Fractured and Weathered Basement Reservoirs: Best Practices for Exploration and Production - Examples from USA, Venezuela, and Brazil*

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Abstract

Fractured and weathered basement rocks are important oil and gas reservoirs in various basins in the worldwide. This author has followed this subject very closely for 30 years and hereby shares his knowledge and experience. This paper focuses on relevant fields in the USA including the Kansas fractured quartzite "buried hill" oil fields and basement oil fields in California including the El Segundo and Edison oil-bearing schist reservoirs. Also reviewed are the La Paz and Mara basement oil fields in Venezuela and basement reservoirs in the Carmopolis oil field, onshore Brazil.

Best practices include the following: production wells should be drilled near perpendicular to the dominant fracture system. Exploration wells should also be drilled highly deviated rather than vertical in order to optimally intersect the dominant fracture systems. Highly focused 3-D seismic such as CBM (Controlled Beam Migration) is needed to define the fracture systems in basement. Extensive core coverage is necessary to provide critically important information on the lithologies and reservoir parameters. Some of the cores should also be radiometrically age dated in order for the geologists to understand the complexities of the basement reservoirs they are dealing with. Development wells must be sufficiently deep to fully drain the reservoir. Wells should not just "tag" into the top of basement. For example, wells in the La Paz field, Venezuela were typically drilled 500 meters into the basement.

In a general sense, fractured granites and quartzites are the optimum reservoirs. Weathered "rotten" granites can also be excellent reservoirs as can be observed in outcrop in tropical areas. Rocks such as schists and gneisses are less attractive since they are ductile and tend to "smear" and not fracture when subjected to tectonic stress. The high mafic content of schists also negates the creation of secondary porosity by weathering. Likewise, granites and quartzites are more likely to provide attractive, highly porous "granite wash" sands whereas eroded schists do not produce such good reservoirs.

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Fractured and Weathered Basement Reservoirs: Best Practices for Exploration and Production - Examples from USA, Venezuela, and Brazil

Poster Paper Presentation to the
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Abstract

Fractured & Weathered Basement Reservoirs – Best Practices for Exploration and Production: Examples from the USA, Venezuela and Brazil. Author: **Tako Koning, Gaffney, Cline & Associates, Luanda, Angola**

Fractured and weathered basement rocks are important oil and gas reservoirs in various basins in the worldwide. This author has followed this subject very closely for 30 years and hereby shares his knowledge and experience. This paper focuses on relevant fields in the USA including the Kansas fractured quartzite "buried hill" oil fields and basement oil fields in California including the El Segundo and Edison oil-bearing Jurassic schist reservoirs. Also reviewed are the La Paz and Mara oil fields in Venezuela and also basement reservoirs in the Carmopolis oil field, onshore Brazil.

Best practices include the following: production wells should be drilled near-perpendicular to the dominant fracture system. Exploration wells should also be drilled highly deviated rather than vertical in order to optimally intersect the dominant fracture systems. Highly focused 3D seismic such as CBM (Controlled Beam Migration) is needed to define the fracture systems in basement. Extensive core coverage is necessary to provide critically important information on the lithologies and reservoir parameters. Some of the cores should also be radiometrically age dated in order for the geologists to understand the complexities of the basement reservoirs they are dealing with. Development wells must be sufficiently deep to fully drain the reservoir. Wells should not just "tag" into the top of basement. For example wells in the La Paz field, Venezuela which produces from basement were typically drilled 500 meters into the basement.

In a general sense, fractured granites and quartzites are the optimum reservoirs. Weathered "rotten" granites can also be excellent reservoirs as can be observed in outcrop in tropical areas. Rocks such as schists and gneisses are less attractive since they are ductile and tend to "smear" and not fracture when subjected to tectonic stress. The high mafic content of schists also negates the creation of secondary porosity by weathering. Likewise, granites and quartzites are more likely to provide attractive, highly porous "granite wash" sands whereas eroded schists to not produce such good reservoirs.

Oil & Gas in Basement

- Quotation from the classic paper on oil & gas in basement reservoirs by K.K. Landes et al (1960 AAPG) Petroleum Resources in Basement Rocks:

  “Commercial oil deposits in basement rocks are not geological ‘accidents’ but are oil accumulations which obey all the rules of oil sourcing, migration and entrapment; *therefore in areas of not too deep basement, oil deposits within basement should be explored with the same professional skill and zeal as accumulations in the overlying sediments*”.

Basic Requirements for Oil or Gas in Basement

- **Reservoir** – need fractured or weathered basement
- **Source** – need hydrocarbon source rocks below, adjacent or above the basement reservoir
- **Closure** – need structural closure
- **Cap** – need cap rocks above the basement reservoir

Tako’s Preferance Scale for Reservoir Rocks for Oil & Gas in Basement

- Fractured quartzites.......*Most preferred*
- Fractured carbonates
- Fractured granites
- Weathered granites
- Fractured gneisses
- Weathered gneisses
- Fractured schists
- Weathered schists...........*Least preferred*

Potential of Gneisses & Schists as Basement Reservoirs: *Basically Bad!*

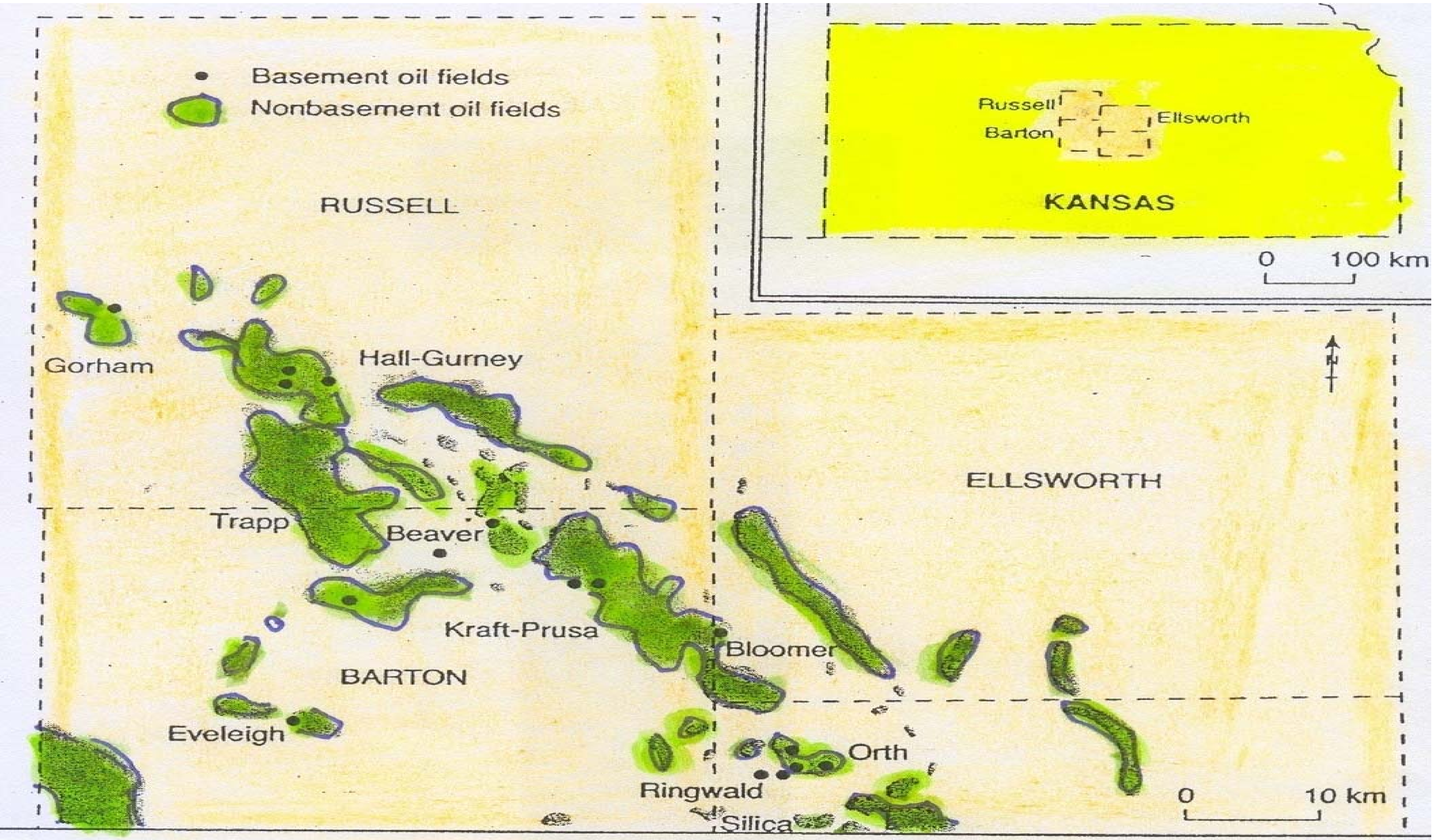
- Gneisses: a foliated metamorphic rocks corresponding in composition to granite or feldspathic plutonic rocks

  Problem: can be massive or dense or slabby with open fractures parallel to the direction of foliatiation; fracturing is too planar

- Schist: a fissile metamorphic rock with closely foliated structure consisting of parallel planes

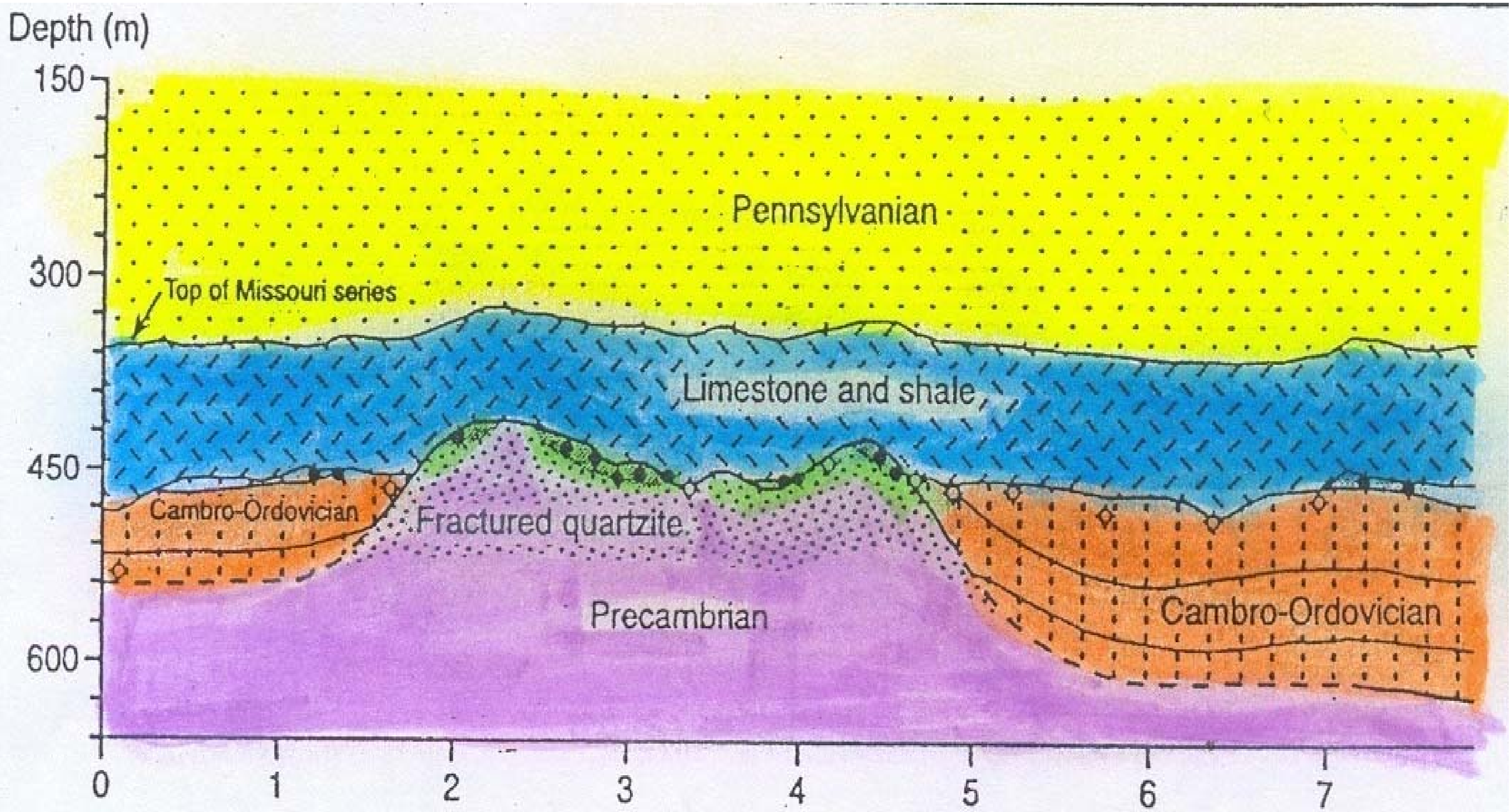
  Problem: are generally too micaceous, thinly bedded, fissile and ductile to be prone to mega-scale fracturing

KANSAS, USA – Precambrian Fractured Quartzite Buried Hill Basement Oil Pools



Map showing the location of the Kansas basement oil fields. (Landes *et al.* 1960).

KANSAS, USA – Precambrian Fractured Quartzite Buried Hill Basement Oil Pools

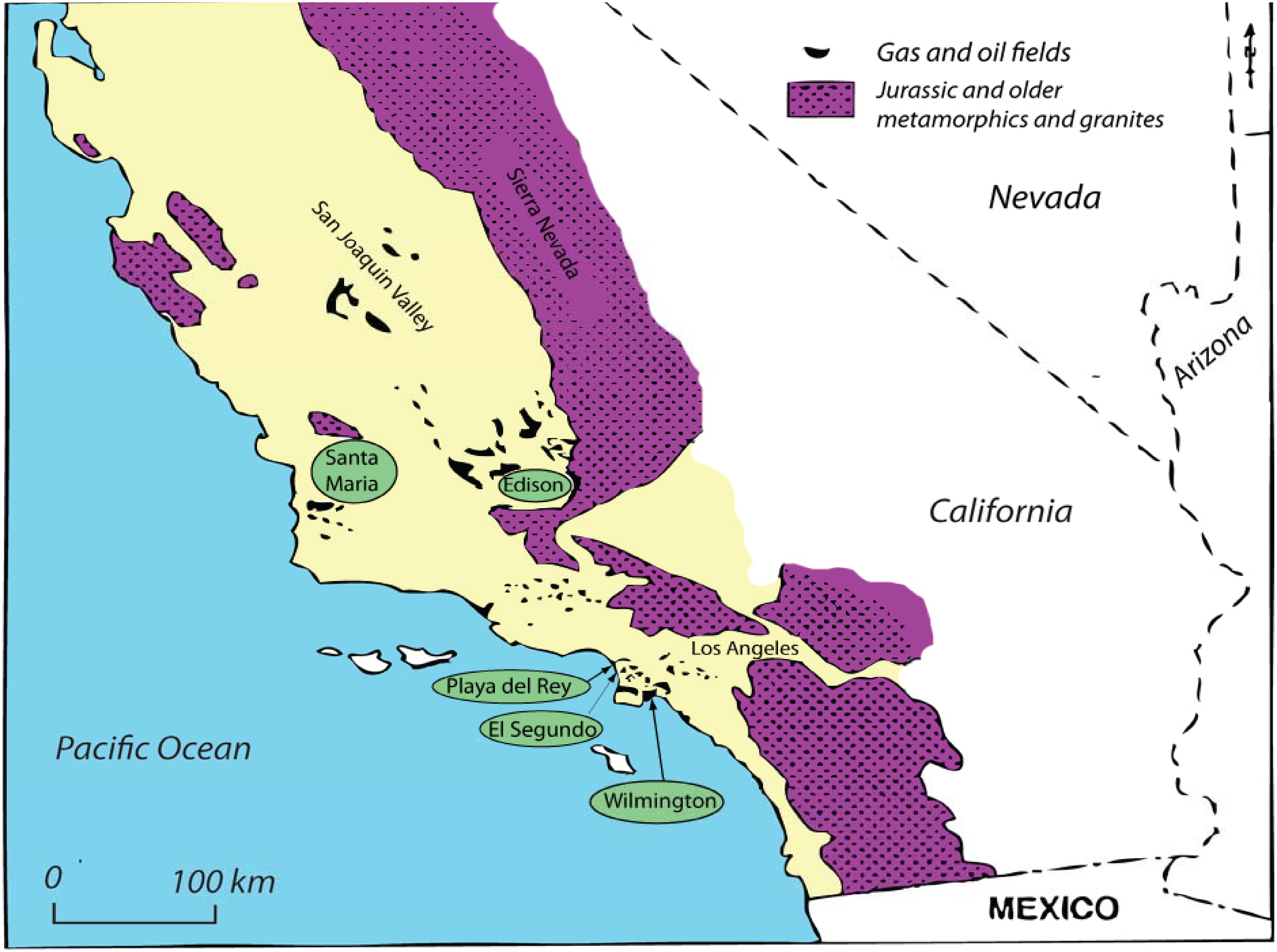


Kansas basement oil production. Oil is produced from Precambrian basement (in section), most ommonly fractured quartzites. Oil is sourced from flanking Cambro-Ordovician or overlying Pennsylvanian ocks. (Landes *et al*, 1960).

KANSAS, USA: Summary of Basement Oil Fields

Small oil pools, approximately 150,000 barrels oil per well. For example, Orth field about 1 million barrels produced from 15 wells.

- Reservoir: Pre-Cambrian fractured quartzites
- Source rocks: Pennsylvanian shales
- Oil is recovered from the top of Pre-Cambrian buried hills, depth of about 1,000 meters
- <u>Best practices</u>: more oil could be produced by drilling horizontal drain holes, also should be oriented perpendicular to the dominant fracture system; 3D seismic is necessary



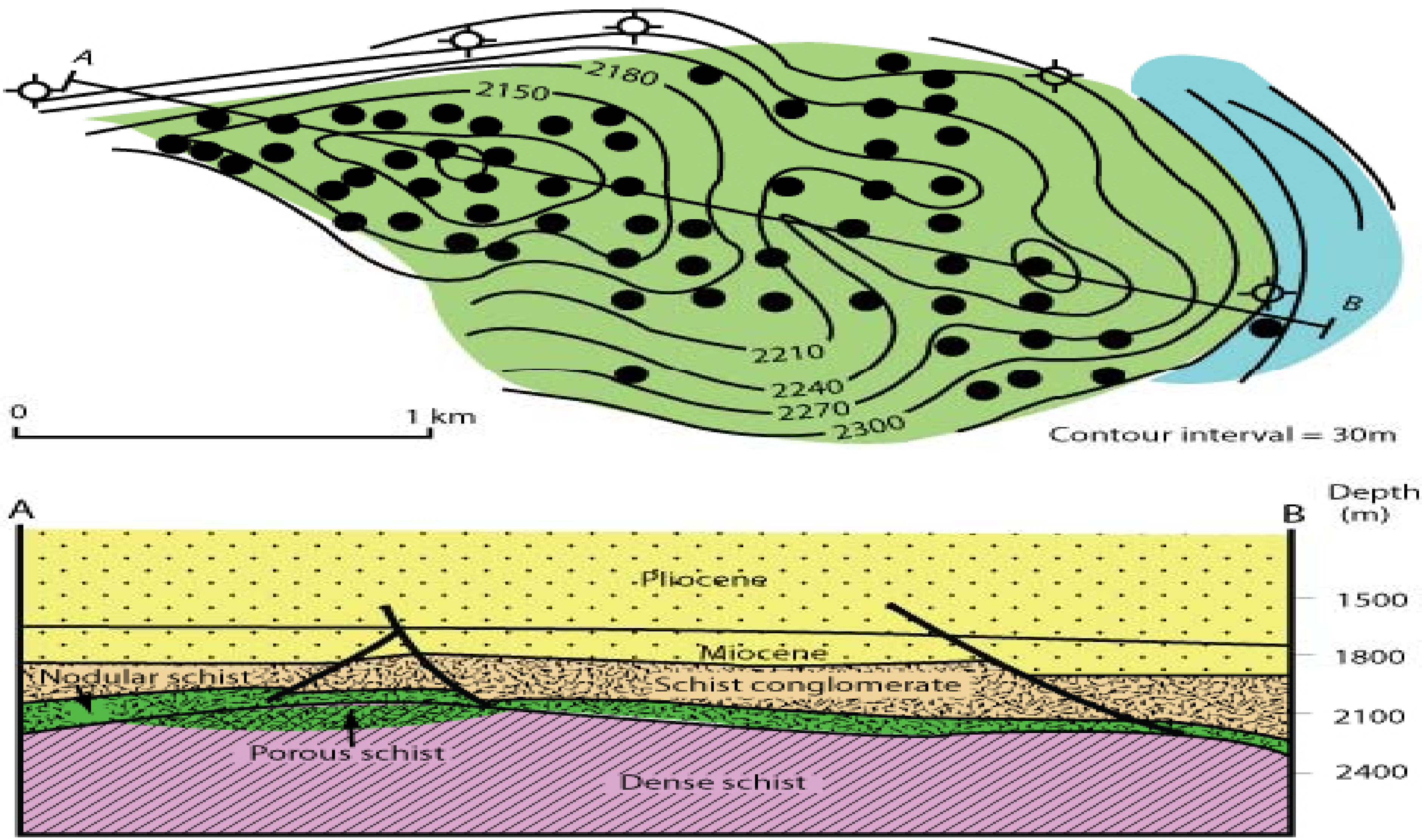
Map showing the main Californian gas and oil wells of El Segundo, Santa Maria, Wilmington, Playa del Ray, and Edison. The fields circled in green produce oil from basement reservoirs. (Landes et al. 1960).

CALIFORNIA: Basement Oil Fields

All of California's oil production is from Tertiary (Miocene) clastics except for the following fields which produce from basement:

- **Playa del Rey**, Santa Monica area, *fractured Jurassic schists*
- **El Segundo**, *fractured Jurassic schists*
- **Santa Maria**, Santa Barbara area, *fractured sandstone basement*
- **Wilmington**, Long Beach area, 22 million barrels produced from *fractured Jurassic schists*
- **Edison**, Bakersfield area, 20 million barrels produced from *fractured Jurassic schists*

CALIFORNIA: El Segundo Basement (Schist) Oil Field

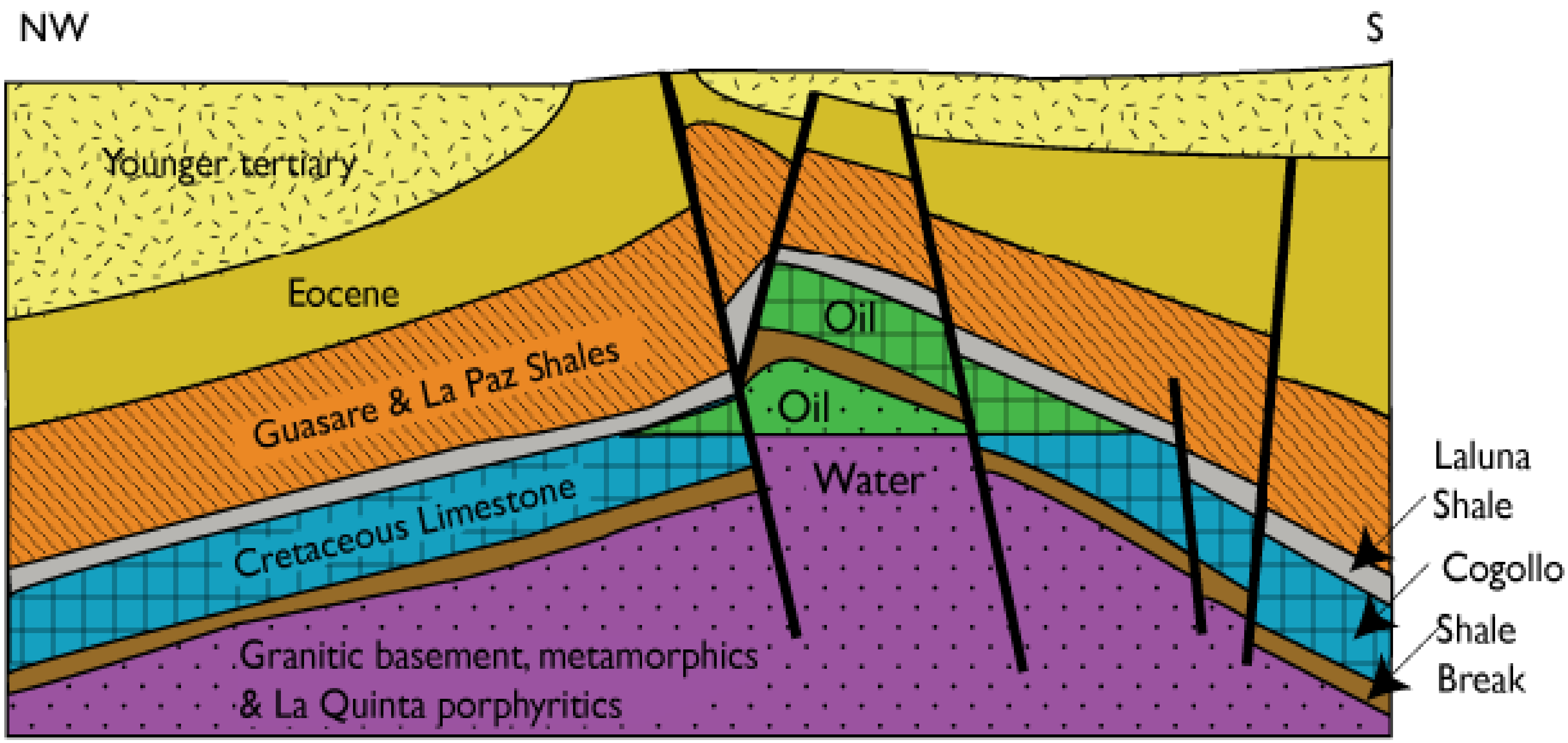


Cross-section through the El Segundo field, California. The reservoir is in fractured Jurassic schists in the west and schist and conglomerate in the east. The average depth of the oil basement production is 2300 m. (Landes et al. 1960).

CALIFORNIA: El Segundo Basement Oil Field

- Reservoir is a Jurassic fractured schist in the west half and schist conglomerate in the east half
- Oil tested up to 4,500 BOPD of 27 deg API gravity crude
- Average depth 2,100 – 2,180 meters (7,000 to 7,200 feet)

VENEZUELA: La Paz Basement Oil Field



Vertical section through the **La Paz field, onshore Venezuala**. Aprox 830 MMbls oil produced from low porosity Cretaceous limestones and 325 MMbls produced from fractured granite basement. Maximum IP of basement wells was 11,500 BOPD average IP of 3,600 BOPD. Average penetration into basement is 500 meters (1,700 feet). Source rock is the Laluna shale which is also the cap rock for the limestone reservoir.

VENEZUELA: La Paz Basement Oil Field

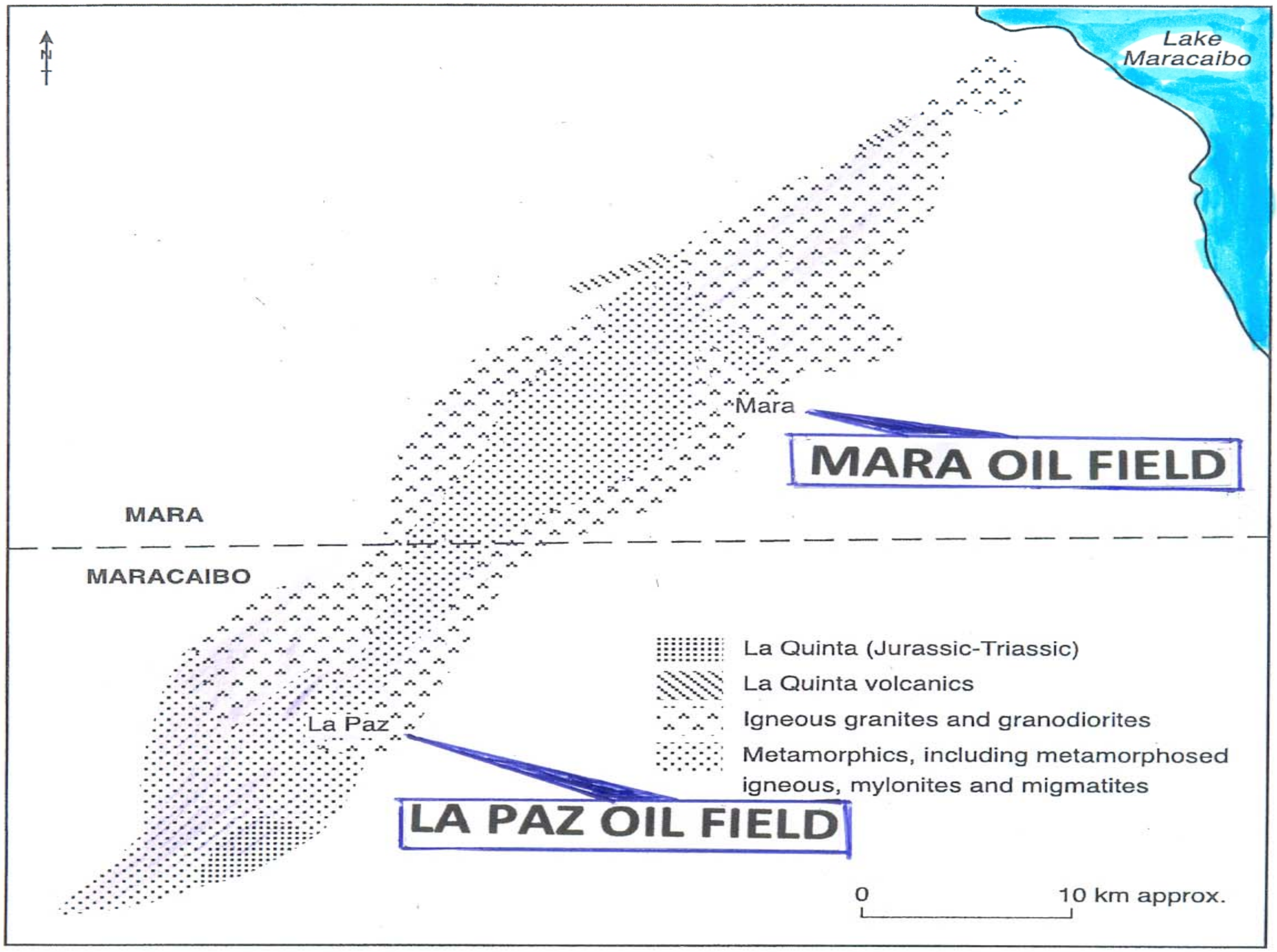


Fig. 10. Summary map showing the main lithologies comprising the Mara and Maracaibo oil fields, Venezuela. (Landes *et al.* 1960).

VENEZUELA: La Paz Oil Field

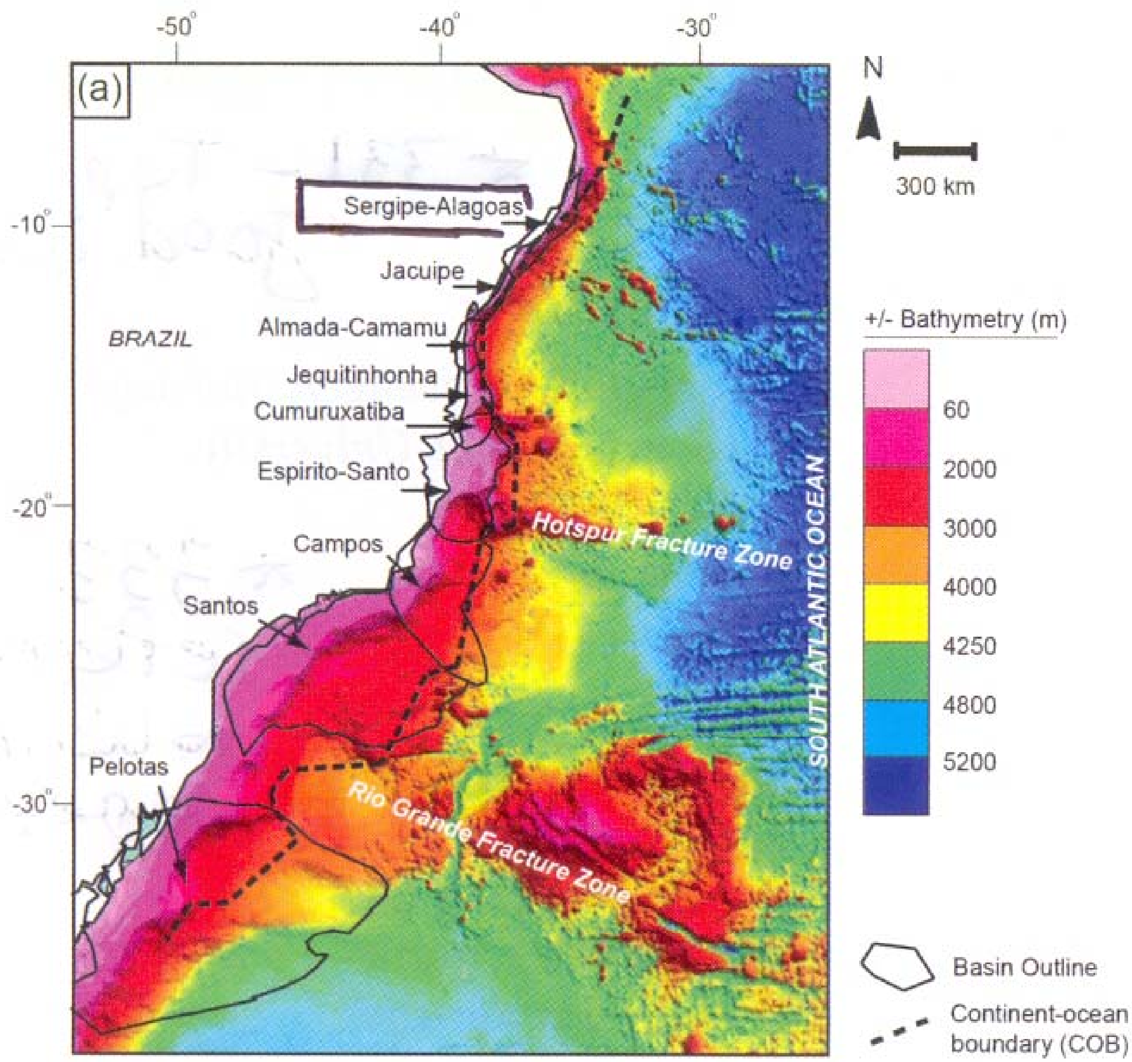
- The main La Paz oil field was discovered in 1923 and produced 830 million bls oil, the basement oil field was discovered in 1953 which was 30 years later and has produced 325 million bls oil; these numbers need to be updated; *this author is seeking more reliable and updated production information on the La Paz and Mara basement oil fields*
- Reservoir is fractured granites and metamorphics

VENEZUELA: La Paz Oil Field

- Maximum IP (initial productivity) from basement wells is 11,500 BOPD, average IP is 3,600 BOPD
- In the initial development of the basement oil, most wells were drilled 500 meters into basement
- **Mara Oil Field** was discovered in 1944, has produced 27 million barrels of oil from basement (numbers need to be updated), average penetration into basement is 360 meters and wells has IP's of 2,200 BOPD

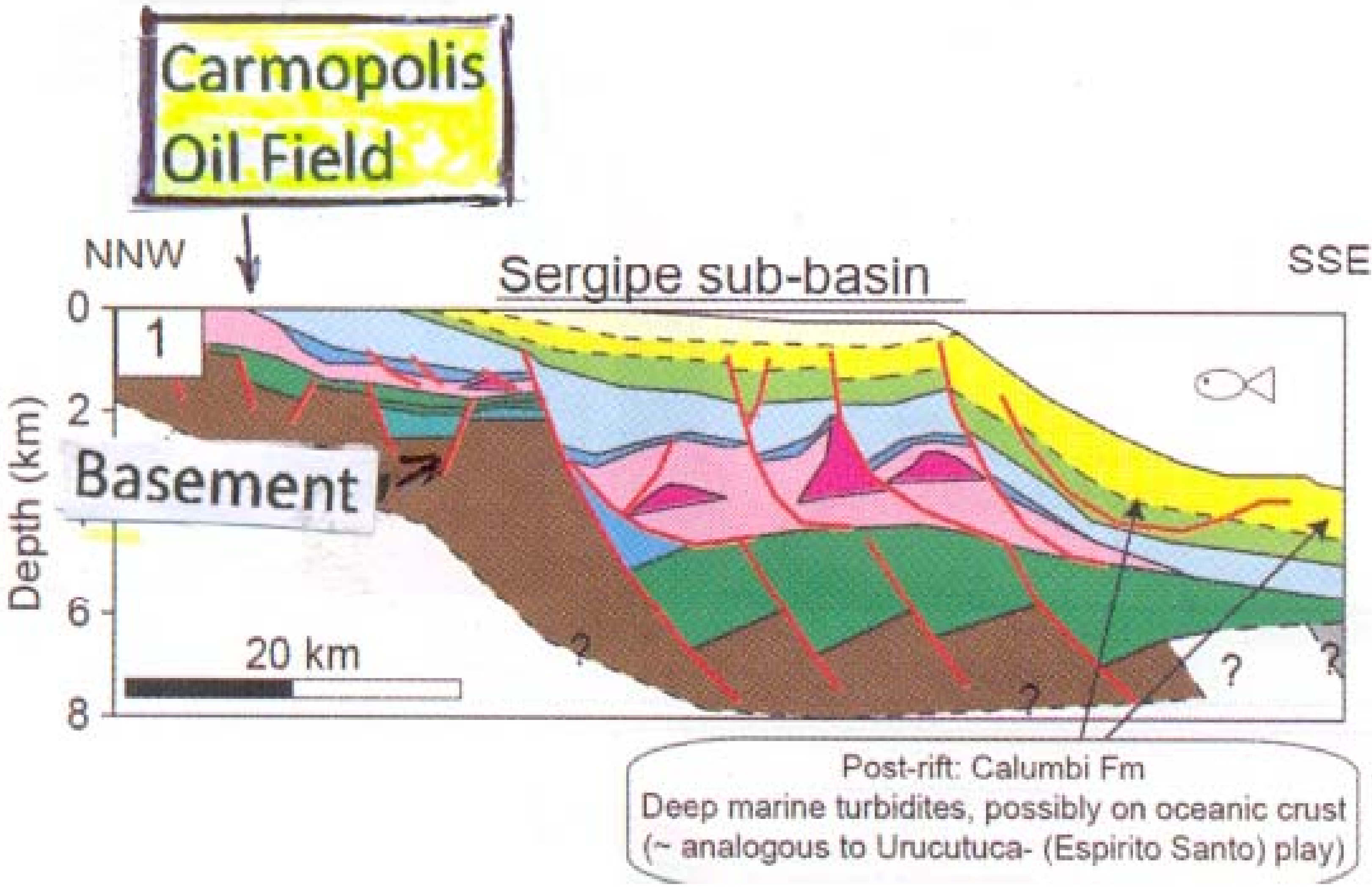
BRAZIL: Carmopolis Basement Oil Field, Sergipe Sub-Basin

-map from Beglinger et al, 2012



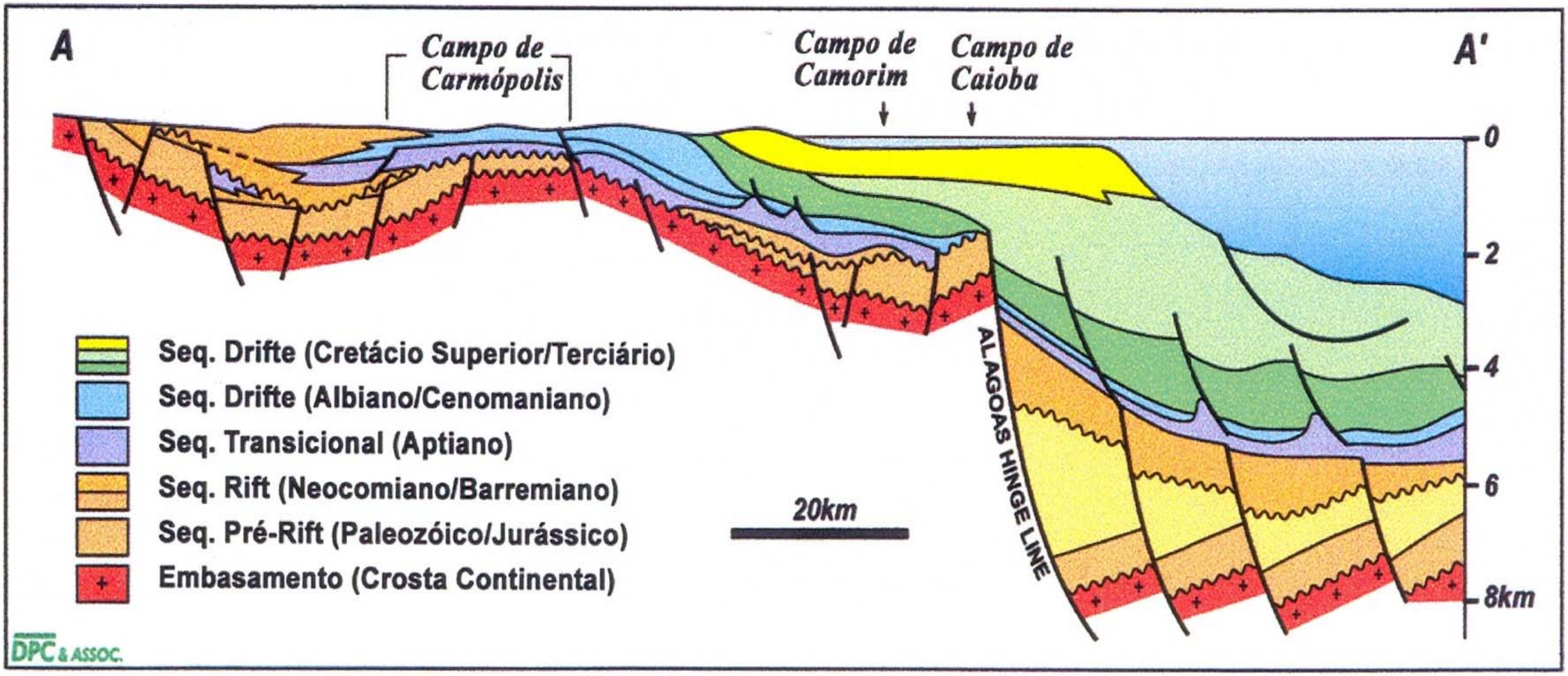
BRAZIL: Carmopolis Basement Oil Field, Sergipe Sub-Basin

X-section from Berlinger et al, 2012

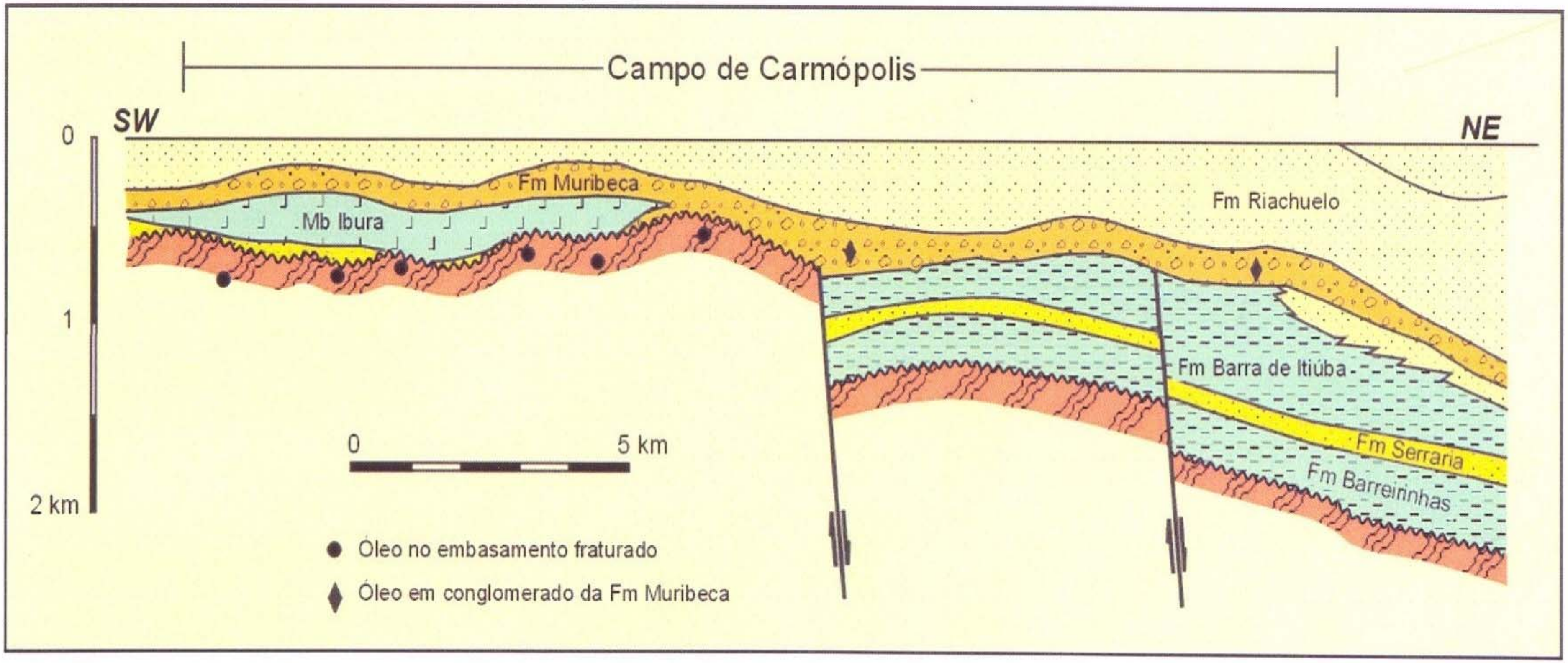


Main Fields

Geological cross-section – Sergipe Sub-Basin



Main Fields



Geological cross-section of Carmópolis Field, Sergipe–Alagoas Basin (Bizzi *et al.* 2003 - mod. from Piscetta and Michelli,1988)

BRAZIL: Carmopolis Basement Oil Field, Sergipe Sub-Basin

- Field discovered in 1963, biggest field in Sergipe Sub-Basin
- Petroleum systems: Carmopolis member reservoirs and fractured basement
- Original oil-in-place 268 million cubic meter (1.7 billion barrels); approx 55 million cubic meters produced (350 million barrels) of which approx 10 -15% is from basement or 5.5 million cubic meters (35 million barrels)
- These production numbers are very approximate, this author is trying to obtain more specific & reliable production data

BRAZIL: Carmopolis Basement Oil Field, Sergipe Sub-Basin

- Oil is of a mixed base ranging from 24 to 30.5 degrees API

- Depth range of all reservoirs is a shallow 400 – 800 meters depth

- *This author is seeking more published data on this field about the basement reservoirs in Carmopolis*

SUMMARY: Best Practices for Exploring and Producing Basement Reservoirs

- 1.) Look for oil in basement beneath existing oil fields, e.g. La Paz basement was found 30 years after discovery of oil in overlying Cretaceous sediments.

- 2.) Wells should not just "tag" into the top of basement but must penetrate basement 100 – 200 meters.

- 3.) Basement should be targetted using 3D seismic like CGGVeritas' CBM (controlled beam migration).

- 4.) Wells should not be drilled vertical but rather should be high angle wells drilled perpendicular to the dominant fracture patterns.

SUMMARY: Best Practices for Exploring and Producing Basement Reservoirs

- 5.) Basement needs to be cored to provide critically important reservoir data; with most basement reservoirs the oil is stored only in the fractures and the basement itself is tight, however weathered zones at the top of basement can be excellent oil and gas reservoirs.

- 6.) Initial wells need to be extensively tested to be sure that there is not a situation of very high IP but then followed by a rapid decline; testing may also point out to the existence of unrecognized water-bearing fracture systems.

SUMMARY: Best Practices for Exploring and Producing Basement Reservoirs

- 7.) Some of these fields can be complicated. They may have early water breakthrough, rapid production decline, very questionable reserves. For example, this author's initial experience was in 1982 with the Beruk NE basement oil field in Sumatra which watered out after producing only 2 million barrels oil. Lesson learned was that you must do extensive fracture analysis based on well data and seismic. For example, differentiate between fractures which conduct oil or gas or water and those which are non-transmissable. You may need to out-source this work to "experts" to get second opinions about your basement field.

- 8.) BUT, highly prolific basement oil and gas fields worldwide such as Bach Ho (Viet Nam), Suban (Indonesia), La Paz (Venezuela) and such fields in Libya, Egypt, Russia, and China serve as a reminder: ***do not forget your basement!***

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