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# Study on the development of regional fractures and characteristics of tectonic faults in high stress difference stratum

## Ziyi Guo<sup>1</sup>, Da Lv<sup>2\*</sup>, Yong Zhang<sup>1</sup>, Tingsong Xiong<sup>1</sup>, Hai Lin<sup>1</sup>, Youyu Wan<sup>1</sup>, Ting **Zhang**<sup>2</sup>

<sup>1</sup> Research Institute of drilling and Production technology in Qinghai Oilfield of China Petroleum

<sup>2</sup> Southwest Petroleum University

Address correspondence to E-mail: 1758310834@qq.com

Abstract: The development of fissures and the study of tectonic faults in the stratigraphic area are important geological parameters for the study of oil and gas reservoirs, which is of great significance to the exploration, development and exploitation of oil and gas fields. However, due to the variable conditions of the underground stress field, especially the high stress difference stratum, the characteristics of regional fractures and faults are not yet clear. In this paper, the Wunan oil field in Qaidam Basin, Qinghai, which has a significant feature of high stress difference, has been selected as the research object. Combined with the Kaiser effect experiment and the analysis of the dip-log, the magnitude and direction of the main target segment in the region are determined the stress distribution characteristics of the region, and discusses the development and the relationship between faults distribution and stress distribution of the cracks. The results show that: 1) The distribution of the ground stress in this area is dominated by the maximum horizontal stress > vertical stress > minimum horizontal stress and the maximum horizontal principal stress is about 300°-310°, which belongs to typical high stress difference stratum. 2) The development direction of fractures in this area mainly converge between 314 ° and 325 °, which shows that it is more developed along the direction of the maximum principal stress, and the natural fractures are extremely developed, the fracture types are vertical seams. 3) The faults in this block have a general trend of NWW, which tends to be SSW, and basically the same as the horizontal maximum principal stress direction. The larger the difference of the horizontal in-situ stress is, the more obvious the formed faults will be, and the distance between the faults is significantly larger.

#### **1. Introduction**

The development of regional fissures and the distribution of structural faults are important parameters for the study of fault-block reservoirs<sup>[1]</sup>. For example, the structure of the fault dredging fluid capacity, namely fault sealing, the upward direction of fracture development zone and the closed occlusion of the unconformity faults, play a crucial role in formation lithology and oil as well as gas accumulation to form oil and gas reservoirs,<sup>[2]</sup> When the stress value of the local layer is higher than the strength of the rock itself, it will cause discontinuous rock fractures which called cracks. Cracks are the main percolation channels and reservoir spaces for reservoirs with strong heterogeneity and anisotropy <sup>[3]</sup>. Because of the high degree of fissure development in the active faults, the physical properties of the reservoir are improved. Once high quality caprocks are developed on the upper part of the faults, it

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will be possible to form large-scale oil and gas fields <sup>[1]</sup>. Therefore, the study of regional fracture development and structural fault characteristics is of great value to our exploration and development of oil and gas geological resources.

The development of regional fractures and structural faults is closely related to the formation stress. Especially, the effect of high stress differential formation stress on fracture development and fault formation is particularly significant <sup>[4]</sup>. The spatial action state of tectonic stress field is the decisive factor that affects the characteristics of the faults. Next is the rock mechanics properties, rock mass structure, fault occurrence and geological environment formed by faults <sup>[5]</sup>. Under the action of a unified tectonic stress field, the main cause of azimuth stress change in the plane is the non-uniformity of the stratum mechanical properties, and the existence of the interruption layer has the greatest impact <sup>[6]</sup>. The high horizontal stress often occurs in the uplift zone on the regional map, while in the crust subsidence area, the horizontal stress is generally less than the vertical stress <sup>[7]</sup>. In general, the maximum horizontal stress is low at the anticline axis and gradually increases toward the wings. The maximum horizontal stress change is faster at the anticline axis, which is more gradual at the wings, while the syncline axis (low position) often has higher stress <sup>[8]</sup>. Structures in steep areas, sloping ends, saddles, or nose structures tend to have stress concentrations, and the main stress direction changes as the structural profile changes <sup>[9]</sup>. Due to the movement of the earth's crust, the distribution characteristics of the actual oilfield blocks are similar to those of the shattered glasses. The stresses of the reservoirs between various blocks are more complex, mainly manifested in three types of extrusion, expansion and distortion<sup>[10]</sup>. There are differences in the fracture development of the two fault plates. Under normal circumstances, the fracture density of the active fault plate is larger than that of the passive plate, and some cracks do not develop at all in the passive plate fracture. A large number of normal faults are developed in the continental faulted basin and the fault is on the plate. Advancing oil and gas is favorable to oil and gas dredging, while the lower plate is favorable to the accumulation of oil and gas., especially the fault block reservoirs in reverse shielding <sup>[11]</sup>. The origin and expansion of fractures in the formation are mainly constrained by the local stress fields, rock types, and natural fractures <sup>[12]</sup>. Tectonic fractures are the most important reservoir space in shale reservoirs and able to increase reservoir permeability significantly. The development and distribution of these fractures are controlled by the paleotectonic stress fields <sup>[13]</sup>.

Although some achievements have been made in the study of tectonic stress fracture and fault distribution, the research on the fracture development and fault distribution of high stress difference strata formed by the largest horizontal principal stress is relatively few. Therefore, the accurate evaluation method of stress testing technique and stress interpretation of well logging which based on the development of high stress difference formation should be studied with regional fracture and fault characteristics of the stress distribution to determine the oil reserves, and the formulation of the reservoir fracturing measures have important theoretical and practical significance.

#### 2. Brief introduction for research area

Wunan Oilfield is located in the southern part of the western Qaidam Basin in Qinghai Province. The elevation of the area is about 3000m. The structural position of the oil field is located in the Meuse fault depression of the Kunbei fault zone in the Qaidam Basin and is a third-grade structure of the nose belt in the Wunan Green Grass Beach. The oil field is located in the Zaha Fault Depression, the eastern end of the cut Creek Depression and the south end of the Heroes Ridge-Yanya Depression. The Mangya depression was the main depositional area of the Qaidam Basin in the Tertiary period, and there are two provenance areas named the source area of the southwestern Kunlun Mountain and the source area of the northwest Altun Mountains. In the southern area of the west, there is a good combination of source, reservoir and cover, E32 and N11 are oil production layers, and E31, N12, N21, and N22 are the main reservoirs.

Wunan Oilfield is a nose-like anticline with empties from the southeast to the northwest, including two areas, Wunan and Qingcao. In the south, it is bounded by a large fault XIII, which connects with the Che Creek depression in the north is south US surface structures and connected to the East by the

Dongchaishan structure to the Zhahaquan structure in the west, as well as the Youshashan structure in the northwest. The structural axis is the northwest direction, the southwest wing has a large dip, while the northeast wing has a relatively small dip. The regional structure map is shown in Figure 1.



Fig.1 Structural geological map of the research area

#### 3. Analysis of stress distribution characteristics in high stress differential stratigraphy

#### 3.1 Kaiser effect testing ground stress results and analysis

In-situ stress is the stress existing inside the rock under natural conditions. It is also called natural stress, original stress or initial stress, etc. Generally speaking, the in-situ stress includes only vertical stress, horizontal maximum stress, and horizontal minimum stress. This paper mainly uses the Kaiser effect to test the stress method and tests the core of the Well South Wells area with high stress difference characteristics. The experimental results are shown in Table 1. From Table 1 it is able to tell that, 1) the vertical stress in Wunan well area varies from 30.58 to 60.88MPa, the average value is 43.62MPa, the vertical ground stress gradient is 2.338-2.681MPa/100m, the average value is 2.500MPa/100m; 2) The maximum horizontal stress in Wunan well area is from 37.77 to 79.73MPa, the average value is 53.025MPa, the maximum horizontal stress gradient is 2.830-3.316MPa/100m, the average value is 3.000MPa/100m, 3) the minimum horizontal stress is between 27.49 and 66.90MPa, the average is 42.10MPa, the minimum horizontal stress gradient is ranges from 2.118 to 2.783MPa/100m, the average value is 2.366MPa/100m; the average maximum and minimum horizontal stress gradient ratio is 1.27, and the difference is big. The distribution of the three-dimensional in-situ stresses in the area of south well is mainly based on the types of maximum horizontal stress > vertical in-situ stress > minimum horizontal in-situ stress, which shows the distribution of strike-slip stress, and the maximum horizontal in-situ stress is significantly greater than the minimum horizontal in-situ stress, showing high differential stress characteristics.

Table 1 Kaiser acoustic emission test calculation of ground stress results

Well name	Well depth (m)	$\sigma_V$ (MPa)	$\sigma_H$ (MPa)	$\sigma_h$ (MPa)	$\sigma_V$ gradient (MPa/100m)	$\sigma_H$ gradient (MPa/100m)	$\sigma_h$ gradient (MPa/100m)
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W 6-501	1323.50	33.64	37.77	29.64	2.54	2.854	2.240
W 6-501	1297.50	34.79	38.88	27.49	2.68	2.997	2.118
W 9-17	1308.00	30.58	38.52	30.32	2.34	2.945	2.318
W 10-12	1339.90	33.09	39.14	30.30	2.47	2.921	2.261
W 11-1401	1361.00	36.04	38.63	31.42	2.65	2.839	2.309
W 11-1401	1360.00	35.09	38.63	29.50	2.58	2.841	2.169
W 105	2011.50	48.04	56.92	46.82	2.39	2.830	2.328
W 107	2316.50	55.07	76.12	59.82	2.38	3.286	2.583
W 107	2307.20	60.88	72.42	60.79	2.64	3.139	2.635
W 108	2404.20	58.01	79.73	66.90	2.41	3.316	2.783
WB 2-3	1854.80	45.45	54.97	42.84	2.45	2.964	2.310
WB 2-3	1849.50	45.96	57.81	42.56	2.48	3.126	2.301
WB 17-9	2031.40	50.47	59.77	48.92	2.48	2.942	2.408

#### 3.2 Azimuth analysis of ground stress based on formation dip logging

Through the collected data of dip logging, the dual-wellbore curves of 6 wells in WB 4-3, Wu 101, WB 7-6, Wu 26, Wu 5-01, and Wu 103 were analyzed, and the method of the tilt angle logging was used to find the wells in the target interval of these wells, and read the short axis orientation of the wells, then use the azimuth frequency map to calculate the main azimuth of the minor axis of the elliptical well, which represents the maximum horizontal principal stress orientation of the stratum. The analysis of the maximum horizontal stress frequency distribution is shown in Figure 2, and the statistical results are shown in Table 3. It can be seen from Figure 2 and Table 2 that the maximum horizontal stress orientation in the area of south well is between 280° and 340° and the average value is 305.42°. The difference among the interpretation results of the wells is small, basically within 10°, explaining the interpretation of the single well is consistent. The results are relatively consistent. There is no significant difference in the interpretation results for the six wells. Comprehensive analysis indicates that the maximum horizontal stress orientation of the well is between 300° and 310°.





Table 2 Azimuth statistics of formation forces in Wunan well area										
Well number	WB 6-2	WB 4-3	Wu 101	WB 7-6	Wu 26	Wu 5-01				
Maximum										
horizontal	280°~290°	305°~310°	280°~290°	330°~340°	330°~340°	280°~290°				
stress azimuth	L									
Maximum				North North	North North	North West				
horizontal	North West	North West	North West	West to	West to	West to				
stress	to South East	to South East	to South East	South South	South South	South East				
orientation				East	East	East				

# 4 Correlation analysis of fracture development law and ground stress distribution in high stress difference stratum

The development direction of the fractures in the Wunan well area is mainly concentrate at  $314^{\circ}-325^{\circ}$ , and the natural fractures are extremely developed, the fracture types are vertical seams. Figure 3 shows the orientation of fracture development in Wunan well area. According to the direction of fracture development in Wunan oilfield (Table 3) and combined with the analysis results in section 3.2, it can be known that the maximum horizontal permeability of the reservoir is generally in the same direction parallel to the horizontal maximum principal stress, and the cracks which generally follow the fracture is more developed along the direction of  $134^{\circ}-145^{\circ}$ . On the other hand, the development of fractures in the Well South area reveals that the orientation of the maximum horizontal principal stress is approximately varies from  $300^{\circ}$  to  $310^{\circ}$ , while the development direction of the fracture is mainly concentrate at  $314^{\circ}-325^{\circ}$ , showing that along the direction of the maximum horizontal principal stress, the natural fractures are extremely developed.



Fig. 3 Rose in the direction of crack development

Table 3 Direction of development of fractures in Wunan									
Well number	Fracture orientation	Wall number	Fracture orientation						
	(degree)	wen number	(degree)						
Wu 2-19	50	Wu 2-03	68.5						
Wu 8-25	105.5	WB 3-2	135						
WB 1-16	134	WB 3-15	135						
WB 1-18	144.5	WB 4-17	139.5						
WB 2-2	138.5-152.5								

Which type of the fracture will develop in the formation depends on the relative magnitude of the vertical principal stress  $\sigma_z$  and the horizontal principal stress  $\sigma_h$  (including  $\sigma_x$  and  $\sigma_y$ ) in the ground stress. When  $\sigma_z < \sigma_h$ , there will be horizontal cracks perpendicular to  $\sigma_z$ ; when  $\sigma_z > \sigma_h$ , vertical cracks will appear. The specific orientation of this vertical fracture is in turn determined by the values of the two horizontal principal stresses  $\sigma_x$  and  $\sigma_y$ . If  $\sigma_x > \sigma_y$ , the fracture will be in an orientation that is perpendicular to the minimum horizontal principal stress parallel to  $\sigma_x$ ; if  $\sigma_x < \sigma_y$ , the fracture will be in an orientation that is perpendicular to the minimum horizontal principal stress parallel to  $\sigma_x$ ; if  $\sigma_x < \sigma_y$ , the fracture will be in an orientation which perpendicular to the minimum horizontal principal stress  $\sigma_x$  and  $\sigma_y$ . From the mechanical point of view, cracks always arise from the weakest and least resistant places. Cracks in the formation also meet this principal <sup>[4]</sup>.

According to the above analysis datas, the maximum principal stress and minimum principal stress in the well of Wunan lies in the horizontal direction, and the vertical principal stress is the second principal stress; from the above-mentioned relationship between the fractures and the ground stress as well as the geo-stress field in the southern area of Wunan. The main principal stress > vertical stress > minimum principal stress is dominant. It can be seen that the active fracture development surface should be perpendicular to the minimum principal stress, and the fracture type is vertical. The difference between the average maximum horizontal principal stress and the average minimum horizontal principal stress is 1.27, which belongs to the high stress difference stratum. Therefore, the fractures in the Well area of Wunan are developed along the direction of the maximum principal stress.

# 5. Analysis of the characteristics of faults in high stress differential strata and their correlation with ground stress distribution

Table 4 is the statistical table which shows the N21 formation faults in the Wunan well area. The fault area has reached more than 20 faults in total, including 7 faults of Level II, 12 faults of Level III, and a boundary fault of fault block; 3 faults of Category IV make reservoir structure furtherly complicated. Research has shown that the area in south well is a nose-like structure in general. Under the background of this large nose structure, several fault blocks are divided by multiple faults. There are 31 faults in Wu 4 and Wu 14 fault block structures. The faults are roughly divided into two groups: north-north west or north-east east. Most of them are reverse faults, but there are also several normal faults, there are both intersecting and tangent between faults., and the fault system is very complex (Figure 1). Because the area in south well is a nose-like uplift structure which cut by faults complicatedly, a number of small broken blocks are formed by cutting the two major faults between the northwest and north-north west. The structural traps are mainly fault traps, and the internal faults extremely developed and the system of fault block is complex, which can be roughly divided into Wu 14 fault block, Wu 5 fault block, Wu 4 fault block, Wu 1 fault block, Wu 2 fault block, Wu 8-6 fault block, Wu 7-6 fault block, Wu 7-6 east fault block. The Wu 5 fault block is in the direction of the northwest, and the strata is high in the north and low in the south, and the southern strata is relatively steep. The Wu 4 fault block is dominated by the north of the strata; the structure is high in the south, lower in the north, gentle in the south and steep in the north; the northern strata is almost monoclinic, and the southern fault is complex. It is mainly nasal structure. In short, due to the complexity and miniaturization of fault blocks, the occurrence of strata changes greatly, and the tendency of strata

within different fault blocks varies.

I able 4 Main breaking factors of Wunan oilfield											
No. F	Fault name	Property	Level	Trend	Inclin-a tion	K3 Extension Length (km)	Ν	Maximum Break (m)			Disconnected
	r autt name						K8	K5	K4	K3	horizon
1	North Section of Wunan No. 2	Normal fault	III	SN	Е	8.5	80	40	80	70	K8-K2
2	South Section of Wunan No. 3	Normal fault	III	NNW	EN	3.5	10	30	40	40	K4-K2
3	Wunan No. 1	Normal fault	III	SN	W	5.2	/	/	60	60	K8-K2
4	WB west	Normal fault	III	NNE	NW	6.0	160	220	70	100	K8-K2
5	WB east	Normal fault	II	NNE	NE	6.6	180	100	70	180	K8-K2
6	Wunan east	Normal fault	III	NNW	WS	4.8	100	70	40	30	K8-K2
7	Wunan east-east	Reverse fault	II	NNW	WS	5.5	60	80	120	90	K8-K2
8	Wunan south-east	Normal fault	II	NW	WS	6.5	800	820	810	850	K8-K2
9	North Section of Wundong	Normal fault	III	SN	Е	2.5	20	10	30	20	K8-K2
10	South Section of Wundong	Normal fault	III	SN	Е	3.5	210	20	40	30	K8-K2
11	Yuandong 1	Reverse fault	III	NNW	NEE	3.5	110	120	80	140	K8-K2
12	Yuandong 2	Reverse fault	III	NNW	NEE	3.0	110	80	140	90	K8-K2
13	Yuandong 3	Reverse fault	II	NWW	NNE	10.0-	160	160	160	200	K8-K2
14	Fault No.VII	Normal fault	II	NWW	NNE	10.0-	100	100	100	400	K8-K2
15	Wunan south 1	Reverse fault	II	NWW	SSW	7.0	610	220	380	140	K8-K2
16	Wunan south 2	Normal fault	III	NWW	SSW	9.0-	120	90	150	140	K8-K2
17	Wunan south 3	Normal fault	III	NWW	SSW	7.5-	80	90	110	80	K8-K2
18	Wunan south 4	Normal fault	III	NWW	SSW	6.0-	80	100	90	120	K8-K2
19	Wunan south 5	Normal fault	IV	NNE	ES	5.0	/	90	100	140	K5-K2
20	Wunan south 6	Normal fault	IV	NNE	ES	5.5	/	50	80	100	K5-K2
21	Wunan south 7	Normal fault	IV	NNE	ES	3.0	/	/	20	120	K4-K2
22	Wunan south 8	Normal fault	II	NNE	ES	9.0-	120	80	200	200	K8-K2



Fig.4 Schematic diagram of fault distribution in Wunan oilfield

As shown in Figure 4, combined with the main fault zone in the southern part of the country, the principal fault zone is K8-K2. The largest fault is the normal fault of level II in south-east of Wunan, with a maximum fault distance of 850 m at the K3 level, on the whole, the faults in the Wunan block

are mainly dominated by the southern Wunan faults, which approximately trend to be NWW, inclination is SSW, such as the faults of Wunan south 1, 2, 3, and 4 faults. Because the fracture develops to a certain degree, faults will be formed, which will lead to the same trend of fault strikes and fractures. For example, in Wu 5 fault block, the fractures of Wu 5-2, Wu 5-4, Wu 5-6 and Wu 6-3 are developed, basically in the northeast direction, other faults are similar, and if the natural fractures of Wu4-5 and Wu-4-6 develop, the orientation is basically in the northwest-west direction, and the development of the fault will promote the development of the fracture along with the fault.

From the relationship between the ground stress and the cracks obtained above, it can tell that the fractures are relatively developed at  $314^{\circ}$ - $325^{\circ}$ , that's to say, the direction of the maximum principal stress of the fault and the horizontal of the Wunan oilfield is also consistent. In particular, for the south-east fault of Wunan, because the difference between the maximum horizontal principal stress and the minimum horizontal principal stress is larger, under the condition of high stress difference, the fault spacing of the fault is significantly larger than that of other faults. Secondly, although some wells are affected by different faults, as long as these faults are in the same trend, the fracture development of these wells is basically the same (such as Wu 6-3, Wu 5-4), considering the extension direction of the fracture development azimuth, the big possibility is perpendicular to the direction of the fault. From the stress distribution in the well zones of Wunan and the charts of the major fault zones, the difference between the maximum and minimum horizontal principal stress is larger, the faults is consistent with the direction of the maximum horizontal principal stress of the major fault sorts of the maximum horizontal principal stress is larger, the faults formed in this area are very obvious, in addition, the orientation of the these faults is consistent with the direction of the maximum horizontal principal stress develop well.

### 6. Conclusion

- The geological structure in the southern part of Wunan is complex and the ground stress values are significantly different. The average vertical stress gradient is 2.500 MPa/100m. The average value of the maximum horizontal stress gradient is 3.000 MPa/100m. The average gradient of the minimum horizontal stress is 2.366MPa/100m; the main maximum and minimum horizontal stress gradient ratio is 1.27, and the three-dimensional in-situ stress distribution is dominated by the type of maximum horizontal stress > vertical in-situ stress, and the orientation of the maximum horizontal principal stress is approximately between 300 ° and 310°.
- The development direction of the fractures in the Wunan well area is mainly concentrate in the direction of 314°-325°, showing the development along the direction of the maximum principal stress, and the natural fractures are extremely developed, and the fracture types are vertical seams.
- The faults in the Wunan block are mainly dominated by the southern Wunan faults, with a general trend of NWW, incline to be SSW, which is basically the same as the direction of the maximum principal stress of the fracture and the horizontal. The difference between the maximum horizontal principal stress and the minimum horizontal principal stress is large, the formed fault is very obvious, and the fault distance of the fault is significantly larger.

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