[PS]Petroleum System Modeling and Exploration Potential of Abu Sufyan Sub-Baisn, Muglad Basin, The Republic of Sudan*

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Abstract

Abu Sufyan Sub-basin is located in the northwest of the Muglad Basin inthe Republic of Sudan, which is an intra-craton rift basin related to the Central Africa Shear Zone. The hydrocarbon potential and favorable exploration trends are unclear due to complicated geological conditions of the Central Africa Shear Zone. The geological models of stratigraphic framework, structure, sedimentary facies, source rock, reservoir rock, and cap rock were built based on the available seismic data, well data, Rock-Eval data of shale cuttings, and GC-MS analysis data of cutting and oil samples in the sub-basin and nearby area, and 1D/2D/3D petroleum system modeling were carried out and analyzed with IES PetroMod software. The study proved that the major source rock in the sub-basin was the lacustrine shale in AG formation formed during Early Cretaceous, and mainly developed in the AG-2 and AG-4 sections. Three heat flow history scenarios, such as high, middle and low cases were assumed to model the hydrocarbon generation history due to the data limitation and uncertainty of the paleo-thermal history. The middle case of heat flow model, which was 35 mW/m^2 in the Early Cretaceous, 54 mW/m^2 in the Paleocene, and 40 mW/m^2 in the Present, was considered to be reasonable. The hydrocarbon generation and expulsion history modeling results indicat that the source rock in AG-4 section entered the oil window in the end of Early Cretaceous, and the major expulsion period was Late Cretaceous, while the source rock in AG-2 section entered the oil window during the end of Late Cretaceous, and the major expulsion period was during the Paleocene. The major migration pathway was from the western active source kitchens to the Central Structure Belt and the North Flank. Vertically, hydrocarbons were mainly accumulated in reservoir-cap assemblages under AG-2 and within AG-2 sections. There were two petroleum systems developed in the sub-basin - the AG-2 and AG-4 systems. 43% volume of total resources were generated from the source rock of AG-2 which mainly accumulated within the AG-2 assemblage, while 57% volume of total resources were generated from the source rocks of AG-4 which mainly accumulated under the AG-2 assemblage. The favorable exploration trends are the Central Structure Belt and the North Flank, and the main targets are the reservoirs within AG-2 and under AG-2 assemblages.

Petroleum System Modeling and Exploration Potentiality in Abu Sufyan Sub-baisn, Muglad basin, the Republic of Sudan

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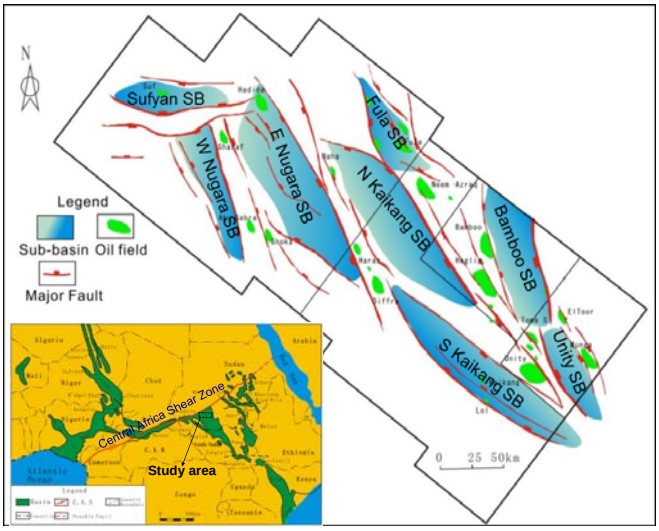
1. Introduction

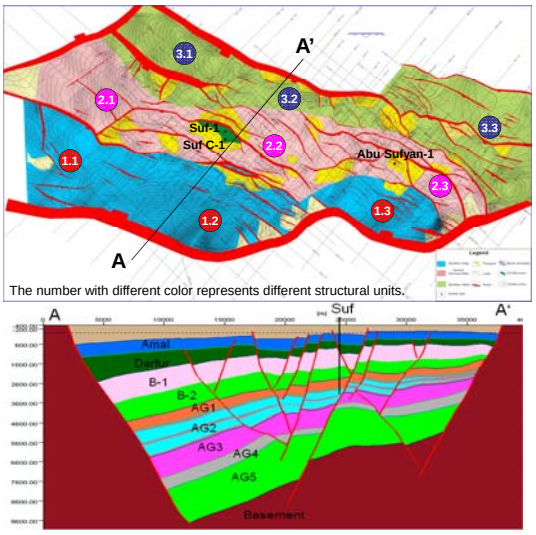
Abu Sufyan Sub-basin is located in the Northwest of Muglad Basin, the Republic of Sudan, which is an intra-Craton rift basin related to the Central Africa Shear Zone. The hydrocarbon potentiality and favorable exploration trends are unclear due to complicate geological condition caused by the Central Africa Shear Zone.

Three rift-sag stages suffered in the Muglad basin since early Cretaceous, such as early Cretaceous, late Cretaceous and early Tertiary. There deposited about 10,000 to 15,000m thick no-marine clastic sediments. The source rock of the basin is lacustrine shale formed in the Early Cretaceous rifting stage. Three reservoir-cap assemblages developed, such as Bentiu-Aradeiba of Late Cretaceous, Inner Abu Gabra of Early Cretaceous and Inner Darfur Group of Late Cretaceous.

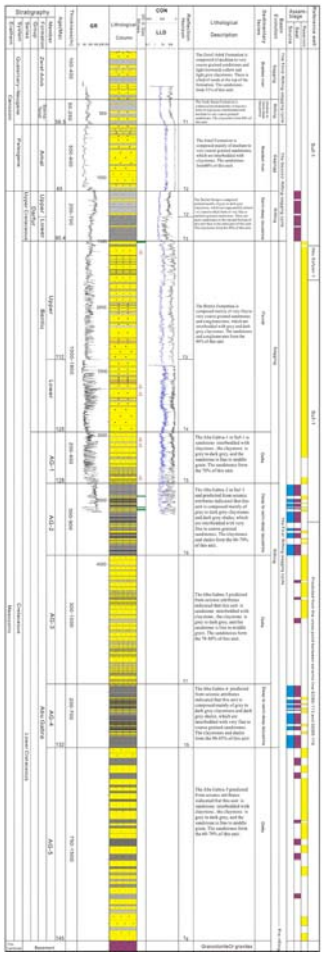
The area of Abu Sufyan Sub-basin is about 2800Km^2. It is a relatively independent structural unit trending east-west, which is different from the other Sub-basins in the Muglad Basin. There were only three wells were drilled in the Sub-basin with one discovery. The Sub-basins covered by 2D seismic lines of 2350Km with the line grid of 1×2Km to 2 ×4km.



Main map shows structural units in the Muglad Basin, Smaller maps shows the regional location of the study area



Structural map and cross section of Abu Sufyan Sub-basin



Comprehensive Stratigraphic Column in Abu Sufyan Sub-basin

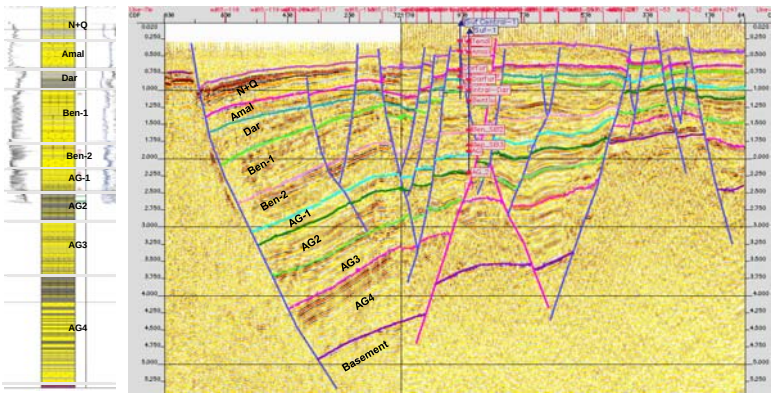
2. Methodology

The geological models of stratigraphical framework, structure, sedimentary facies, source rock, reservoir rock and cap rock were built based on the available seismic data, well data, Rock-Eval data of shale cuttings and GC-MS analysis data of cutting and oil samples in the Sub-basin and nearby area, and 1D/2D/3D petroleum system modeling were carried out and analyzed with IES PetroMod software.

3. Geological Model

3.1 Stratigraphical model

Nine seismic-stratigraphic sequences from early Cretaceous to Recent were built and input to the model.



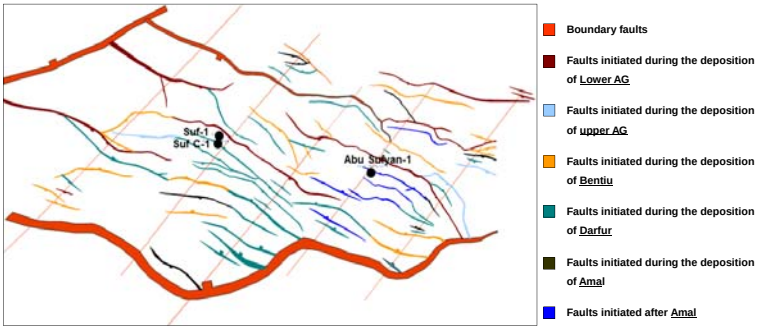
Stratigraphical model of Abu Sufyan Sub-basin

3.2 Structural model

Three second order and nine third order faulted structural belts were divided in the Sub-basin. About 108 faults were input to the model with open/close attributes in different geological time.

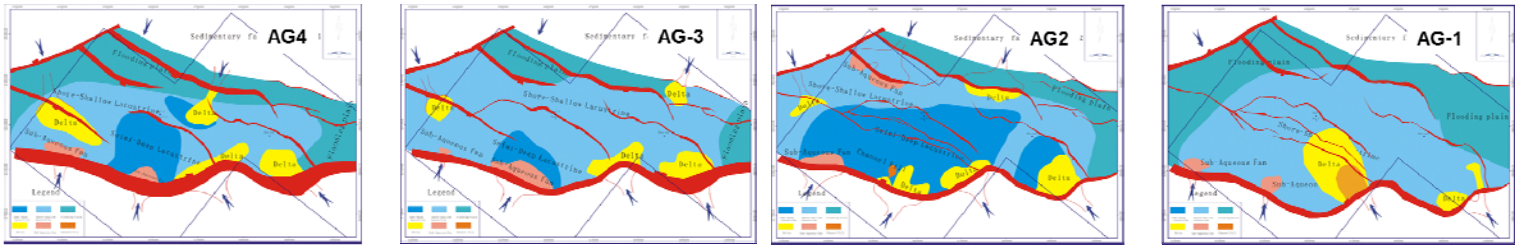
Name of different structural units in the Abu Sufyan Sun-basin

First order	Second Order	Third order
Abu Sufyan Sub-basin	1. South structural belt	1.1 Western part of south structural belt
		1.2 Middle part of south structural belt
		1.3 Eastern part of south structural belt
	2. Central structural belt	2.1 Western part of central structural belt
		2.2 Middle part of central structural belt
		2.3 Eastern part of central structural belt
	3. North structural belt	3.1 Western part of north structural belt
		3.2 Middle part of north structural belt
		3.3 Eastern part of north structural belt



3.3 Sedimentary model

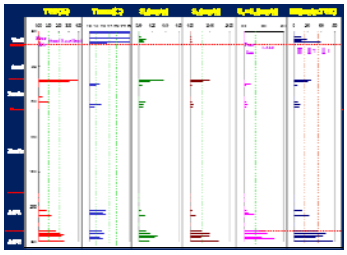
Four sediments infilling directions in Abu Gabra stage.



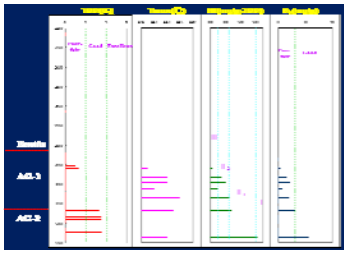
Sedimentary facies map for four sections of Abu Gbara formation in the Abu Sufyan Sub-basin

3.4 Source rock model

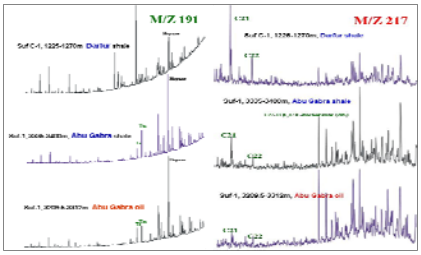
Good source rock in AG2, TOC in well Suf-1 is about 2.08% and 1.7% in well Abu Sufyan-1. Kerogen type in AG2 shale is mostly type I to II1 with high oil prone potential. Oil/source correlation indicates that oils are from AG2 shale. Based on the source rock analysis by well and seismic data, two sets of source rock are predicted in Abu Gabra formation, which are AG2 and AG4 sections.

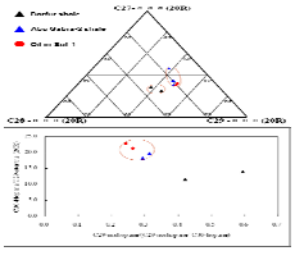


Geochemical profile of well Suf-1

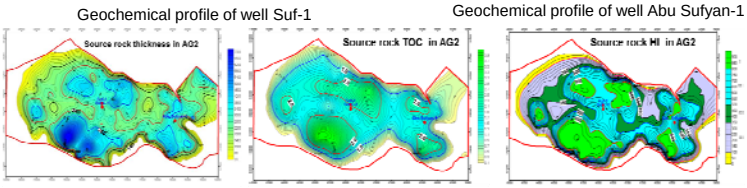


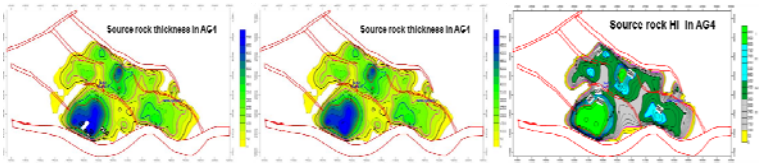
Geochemical profile of well Abu Sufyan-1





Oil/source correlation

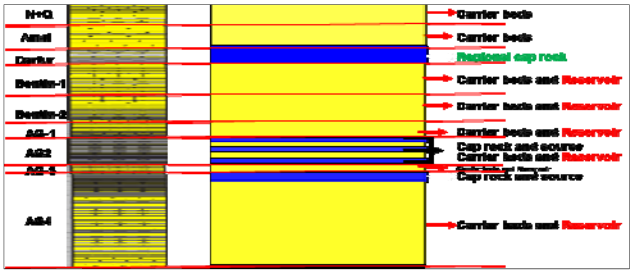




Source rock thickness, TOC and HI distribution maps for AG2 and AG4 sections

3.5 Source-reservoir-cap assemblages model

Shale in Lower Cretaceous Darfur Group is regional cap rock. In additional, shale inner Abu Gabra is local caps. Four sets of main assemblages can be divided by regional and local caps, such as reservoir in AG1 and Bentiu sands sourced from shale in AG2 capped by shale in Darfur group, inner AG2 assemblage, reservoir in AG3 sands sourced from shale in AG4 caped by shale in AG2, and inner AG4 assemblage. The first two assemblages were proved by exploration in the Sub-basin and the others were predicted by regional information.

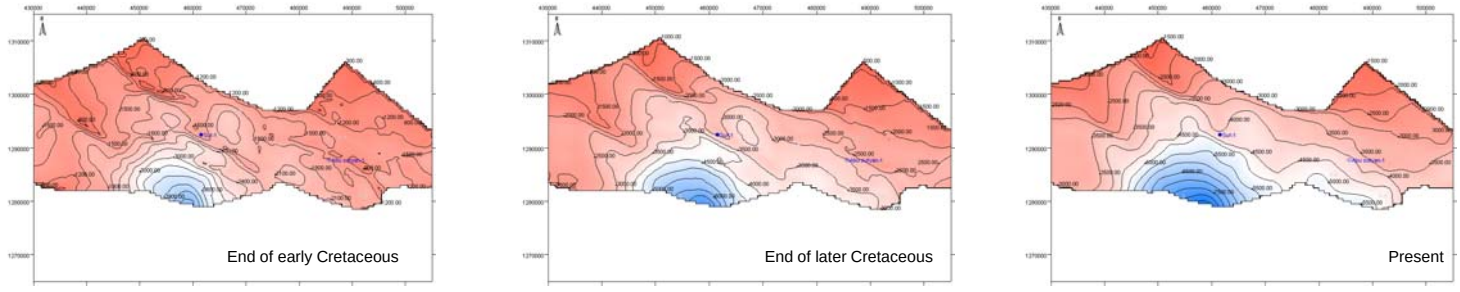


Source-reservoir-cap assemblages Model

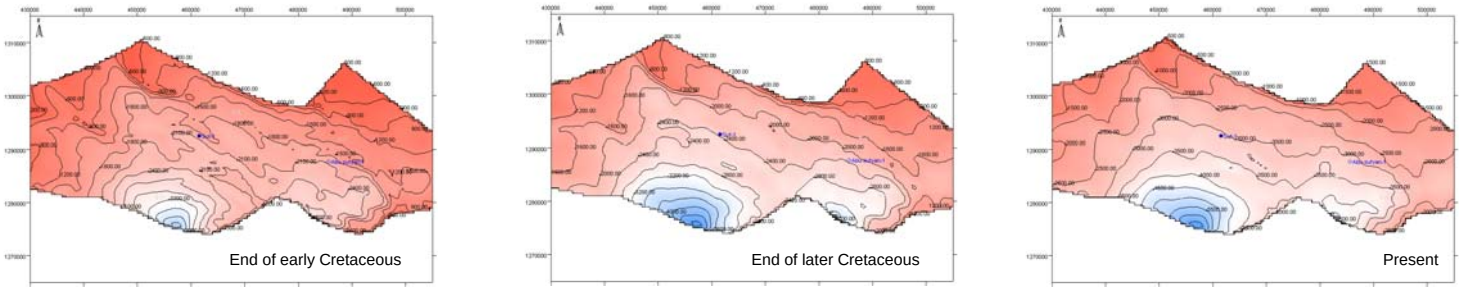
4. Modeling Results

4.1 Burial history reconstruction

During the deposition of AG4, there developed only one depo-center in the western part, and the depo-center successively developed since the end of early Cretaceous. During the deposition of AG2, there developed one major depo-center and one minor depo-center, and the major depo-center successively developed since the deposition of AG2, while the minor depo-center developed since the end of later Cretaceous.



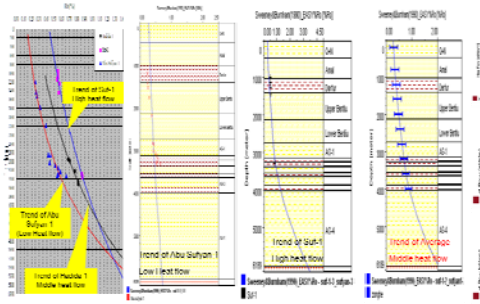
Top AG4 (source rock section) depth burial history reconstruction



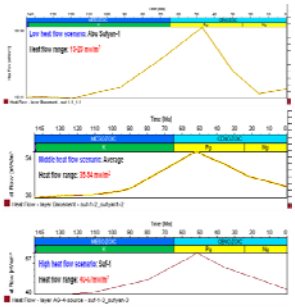
Top AG2 (Source rock section) depth burial history reconstruction

4.2 Thermal history

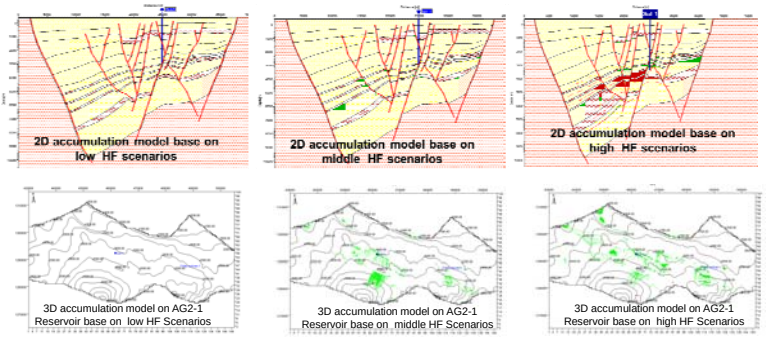
Three heat flow history scenarios, such as high, middle and low cases were assumed to model the hydrocarbon generation history due to the data limitation and uncertainty of the paleo-thermal history. The middle case of heat flow model, which was 35mW/m^2 in early Cretaceous, 54mW/m^2 in Paleocene, and 40mW/m^2 in the present, was considered to be reasonable compared with the hydrocarbon distributions and properties of modeled results and real discoveries.



The relation of Ro and depth with Lab data shows three heat flow scenarios

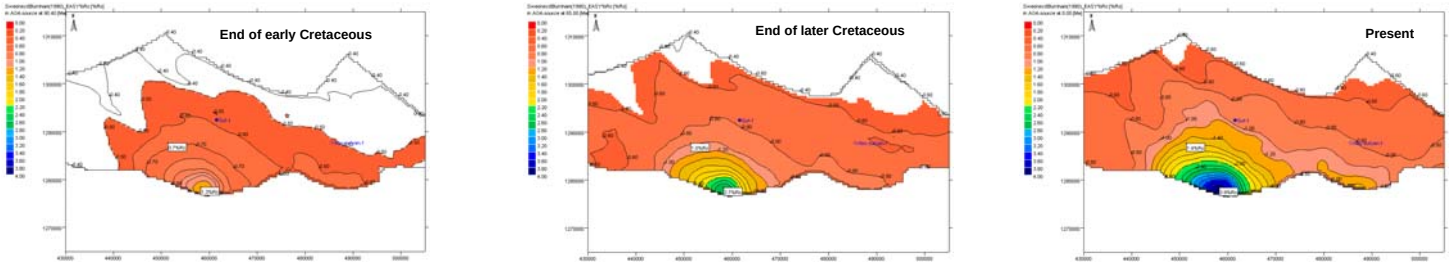


Three heat flow models calibrated by wells

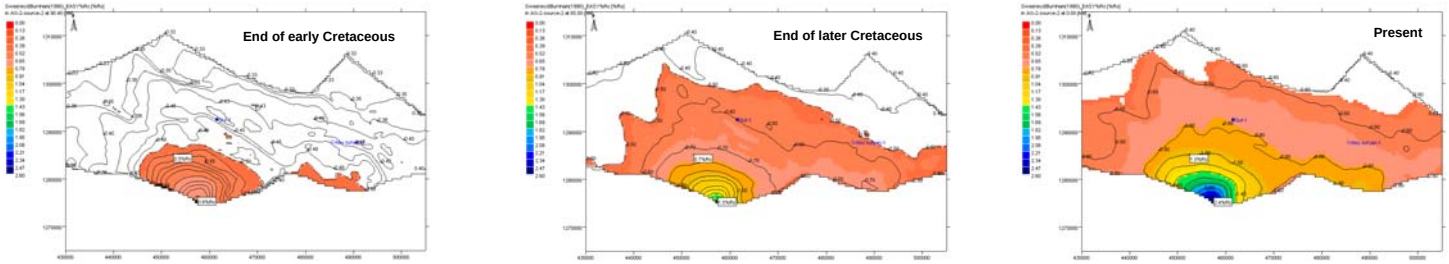


4.3 Hydrocarbon generation and expulsion

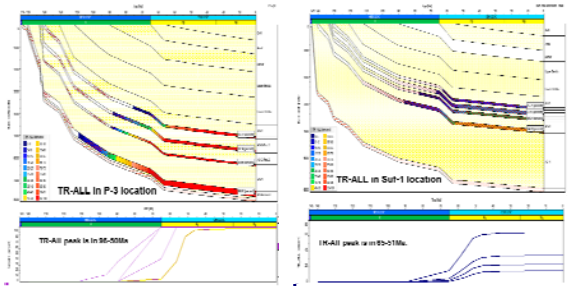
The hydrocarbon generation and expulsion history modeling results indicated that the source rock in AG4 section entered the oil window in the end of early Cretaceous, and the major expulsion period was late Cretaceous, while the source rock in AG2 section entered the oil window in the end of late Cretaceous, and major expulsion period was Paleocene

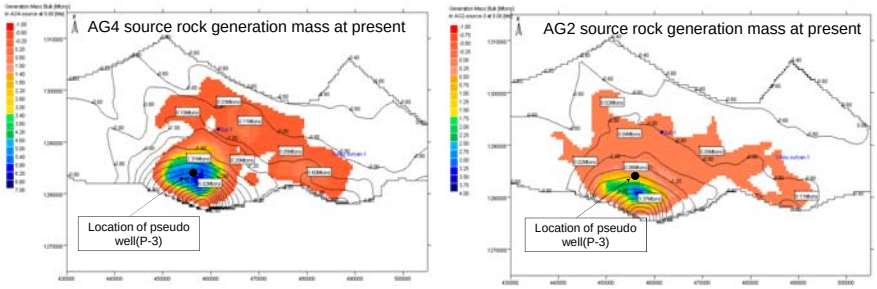


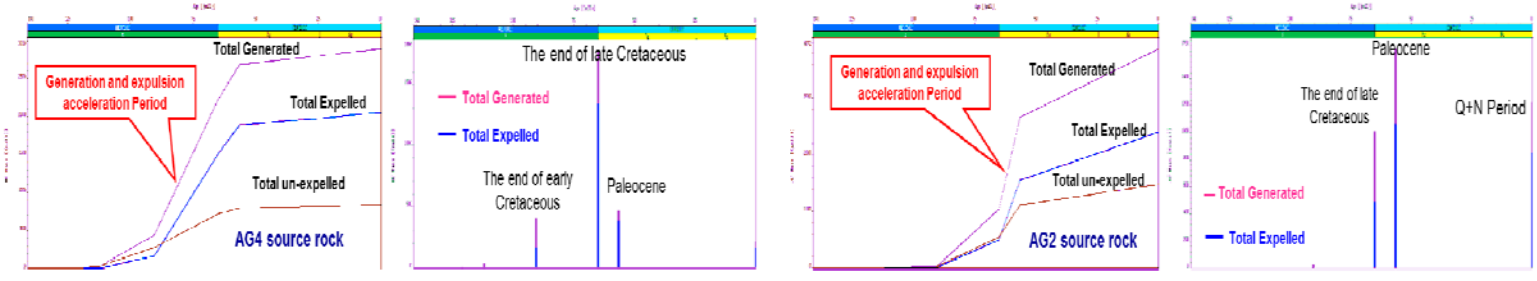
AG4 source rock Ro history



AG2 source rock Ro history



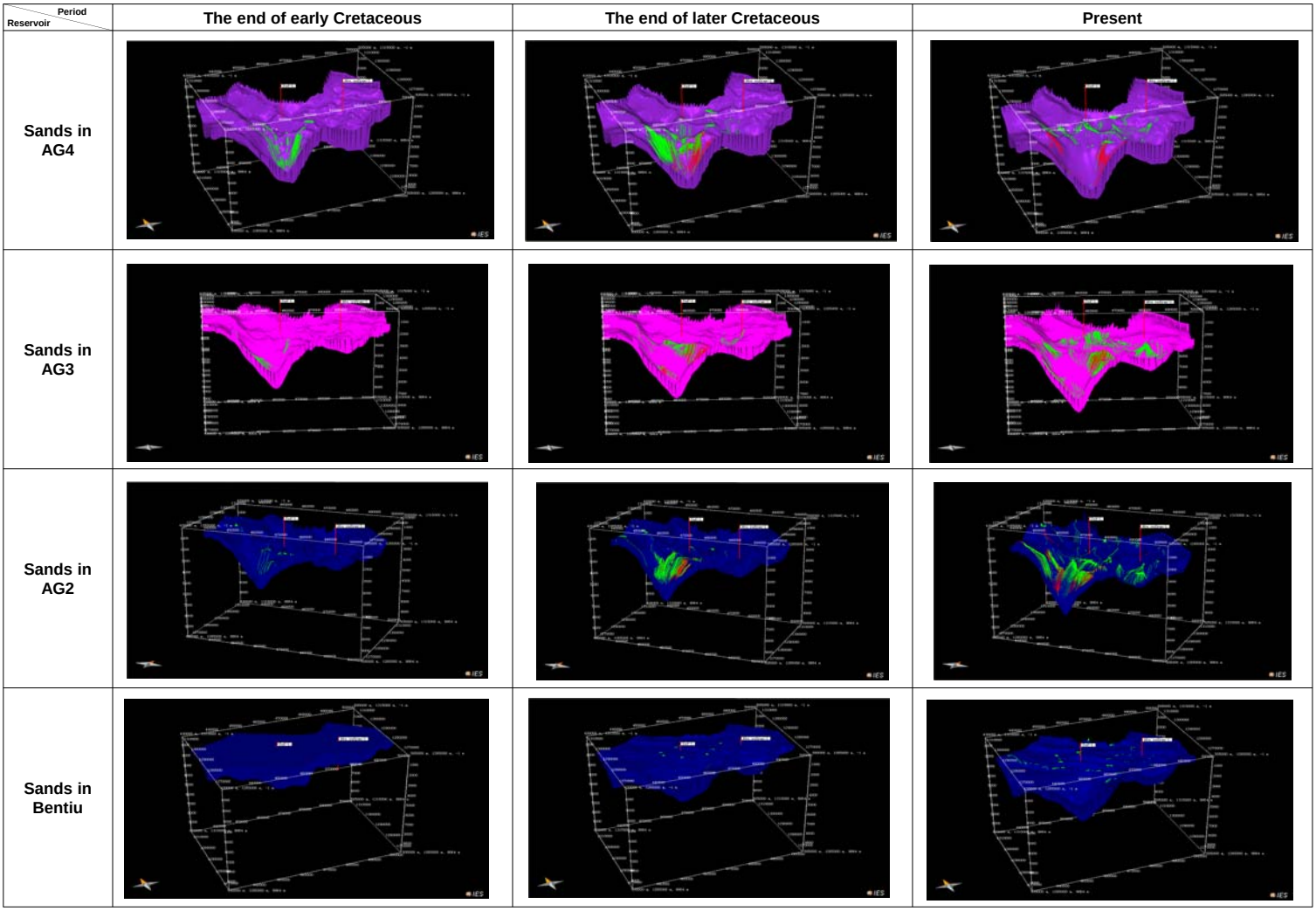




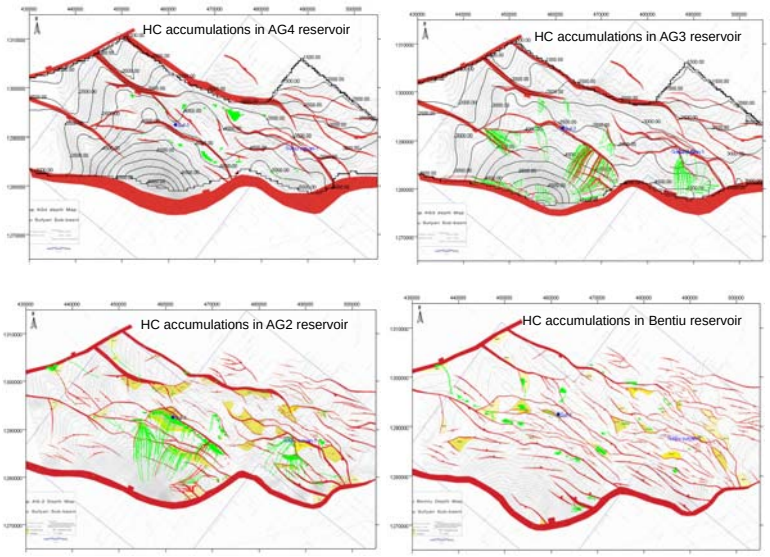
Source rock expulsion history

4.4 Hydrocarbon migration and accumulation

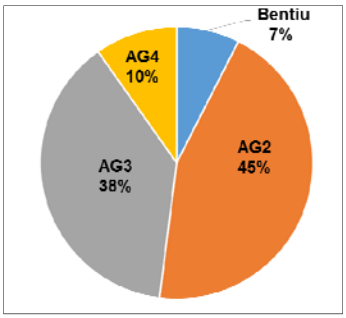
The migration started at the end of later Cretaceous. The majored migration pathway is from the South deep sag to the Central and Nortern structural units. Most of high maturity gas migrated into AG4 reservoir, Condensate and part of high maturity gas migrated into AG3 and lower part of AG2 reservoirs, and normal oil mainly migrated into the upper part of AG2 reservoir. Vertically, hydrocarbons were mainly accumulated in reservoir-cap assemblages under AG2 and within AG2 sections.



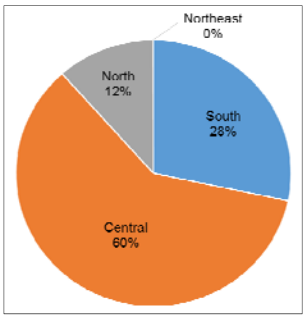
3D model of HC migration pathway in different reservoirs from the end of early Cretaceous to the present



HC accumulations overlaid on structural maps in different reservoir at present



(a) Percentage of accumulative HC accumulation in different reservoirs



(b) Percentage of accumulative HC accumulation in different structutal units

The statistics of accumulative HC accumulation in different reservoirs showed that 45% volume of HC acculumated in the AG2 reservoir, and 38% in AG3 reservoir. However, only 7% volume of HC were acculumation in Bentiu reservior, which was the main target in other Sub-basins. The results indicat that the main target in the study area was sands in AG2 and AG3, not sands in Bentiu. The favorabe structural belts were the central and south structual belts, where 60% and 28% volume of HC were accululated respectively.

4.5 Petroleum system

There were two petroleum systems developed in the Sub-basin, such as AG2 and AG4 systems. In AG2 system, hydrocarbon generation volume is 58.1% of the total, and hydrocarbon expulsion volume is 54.9% of the total. In AG4 system, hydrocarbon generation volume is 41.9% of the total, and hydrocarbon expulsion volume is 45.1% of the total. About 43% volume of total resources generated from the source rock of AG2 mainly accumulated within AG2 assemblage, while 57% volume of total resources generated from the source rock of AG4 accumulated under AG2 assemblage.

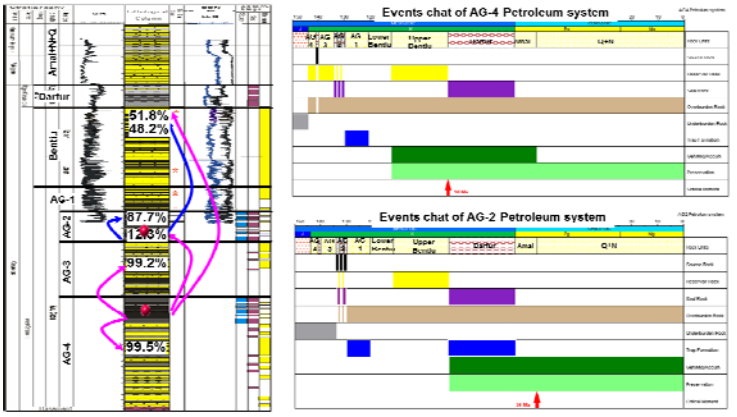
The contributions for HC generation, expulsion and accumulation in each petroleum system

Source rock		Generation volume(MMBBL)	Expulsion volume(MMBBL)	Contributions of accumulation volume (MMBBL)
AG2	AG2-source-1	11.4%	7.9%	43.0%
	AG2-source-2	20.2%	17.9%	
	AG2-source-3	26.4%	29.1%	
	Sub-Total of AG-2	58.1%	54.9%	
AG4		41.9%	45.1%	57.0%

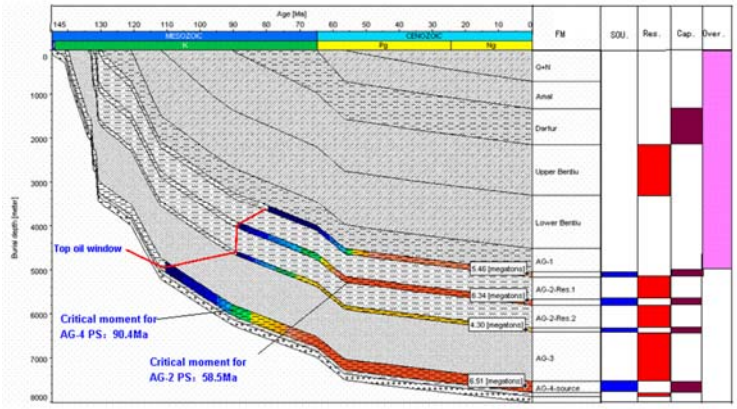
Contributions of each source rock for accumulations in different reservoir

		From AG2 source-Rock	From AG4 source-Rock
Bentiu		48.2%	51.8%
AG2	AG2-1	95.2%	4.8%
	AG2-2	85.1%	14.9%
	sub-total	87.7%	12.3%
AG3		0.8%	99.2%
AG4		0.5%	99.5%
Total		43.0%	57.0%

About 48.2% of the accumulation in Bentiu reservoir is generated from AG2 source rock, and other 51.8% from AG4 source rock. About 87.7% of the accumulation in AG2 reservoir is generated from AG2 source rock, and other 14.9% from AG4 source rock. About 0.8% of the accumulation in AG3 reservoir is generated from AG2 source rock, and other 99.2% from AG4 source rock. About 0.5% of the accumulation in AG4 reservoir is generated from AG2 source rock, other 99.5% from AG4 source rock.



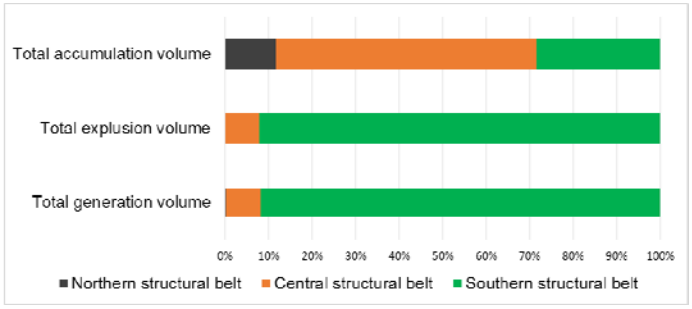
Contributions of each source rock for different reservoirs and events chats for two systems



Burial history for Petroleum systems

4.6 Favorable play fairways

About 91.9% volume of HC were generated from the Southern structural belt, and 7.9% from the Central structural belt. About 92.1% volume of HC were expelled from the Southern structural belt and 7.9% from the Central structural belt. About 28% volume of HC were accumulated in the Southern structural belt, 60% in the Central structural belt, and 12% in the Northern structural belt. The favorable exploration trends are the Central and the southern structure belts which accumulated 88% volume of the total resources. The main targets should be reservoirs within AG2 and under AG2 assemblages which accumulated 93% volume of the total.



The percentages of HC generated, expelled and accumulated in different structural units

5. Conclusions

(1) The study proved that the major source rock in the Abu Sufyan Sub-basin was the lacustrine shale of early Cretaceous AG formation, and mainly developed in the AG2 and AG4 sections.

(2)The middle heat flow case was considered to be reasonable.

(3)There was only one depo-center during deposition of AG4 section while two depo-centers during deposition of AG2 section.

(4)The AG4 source rock entered the oil windows in the end of early Cretaceous, and major expulsion period was late Cretaceous, while the AG2 source rock entered the oil windows in the end of late Cretaceous, and major expulsion period was Paleocene

(5)The major migration pathway was from the western active source kitchens to Central and Northern structure belts, and 60% hydrocarbons were accumulated in the Central structure belt.

(6)Vertically, hydrocarbons were accumulated in three reservoir-cap assemblages, and assemblage under AG2 section accumulated 48% of total volume, and 44.5 % within AG2 section

(7)There are AG2 and AG4 two petroleum systems developed in the Sub-basin, the contributions of each source rock to the accumulation in each reservoir can be estimated.

(8)The favorable exploration trends are the Central and Northern structure belts, and the main targets should be reservoirs inner AG2 and under AG2 assemblages.

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