[PS]Global Accumulations of Oil and Gas in Fractured and Weathered Basement: Best Practices for Exploration and Production*

Tako Koning[1]

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[1]Gaffney, Cline & Associates, Luanda, Angola (tako.koning@gaffney-cline.com)

Abstract

Fractured and weathered basement rocks are important oil and gas reservoirs in various basins world-wide. This author has followed this subject very closely for over thirty years and hereby shares his knowledge and experience. This paper focuses on important oil and gas fields in Indonesia, Viet Nam, China, and Venezuela and explains how these fields were eventually discovered despite their complicated geology. Also reviewed is how the operators of these fields are able to efficiently and economically produce oil and gas from the basement reservoirs. 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 and reservoir engineers 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 granitic basement were typically drilled 500 meters into the basement. Similarly exploration wells should penetrate at least 100 meters into basement rather than just barely penetrate the top of 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.

Global Accumulations of Oil & Gas in Fractured and Weathered Basement: Best Practices for Exploration & Production

Gaffney, Cline & Associates

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Poster Presentation to the AAPG 2014 International Conference & Exhibition
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Tako Koning
Senior Petroleum Geologist
Gaffney, Cline & Associates
Luanda, Angola

Global Accumulations of Oil & Gas in Basement Reservoirs

- **ASIA:** ***Viet Nam*** -Bach Ho oil field, CNV oil field, China "buried hill" oil fields, ***Indonesia*** - Suban gas field, Tanjung oil field, Beruk NE oil pool
- **EUROPE:** ***U.K.*** - Lancaster oil field, North Sea, ***Russia*** Siberian oil fields, ***Norway*** - Luno
- **MIDDLE EAST:** ***Yemen, Libya, Egypt*** - Gulf of Suez
- **AFRICA:** ***Libya, Algeria, Angola*** - onshore Cabinda
- **NORTH AMERICA:** ***Kansas, Texas, California***
- **SOUTH AMERICA:** ***Venezuela*** - La Paz oil field, ***Brazil*** - onshore Carmopolis oil field

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"*.

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

Preference Scale for Reservoir Rocks for Oil & Gas in Basement – Need *Brittle* Rocks

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

Potential of Gneisses & Schists as Basement Reservoirs

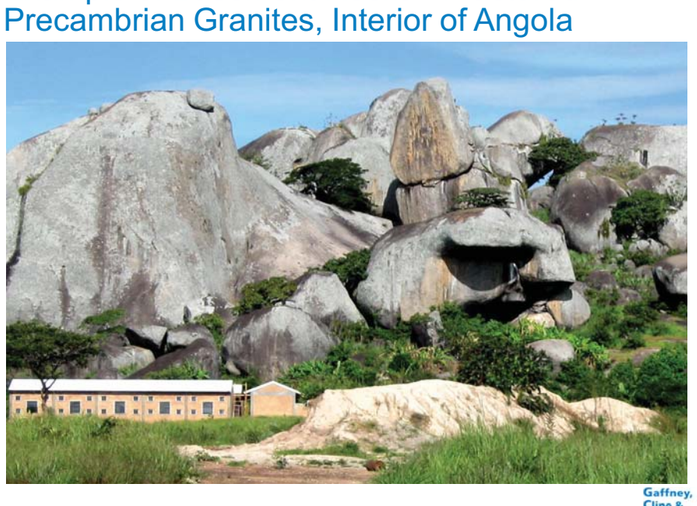
- **Gneisses:** a foliated metamorphic rocks corresponding in composition to granite or feldspathic plutonic rocks

  Problem: can be massive or dense or slabby with open fractures parallel to the direction of foliation; 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

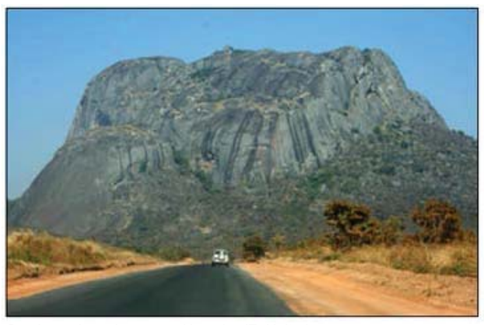
Example of Basement Rocks - Fractured Precambrian Granites, Interior of Angola



Fractured Precambrian Granite – Left Half of Outcrop is an Example of a *Fracture Corridor*, Interior of Angola

Fractured Precambrian Granite – Detail of the *Fracture Corridor*, Interior of Angola

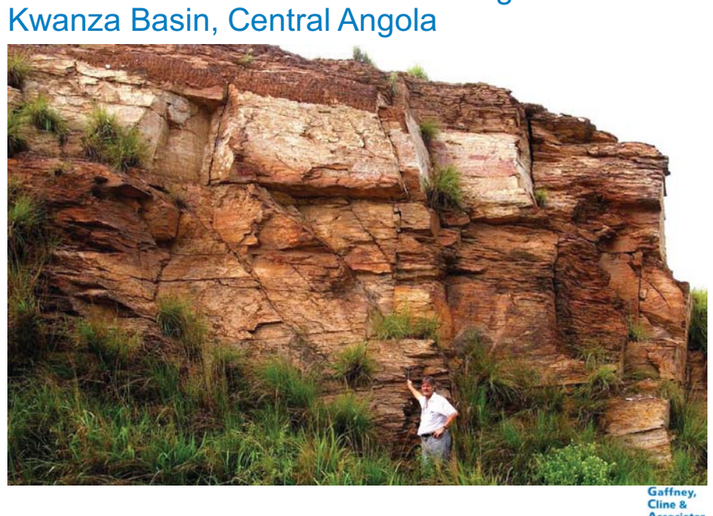
Fractured Precambrian granite – vertical fractures, interior of Angola



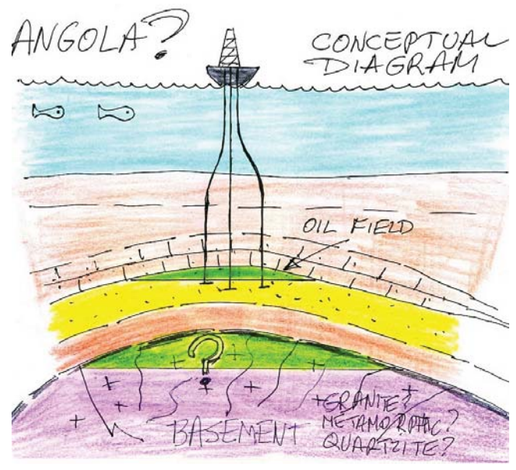
Granite rock on the way to Huambo (E. Holtar)

Source: Statoil

Fractured Gneisses – Eastern Margin of Kwanza Basin, Central Angola



Sketch Diagram of an Untested Basement High, an Example from Angola



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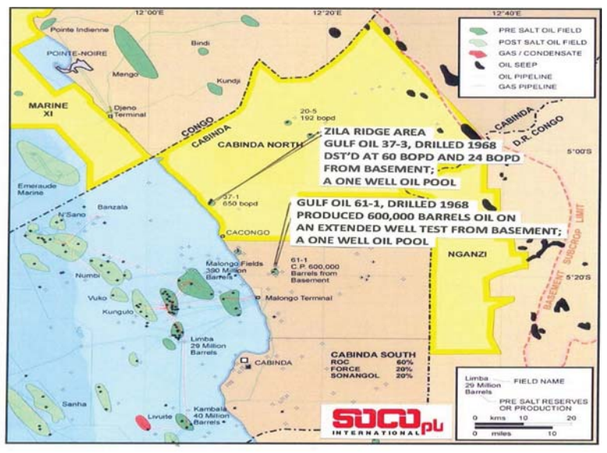
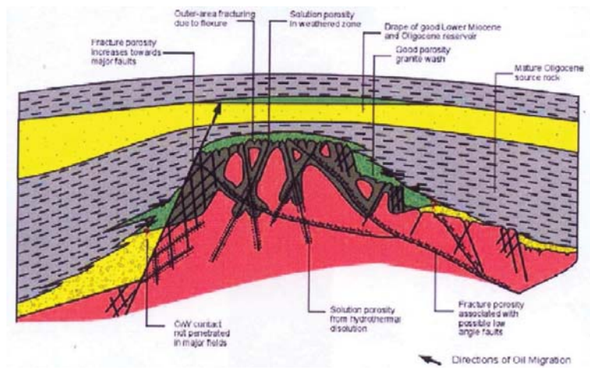
ANGOLA – Onshore Cabinda Basement Oil Pools



Modified after Soco International website 2005

Bach Ho – (White Tiger) Fractured Precambrian Basement Oil Field, Viet Nam



Two-dimensional model of the play concept for the Cuu Long basin.

From- Huang & Lee, Huang JV JOC, AAPG 2004

Bach Ho Fractured Precambrian Basement Oil Field, Viet Nam

- Giant oil field with reported estimated recoverable oil of 1.0 – 1.4 billion barrels
- Discovered by Mobil in 1975, oil found was in Oligocene sediments
- 1988 Vietsovpetro found oil in fractured granite basement
- Oil production peaked at 280,000 BOPD in 2005
- 2009 production down to 125,000 BOPD and declining 20,000 BOPD between 2009 & 2014
- Oil is 90% from basement and 10% from Oligocene sediments

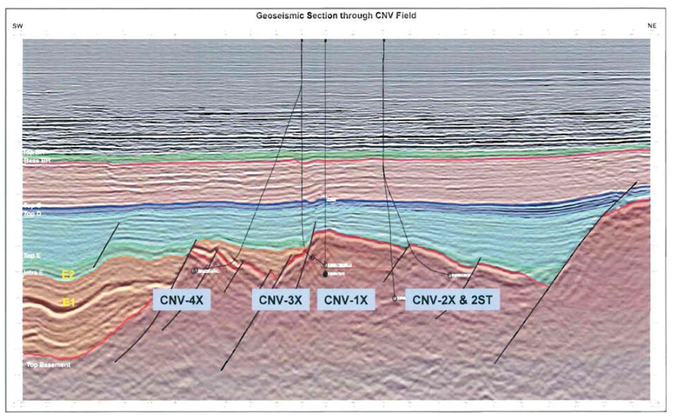
Bach Ho Oil Field: Lessons Learned for Exploration in Asia & Elsewhere

- Most fractures inside basement are high dip angles (40- 75 degrees)
- Matrix porosity in the granite is negligible
- Oil stored in macrofractures, microfractures and vuggy pores in fractures
- Porosity in fractures is only 2 – 3% but permiabilities are good to excellent at ten to thousands millidarcies MD
- **Flow rates of up to 14,000 BOPD**
- **Giant reserves due to up to 1,500 meters of oil column**

CNV Basement Oil Field in Viet Nam – Success by SOCO – Well CNV-3X Tested at 13,040 BOEPD from Fractured Granite

Information from SOCO International Website 2005 & 2006

CNV Basement Oil Field, Viet Nam, Seismic Line Over Basement Structures



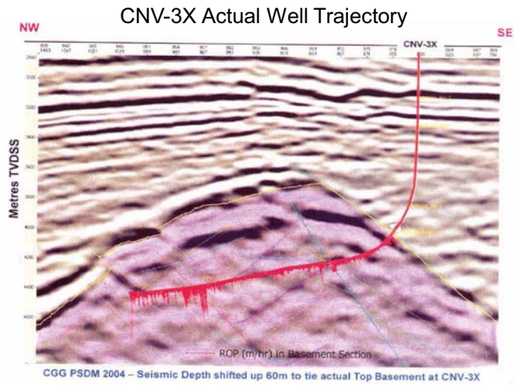
Source: SOCO International Plc.

Viet Nam – Outcrop of Fractured Basement

from SOCO website 2005

CNV Basement Oil Field – Longest Measured Depth Well Drilled in Viet Nam at 6,123m With Over 2,000m in Granite

CNV-3X Actual Well Trajectory

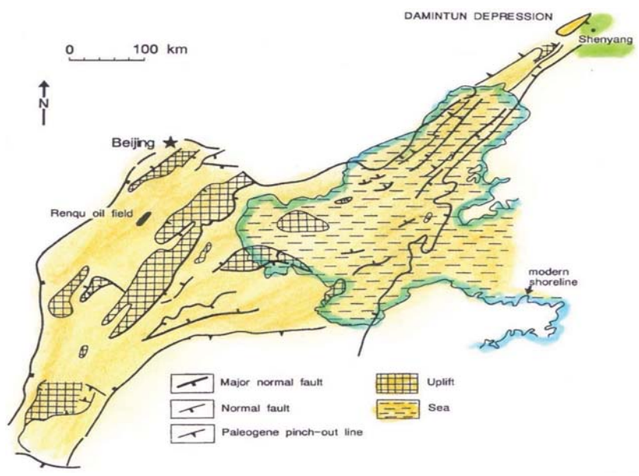


CGG PSDM 2004 – Seismic Depth shifted up 60m to tie actual Top Basement at CNV-3X

Source: SOCO International Plc.

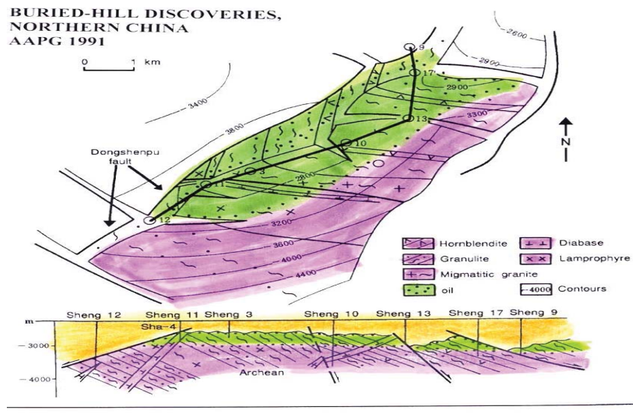
CGGVeritas Seismic Processing (CBM) in Fractured Granite Reservoirs, Viet Nam Which Highlights Fractures in Basement

Chinese "Buried Hill" Basement Oil Fields – North China Basin



From: Tong XiaoGuang & Huang Zuang, 1991, AAPG

Chinese "Buried Hill" Basement Oil Fields



Lithological characteristics of the Dongshenpu buried hill. This field was discovered in 1983 with Sheng-3 which tested at 1,570 BOPD and 0.5 MMCFGPD from Archean metamorphics. The buried hill consists of biotite-plagioclase granulite and granitic migmatite. The metamorphic rocks do not have original porosity but have secondary porosity and fracture porosity. As shown above, the oil column is about 400 meters thick. From: Tong XiaoGuang & Huang Zuan (1991).

Chinese "Buried Hill" Oil Fields
(information in AAPG paper by Guang & Zuan, 1991)

- Dangshenpu buried hill oil field found in 1983
- Discovery well tested at 1,570 BOPD and O.5 MMCFG/D
- Reservoir rock are PreCambrian in age and are mainly migmatic granite, granulite, diabase, hornblende
- Rocks had no primary porosity but have secondary weathering and fracture porosity
- **Oil column is 400 meters thick**
- **Estimated reserves of 190 MMbls oil**

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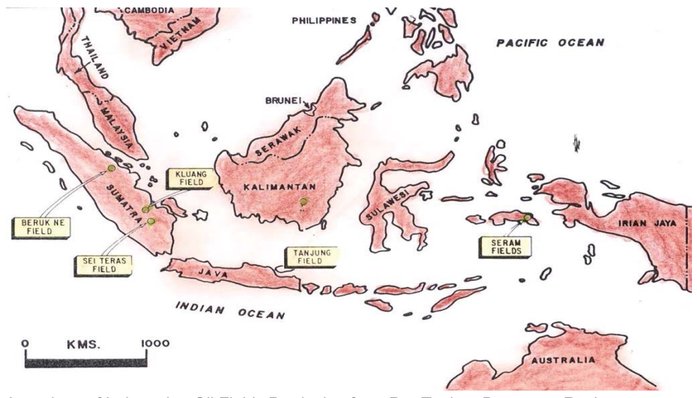
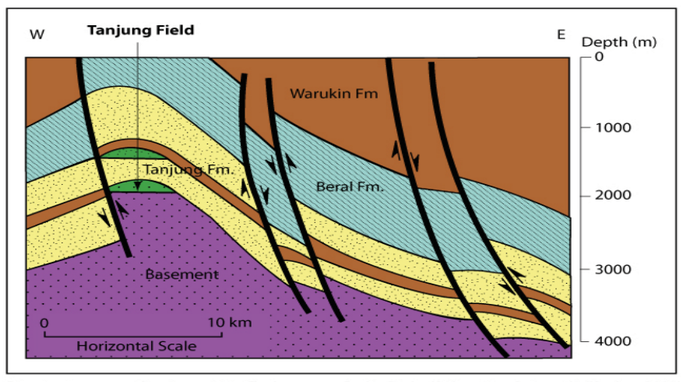
Locations of Tanjung Oil Field, Kalimantan, Beruk NE Oil Pool, Sumatra & Suban – Sei Teras Gas Field, Sumatra



Locations of Indonesian Oil Fields Producing from Pre-Tertiary Basement Rocks

Tanjung Oil Field, Kalimantan, Indonesia



Structural cross-section through the Tanjung area, Barito Basin, Kalimantan, Indonesia (Koning, 2000)

In the **Tanjung oil field**, approximately 21 million barrels of oil has been produced from Pre-Tertiary basement rocks. Fractured and locally weathered volcanic rocks, pyroclastics and metasediments are the dominant basement lithologies. Approximately 74 million barrels of oil has been produced from the overlying Eocene sandstones and conglomerates.

Suban Gas Field, South Sumatra Gas Reserves of Approx 7 TCF

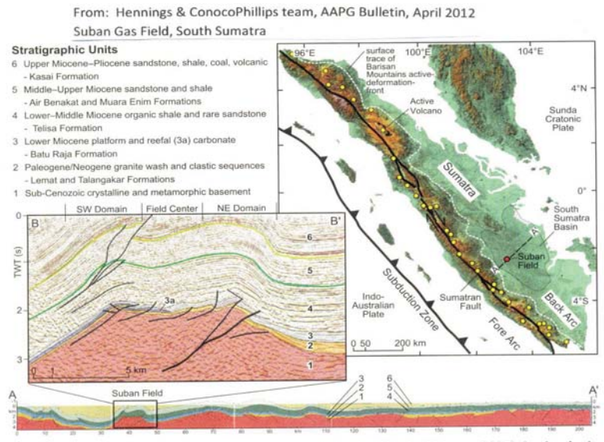
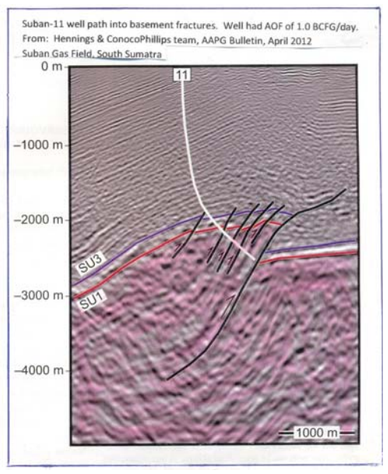
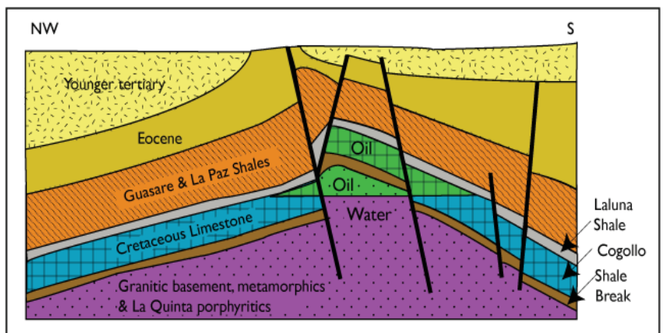


Figure 1. Tectonic setting, regional structural configuration, and simplified stratigraphic units of Suban gas field. The location of regional seismic cross section AA' is shown in the inset map. The location of field-specific cross section BB' is shown in Figure 2. TWT = two-way traveltime.

Suban Gas Field, South Sumatra 7 TCFG in Fractured Granite & Quartzite



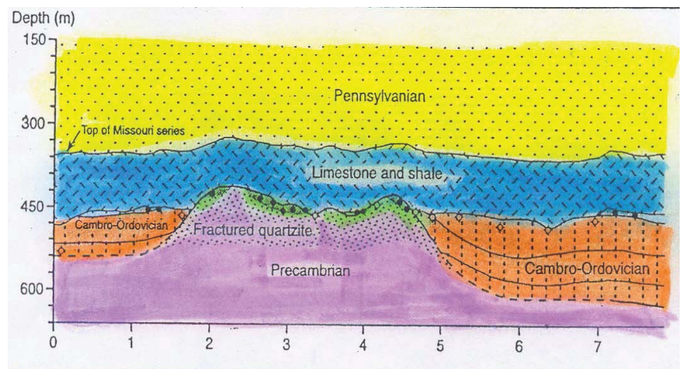
La Paz Oil Field, Venezuela



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.

From: Lands & all, 1960 AAPG

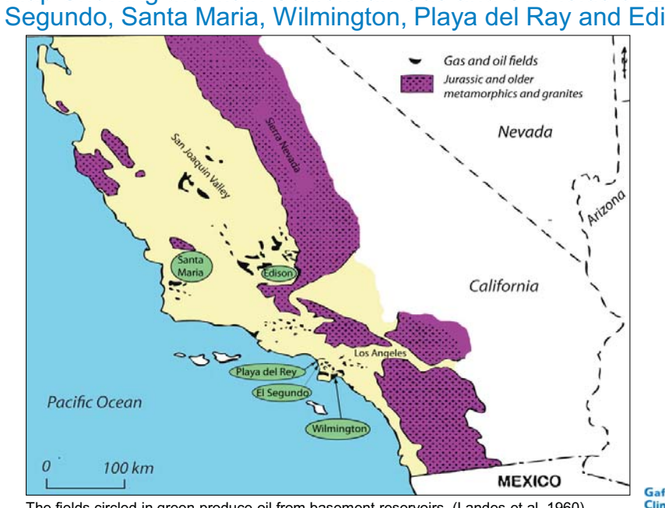
Kansas, USA – Precambrian Fractured Quartzite Buried Hill Basement Oil Pools



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 cks. (Landes *et al*, 1960).

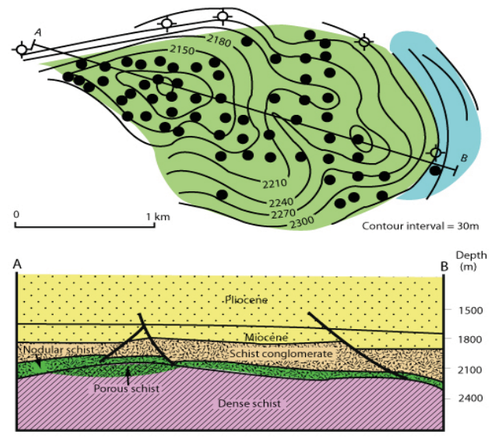
From: Lands & all, 1960, AAPG

Map Showing the Main Californian Gas and Oil Fields of El Segundo, Santa Maria, Wilmington, Playa del Ray and Edison



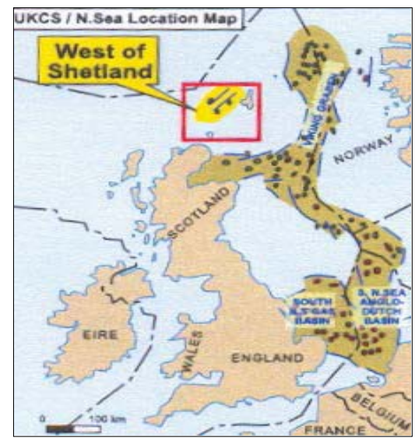
The fields circled in green produce oil from basement reservoirs. (Landes et al. 1960)

El Segundo Basement Schist Oil Field, Southern California



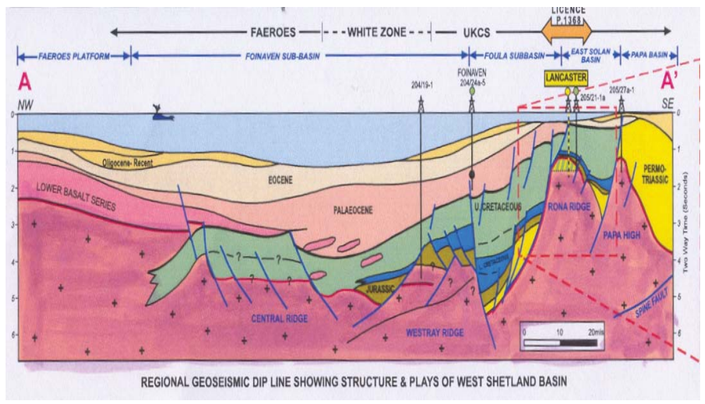
Cross-section through the El Segundo field, California. The reservoir is in fractured Jurassic schists in the west and schist and conglomerate in the east. The average depth of the oil basement production is 2300 m. (Landes et al. 1960).

Hurricane Exploration PLC – Lancaster Basement Oil Discovery – West of Shetlands, UK North Sea,



From: Hurricane website

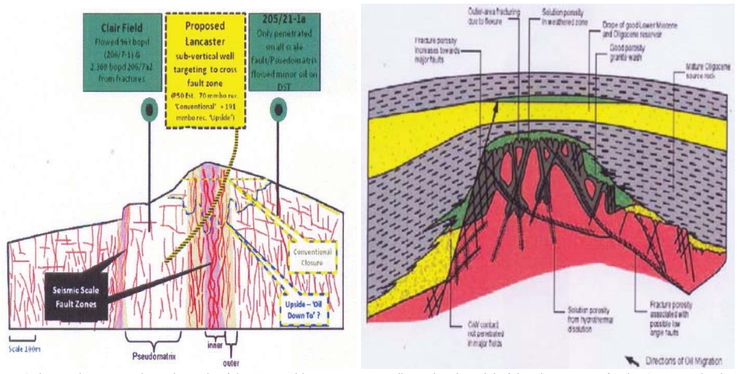
Hurricane Exploration PLC – Lancaster Basement Oil Discovery – West of Shetlands, UK North Sea



REGIONAL GEOSEISMIC DIP LINE SHOWING STRUCTURE & PLAYS OF WEST SHETLAND BASIN

200 MMboe 2C Contingent Resources @Hurricane website & press releases

Lancaster UK Basement Structure vis-a-vis Bach Ho (White Tiger) Basement Structure



Orthogonal cross section schematic of the Rona Ridge fracture porosity

Two-dimensional model of the play concept for the Cuu Long basin

From: Huang & Lee, 2004, AAPG; Hurricane website

Best Practices - Lessons Learned!!!

- Look for "profound" basement structures like Bach Ho (Viet Nam), Tanjung (Indonesia), La Paz (Venezuela), Lancaster (UK North Sea).
- Look for oil in basement beneath existing oil and gas fields – "the best place to find oil is where oil has been already found".
- Look for optimum basement rock types like granites or quartzites
- Drill 200 meters into basement, don't just "tag" into it. Also drill perpendicular to the fractures, don't drill parallel to the fractures.

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