Research Progress on Prediction Methods of Coupling Natural and Artificial Fractures

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Abstract. There are both differences and relations between natural fractures and artificial fractures. Natural fracture research is the foundation, while artificial fractures aggravate the complexity of fracture development. The coupling relationship between them is the core of research on unconventional reservoir fractures. Through a large number of domestic and foreign literature surveys, combined with the author's own practice, this paper systematically analyzes the characteristics and interrelationships of artificial fractures and natural fractures. It is expounded from three aspects: the quantitative prediction method of natural fracture, the detection method of artificial fracture and the coupling relationship between natural fractures and artificial fractures. Firstly, in terms of natural fracture prediction, analyses geological analysis methods, logging interpretation methods, seismic detection methods, nonlinear quantitative predictions and numerical simulation methods of quantitative prediction, and examples of author's own research, analyzes the effect of fracture prediction, and simulates the influence of natural fracture network on water injection development. Secondly, in the monitoring of artificial fractures, methods such as micro-seismic detection and well test detection are analyzed, and it is pointed out that the artificial fracture network reconstruction volume of the reservoir is the main controlling factor that affects the stimulation effect of reservoirs. Based on the analysis of natural fractures and artificial fractures, the coupling relationship between artificial fractures and natural fractures in the water injection process is studied by applying an example of oilfield water injection development, and it is clear that the dynamic fractures opened during the water injection development are the comprehensive reflection of the two. Finally, according to the latest development of reservoir fracture research, it is proposed that the multi-scale fracture simulation using artificial intelligence technology combined with fracturing fracture simulation is the future development direction of fracture prediction technology.

Keywords: Natural fracture · Artificial fracture · Conceptual model · Discrete fracture network model · Coupling

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1 Introduction

Fracture is the most complex structure on the earth [1]. It can not only increase the reservoir space, but also improve the seepage capacity of the reservoir. It is the key factor for the tight reservoir to obtain high and stable production [2]. However, due to the complex genesis, various influencing factors, random formation and development, and highly heterogeneous distribution of fractures [3], the quantitative prediction of fractures has long become a difficult and hot topic in oil and gas exploration and development [4–6].

The studies on fractures abroad are very early and have a history of more than one hundred years. Dennis, Friedman, Pllard and other famous scholars have done many researches and put forward the concept, classification methods and other aspects of natural fractures. Olson [7] and Dahi Taleghani [8] studied the propagation mechanism of artificial fractures after encountering natural fractures based on boundary element model, finite element and discrete element simulation. Based on four-dimensions/nine components, micro seismic interpretation method and four-dimension delay multi-component seismic technology, Alfataierge et al. combined geomechanical model with fracture propagation simulator to comprehensively study fracture propagation process [9, 10]. In the 1980s, there was an upsurge in the study of natural fractures in China, mainly from four aspects: field outcrop, core description, well logging and seismic interpretation. Zeng Lianbo, Dai Junsheng and Ding Wenlong et al. ever systematically summarized the research progress of fractures at home and abroad [11, 12]. It includes the relationship between faults and fractures, the geomechanical mechanism and model of natural fractures, and the development law of fractures in low permeability sandstone.

Unconventional reservoirs often have poor physical properties, small pores and throats, poor connectivity, and low or no natural productivity. It is necessary to improve single well production by fracturing. In recent years, volume fracturing has become the core technology of unconventional oil and gas development, and artificial fractures by fracturing are paid more attention [13]. In particular, the successful development of tight oil in North American has greatly changed the traditional development concept. From predicting the "sweet spots" of natural fracture development to increasing the initial production of single well, to implementing large-scale volume fracturing of horizontal wells to break reservoirs and build complex network fracture system of coupling natural fractures and artificial fractures, the "fracture controlled" reserves and cumulative production have been improved, and the role of fractures in the development of tight reservoirs has been maximized [14].

Based on the investigation of a large number of literatures at home and abroad, this paper systematically summarizes the quantitative prediction methods of natural fractures and artificial fractures from geology, well logging, seismic data, engineering and other disciplines, and analyzes the advantages and disadvantages of different research methods. The author based on many field outcrop investigations and field practices, the concept model of volcanic rock fracture development and discrete fracture network model are established. The main controlling factors of fracture development, the influence of natural fracture network on water injection development, and the coupling relationship between artificial fractures and dynamic fractures are analyzed. Based on the latest progress of fracture researches, the future development direction of fracture prediction technologies is proposed, which provides a theoretical basis for the benefit development of unconventional oil and gas.

2 Research Progress on Quantitative Prediction Methods of Natural Fractures

Many scholars have systematically studied the identification and prediction of natural fractures, which can be summarized as geological, well logging and seismic methods. In the process of practical research, the three methods verify each other in comprehensive evaluation. In recent years, nonlinear quantitative prediction method and discrete fracture network model etc. have been developed gradually, which makes fracture identification tend to be quantitative.

2.1 Geological Analysis Methods of Fractures

Geological analysis methods are the most basic methods to predict fractures. In 1947, Bogdonov first proposed a new understanding that fracture density decreases with the increase of formation thickness [15]. Handin et al. studied in detail the influence of Mineral rock composition on fracture density in rock through field outcrop profile [16]. On the basis of outcrops and core analysis, the main content of geological analysis is to study the influencing factors of fracture development, and quantitatively calculated the parameters of fracture density, length and opening, so as to provide theoretical basis for the establishment of fracture model.

Field Outcrop Analysis Method: To select the field outcrops similar to the geological characteristics of the study area to study the occurrence, scale and genetic type of fractures, and the relationship between fractures of different formations, and summarize the main geological factors controlling the formation and distribution of fractures and fracture development rules. Through similarity analogy analysis, to establish the conceptual model of reservoir fractures and apply it to the prediction of fractures in the study area [17]. Through outcrop study, the main controlling factors of fracture development can be analyzed, mainly including fracture, fold, lithology and rock thickness etc. Kajari Ghosh studied the outcrops of Teton complex anticline belt in Montana, Rocky Mountains in USA, and found that the fracture density near the junction is higher, while that far away from the junction is lower, showing a linear negative correlation [18]. According to Zhang Qinglian and Pan Wenqing et al., the smaller the grain size of clastic rock, the more favorable to fracture development [19], while the larger the grain size of carbonate rock is, the more favorable to fracture development [20]. Based on the measurement and analysis of volcanic outcrops in the Guajishan limestone area in Xishan Mountain of Beijing, the author established a fracture development model of volcanic rocks under the control of strike slip faults, and applied it to guide the fracture prediction of the same type of volcanic oil reservoirs (Fig. 1). Research results show that faulting has an obvious control effect on the development of fractures in volcanic rocks: a series of fractures related structures can be formed near a fracture zone, including broken rock zone, echelon fold zone, strong fractured zone and pinnate joint. Meanwhile, there is an obvious negative exponential relationship between the degree of fracture development and the distance to the main fault. Field outcrop analysis is the most direct and accurate method to quantitatively characterize fractures. The conceptual model based on field outcrop description provides a basis for establishing the discrete fracture network model of the reservoir. However, it should be noted that when applying the field outcrop conceptual model to guide fracture modeling, it is necessary to clarify whether the two are comparable, such as whether the geotectonic background, the in-situ stress field, the fault properties, lithology and lithofacies types are consistent.

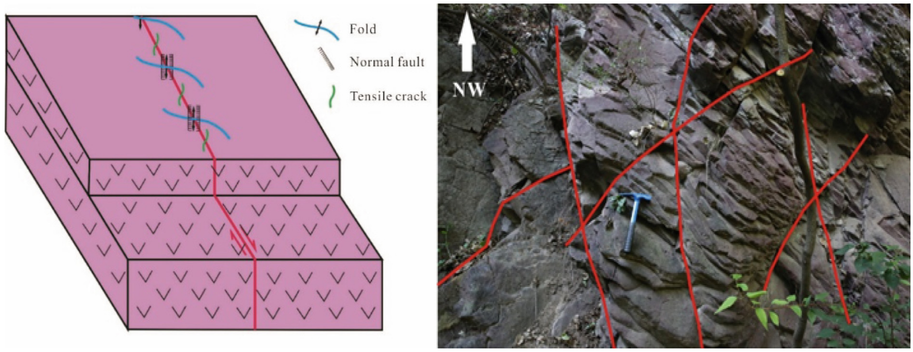


Fig. 1. A conceptual model of volcanic fracture development controlled by strike-slip faults (Guajishan Formation, Xishandatai, Beijing)

Core Analysis Method: Outcrop, core and other entity data are the most reliable information carrier to describe fractures. Various parameters of fractures can be accurately characterized through core observation and description. Core analysis has developed from visual observation and description to thin section analysis to digital core technologies (such as field emission scanning electron microscope, nano CT scanning imaging and nuclear magnetic resonance). The cross section of a core can be scanned segment by segment, and the scanned cross sections are recombined to carry out 3D reconstruction of the core [16]. The macro fractures, micro fractures and nano-micron fractures of the reservoir are analyzed qualitatively and quantitatively, such as the type, occurrence, starting position, direction, density, opening and filling degree [6]. The drawback of this method is that the core data can only reflect the point information of a formation, and often cannot drill into high-angle fractures; the representativeness of the 3D structural geology occurrences such as fracture is limited.

2.2 Well Logging Interpretation Methods of Fractures

Well logging is the most common and comprehensive data except core. Such methods include quantitative prediction methods by conventional well logging data and special well logging data. The biggest advantage of using logging data to interpret fractures is high characterization accuracy (especially imaging logging) and large longitudinal detection range. The biggest defect is similar to the core analysis method in that it can only reflect the information of a certain well. The three-dimensional spatial distribution forecasting guidance is limited.

Conventional Well Logging Method: The general characteristics of conventional well logging curves in a fractured zone are “two highs, one low and one amplitude difference”, i.e. high neutron porosity, high acoustic time difference, low amplitude difference between density and bilateral resistivity [21]. There are some limitations in using single well logging data in practice, so it is necessary to consider various well logging information comprehensively, establish cross plot, and quantitatively predict the well intervals without core [22]. The interpretation method is relatively mature, but the accuracy and effectiveness of fracture prediction are poor, and it is difficult to determine the dip angle, strike direction and distribution density of fractures [3].

Special Well Logging Method: Special well loggings include full hole formation micro resistivity imaging (FMRI), formation micro resistivity scanning imaging (FMS), azimuth lateral imaging and acoustic imaging etc. Imaging well loggings can be used not only to determine fractured intervals, but also to quantitatively calculate fracture parameters [21]. Special well loggings have high resolution, high precision and high cost, so they can only be used in a few wells. In actual production, core and imaging well logging data are used to calibrate conventional well logging data, and then conventional well logging data are used to predict fractures in the whole well section [22, 23].

Based on imaging well logging and conventional well logging methods, the author quantitatively characterized the occurrence of different types of fractures in single well volcanic rocks of the Jiamuhe Formation in Jinlong-2 area, Xinjiang. Figure 2 shows the analysis of fracture occurrence in Well JIN220 in this area. Different colors of tadpoles represent different fracture types. Red represents high conductivity fracture, yellow represents high resistance fracture, purple represents micro fracture, and pink represents induced fracture. Fractures in the measurement section of the Jiamuhe Formation of Well JIN220 are relatively developed in some well sections, and they are mainly distributed in the pyroclastic rocks of Jiamuhe Formation. Among them, two groups of high guide fractures are mainly developed, and the trend is NNE-NWW and NWW-NEE, respectively, with the dip Angle ranging from 50 to 70°. A small number of micro-fractures are developed in the pyroclastic rocks strata. They tend to be NW trending, and their strikes are NE-SW trending, with dip angles ranging from 10 to 20°. The tendency of high-resistance fractures is also mainly in the southwest direction, with a northwest-south east direction, and the inclination range is between 20 and 70°. Drilling induced fractures are relatively developed in volcanic lava, and their strikes are nearly NSW-SSE, with dip angles ranging from 72 to 80°. Natural fracture parameters (stroke, tendency, dip, fracture density, etc.) characterized by high-resolution imaging logging are often the basic “hard data” for establishing discrete fracture network models.

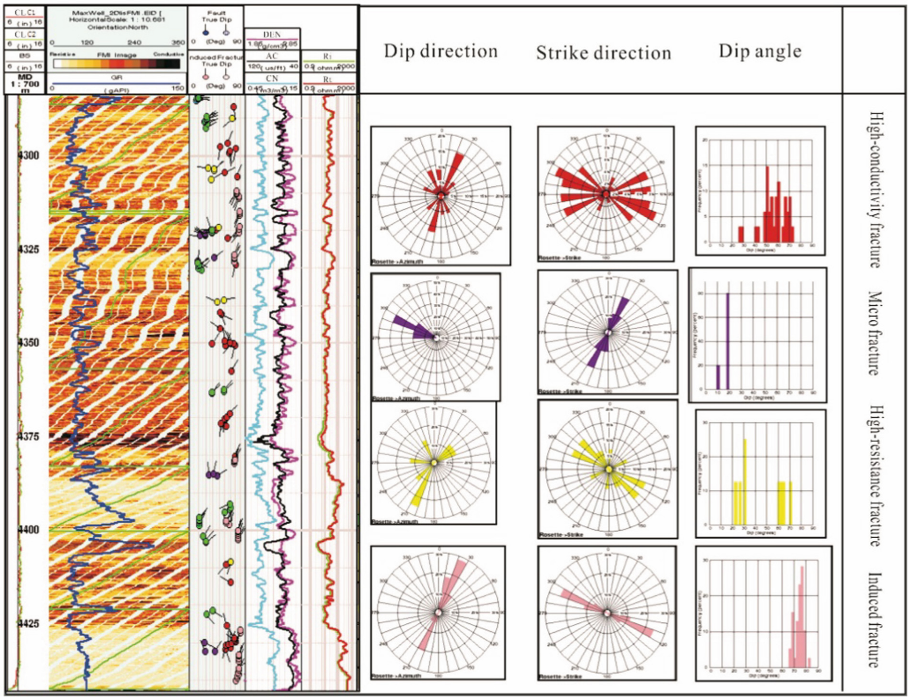


Fig. 2. Occurrence characteristics of fractures in Well JIN-220

2.3 Seismic Detection Methods of Fractures

The principle of seismic detection methods is that fractures aggravate the anisotropy of reservoir, and then produce significant response in seismic wave. There are many seismic prediction methods, each of which has its own applicable conditions. For examples, using seismic attributes (such as P-wave and S-wave coherence, dip angle and azimuth angle) to predict large-scale fault and fracture system; using P-wave and S-wave azimuthal anisotropy and shear wave splitting to predict small-scale fracture network system; using 3DMove fracture prediction technology and curvature volume technology to analyze the connectivity and effectiveness of fractures. The biggest advantage of multi-wave technologies is that they can reliably predict fracture development zones [24].

Post Stack Seismic Data Analysis Method: In 1968, Murray G.H first applied structural surface curvature to quantitatively analyze fractures in Sanish oilfield, North Dakota, USA. The structural curvature analysis method mainly uses trend surface fitting and difference method [25]. In recent years, Gersztenkorn et al. proposed the third generation coherence cube technique of eigenstructure algorithm [26].

AVO Analysis Method of Prestack Seismic Data Volume: AVO technology uses the principle that the reflection coefficient changes with the incident angle to analyze the variation law of amplitude with offset on prestack gathers. In 1996, Ruger derived the formula of reflection coefficient in anisotropic media and used P-wave azimuth AVO to detect fractures [27]. In 2017, Li Bonan et al. proposed a new method for inversion of reservoir fracture parameters based on equivalent medium model and frequency-dependent AVO [28].

S-wave Splitting Detection Method: In 1978, Grampin's research and experiment proved that S-wave splitting is widespread [29]. In 2017, Zhang Jianli et al. used three types of double scanning S-wave splitting algorithms to predict fractures in tight gas-bearing sandstone reservoirs [30].

Multiwave and Multicomponent Seismic Detection Method: The British Geology Survey, Calgary University in Canada, Colorado Mining Institute in the United States and major oil companies launched multiwave and multicomponent seismic exploration [31]. In 1999, Li Xingyang, a Chinese scholar, used multicomponent PP wave and PS wave to detect fractures, marking a substantial breakthrough in fracture prediction technology of combined P-wave and S-wave [32].

In the study of fractures in deep volcanic reservoir in Jinlong 2 well area, Xinjiang, the author has successfully realized fracture prediction and guided the development of fractured volcanic reservoir by applying various prestack azimuth prediction methods. Since the volcanic rocks of Jiamuhe Formation in the study area are buried at about 4000 m, in order to improve the signal-to-noise ratio of the data, the superposition method of 50 × 50 m super-panel stacking method is adopted. The velocity field obtained by conventional velocity analysis is used to superimpose the data volume with different azimuth angles. The processing results are shown in Fig. 3. It can be seen that there is obvious anisotropy in the target interval in the stacking profile of each Angle gather, which can be used for fracture anisotropy ellipse calculation and fracture prediction.

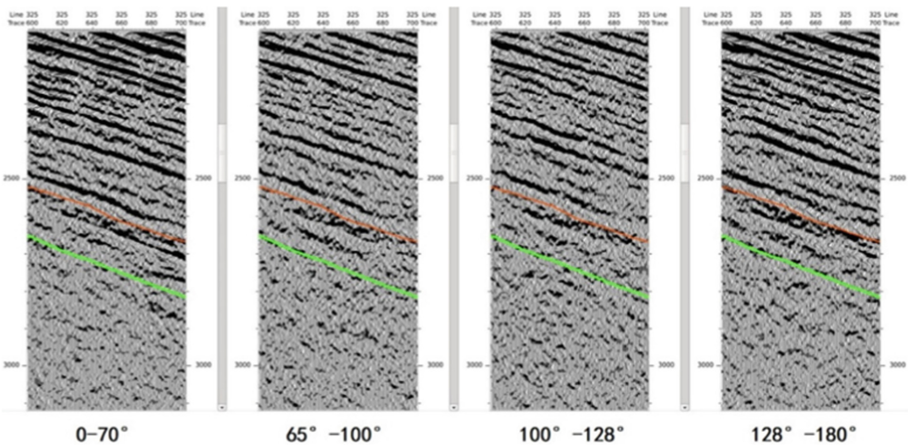


Fig. 3. Migration profile superimposed with different azimuth angles

On this basis, attribute anisotropic ellipse calculation is carried out, nearly 10 seismic attributes are calculated and their prediction accuracy is compared (Fig. 4). The curve in the figure represents the fracture density interpreted by FMI. The red attribute represents the favorable area for seismic prediction of fracture development, and the blue attribute represents the relatively underdeveloped area. It is found that the prediction effect of attenuation start frequency is the best. Its principle lies in the absorption and attenuation phenomenon of seismic wave, which is caused by the inherent viscoelasticity inside the rock, including the relative flow of liquid in the pores of the rock, the internal friction loss between the rock particles and the crack surface, local saturation effect and geometric diffusion. The factors that affect the information of absorption attenuation include rock properties, rock porosity and fluid composition in the pores. When fractures develop in the strata, they have a great attenuation effect on the high-frequency components of seismic waves.

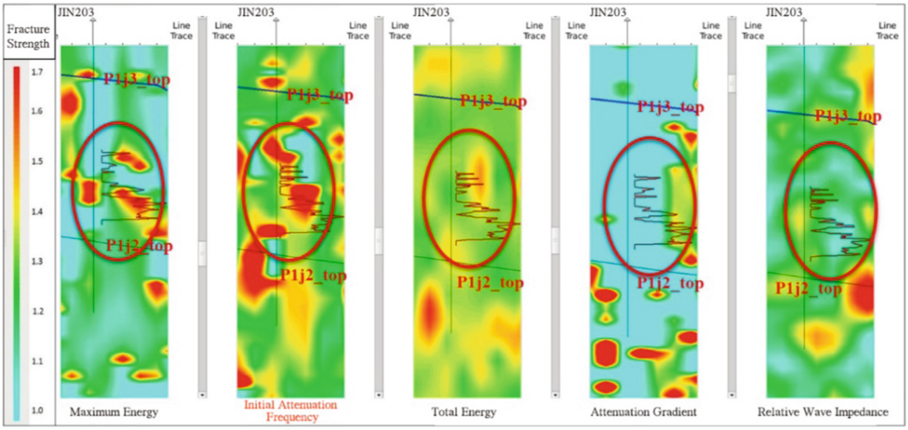


Fig. 4. Comparison of fracture strength by inversion of different attributes

According to statistics, the fracture strength and azimuth predicted by the pre-stack azimuth anisotropic method is 65% consistent with the FMI interpretation results of single well. Due to the limited quality of deep seismic data and other reasons, the accuracy is reasonable, and the prediction results have the advantage of three-dimensional spatial distribution, which can be used to guide the construction of fracture model.

2.4 Nonlinear Quantitative Prediction Methods of Fractures

Neural Network Quantitative Prediction Method: In the 1980s, neural network algorithms emerged. They process information by adjusting the connections between many neurons. The most effective method is back propagation neural network (BP network). According to the existing fractal dimension, sand ratio, fracture rate and other data, Zhou Ziyong et al. constructed a BP neural network to predict the fracture distribution in the study area [33]. The most important characteristic of this method is to confirm the relationship between the input data and whether there is a necessary relationship between them and the fracture distribution. Only when there is a good relationship can an accurate neural network be established to realize the accurate prediction of the fracture.

Quantitative Prediction Method of Grey Correlation Analysis: In 1982, Professor Deng Julong, a Chinese scholar, put forward the grey system theory [34]. Grey correlation degree is to compare the similarity between the unknown model and the standard model to measure the correlation degree between factors. In 1996, Jiang Tongwen et al. introduced the grey correlation degree into fracture prediction and put forward the fracture prediction method of carbonate rock [35]. In 2016, Dong Fengjuan et al. applied the grey correlation analysis method to reveal the geological factors for the development degree of micro fractures in tight sandstone reservoirs [36].

Fractal Prediction Method: In 1975, Mandelbrot proposed fractal geometry. The fractures in reservoir have the complex phenomenon of chaotic size, different rules, but self-similar structure, thus they can be predicted by fractal method. Hou Guiting and Du Xiaowu et al. used fractal method to predict fractures. The studies show that the larger the fractal dimension is, the more developed the fractures are, but the fracture connectivity is worse; the smaller the fractal dimension is, the better the fracture connectivity is, and the easier the fluid migration is [37, 38]. In the study of fractures in Jurassic volcanic rocks in the Xishan area of Beijing, the author made statistics on fracture plane density of volcanic rocks with different thickness (Table 1), the fractal dimension of fractures has a good correlation with areal density, but has no obvious correlation with formation thickness, which is obviously the same as the relationship between natural fractures and formation thickness in sandstones and carbonate rocks [17].

Table 1. Statistics of fracture parameters in volcanic cross sections, Tiaojishan Formation, Xishandatai, Beijing

Parameters	DT1	DT2	DT3	DT4	DT5
Formation thickness (m)	0.62	0.75	1.24	1.58	2.34
Fractal dimension number	1.5432	1.4639	1.6733	1.7296	1.6985
Areal density (m/m^2)	8.74	7.87	10.28	12.13	11.27

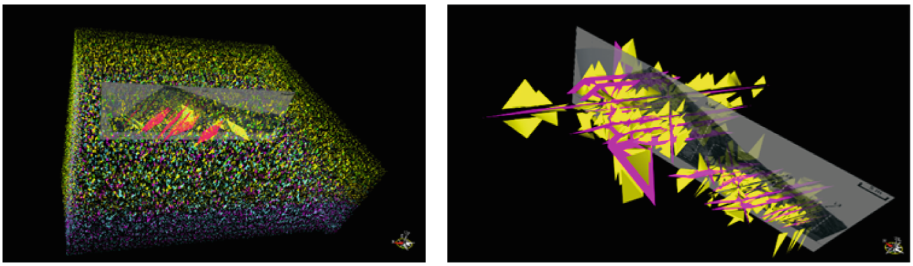
2.5 Quantitative Prediction Methods of Fractures by Numerical Simulation

Tectonic stress field simulation method: In 1947, Li Siguang proposed for the first time to deduce the tectonic stress field from the structural trace. Hubbect put forward in 1957 that in-situ stress is three mutually perpendicular but unequal stresses, namely two horizontal principal stresses and one vertical principal stress [39]. In 1980, Zeng Jinguang et al. developed a quantitative fracture prediction method for complex structures [40]. In 1996, Wen Shipeng et al. developed the reservoir fracture prediction method based on finite element method [41]. In 2016, Ding Wenlong et al. introduced the concept of shale "fracture development coefficient" to quantitatively characterize the development degree and fracture distribution of shale reservoir fractures [42].

Fracture modeling technology: fracture models include equivalent continuum model and discrete fracture network (DFN) model. The equivalent continuous model is to divide a reservoir into finite grids and assign the fracture attribute value to each grid with a simple mathematical formula. The DFN model is a fracture network composed of various types of fracture slices in three-dimensional space in the form of discrete data, which can effectively describe the heterogeneity and discontinuity of fracture network and the seepage process of fluid in fracture system [17].

The author based on the detailed fracture characterization of volcanic outcrop described above, a discrete fracture network model based on actual outcrop is established. At the same time, the effects of natural fracture network and matrix permeability on waterflood development were analyzed by unstructured grid simulation. Because of the volcanic rocks in the discrete fracture network model is established based on the actual outcrop, using unstructured grid processing technology at the same time, the maximum to retain the true form of crack, equivalent to accurately depict the fluid flow channel, to study the change of moisture content in volcanic rock fracture reservoir water flooding development, early failure problem such as water, water injection has obvious advantages.

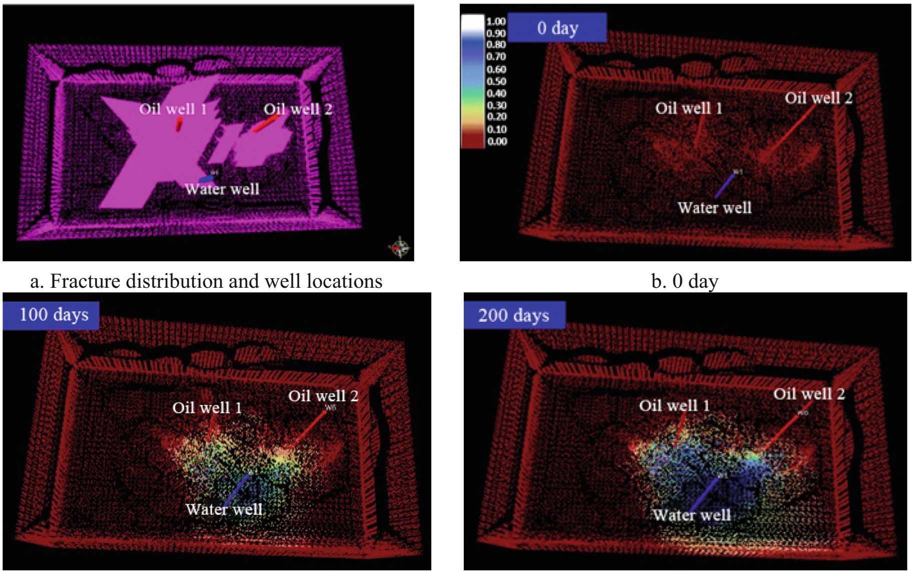
In this model, the deployment of a well and two production Wells and water Wells in the section at the bottom of the middle position, the well profile section at the top of the position of the 1, 2 is located in the southern section of section at the top of the well location, according to the injection Wells day 10, the well bottom hole pressure 15 bar is simulated, simulation model of water injection development for 6 years' time. Studies have found that in fractured volcanic reservoirs, the oil wells directly connected with water wells by fractures have very fast water breakthrough effect, forming the early water flooding phenomenon, while the oil wells indirectly connected with water wells by fractures have water breakthrough effect closer to the matrix system, and the influence of matrix permeability on the water injection development of fractured volcanic reservoirs cannot be ignored (Fig. 5 and Fig. 6) [43].



a. Overall subdivision effect

b. Tetrahedral mesh on both sides of high-angle fractures

Fig. 5. Outcrop DFN model based on tetrahedral mesh



a. Fracture distribution and well locations b. 0 day

c. 100 days d. 200 days

Fig. 6. Numerical simulation results of water saturation field

3 Monitoring Methods of Artificial Fractures by Fracturing

Fracturing is a method that injects fracturing fluid into oil and gas wells to form fractures by hydraulic high pressure. Conventional fracturing can generate double wing plane fractures mainly caused by the tensile failure of rock. Volume fracturing is developed with the large-scale development of tight oil and gas/shale oil and gas in North America in recent years. It can form complex fracture networks mainly caused by tension, shear, tension-shear composite action etc. [44] In 2006, Mayerhofer M.J. et al. first proposed the concept of Stimulated Reservoir Volume (SRV) [45]. In 2011, Wu Qi and Xu Yun et al. introduced the concept of stimulated volume technology, which promoted the significant transformation of unconventional reservoir stimulation [46].

SRV can produce dense fractures that communicate the flow between matrix and fractures and reduce the seepage resistance, so as to realize efficient development of unconventional oil and gas reservoirs. The micro seismic technology during operation and well testing technology after fracturing are mainly used to evaluate the effect of complex fracture network. Through real-time micro seismic monitoring or well test monitoring, the geometric shape and spatial distribution of fractures by hydraulic fracturing can be obtained, the matching relationship between well pattern and fractures can be further studied, and the fracturing design, well pattern and development measures can be optimized, so as to improve oil recovery.

3.1 Fracture Monitoring Method by Micro Seismic

Micro seismic monitoring method is to monitor the artificial fractures induced by fracturing wells by geophones running into adjacent wells, and reproduce the fracture pattern and scale of fractures by hydraulic fracturing in real time. In the mid-1980s, the method of using micro seismic to monitor oil and gas reservoir development was recognized by the industry. In 2002, Maxwell S.C. [47] and Fisher M.K. [48] et al. used micro seismic monitoring technology and other detection technologies for fracturing Barnett shale gas reservoir, and found that the fracture propagation is in complex network shape. In 2008, Mayerhofer M.J. et al. [49] used micro seismic technology to study fracturing fracture changes in Barnett shale gas reservoir. In 2011, Ulrich Zimmer proposed to use micro seismic image to calculate stimulated reservoir volume [50]. In Xinjiang, Changqing and other areas of China, the artificial fracture networks of horizontal wells were identified by micro seismic monitoring technology [51], and the changes of cumulative production under different stimulated reservoir volumes were analyzed, indicating that the larger the stimulated reservoir volume is, the more obvious the effect of oil and gas reservoir production increase is.

3.2 Monitoring Hydraulic Fractures by Well Testing

Well test interpretation can provide more accurate key reservoir parameters than micro seismic technology, but it is difficult to monitor the fracture change after fracturing by traditional well test interpretation method. In 2010, Medeiros established a semi analytical model considering the fracture network of artificial fractures in horizontal wells and formation heterogeneity to study the pressure response characteristics [52]. In 2011, Yao Jun et al. studied the trilinear flow test model of fractured horizontal wells in low-permeability oil reservoirs [53]. In 2018, based on the principle of pressure superposition, Wu Zhiqi established a semi analytical model for pressure dynamic analysis of volume fractured horizontal wells in fractured tight oil reservoirs with box-type closed boundary [54]. In 2021, Shen Chanliang et al. proposed a numerical well test model for multi-stage fractured horizontal wells based on embedded discrete fractures. Micro seismic monitoring results show that there are complex fracture networks formed by natural fractures and hydraulic fractures around the horizontal wells, and the number of discrete natural fractures was predicted; the average length and conductivity of hydraulic fractures and natural fractures were interpreted by well testing (Fig. 7 and Fig. 8) [55].

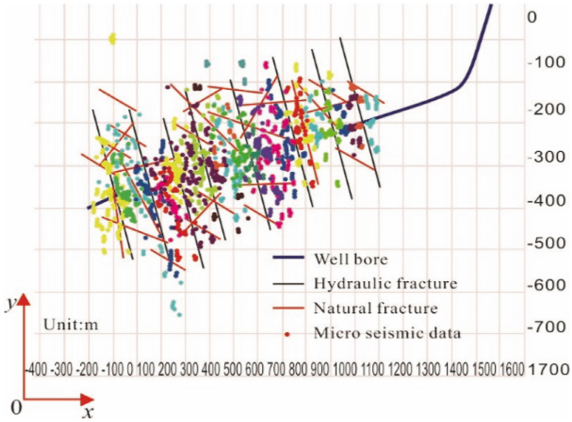


Fig. 7. Micro seismic data of Well JWA

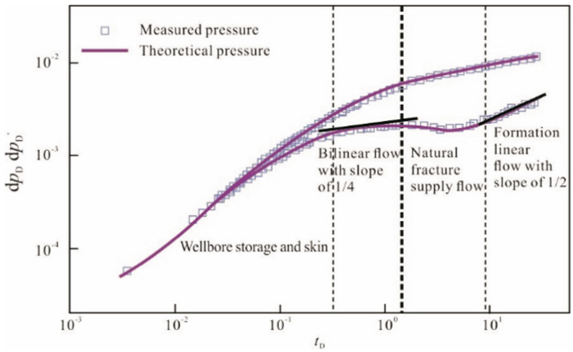


Fig. 8. Fitting curves for the pressure and pressure derivative of Well JWA

4 Coupling Relationship Between Natural Fractures and Artificial Fractures—dynamic Fractures Formed in the Process of Water Injection Development

The response of fractures in the process of water injection development is essentially a comprehensive reflection of the coupling of natural fractures and artificial fractures, which are called dynamic fractures. Dynamic fractures are new fractures produced by rock failure when bottom-hole pressure of a water injection well exceeds formation fracture pressure, or the effective fracture channels formed by reopening the closed natural fractures in the original state. Some scholars at home and abroad have carried out relevant researches on the intersection behavior of fracturing fractures and natural fractures. In 1996, H.H. Abass made experimental analysis of horizontal wells and concluded that when the azimuth angle θ is between 0–50°, multiple fractures may occur; when θ is between 50–70°, single fracture may occur; when θ is between 70–90°, "T"-type fractures may occur [56]. When the hydraulic fractures intersect with the natural fractures, the larger the intersection angle is, the hydraulic fractures tend to penetrate the natural fractures; the smaller the intersection angle is, the easier it is for the hydraulic fractures to turn into and open the natural fractures. If the stress difference is larger, the fractures tend to penetrate the natural fractures [57]. In 2015, Wang Youjing et al. proposed the concept of dynamic fracture and discussed its genetic mechanism and its impact on oilfield development [58]. Fan Tianyi et al. established a new model to describe the dynamic changes of fracture morphology and attributes, and simulated the evolution mechanism of dynamic fractures and its impact on oilfield development [59].

The identification of dynamic fracture adopts the comprehensive method of geology and dynamic data. The dynamic data can often directly show the fracture seepage characteristics, such as the stepped rise of water cut in oil wells, the inflection point of water injection indication curve, the peak-shaped water absorption of water injection profile, and the obvious directivity of tracer monitoring [55]. The research shows that the large horizontal stress difference is easy to form individual fractures. If oil and water wells are deployed in the direction of fractures, water channeling will be formed, resulting in rapid flooding of oil wells. For this problem, Daqing Oilfield put forward the development concept of "injecting water along the fracture direction and displacing to both sides". The linear well pattern with drawing water line not only makes use of fractures to expand the swept volume, but also improves the development effect. If the horizontal stress difference is smaller, multi-direction fractures can be formed. If volume fracturing is conducted in a horizontal well, wide fracture network will be formed on both sides of the horizontal well, so as to greatly improve single well production. The large-scale beneficial development of unconventional oil and gas makes full use of this feature.

5 Development Direction of Reservoir Fracture Research

(1) In the future, more attention should be paid to quantitative fracture evaluation technology by multi methods. In fracture evaluation, to combine geological description, well logging interpretation and seismic detection, integrate macro-scale and micro-scale fracture research, and bind dynamic data and static data analysis, so as to continuously improve fracture prediction accuracy.

(2) Several key technologies need to be solved in reservoir fracture characterization in the future. To stylize fracture development according to the field fracture geological knowledge base; to use digital core technology to clarify the fracture seepage mechanism; to deepen the practicability of geophysical methods; to accelerate the research, development and application of dynamic fracture numerical simulator.

(3) In the future, the geological modeling and numerical modeling of fractures based on the coupling of natural fractures and artificial fractures will be more standardized. To develop artificial intelligence technology combining multi-scale fracture simulation with fracturing fracture simulation. To realize seamless connection between fracture modeling, reservoir numerical simulation and fracturing fracture simulation on one platform; to optimize the overall scheme; to solve a series of technical problems in oil and gas field development.

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