Earth Sciences
2024; 13(1): 1-7
http://www.sciencepublishinggroup.com/j/earth
doi: 10.11648/j.earth.20241301.11
ISSN: 2328-5974 (Print); ISSN: 2328-5982 (Online)

Favorable Reservoir Formation Models for Nearshore Underwater Fans in Narrow and Long Graben Type Fault Basins: A Case from Botai Sag of Yitong Basin

Ke Qin*, Li He, Ding Chaolong, Li Li, Wang Lei, Lu Yao, Cheng Jie, Xu Fei

Geological Research Center, Bureau of Geophysical Prospecting Inc, CNPC, Zhuozhou, China

Email address:
511125047@qq.com (Ke Qin)
*Corresponding author

To cite this article:
Ke Qin, Li He, Ding Chaolong, Li Li, Wang Lei et al. (2024). Favorable Reservoir Formation Models for Nearshore Underwater Fans in Narrow and Long Graben Type Fault Basins: A Case from Botai Sag of Yitong Basin. *Earth Sciences*, *13*(1), 1-7. https://doi.org/10.11648/j.earth.20241301.11

Received: December 17, 2023; **Accepted**: January 4, 2024; **Published**: January 18, 2024

Abstract: Yitong Basin is a narrow Cenozoic faulted basin of Tanlu fault zone, in which Sheling Formation in Botai Sag has great exploration potential. Limited by complex geological conditions, unclear reservoir forming control factors and unknown exploration direction, the exploration process is restricted. By utilizing drilling, logging, and seismic data, and through the restoration of ancient landforms, the distribution of underwater fans near the coast of the Botai Depression was finely characterized. Combined with the structural characteristics of the southeastern margin, a favorable reservoir formation model for the northwestern margin of the Botai Depression was conceptualized and established. There are three inshore subaqueous fan bodies in the northwest margin of Botai depression, and two large nose-like structures in the Soudengzhan structural belt in the southeast margin. The two structures are well configured and which can form lithologic structural traps. The southeast margin of the traps is controlled by the pinch-out line of sand bodies and the northwest margin is controlled by the structure. The concept of establishing a favorable reservoir formation model for the nearshore underwater fan of a narrow and long graben style fault basin has expanded the favorable exploration field of the Botai Depression.

Keywords: Botai Sag, Sheling Formation, Fan Characterization, Nose-Like Structures, Hydrocarbon Accumulation Model

1. Introduction

The Yitong Basin is an oil rich basin with a narrow and elongated rift type graben basin. The internal fault depression has good exploration results locally, but the overall exploration level is relatively low [1-3]. Previous studies have conducted extensive research in the Chaluhe Fault Depression of the Yitong Basin, and it is believed that the Bonihe Taiping Depression (Botai Depression) vertically develops two sets of good source rocks, the third member of the Shuangyang Formation and the Sheling Formation. The overall thickness of the source rocks is large, the organic matter type is good, and the abundance is good, providing a good foundation for oil and gas accumulation [4]. During the period of the Sheling Formation, a large fan body developed in the northwest edge of the Botai Depression, with well-developed sandstone reservoirs and good reservoir conditions. The source and reservoir configuration of the first section of the Sheling Formation in the Botai Depression is good, and oil and gas indications have been obtained through drilling, but there has been no major breakthrough in exploration. Due to the limited drilling and complex geological conditions in the Botai depression area, the controlling factors for reservoir formation are unclear, and the exploration direction is unclear, which restricts the exploration process [5-7]. This article uses drilling, logging, and seismic data to finely depict the development of three nearshore underwater fan bodies on the northwest edge of the Botai Depression. It also conceptualizes the establishment of a favorable reservoir formation model for the nearshore underwater fan body on the northwest edge of the Botai Depression, and summarizes the favorable reservoir formation models for narrow and long graben style fault basins. This study effectively guides the next exploration deployment of the Botai Depression and provides favorable exploration targets.

2. General Situation

The Yitong Basin is structurally located within the western half of the Jiayi Fault Zone in the northern section of the Tanlu Fault Zone, and is the westernmost branch of the Northeast Asian strike slip fault system globally. To the northwest, it is adjacent to the Daheishan Fault Uplift, and to the southeast, it is adjacent to the Nadanhadaling Fault Uplift. It belongs to a narrow and long graben controlled by the boundary strike slip fault and sandwiched between the two fault uplifts [8]. The basin is 300km long from north to south and 5km-20km wide from east to west, with an area of nearly 3500km^2. The Yitong Basin is divided into six secondary structural units from south to north: Yehe Fault Depression, Moliqing Fault Depression, Yidan Uplift, Luxiang Fault Depression, Chaluhe Fault Depression, and Shulan Fault Depression. It is further subdivided into 11 tertiary structures: Kaoshan Depression, Ma'anshan Fault Step Belt, Jianshan Structural Belt, Danan Depression, Wuxing Structural Belt, Liangjia Structural Belt, Xinanpu Depression, Wanchang Structural Belt, Bonihe Taiping Depression, Soudengzhan Structural Belt, and Gudian Slope Belt. Due to the varying degrees of evolution in different stages of the basin, each fault depression has its own characteristics of oil and gas accumulation. The research area covers an area of 400 km^2 and is located in the Boni River Taiping Tai Depression in the northern part of the Chalu River Fault in the Yitong Basin [9] (Figure 1).

The basin is mainly composed of Paleogene strata, which mainly develop from bottom to top in Shuangyang Formation, Sheling Formation, Yongji Formation, Wanchang Formation, Qijia Formation, and Chaluhe Formation. During the period of the Sheling Formation, the strata were distributed throughout the entire area, with significant thickness changes, generally ranging from 400 to 700 meters. It had a transitional and gradual relationship with the Shuangyang Formation, with the Sheling Formation in the Botai Depression being the most developed, followed by the Xin'anbao Depression. Lithologically, it consists of gray black mudstone, silt, and fine to medium sandstone, which are vertically divided into two lithological sections. The target layer for this study is the first section of the Sheling Formation.

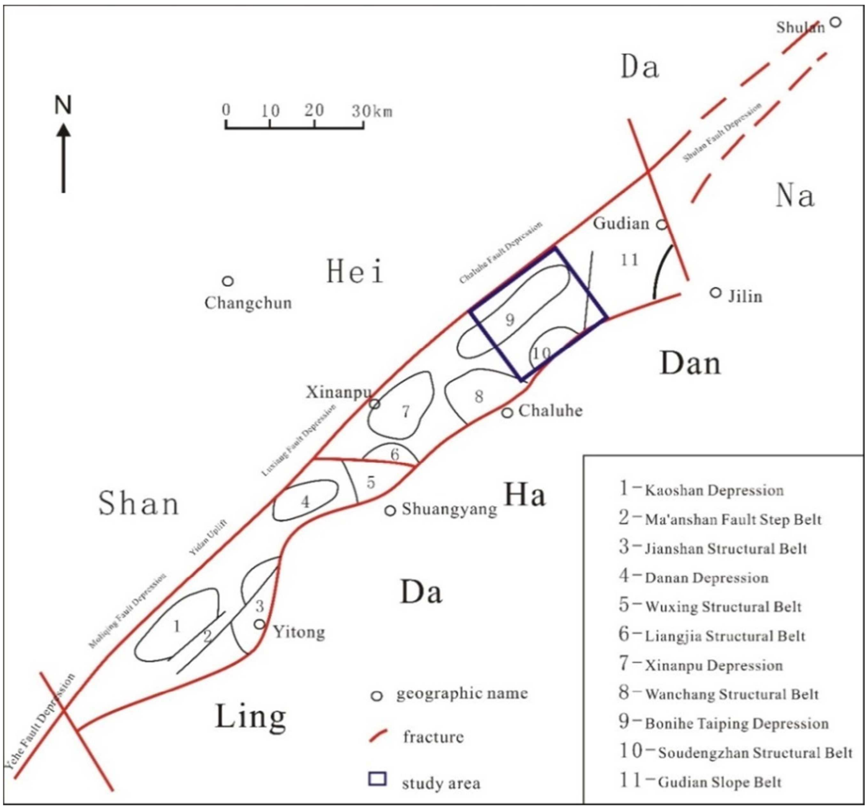


Figure 1. *Location map of the research area.*

3. Characteristics of the Northwest Nearshore Underwater Fan

3.1. Seismic Response Characteristics of Reservoirs

The reservoir of the Sheling section in the Botai depression is mainly developed in the middle of the Sheling section, consisting of a set of fine to medium sandstones and a relatively stable mudstone, which can be used as a good source rock. C60 well encountered 11 layers of fine sandstone with a total length of 31m, C8 well encountered 2 layers of siltstone with a total length of 8.5m, 1 layer of fine sandstone with a total length of 8m, C9 well encountered 5 layers of siltstone with a total length of 19m, 2 layers of fine sandstone with a total length of 4.5m, and C7 well encountered mostly muddy siltstone with a total length of 20m in 5 layers (Figure 2b). Through well seismic calibration, the top of the sandstone concentrated development section in the Sheling Formation exhibits peak reflection during earthquakes. From the well connected seismic profile, it shows a characteristic of stronger peak reflection amplitude as the degree of sandstone development increases. In the C7 well, the reservoir in the Sheling Formation is not developed and mudstone is developed, exhibiting weak amplitude characteristics during earthquakes [10].

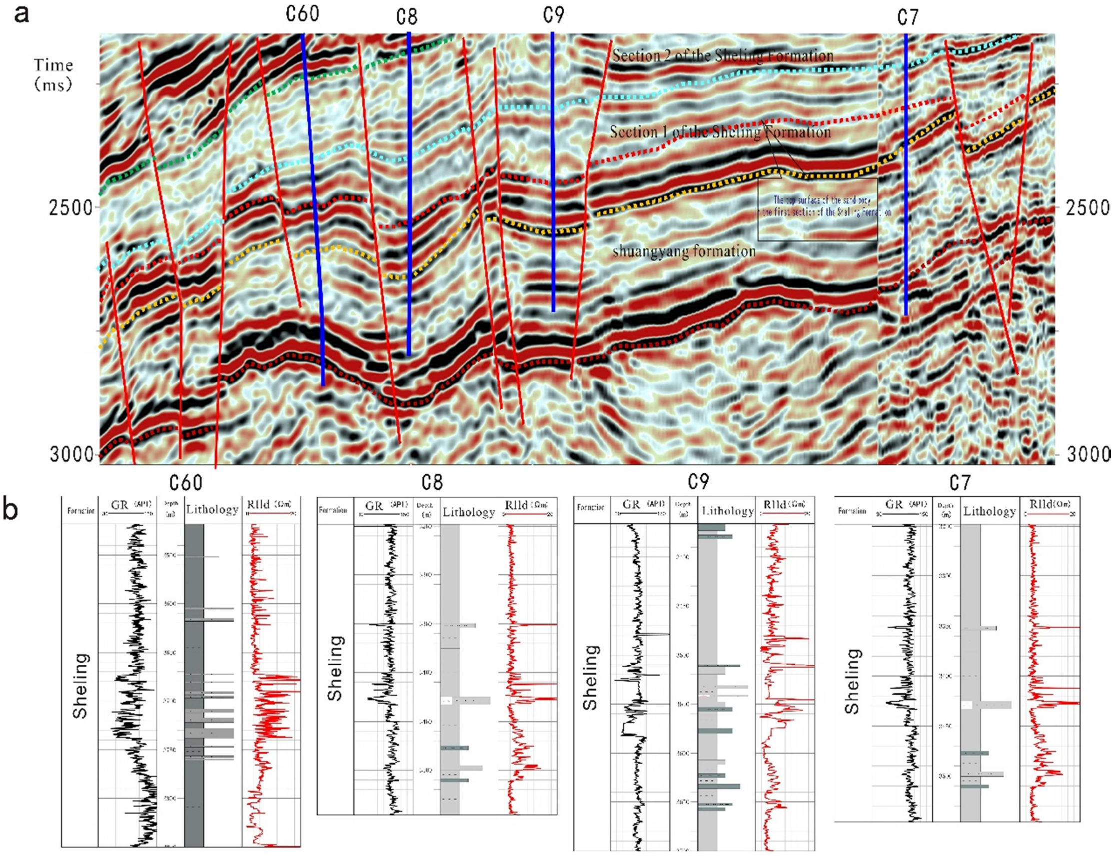
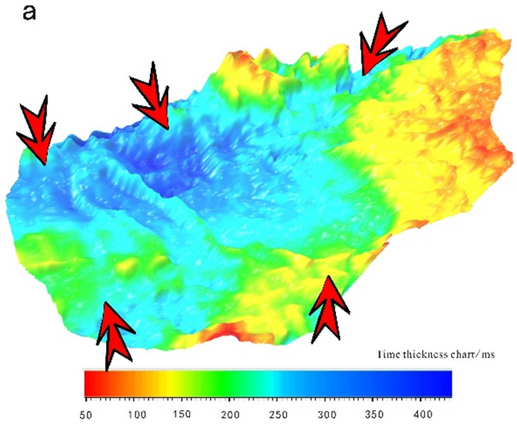


Figure 2. *Comparison of connected wells in Botai Sag(Profile AA1, line location is shown in Figure 3a).*

3.2. Characterization of Nearshore Underwater Fans

During the sedimentation period of the Sheling Formation, a nearshore underwater fan developed in the steep slope zone of the northwest edge. Based on the analysis of ancient landforms and combined with seismic attributes, the distribution of the fan body was predicted. The restoration of ancient landforms has great significance for sedimentary characteristics [11, 12]. Through the restoration of ancient landforms in a section of the Sheling Formation, it was found that during the sedimentary period, the main depression of the Sheling Formation was located at the northwest edge of the Botai Depression. The steep slope zone developed nearshore underwater fans, and the protruding area was located at the southeast edge of the Botai Depression. The gentle slope zone developed fan delta sedimentation (Figure 3a). During this period, the northwest edge had abundant sediment sources, and the fan body was widely distributed, while the scale of the southeast sediment sources was relatively small. Based on the correlation between the development degree of the reservoir in the first section of the Sheling Formation and the seismic amplitude attribute, that is, the more developed the sand body, the stronger the amplitude attribute. The amplitude attribute can be used in combination with ancient landforms to characterize the nearshore underwater fan body. Finally, it is predicted that three nearshore underwater fans will develop in the northwest edge, with a total area of 96 km^2, and two fan bodies will be predicted to develop in the southeast edge, with a total area of 24 km^2 (Figure 3b).

At present, wells have been drilled in the northern and southern fan bodies of the three nearshore underwater fans on the northwest edge. The scale of the southern fan body is small, and the C48 well drilling has encountered the root of the fan, resulting in rapid accumulation of steep slopes and mixed accumulation of sand and mudstone. On the seismic profile, there are medium to strong scattered reflections, and the characteristics of the fan body are unclear in terms of seismic attributes (Figure 5, Figure 3b); In the northern fan body, three wells, C60 well, C8 well, and C9 well, were drilled. The C60 well encountered the middle part of the fan, and the sand reservoir was relatively developed. The seismic attribute was medium strong amplitude, while the C8 and C9 wells encountered the end part of the fan, and the degree of sand development decreased. The seismic attribute was weak amplitude (Figure 2a and Figure 3b); The fan body in the middle is relatively large, with an area of 60km^2, and there have been no well drilling encounters so far. From the seismic profile along the direction of the fan, the northwest source fan extends to the middle of the depression, exhibiting obvious wedge-shaped characteristics. On the seismic phase, the root of the fan exhibits medium strong amplitude chaotic reflection, the middle of the fan exhibits medium strong amplitude continuous reflection, and the end of the fan exhibits weak amplitude continuous reflection, exhibiting obvious progradation characteristics [13, 14]. The C7 well drilled in the high part of the central fan encountered a sandstone thickness of 20m and a mudstone thickness of 230m. The reservoir is not well-developed, and the seismic attribute map shows weak amplitude (Figure 4, Figure 3b).



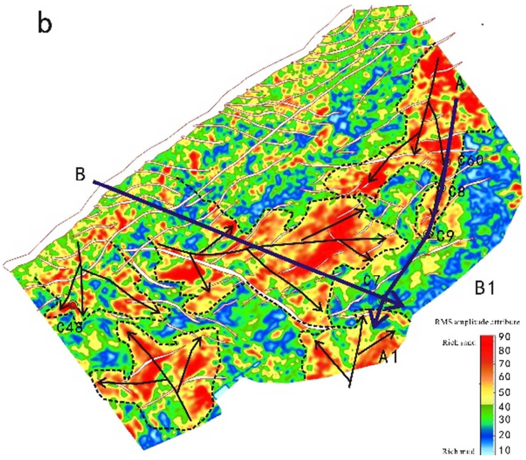


Figure 3. *Depiction of fan body of Sheling 1 Member in Botai sag.*

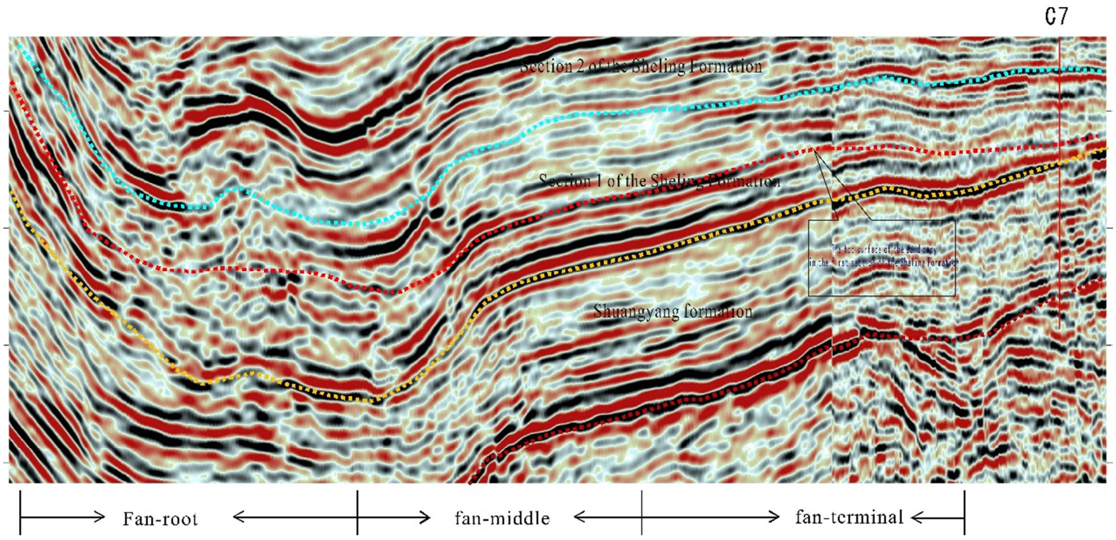


Figure 4. *Seismic profile of the central fan in the northwest margin of Botai Depression. (Profile BB1, line location is shown in Figure 3a)*

4. Structural Characteristics of the Southeastern Margin

The tectonic evolution of the Botai Depression can be generally divided into two major periods of tectonic activity: extensional strike slip and compressive strike slip. The sedimentation of the Shuangyang and Sheling formations is mainly characterized by extensional strike slip activity controlled by the northwest boundary faults. The basin formed early sedimentary Shuangyang and Sheling formations, while the southeast edge was a continuously developing slope. The late stage of sedimentation of the Wanchang formation was a transition period from extensional to extensional strike slip compression. The late stage of compression and strike slip resulted in the formation of a fault fold zone in the northwest margin [15-17], while the southeastern margin underwent weak uplift and transformation during the sedimentation period of the Yongji Formation and compression inversion and shaping during the sedimentation period of the Qijia Chaluhe Formation [18, 19].

During a period of time in the Sheling Formation, the southeast edge was a sloping area, with an overall high southeast edge and low northwest edge in structure. The southeast edge of the Sudeng Station structural belt does not develop structural traps, but two larger nose shaped structures are developed. Two nose shaped structures tilt northwest, and from the seismic profile that cuts across the two nose shaped structures, it shows two anticline structures with the characteristics of high in the south and low in the north. At present, there are C60 well drilling encounters in the northern nasal structure, while there are no well drilling encounters in the southern nasal structure (Figure 5).

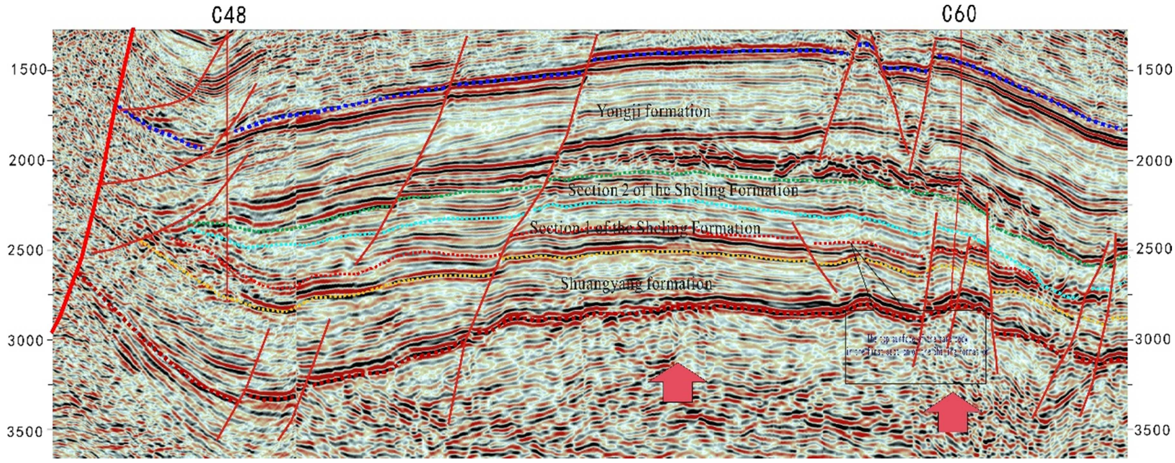


***Figure 5.** Seismic profile of nose-like structure from northwest margin to southeast margin of Botai Depression.(Profile CC1, line location is shown in Figure 7a).*

5. Favorable Reservoir Formation Models of Nearshore Underwater Fans

During a period of time in the Sheling Formation, the Botai Depression spanned only 1.5km from the northwest to southeast edge, with a narrow northeast distribution. Based on the structural and sedimentary characteristics of the Sheling section of the Botai depression, a favorable reservoir formation model for the nearshore underwater fan of the Sheling section of the Botai depression was conceived. The three fan bodies developed on the northwest edge of the Botai Depression are controlled by sedimentary facies belts. The sandstone in the updip direction of the fan body gradually fades out, and thick layers of mudstone are developed in the updip direction, which can serve as shielding layers. The second member of the Sheling Formation reservoir is not developed, and mainly develops mudstone, which can serve as the top cover layer. In the later stage, the southeastern edge reversed and formed the Sudeng Station structural belt, with the development of two larger nose shaped structures. The good configuration of the nearshore underwater fan body in the northwest edge and the nose shaped structure in the southeast edge forms a lithological structural oil and gas reservoir type. The southeast edge of the oil and gas reservoir is mainly controlled by the pointed out boundary of the fan body sandstone, while the west is controlled by the nose shaped structure (Figure 6).

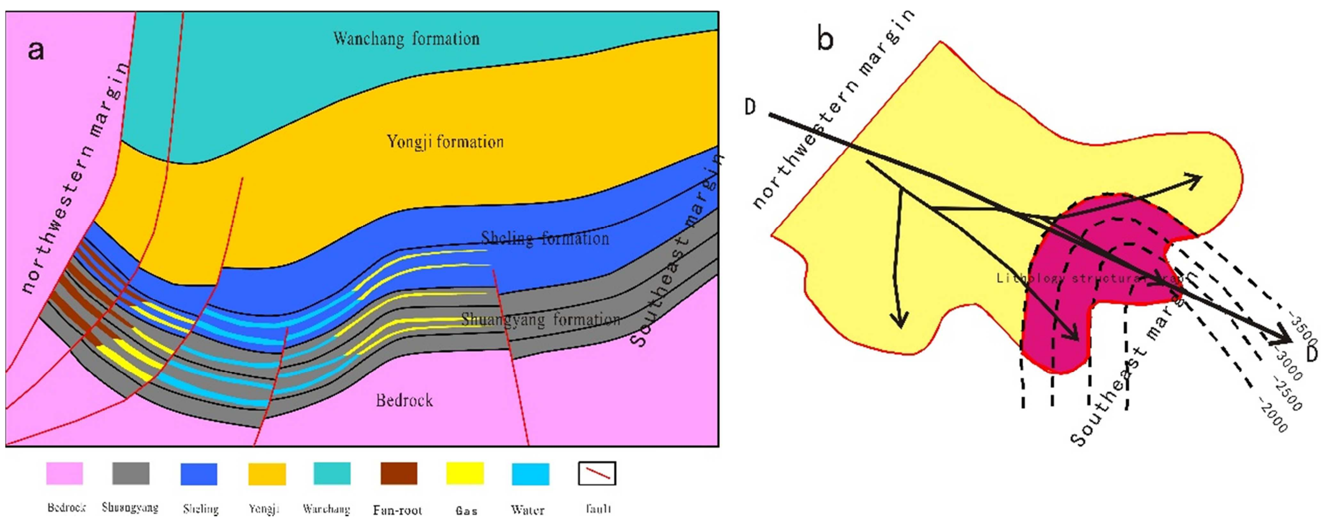


***Figure 6.** Favorable hydrocarbon accumulation model of fan of Sheling 1 member in Botai Sag.*

By superimposing the top structure of a fan body and sand body in the Sheling Formation, a total of 2 lithological structural traps with an area of 26.5km^2 were identified. The lithological structural trap in the north has already been drilled by Chang 60 well, with an area of 8.5km^2. It is formed by the configuration of the fan body in the northern northwest margin and the nose shaped structure in the northern southeast margin. After drilling the Chang 60 well, gas logging shows 7 layers with a thickness of 16m. Logging interpretation shows 4 layers of gas and water layers with a thickness of 19.6m, and 9 layers of dry layers with a thickness of 26.7m. From the results of well logging interpretation, it can be seen that the Chang 60 well has formed a reservoir and meets the conditions for lithological structural lithological traps. In the southern part of the Chang 60 well trap, a lithological structural trap is formed by the configuration of the central fan body in the northwest margin and the nose shaped structure in the southern part of the southeast margin. The fan body has a larger scale and the amplitude of the nose shaped structure is larger, forming a larger lithological structural trap with an area of 18km^2, which has better conditions and is a favorable exploration target for the next step (Figure 7).

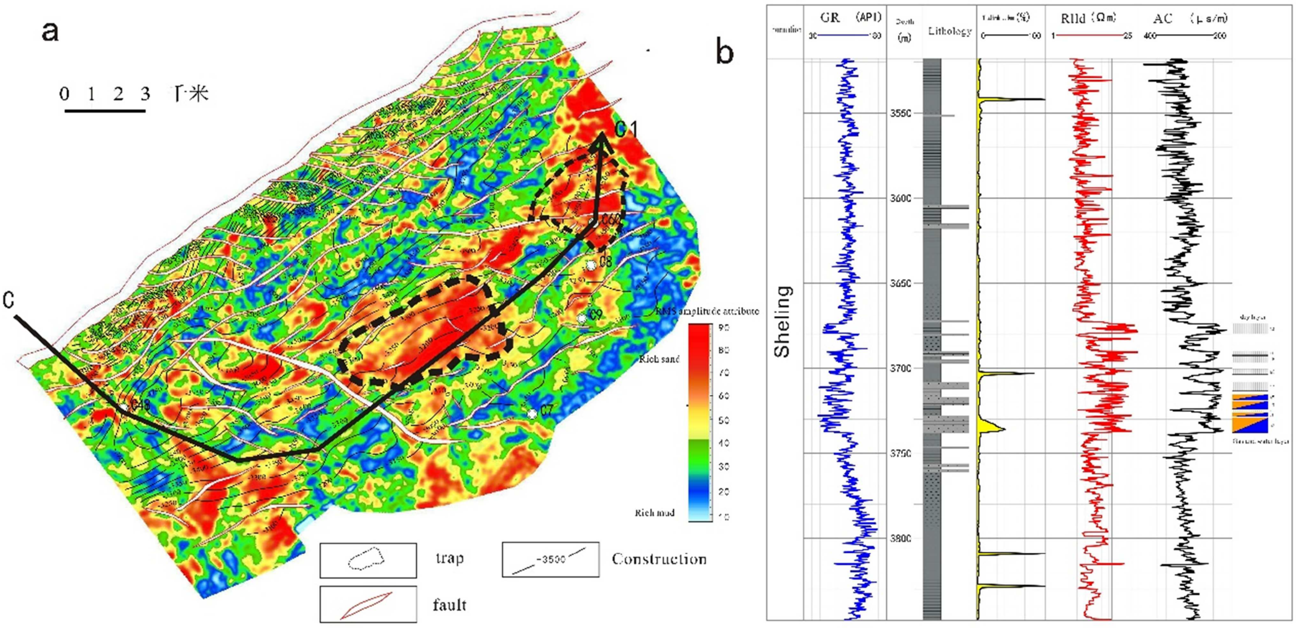


Figure 7. *Lithologic-structural map diagram of Sheling 1 Member in Botai Sag.*

6. Conclusion

(1) Narrow and long graben type fault basins, controlled by rapid subsidence during extensional and extensional periods, have developed thick dark mudstone layers that provide a good material basis for hydrocarbon generation. At the same time, large underwater fan bodies are developed near the shore, integrating source and reservoir, which has great exploration potential and is a favorable area for exploration deployment;

(2) Narrow and long graben type faulted basins, developed nearshore underwater fans during extensional periods, and well configured nose shaped structures opposite to the fault can form lithological structural oil and gas reservoirs, which are favorable reservoir types that need to be explored in the next step.

Conflicts and Interest

The authors declare no conflicts of interest.

References

[1] Li B C, Liu H Y, Du H X. The Petroleum System and Accumulation in Yitong Basin [J]. China Petroleum Exploration, 2003, 8(3): 38-44.

[2] Wang J, Xu X J, Chen X Y. Structural and Sedimentary Features and Types of Hydrocarbon Reservoir in Southern Chaluhe Fault Depression of Yitong Graben [J]. Global Geology, 2007, 26(2): 240-244.

[3] Jiang T, Qiu Y C, Deng X G. Controlling Effect of Channel Strike-Slip Fault Basin on Deposition and Accumulation:A Case Study in Yitong Basin [J]. Petroleum Geology and Experiment, 2012, 34(3): 267-271.

[4] Guo J. Evaluation of Hydrocarbon Source Rock in Yitong Basin [D]. Thesis for the Graduate Candidate Test of Northeast Petroleum University, Daqing, 2015.

[5] Feng Y, Chen H H, Ye J Q. Reservoir-Forming Periods and Accumulation Process of Chaluhe Fault Depression of Yitong Basin [J]. Earth Science—Journal of China University of Geosciences, 2009, 34(3): 502-510.

[6] Gan L Q, Ma S Z, Zhao H. Seismic Facies of the Sheling Formation of the Chaluhe Depression in the Yitong Basin [J]. Science Technology and Engineering, 2013, 13(2): 428-433.

[7] Dong Q S, Shi B Y, Miao H B. Analysis of Hydrocarbon Accumulation Rule in Graben Style Basin-A Case from South Chaluhe Fault Depression of the Yitong Graben [J]. Petroleum Geology and Experiment, 2008, 30(1): 6-15.

[8] Tang D Q, He S, Chen H H. Fault System's Characteristics of Yitong Basin and Its Evolution [J]. Journal of Jilin University (Earth Science Edition), 2009, 39(3): 386-396.

[9] Miao H B. The Coupling Relationship between Hydrocarbon Migration and Accumulation Processes and Tectonic Evolution of Northwest Margin in Yitong Basin. A Dissertation Submitted to China University of Geosciences for the Doctor Degree of Philosophy, 2013.

[10] Lin S H, Wang H, Wang X M. Seismic Reflection Feature of Glutenite Fan in Abrupt Slope Zone of Rift-Subsidence Lake Basin: A Case in Dongying Depression [J], Geological Science and Technology Information, 2005, 24(4): 55-59.

[11] Xin Y L, Ren J Y, Li J P. Control of Tectonic-Paleogeomorphology on Deposition: A Case from the Shahejie Formation Sha 3 member, Laizhouwan Sag, Southern Bohai Sea [J]. Petroleum Exploration and Development, 2013, 40(3): 302-308.

[12] Liu J E, Jian X L, Kang B. Paleogeomorphology of the Middle Part of 3rd Member of Shahejie Formation and Their Effects on Depositional Systems, Dongying Delta, Dongying Depression [J]. Petroleum Geology and Recovery Efficiency, 2014, 21(1): 20-23.

[13] Wei Y J, Li D S, Hu S Y. Fans Sedimentation and Exploration Direction of Fan Hydrocarbon Reservoirs in Foreland Thrust Belt of the Northwestern Junggar Basin [J]. ACTA Geoscientica Sinica, 2007, 28(1): 62-71.

[14] Zhao H B, Yan K. Depositional Characteristics of Glutenite and Distribution Pattern of Fan on Nearshore Subaqueous Fan [J]. Fault-Block Oil and Gas Field, 2011, 18(4): 438-441.

[15] Chen S, Guo S J, Qi J F. Three-Stage Strike-Slip Fault Systems at Northwestern Margin of Junggar Basin and Their Implications for Hydrocarbon Xxploration [J]. Oil and Gas Geology, 2016, 37(3): 324-331.

[16] Sui F G. Tectonic Evolution and Its Relationship with Hydrocarbon Accumulation in the Northwest Margin Junggar Basin [J]. ACTA Geologica Sinica, 2015, 89(4): 779-793.

[17] Jiang T, Qiu Y C, Song L B. Fault Nature of North-West Fault Zone in Yitong Basin and Its Relation with Reservoir Accumulation [J]. Geoscience, 2009, 23(5): 860-863.

[18] Tang D Q, He S, Chen H H. Characteristics of Inversion Structures in Yitong Basin since Neogene [J], 2009, 30(4): 506-512.

[19] Tang D Q, Chen H H, Jiang T. Neogene Differential Structural Inversion and Hydrocarbon Accumulation in the Yitong Basin, East China [J]. Petroleum Exploration and Development [J]. Petroleum Exploration and Development, 2013, 40(6): 682-691.