Mechanism Study of Hydrocarbon Differential Distribution Controlled by the Activity of Growing Faults in Faulted Basins: Case Study of Paleogene in the Wang Guantun Area, Bohai Bay Basin, China

Xixin Wang, Xinrui Zhou, Shaohua Li, Naidan Zhang, Ling Ji, and Hang Lu

1Cooperative Innovation Center of Unconventional Oil and Gas, Yangtze University (Ministry of Education & Hubei Province), Wuhan 430100, China
2State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Chengdu University of Technology, Chengdu 610059, China
3School of Geosciences, Yangtze University, Wuhan 430100, China
4Dagang Oilfield Company, CNPC, Cangzhou 061000, China
5Jilin Oilfield Company, CNPC, Jilin 130000, China

Correspondence should be addressed to Shaohua Li; li534354156@sina.com

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Mechanisms that lead to different quantities of hydrocarbon accumulation in complex fault blocks are a major subject that impacts further development plans of oil and gas fields. To better understand such mechanisms, fault activity has been interpreted along with existing electron micrographs from the fault zone, petrophysical data, and the occurrence of the seismic pump. This enabled us to investigate the controlling mechanisms of the growth faults and other associated faults with the main growth fault in the Wang Guantun area that could have impacted hydrocarbon distribution. The results showed that the activity of Kongdong growth fault is periodic and intermittent, which produced strong seismic pumping action. Furthermore, a series of secondary faults were generated in adjacent strata due to the fault activity, which could have led to the formation of a secondary seismic pump source. A combination of these two incidents is believed to influence the differential distribution of hydrocarbons in the area, in fault-associated reservoirs. Ultimately, we correlated the activity of the growth fault to the strength of the pumping force causing the distribution of hydrocarbons in the active parts of the faults (pump source position) on the horizontal plane and vertically located reservoirs to be more dominant.

1. Introduction

During an earthquake, the dynamic conditions of groundwater change dramatically, which is often accompanied by the occurrence of water, to spill from dry wells [1, 2]. It is generally recognized that water well bubbling, flower’s sudden bloom, increase in the temperature, discoloration caused by minerals or sediments in the water, sudden rise in the water table towards shallower depths, and other phenomenon are the precursors of the earthquake [3, 4].

The earthquake will affect oil fields near the epicenter and will cause abnormalities in the production of oil wells, i.e., the Haicheng and Tangshan earthquakes [5, 6]. Scholz et al. [7] reported that faulting activity could result in large-scale movement of fluids from or near faults and Sibson et al. [8] defined this phenomenon as seismic pumping. They pointed out that fault activity acts as a pump, creating a huge suction force that draws the fluid from the surrounding formation into the fractured or fault zones. Hooper [9] was the first who explained that seismic pump could cause...
the secondary migration of oil and gas and believed that growth faults, in particular, can become an effective pathway for the secondary migration of hydrocarbons. This concept has been applied for exploration in the faulted basin of eastern China [10–13]. Later on, Sun et al. [14] studied the migration and accumulation mechanisms of natural gas during the seismic pump through a physical simulation of oil and gas migration and accumulation.

The migration of hydrocarbons controls hydrocarbon accumulation, and it has been widely accepted that faults are the secondary migration pathway for hydrocarbons. This can become the main controlling factor of oil and gas accumulation in faulted basins, in particular [15–20]. However, the controlling factors of oil and gas distribution in structurally complex reservoirs such as the Wang Guantun area in the Bohai Bay Basin with well-developed growth faults are still unclear and require further studies.

In this study, based on oil and gas distribution characteristics and the growth fault activity in the Wang Guantun area, the "seismic pumping" theory was utilized to understand hydrocarbon differential accumulation and distribution in the reservoir fault blocks.

1.1. Geologic Setting and Hydrocarbon Distribution Characteristics. The Wang Guantun area is located on both sides of the Kongdian Structural Belt in the south of Huanghua depression, Bohai Bay Basin, China (Figure 1). The Wang Guantun area is a complex anticline structure controlled by Kongdong and associated faults, with an area of 140 km². The Kongdong Fault divides Wang Guantun into two regions, Kongdong region and Kongxi region (Figure 1(d)). As one of the main prolific areas in Bohai Bay Basin, there are more than 1,700 wells including exploration, evaluation, and development wells that have been drilled in this area. More than 230 wells were cored. Paleogene Kongdian, Shahejie, and Neogene Dongying, Guantao, and Minghuazhen groups constitute the stratigraphic column of the study area (Figure 2), where the Kongdian Formation is further divided into Ek1,Ek2, and Ek3 members. The second member of the Kongdian Formation (Ek2) is a thick lacustrine deposit with rich organic matter, which is an effective source rock in this area [22–25]. Alluvial fan and fan delta depositional systems are mainly developed in the first member of the Kongdian Formation (Ek1) making it the main reservoir in this area [26]. The thick gypsum-salt rocks are developed in Z1 and Z0 beds, which are regional caprocks (Figure 2). Volcanic rocks, sandstones, conglomerates, and other lithologies are developed in the lower member of the Es3 group, and thick mudstone is developed in the upper member of the Es3 group. The bottom of the Es1 member is shallow lacustrine deposits, which are mainly biogenic limestone and sandstone reservoir, while the thick mudstone was deposited above the Es1 member. Ultimately, the Shahejie Formation has two sets of separate traps with reservoir and caprock [26] (Figure 2).

There are great differences in hydrocarbon accumulation and distribution in Wang Guantun area. The terrain of the target layer of Wang Guantun area is characterized by higher in the north and lower in the south. However, most of the oil and gas in Wang Guantun area are concentrated in the central region of the study area, not in the north region of the study area. In addition, more hydrocarbon-bearing fault blocks in Kongdong region, the downthrow wall of Kongdong Fault, than in Kongxi area. The oil and gas-bearing area in the downthrow wall is much larger than that in the upthrow wall (Figure 1(d)). In a vertical profile, hydrocarbons are distributed in the Ek1,Ek2 members of the Kongdian Formation, and the Es1 member of the Shahejie Formation. The amounts of hydrocarbon accumulation in the ZIII and ZII beds of the Ek1 of the Kongdian Formation is greater than those of the Shahejie Formation. The reasons for the differential distribution of oil and gas are extremely important to be studied for further exploration and development in fault block oil and gas fields.

1.2. Data and Experimental Method. The porosity and permeability of 4,547 data points along with the 3D seismic sections were retrieved from the Dagang Oil-field Company, China National Petroleum Corporation (CNPC) database. The dominant frequency of the seismic data is 30 Hz, and the bandwidth is from 10 to 70 Hz. The commercial software, Petrel (Mark of Schlumberger), was used to pick the horizons on the seismic data. Next, available samples were cut into a cuboid with 15 mm width and 5 mm length and were polished with silicon carbide papers; then, a Hitachi S4800 microscope was used to obtain micrographs of the samples.

Growth index, fault falling difference, and activity rate methods are the most commonly used methods to study fault activity [27–31]. The fault falling difference refers to the difference between the upthrown wall thickness and the downthrown wall thickness. The growth index refers to the ratio between the upthrown wall thickness and the downthrown wall thickness. In this study, the fault falling difference and the growth index methods were used to evaluate the activity of growth faults. Based on seismic horizon interpretation and comparison between seismic and drilling, we obtained the thickness of the strata on both sides of growth faults and calculated the difference and the ratio of strata thickness.

Under stress, the weaker parts of the rock stratum will fracture and form cracks, and the cracks will further develop into a fracture zone. Because the stress is concentrated at the crack’s tip, it will extend and connect and develop into a macro fault plane. Stress changes occur either during the formation of the faults or during the activity of growth faults. The fracturing of the stratum in the direction of σ2 is caused by the differential stress between σ1 and σ3, which causes the rock inside the fracture zone to expand due to an increase in the pore space. This creates a negative pressure or a suction zone. Hence, the differential pressure between the inside and outside causes fluids to migrate into the fractured zone (Figure 3), which is known as the suction by the seismic pump. When the fluid enters the fractured zone, the fluid pressure gradually increases so that the shear strength of the rock will gradually decrease. When the external stress becomes greater than or equal to the shear strength of the
rock layer, a fault surface in the direction of the dominant shear fracture will form. As the fault blocks move, the fluids will move to the lower pressured zones upward which represents the displacement process of the seismic pump. The same process happens when hydrocarbons are expelled from the source rock and would later enter the fault zone to get accumulated in the reservoir rock while this process can take place in several stages since the fault activity can be a multi-stage process.

2. Results

2.1. The Activity of Kongdong Fault. Kongdong Fault is one of the most important synsedimentary faults in Wang Guantun area. Kongdong Fault strikes NNE and tends to SE, extending about 25 km (Figure 4). Due to the continuous activity of Kongdong Fault, the fault distance of Kongdong Fault varies greatly in different regions. The fault distance of Mesozoic strata increases gradually up to ~2000 m. The formation thickness of two walls of fault in Ek2 and Ek3 members is the same. Kongdong Fault did not have the characteristics of synsedimentary in the sedimentary period of Ek3 and Ek2.

The activity of the Kongdong Fault was studied using the fault falling difference and the growth index methods. The fault amplitude of the Kongdong Fault varies notably in different areas. As shown in Figure 5, the falling difference and growth index of the Kongdong Fault are largest in the ZIII and ZII members vertically, while the distance of the Kongdong Fault on the 2D horizontal plane is relatively short.
The fault activity decreased in the Es3 and Es2 stages of the Shahejie Formation. In Es1, fault activity is still significant and the extension of the fault on the 2D plane reaches the maximum. When Guantao was formed, the fault activity was stopped and this being said, the fault activity on a horizontal plane would become significant that can be identified near inline 384 (Guan195 area and Guan3 area). Then, the fault activity decreases away from both fault blocks. That
means the seismic pumping effect of the Kongdong Fault should be the strongest in the upper Ek1 member and the Shahejie Formation, in the Guan195 area and Guan3 area.

2.2. Formation of Secondary Faults in Wang Guantun Area. As shown in Figure 1, the Wang Guantun area is bounded on the east by synthetic Xuxi Fault and by the Kongdong Fault as the antithetic fault on the other side. The throw of the Xuxi Fault and Kongdong Fault is “H” and “h,” respectively. When “H” and “h” as well as the difference between the throws are large, the graben will produce a large external synthetic rotation. This will lead to the formation of relative shear stress in the strata. Furthermore, with the gradual increase in the shear stress, a series of en echelon faults in the strata, as shown in Figure 6, will be generated. In Wang Guantun area, the difference between the throws generated by the Xuxi Fault and the Kongdong Fault activities has led to many secondary faults in the hanging wall of Kongdong Fault. The formation of these secondary faults can produce secondary seismic pumping effects that increase the suction power of the strata.

2.3. Reservoir Capacity Difference between Two Sides of the Kongdong Fault. There are two main types of pores in the Ek1 member of Wang Guantun area, primary intergranular pores and dissolution pores. The primary intergranular pore is the residual pore volume after the intergranular volume is greatly reduced under compaction. The dissolution pores are mainly feldspar leaching pores formed by acidic fluids that have dissolved feldspar. Many dissolution pores are developed in the downthrow of the Kongdong Fault (Figures 7(a) and 7(b)), and the average porosity of dissolution pores in a 2D horizontal plane ranges from 2.95% to 5.22% (Figure 7(c)). On the contrary, the pore types in the upthrow of Kongdong Fault are mainly primary intergranular pores. It is a common phenomenon to encounter pores that are filled with clay minerals (Figures 7(d) and 7(e)). Hence, the average porosity of dissolution pores in the upthrow of Kongdong Fault is mainly between 1.38% and 2.75% (Figure 7(f)).

Reservoir limit test results show that the porosity of the two sides of the Kongdong Fault is extremely different. The porosity of samples in the downthrow side of the Kongdong Fault is from 1.4% to 32%, with an average value of 23%, and nearly 60% of the samples are mainly distributed in 15%-25%, while the porosity of the samples in the upthrow side varies from 1.5% to 29%, with an average of 18%, and 47.3% of the samples' porosity are distributed between 10% and 20% (Figure 8).

3. Discussion

3.1. Determination of Pump Source Location and Dominant Reservoir. Considering seismic pump suction mechanisms, the negative pressure of the crack zone is the driving force of the seismic pump suction. In fault zones, seismic pump action generally occurs at the active site of the growth faults, and its power increases as the growth fault activates. This would be the zone where oil and gas will preferentially accumulate which will eventually control the distribution of hydrocarbons in the fault zone.

When the growth faults connect multiple reservoirs, the key factor is to determine which reservoir will be the first candidate for the hydrocarbon to migrate. Since fluids move in the direction of least resistance, which depends on the reservoir properties on both sides of the faults, fluids will first enter the side with poor sealing, causing a majority of hydrocarbons to be lost. When the sealing degree of reservoirs on both sides of faults is similar, hydrocarbons will enter the reservoir causing an increase in the fluid pressure (pore pressure). Additionally, in the fault zone, the reservoir with a larger thickness would be easier to enter, as shown in Figure 9(a). When the reservoir thickness on both sides is approximately the same, the reservoir with higher porosity will be filled, as shown in Figure 9(b). In addition, the side where en echelon faults are developed, will have a greater pumping capacity, and the hydrocarbons in the fault zone are easily entered into this side, as shown in Figure 9(c).

The activity of the growth faults controls the accommodation potential of both sides of the fault [32–37]. In Ek1, the thickness of the downthrow side of Kongdong Fault is larger than that of the upthrow side. The dissolution pores of the downthrow side are more developed so that the reservoir capacity of the downthrow side is better overall. In addition, the presence of en echelon faults in the downthrow side of Kongdong Fault can produce stronger secondary seismic pumping. Therefore, oil and gas in the fault zone are more likely to enter the ZIII and ZII beds in the hanging wall of the Kongdong Fault. This being said, the ZIII and ZII beds in the hanging wall of the Kongdong Fault are considered the dominant reservoirs in the zone.

3.2. Control of Gypsum-Salt Rock Caprock on Oil and Gas Preservation. During the deposition period of Guantao and Minghuazhen Formation, Kongdong Fault stopped moving, and seismic pumping is weakened. As a result, oil and gas migrate upward along the fault plane due to the buoyancy force. Moving upward the migration speed was slow, and the accumulation efficiency deteriorated. It is worth noting that a set of thick gypsum and salt rocks are deposited between Shahejie Formation and Ek1 member (Figure 2). As the main cap rock of ZII bed, the sealing ability of
gypsum-salt determines the hydrocarbon retention degree of ZII bed. If the sealing ability is poor, the oil and gas that have entered in ZII bed will be lost again. By studying the relationship between the thickness of gypsum-salt rocks and the reserve abundance of ZII bed, an obvious positive correlation can be obtained. With the increase of thickness of gypsum-salt rock, the reserve abundance in ZII bed gradually increases. The thickness of gypsum-salt rock is the key to oil and gas preservation in the study area. Figure 10 showed that the critical thickness of effective sealing capacity of gypsum-salt rock is about 25 m. When the thickness of gypsum-salt rock is less than 25 m, the reserve abundance...
Figure 7: The main pore types and the average plane porosity of dissolution pores (PPDP) in two sides of Kongdong Fault.

Figure 8: (a) The porosity distribution in the downthrow wall of Kongdong Fault; (b) the porosity distribution in the upthrow wall of Kongdong Fault.

Figure 9: Analysis of hydrocarbon migration direction. (a) The reservoir space of two sides is different. (b) The property of two sides is different. (c) The number of faults of two sides is different.
of ZII bed is close to zero. Many scholars have concluded that when the gypsum-salt rock acts as the caprock of the reservoir, the thickness of the gypsum-salt rock is indeed the key condition for oil and gas occurrence [38–40].

3.3. Model of Hydrocarbon Differential Distribution. The reservoir in the Wang Guantun area is a complex fault block that is self-sourced. The oil shale of Ek2 member is the most important source rock in this study area. Moreover, there are some fine sandstones and siltstones adjacent to the oil shale that would become the first reservoir: Guan 68 well area, as shown in Figure 10, produces from such reservoirs.

Hydrocarbons in ZIV and ZV beds of the Ek1 member are mainly from primary migration, while in ZII and ZIII beds of the Ek1 member, secondary migration is responsible for the accumulation of oil and gas. In the late period of Ek1 and Shahejie Formation, the source rocks of the Ek2 member began to expel large quantities of hydrocarbons when the activity of Kongdong Fault was strong. This resulted in a notable seismic pump and abnormally higher pressures acting on the source rock, so the hydrocarbons enter the Kongdong Fault and move in the direction of minimum resistance. Oil and gas entered into a suitable reservoir space of the Ek1 member to form prolific reservoirs. Because of the multistage activity of the growth fault, hydrocarbons that initially entered the ZV and ZIV beds returned to the Kongdong Fault zone under the seismic pump phenomenon and entered ZIII and ZII beds finally, leaving the former beds less prolific.

There are clear differences between the two reservoirs at two sides of the Kongdong Fault, causing the amount of accumulated hydrocarbons to be more in the hanging wall of the Kongdong Fault compared to the footwall (Figure 10). During the deposition of the Guantao Formation, the Kongdong Fault was not active; therefore, the seismic pump was weak. This caused the hydrocarbons to migrate upward to the Shahejie Formation reservoir due to buoyancy. The thick gypsum-salt rock between Ek1 and Shahejie Formation has an important influence on preserving the oil and gas in the Ek1 member. Hence, if the thickness of gypsum-salt rock was small, the oil and gas in the ZIII and ZII layers could have been lost, escaping upward, or accumulated in the Shahejie Formation (Figure 11).

Several stages of the growth fault activity result in the multiphase pumping phenomenon sucking in the fluids.
During the first active period of the growth faults, fluid in the source rock was sucked into the fault zone and migrated to the reservoirs on both sides because of the pressure difference. When the second activity of the growth fault happened, the pumping force that was produced acted on the source rock and the underlying reservoirs simultaneously. This means later seismic pumping activities impacted the earlier accumulated hydrocarbons in the first reservoirs. Collectively, in this process, the fluid that entered the growth fault zone always would migrate to the layers with larger storage space and higher permeability, which is extremely different from fluid migration driven by the buoyancy force.

4. Conclusions

In this study, the difference in hydrocarbon accumulation in a growth fault is studied and underlying reasons are investigated and inferred to the fault activity and the seismic pump effect. Overall, the following conclusions can be made from this study:

1. The main driving force of the secondary migration of oil and gas is inferred to the seismic pump caused by the activity of the growth fault. This has controlled the development of reservoir spaces, various reservoir properties on both sides of the faults, and ultimately the source of secondary seismic pumps to impact hydrocarbon distribution.

2. In a complex fault block and associate reservoirs, the distribution of oil and gas is controlled not only by the relief and reservoir property distribution as stated in the previous point but also by the activity of growth faults. This means in a horizontal plane, hydrocarbons are mainly accumulated in regions with strong fault activity; furthermore, in the vertical profile, oil and gas are mainly found in shallower reservoirs because of the secondary seismic pump effect to cause hydrocarbons to leave initially filled reservoirs in the deeper parts.

Data Availability

All data can be obtained from the corresponding author.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

[1] F. Zhen, H. Xianliang, W. Xiaoli, Y. Yuanyuan, N. Hongyu, and Z. Bin, “The post seismic effect of far-field strong earthquakes of water radon and its mechanism analysis for L01 well of Lujiang geothermal hot spring,” Acta Seismologica Sinica, vol. 42, no. 6, pp. 732–744, 2020.
[2] S. H. Lee, J. M. Lee, S. H. Moon et al., “Seismically induced changes in groundwater levels and temperatures following the ML5.8 (ML5.1) Gyeongju earthquake in South Korea,” Hydrogeology Journal, vol. 29, no. 4, pp. 1679–1689, 2021.
[3] S. K. Sahoo, M. Katlamudi, and U. L. Gakka, “Singular spectrum analysis on soil radon time series (222Rn) in Kachchh, Gujarat, India, detection of periodic oscillations and earthquake precursors,” Arabian Journal of Geosciences, vol. 13, no. 19, pp. 55–57, 2020.
[4] H. J. Su, L. L. Cao, and H. Zhang, “The method for identifying the earthquake precursor of water radon - taking the water radon anomaly of Qingshui hot spring in Gansu Province as an example,” Earth, vol. 40, pp. 198–213, 2020.
[5] Q. L. Wu and J. N. Liu, “Anomalous variations in production oil wells before and after the great Haicheng and Tangshan earthquakes,” Acta Seismologica Sinica, vol. 5, no. 4, pp. 461–466, 1983.
[6] D. Y. Zhang and G. M. Zhao, “Anomalous variations in oil wells distributed in the Bohai bay oil field before and after the Tangshan earthquake of 1976,” Acta Seismologica Sinica, vol. 5, pp. 360–369, 1983.
[7] C. H. Scholz, L. R. Sykes, and Y. P. Aggarwal, “Earthquake prediction, a physical basis,” Science, vol. 181, no. 4102, pp. 803–810, 1991.
[8] R. H. Sibson, J. M. Moore, and A. H. Rankin, “Seismic pumping - a hydrothermal fluid transport mechanism,” Journal of the Geological Society, vol. 131, no. 6, pp. 653–659, 1975.
[9] E. C. Hooper, “Fluid migration along growing faults in compacting sediments,” Journal of Petroleum Geology, vol. 14, pp. 161–180, 1991.
[10] B. Liu, S. He, L. Meng, X. Fu, L. Gong, and H. Wang, “Sealing mechanisms in volcanic faulted reservoirs in Xujiawei extension, northern Songliao Basin, northeastern China,” AAPG Bulletin, vol. 105, no. 8, pp. 1721–1743, 2021.
[11] F. Qu, Q. H. Shen, C. B. Lian, J. T. Zhang, and F. L. Cai, “Distribution and accumulation of oil and gas in southern Huanhua Depression,” Petroleum Exploration and Development, vol. 35, no. 3, pp. 294–300, 2008.
[12] X. Wang, J. Hou, S. Li et al., “Insight into the nanoscale pore structure of organic-rich shales in the Bakken Formation, USA,” Journal of Petroleum Science & Engineering, vol. 191, article 107182, 2020.
[13] F. L. Yan, D. Jia, H. F. Lu, and G. W. Xu, “Seismic pumping mechanism of hydrocarbon migration in Dongying depression,” Oil and Gas Geology, vol. 4, pp. 295–298, 1999.
[14] Y. H. Sun, X. F. Fu, Y. F. Lu, and G. Fu, “Suction role of seismic pumping and physical simulation on hydrocarbon migration and accumulation,” Journal of Jilin University (Earth Science Edition), vol. 1, pp. 98–104, 2007.
[15] G. Fu and L. Lei, “Research on differences of controlling of fault to oil accumulation in and outside oil source area - an
example of Fuyu - Yangdachengzi oil layers in Sanzhao Depression and Chang 10 block, Songliao Basin,” *Geological Review*, vol. 56, pp. 719–725, 2010.

[16] Y. Liu, R. Li, H. Zhao, W. Wei, X. Wang, and C. Cao, “Characteristics of deep large fault and its effects on gas accumulation, a case study on Wanjinta area in Dehu fault depression of the Songliao Basin,” *Natural Gas Exploration and Development*, vol. 40, pp. 23–29, 2017.

[17] Y. Liu, Z. Deng, G. Sun, and H. Cao, “Reservoir characterization of banqiao rupture structural belt,” *Natural Gas Geoscience*, vol. 14, pp. 275–278, 2003.

[18] B. Liu, J. Sun, Y. Zhang et al., “Reservoir space and enrichment model of shale oil in the first member of Cretaceous Qingshan-kou Formation in the Changling sag, southern Songliao Basin, NE China,” *Petroleum Exploration and Development*, vol. 48, no. 3, pp. 608–624, 2021.

[19] Q. Luo and X. Pang, “Reservoir controlling mechanism and petroleum accumulation model for consequent fault and anti-thetic fault in Fushan Depression of Hainan area,” *Acta Seismoologica Sinica*, vol. 29, pp. 363–367, 2008.

[20] C. Zhang, X. Xie, T. Jiang, and X. Liu, “Hydrocarbon migration and accumulation along a long-term growth fault: Example from the B225-1 oilfield of Bohai basin, eastern China,” *Journal of Geochemical Exploration*, vol. 89, no. 1-3, pp. 460–464, 2006.

[21] X. Wang, Y. Liu, J. Hou et al., “The relationship between syn-sedimentary fault activity and reservoir quality - a case study of the Ek1 formation in the Wang Guantun area, China,” *Interpretation*, vol. 8, no. 3, pp. Sm15–Sm24, 2020.

[22] Q. Y. Dong, X. P. Liu, H. X. Li et al., “Formation conditions of shale oil reservoir in the second member of Kongdian formation in southern Songliao area, Huanghua depression,” *Natural Gas Geoscience*, vol. 1, pp. 188–198, 2013.

[23] N. E. Yuan, Q. Jia-Fu, L. I. Ting-Hui, Z. H. Ge, L. Ming-Gang, and S. H. Kui-Tai, “Characteristics of Cenozoic fault system and its significance in petroleum geology in Kongnan area, Huanghua Depression,” *Geoscience*, vol. 6, pp. 1077–1084, 2009.

[24] X. Wang, J. Hou, Y. Liu, L. Ji, and J. Sun, “Studying reservoir heterogeneity by analytic hierarchy process and fuzzy logic, case study of Es1x formation of the Wang guan tun oilfield, China,” *Journal of Petroleum Science & Engineering*, vol. 156, pp. 858–867, 2017.

[25] E. A. Xu, X. L. Li, Q. K. Wang, G. Xia, L. Dong, and Z. Li, “Main controlling factor and model of Kongdian Formation hydrocarbon accumulation in Kongnan Area of Huanghua Depression,” *Fault-Block Oil and Gas Field*, vol. 3, pp. 278–281, 2014.

[26] K. Song, S. Wu, W. Zhu, Q. S. Gong, Q. Z. Huang, and Z. B. Lv, “Reservoir quality of the lower part of Member 1 of Shahejie Formation of Paleogene in Tangjialue Oilfield, Huanghua Depression,” *Journal of Palaeogeography*, vol. 7, pp. 275–282, 2005.

[27] G. Chen, J. Dai, X. S. Ye, L. Rong, and Y. Liang, “Comparative research on growth index and fault difference,” *Journal of Southwest Petroleum University*, vol. 29, pp. 20–23, 2007.

[28] Q. Li, F. Z. Luo, and C. Z. Miao, “Discussion on the research method and application of fault activity rate,” *Fault-Block Oil & Gas Field*, vol. 7, pp. 15–17, 2000.

[29] Z. H. Mou, “Study for moving velocity of contemporaneous fault,” *Xinjiang Petroleum Geology*, vol. 12, pp. 212–217, 1991.

[30] H. Wang and T. Liu, “Quantitative estimation of small fault drop by resampling time difference gradient method,” *Coal Geology & Exploration*, vol. 28, pp. 59–61, 2000.

[31] Y. Y. Xiao and X. Hao, “Limitations of fault growth index in sequence stratigraphic units,” *Petroleum Geology and Recovery*, vol. 10, pp. 1–12, 2003.

[32] C. Armstrong, D. Mohrig, T. Hess, T. George, and K. M. Straub, “Influence of growth faults on coastal fluvial systems: Examples from the late Miocene to Recent Mississippi River Delta,” *Sedimentary Geology*, vol. 301, pp. 120–132, 2014.

[33] L. E. Frostick and R. J. Steel, *Tectonic Signatures in Sedimentary Basin Fills, An Overview*, Blackwell Publishing Ltd., 2009.

[34] J. Z. Li and T. Yang, “The fault structure and its controlling role to hydrocarbon accumulation in Daqingzijing area, Southern Songliao Basin,” *Petroleum Exploration and Development*, vol. 31, no. 1, pp. 18–20, 2004.

[35] Z. Y. Lu, “Influence of the Paleogene structural styles on deposition and reservoir in Chezhen Sag, Bohai Bay Basin,” *Journal of Palaeogeography*, vol. 10, pp. 277–285, 2008.

[36] D. A. Pivnik, M. Ramzy, B. L. Steer et al., “Episodic growth of normal faults as recorded by syntectonic sediments, July oil field, Suez rift, Egypt,” *AAPG Bulletin*, vol. 87, no. 6, pp. 1015–1030, 2003.

[37] X. F. Shang, J. G. Hou, Y. Dong, and Y. Li, “Sedimentary mechanism and distribution pattern of beach-bar sandbodies mainly dominated by contemporaneous faults in Banqiao Sag,” *Journal of China University of Petroleum*, vol. 38, no. 6, pp. 32–39, 2014.

[38] K. Lerer, *Gypsum, Calcite, and Dolomite Caprock Fabrics and Geochemistry from the Gypsum Valley Salt Diapir, Paradox Basin, Southwestern Colorado*, The University of Texas at El Paso, 2017.

[39] Y. Lv, S. Zhang, and Y. Wang, “Quantitative relationship between caprock sealing capacity and caprock thickness,” *Acta Petrolei Sinica*, vol. 21, pp. 27–31, 2000.

[40] J. Shi, L. Li, L. Du et al., “Dynamic damage of fault to caprock and its influence on hydrocarbon transport: a case study of Gangdong fault in Qikou sag, Bohai Bay Basin,” *Acta Petrolei Sinica*, vol. 40, no. 8, pp. 956–964, 2019.