American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-12, Issue-1, pp-50-56
www.ajer.org
Research Paper Open Access

The Identification and Influence of Micro-faults in Oilfield Production

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ABSTRACT: *Micro faults are pretty difficult to be identified and need to be studied systematically in reservoirs. Micro faults are becoming more and more important to the oilfield development and production. In this paper, faults in complex fault block have been taken to establish the relationship model between the fault throw and the different fault number, so as to predict the existence and numbers of micro faults. The precaution measures are proposed base on the field performance to optimize the injection pressure injection-production patterns and surface engineering etc. The paper provides a comprehensive analysis of the impact of micro faults in oilfield development and provides strategies for the safe and effective development of similar oil and gas fields.*

Key words: *Micro-faults; Generation mechanism; Fault-sealing; Activate; Precaution measures.*

Date of Submission: 01-01-2023 Date of acceptance: 11-01-2023

I. INTRODUCTION

Petro-geologists pay much attention to geometry and morphology of master faults, but seldom investigate the significance of micro and minor faults in oilfield development. Micro faults usually under the category of microstructural studies in reservoirs. Micro faults can be good use for water injection in oilfields, but can also damage the reservoir. As the reservoir injection pressure increases, the injection water goes through faults, resulting in poor sealing and even activation, which can cause production accidents.

Faults resulting in water channeling and well blowout frequently during oilfields development, and the injected water often breaks through faults to the surface. The accident does not catch much attention when occurs in the onshore oilfields. More attention should be paid to prevent various accidents caused by faults for safety operations, especially for offshore oilfields.

In recent years, the authors have made some useful explorations on the research and application of the fault-sealings in developed oilfields, and the results have improved the production of oilfields.

II. DISTRIBUTION OF DIFFERENT FAULTS

Faults are well generated in complex fault-block oilfields in eastern China. Natural fault blocks generated by different faults cutting into each other. Faults with larger throw (>30 m) can be distinguished easily, with clear displayed in seismic profiles. The faults with smaller throw (5m-30m) can be hardly identified, and distinguished by using high-resolution fine seismic interpretation, isochronal stratigraphic fine correlation and imaging logging techniques. Tectonic interpretation experts did not map small faults which were difficult to identify. Although it is difficult to identify small faults with a fault throw less than 5 meters by conventional technical method, it does not mean that they are not exist. Therefore, it is meaningful to determine the occurrence and sealing capacity of micro and minor faults in the oilfield safe production.

III. GENERATION AND OCCURRENCE OF MICRO/MINOR FAULTS

Major faults which control the hydrocarbon accumulation attract much attention in the past years. Mechanisms of micro faults generation and their impact on oil and gas reservoir have not been studied systematically in the whole world. Micro faults have been discovered in coring wells and the occurrence of micro faults has been verified in the operations. The generation and occurrence of micro faults are investigated through the experiments which were performed previously for master boundary faults (Wang K et al. 2008; Zheng XJ et al.2004).

3.1 Tectonic Stress

The basins sedimentation and structure are mainly affected by geodynamic, so the basins are classified as tensional and extensional according to their generation mechanisms. The basins are mainly controlled by the stretching equilibrium of the lithosphere, and the basin boundaries are controlled by normal faults (Amy E Clifton et al. 2000; Cander H 2012; Cao SL et al.1996; SCHMATZA J et al. 2010; WU KY et al. 2011).

3.2 Evolution of Micro and Minor Faults

The sedimentary faults in the eastern basins of China are large scaled, the main control faults have the same sedimentary characteristics. Active deformation belts are easily formed at the extensional fault-bend folds in sedimentary strata. The evolution of micro and minor faults in active deformation belts are mainly dominated by the surface morphology of master faults.

During the initial stage of tectono-sedimentary evolution, continental rifted basins were mainly isolated sedimentary basins controlled by small-scale normal faults and flexural folds. Faults were generated deeply and disorganized. The faults broke upward through the surface, resulting in fracturing and surface rifting. With the continuous extension of faults, half graben-like basins were formed. Fig.1 shows a series of micro and minor faults are formed along with the generation of the main fault. With the experimental model of normal fault evolution proposed (Martha O. Withjack and Cynthia Scheiner 1982; M. R. Leeder and R. L. Gawthorpe 1987; CHILDS C 2009), the occurrence of micro and minor faults accompanying master faults and their continuous change process can be observed.

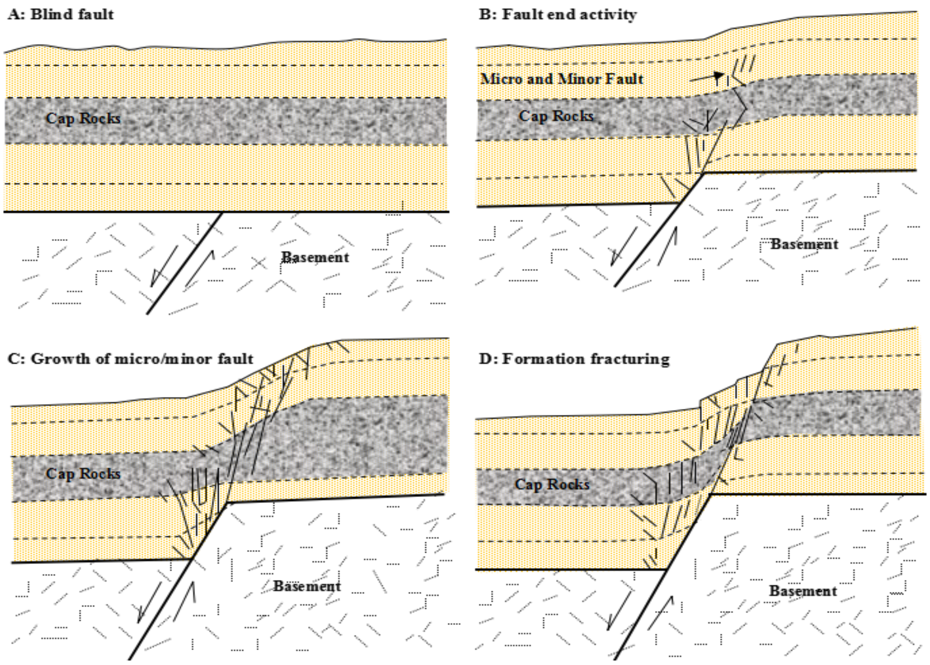

Fig.1. Experimental model of normal fault (Withjack et al.,1990)

Withjack et al. simulated the generation of active deformation zones at the hanging walls in continental rifted basins by physical tension experiments. Two main deformation zones were formed after tension. One is close to the main fault zone, generate multiple normal faults which have same direction with the main fault. The other one is far away from the main faults zone, generate multiple normal faults which have opposite direction with the main fault. Shovel faults may lead to more complex deformation at the hanging wall, and the deformation zone provides conditions for the formation of micro faults that are regular in geometry, structural position and development sequence. Similarly, the structural transformation zones and structural slope break zones in rifted basins are the main area of micro and minor faults, affected by the movement of adjacent segmented faults and the differential subsidence of sedimentary slopes respectively.

3.3 Occurrence of Micro Faults in Cores

The micro faults with small throw are always neglected due to the precision errors in stratigraphic correlation and structure interpretation. The micro faults can be distinguished by special imaging logging methods, such as micro resistivity scanning imaging logging (XRMI).

Fig.2. The micro-fault diagram in cores of Well T12C

Coring wells for cores is the most effective and direct way to verify microscopic faults, micro faults can be found in drilling cores. At the transition zone from Chenghai slope to Tanggu structure in Dagang Oilfield, the stress is concentrated and micro faults may occur easily. The well T12C encounters Es3 in Tanggu area. A large number of micro faults generated in depth interval of 3084.09~3131.14m where drilling core was taken. Fig.2A and Fig.2B show two angles of a core (18 cm long) from depth 3138m. Fig.2C and Fig.2D provide the interpretation of faults shown in Fig.2A and Fig.2B. The black layers in the core are organic rich carbonaceous interbeds, with single layer about 0.25 cm thick. The throw of micro faults is around 0.4 cm to 4 cm. There is a crush zone about 2cm thick between the red line and the blue line. Falling cuttings can be seen from the crush zone in Fig.2a. Crude oil can be found at the top section of the micro fault in Fig.2a and in faults marked blue and green in Fig.2D.

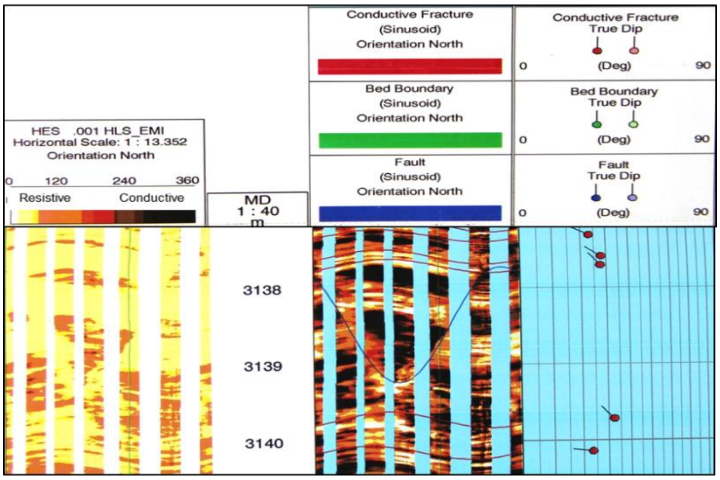

Fig.3. The XRMI maps of Well T12C

Imaging logging data can be utilized to identify micro or minor faults and fillings. The XRMI chart of the well Tang12C in Fig.3 shows the micro faults marked with blue-black line generated by the dislocated layers in 3138~3139m depth. Compared to cores observation from coring wells, imaging logging can have multiple solutions for micro fault identification.

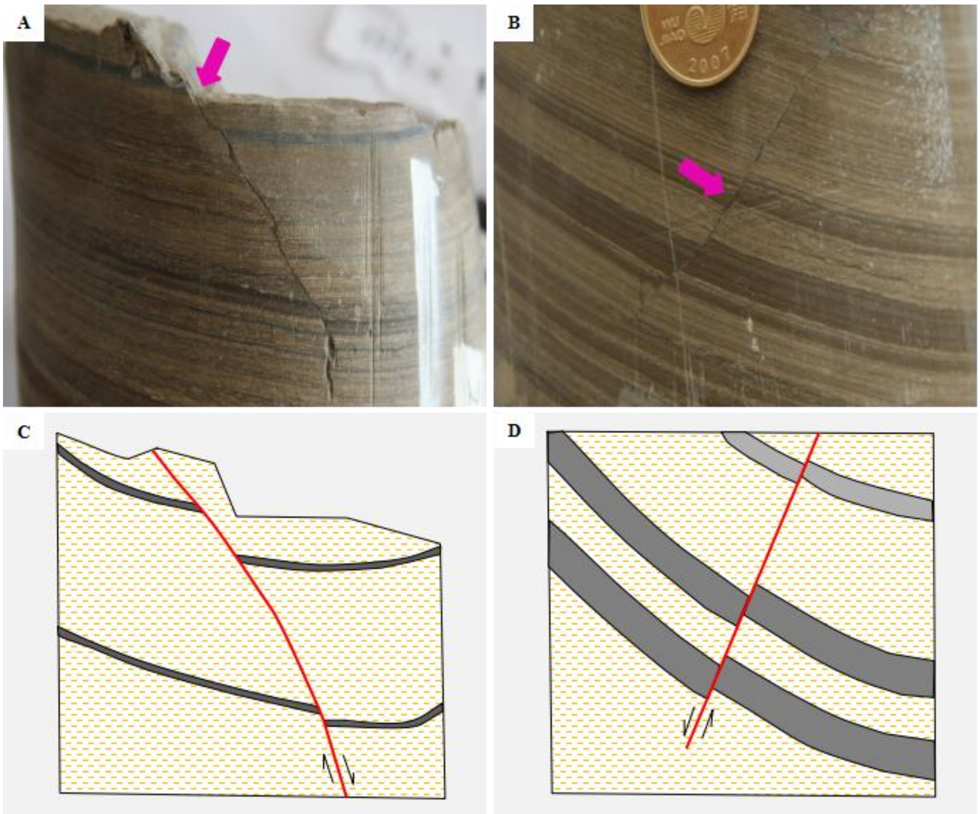

Fig.4. Micro-faults in Well ZH27-34

Fig.4 shows the core taken from the Es1 layer of well ZH27-34. The pink arrow indicates the occurrence of micro faults. Fig.4C and Fig.4D provide the interpretation of faults shown in Fig.4A and Fig.4B 14 micro faults are found and the throw ranges is around 0.2 cm to 0.8 cm. Based on core observation from two coring wells, the section width of micro faults is around 50 to1000 μm and the extension length is around 0.1 to 5 m. The experiment shows that most micro faults cannot be sealed. These two samples verify the existence of micro faults in oil reservoirs.

IV. FAULT-SEALING ANALYSIS

For complex reservoirs, determining the faults type is not the point, but how to make use of them to help developing the reservoirs effectively. Micro fault-sealing research is meaningful for well pattern adjustment, residual oil development and the safety of oilfield development.

4.1 Distribution Characteristics of Different Faults

Complex fault blocks with different sizes of faults are pretty generated. These different faults can be identified by the seismic data and stratigraphic comparisons. In this study, 20 samples from Wangguantun, Gangdong, Liushafang, Gangxi and Banqiao in Dagang oilfield have been seleted to investigate the distribution characteristics of different faults. The average fault throw (X) of different faults is well correlated with their number of faults (Y) in Fig.5, modeling the existence of different sizes of fault throw within a tectonic unit. The number of different faults is directly related to the fault throw. According to the model equation in Fig5, there will be 178 minor faults in the area when the fault throw is 15 meters. And 11895 micro faults when the fault throw is 1 meter. It indicates that there may be a large number of faults within a certain tectonic unit with smaller fault throw than the minor faults, which may have an impact on reservoir stress structure and reservoir physical modification.

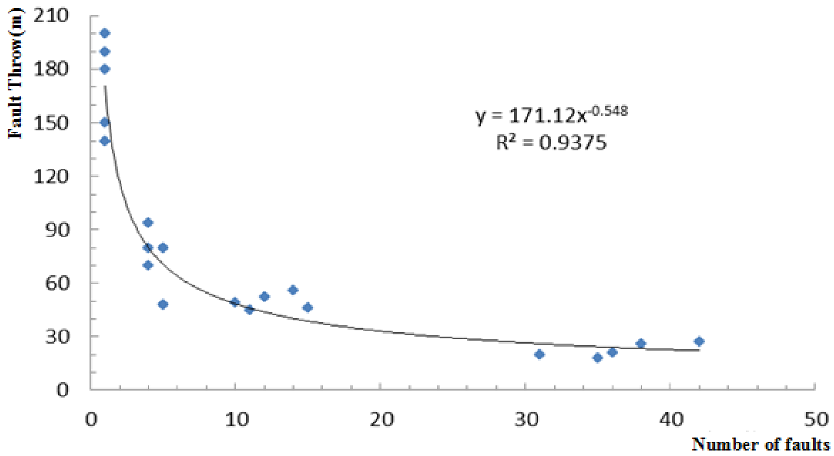

Fig.5. The correlation analysis in different faults

4.2 Fault-sealing Analyzed by Different Methods

Fault-sealing is mainly determined by static methods, material balance methods, numerical simulation methods, and field performance analysis methods. Identify the fault distribution by reservoir static analysis, and analyze the fault-sealing through the reservoir dynamics. Static method to determine the fault-sealing mainly from the analysis of seven influencing factors on the fault activity period, lithological configuration, oil-water interface, fault dip, fault type, mudstone coating coefficient, lateral sealing coefficient. In this study, the influence of different factors was considered to establish the fault-sealing evaluation criteria, and 34 faults with different fault throw in Dagang Oilfield were selected for evaluation. The fault sealable index is directly related to the fault throw. The larger of the fault throw, the better of the sealing, and the core well data also confirmed that most of the micro faults is not sealable. Combined with the dynamics analysis for different types of faults, the poor sealing behaved when the fault sealable index (Φ) is less than 0. 5. And the good sealing behaved when Φ is larger than 0.7 as shown in Fig.6. Therefore, it is important to pay attention to faults with the fault sealable index less than 0.7 to prevent the impact of micro and minor faults on oilfield production.

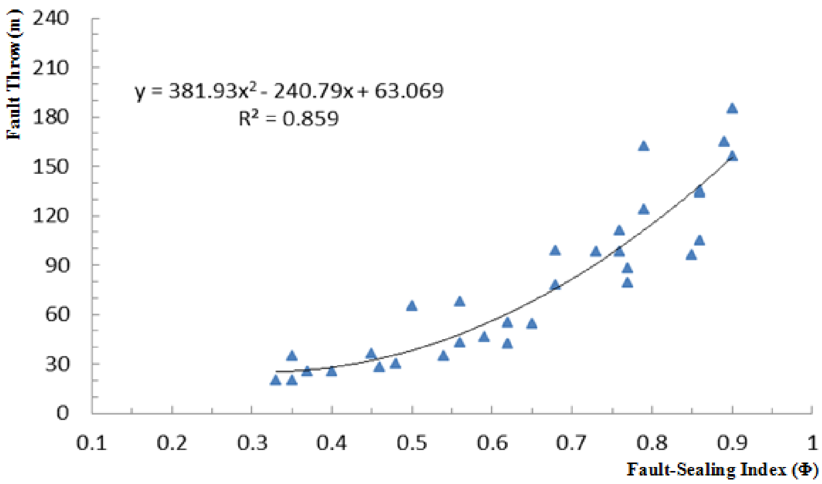

Fig.6. The sealing analysis in different faults

4.3 Injection Pressure Analysis

There is a series of micro and minor faults caused by stress from different angles near the faults where the pressure gradient is lower than the oil layers, which have not been interpreted or recognized. Injection pressure that is close to or exceeds the formation breakdown pressure will fracture micro faults and make them extend. Some micro faults will even connect with large faults, which can cause different types of fault activation and resulting in ineffective water injection. It may also make the formation pressure unbalanced, which will resulting in casing deformation and damage.

There is a critical injection which can be calculated:

$$P_h = P_F\,(1 - X) \qquad (1\text{-}2)$$

P_h—maximum bottom flow pressure of injection well, *Mpa*;
X—breakdown probability, usually taken as 5%;
formation breakdown pressure can be determined by the Dickey method:

$$P_F = CH_Z \qquad (1\text{-}3)$$

C—rock pressure gradient, usually taken as 0.0227~0.0247 *Mpa/m*;
Hz —mid depth of oil layer, *m*.
When the maximum bottom hole pressure of injection well is calculated, the breakdown probability (X) is usually set at 5%. When dealing with the block with micro and minor faults, the breakdown probability (X) is set at 10-15% and the reservoir depth (Hz) is set at the upper layer of reservoirs to avoid the reactivation and connection of different level faults caused by the high injection pressure.

4.4 Deployment of Injection-production Patterns

It is necessary to locate injection wells away from the fault zones. Generally, the injection wells shall be one development well spacing away from the boundary faults. In reservoirs with poorly sealed faults, if the production is not significantly affected by the injection wells, and the water injection overflow is higher than 80% of the water injection or the pressure drop of the well group exceeds 20%, the water injection-production mode should be adjusted by changing the production mode or stopping the injection. Large channels can be easily formed in the blocks with micro faults and high permeability, and the injection wells must be properly arranged to develop the remaining oil near different faults.

4.5 Results

The fault-sealing has been paid more and more attention in Dagang Oilfield for the past few years. For offshore oil and gas reservoirs, the distribution of controlling faults and the sealing capacity shall be clarified. The mud density during drilling process should be controlled to avoid faults activation. The micro faults in developed oil and gas fields and the deployment of injection and production wells should be focused especially in the reservoir with complex faults. The application of fault sealing study presenting good results in both economic benefits and ecological protection. The yearly invalid water injection is reduced by 2600×10^3 m^3 by removing 82 inefficient water injection, and the yearly cumulative oil increment is 79.8×10^3 t.

V. CONCLUSION

This paper presents the distribution characteristics of micro and minor faults. The generation mechanisms of micro and minor faults are investigated by virtue of the experimental models which were used previously for ascertain boundary faults. Theoretical and experimental analyses proof the existence of a large number of micro faults. The fault-sealing is analyzed from the aspects of statics, reservoir engineering, numerical simulation and field performance. The precaution measures are proposed base on the field performance in Dagang Oilfield. The results will provide guidance and reference for the development of oil & gas fields.

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