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

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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 Tanezzuft 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


‘World Source Rock Potential Through Geological Time’

a function of

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

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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
Outline

- Significant Source Rocks through Time
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# World's Source Rocks & Reservoirs

## World wide stratigraphic distribution of major source rocks

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<th>Era</th>
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- **Upper Tertiary 12.5%**
- **U Cretaceous – Lw Tertiary 2.8%**
- **Aptian-Turonian 29%**
- **Lower Cretaceous 2.6%**
- **Upper Jurassic 25%**
- **M Jurassic to U Permian 1.2%**
- **Penn.-U Permian 8%**
- **M-U Miss. 0.4%**
- **U Devonian - U Miss. 8%**
- **L - M Devonian 0.3%**
- **Silurian 9%**
- **Cambro-Ordovician 1%**
- **Oil 22.3%**
- **Gas 7.6%**
- **Upper Proterozoic 0.2%**

## Stratigraphic distribution of the major reservoir rocks world wide

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- **Silurian**
- **Cambro-Ordovician**
- **Oil 20.5%**
- **Gas 14.2%**
- **Upper Proterozoic 0.4%**

(Modified from Ulmashek and Klemme, 1990)

Kendall, Chiarenzelli, & Hassan “Sources - World Petroleum”
Outline

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- Summary & Conclusions
**Basin Restriction & Anoxia**

Enable higher concentrations organic carbon:
- **Allochthonous**
- **Autochthonous**

Preserved in:
- **Black (Anoxic) Shale**
- **(Anoxic) Carbonates**

Devonian Ohio Shale 164 Kty
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Climate and Source Rock Potential

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

Phanerozoic eustatic curves (after Waite)

World Climate
Change (after Craig)

Late Ordovician Glaciation

Ice sheets

Cool

Greenhouse

Icehouse

Supercycle 1

Supercycle 2

Supercycle 3

Age (million years)

Precambrian

Proterozoic

Phanerozoic

Christopher Kendall, 2009
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Kendall, Chiarenzelli, & Hassan “Sources - World Petroleum”
Transgressive Beat To Mesozoic & Tertiary Source Rocks

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

Phanerozoic eustatic curves
(after Waite)

Christopher Kendall, 2009
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Super-plume Forcing of Organic production

- Very fast Seafloor spreading
- Enhanced organic production of oceans from massive amounts of CO₂ 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!

Super Plume: Age Errors as Is

Super Plume: $M=5$ Ma

Phanerozoic!
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Break Up - Mesozoic of Northern Atlantic

- Isolated linear belt of interior drainage
- Restricted entrances to sea
- Regional drainage away from margin
- Juxtaposed source, seal & reservoir
- Arid tropics air system
- Wide envelope of surrounding continents

Sweet Spot!
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 Margin Restricted Basin

- regional drainage into basin
- restricted entrance to sea
- isolated linear belt of interior drainage
- SWEET SPOT!
- juxtaposed source seal & reservoir
- arid tropics air system
- wide envelope of surrounding continents
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
- eustasy and time
  - low

**restricted deep water rifted basin**

- anoxia favors organic preservation

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*Christoph Kendall, 2009*
Example of Barred Basin Mesozoic – Arabian Gulf

Upper Jurassic
Saudi Arabia
Kuwait, Iran
& UAE

restricted entrance to sea

juxtaposed source seal & reservoir

structural & depositional barrier over Hercynian horst blocks

arid tropical air system

wide shadow from adjacent continents

(Rees et al. 2000)

Late Jurassic
Volgian (150 Ma)

SWEET SPOT!
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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

After Fox & Albrandt, 2002
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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

Modified from various sources
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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

- South Punjab (Bikner-Nagaur) Basin, Pakistan - India
- South Oman Salt Basin
- Tindouf Basin, Morocco, Algeria
- Taoudenni Basin, Mauritania, Mali, Algeria
- Kufra Basin, SW Libya
- Murzuq Basin, SW Libya
- Ahnet Basin, Algeria
- Sirte, Cyrenaica Basin, Libya
- Argentina, Bolivia, & Paraguay
- Volga Ural Province
- Potwar Basin
- Lena-Tunguske Province, Siberia
- USA Nonesuch Michigan

Proven potential

After Jonathon Craig - ENI

Kendall, Chiarenzelli, & Hassan “Sources - World Petroleum”
World Record Holder Karelian Shungites

- Paleoproterozoic ~ 2.0 Ga, NW Russia
- 600 m thick Upper Zaonezhskaya Formation
- $C_{org}$ up to 98%; averages 25% over 9000 km$^2$ 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 allochthonous vs. autochthonous 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
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

Kendall, Chiarenzelli, & Hassan “Sources - World Petroleum”
Plate Phase & Restricted Basins

break up

collision

lee of barrier

arid setting

after warren, 2009

Kendall, Chiarenzelli, & Hassan “Sources - World Petroleum”
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?

Kendall, Chiarenzelli, & Hassan “Sources - World Petroleum”
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)