Analysis technology and application of natural fractures based on microseismic monitoring results

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Abstract. In general, the matrix permeability of shale reservoirs is small, and a developed natural fracture network is required to obtain a good mining effect. Therefore, analyzing and understanding the development of natural fractures in the reservoir plays an important role in increasing the production capacity of shale gas. Microseismic monitoring is the key technology of fracture imaging during hydraulic fracturing. Based on the results of ground microseismic monitoring, this paper analyzed both the waveform and energy of microseismic event, as well as the spatial distribution law, and also combined it with the surface seismic attribution data, formed a natural fracture analysis technology based on the results of microseismic monitoring, which played an important supporting role in real-time optimization and guidance of hydraulic sand fracturing.

1. Introduction

At this stage, under the condition of the world's original resources being extremely scarce, the development of new energy sources is particularly important. Shale gas is one of the new energy sources. As an important unconventional natural gas resource, China is abundant in shale gas which means great potential and prospects for exploration. At present, the main method of shale gas exploitation is hydraulic fracturing technology. The most direct and effective method for how to effectively evaluate the hydraulic fracturing transformation effect and find potential construction risks in real time is to use microseismic monitoring technology[1].

At the same time, during the development of shale gas, natural fractured reservoirs have brought a contradiction to exploitation. These reservoirs may initially show high yields, but production capacity declines very quickly. In addition, during the process of hydraulic fracturing in the formations with natural fractures, abnormal high pressure and desanding are often encountered, leading to construction failure and even serious accidents. On the other hand, some natural fractured reservoirs are also the largest and most productive reservoirs in the world. This paradoxical nature of this type of reservoir has inspired the industry to do its best to understand its characteristics in order to develop it with greater confidence.

This paper analyzed the waveform, energy, and spatial distribution of natural fracture events and hydraulic caused events, and summarizes the microseismic response characteristics and identification methods of natural fractures. In the hydraulic fracturing construction, the hydraulic caused fractures and natural fractures were effectively distinguished, and the fracturing production construction was optimized.
2. Microseismic response characteristics of natural fractures

The shale in Longmaxi Formation in Sichuan belongs to marine sediments. Because the strata have undergone multiple stages of tectonic movements, the lateral geostress changes greatly, and is rich in small faults and natural fractures. Due to the different mechanisms induced by natural fractures and hydraulic caused fractures, some attributes of microseismic events are also different from one another[2].

2.1. Waveform characteristics of microseismic event

The difference of waveforms between microseismic events is mainly caused by the difference of spatial position of the event point. In terms of surface microseismic monitoring, relate to the distance from the horizontal section of the fracturing well to the geophone, the distance between the natural fracture event point near the fracturing section and the fracturing event point of the section is very short, so the waveform is basically the same. However, because the energy of natural fracture events are much stronger than that of hydraulic caused events, the single-channel amplitude energy displayed on the profile will be greater.

![Figure 1. Surface microseismic monitoring of natural fractures and fractured fracture profiles](image)

2.2. Energy characteristics of microseismic events

Microseismic event energy is a direct response to rock fracture and reflections the geophysical characteristics of fractures. The microseismic caused by hydraulic fracturing leads to relatively simple pulsed seismic waves. The propagation medium and velocity changes mainly affect the complexity of the microseismic wave field. The microseismic waves caused by natural fractures are relatively complicated, and have more later arrivals, and also longer propagation duration, in addition, the average energy is much larger than microseismic events caused by hydraulic fracturing.

2.3. Spatial distribution

In-situ stress is a three-dimensional stress composed of one vertical principal stress and two horizontal principal stresses. The research domestic and abroad results showed that the shape and extension direction of fractures extruded during hydraulic fracturings are controlled by three-dimensional stress in the formation. During the fracturing process, when the pressure of the fracturing fluid injected into the well reached the critical point of formation fracture pressure, the formation began to fracture. If the liquid is continuously injected, the fracture seam will continue to grow. Due to the pressure change in the formation, the fracture extends forward, and the energy of each fracture extension is propagated outward in the form of elastic waves. The formation rock failure is not only related to the size of the void pressure, but also to the rock mechanical properties of the formation. According to the Mohr-Coulomb criterion, microseismic events will occur near the fractures when the local pressure increases.

The hydraulic fracturing process caused the rock to rupture, and the microseismic events started to extend to both sides of the wellbore as the construction progressed, and the extension direction was
basically consistent with the direction of the maximum principal stress in the area. The hydraulic fracturing process causes natural fractures to generate stress responses, which will generate a large number of microseismic events. The fracture propagation speed is faster than hydraulic fracturing fractures, and the spatial distribution is more concentrated. Obvious relationship.

3. Case

The study area is located in the Weichuan-Longnüsi structural group in the gentle structural area of the Middle Sichuan ancient paleontology. It is a giant near-dome-like anticline structure formed on the Leshan-Longnüsi Caledonian ancient uplift. The Xindianchang syncline is adjacent to the artesian well, Guanyin field, and Maliu field, and is connected to the north end of the Laolongba structure to the southwest. In the Weiyuan area, the structure of the ground and the interior of the three-dimensional block of shale gas is consistent, simple in structure, high in the northwest and low in the southeast, and near the east-west axis. The buried depth of the target layer in the well area is generally shallow, and the buried depth is shallow in the northwest and deep in the southeast. Most of the buried depths in the area are within 3000m, and most of the cold bottoms are within 4000m, which is a favorable area for shale gas exploration.

The average horizontal length of the wells in this area is about 2000m, and the single well design fracturing section is 20-40. The hydraulic fracturing process is mainly fracturing fluid with slippery water, and the fracturing mode of soluble bridge plug + cluster perforation In a single section, 3-4 cluster perforations, cluster spacing is about 20m, fracturing fluid is about 2000m³ + proppant 100 tons, and construction displacement is about 13-14 m³ / min. The monitoring method mainly uses ground microseismic monitoring. The number of measuring lines is about 10, the number of receiving channels is about 800, and the channel spacing is 50m. The survey line is laid out with the wellhead as the center and is distributed radially.

The platform well group with natural fractures developed in this area was selected for analysis. The F1 platform is four horizontal wells in the same direction. The fracturing construction sequence is fracturing construction 1, 2 wells, and then 3 and 4 wells. Fracturing construction. The results of microseismic monitoring are shown in the left figure of Figure 2. A total of 2700 effective microseismic events were monitored on the F1 platform, and the magnitude of the event points ranged from 0.01 to 0.21. Among them, there are 507 strong energy events with magnitude greater than 0.1, accounting for 18.7% of the total number of events. The distribution of these strong energy microseismic events is shown in the right figure of Figure 2, which is 2-10 times.

Figure 2. Top view of results of microseismic monitoring on F1 platform and results of microseismic events with magnitude greater than 0.1
From the spatial distribution of microseismic events, when the fracturing wells 1 and 2 are close to the vertical well section, more and more strong energy events gradually respond in the area near the 19th section of the well 3 to the deflection point. When fracturing wells 3 and 4, a large number of high-energy event points responded in the fracturing section of the 4th to 17th sections of well 4, and the high-energy events generated by the two constructions tended to be gradually connected. Compared to fracturing fracture events that occur on both sides of the wellbore during construction, these high-energy events are very aggregated and linearly distributed as a whole. The presented fracture azimuth angle is also very different from the fracture fracture. As shown in Figure 3, the platform well cross dipole array acoustic wave explains the maximum principal stress direction is 95-110 °, and the monitored fracture azimuth angle is about 85-115 °, which is basically the same as the direction of the maximum principal stress in this area, and the azimuth angle presented by the high-energy event as a whole is about 24 °. Therefore, it is considered that the maximum principal stress is not affected.

![Figure 3. Top view of microseismic monitoring results on F1 platform](image)

Combined with the analysis of the ant body fracture prediction map, the fractures displayed on the ant body in this area are more complicated, and only a part of them has detected the microseismic response during the fracturing process. The main high-energy event gathering areas monitored are displayed at the corresponding positions of the ant body, and the overall fit is good, as shown in Figure 4.
In summary, the event energy and spatial distribution of microseismic monitoring results are comprehensively analyzed, and combined with the ant body fracture prediction map, it is considered that the strong energy events in this area are natural fracture events.

Secondly, combined with the fracturing construction curve analysis, the results of microseismic monitoring can effectively evaluate the impact of natural fractures on fracturing construction, play a role of early warning of the risks during construction, and finally achieve the optimization of fracturing construction by adjusting fracturing construction parameters purpose.

Taking this well group as an example, natural fracture events in the late stage of fracturing wells 1 and 2 responded in the area from the 19th section of well 3 to the vicinity of the deflection point and gradually extended to well 4. During the subsequent construction of the fracturing section where Well 3 is close to and coincides with the natural fracture, due to the influence of the natural fracture, the fluid filtration effect is large. The fracturing curve fluctuates greatly when the high sand ratio is added to the silt stage and the ceramsite stage. The pressure rise is obvious, as shown in Figure 5.

Combining the analysis results of microseismic monitoring and fracturing construction curve, it is concluded that some stages of Well 4 also pass through the same activated natural fractures. It is likely that similar situations will occur when these fracturing sections are constructed. And it is suggested to adjust the fracturing construction parameters of some stages of Well 4 according to the current situation. In the subsequent fracturing process, due to the early warning of microseismic monitoring and the use of adjusted parameters for fracturing construction, the construction pressure was relatively stable, and the purpose of guiding optimization of fracturing construction was achieved.
Figure 6. Fracturing construction curve in typical section of Well 4

4. Conclusion
Microseismic monitoring technology is capable of locating the spatial location of event points in real time and show the extension and extension of cracks. Through the analysis of the waveform characteristics, energy characteristics, spatial distribution characteristics of the microseismic events, and the combination of ant body fracture prediction maps, natural fracture events and fracturing fracture events can be effectively identified. Natural fractures are often affected by natural fractures during the construction of fracturing sections where natural fractures develop, making construction difficult. Using microseismic monitoring technology in combination with field construction anomalies to analyze in real time, further evaluate the impact of natural fractures on fracturing construction, and optimize and guide hydraulic sand fracturing in real time.

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