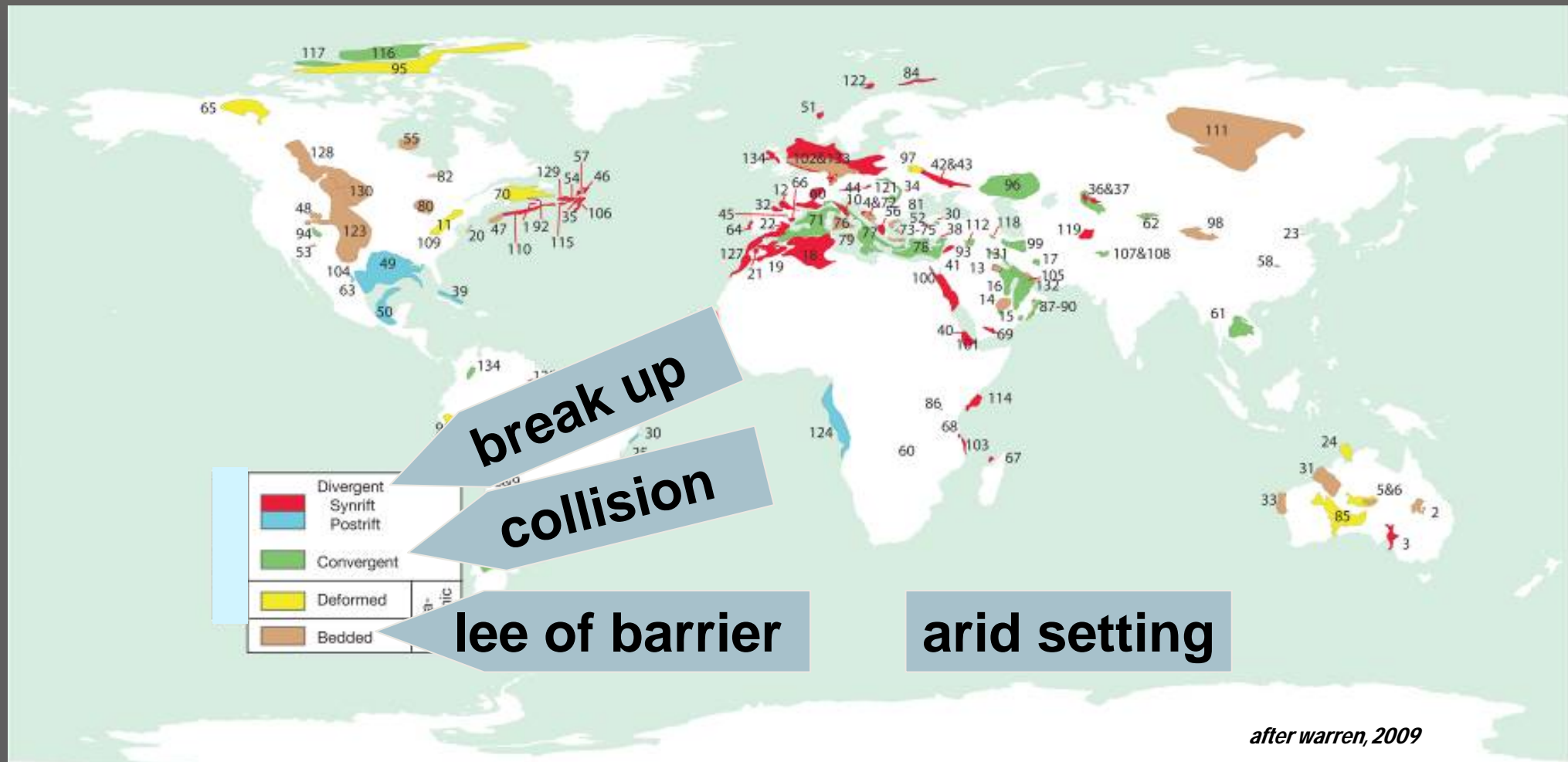
**Successions of carbonate & evaporite sediments associated with:**

- **High rates of organic production**
- **Arid rain shadow of lee shores**
- **Restricted basins confined behind structural and/or depositional barriers**

# Conclusions – Arid Climate Thru' Time

- **Common through earth history**
- **Signaled by thick sections of evaporites from lacustrine & marine settings adjacent to margins of**
  - **Pulled apart continental plates**
  - **Compressional terrains of colliding margins**
- **Evaporites also common through earth history forming great marker horizons**

# Plate Phase & Restricted Basins



# Hydrocarbon Play Settings

- Global platform subaqueous **shallow** shelf basins and **saltern** settings favor evaporite accumulation within:
  - Lowstand systems tracts (*Common*)
  - Transgressive systems tracts (*Common*)
  - Highstand systems tracts (*Uncommon*)
- Carbonates interbedded in evaporites often limestone from TST & early HST
- Decreased rate of relative sea level rise during late HST forms aggraded carbonate sills that favor percolation & so evaporite formation

# Evaporite Conditions & Impact on Play Elements

## Source Rocks

- Source & reservoir juxtaposed (90% same basin phase; >80% same super-sequence)
- Silici-clastic source rocks not necessary (75% source rocks = carbonates)
- Arid rain shadow of lee shores with low rain fall and low siliciclastic influx
- High rates of organic production; algae & bacteria proliferate; limited in-fauna

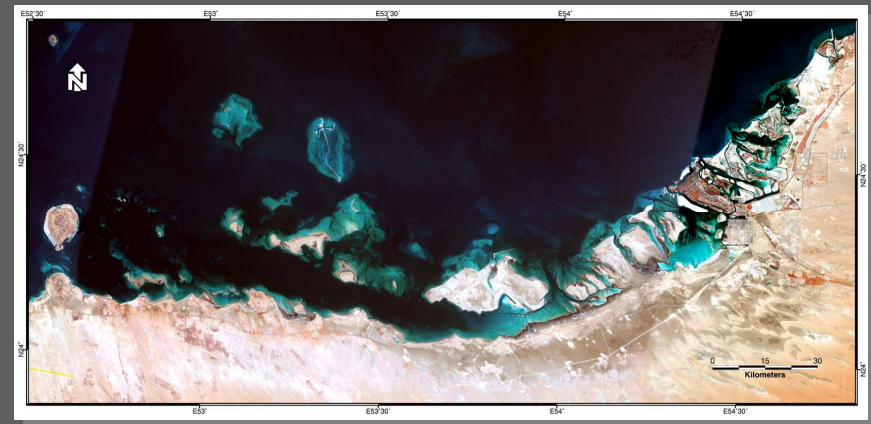
## Reservoir Rocks

- Exposed carbonate terrains less likely to experience pervasive pore occluding meteoric diagenesis

## Seal Rocks

- Reservoir and seal (successions of carbonate & evaporite sediments) juxtaposed (81% same basin phase; ~60% same super-sequence)
- Evaporites form regional seals

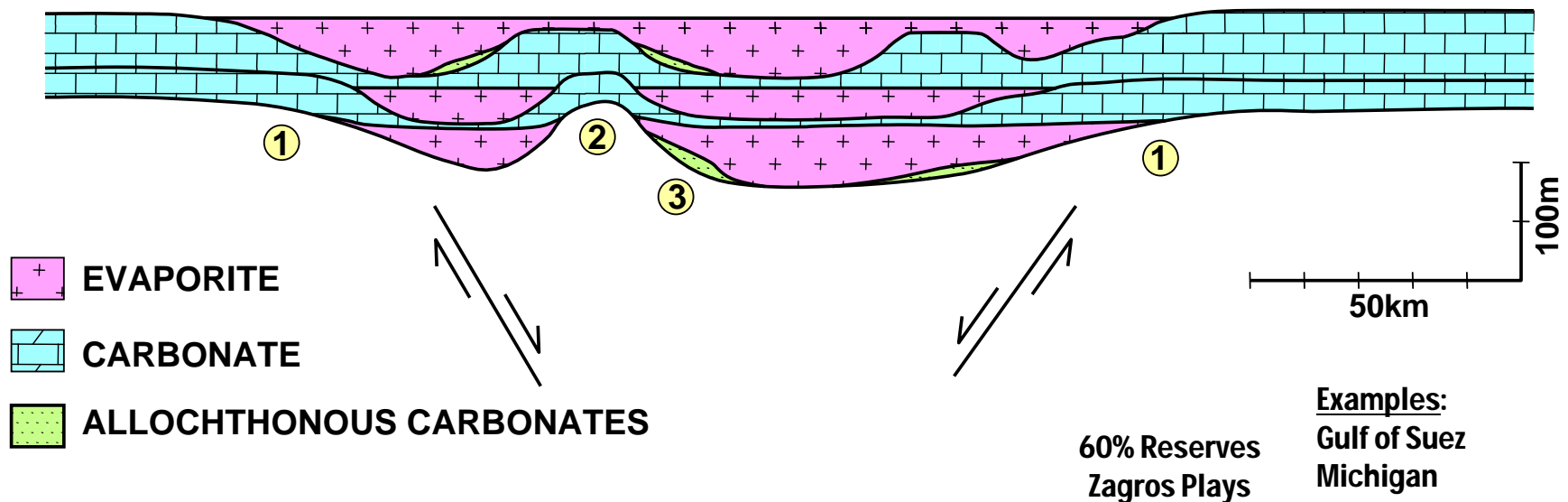
**Requisite Conditions =  
Restriction & Aridity**



**Abu Dhabi Arid Carbonate Coastline**  
Photo courtesy of NASA

# Plays & Basin-Center Evaporites

## SHALLOW MARINE SHALLOW BASIN

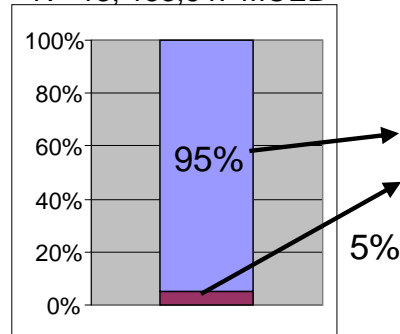


60% Reserves  
Zagros Plays

### Examples:

Gulf of Suez  
Michigan  
Paradox  
Oman Salt Basin  
Zagros Fold Belt  
W. Canada Plains  
Pripyat  
Dnepr/Donets  
Amu Darya  
Williston  
Central Iran

N = 13; 153,647 MOEB



### POSSIBLE CARBONATE PLAYS

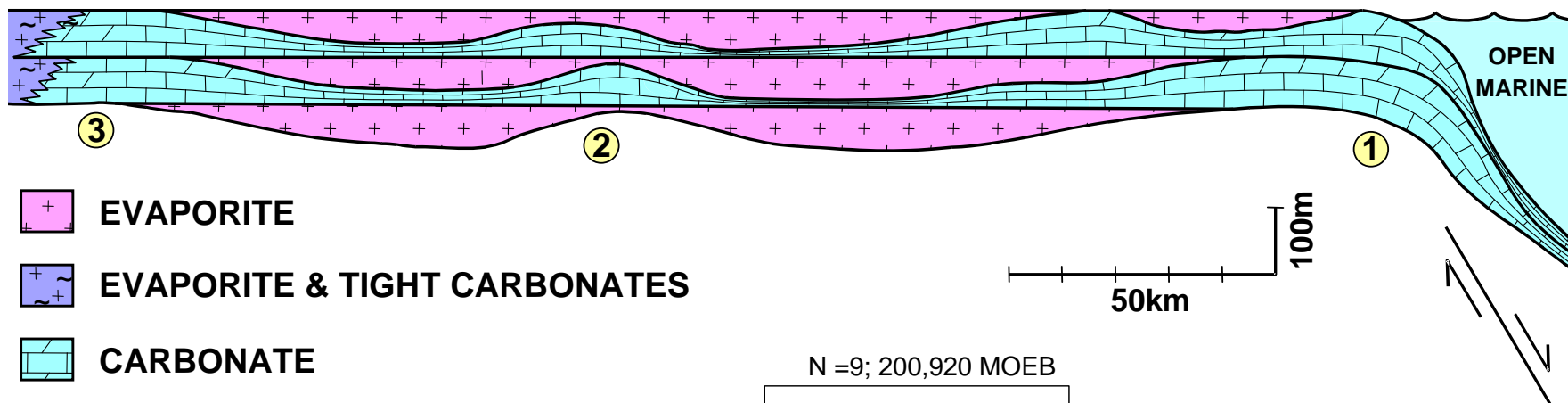
1. PLATFORM (MARGIN) BUILDUP
2. ISOLATED BUILDUP
3. ALLOCHTHONOUS DEPOSIT (MEGABRECCIA, TURBIDITE, GRAIN FLOW)

Weber & Sarg, 2005



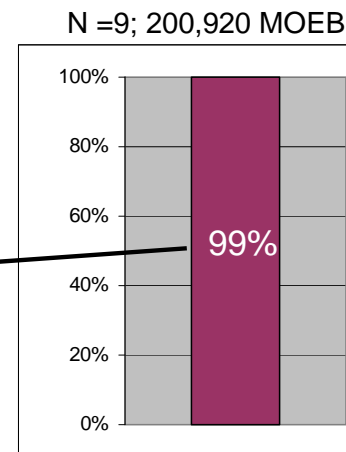
# Platform Evaporite Saltern Plays

## PLATFORM - SUBAQUEOUS SALTERN



### POSSIBLE CARBONATE PLAYS

1. PLATFORM (MARGIN) BUILDUP
2. ISOLATED BUILDUP
3. NEARSHORE/TIDAL FLAT



### Examples:

Arabian Platform  
Timan-Pechora  
Angara-Lena  
Pelagian Platform  
Gulf Basin  
Peten Basin

Weber & Sarg, 2005