Hydrocarbon Accumulation Pattern and Exploration Direction in Southern Chad Basin

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Abstract. The Southern Chad Basin is a Cretaceous-Paleogene rift basin developed along the Central African Shear Zone (CASZ). The Southern Chad Basin can be subdivided into three depressions, namely Doba, Doseo and Salamat. This basin went through four evolution phases: rifting, sagging, strike-slip and inversion. This paper focuses on hydrocarbon accumulation pattern and exploration direction in different depressions of Southern Chad Basin. Controlled by depositional settings and reservoir-seal combination, the hydrocarbon distribution in Southern Chad Basin is characterized as "prolific in the west and poor in the east, normal oil in the lower payzone and heavy oil in the upper payzone". Oil are both found in upper and lower Cretaceous lacustrine sandstones in Doba depression. However, lower Cretaceous become the only target in Doseo and Salamat depression. Effective source kitchen, structural history, faults/seals combination are key conditions for hydrocarbon accumulation. There is huge exploration potential in Southern Chad Basin. Future exploration directions includes: lithological or basement traps in Doba depression, inverted structures in Doseo depression and central uplift in Salamat depression.

Keywords: Southern Chad Basin · Inversion · Accumulation pattern · Exploration direction

1 Introduction

The Southern Chad basin, covering an area of 13×10^4 km^2 and mainly located in the south part of the Republic of Chad, is a Meso-Cenozoic rift basin developed along the Central African Shear Zone (Fig. 1). In previous literatures, the Southern Chad basin was usually considered as three separated basins, namely Doba basin, Doseo basin and Salamat basin [1–4]. However, gravity data, tectonic evolution and strata correlation shows that these are three depressions of one unified sedimentary basin.

Hydrocarbon exploration in the Southern Chad Basin starts in 1960s. After that, a series of major breakthroughs were made in this basin, including the great Kome field in Doba depression [2]. Till now, there are more than 30 oil/gas discoveries in

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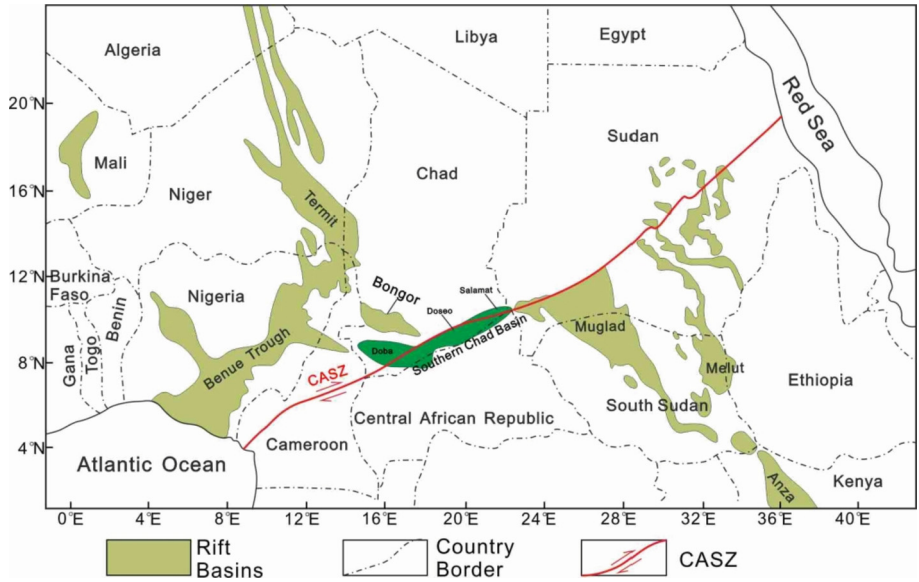

Fig. 1. Generalized map of Mesozoic-Cenozoic sedimentary basins developed along CARS (after [3])

Southern Chad Basin with a total recoverable reserve of 1.2 billion barrels. However, major discoveries are mainly located in the Doba depression, and the huge area in Doseo and Salamat depression remain under-explored with great hydrocarbon potential. This paper overviews previous research results in Southern Chad basin, analyzes geological feature and tectonic evolution of the basin. The hydrocarbon accumulation pattern and main controlling factors in this basin were summarized. The exploration potential and favorable plays were also predicted based on petroleum geology features and oilfield distribution.

2 Tectonic and Sedimentary Evolution of Southern Chad Basin

The Southern Chad basin is a W-E trending rift basin, with 900 km long by 150 km wide. The majority part of this basin is located in Chad, while the east end extends to the Central African Republic. The basin, which lies on pre-Cambrian granitic basement, is classified as an asymmetric rift developed under the dextral stress field of Central African Shear Zone (CASZ). The Central African Shear Zone goes across the Southern Chad basin and divide the basin into three depressions, namely Doba, Doseo and Salamat from west to east (Fig. 2). The Southern Chad basin was formed along with the breakup and separation of Africa and South America [5, 6]. Its tectonic evolution was controlled by the Central African Shear Zone as well as other regional tectonic events, and experienced multi-stage of extension and structural inversion, resulting in a complex basin structure and sedimentary strata features [7, 8].

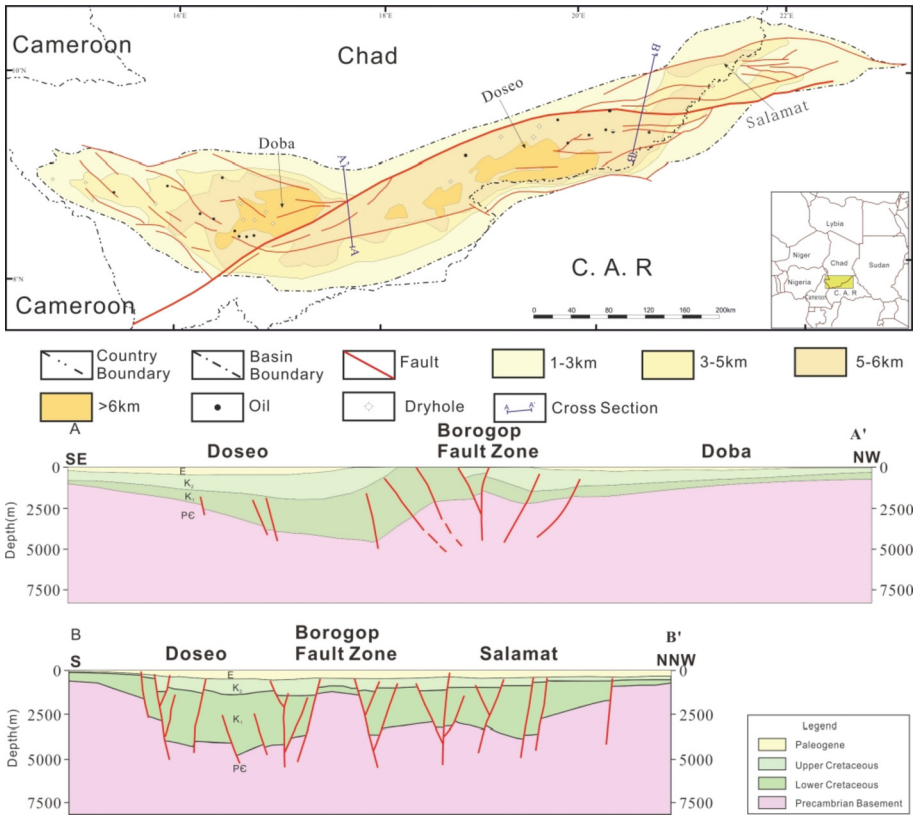

Fig. 2. Tectonic units and cross sections of Southern Chad Basin

Drilling data and outcrops shows that the basement of the Southern Chad basin is similar to those of other rift basins in Central and Western African Rift System (CWARS). The lithology is mainly composed of pre-Cambrian granites and granitic gneiss, dated back to the crystalized Gondwana basement formed in Pan African period (750-450 Ma) [3].

Early Cretaceous is the main time of rifting in Southern Chad basin. The rifting stage is generally considered as a result of the breakup of Africa and South America starting around 130 Ma, which caused large scale extension in Central African Shear Zone. NE-SW trending normal faults, which are parallel to the direction of Central African Shear Zone, are well developed in this stage, forming a series of half-grabens, steeps sided to the north or south in different positions in the basin.

Starting from 110 Ma, the direction of regional stress field in Central and Western Africa changed from NNW-SSE to NE-SW. This change has important impact on Southern Chad basin. First of all, the whole basin's sedimentation turn from rifting to sagging stage. Secondly, the change of stress field caused large scale lateral strike-slip of Central African Shear Zone, accompanied by extensional subsidence in different depressions. The Doseo depression, which is directly controlled by the shear zone, was stretched in

length by the strike-slip movement. The length and width ratio of Doseo Depression reached 7:1. Regional seismic profile and strata correlation shows that the sagging sediments in Doba and Doseo depression can be easily correlated and traced, indicating different depressions were essentially united as one basin during this period.

In Santonian period, the sedimentation in Southern Chad basin was interrupted by another regional tectonic event. The collision of African and Eurasian plate in 85 Ma caused an N-S compressional stress field in this area. It caused large scale folding and basin inversion in W-E trending basins, like Bongor, Southern Chad basin. While N-S trending basins, like Termit and Muglad, are less impacted. The compression caused

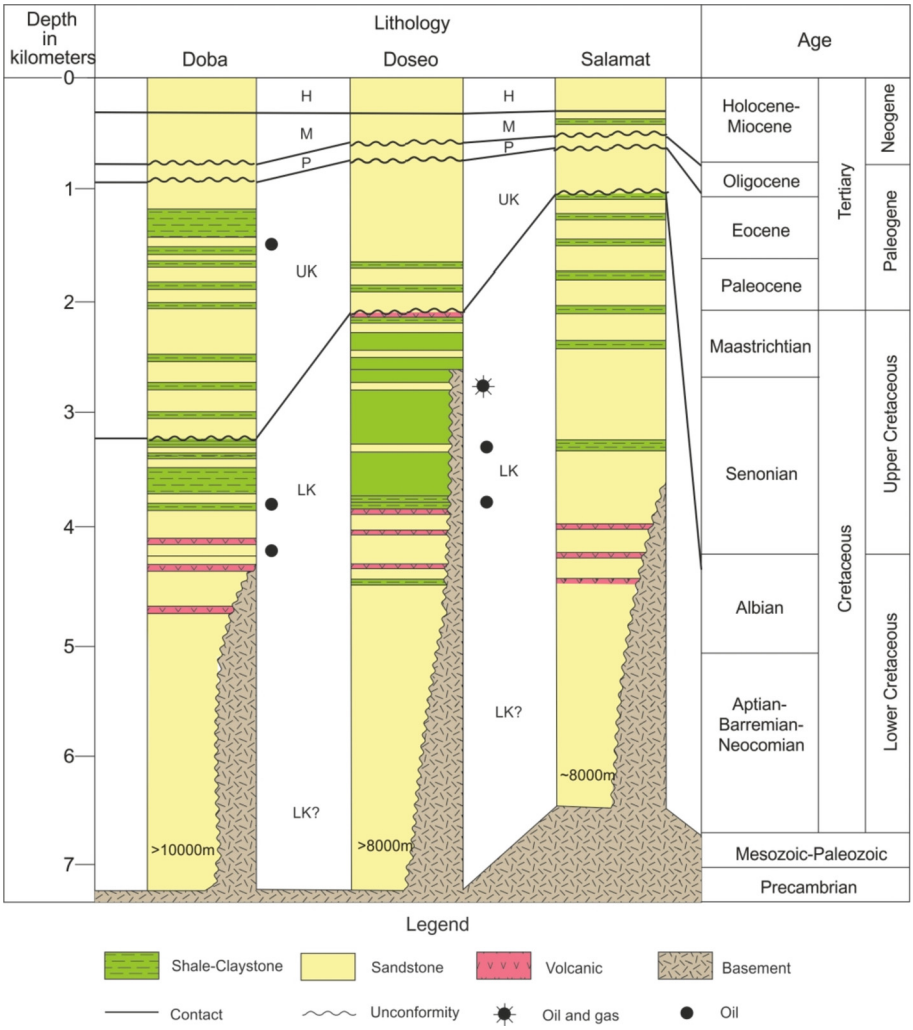

Fig. 3. Comprehensive stratigraphy Southern Chad Basin

re-activation of existing extensional faults and a series of long-axis anticlines for hydrocarbon accumulation in the Southern Chad basin. It is during this period when uplifts in Southern Chad basin were formed along the strike-slip fault and separated this basin into three independent depression.

The post-rift stage in Southern Chad basin began since 75 Ma when regional stress field became extensional again. The basin was generally stable and accepted thermal subsidence, accompanied by occasional weak structural inversion and igneous intrusions. This stage is favorable for hydrocarbon migration and preservation.

The basin was filled by up to an estimated 10000 m of Cretaceous to Recent, predominantly continental clastics (Fig. 3). The main source rock is the dark shale of rifting stage in lower Cretaceous, which is wide-spread and reaches several hundred meters in thickness. Geochemistry of Lower Cretaceous source rock in Doseo depression shows that the average TOC reaches 3.8%, and the kerogen type is mainly type I and type II1. In Doba depression, the main reservoir is the channel sand in Kome Fm of upper cretaceous which is overlapped by a regional caps rock, the Miandom shale. In Doseo and Salamat depression, the inter-bedded sandstone in lower Cretaceous become the only exploration target.

3 Petroleum Geology in Southern Chad Basin

Hydrocarbon exploration in the Southern Chad Basin starts in 1960s. After that, a series of major breakthroughs were made in this basin, including the great Kome field in Doba depression [2]. Till now, there are more than 30 oil/gas discoveries in Southern Chad Basin with a total recoverable reserve of 1.2 billion barrels. However, major discoveries are mainly located in the Doba depression, and the huge area in Doseo and Salamat depression remain under-explored with great hydrocarbon potential. This paper overviews previous research results in Southern Chad basin, analyzes geological feature and tectonic evolution of the basin. The hydrocarbon accumulation pattern and main controlling factors in this basin were summarized. The exploration potential and favorable plays were also predicted based on petroleum geology features and oilfield distribution.

Hydrocarbon distribution in the Southern Chad basin can be characterized as "prolific in the west and poor in the east, normal oil in the lower payzone and heavy oil in the upper payzone".

The Doba depression in the west part is the most prolific area in the basin. More than 1 billion of recoverable reserve has been proved in Doba depression. Oil is being commercially produced from both upper and lower Creatceous reservoirs (Fig. 4).

It is in recent years when the Doseo depression become an exploration focus. Several important exploration breakthroughs has been made in this area. Because of sedimentary facies change in upper Cretaceous and structural inversion, the lower Cretaceous become the main exploration target in Doseo depression (Fig. 5).

The Salamat depression remain under-explored and no hydrocarbon has been found in this depression yet. From a wild cat well drilled in 1970s and 2D seismic imaging, it is presumed that Salamat depression is close to the provenance area and the source and caps rock are not proven yet.

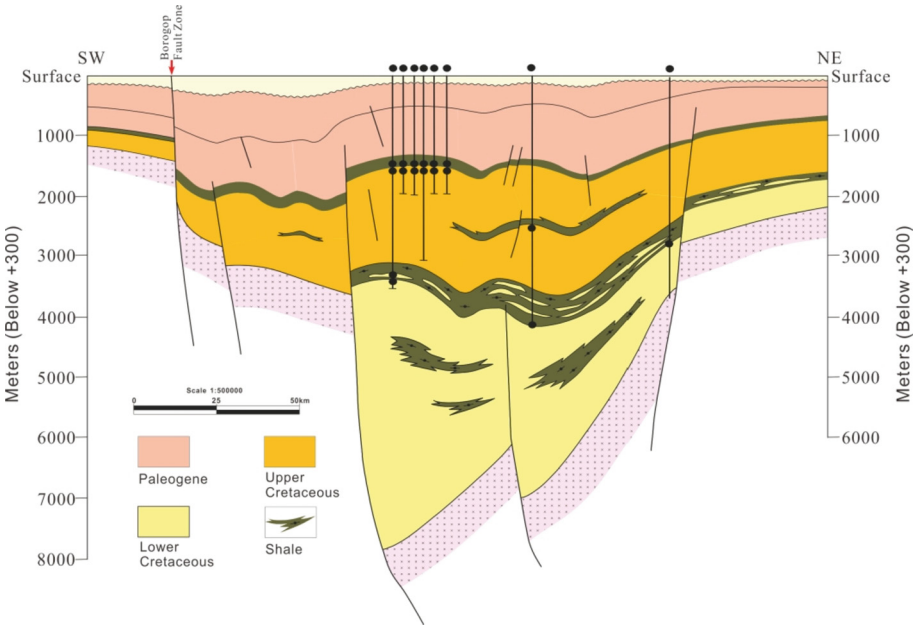

Fig. 4. Typical reservoir profile in Doba depression

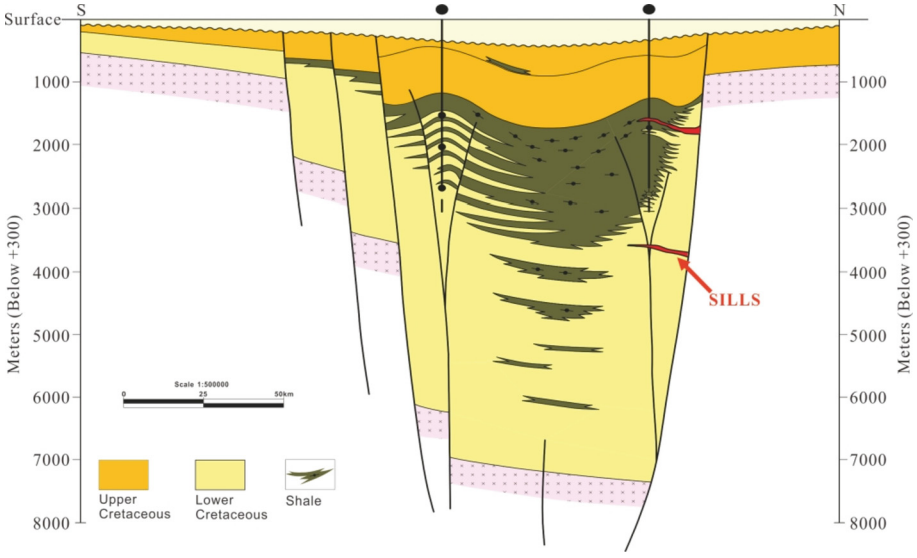

Fig. 5. Typical reservoir profile in Doseo depression

Two reservoir-seal combinations have been revealed in the basin, namely upper Cretaceous payzones and lower Cretaceous payzones. The Kome sand and Miandom shale combination of upper Cretaceous is the most important payzone in the Southern

Chad basin, which contributes 80% of reserve. Heavy and viscous crude oil (Gravity: 15–25°API) was produced from the porous Kome sandstone (Porosity: 23%-30%). However, this combination can only be found in Doba depression.

In the lower Cretaceous payzone, the combination is inter-bedded sandstone and locally developed shale. The quality of oil produced from lower Cretaceous is generally waxy, light to medium in gravity (average 34°API). The difference of oil quality between upper and lower Cretaceous is often interpreted as biodegradation and water washing during oil migration from the source rock in lower Cretaceous to upper Cretaceous.

4 Controlling Factors on Hydrocarbon Accumulation

The hydrocarbon distribution in the Southern Chad basin is mainly controlled by the sedimentary environments and structural history. Based on the geological background and hydrocarbon accumulation pattern, we propose three controlling factors on hydrocarbon distribution in the basin.

4.1 Effective Source Kitchen Controls the Scale of Hydrocarbon Potential

Oil-source correlation shows that the oil in the basin are generated from lower Cretaceous lacustrine shale of rifting and depression stage. Two hydrocarbon kitchens have been proven in the Southern Chad basin, which are located in Doba and Doseo depression respectively. Geochemical analysis indicates the dark shale of lower Cretaceous are good-excellent quality source rocks, with rich organic matter and high TOC. The hydrocarbon was preserved in sandstones of lower Cretaceous nearby the source rock or migrated upwards into the upper Cretaceous reservoir through faults or permeable strata.

In Doba depression, the area and thickness of mature source rock in lower Cretaceous is larger than that in Doseo and Salamat depression. Therefore, the Doba depression has the largest hydrocarbon potential. The abundance of source rock can explain why the majority of oil was found in Doba depression.

Affected by the strike slip of CASZ, the Doseo depression is a narrow, elongated rift, with a length to width ratio of 7:1. The mature hydrocarbon kitchen was developed in the northeast part of depression. Basin modeling shows that there is still huge exploration potential in Doseo depression. More than ten oil-bearing structures have been found in the east part of Doseo depression, around the kitchen area. While in the west part, there is no oil/gas discovered yet.

From a wild cat well drilled in Salamat depression, bitumen was encountered in the sand reservoir of lower Cretaceous, indicating oil was generated in this area. However, the thickness and lithology of lower Cretaceous in Salamat depression is not favorable for hydrocarbon generating. Therefore, the hydrocarbon potential is smaller than Doba and Doseo depression.

4.2 Structure Activity Controls the Trap Type

Oilfields in the basin are mainly found in uplifts or faulted-related structures near hydrocarbon kitchen area, showing structural history has strong influence on the hydrocarbon distribution.

The structure inversion during Santonian period is the main stage of trap forming. The major trap type of upper Cretaceous is huge long-axis anticlines formed during structural inversion, such as the Kome field in Doba depression. In the lower Cretaceous, the structural traps are usually controlled by faults, such as faulted noses or tilted fault blocks. Although structures in lower Cretaceous is greater in number, they are more complex and faulted. The scale and amplitude of structural traps in lower Cretaceous is also smaller than that in upper Cretaceous.

The strike slip activity of CASZ also has strong influence in the basin. In Doba and Doseo depression, the stress field is transpressional by the dextral movement, which is favorable for trap forming and fault sealing. However, the Salamat depression is located in the horsetail splays at the east end of the CASZ. The stress field in this depression is tanstensional, which developed very complex and high throw normal faults. Although a huge uplift is developed in the central of depression during the structural inversion, it is commonly considered the preservation condition is poor and exploration potential is small.

4.3 Faults and Seals Rock Controls the Vertical Distribution of Hydrocarbon

Faults plays an important role in hydrocarbon reservoirs of the Southern Chad basin. First of all, most of the structures in lower Cretaceous are fault related and lateral sealing of faults is key for hydrocarbon accumulation. In Doseo depression, a group of symmetrical normal faults, which is conjugate to the CASZ, is developed in the central uplift and controls most of the structures in this area (Fig. 6). Secondly, faults are important path for hydrocarbon migration from lower to upper Cretaceous traps.

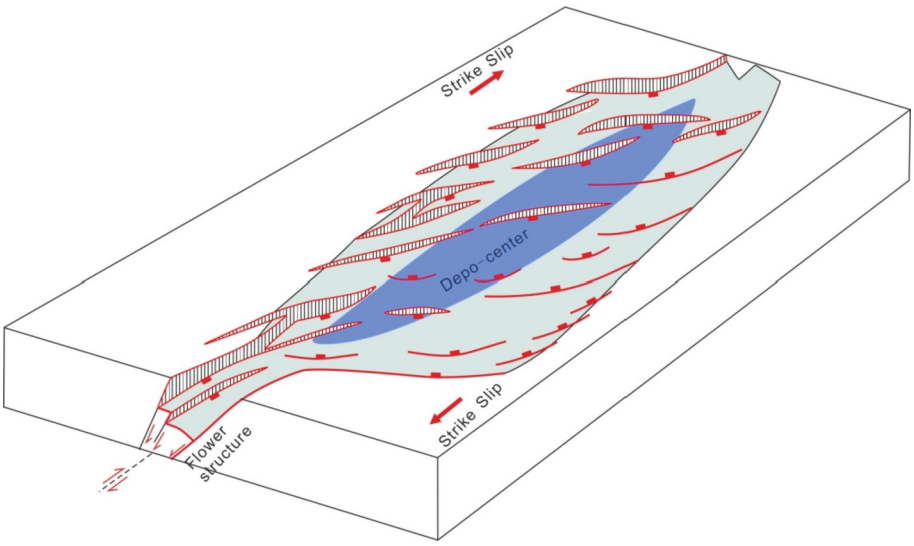

Fig. 6. Strike slip related faults in Doseo depression

Meanwhile, the sedimentary environment during upper Cretaceous is different in the basin. The paleo-water depth is deeper in Doba depression than in Doseo and Salamat depression. Therefore, the Miandom shale of upper Cretaceous was deposited in Doba depression and acts as a regional seals rock. However, this shale become sandy in Doseo and Salamat depression, making the upper Cretaceous reservoir ineffective in the two depressions.

5 Exploration Potential

Given the vast area (13×10^4 km^2) and remarkable thickness of sediments (>10 km), the Southern Chad basin is one of the most prolific basins among the rift basins along the CASZ. Although more than 1.2 billion barrels of recoverable reserve has been found in the basin, the exploration degree varies in different depressions and the exploration potential remain huge.

In Doba depression, the upper Cretaceous reservoir in the central depression has been widely explored and favorable structures are increasingly hard to identify. The exploration direction is the lower Cretaceous play inside or near the boundary of Doba depression. In recent years, oil companies (Glencore and OPIC) has made several important discoveries in lower Cretaceous play in Doba depression, suggesting there is still potential in this area. Meanwhile, the basement play is attracting more and more attention in rift basins of CARS, after the basement breakthrough in Bongor basin [9].

In Doseo depression, the main exploration target is complex fault-related structures in lower Cretaceous. Oil and gas discoveries are mainly located in the northeast boundary and the central uplift, around the existing source kitchen. The future exploration direction is to identify and screen small-scale structures in lower Cretaceous through detailed exploration, such as 3D seismic data and reservoir prediction.

Despite the extremely low exploration degree in Salamat, it is inferred that hydrocarbon has been generated and migrated in this depression. A large scale uplift, which is strongly faulted and altered by multi-stage tectonic movements, can be identified in the center of the depression. Future exploration will focus in this area.

6 Conclusion and Discussion

The Southern Chad Basin is a Cretaceous-Paleogene rift basin developed on a pre-Cambrian basement. Affected by multi-staged tectonic events, the structural and sedimentary geology of this basin has its own features, which is different from other rift basins in CARS.

The hydrocarbon geology in Southern Chad Basin is characterized as “prolific in the west and poor in the east, normal oil in the lower payzone and heavy oil in the upper payzone”. Effective source kitchen, structural history, faults/seals combination are key conditions for hydrocarbon accumulation.

There is huge exploration potential in Southern Chad Basin. The Doseo depression in the middle of the basin become an exploration focus in recent years. Future exploration directions includes: lithological or basement traps in Doba depression, inverted structures in Doseo depression and central uplift in Salamat depression.

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