

# World Source Rock Potential through Geological Time: A Function of Basin Restriction, Nutrient Level, Sedimentation Rate, and Sea-Level Rise\*

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Please refer to companion article, "The Giant Oil Field Evaporite Association: A Function of the Wilson Cycle, Climate, Basin Position and Sea Level," [Search and Discovery Article #40471 \(2009\)](#).

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## Abstract

The world's source rocks include black shale and carbonates, and these large accumulations of organic matter and petroleum have an irregular temporal beat. The higher concentrations of organic matter are tied to sporadic super-plumes, plate configurations, climate, east coast / west coast ocean circulation, monsoons, allochthonous vs. autochthonous carbon, preservation mechanisms, and other phenomena. Most of the world's largest oil fields are restricted to areas along the southern margin of the Tethys, where specific areas are sweet and others not so productive!

We argue that though 60% of the globe's (preserved) oil deposits are associated with super-plume timing; the explanation for its (preserved) oil potential is also controlled by a combination of an enveloping continental rain shadow, lack of clastic input, and organic production fostering concentrations of organic matter in the geological section from the Precambrian through the Phanerozoic, particularly the Mesozoic. This is principally true of the lee shore of Pangea and the resulting Middle Eastern Giant Fields. Here accumulation of organic-rich sediments appears tied to marine transgressions with shelf-margin flooding as one of the major factors controlling accumulations of organic-rich sediment. Evidence for this relationship is recorded in the Cretaceous section of the southern Mediterranean margin and the Eastern Arabian shelf. The Silurian section of northern Gondwanaland records a glacial ice-cap melt, and a major transgression occurred during the Early Silurian, resulting in organic-rich sediments represented by the Tanezzucht Shale of Libya, the Mudawwara Formation of Jordan, and the Qusaiba Member of Saudi Arabia and the Akkas Formation of Iraq.

In the Precambrian the Shunga Event ~2.0 Ga also records accumulation of vast quantities of organic carbon preserved in organic-rich black shale source rocks. Details of this accumulation of petroleum are poorly defined but appear tied to plume magmatism and/or

volcanism plus interlayered volcanic rocks that may have played a role in preservation. The Shunga Event occurred during the dispersal of continents rather than the closure of oceans associated with the Mesozoic Middle Eastern oil reserves. This highlights a major requirement for accumulation and preservation of organic matter through time as the presence of a restricted basin, rich in nutrients, exposed to rapid sedimentation during times of transgression (relative sea-level rise).

### References

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# 'World Source Rock Potential Through Geological Time'

a function of

**Basin Restriction, Nutrient Level ,  
Sedimentation Rate & Sea-level Rise**

**CHRISTOPHER G. ST.C. KENDALL<sup>1</sup>, JEFFREY CHIARENZELLI<sup>2</sup>,  
& HASSAN S. HASSAN<sup>1</sup>**

***1-University of S. Carolina***

***2-St. Lawrence University***

Kendall, Chiarenzelli, & Hassan "Sources - World Petroleum"



# Acknowledgments

We extend our thanks & appreciation to:

● **University of South Carolina**



● **St. Lawrence University**

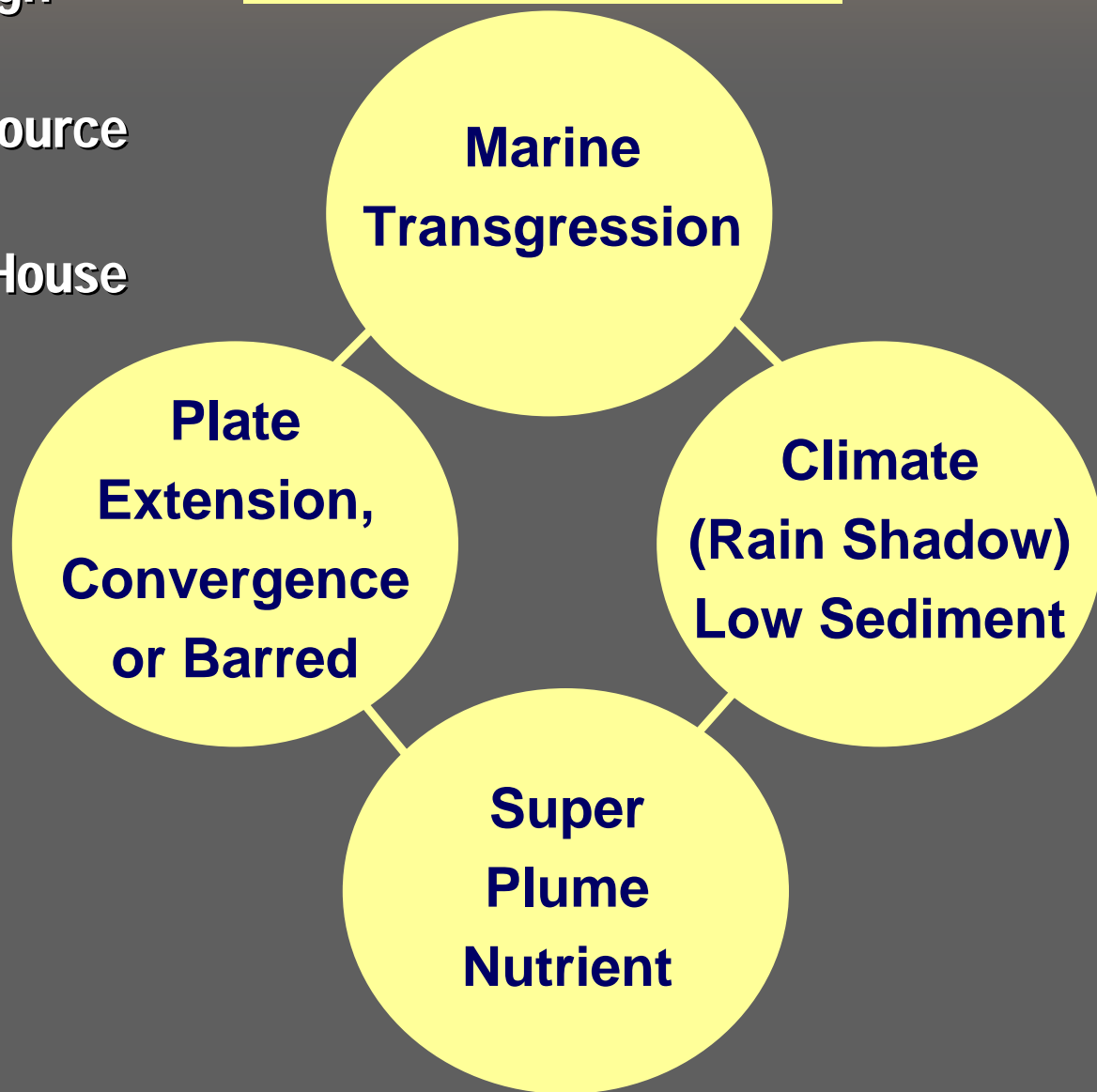


**for making the study reported in this presentation possible**

# Summary & Outline

- Significant Source Rocks through Time
- Basin Restriction's Impact on Source Rocks
- Climate (Rain Shadow & Green House versus Ice House)
- Transgressions
- Super-plumes (Nutrients)
- Basin Phase (extension, compression, or barred)
- Middle East
- North Africa
- Precambrian Continents
- Summary & Conclusions

## Restricted Basin



# Outline

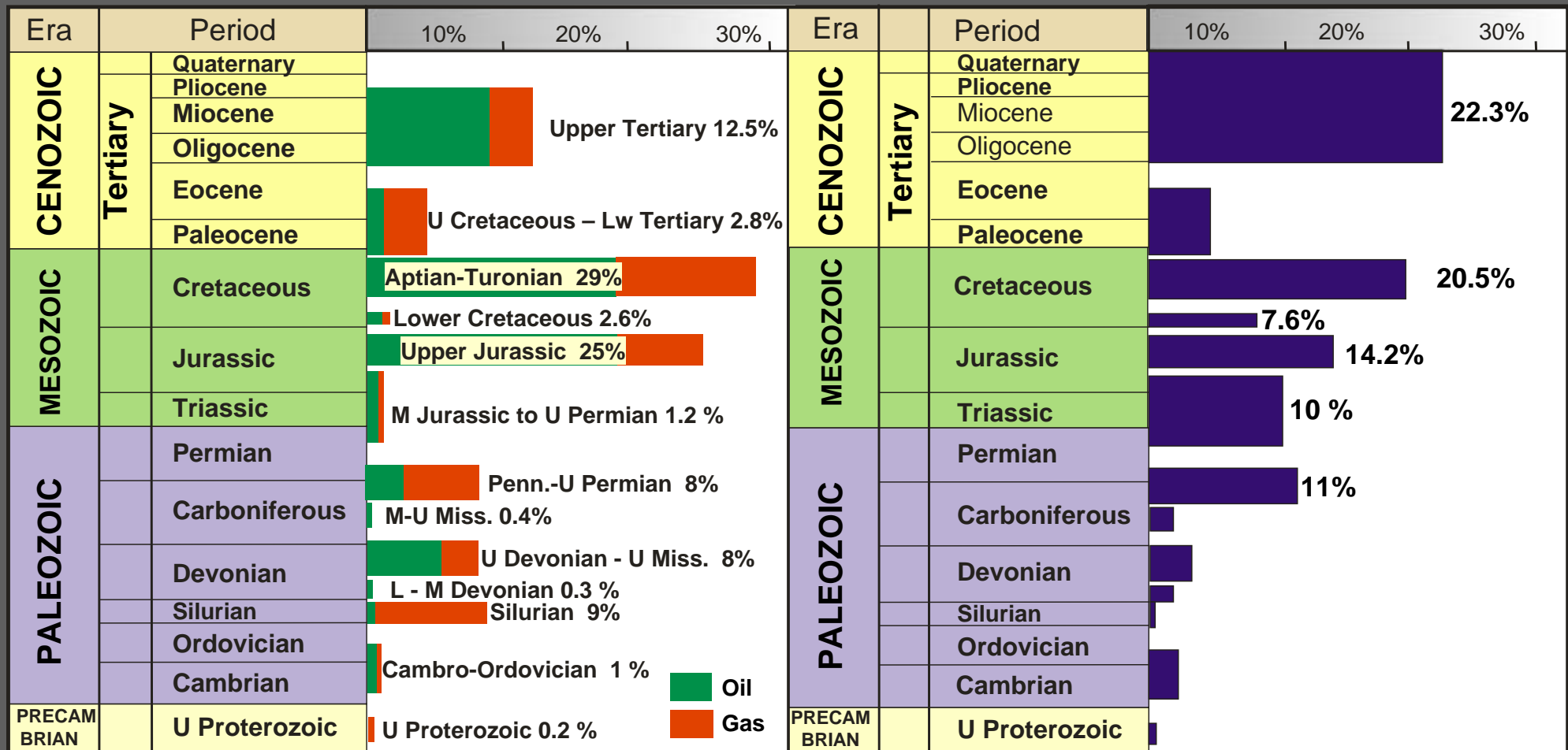
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# World's Source Rocks & Reservoirs

World wide stratigraphic distribution of major source rocks

Stratigraphic distribution of the major reservoir rocks world wide



(Modified from Ulmashek and Klemme, 1990)

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# Basin Restriction & Anoxia

Enable higher concentrations organic carbon:

- Allocthonous
- Autothonous

Preserved in:

- Black (Anoxic) Shale
- (Anoxic) Carbonates



(Kendall Photo)

**Devonian Ohio Shale | 64 Kty**

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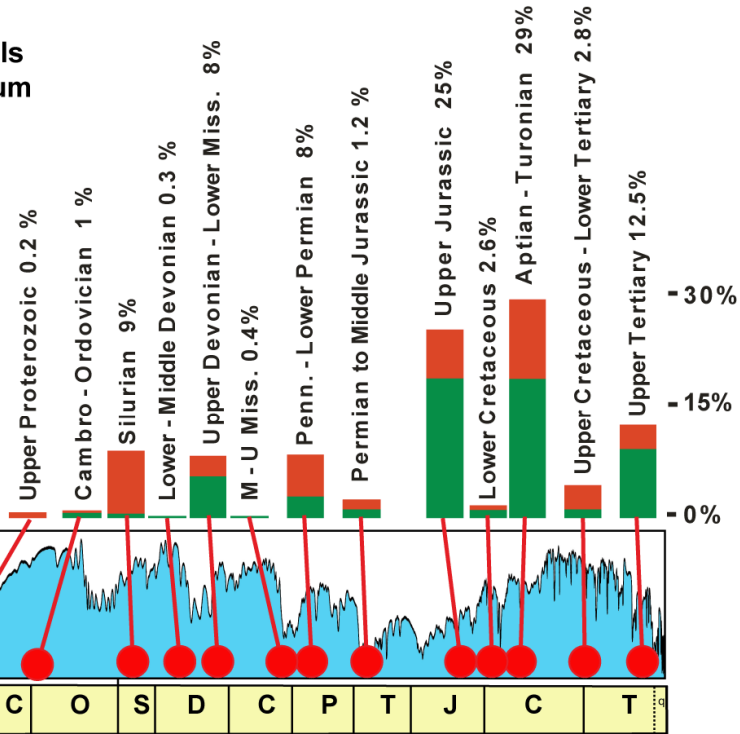


# Climate and Source Rock Potential

**CYCLIC CHANGES IN CLIMATE, SEA POSITION, ORGANIC PRODUCTIVITY AND SEQUESTRATION**

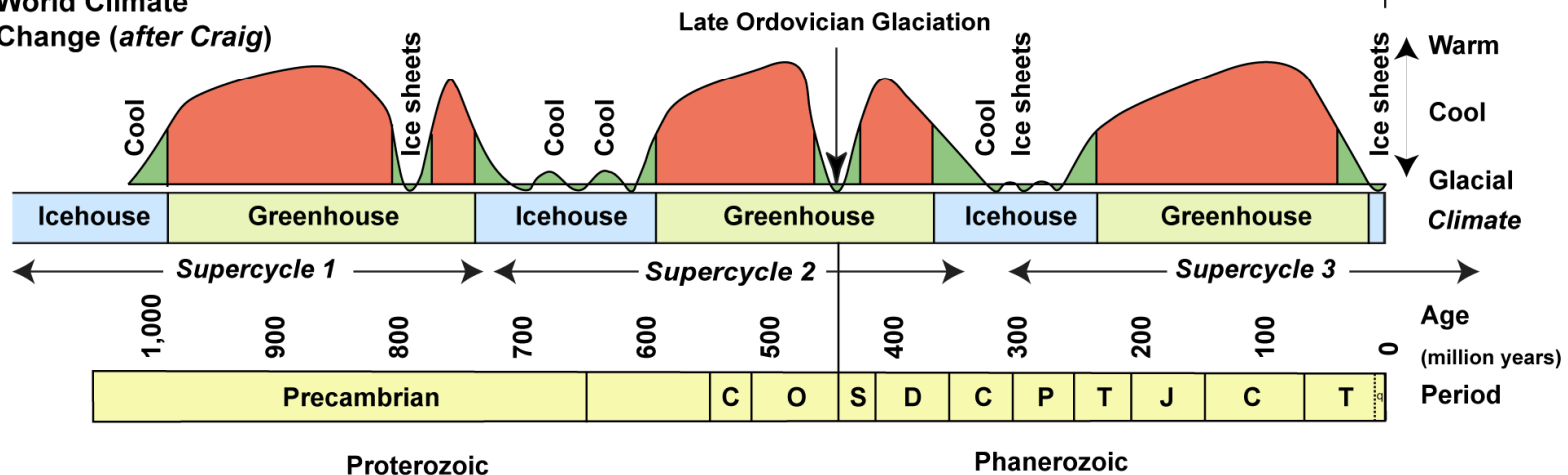
Source rock intervals & % world's petroleum reserves generated  
(after Klemme & Ulmishek, 1991)

Oil  
Gas



Phanerozoic eustatic curves  
(after Waite)

World Climate Change (after Craig)



Christopher Kendall, 2009

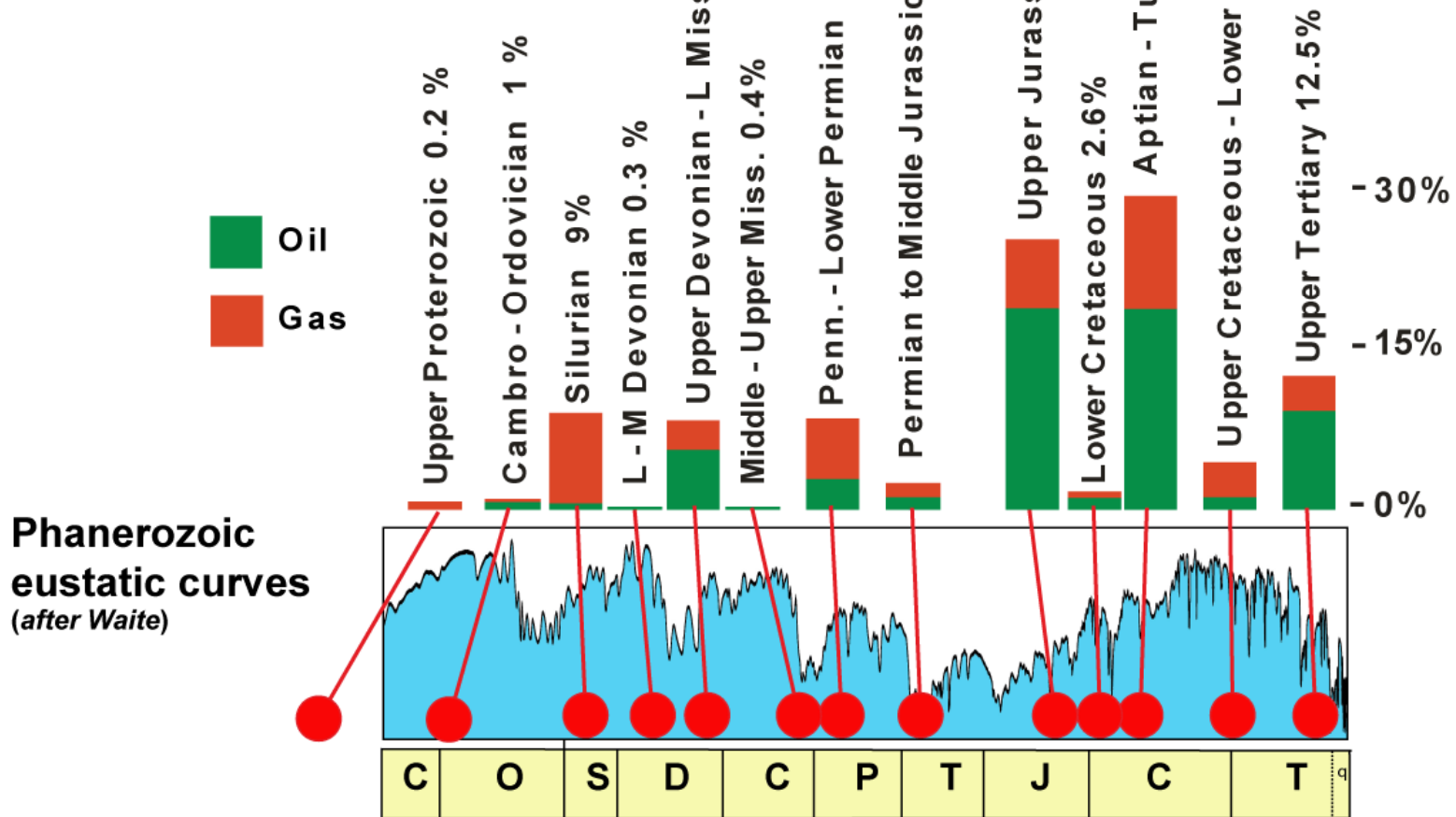
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# Transgressive Beat To Mesozoic &

Source rock intervals  
& % world's petroleum  
reserves generated  
*(after Klemme & Ulmishek, 1991)*



Christopher Kendall, 2009

# Outline

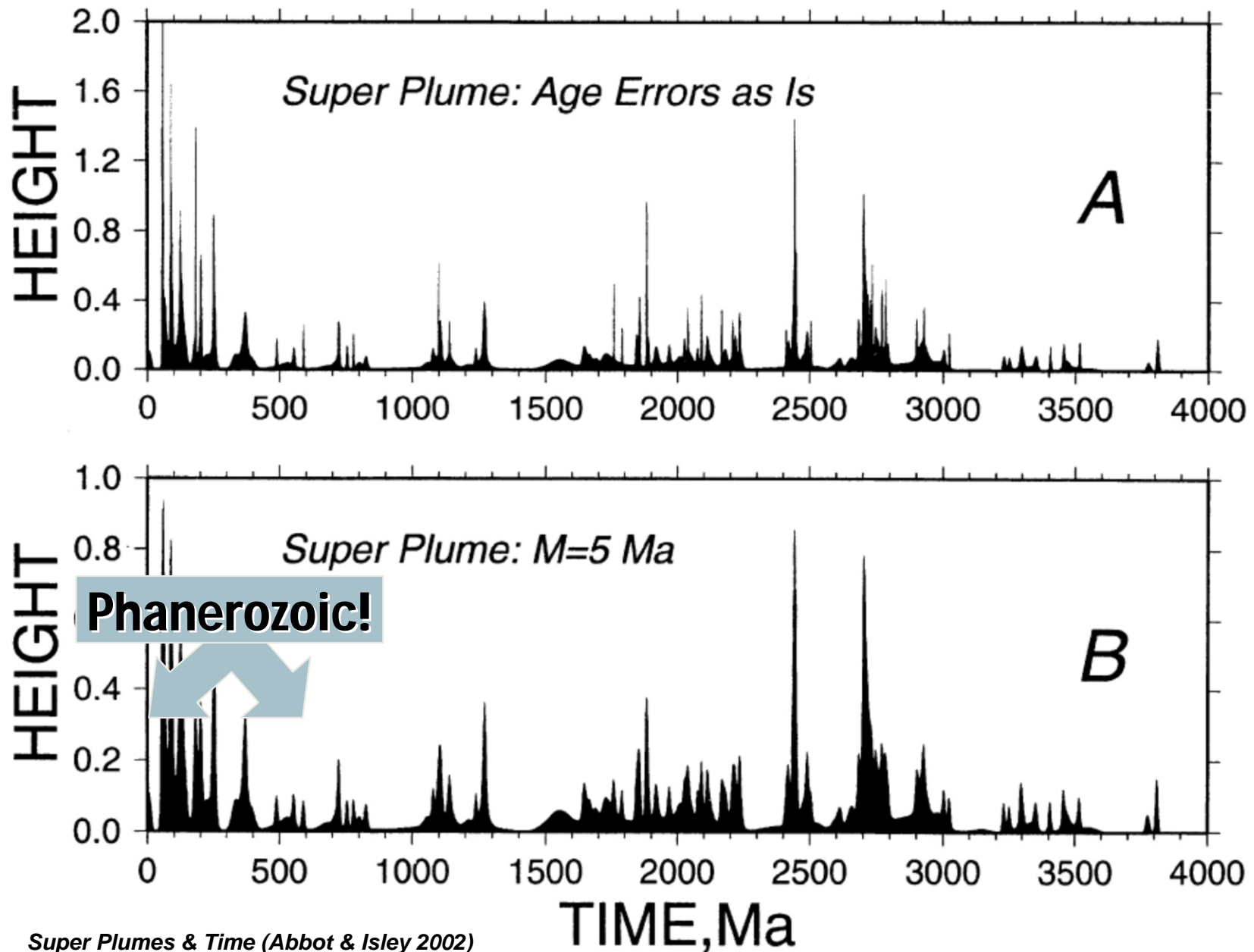
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# Super-plume Forcing of Organic production

- Very fast Seafloor spreading
- Enhanced organic production of oceans from massive amounts of CO<sub>2</sub> from oceanic lava flows
- Produce oceanic anoxic events (OAEs) & super-greenhouse events in Mesozoic
- Organic matter preserved by anoxia on sea floor with accumulation of organic rich sediments

# Plumes : A Nutrient Beat!





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Up - Me Northern Atlantic

isolated linear belt of interior drainage

restricted entrances to sea

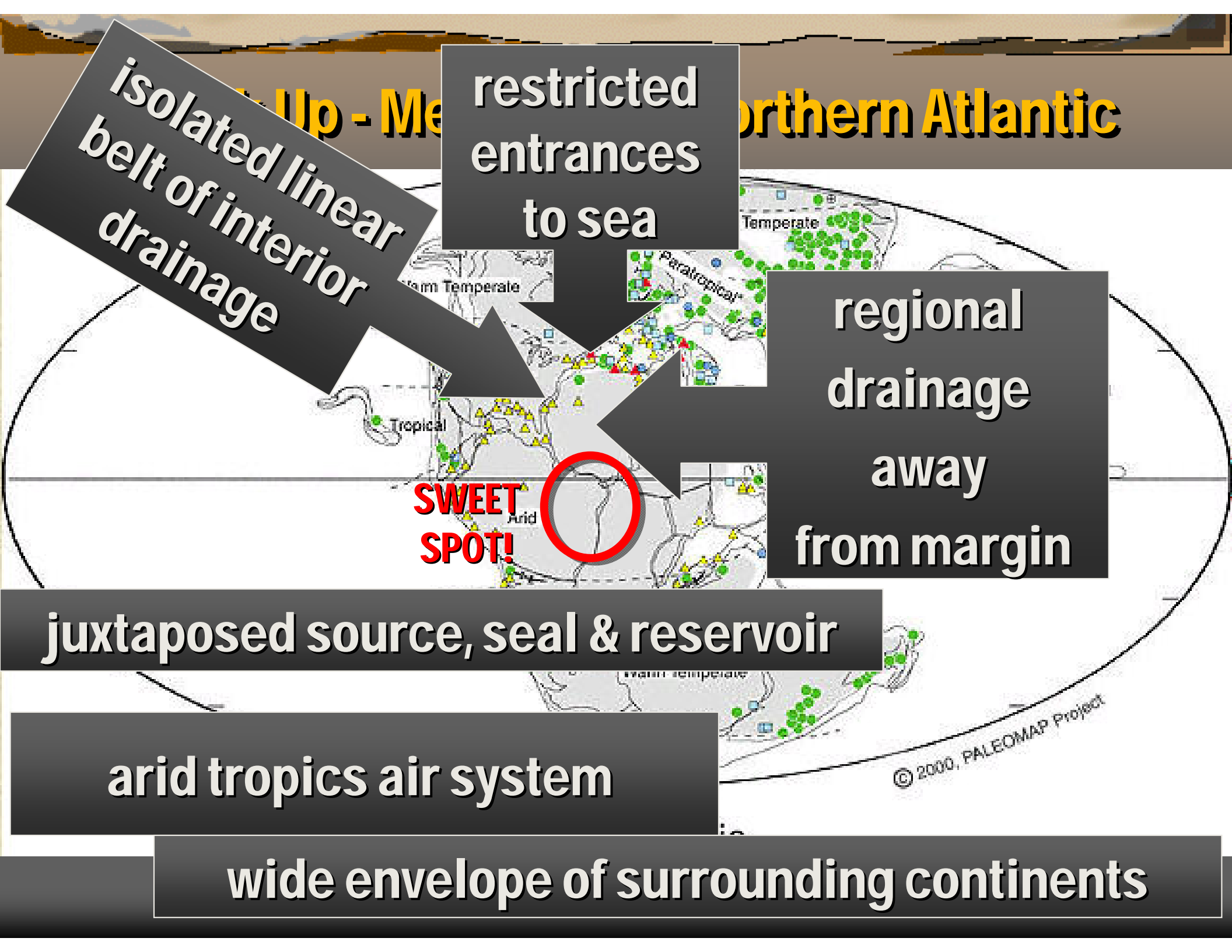
regional drainage away from margin

**SWEET SPOT!**

juxtaposed source, seal & reservoir

arid tropics air system

wide envelope of surrounding continents



# Examples of Organic rich rocks at Break Up Margins

- 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 Ma**

**stricted Basin**

regional  
drainage  
into basin

restricted  
entrance  
to sea

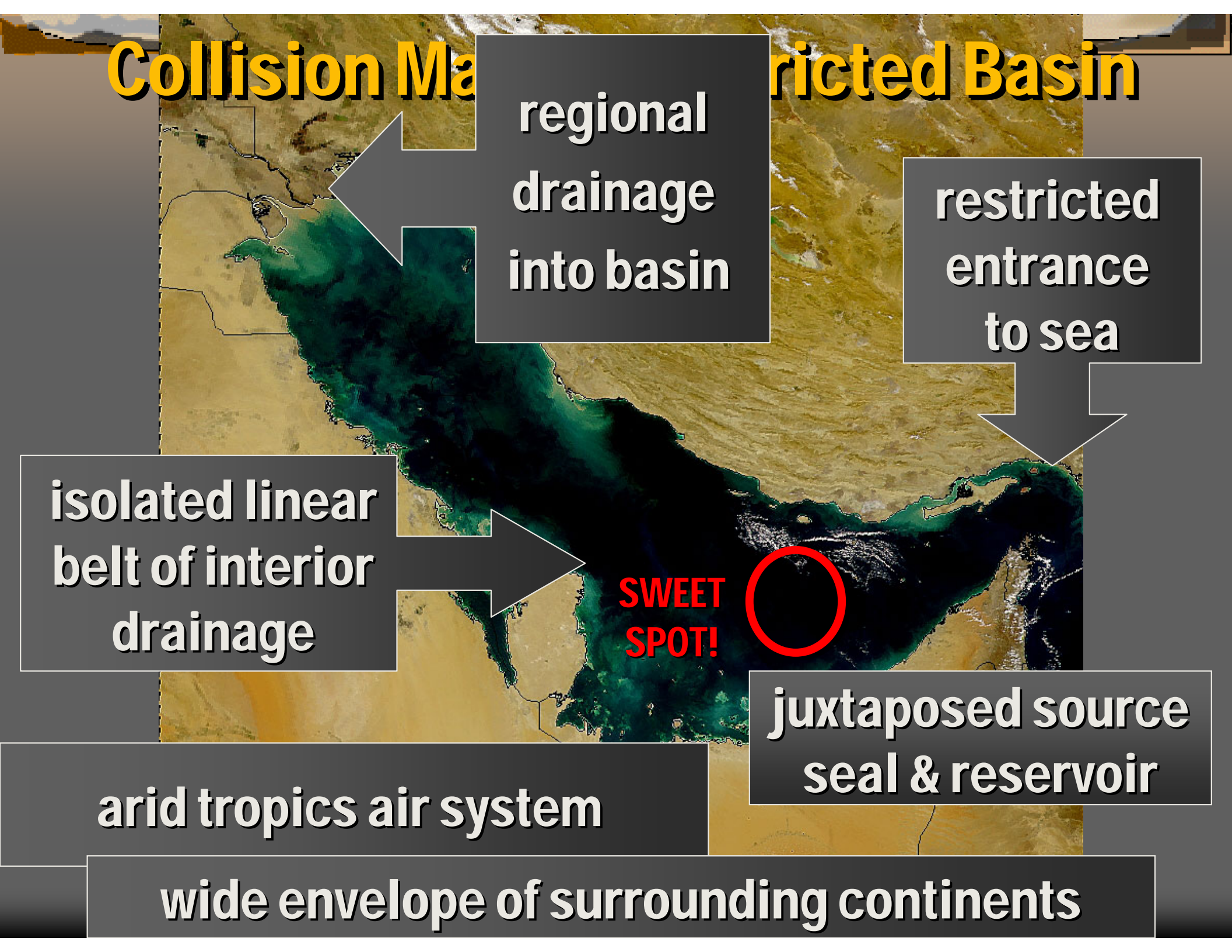
isolated linear  
belt of interior  
drainage

**SWEET  
SPOT!**

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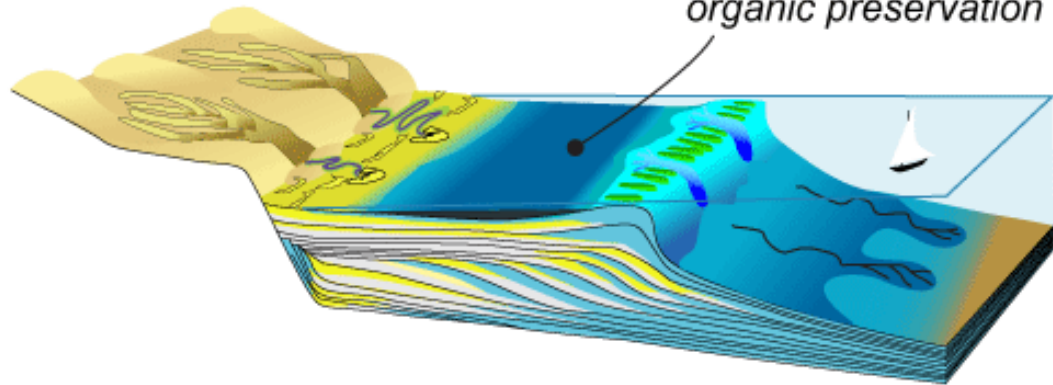
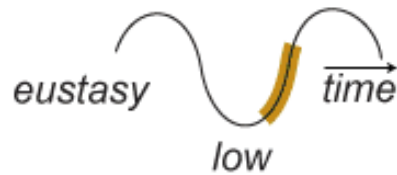
# Examples of Organic rich rocks at Collision Margins

- 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

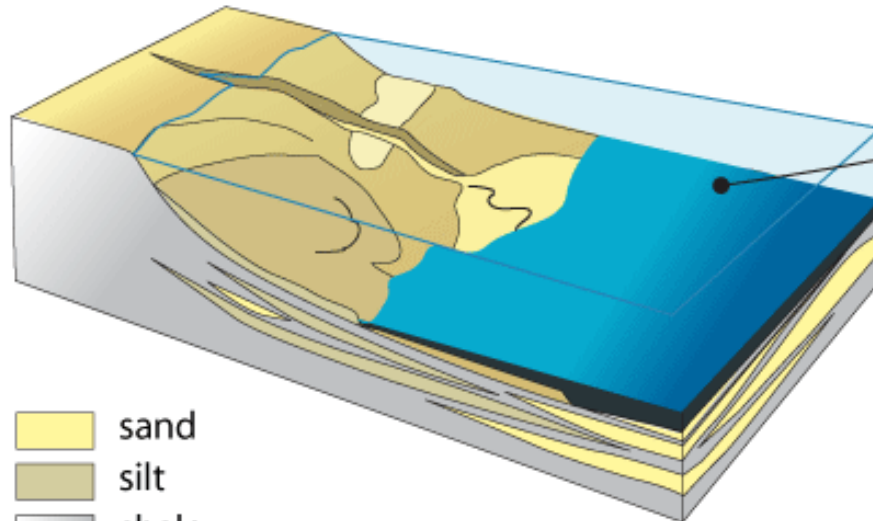
# Restricted Basin Settings

*restricted shallow shelf to lee of carbonate margin*

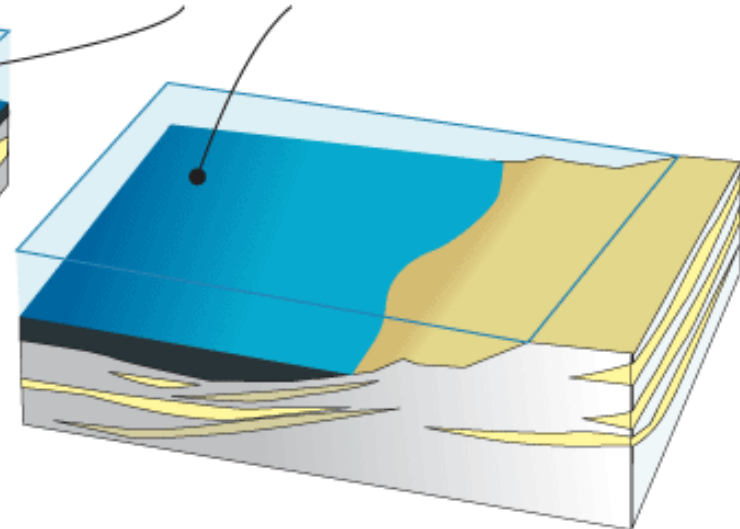
*transgression lowers  
sediment input  
& organic accumulation  
dominates*



*restricted deep water rifted basin*



*anoxia favors  
organic preservation*



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

# Example of Barred Basin Mesozoic - Arabian Gulf

Late Jurassic  
Volgian (150 Ma)

restricted  
entrance  
to sea

juxtaposed source  
seal & reservoir

structural &  
depositional  
barrier over  
Hercynian  
horst blocks

Upper Jurassic  
Saudi Arabia  
Kuwait, Iran  
& UAE



arid tropical air system

(Rees et al. 2000)

wide shadow from adjacent continents

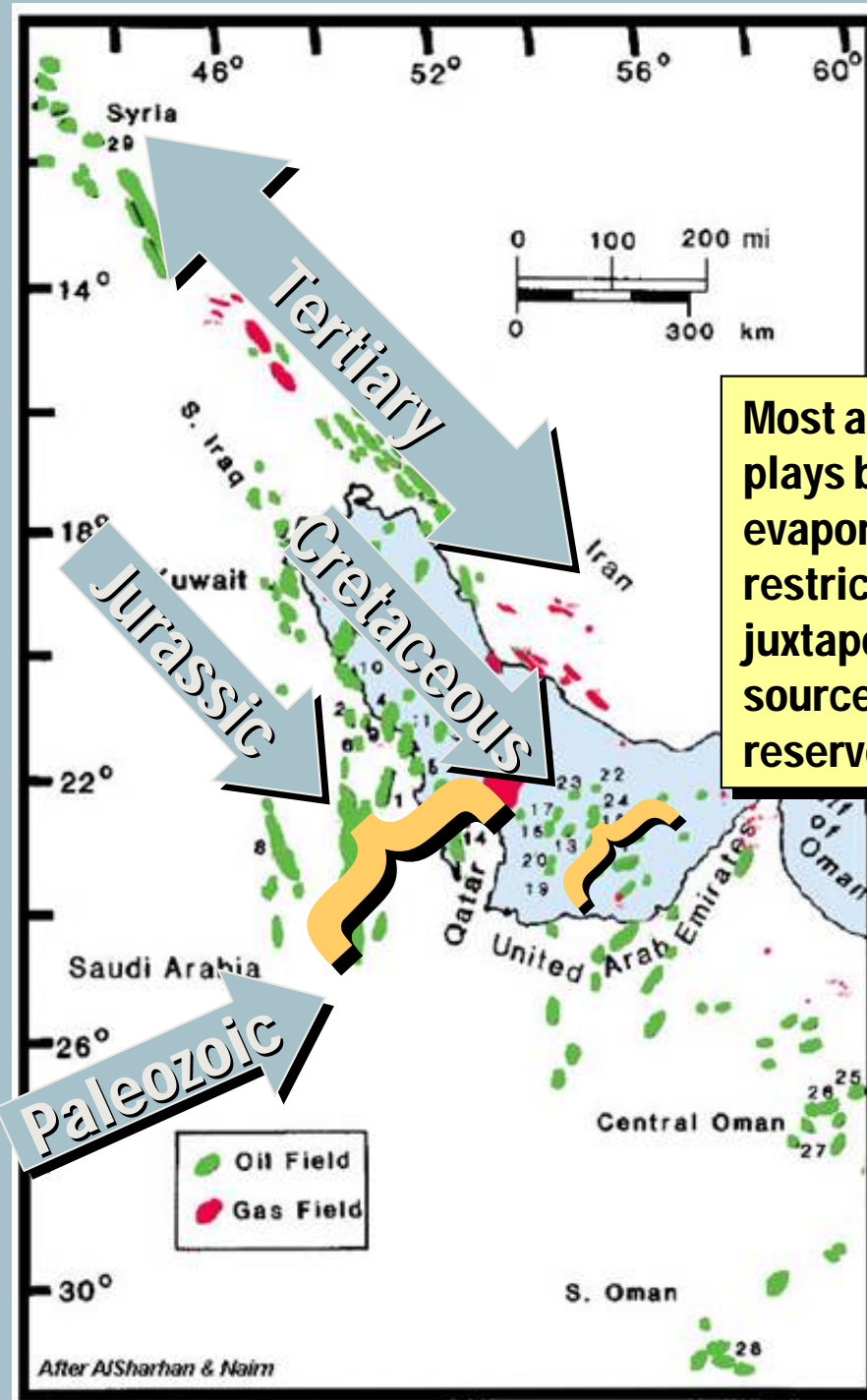
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**Location of  
Oil & Gas  
Fields of  
Arabian Gulf  
-  
Reservoirs  
are  
Younger  
to East**



Most are carbonate plays beneath evaporite seals in restricted basins juxtaposing source, seal and reservoirs

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

Gotnia Basin

Arabian Basin

South Arabian Basin

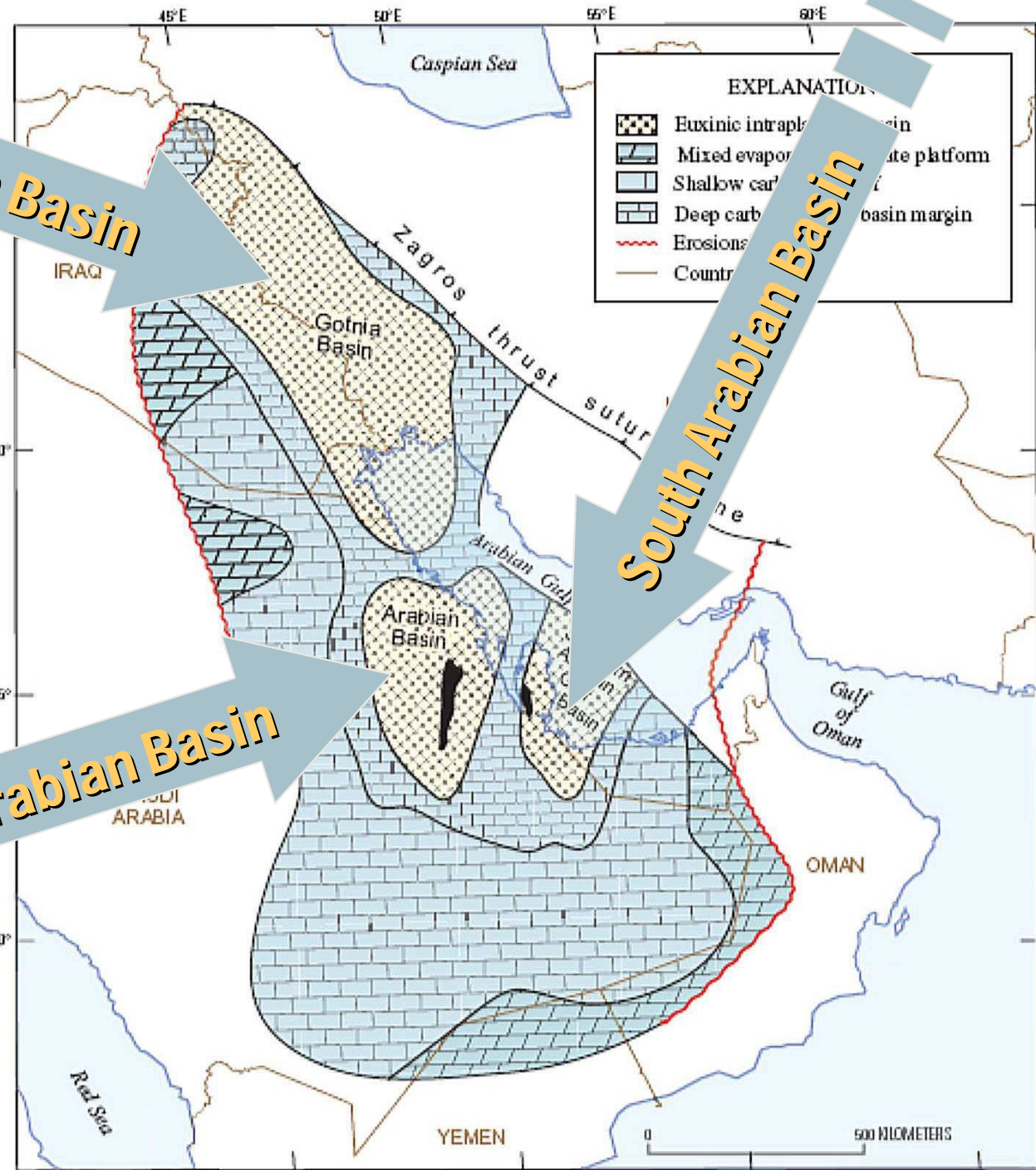


Figure 13. Gotnia, Arabian, and Southern Arabian Gulf Basins in which Jurassic hydrocarbon source rocks accumulated (modified from Asharhan and Kendall, 1986). Sawtooth on upthrown block of Zagros thrust suture zone.

After Fox & Albrandt, 2002

# Outline

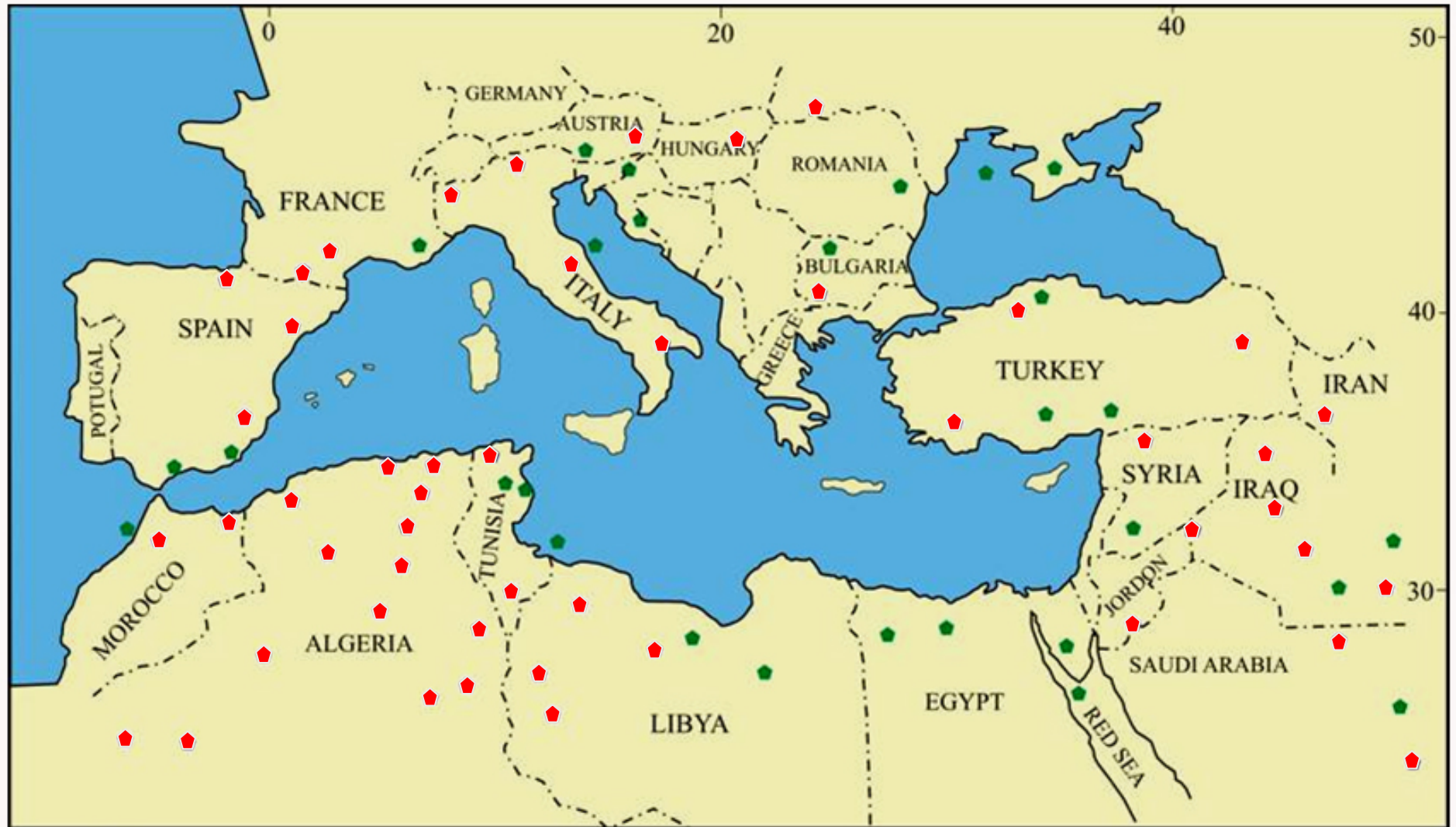
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# North African Source Rocks

- Regional Upper Cretaceous (Senonian) Petroleum Source in argillaceous limestones of North Africa
- Lower Paleozoic of North Africa proven and prolific plays
  - eg: Tanezzuft Shale of Libya

# Two major source rocks distribution around Mediterranean



◆ Potential Upper Cretaceous Source Rocks

◆ Potential Silurian Source Rocks

0 500 1000 km



Modified from varies sources

# Outline

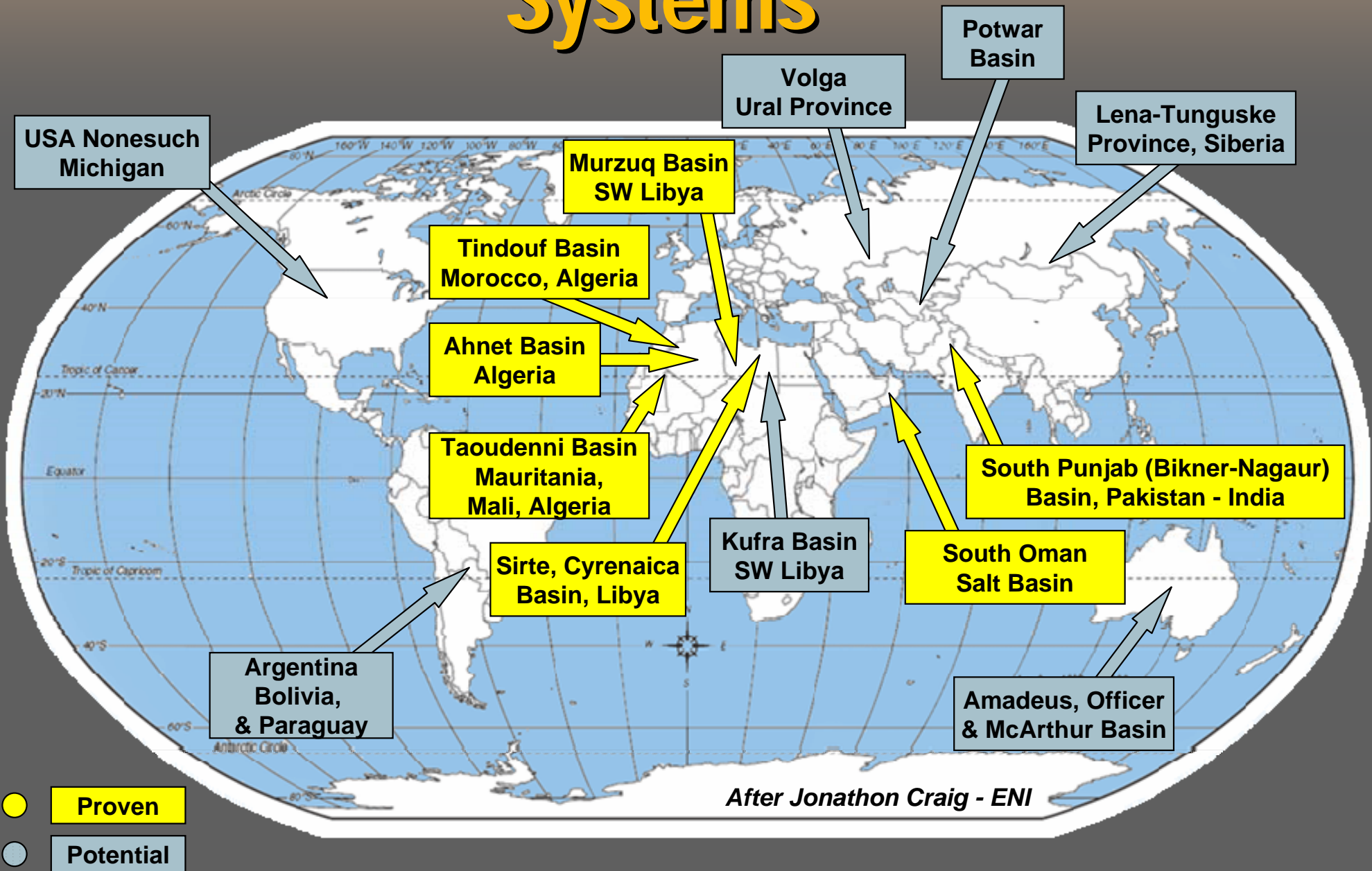
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# Precambrian Oil?

- Precambrian play of North Africa “is still immature & deserves more investigation”  
*quote from Jonathon Craig - ENI*
- Large autochthonous accumulations of organic matter rare in Precambrian rocks
- Occurs in Paleoproterozoic sedimentary rocks as coal-like material
- Derived from Precambrian oil?
- Potential matches younger oil plays?

# World Neoproterozoic Petroleum Systems



After Jonathon Craig - ENI

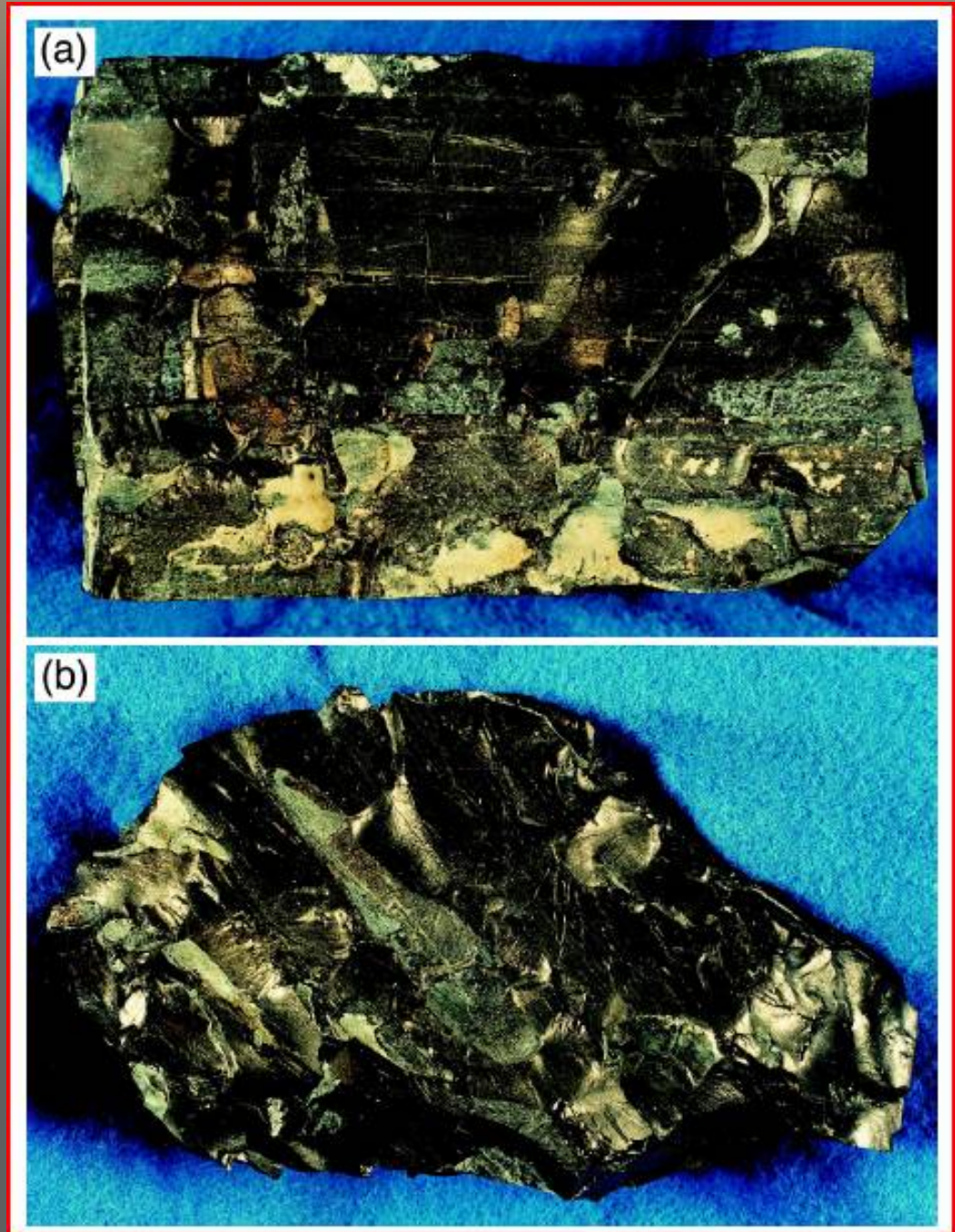


# World Record Holder Karelian Shungites

- Paleoproterozoic ~ 2.0 Ga, NW Russia
- 600 m thick Upper Zaonezhskaya Formation
- C<sub>org</sub> up to 98%; averages 25% over 9000 km<sup>2</sup> along narrow rifted margin
- Include coal-like seams of layered shungite, cross-cutting diapirs & veins of remobilized liquid petroleum
- Interlayered with mafic volcanics

# Karelian Shungites

V.A. Melezhik et al. 1999



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# World's Source Rocks

- **Contain higher concentrations of allocthonous vs. autothonomous organic carbon preserved in:**
  - **Black (Anoxic) Shale**
  - **(Anoxic) Carbonates**
- **Have irregular temporal beat driven by**
  - **Basin restriction**
    - **Continental plate configuration**
      - ◆ **Initial extension**
      - ◆ **Final collision**
    - **Structural barriers &/or buildup barriers**
  - **Climatic response**
    - **Rain shadow**
    - **East coast/west coast ocean circulation**
    - **Monsoons**
  - **World wide transgressions & restricted basins**
  - **Sporadic super-plumes**

**Most of world's largest oil fields restricted to southern Tethyan margin**

# Source Rock Potential

Low rainfall & low siliciclastic influx favor lower levels of oxygen & elevated salinities, & high **organic productivity**:

● Products include:

- Algal
- Cyano-bacterial & phyto plankton bloom
- Limited infauna

● 90% occur in same **basin phase**

● 80% occur in same **super-sequence**

# World's Source Rocks

## Principal Oil Provinces matching this paradigm

- **Mesozoic lee shore of Pangea**
  - Eastern Arabian shelf Giant Fields
  - Southern Mediterranean margin
- **Early Silurian section of northern Gondwanaland (ice cap melt, & transgression)**
  - Tanezzuft Shale of Libya

# World's Source Rocks

## Precambrian Continents

### Precambrian Shunga Event ~2.0 Ga

- Rich in organic carbon
- Plume caused magmatism &/or volcanism
- Inter-layered volcanic rocks

# Conclusions

**Now for a few  
barrels of oil!**





A horizontal banner image at the top of the slide showing a landscape with rolling hills and a cloudy sky.

# Lecture Ends!!

# Source Rock Conditions & Impact on Play Elements

Basin restriction juxtaposes:

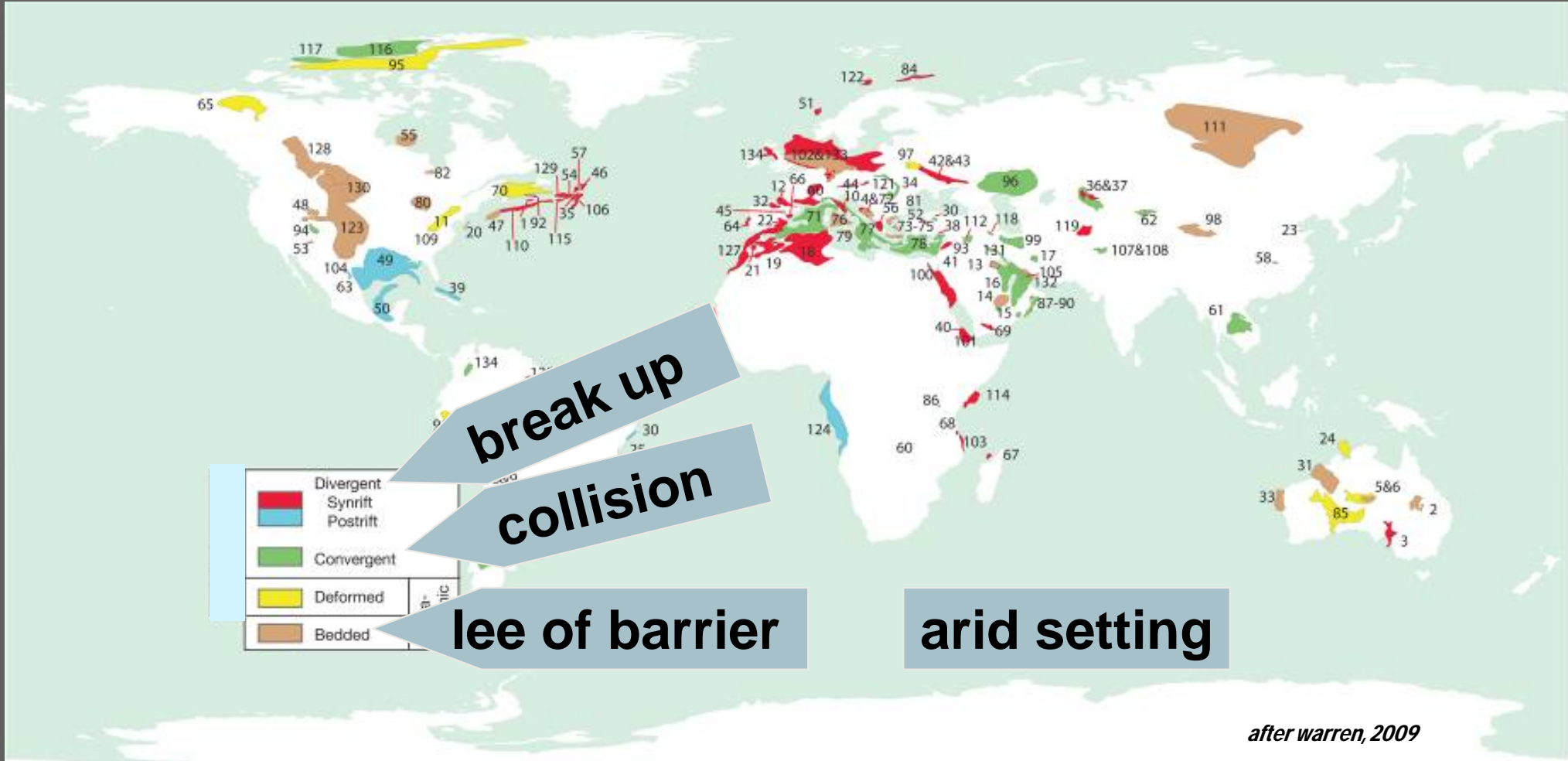
- Source Rocks **Source** and **Reservoir** (90% same basin phase; >80% same super-sequence)
  - 75% Source rocks = **Carbonates** & Silici-clastic Source Rocks not Necessary
  - Low **Rain** Fall & Low **Siliciclastic** Influx
  - **Algae** & **Bacteria** Proliferate; limited Infauna
- Reservoir Rocks
  - Carbonates
  - Clastics
- Seal Rocks
  - Reservoir and Seal
  - Effective Regional Seals formed by
    - Evaporites
    - Shales
    - Dense Limestones

Requisite Conditions  
Restriction & Aridity



Abu Dhabi Arid Carbonate Coastline  
Photo courtesy of NASA

# Plate Phase & Restricted Basins



# Organic rich source rock generation at break up of continental plates

- Isolated linear belts of interior drainage.
- Linear belts connected by restricted entrance to the sea.
- Regional drainage tends to flow away from break up margin
- Air system of the arid tropics
- Wide envelope of surrounding continents

**Mesozoic of Northern Atlantic**

# World's Source Rocks

Particularly in Mesozoic but into rest of Phanerozoic section & even Precambrian. Most associated with:

- Restricted basins rich in nutrients fostering high organic matter productivity
- Lack of clastic or carbonate input
- Extensional, & compressional plate boundaries, &/or barred basins
- Enveloping continental rain shadow
- Marine transgressions
- Globe's unexploited & preserved oil deposits associated with timing of super-plumes?

# Precambrian Basins with Oil potential

## Basins with autochthonous organic material

- Michigan - Tyler Formation / Michigamme Slate (1.82 Ga)
- S.W. Greenland – Ketilidian (>1.8 Ga)
- Australia – McArthur Basin (1.4-1.7 Ga)
- Gabon – Franceville Series Oklo (~2.1 Ga)
- Ontario – Huronian Supergroup (2.1-2.4 Ga)
- Labrador – Mugford Group (>1.97 Ga)