

Petroleum Exploration Potential of Abu Gabra Formation in Fula Sub-Basin, Muglad Basin, Sudan*

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Search and Discovery Article #10912 (2017)**

Posted July 3, 2017

*Adapted from oral presentation given at AAPG/SPE Africa Energy and Technology Conference, Nairobi City, Kenya, December 5-7, 2016

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Abstract

The Fula sub-basin is a rift structure with units rich in petroleum accumulation within the Muglad Basin. In the past, thick sandstones of Bentiu were considered the main petroleum accumulation targets sealed by faults and anticlines, and most petroleum generated by the Abu Gabra Formation source kitchen migrated to the upper formations along big faults, and sandstones within the Abu Gabra are thin with poor permeability and porosity caused by compaction. Recently, some works have been done especially on the Abu Gabra Formation, including interpretation of small faults, seismic sedimentary analysis, and thin layer inversion, resulting in new petroleum discoveries within the Middle Abu Gabra, which reveals good petroleum accumulation abilities.

Comprehensive study shows that there are many small faults developed within the Abu Gabra, which could seal sandstones laterally and forming effective faulted blocks. Sandstones of delta and sub-water channels could be found. Within the AG4 and AG2 formations, there are mainly lacustrine facies. As the channel sandstones regressed, the area of alluvium fans decreased. The Abu Gabra shale has high organic matter abundance, high hydrocarbon generating potential and kerogen type I, II with middle to high maturity. Although sandstones of the Abu Gabra have relatively low permeability and porosity, these sandstones have good logging response on hydrocarbon could be sealed by local surrounding mudstones. All the above reveals that the Abu Gabra combination is a near-source reservoir combination. Low-amplitude anticline and structure-lithology reservoir models are favorite reservoir models in the Fula sub-basin. In the west slope, especially the lower places of the slope, are areas of huge

sedimentary accumulation and should be favorite prospects. As for the east slope, low-amplitude anticlines bounded by small faults that developed during Abu Gabra deposition should be a favorite area for exploration, which has been proved by successful drilling activities. In the Fula sub-basin, the Abu Gabra structure-lithology complex reservoir combination should be the favorite type for drilling as per under these two key factors, the petroleum could be well accumulated. Currently, there have been two important petroleum discoveries of channel sandstones and delta sheet sandstones in the Abu Gabra, proving that the Abu Gabra still has good potential for drilling.

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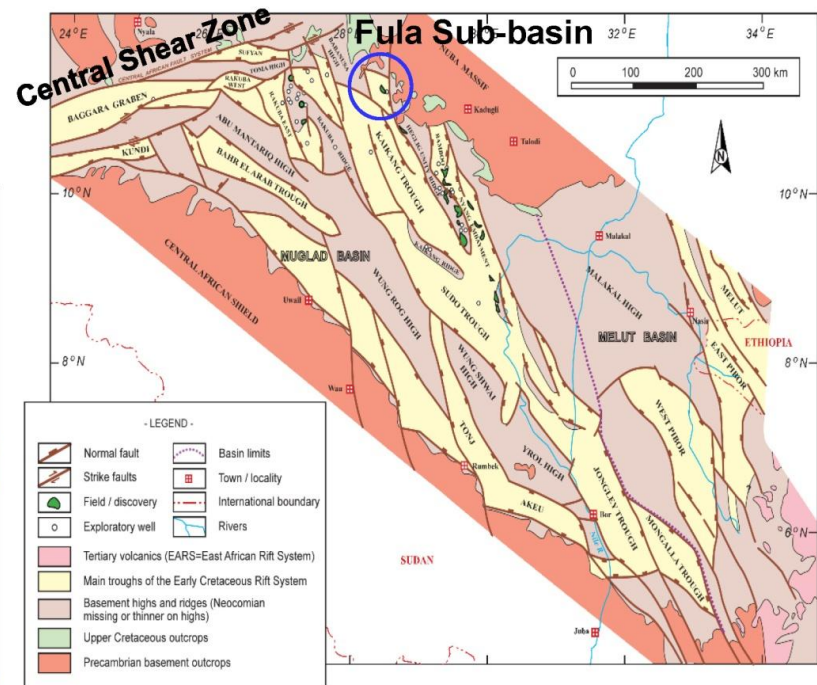
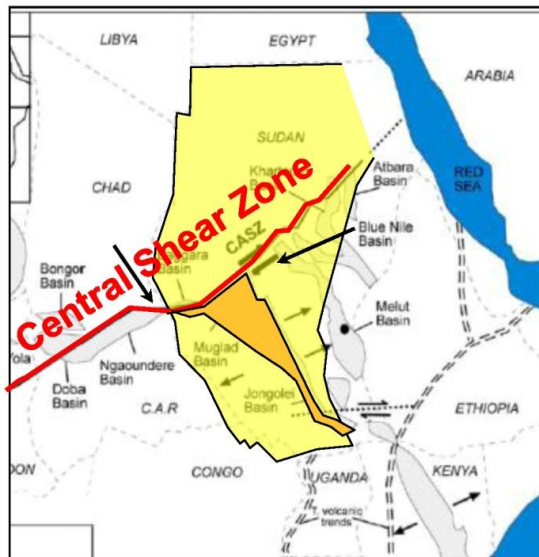
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1. **General Background**
2. **New Discoveries inside Abu Gabra**
3. **Discussions**

1. Regional Geological Background

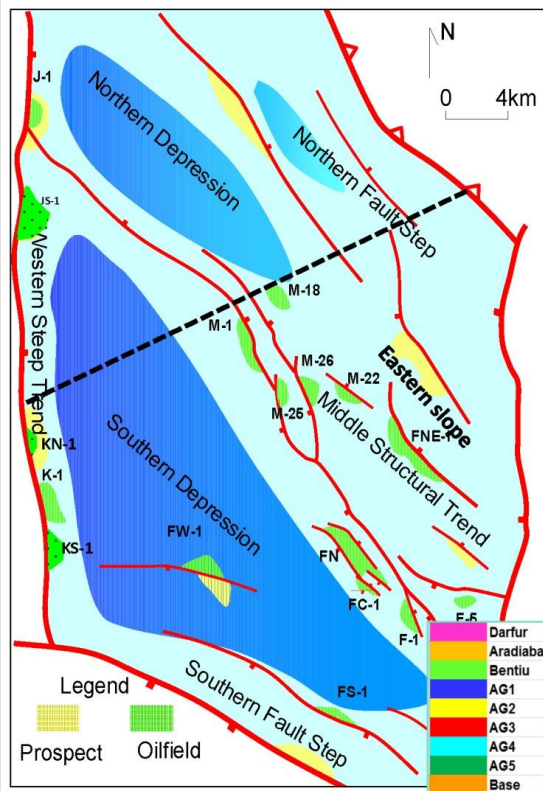
- Muglad basin is one of the Cretaceous-Tertiary rifts related to the Central African Shear Zone (CASZ)
- Fula sub-basin is in the north area with area of 3300 km²

Structure Schema of Muglad Basin (IHS, 2009)

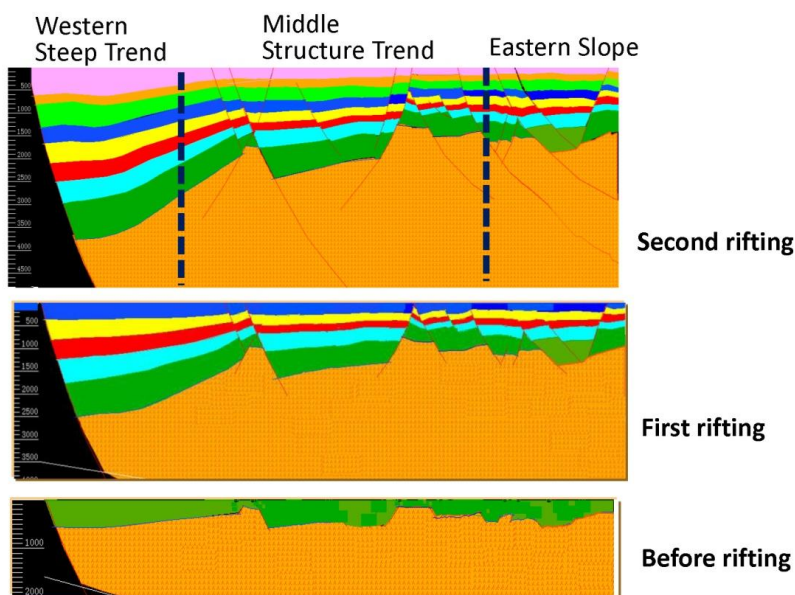


Presenter's notes: Muglad Basin is located in Sudan, middle-north part of Africa. It formed by the extensional movement of dextral shear stress controlled by Central African Shear Zone.

Structure Units of Fula Sub-basin

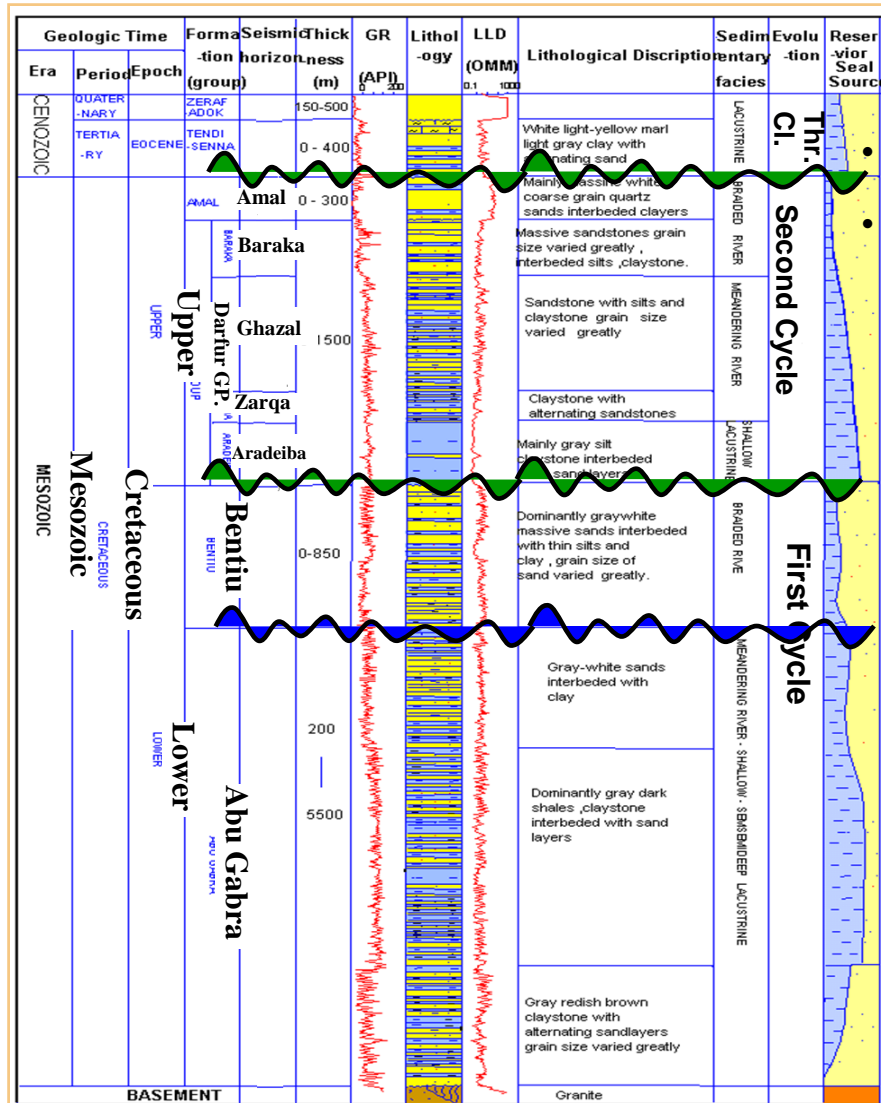


- The sub-basin has feature of overlap in the east slop area and fault-depression in the west.
- Suffered several rifting stages with stable uplifting and depressing.



Presenter's notes: The tectonic evolution of the Basin can be divided into three phases: early initial chasmic phase of early Cretaceous, successive chasmic phase from early Cretaceous to late Cretaceous, and Cenozoic depression phase. The Basin has experienced three large rifting movements and three thermal subsidence depression movements of post-rift phase, of which the deposition period of Abu Gabra Formation corresponds to the movement period of initial rift structure.

Stratigraphy Chart



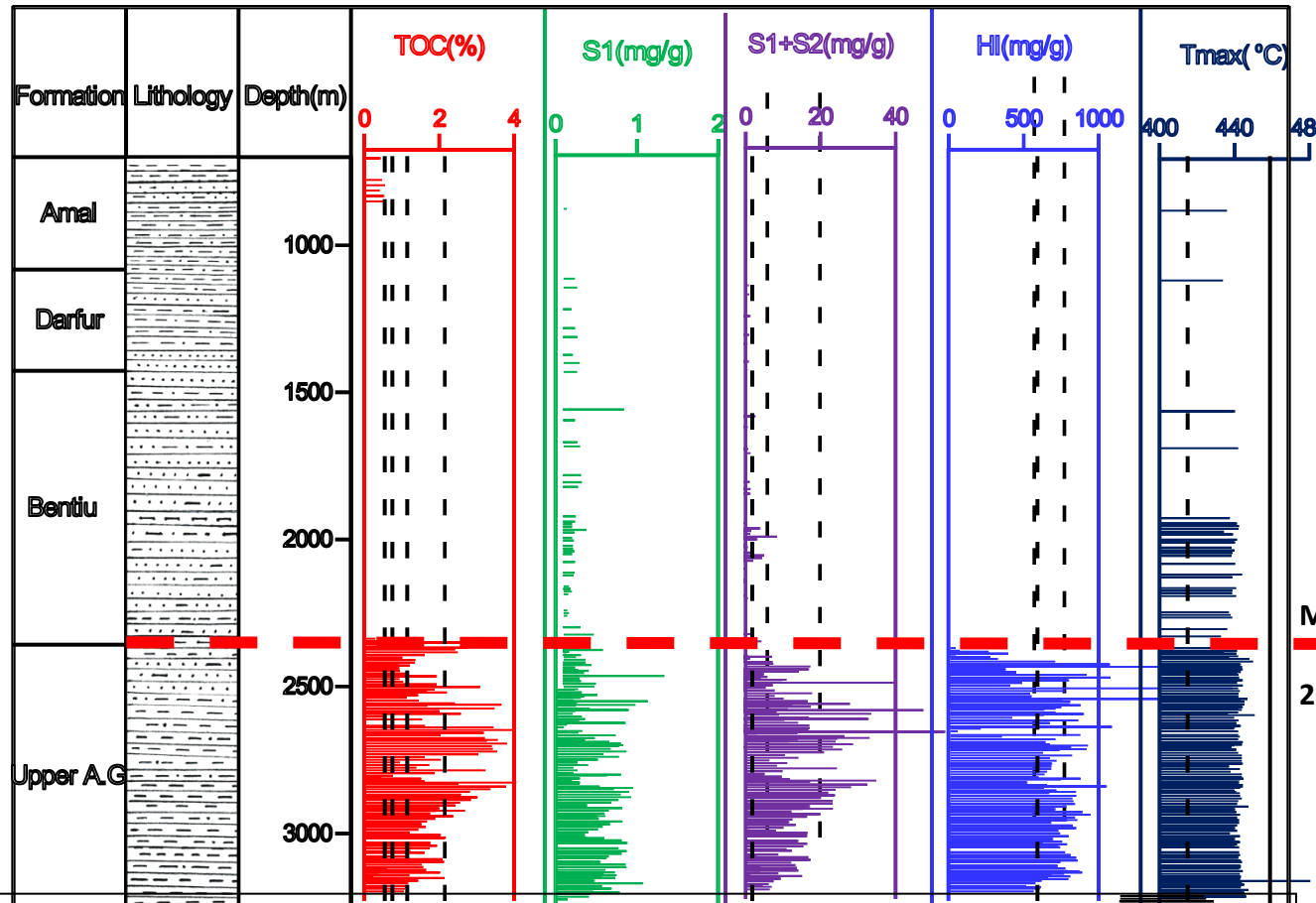
Clastic, Non-marine sediments

Fluvial and lacustrine system

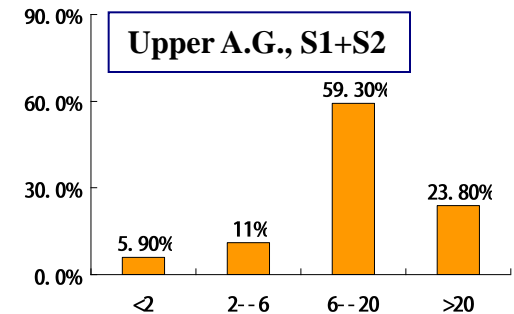
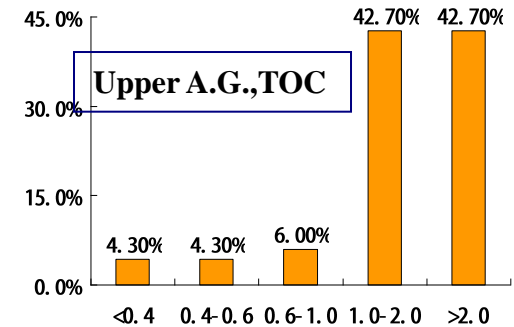
Formation	Feature	Facies	Micro-facies	Type
Aradeiba	very fine-fine grain, minor medium grain, subround-round, moderately sorted, quartz,	Semi-lake	delta sandstone	Main Reservoir
Bentiu	medium-coarse grain, trace very coarse grain, subangular subround, trace angular, moderately sorted, quartz, trace angular matrix,	braided river sandstone	Channel sandstone	Main Reservoir
Abu Gabra	Olive grey-olive block, hard-moderate hard, trace sub-black, brittle, interbedded with claystone: medium grey, minor medium dark grey, moderate hard-hard,	delta or semi-lake	Sheet sandstone of delta	Main Source Rock

Modified by Ke, 2014

The Rock-Eval Profile of Well B-1

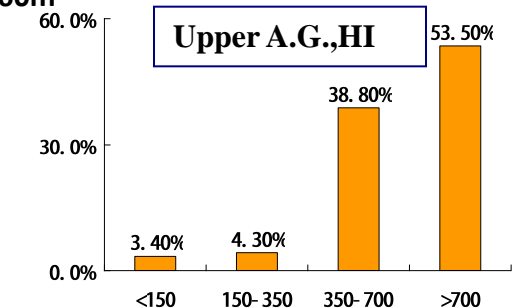


There develops good-excellent source rocks in Abu Gabra shale and oil shale with kerogen type I ~ II₁, their TOC are up to 3.29% with moderate maturity, and their threshold depth is 2100m.



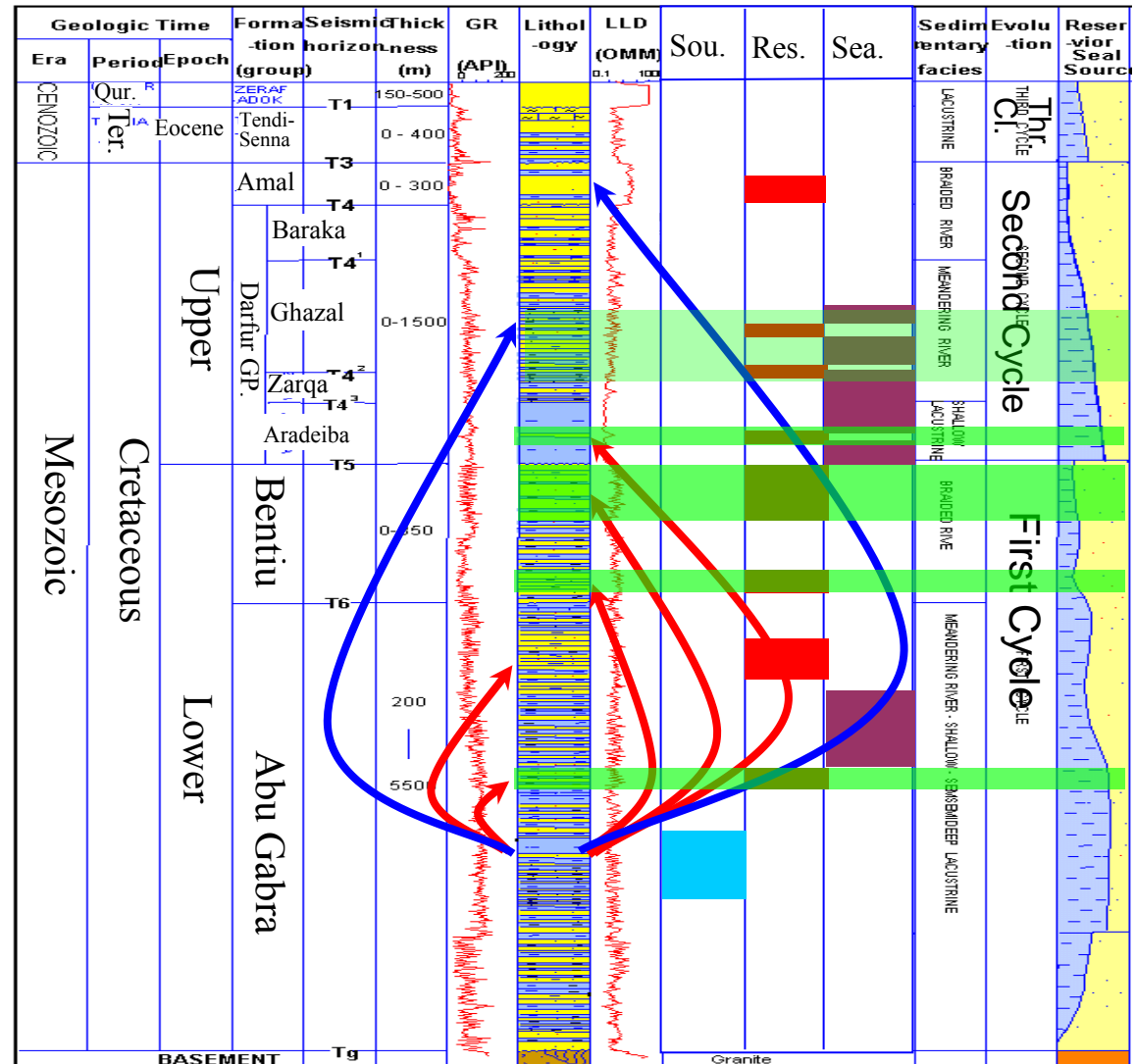
Mature depth

2360m



Petroleum System

- Darfur system(in source)
- Bentiu system(migrated into)
- Abu Graba system(in source)
- Bentiu system: thick and almost 55% reserve
- Darfur: thin and 15% reserve
- Abu Gabra: thin but many layers, 15% reserve
- More hydrocarbon potential exists and yet to be discovered



Main Discoveries

Greater Fula OF

(3D/75wells)

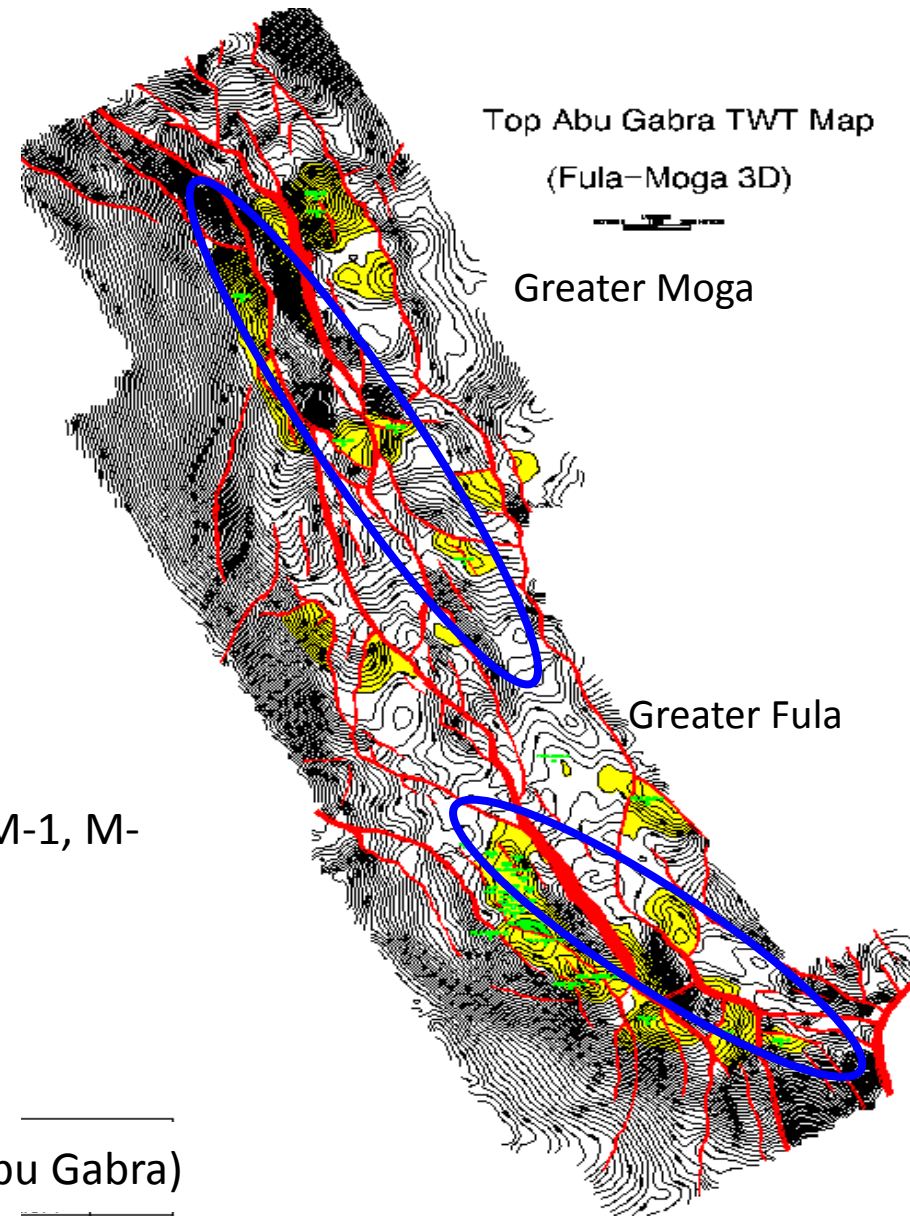
- Fula North oilfield
- Fula Central oilfield
- Fula oilfield

Greater Moga OF

(3D/35wells)

8 oil-bearing Blocks: M-1, M-2, M-21,

(Reservoir: mainly Aradeiba, Bentiu and upper Abu Gabra)





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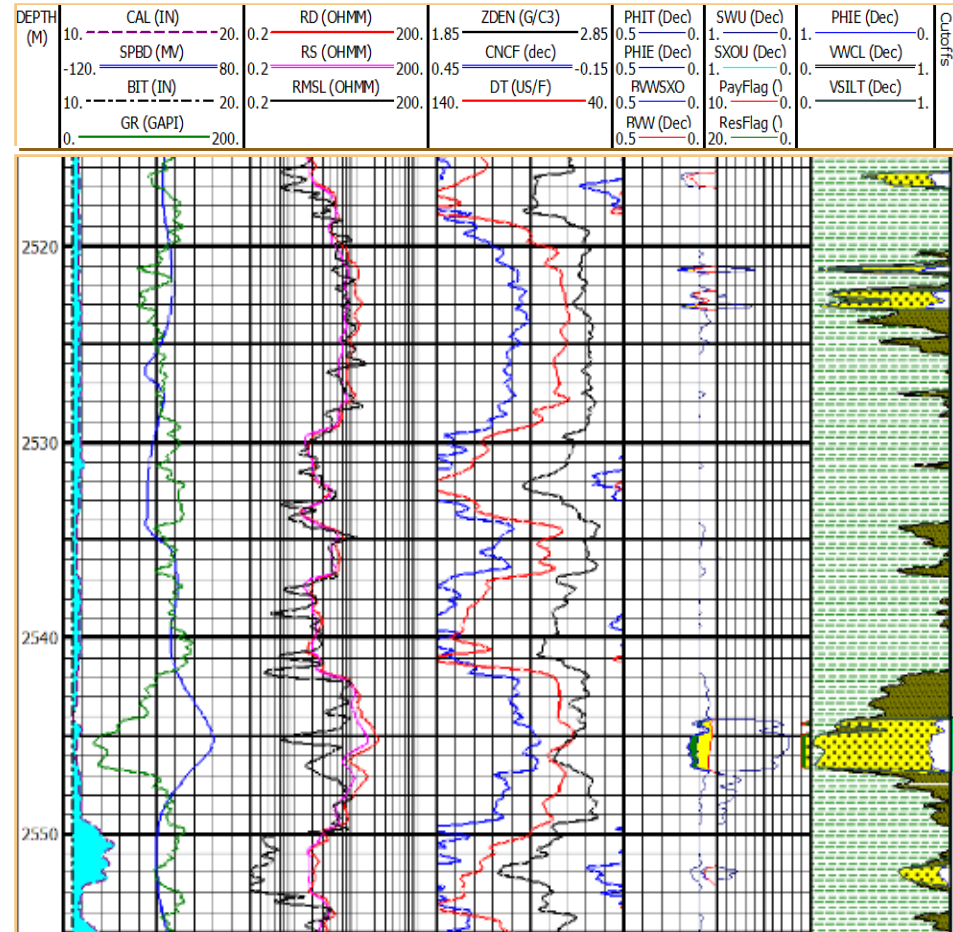
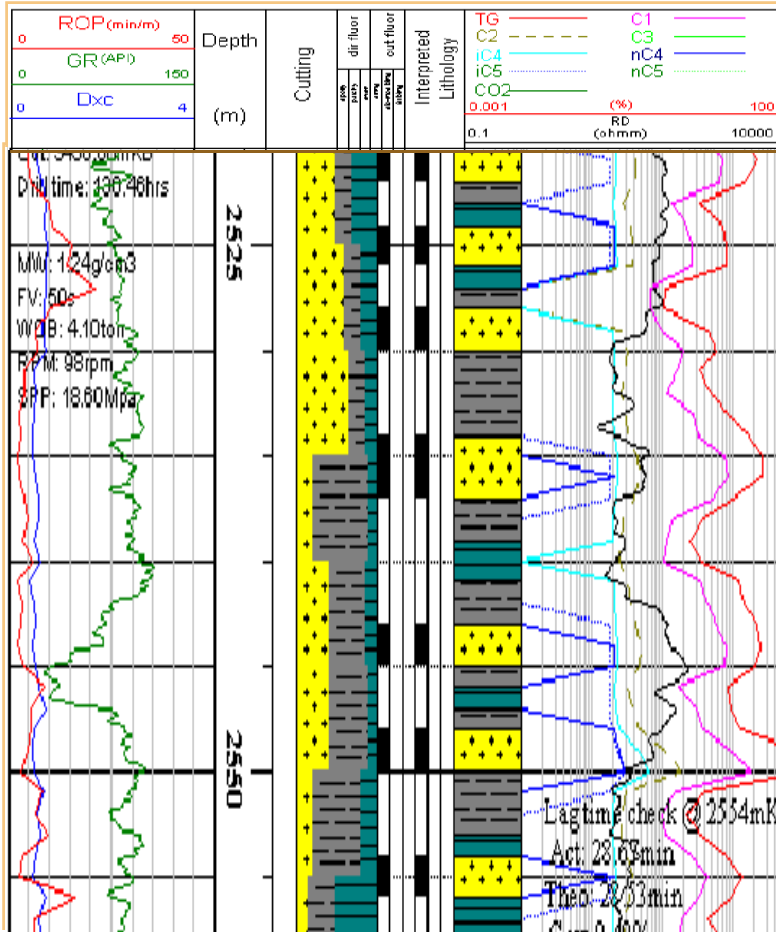
Society of Petroleum Engineers

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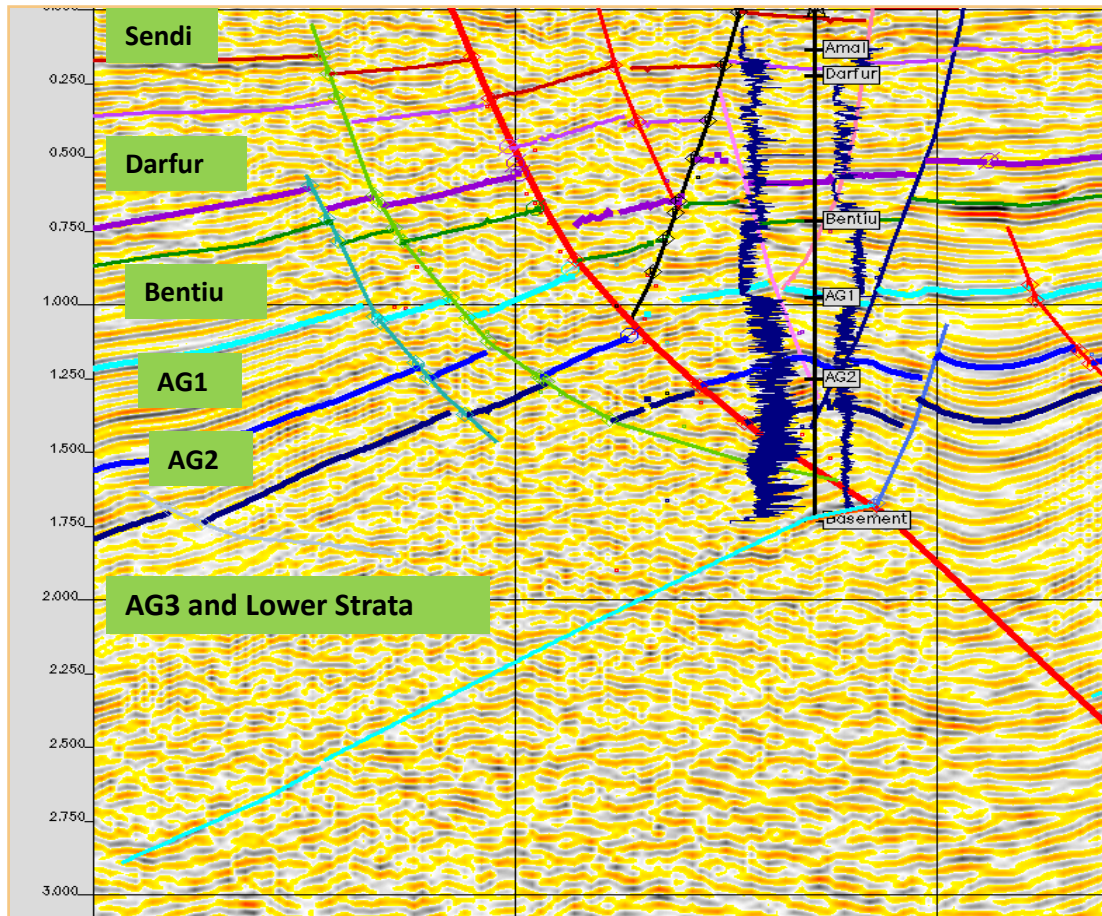
1. General Background
2. New Discoveries inside Abu Gabra
3. Discussions

- **Why Abu Gabra sandstone reservoir is ignored before?**
 - Thin from 2 to 3 meters with fine and middle grains
 - Low porosity and permeability in well-logging interpretation
 - Seismic data quality led to bad structure description
 - Hydrocarbon mostly migrated into upper Bentiu sandstones reservoir
 - Reserves discovered to-date are modest and low economic value
 - Abu Gabra drilling costs higher

- Thin, fine-to-medium-grained sandstone beds (2-3 m)
- Low porosity and permeability in well-logging interpretation



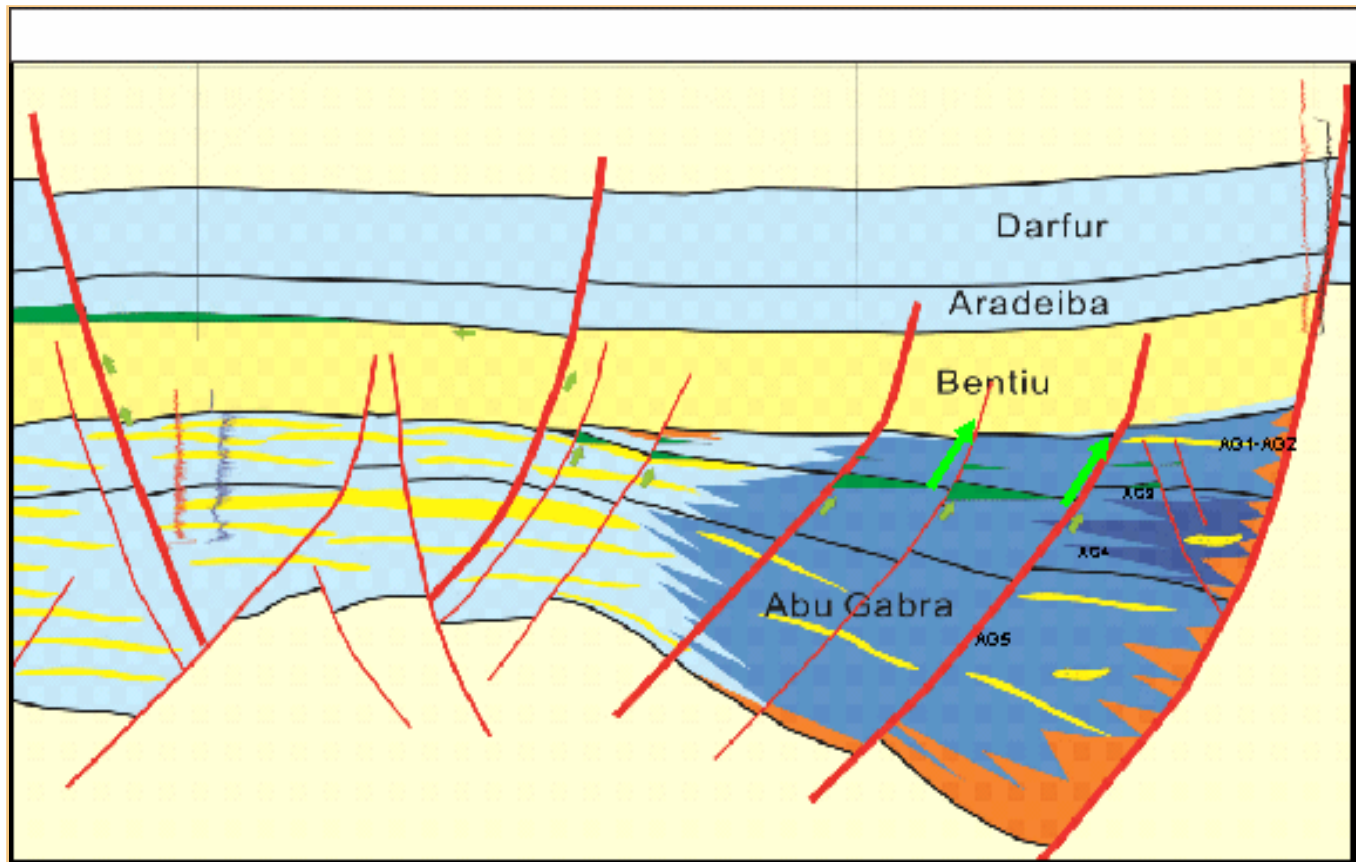
- Seismic data quality led to poor structure identification**



From Sendi to Bentiu:
Quality is good to fair,
easy to identify accurate
structure features like
anticlines, faulted blocks

From AG to basement:
Quality is fair to poor,
hard to identify small
fault and get clear image
of structures

- Hydrocarbon mostly migrated into upper Bentiu sandstones reservoir
- Small reserves with low economic value expected in small leads

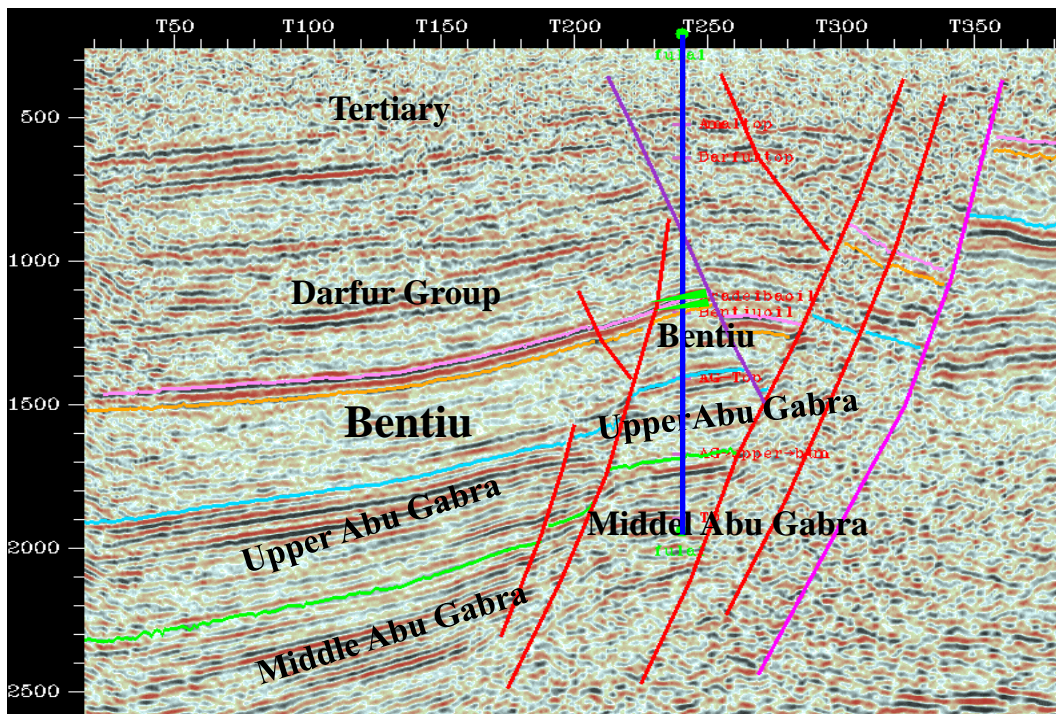


Referred from GNPDOC,2014

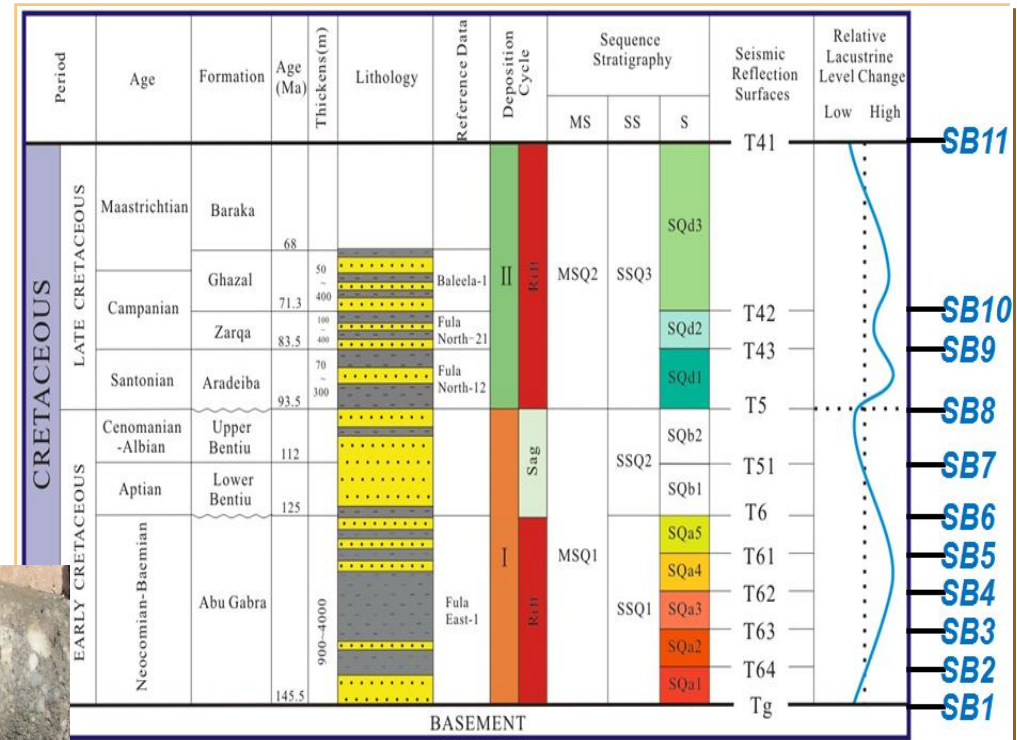
- **Why Abu Gabra sandstone reservoir is discovered now?**
 - New theory of hydrocarbon migration of source rock
 - Reprocessing on seismic data
 - Focused on fault interpretation at Abu Gabra level
 - Deep studies have been finished like inversion, sedimentary, cores analysis focused on AG formation
 - Business requires deeper exploration evaluation

Trap sealing mechanism

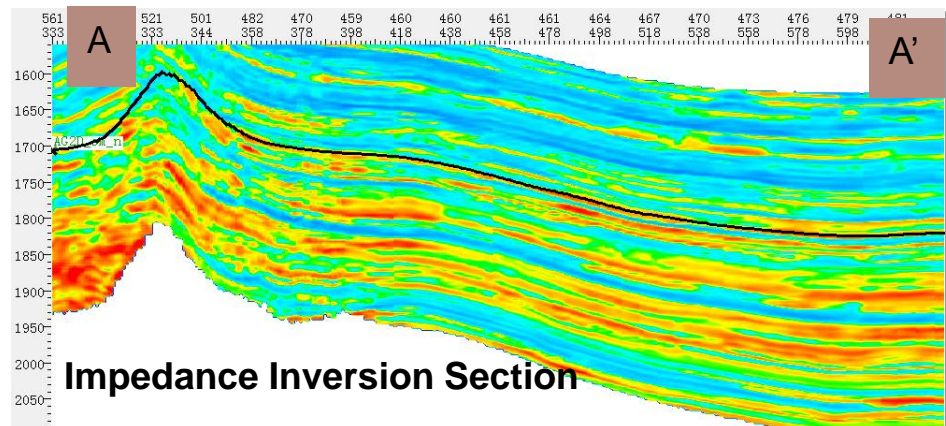
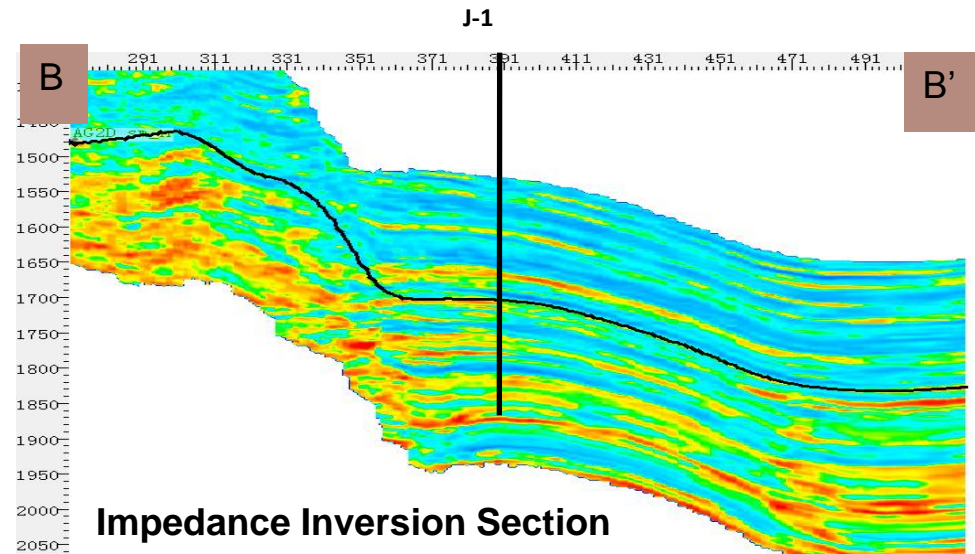
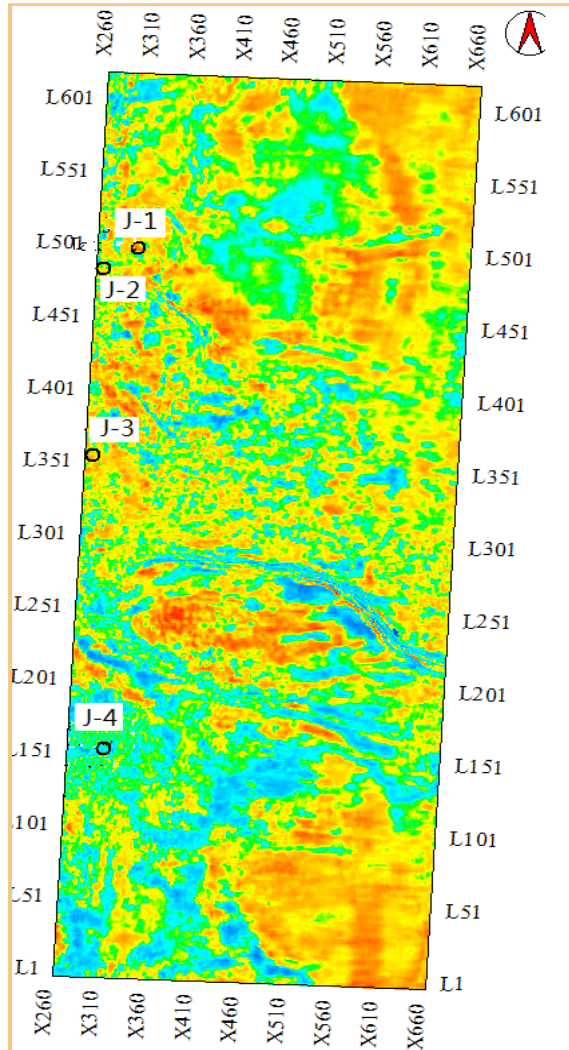
- Main types of faulted anticline
 - Antithetic fault block
 - Synthetic fault block
 - Complex fault block

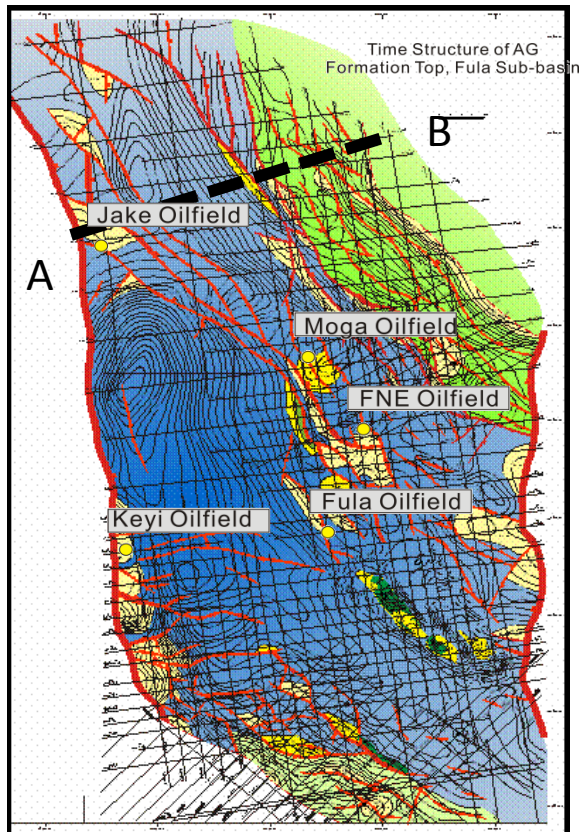


Class	Type	Sketch map	
Structural Trap	Anticline		
	Faulted Anticline		
	Antithetic Fault Block		
	Synthetic fault block		
	Complex Fault Block		
Stratigraphic Trap	Erosion		
	Overlap		



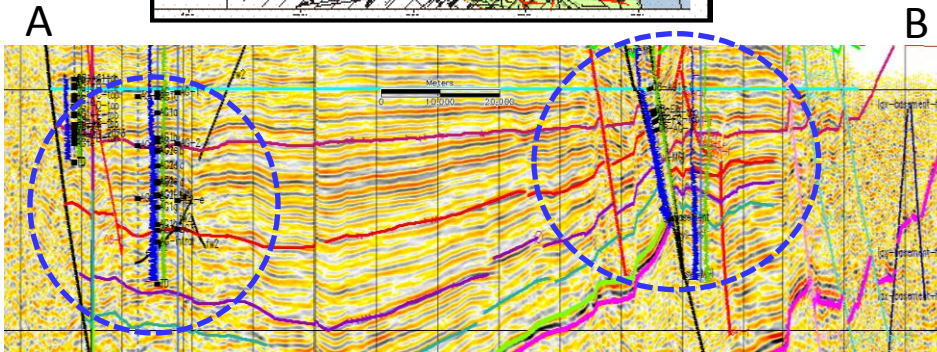
Inversion to predict effective sandstones of AG surrounded by lacustrine muds and deltaic deposits





In deeper areas of middle structure trend and west structure trend, there should develop more traps with hydrocarbon migrated and reserved locally, inside AG, the source rock formation

- Belt along boundary fault:
 - **Mainly develops** stratigraphy trap controlled by fault and strata wedge out
 - Low relief trap controlled by fault
- Middle structure belt(including break slope belt):
 - **Mainly develops** low relief trap controlled by fault
 - Stratigraphy trap controlled by strata wedge out



Several AG discoveries have been made at:

- **Jake Oilfield:** Middle and Upper AG formation, Faulted blocks, Jake E Oilfield, still more stratigraphy traps for drilling
- **Keyi Oilfield:** Middle and Upper AG formation, Faulted blocks, Keyi Oilfield, no stratigraphy traps
- **Moga Oilfield:** Upper to Lower AG formation, Possible great stratigraphy traps in the middle structure trend
- **Fula/FNE Oilfield:** Similar with Moga area

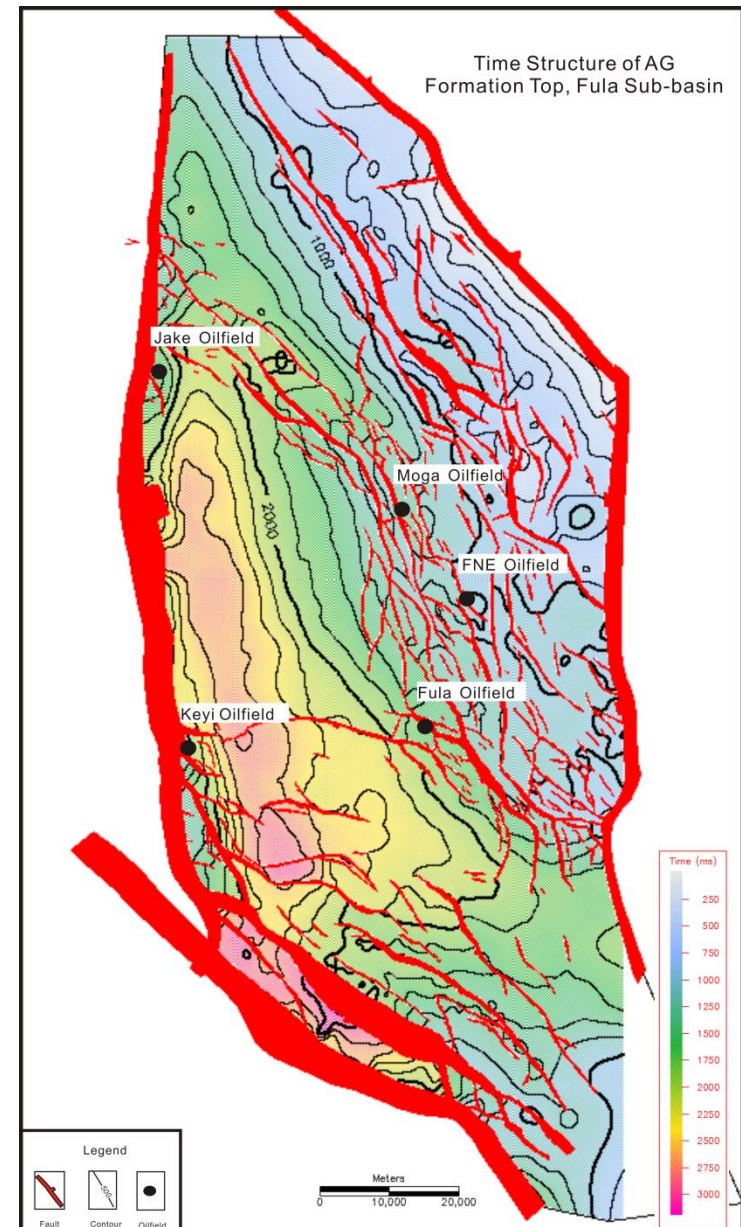


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Discussions

1. As main source rock formation, AG has great exploration potential
2. AG traps have variable seals along faults
3. For mature basins, deeper exploration is a good way to increase production
4. New ideas and technologies should be applied on mature basins
5. Open mind is needed for hydrocarbon explorers
6. Lacustrine rift basins are economic

**Thank for cooperation of the experts from
Petro-Energy E&P and RIPED, CNPC**

Thank You !

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