

PS Favorable Play Fairways for Abu Gabra Formation in Muglad Basin, Republic of Sudan*

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Search and Discovery Article #11024 (2017)**

Posted December 4, 2017

*Adapted from poster presentation given at AAPG/SEG 2017 International Conference and Exhibition, London, England, October 15-18, 2017

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Abstract

Muglad Basin is an intra-Craton passive rift basin related to the Central Africa Shear Zone (CASZ), which is located in the Southern-Central Republic of Sudan. Three rifting-sagging cycles were developed in the basin since early Cretaceous. The main targets in the basin are sands formed in the sagging stage, which were highly explored with limited potential remained. The first rifting sequence in the early Cretaceous Abu Gabra Formation is considered as the new play in the basin, while the favorable play fairways are unclear due to complicated sedimentary systems developed in the Abu Gabra period. Based on the analysis of more than 60,000 km of 2D seismic, 5,000 km² of 3D seismic data, and 200 wells data in the whole basin, five third order sequences can be divided in the Abu Gabra Formation, which corresponds as five stages of sequence evolution such as Pre-rift fast infilling, first flooding, retrograding, maximal flooding, and final retrograding stages. Facies mapping showed that during the fourth (AG2) and the last (AG1) sequences lacustrine was predominant and delta systems developed in the Western Kaikang Trough, Neem, the south of Shelungo and Fula south areas. There are two sets of source rock developed in the Abu Gabra Formation, such as shale developed the fourth sequence (AG2) during the maximal flooding period and shale developed in the second sequence (AG4) during the first flooding period. Three reservoir-cap assemblages developed in the Abu Gabra Formation. The first assemblage was inner AG1 reservoir charged from AG2 source rock, the second one was inner AG2 self-sourced assemblage, and the last one was AG3 reservoir charged from AG4 source rock. The inner AG2 self-sourced assemblage was also potential for lithological traps. The favorable facies for both structural and lithological traps were delta fronts with appropriate shale content, the areas were Neem-Azraq, the western flank of Bambo-Unity sub-basins, the eastern slope of Unity sub-basin, Haraz-Diffra in Western Kaikang Trough and Fula South.

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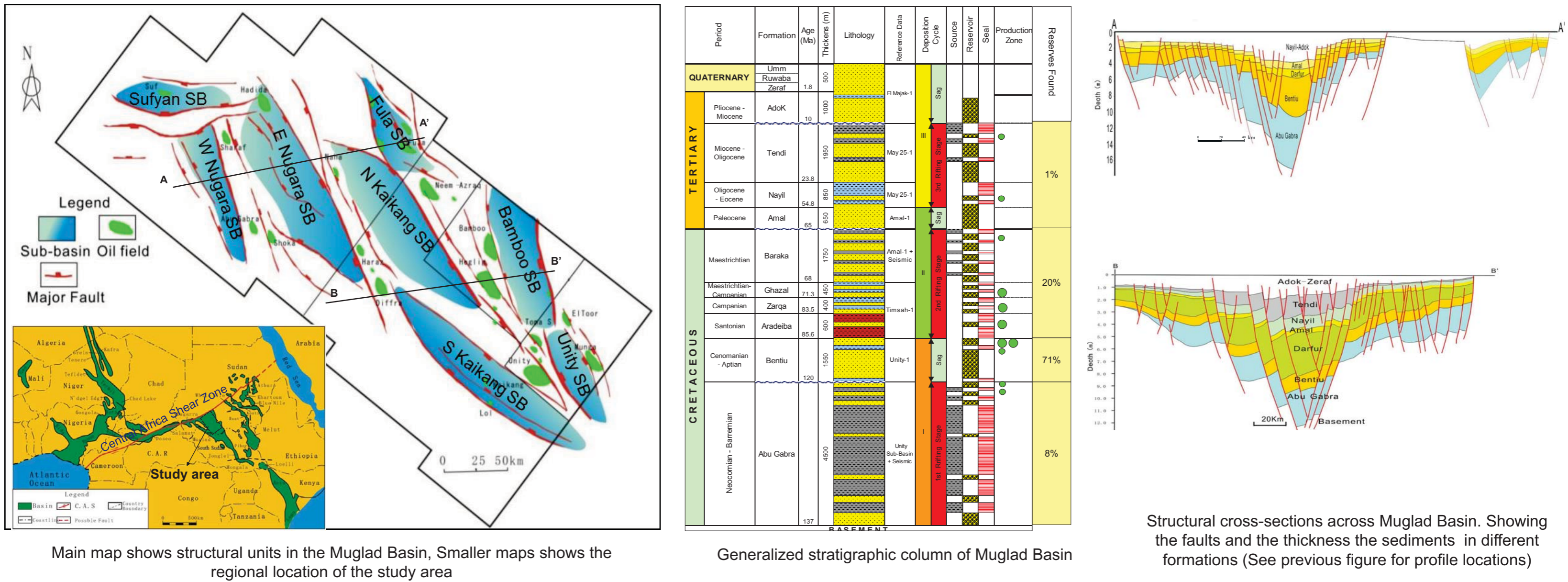
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Abstract: Muglad Basin is an intra-Craton passive rift basin related to the Central Africa Shear Zone (CASZ), which is located in the Southern-Central Republic of Sudan. Three rifting-sagging cycles were developed in the basin since early Cretaceous. The main targets in the basin are sands formed in the sagging stage, which were highly explored with limited potential remained. The first rifting sequence in the early Cretaceous Abu Gabra Formation is considered as the new play in the basin, while the favorable play fairways are unclear due to complicated sedimentary systems developed in the Abu Gabra period. Based on the analysis of more than 60,000 km of 2D seismic, 5,000 km2 of 3D seismic data, and 200 wells data in the whole basin, five third order sequences can be divided in the Abu Gabra Formation, which corresponds as five stages of sequence evolution such as Pre-rift fast infilling, first flooding, retrograding, maximal flooding, and final retrograding stages. Facies mapping showed that during the fourth (AG2) and the last (AG1) sequences lacustrine was predominant and delta systems developed in the Western Kaikang Trough, Neem, the south of Shelungo and Fula south areas. There are two sets of source rock developed in the Abu Gabra Formation, such as shale developed the fourth sequence (AG2) during the maximal flooding period and shale developed in the second sequence (AG4) during the first flooding period. Three reservoir-cap assemblages developed in the Abu Gabra Formation. The first assemblage was inner AG1 reservoir charged from AG2 source rock, the second one was inner AG2 self-sourced assemblage, and the last one was AG-3 reservoir charged from AG4 source rock. The inner AG2 self-sourced assemblage was also potential for lithological traps. The favorable facies for both structural and lithological traps were delta fronts with appropriate shale content, the areas were Neem-Azraq, the western flank of Bambo-Unity sub-basins, the eastern slope of Unity sub-basin, Haraz-Diffra in Western Kaikang Trough and Fula South.

1. Introduction

Muglad rift basin is up to 200km wide and over 800km long, covering an area of 120,000 km². Eight sub-basins can be divided, such as Abu Sufyan, Western Nugara, Eastern Nugara, Fula, Bamboo, Unity, North Kaikang and Southern Kaikang sub-basins. Three rift-sagging stages were developed since the early Cretaceous, such as the early Cretaceous (approximately 140-95 Ma), the late Cretaceous (95-65 Ma) and Paleogene (65-30 Ma). Each cycle boundary is regionally or locally expressed by an angular unconformity. The basin is filled with a Cretaceous -Tertiary non-marine clastic sediments which is over 15,000 m thick in the deepest part. The source rock is lacustrine shale formed in the Early Cretaceous rifting stage. The traditional major play fairways was antithetic faulted blocks with Bentiu sands formed in the early-late Cretaceous sagging stage which was regionally capped by Aradeiba shale deposited during the second sagging stage, where more than 70% reserves were found till now. More than 30 oilfields have been found and most of them are around the eastern side of the Basin, such as Bamboo, Unity and Fula Sub-basins.

The main play fairways in the basin was highly explored with limited potential remained. The first rifting sequence in the early Cretaceous Abu Gabra formation is considered as the new plays in the basin, while the favorable plays fairways are unclear due to complicated sedimentary systems developed during the deposition of Abu Gabra formation. The purpose of the paper is to reveal the exploration potentiality and favorable play fairways for Abu Gabra Fm. through sequence stratigraphic approach due to limited wells fully penetrated Abu Gabra Fm.



2. Methodology

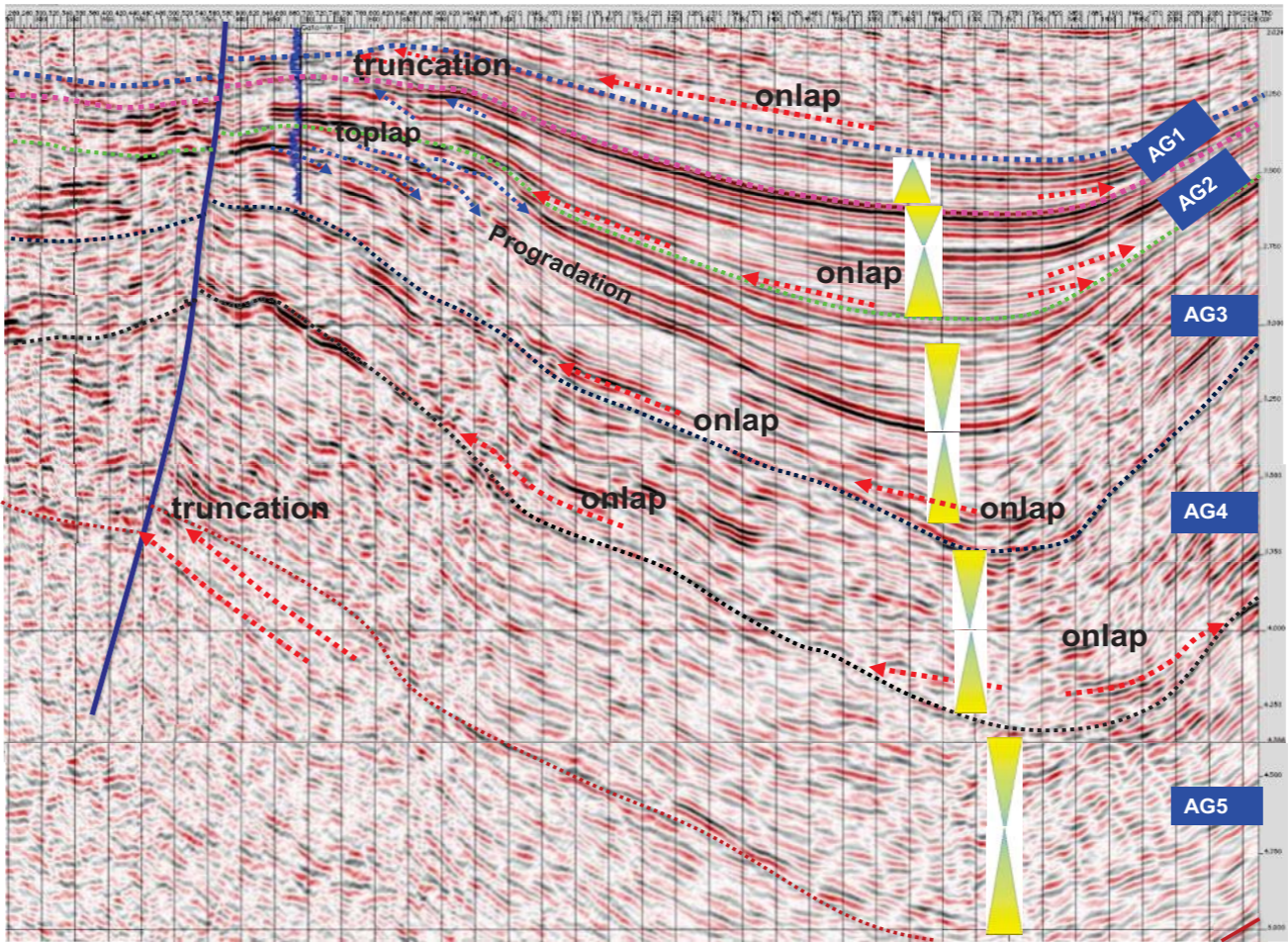
This study was carried out with synergistic using of limited well logs, cuttings, core and plenty of seismic data. More than 60,000 Km length of 2D seismic and 5,000km² of 3D seismic and about 200 well data were reviewed and interpreted. Through the key well and regional seismic lines analysis, the sequence framework of Abu Gabra formation was built, and then mapping the sedimentary facies for each sub-sequences. The favorable sub-sequences can be selected with analysis of the sequence evaluation history, and combined with structure, reservoirs and effective source rocks, the favorable play fairways were identified.

3. Main Understandings

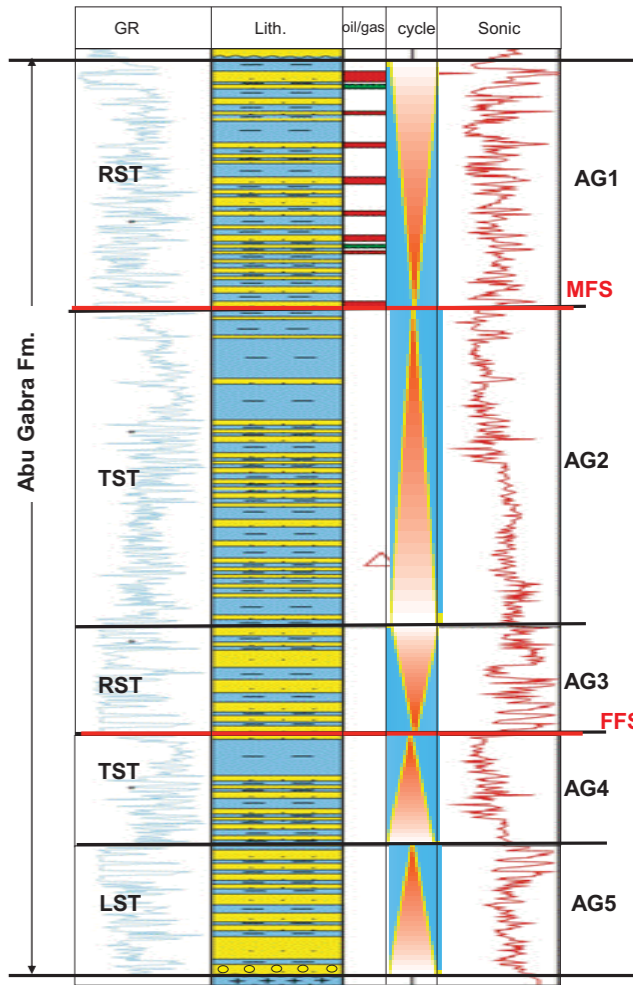
3.1 Sequence framework

Five third order sequences can be divided in Abu Gabra, which were corresponded to five stages of sequence evolution history such as Pre-rift fast infilling, first flooding, retrograding, maximal flooding and final retrograding stages.

The first sequence (AG5) was formed in the pre-rifting stage of the basin, and the sediments were dominated by coarse sandstone and conglomerate, which constituted the Lowstand System Tract during the pre-rifting fast infilling stage. The sequence was marked by massive chaotic reflection and unconformity contacted with the underlying Basement in the seismic section. It was 500 to 1000 meters' thick and wildly distributed in the whole basin.



Sequence boundary and typical reflection features for Abu Gabra Fm.



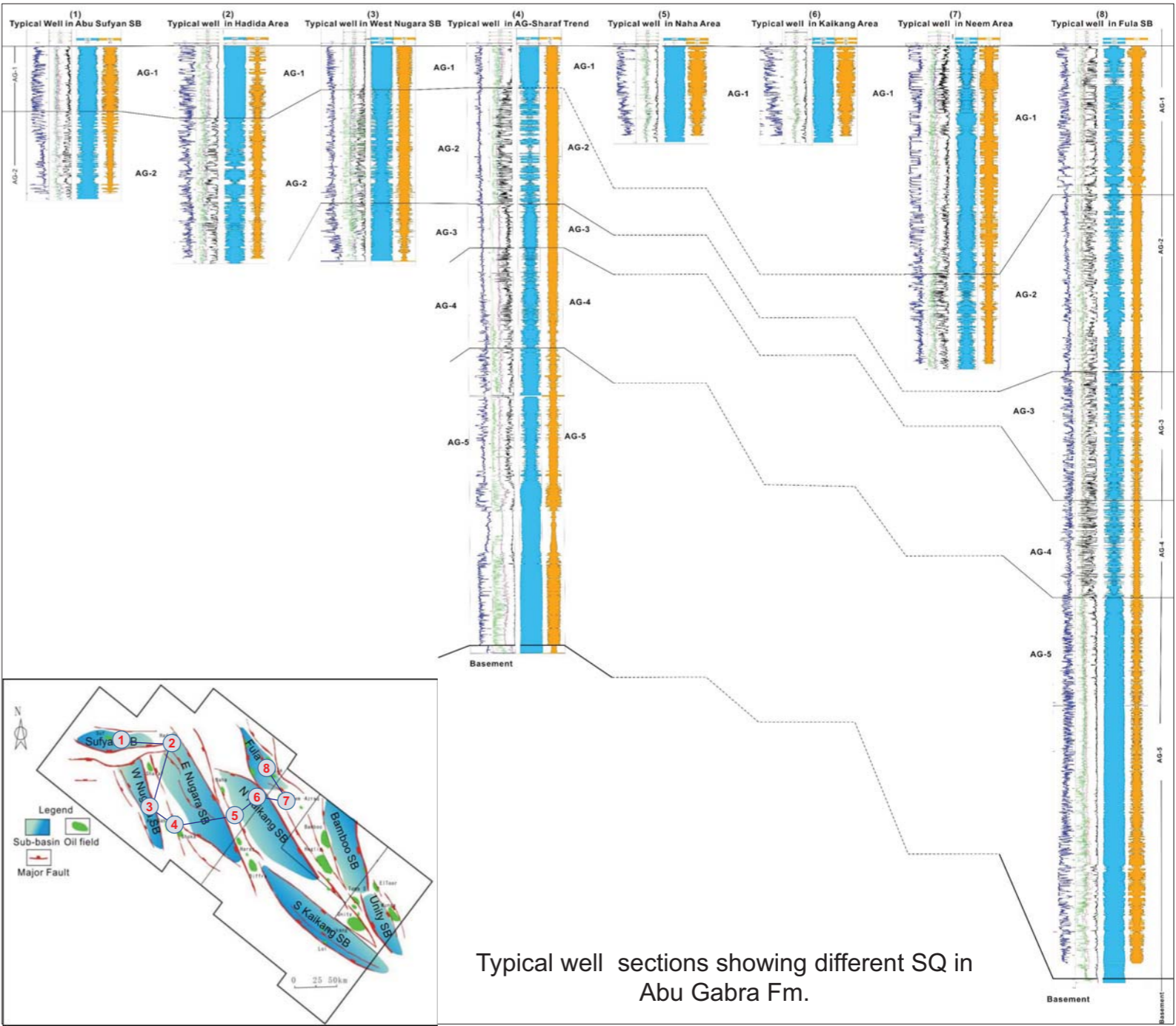
Sequence framework for Abu Gabra Fm.

The second sequence (AG4) was shaly interval interbedded with sandstone, and the shale was marked by high conductivity in the well log. It was deposited in the first flooding period, and the top boundary of the sequence was the first flooding surface. The sequence was strong and continuous reflection the in seismic section. The thickness of the sequence varied from 200 meters to 1000 meters, and the high shale content sediments were deposited only the in main depo-centers.

The third sequence (AG3) was marked by up-coarsening sandstone formed in the retrograding period. It was chaotic or blank reflection in the seismic section with 300-1000 meters’ thick.

The fourth sequence (AG2) was shaly interval marked by high conductivity in the well log which was deposited in the maximal flooding period. There were 2-3 groups of strong evens in the seismic with the total thickness about 200-800 meters. The shale was stably and widely distributed in the whole sub-basins. The top boundary of the sequence was Maximal Flooding Surface.

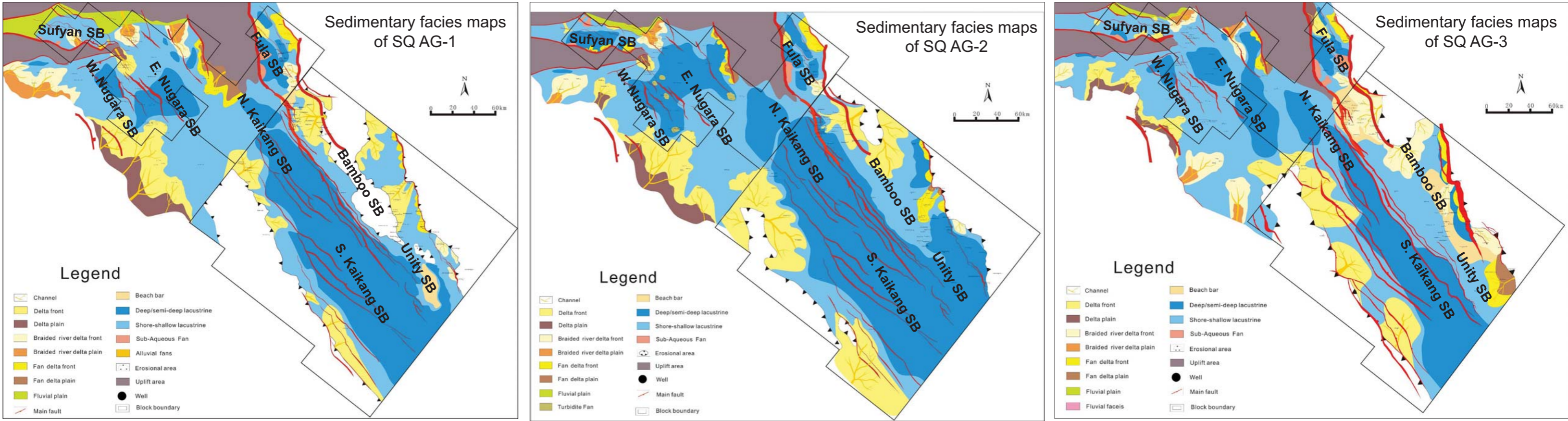
The last sequence (AG1) was marked by several up-coarsening cycles formed in the retrograding period. The lithology of the sequence was normally sandstone and shale intervals with 200-500meters’ thick.



Typical well sections showing different SQ in Abu Gabra Fm.

3.2 Sedimentary facies

Facies mapping showed that there developed lacustrine, delta (braided delta and normal delta), turbiditie fan, sub-aqueous fan in different sequences. The sediment source mostly from the North and SW. During SQ AG3, delta systems were wildly developed both in the east of Bamboo-Unity-Fula Sub-basins and the west part of W. Nugara-Kaikang Sub-basins. During the SQ AG2 lacustrine was predominant, and delta systems mainly remained in the uplift areas, such as the Western flank of Kaikang Sub-basin, the North part of Bamboo Sub-basin and the South of Fula Sub-basin (Neem-Aqraq area). During the last sequence (AG1) most of the sediments were eroded in the east and north parts of Bamboo Sub-basin and the west flank of Kaikang Sub-basin. Five major delta systems, such as Neem-Azraq, Fula South, Northeast Fula, North Nugara and South Nugara were predominate and successively developed from early SQ AG4 till to late SQ AG1.



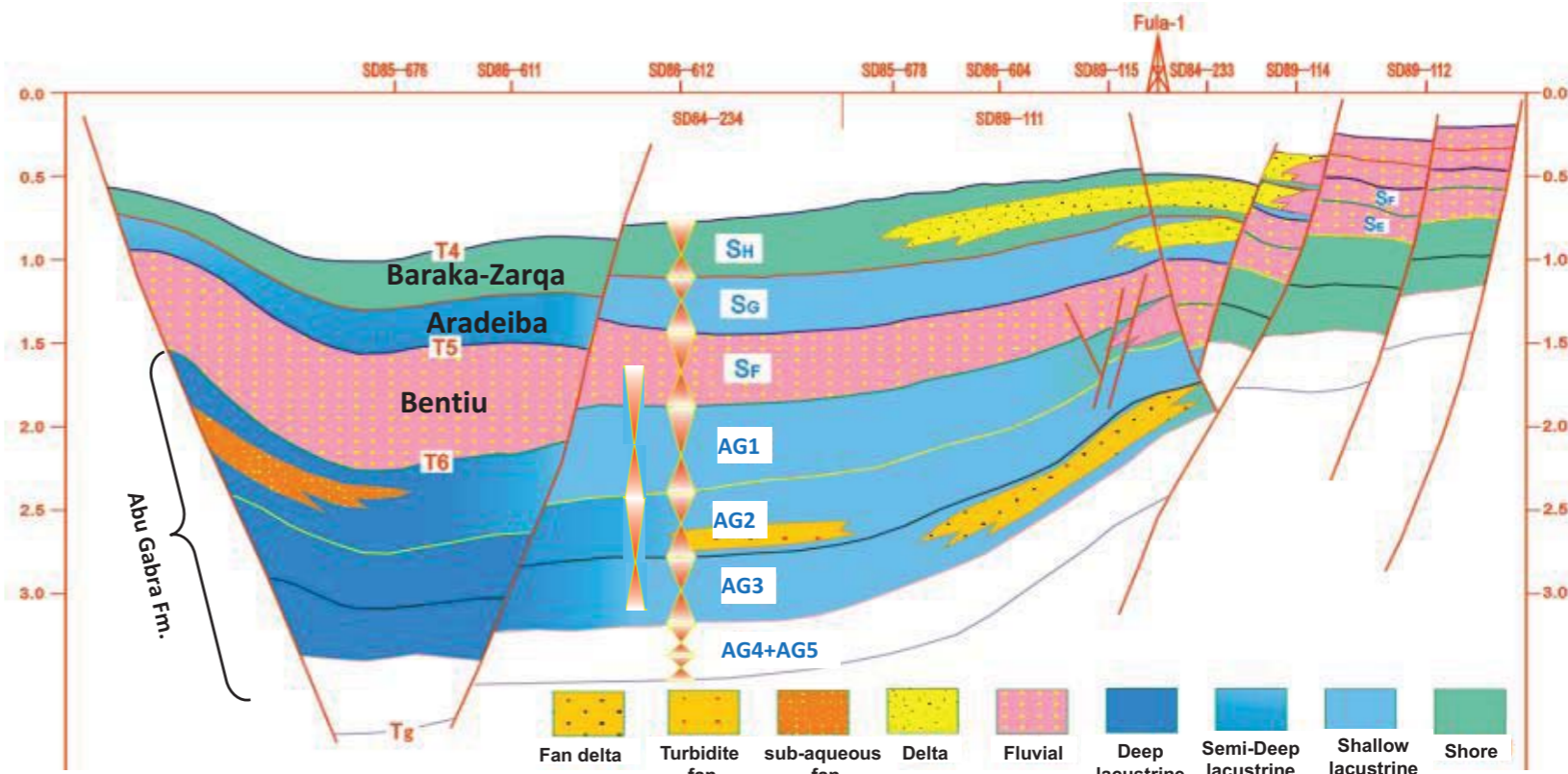
Sedimentary facies maps of different sequences in Abu Gabra Fm.

3.3 Favorable sub-sequence

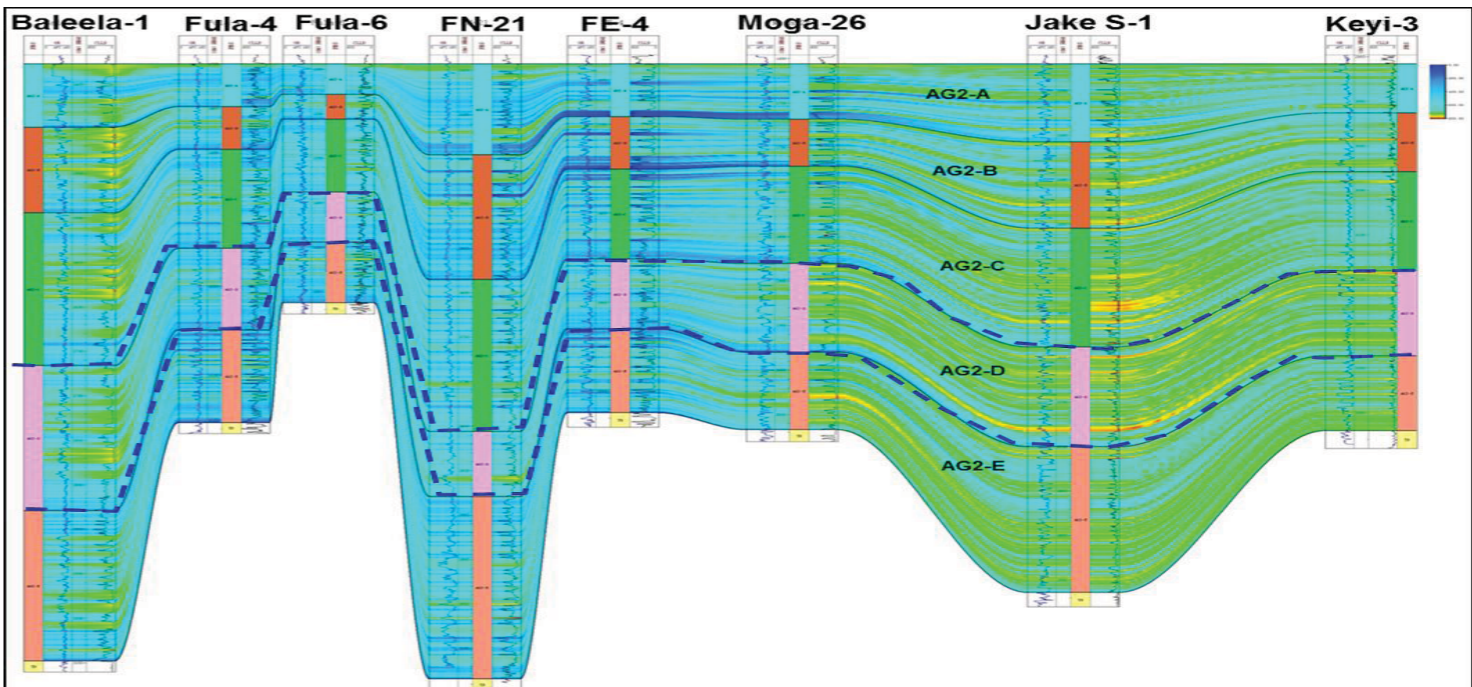
There are two sets of source rock developed in Abu Gabra formation, such as shale developed the SQ AG2 during the maximal flooding period and shale developed in SQ AG4 during the first flooding period. Three reservoir-cap assemblages developed inner Abu Gabra formation. The first assemblage was inner AG1 reservoir charged from AG2 source rock, the second one was inner AG2 self-sourced assemblage, and the last one was AG3 reservoir charged from AG4 source rock. SQ AG2 and SQ AG3 were the most favorable sub–sequences for inner Abu Gabra Fm.

SQ AG2 was deposited during the basin expanding period with thick dark shale, which is the major source rock in the basin. Within SQ AG2, there developed shale and sands intervals, and the shale distributed widely which can act as both source rock and cap rock for inner AG2 sands. Fan delta and turbidite fan developed in the east flank for the basin. According to detailed well correlation and sub-sequence division, five fourth-order sequences can be identified in AG2, such as AG2A, AG2B, AG2C AG2D and AG2E. Sub-sequences AG2D and AG2E can be tracked laterally, and the shale intervals on the top of AG2D and AG2E are stably distributed in the whole area. Sands inside AG2D and AG2E are potential for HC accumulation.

SQ AG3 was formed during the lake shrinkage period with coarsening upwards sandstone deposited. The delta systems were wildly developed during SQ AG3 with potential reservoir sand. The shale developed in the SQ AG2 can act as region cap rock for SQ AG3 sandy section.



Section for sedimentary model in Muglad Basin



Detailed sub-sequence correlation for SQ AG2

3.4 Favorable play fairways

1. key factors for Abu Gabra Play

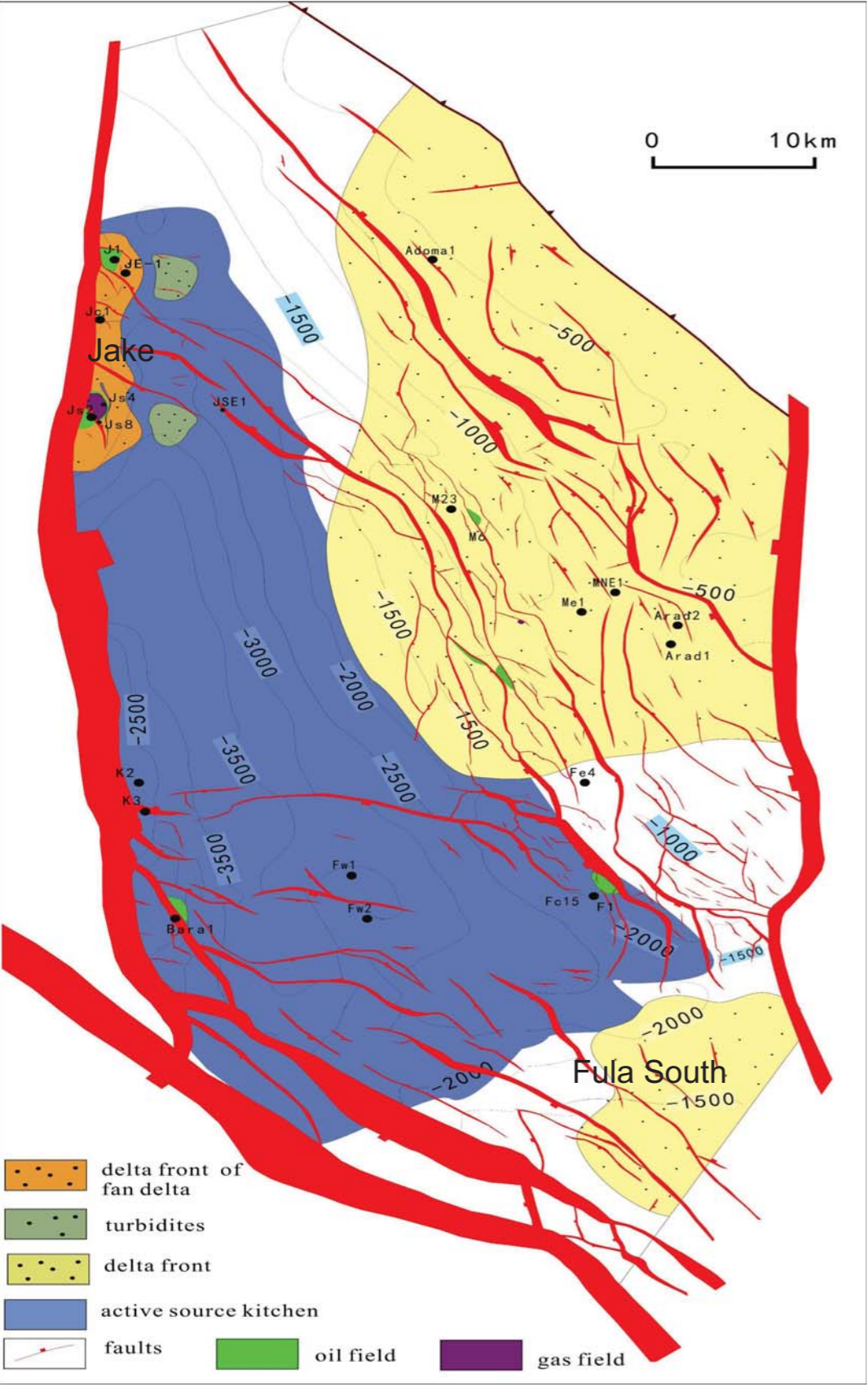
For Abu Gabra Play, the key factor is reservoir property because the reservoir burial depth is more than 3000m. The favorable play type is faulted block and faulted anticline. The thickness of reservoir sands are normally 5-10m, which are laterally sealed by Abu Gabra itself. The favorable play fairways of Abu Gabra Fm. should be the area where are in suitable sedimentary facies, good reservoir property and anticline structural background.

For SQ AG3, upthrow faulted block is favorable which is laterally sealed by shale developed in SQ AG2, and for SQ AG2 both upthrow/downthrow faulted blocks are favorable. The fault throw should suitable for lateral sealed by itself in the downthrow faulted block, and in the upthrow faulted block the fault throw should be big enough for lateral sealed by Aradebia shale.

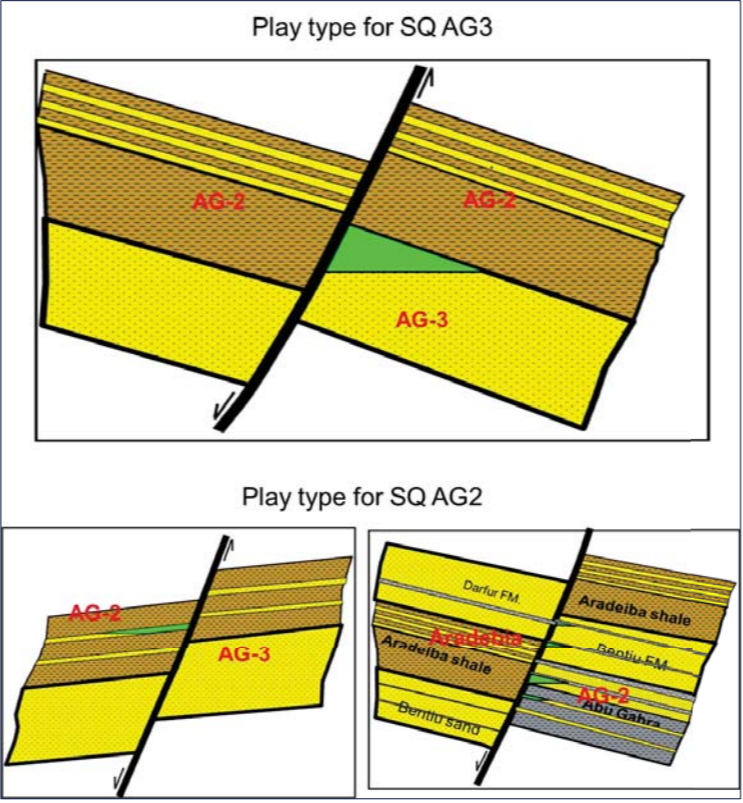
2. Favorable play fairways

In Kaikang-Bamboo-Unity Sub-basins, delta fronts between uplifts and depo-centers are the most favorable fairways, and the areas are Neew-Azraq delta, Unity-Bamboo ridge in the west flank of Bamboo-Unity Sub-basins. The secondary fairways are delta fronts between flank and depo-centers, such as areas in the east of Unity-basin, Haraza-Diffra trend in the Western flank of Kaikang Sub-basin.

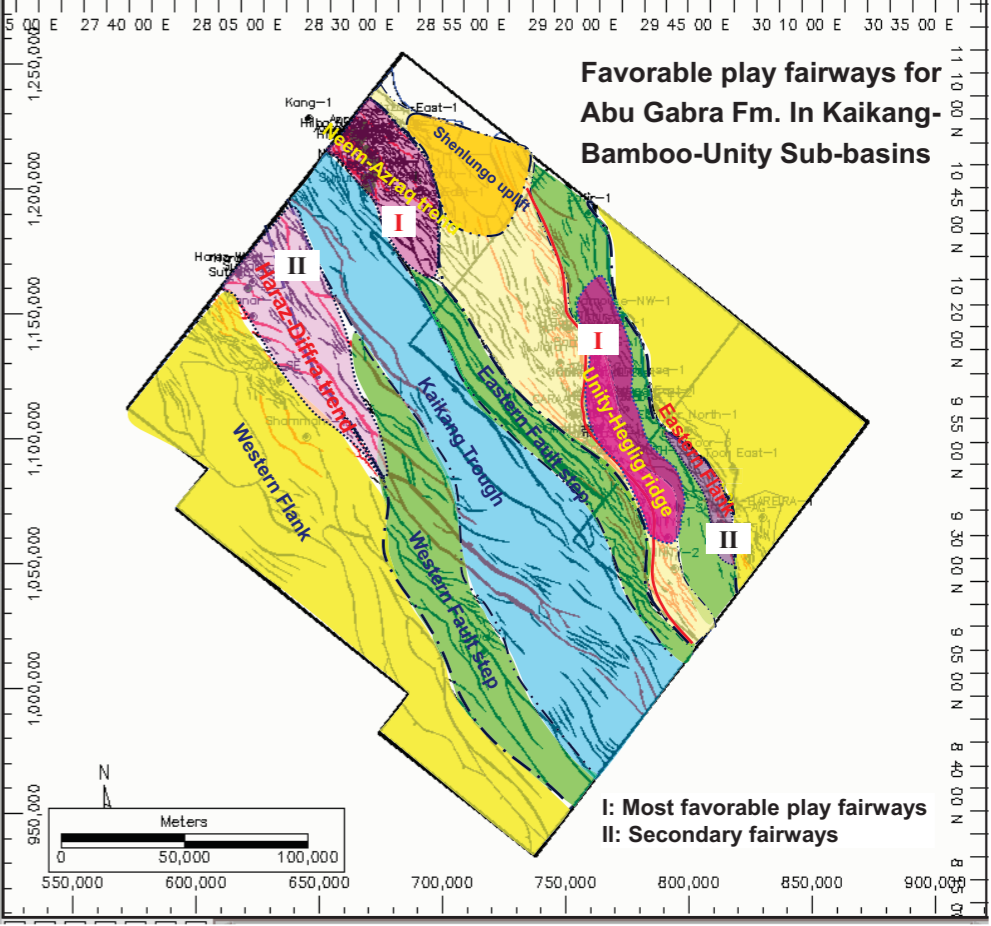
In Fula Sub-basin the favorable play is Jake area in the western trend with fan delta and slumps development in SQ AG2. In Fula South there developed structural slope-break, which is favorable for forming of structural-lithological traps. In the structural slope break area lithological traps near MFS(Near top SQ AG2) can be formed, and in the flexure slop break turbiditie reservoirs can be formed due to the slop of topography.



Facies, structural, source kitchen overlap maps in Fula Sub-basin



Play types for SQ AG2 and SQ AG3



Play fairways for Abu Gabra in Fula South, Fula Sub-basin

4. Conclusions

- (1)Five third sequences can be divided within the lower Cretaceous Abu Gabra sand and shale deposits which were formed in the first rifting stages.
- (2)Lacustrine, delta (Braided delta and normal delta), turbiditie fan, sub-aqueous fan developed in different sequences, and SQ AG2 and SQ AG3 were the most favorable sub–sequences for inner Abu Gabra Fm.
- (3)For Abu Gabra Play, the key factor is reservoir property which controlled by sedimentary facies. The most favorable facies is delta front and tuibidites, slumps in SQ AG2 and AG3.
- (4)In Kaikang-Bamboo-Unity Sub-basins, the most favorable fairways are Neew-Azraq delta, Unity-Bamboo ridge in the west flank of Bamboo-Unity Sub-basins.
- (5)In Fula Sub-basin the favorable play is the Jake area in the western trend with fan delta and slumps development in SQ AG2. In Fula South the structural-lithological traps were formed in the structural slope-break area, and lithological traps were formed in the structural slope break area near MFS.

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LI Zhi, PhD majored in Petroleum Geology, Senior geologist, Section Head in the Department of Global Resources & Exploration Planning, PetroChina Research Institute of Petroleum Exploration & Development. He was involved petroleum geological study for Central-Western African rifts since 2002, and participated more than ten G&G studies focused on Muglad, Melut, Bongor and Termit basins.
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