Earth Sciences
2025, Vol. 14, No. 4, pp. 142-148
https://doi.org/10.11648/j.earth.20251404.12

Research Article

Fault Block Trap Evaluation Technology and Application Effect Combining Static and Dynamic Characteristics of Gas Reservoirs in Complex High Steep Structural Zones

Ke Qin[1, *], Gao Wei[2], Li He[1], Ji Xuewu[1], Qu Weihua[2], Liu Xiaohong[2], Pan Zhihao[2], Wang Lei[1], Li Li[1], Wang Qing[1], Zou Wen[1]

[1]Geophysical Research Institute, China National Petroleum Corporation, Zhuozhou, China
[2]Jilin Oilfield Company, PetroChina, Songyuan, China

Abstract

Due to strong compression in the later stage, multiple rows of positive structural zones were formed in southern Sichuan. The Dengjingguan structure is a high and steep structure with a complete anticline morphology, which develops from bottom to top and has favorable overall structural conditions. There are many drilling wells in the Jialingjiang Formation of the Dengjingguan structure, with drilling concentrated in the 1950s and 1960s. There are only three wells with complete drilling curves, and the faults within the structural zone are developed and fragmented as a whole. It is difficult to accurately identify the structural traps of the fault blocks within the structural zone, making it difficult to evaluate exploration potential and affecting subsequent well site deployment. In response to this issue, this article uses newly acquired 3D seismic data to carry out fine structural interpretation, combined with the actual drilling situation of production dynamic data, and combines static and dynamic to complete the evaluation of the Dengjingguan structural block. Dynamically leveraging the advantages of the new 3D, we can sort out the development patterns of faults from regions to blocks, and then from blocks to local systems, and use coherent attributes to determine the distribution of faults. Dynamically utilize the pressure coefficient of drilling and the production data of gas wells to validate the static interpretation plan, conduct well to well comparisons, and repeatedly revise the static interpretation results. The evaluation of fault block traps through the combination of static and dynamic gas reservoirs effectively reduces the ambiguity of complex high steep structural fault block interpretation, improves the rationality between wells, and provides reliable basis for the subsequent exploration and well location deployment of oil fields. It has good guidance and reference significance for the potential evaluation of complex high steep structural fault blocks in southern Sichuan in the future.

Keywords

Complex Steep Structural, Fault Block Trap, Static and Dynamic Combined, Production Dynamic Data, Zigong Block

1. General Situation

The Zigong block in southern Sichuan is located in the southwest Sichuan low fold structural belt of the Sichuan Basin. It has formed four rows of positive structural belts due to strong compression in the later stage, forming an

*Corresponding author: keqin@cnpc.com.cn (Ke Qin)

Received: 5 March 2025; **Accepted:** 22 April 2025; **Published:** 16 July 2025

overall pattern of "alternating depressions and uplifts". The Dengjingguan structure is located within the second row of positive structural zones and is a complete northeast trending long axis anticline structure trap. It is complexed by northwest and northeast trending faults to form a fault block trap group. The Jialingjiang Formation of the Triassic has developed dolomite reservoirs with a porosity of 4-15% and a permeability of 0.01-2mD. The gas reservoirs are mainly controlled by structures. The Dengjingguan structure has a relatively shallow burial depth, ranging from 1000-1800m. A total of 26 wells have been drilled, 22 have been tested, 17 are industrial, and 16 have been put into production within the structure, making it a favorable area for conventional gas exploration. In the Dengjingguan structure, drilling was concentrated in the 1950s and 1960s, with 4 wells having relatively complete curves, 13 wells having incomplete curves, 4 wells without curves, and no core and laboratory analysis data. In order to further implement the exploration potential of the Dengjingguan structure and tap into the remaining natural gas, it is necessary to further evaluate the fault block traps within the Dengjingguan structure. A set of fault block trap evaluation techniques combining static and dynamic characteristics for gas reservoirs in complex high steep structural zones has been summarized based on the actual situation of the Dengjingguan structure. Using newly acquired 3D data to carry out fine structural interpretation of the Jialingjiang Formation, from region to block, and then from block to local system to sort out the development rules of faults. Guided by geological knowledge and combined with seismic attributes, the distribution of faults is implemented to achieve a static description of the Dengjingguan structure. Due to the limited and incomplete drilling data of the Dengjingguan structure, the static interpretation plan was dynamically validated by combining the pressure coefficient of drilling and the production dynamic data of gas wells. Inter well comparisons were made, and the static interpretation results were repeatedly corrected. Finally, a reasonable evaluation of the fault block trap was conducted to realize the potential for further exploration [1-9].

2. Static Description of the Structural Characteristics of Dengjingguan

2.1. Distribution Pattern of Fractures

The Dengjingguan structure as a whole is a complete northeast trending long axis anticline structure. Due to strong compression in the later stage, the structure is fragmented and the faults are well-developed. Describing the distribution of internal faults in the Dengjingguan structure is crucial for implementing the structure of the Dengjingguan structure. This study is based on the newly collected 3D seismic data to conduct continuous interpretation and mapping, from region to block, and then from block to local, to clarify the development law of the Dengjingguan structural fault.

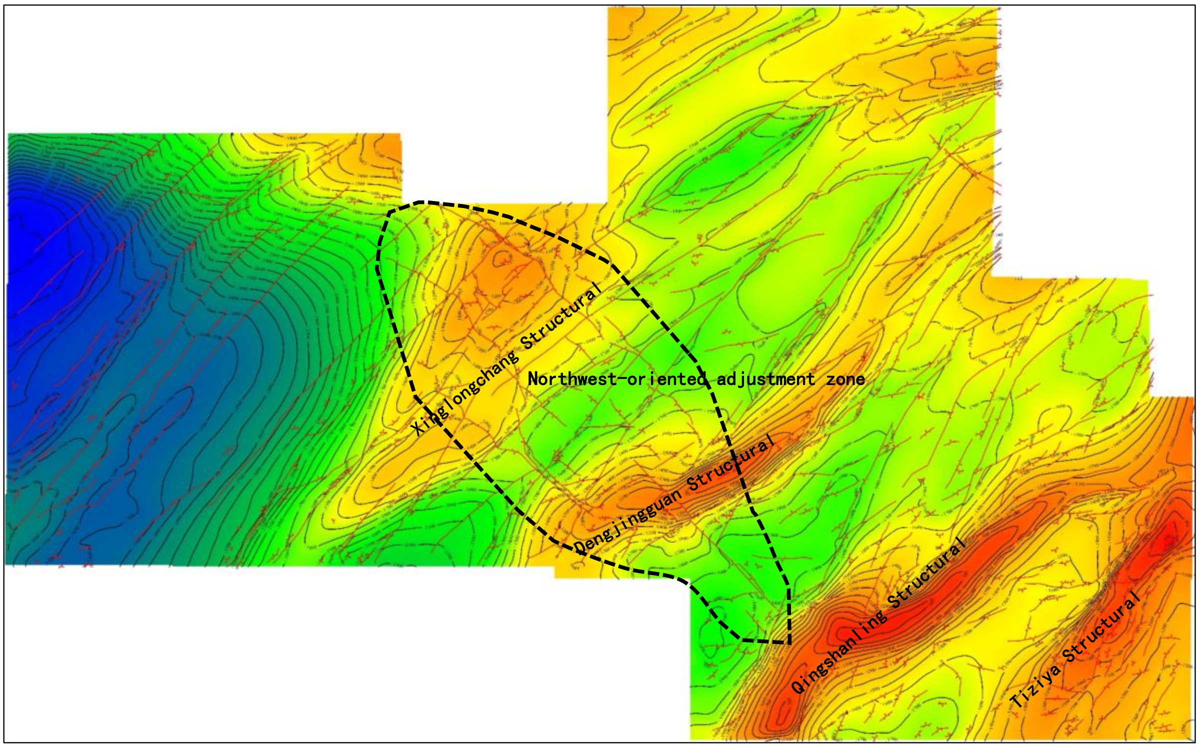

Figure 1. *Bottom structure map of Jialingjiang Formation Jia22 in Zigong 3D Zone.*

Through the continuous mapping of the Jialingjiang Formation, it is clear that the Jialingjiang Formation develops two sets of faults in the northeast and northwest directions, with the northeast fault being the main one and the northeast fault controlling the four rows of positive structural distribution. Only northwest trending faults are developed in the core of Xinglongchang and Dengjingguan structures, as well as between the two structures, forming a northwest trending regulatory zone as a whole. Through regional analysis, it is believed that the northwest trending fault within the northwest trending adjustment zone is a regulating fault formed under left lateral compression, which is cut by the northeast trending fault and forms multiple independent fault block structural traps. From a regional perspective, in the early Yanshan period, the Xuefeng uplift transmitted compressive stress in the SE-NW direction, forming a high and steep structural zone in the eastern Sichuan Basin. A large number of northeast faults were developed, with large fault displacement and long extension, controlling the distribution of anticline zones. The Zigong block was adjacent to the Huaying Mountain and was subjected to strong compression, resulting in the development of a large number of northeast trending faults. In the late Yanshan period, the Ziyun Luodian fault wedged northward into the Daloushan area, causing a nearly SN compression deformation of the Daloushan tectonic belt, accompanied by strong sinistral deformation. The Zigong block was subjected to sinistral compression and torsion, and a northwest oriented regulating fault was developed between the core of the Xinglongchang and Dengjingguan structures, forming a Northwest-oriented adjustment zone as a whole (Figure 1).

2.2. Fracture Characterization

The Dengjingguan structure is a typical high steep structure in southern Sichuan. High steep structures have low signal-to-noise ratio in seismic data, unclear fault sections, and poor imaging quality. By conducting stress analysis from region to block, the characteristics and planar distribution patterns of the Dengjingguan structural faults were clarified. The Dengjingguan structure is located within the northwest adjustment zone and develops two sets of faults in a northwest northeast direction. The coherent attributes were used to identify and characterize the small faults in the Dengjingguan structure, and to implement the Dengjingguan structural block trap.

The main production layers of the Jialingjiang Formation in the Dengjingguan structure are Jia41-Jia32 sub layers, and the top of the target layer (bottom of Jia42) is a relatively continuous set of strong strong amplitude wave crest reflections. The prediction effect of coherent attributes at the top (bottom of Jia42) of the main target layer is poor. When explaining, the main reference is to infer the fracture of Jia42 by interpreting the bottom of Jia22 in the marker layer. Interpreting the better quality of seismic data from the wing section of the Dengjingguan structure, and then inferring the location of faults in the axial section of the Dengjingguan structure where data is poor, to achieve a static description of the Dengjingguan structural faults [10-15].

2.3. Tectonic Characteristics of Dendjingguan Structure

By finely characterizing the faults, the structural morphology of the Dengjingguan structure was ultimately determined. The Dengjingguan structure is a northeast trending anticline, which is complicated by northeast and northwest trending faults, forming a fault block trap group and developing a series of fault block traps (Figure 2). The Dengjingguan structure can be divided into three zones in the north and south: the North Fault Nose Structure Zone, the Central Anticline Zone, and the South Fault Nose Structure Zone, which extend in a north northeast direction. The central anticline belt gradually rises along the northeast direction, and is controlled by three sets of northwest trending faults to develop three local high points in the west, middle, and east (Figure 3). Through a detailed structural interpretation of the Dengjingguan structure, a total of 17 fault block traps can be identified statically, including 10 fault block traps developed in the central anticline belt with an area of 62.9km^2, and 7 fault block traps developed in the north-south nose structure belt with an area of 70.1km^2. At present, drilling is concentrated in the eastern part of the central anticline zone. The central western and north-south fault nose structural zones of the central anticline zone have not been drilled and the degree of well control is low, which has great exploration potential and is the next favorable benefit block (Figure 4).

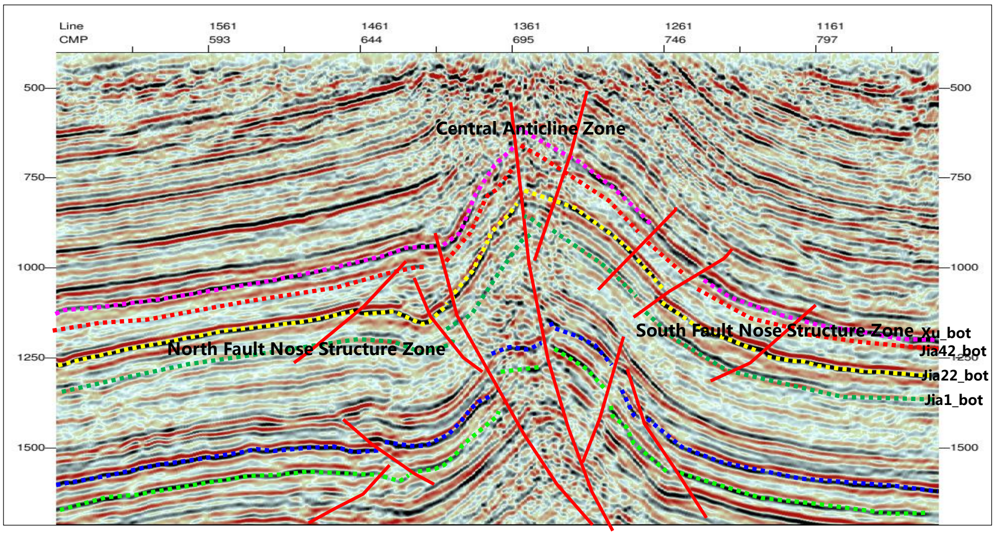

Figure 2. Northwest seismic profile of the Dengjingguan structure.

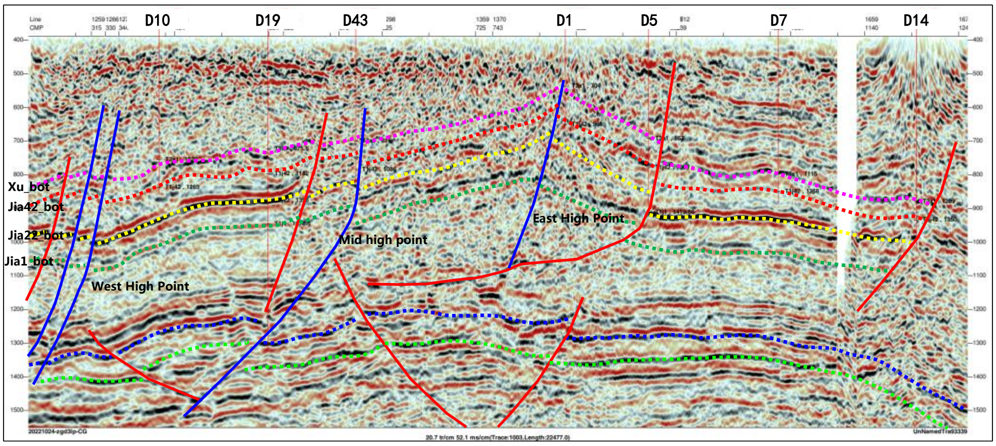

Figure 3. Northeastward seismic profile of the Dengjingguan structure.

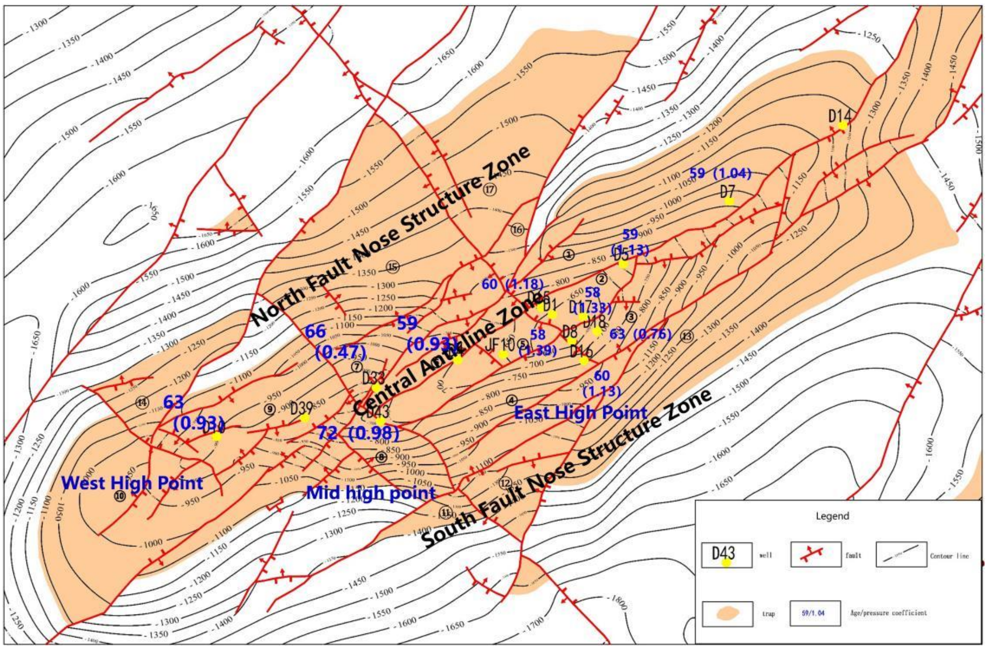

Figure 4. Bottom structure diagram of Jia42 in Dengjingguan structure.

3. Combining Dynamic Optimization with Static Solutions

Drilling within the Dengjingguan structure was concentrated in the 1950s and 1960s, with a sequence of drilling operations. Through statistical analysis of the pressure coefficients of drilling tests, it was found that there were significant differences in the formation pressure coefficients between different fault blocks, indicating that the gas reservoir was not connected. Three high points are formed under the control of northwest trending faults. In the early stage of production, the pressure coefficient in the eastern part of the central anticline belt is higher than that in the central and western parts, and there is a large difference in pressure drop during production. The D10 well in the western part has a higher production pressure than other high point production wells in the same year. It is believed that different independent gas reservoirs are formed in the west middle east of the central anticline belt (Figure 5a). To the east of the North High Point, three fault blocks are formed by two northeast trending faults. Through analysis of the formation pressure coefficient and production pressure, it is believed that the gas reservoirs in different fault blocks are independent of each other. During production, the pressure drops simultaneously in the fault blocks where D8 and D18 wells and D1 and D15 wells are located, but at different rates. D1 and D15 wells are the same block, and the wellhead pressure and its decreasing trend during production are similar. The pressure drop of adjacent block D8 well is significantly faster. There are significant differences in wellhead pressure and pressure drop trends between adjacent blocks that were put into production in the same year, confirming that the gas reservoir is not connected (Figure 5b). Five wells have been put into operation east of the North High Point, with a cumulative gas production of 1.9 billion cubic meters, a gas trap area of 19.5 km^2, and a reserve scale of 1.95 billion cubic meters. The comprehensive evaluation is at the end of gas production. There are four fault blocks developed between the east high point and the west middle high point, with significant differences in formation pressure coefficients. Analysis suggests that the fault blocks control the reservoir, with 8 wells drilled, a trap area of 22.3km^2, a reserve scale of 2.23 billion cubic meters, and 4 wells producing 870 million cubic meters of gas. The remaining potential is large. There are three fault blocks and two pressure measuring wells developed between the west high point and the middle high point. Based on pressure analysis, it is believed that different fault blocks independently form reservoirs with an area of 20.8 km^2 and a reserve scale of 2.08 billion cubic meters. Currently, 81 million cubic meters have been extracted, indicating great potential for expansion.

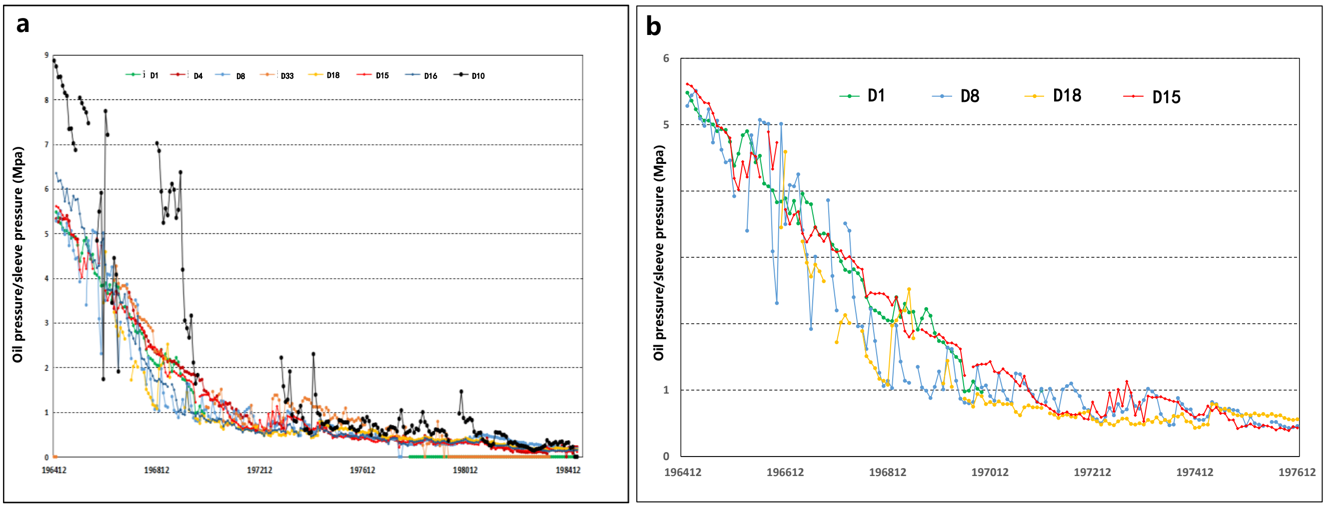

Figure 5. *Pressure and Time Variation of Production Well in Dengjingguan Structure.*

By analyzing the dynamic data of drilled production and optimizing the interpretation plan, the final evaluation includes 52.9km^2/7 fault blocks with low well control in the central western region, a reserve scale of 5.9 billion cubic meters, 70.1km^2/7 fault nose traps on both wings, and a resource potential of 5.3 billion cubic meters (Table 1).

Table 1. *Potential Evaluation Data of Jialingjiang Formation Block in Dengjingguan Structure.*

Zone	Trap number	trap type	Trap area (km^2)	drilled well	Industrial well	reserve scale (Billion square meters)	potential evaluation
Central Anticline Belt	1	fault block					Late stage of gas production
	2	fault block	32	8	6	36	Late stage of gas production
	3	fault block					Late stage of gas production
	4	fault block	9.5	1	1	10.9	Potential
	5	fault block	4.2	5	2	4.8	Potential
	6	fault block	3.4	1	1	3.9	Potential
	7	fault block	5.1	2	1	5.9	Potential
	8	fault block	5.4	2	1	6.20	Potential
	9	fault block	9.7	3	1	11.1	Potential
	10	fault block	15.6	Not drilled		17.9	Potential
North South Broken Nose Belt	11	fault nose	3.6	Not drilled		4.1	Potential
	12	fault nose	4.7	Not drilled		5.4	Potential
	13	fault nose	21.5	Not drilled		24.7	Potential
	14	fault nose	4.9	Not drilled		5.6	Potential
	15	fault nose	17.7	Not drilled		20.3	Potential
	16	fault nose	1.4	Not drilled		1.6	Potential
	17	fault nose	16.3	Not drilled		18.7	Potential

4. Conclusion

1) The Dengjingguan structure in Zigong block is a northeast trending anticline structure, which is complicated by northeast and northwest trending faults, forming a fault block trap group and developing a series of fault block traps. The northwest trending fault is formed by left lateral compression and twisting, and is only co developed between the core of the Xinglongchang and Dengjingguan structures, forming a northwest trending regulatory zone as a whole;
2) The fault block trap evaluation technology that combines static and dynamic data of gas reservoirs in complex high steep structural zones can achieve complementary static and dynamic data, effectively reduce uncertainty in seismic interpretation, and better carry out fault block evaluation on complex high steep structural zones. Ultimately, a reasonable evaluation of fault block traps can be carried out to realize the potential for further exploration.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Bi Y B, Zhang X N, Ma X L. Analysis method of development potential of complex fault block reservoir -by taking A oilfield in intertidal area as an example [J]. Petroleum Geology and Engineering, 2021, 35(5): 56-61.

[2] Wu X Z, Jiang C, Wang L. Evaluating the Potential Force of Complex Fault Block oil fields Based on Seismic and Dynamic Data [J]. Journal of Yangtze University (Natural Science, 2018, 15(19): 22-25.

[3] Bao H Y, Liu H T, Chen M K. Accumulation conditions of natural gas of Cambrian Xixiangchi Group in high-steep structural zones, eastern Sichuan Basin [J]. Lithologic Reservoirs, 2024, 36(2): 44-51.

[4] Du R, Yang X C, Han Y Z. Application of dynamic and static combination in characterization of remaining oil in complex fault block reservoir [C]. 2021 IFEDC conference.

[5] Leng J G, Pang X Q, Yang K M. Hydrocarbon accumulation model of fault block trao-a case study of west sag of Liaohe basin [J]. etroleum Geology and Recovery Efficiency, 2011, 18(2): 1-6.

[6] Zhao Y Q, Zhang Y H, Li C. Identification and Application Research of Comolex Fault-Block Trap-Take Weigang Nose Structure Zone in Nanyang Depression as an Example [J]. Fault-Block Oil & Gas Field, 2005, 12(6): 18-20.

[7] Fan J W, Shao G J, Tang Y L. Fine Structural Interpretation And Evaluation of Resources Potential For Fault Block Reservoir [C]. 2017 IFEDC conference.

[8] Li G Y. Key technology of fine description of complex fault block reservoir and its application [J]. Petroleum Reservoir Evaluation and Development, 2023, 13(2): 152-162.

[9] Huang J S, Li Y, Lu T G. Reservoir evaluation method of complex fault block and practical application—taking northern Weigang area for example [J]. Petroleum Reservoir Evaluation and Development, 2014, 4(2): 29-33.

[10] Li X N, Yang T, Zhang Y. Study on Fast and Accurate Location of Fault in Complex Fault Block [J]. Journal of Chengdu University (Natural Science Edition), 2023, 42(3): 330-336.

[11] Wang D P, Liu Q. Fine Reservoir Description of Complex Fault-Block Oil Field [J]. Acta Petrolei Sinica, 2000, 21(6): 111-116.

[12] Mu R. Identification and description of complicated small faylt-block trapsinSubei basin [J]. Oil & Gas Geology, 2006, 27(2): 269-274.

[13] Zhao M Z, Fan X H, Liu C F. Complex fault-block traps identification with structure oriented filter [J]. Oil Geophysical Prospecting, 2011, 46(S1): 128-133.

[14] Qiu X M, Chen W, Li H Y. Strike-slip structures and hydrocarbon accumulation in complex fault blocks in Subei Basin [J]. Petroleum Geology & Experiment, 2023, 45(3): 393-401.

[15] Li C Y, Xiao H Q, Fan C T. Comprehensive evaluation of small fault trap — A Case study of Qianguantun area [J]. Special Oil & Gas Reservoirs, 2003, 10(3): 23-26.