

Oil Shale Stratigraphy — A Global Perspective*

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Abstract

Depositional controls on large oil shale deposits of the world.

Four large oil shale deposits of the world (the largest?) were deposited in Eocene lakes of the U.S. Rocky Mountains (Green River Formation), Cretaceous shelves across the southern margin of the Tethys Ocean (Morocco to Egypt, Israel, Jordan and Iraq), Upper Permian lakes in NW China's Junggar-Turpan-Hami basin (Lucaoguo Formation), and also Upper Permian lakes of South America and South Africa (Gondwana; Irati-Whitehill Formations). Together, these contain vastly greater oil resources than all the oil the world has consumed since the industrial era began.

These oil shale deposits (like hydrocarbon source rocks in general) share conditions of high productivity of organic material (mostly algae, with or without admixture of terrigenous organics) and anoxic bottom conditions for good preservation. Organic carbon concentrations are very high in all these four deposits, with common values of 15% to 20% TOC by weight, reaching a maximum of 35%. For the Cretaceous marine oil shales, these optimal conditions were attained in the very late Cretaceous (mostly in the very early Maastrichtian stage) during periods of rapid sea level rise which shifted the ocean anoxic zone far landward into fold-related minibasins with stagnant bottom conditions. Interbedded phosphorites probably represent the regressive and lowstand conditions.

The three large lacustrine oil shale deposits all occupy lakes in major orogenic zones (where most large lakes tend to form), and may - like the rich sapropels of the Black Sea today - record those particular conditions when near-surface organic productivity coincided with anoxic lake floors. These conditions appear to have occurred when marine waters started spilling over the Bosphorus into the Black Sea to mix nutrients and increase productivity of organic-rich sapropel.

Oil Shale Stratigraphy – a Global Perspective

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Cape Town, South Africa**

by

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Pica



What is oil shale?

- Organic rich sedimentary rock formed in lake or marine environments
- Commonly carbonate rich; most not true shale
- Kerogen-rich, primarily algal and bacterial
- Immature precursor to oil & gas
- Produces oil upon heating



Boak

Points To Be Made

- Brief history of oil shale
- Oil shales are everywhere!
- Very big accumulations exist in
 - The Rocky Mountains (USA),
 - China (East and West)
 - North Africa and Middle East
 - The Whitehills Fm here in South Africa and the correlative Irati Fm in Brazil (perhaps?)
- Their stratigraphic expression

Historical Highlights - 1



Early beginnings

1596 Duke Frederick of Württemberg - mineral oil distilled from oil shale used in healing

1637 Swedish alum shale (Cambro-Ordovician) used to extract potassium aluminum sulfate

1694 British Crown awards patent No. 330 on oil shale extraction

1694(?) Shale oil used for street lighting in Modena, Italy

Start of the modern industry

1832 Oil shale pyrolysis was developed in France. Used as lighting oil

1847 Scotland starts producing "lighting oil," lubricating oil and wax from oil shale

Second half of the 19th century shale oil extraction industries were initiated in

Sweden, Australia, Brazil, New Zealand, Canada and the United States

Industry waned rapidly after start of crude oil production in Pennsylvania

Historical Highlights - 2

First half of 20th century

The oil shale industry started growing just before World War I – concern about supply of conventional crude oil

1918 operations began in Estonia. Tallin Power Plant first to run on shale oil

1950s–1960s

After World War II, the oil shale industry was phased out. Too high costs

1950s and 1960s The industry closed in France, Australia, New Zealand, Spain, Scotland and South Africa, but continued growth in Estonia, Russia, and China continued to grow

1970s–1980s

1973 The oil crisis helped restart the oil shale industry in several countries

1980 Almost all major US oil companies had established oil shale pilot projects in Colorado

1982 On May 2, "Black Sunday", Exxon canceled its US\$5 billion Shale Oil Project in Colorado

Latest developments: growth began again in the 90s

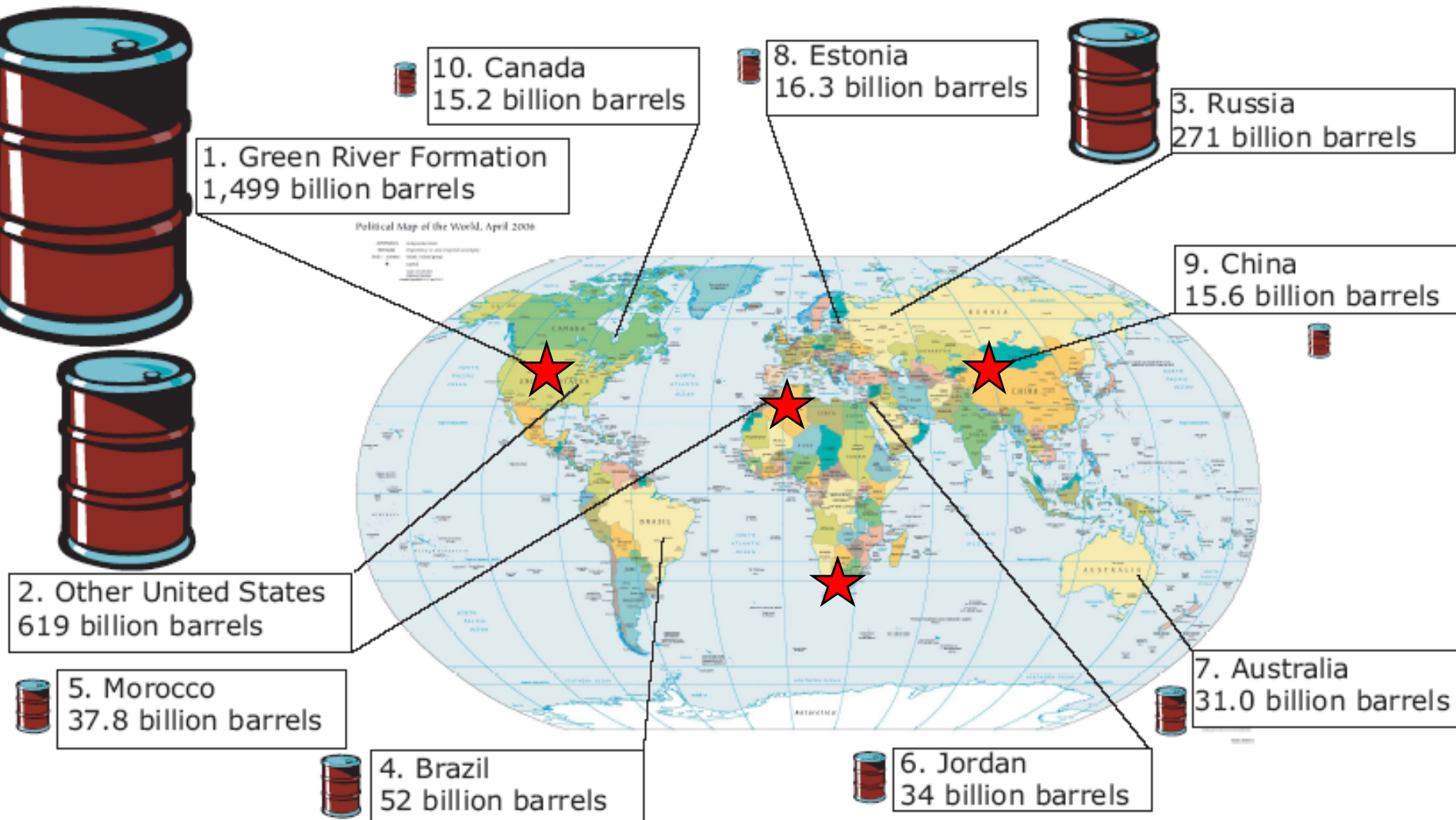
1992 Commercial shale oil production resumed in Brazil

Estonian oil shale production has continuously increased since 1995

In the US, the Energy Policy Act of 2005 opened leasing program for oil shale and tar sands on public lands within the states of Colorado, Utah, and Wyoming

Oil Shale is Global

(But Unevenly Assessed)



Resources and Energy Density are Huge

Magnitude

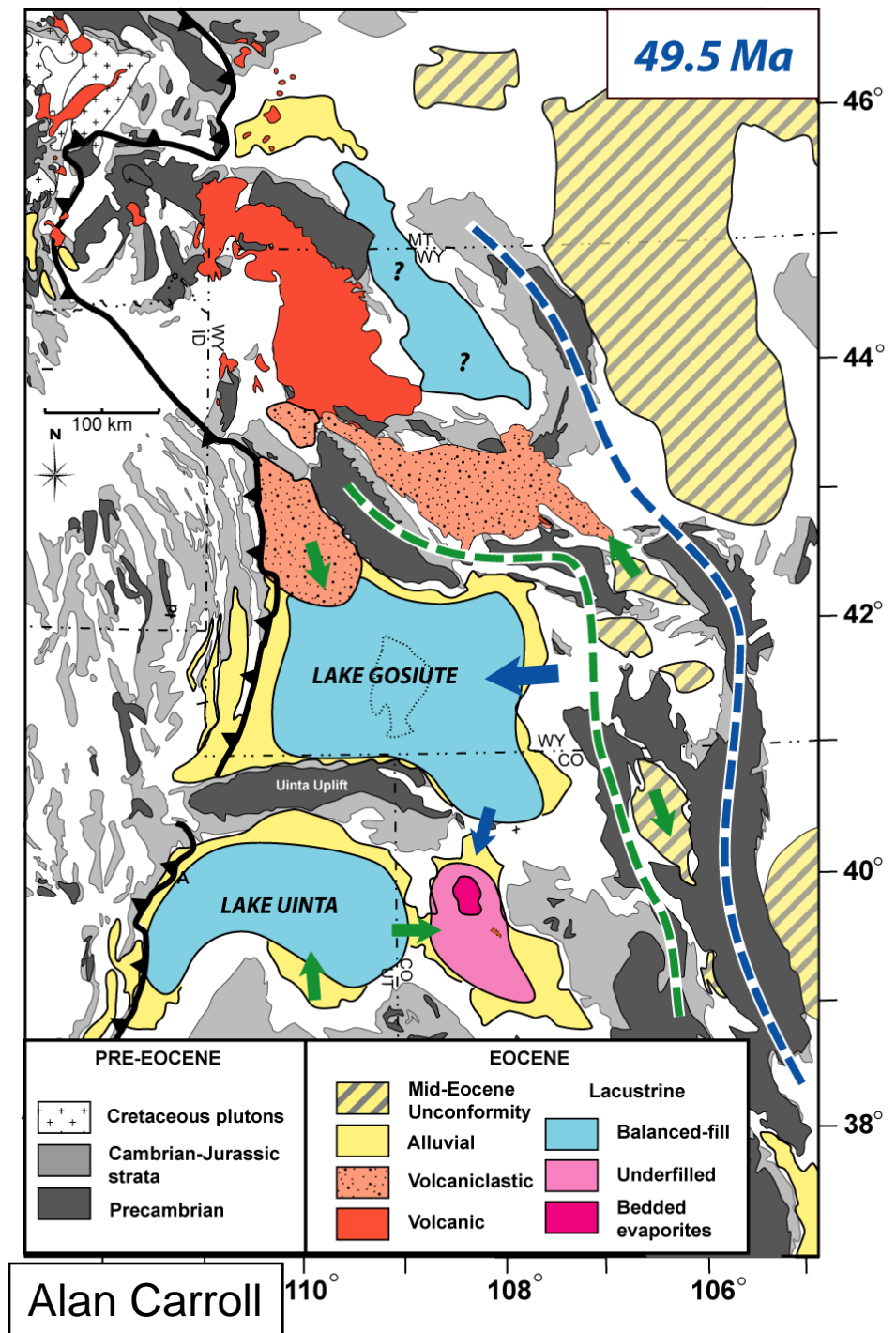
- Global oil shale resource: >2.8 trillion barrels
- ~2X historic conventional production
- Distributed differently than conventional oil
- Very large potential reserves – globally distributed

Energy Density

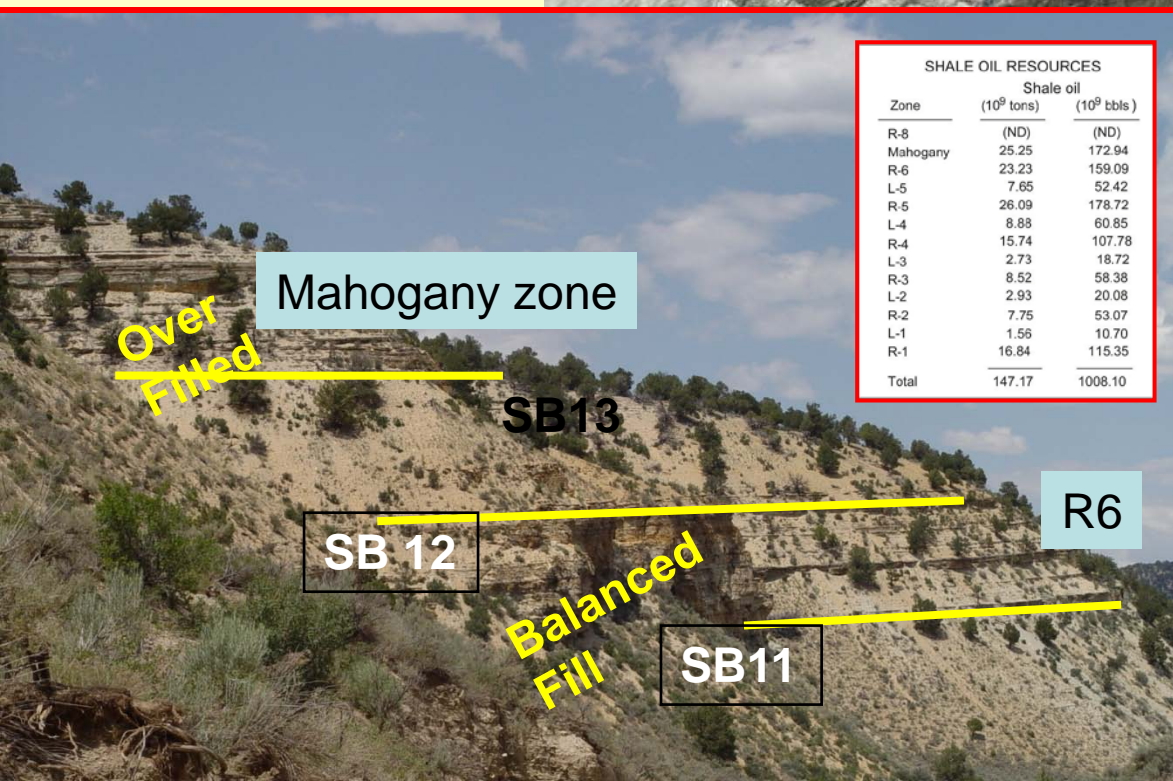
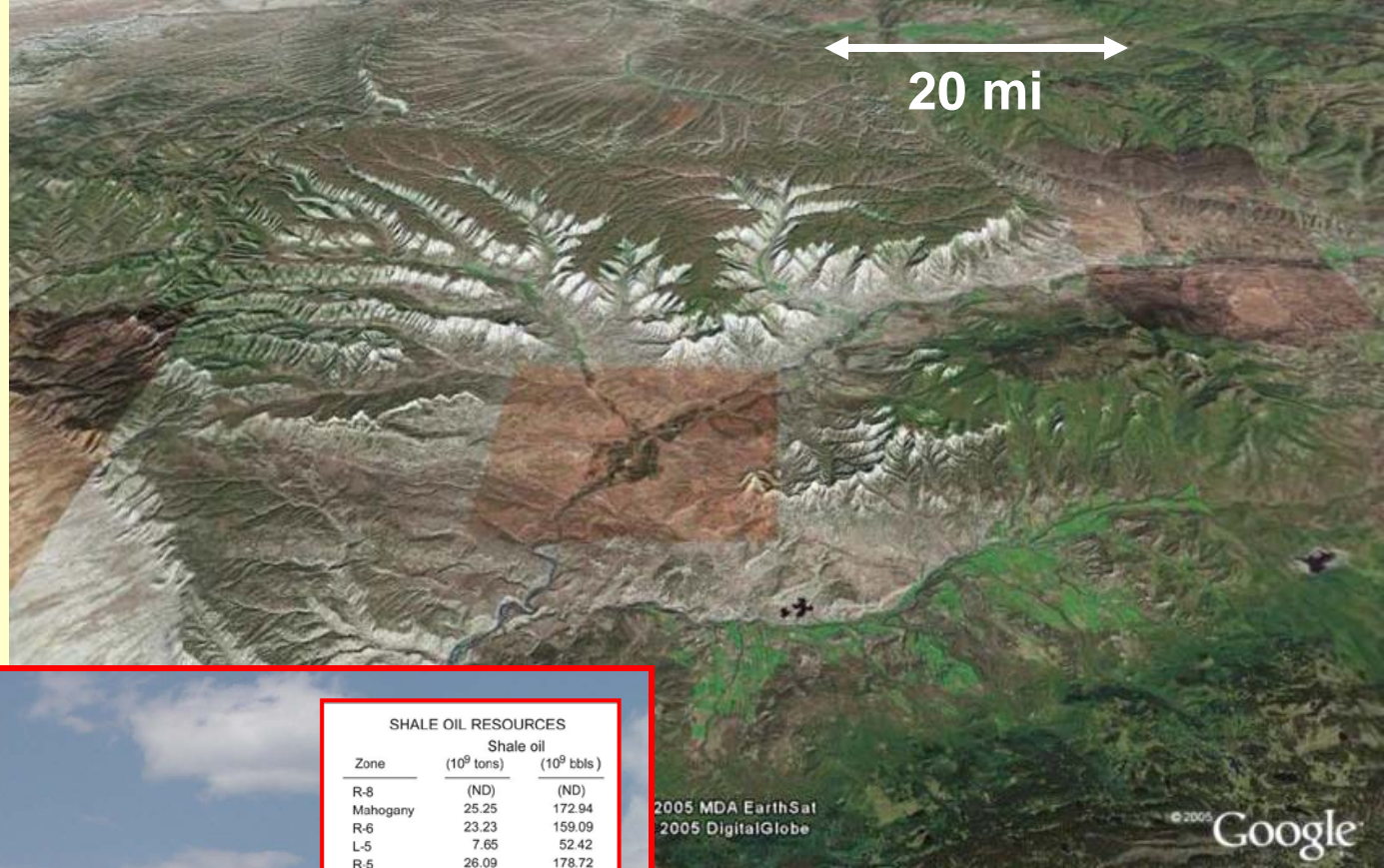
- Colorado has exceptionally rich oil shale:
 - Thick (~300 m) and very rich
 - Areal resource density up to 1.3 million barrels per acre
 - Compared to Wyoming coal (500,000 BOE/acre)
 - Canadian oil sands (100,000 bbls/acre)
- Technologically (& economically) challenging to produce

The Green River Formation, USA

- The world's largest ? known oil shale resources occur in:
 - Eocene lake sediments of Green River Formation
 - Western Colorado and adjacent Utah and Wyoming
- Piceance Basin largest fraction of reserves
- Major basins connected at times during history
- Each basin has a unique history
- Even different evaporite mineralogy



Piceance Basin →

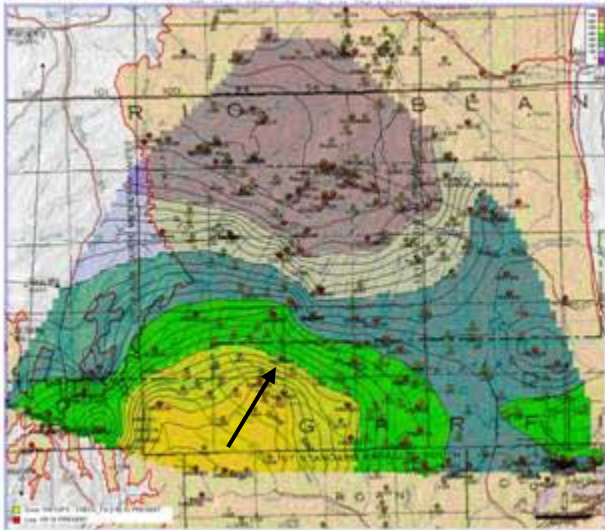


**Green River Fm.
Sequences 11-13**

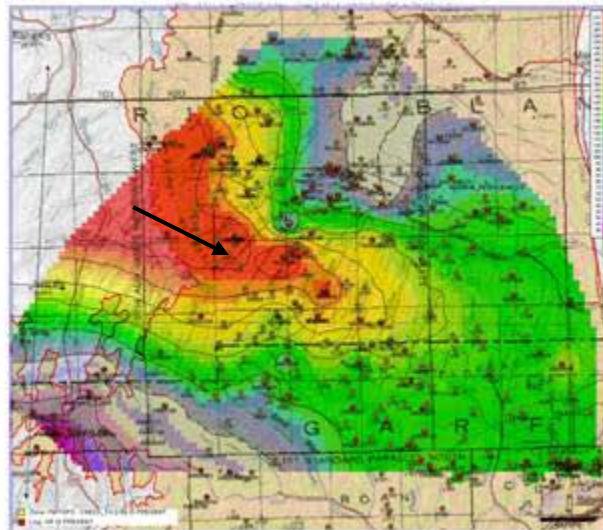


Isopachs of Green River Fm Sequences

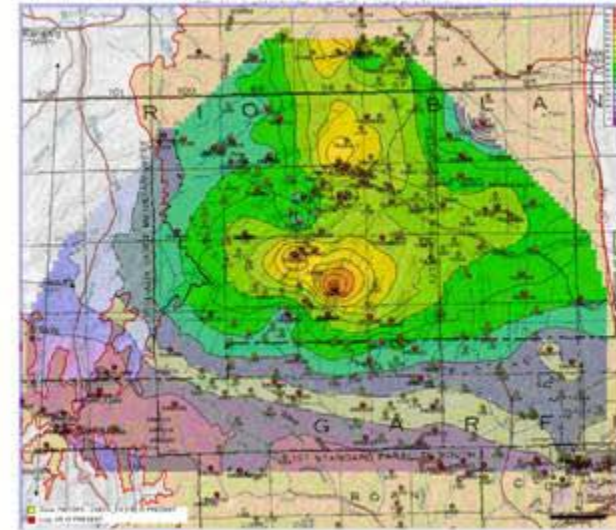
Sequence 3



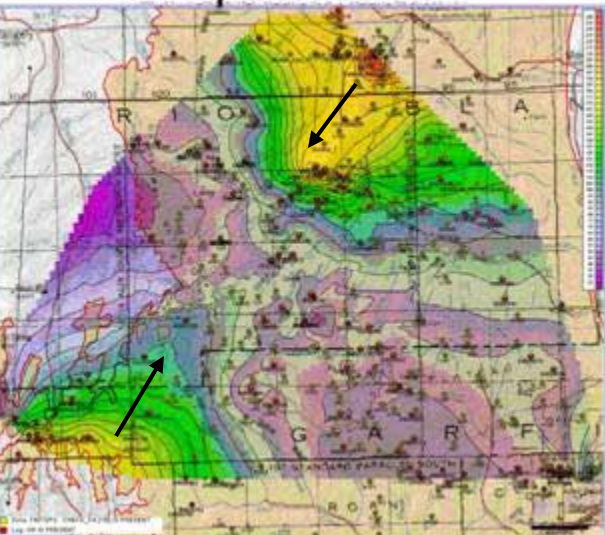
Sequence 4



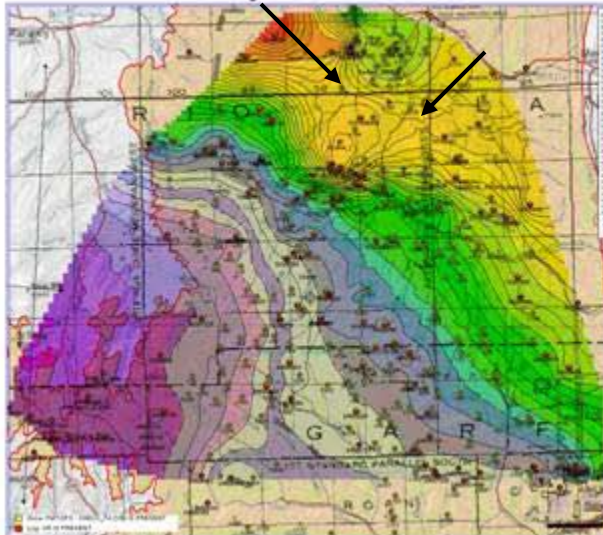
Sequence 5



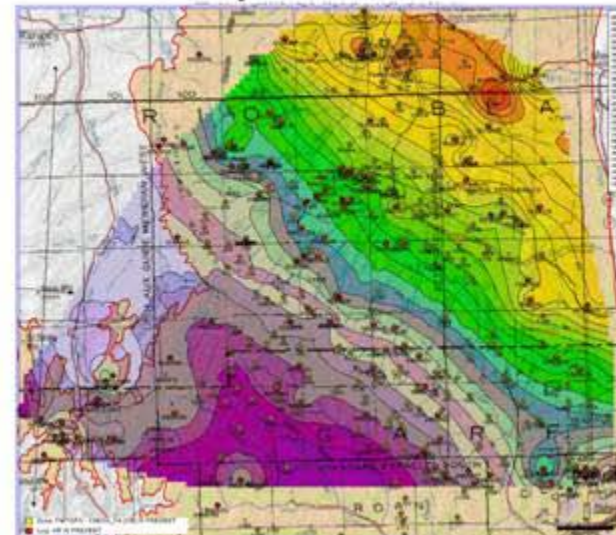
Sequence 8



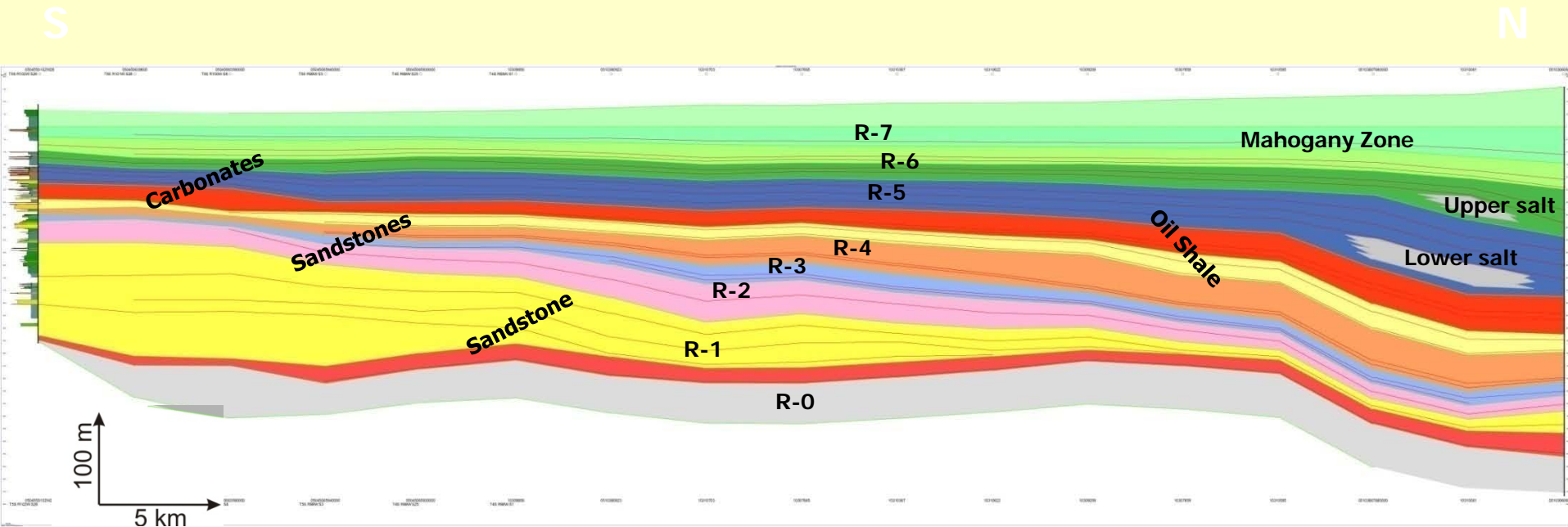
Sequence 9



Sequence 12



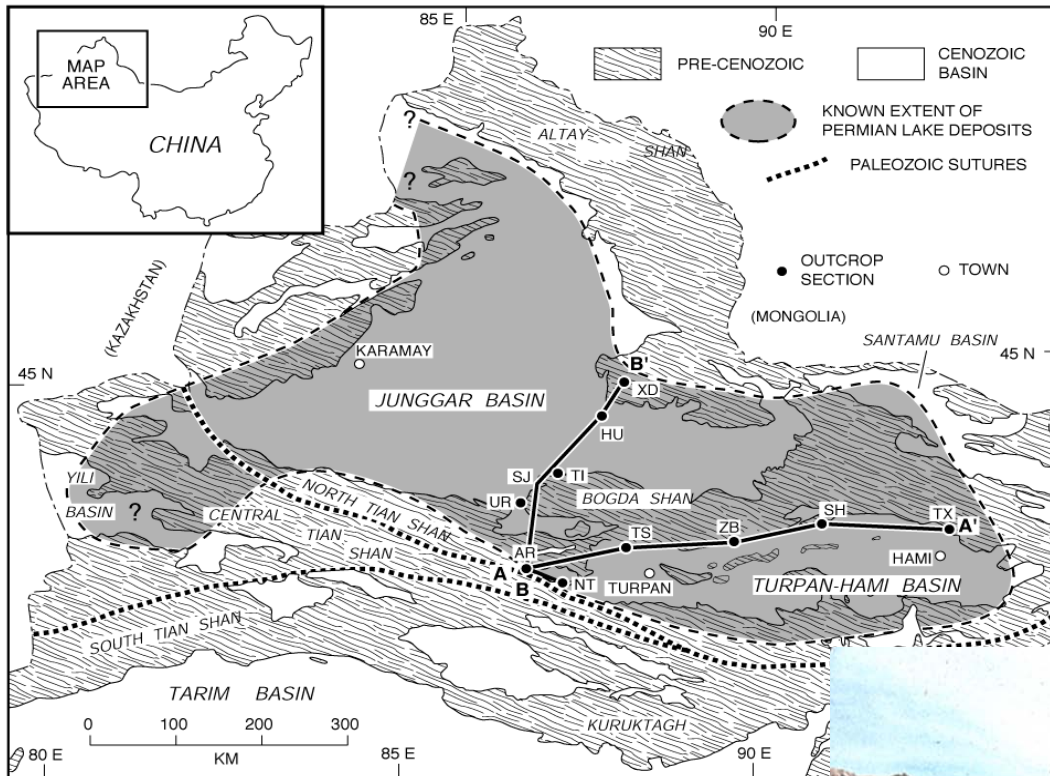
Section: Douglas Pass to Basin Center



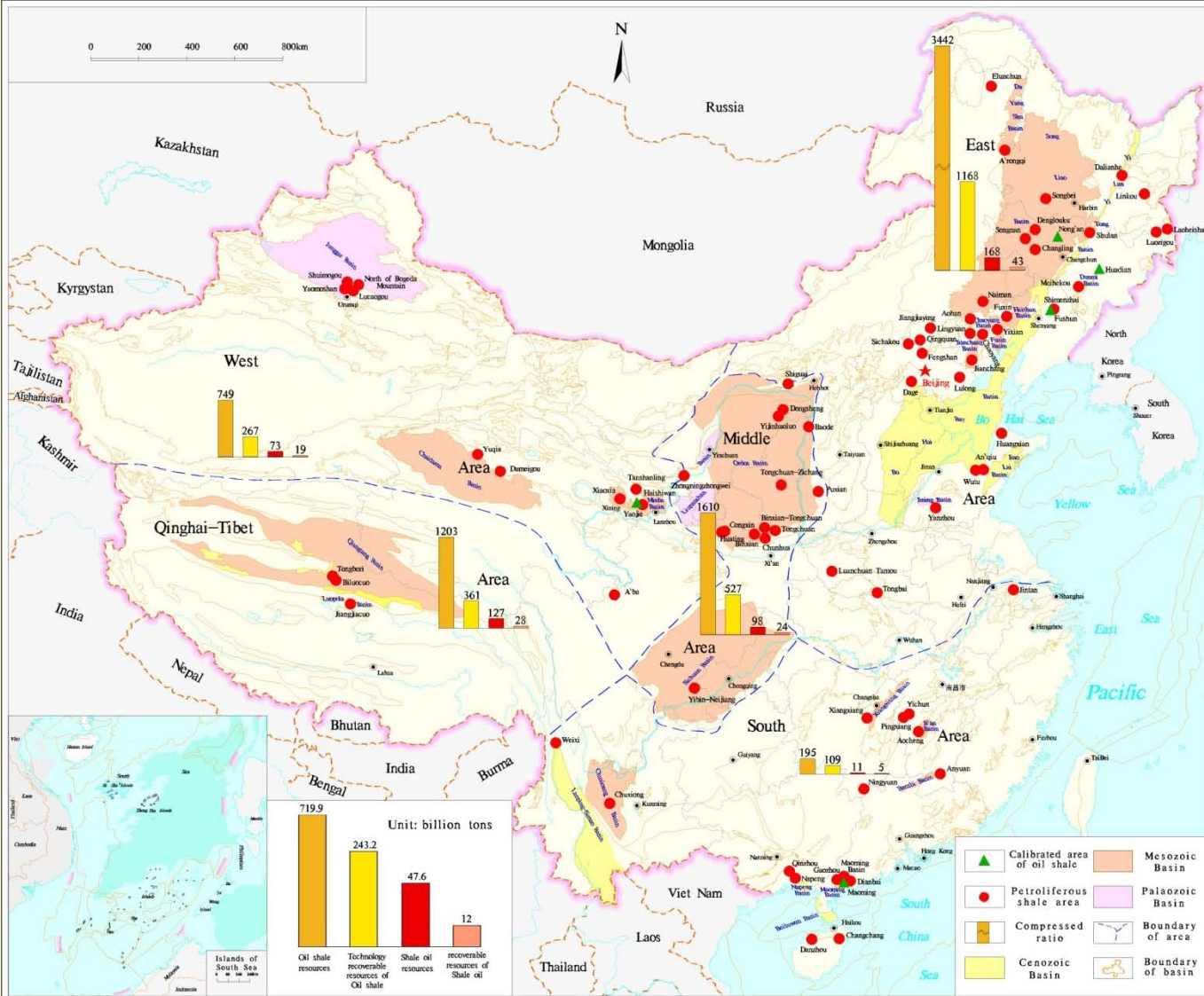
Colors represent the 14 sequences

Richest oil shale in transgressive and late highstand systems tracts (restricted lake circulation)

Permian Oil Shale in Junggar Basin, China



Carroll and Wartes, 2003



First National Oil Shale Evaluation in China (Jilin University 2004-06)

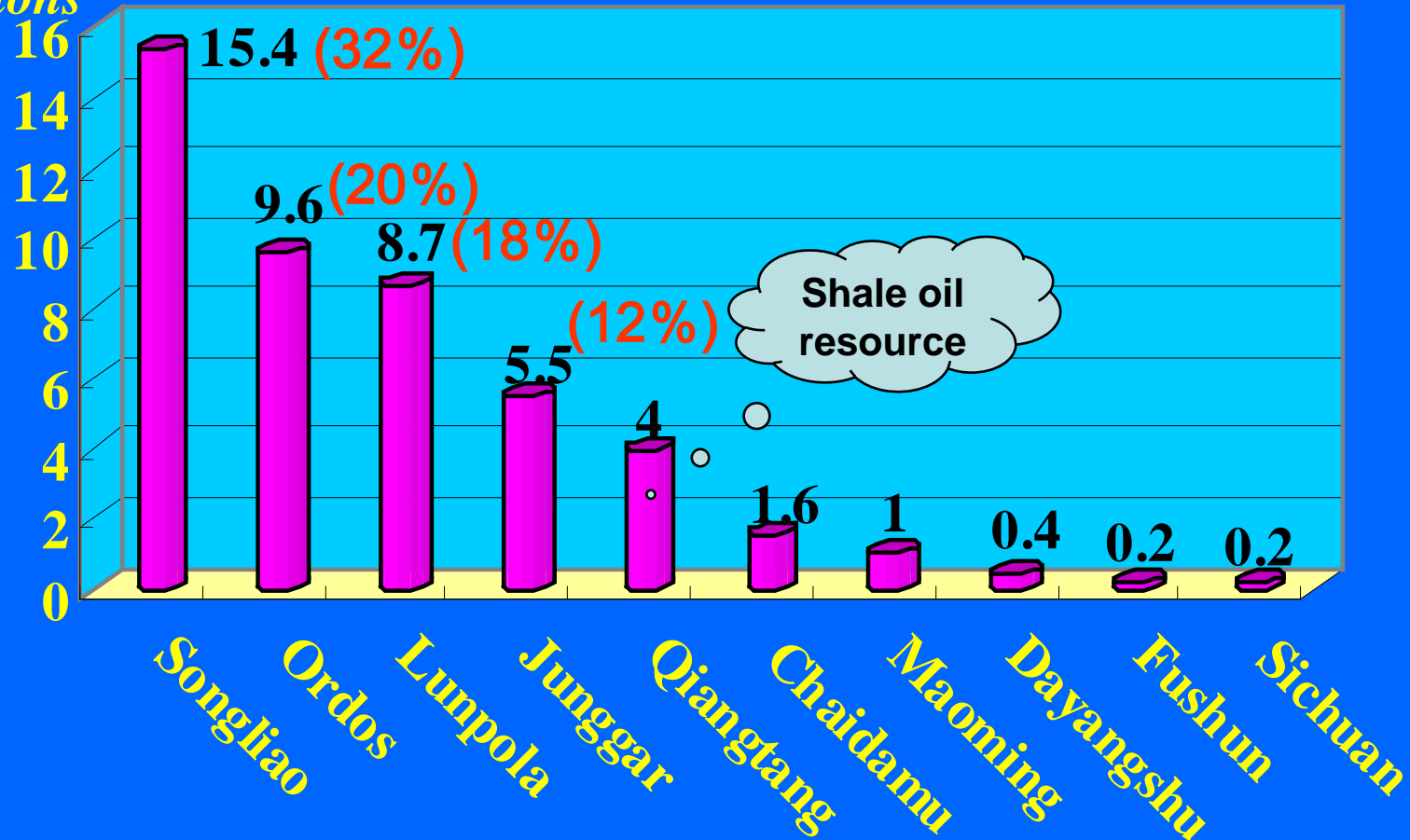
20 Provinces. 47 basins. 80 oil shale source areas
 47.6 billion tons of in-place shale oil
 12 billion tons of recoverable resources

Zhaojun Liu, Qingshui Dong, Qingtao Meng, 2008

Evaluation Results in Different Basins

Billion

tons



Mainly distributed in Songliao, Ordos, Lunpola and Junggar basins

Zhaojun Liu, Qingshui Dong, Qingtao Meng, 2008

North African Oil Shale – 1: Related to Upwelling

- At Timahdit, Middle Atlas Mountains
- 240 km East / South-East of Rabat
- Altitude: 1700 to 2300 meters



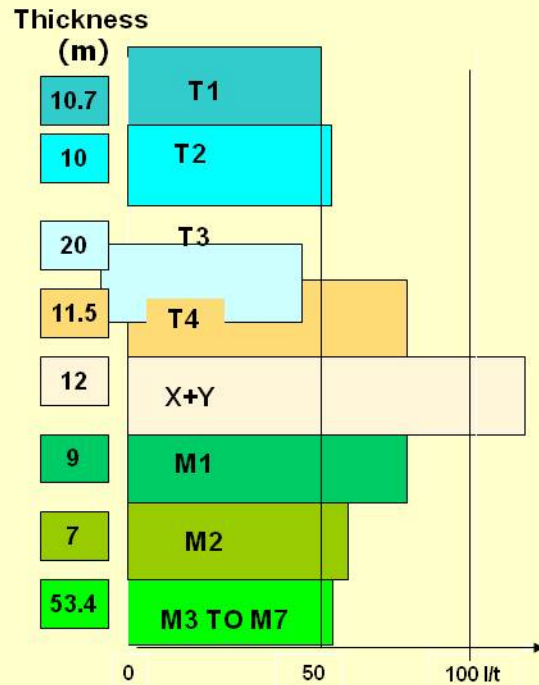
2. Tarfaya

1. Timahdit

Map from Dyni, USGS website

Mohammed Bencherifa, 2008

Timahdit-1 Geology



Modified from: Mohammed Bencherifa, 2008

- Kerogeneous limestone and marls covered by basalt flows (Tasemmakt Plateau)
- Upper Cretaceous (Maastrichtian) age
- Maximum thickness: 250 meters (Tassamakht plateau)
- Resources and reserves:
 - Inferred Resources: 2 billion bbls

The oil shale deposit of Timahdit has been divided into 4 lithologic units, depending on the oil and compounds content, named from top to bottom of the deposit:

- T (4 layers)
- X (1 layer)
- Y (1 layer)
- M (7 layers)

The oil shale deposit of Timahdit has been divided into 4 lithologic units, depending of the oil and compounds content, named from the top to the bottom of the deposit:

-T (4 layers)

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- M (7 layers)

Israeli/Jordanian Oil Shale – Also Related to Upwelling

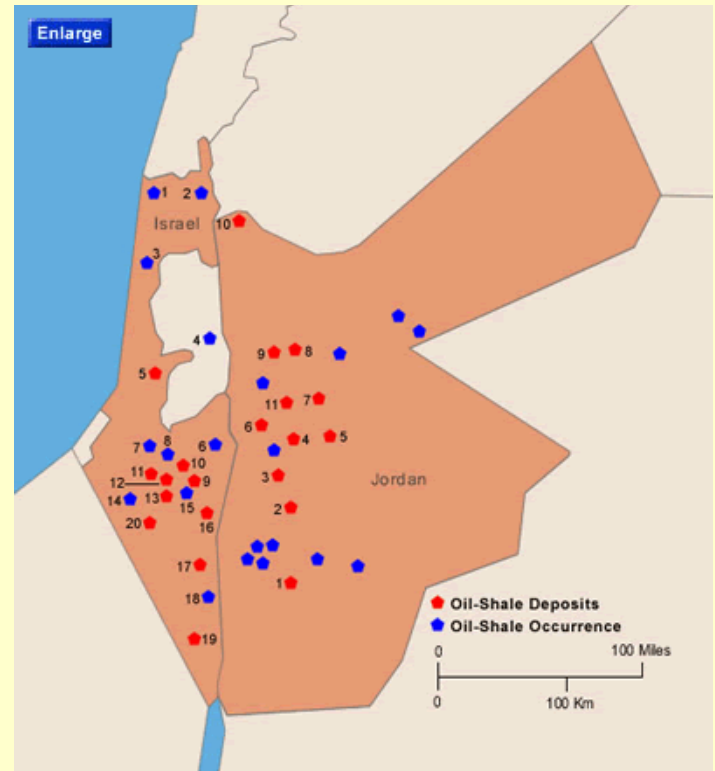
Bituminous chalks of Santonian to Maastrichtian age: 85 – 73 Ma (post OAEs)

Oil shales associated with porcellanites, cherts and phosphates
Maximum TOC values – up to 20%

Sustained duration and permanence of the upwelling system

Productivity and location and depth of the oxygen minimum zone were the primary controls on TOC values

Lateral, predictive shifts in oil shale and phosphate deposits, consistent with very late Late Cretaceous sea level histories



Map from Dyni, USGS website

Geo -Summary from
Bein, Almogi-Labin,
and Sass

North African Oil Shale –

2: Related to Global Anoxic Events



The Mafatma Section
Tarfaya Basin, Morocco

TOC contents up to 18wt%
Hydrogen indices between
400 and 800 (mgHC/gTOC)

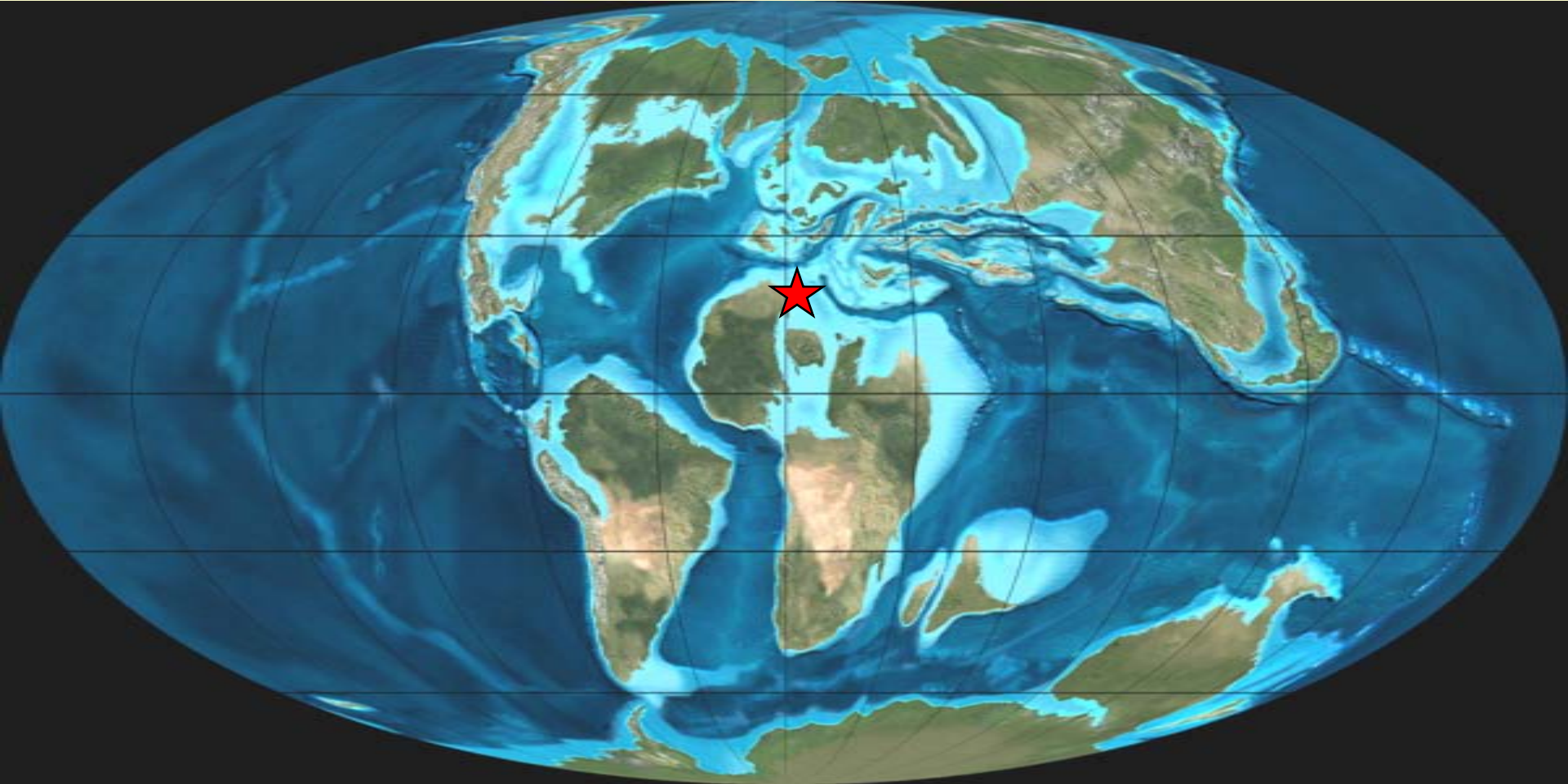
Age: 93.5 Ma (the Bonarelli
Event - or OAE – 2 at the
C/T boundary

Osmium spike: Caribbean
volcanism (Turgeon and
Creaser, 2008)

In the 1980s Shell studied the concept of an open-pit oil shale mine at the Tarfaya basin

Picture from Luning website:
<http://www.blackshale.com/pics/amafat.htm>

Late Cretaceous: Flooding & Upwelling Across North Africa/Middle East



Ron Blakey website: <http://jan.ucc.nau.edu/~rcb7/90moll.jpg>

What About Oil Shale in South Africa?

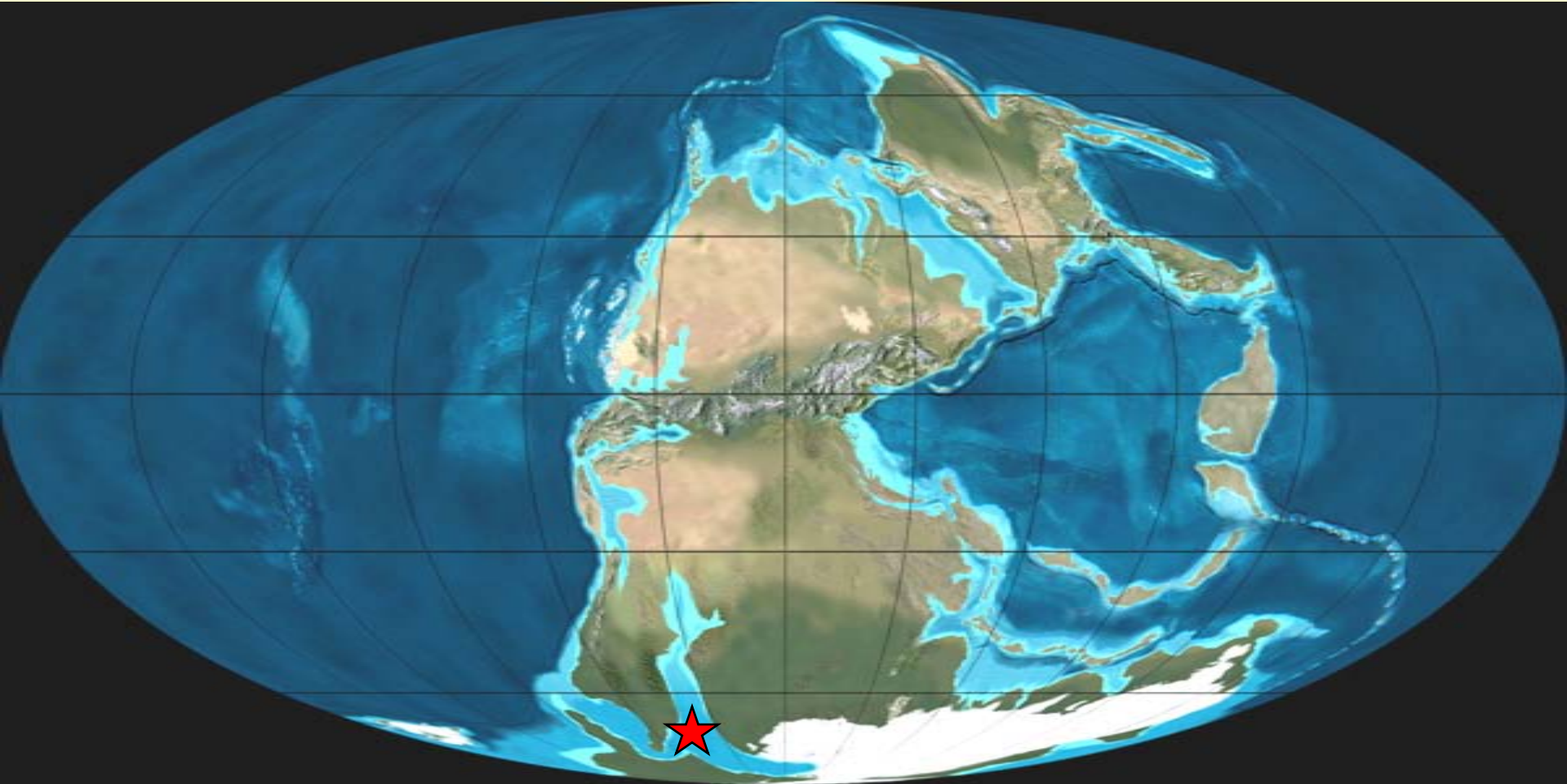
Whitehill Formation of South Africa and the **Irati Formation** of Brazil

Post-glacial flooding of SW Gondwana during the early Permian, by the Whitehill Sea and Irati Sea

Deposition of the Early to Late Permian Whitehill Formation occurred during a sea-level highstand in a juvenile foreland basin (Visser, 1992)

The Whitehill Formation consists of dark, carbonaceous, lacustrine shale overlain by siliciclastic turbidites with tuffs (Wickens, 1992)

Early Permian: Whitehill and Irati Seas



Ron Blakey website: <http://jan.ucc.nau.edu/~rcb7/90moll.jpg>

Conclusions

- Oil shale has been produced since 1596, but has always been more expensive than conventional crude
- Oil shale is global in occurrence, but still in its infancy with respect to assessment
- The sequence architecture of the lacustrine Green River Formation is pretty well understood and well mapped. Rich oil shale mostly occurs in the transgressive and late highstand systems tracts
- Stratigraphic patterns in the lacustrine Chinese oil shale deposits are insufficiently understood
- Shallow marine oil shale in North Africa and the Middle East formed at upwelling zones – with changing locations over time – and (regionally?) during OAE-2 (at the C/T boundary)
- Perhaps South Africa has a ‘hidden’ oil shale treasure?

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