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Research article

Study on Microseismic Monitoring Technology in Borehole in a CCUS-EOR Project

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Abstract:
Carbon Capture, Utilization and Storage (CCUS) is a large-scale greenhouse gas emission reduction technology that can both enhance oil recovery and sequester carbon in the petroleum industry. However, issues such as unclear main direction of oil and gas migration and unknown causes of gas channeling exist in the CO_2 flooding process. With increasing global demand for safe operation of CO_2 geological storage, improving safety monitoring technology is crucial. The study adopted downhole microseismic monitoring technology to monitor the CO_2 flooding process in real-time, combined with dynamic characteristics of microseismic events, and utilized data such as regional 3D seismic fracture attributes and injection-production parameters to evaluate the geological integrity and gas channeling issues in CCUS. Microseismic monitoring technology can assess the integrity of geological layers and caprocks, identify main oil and gas migration paths, determine causes of gas channeling, and optimize injection-production parameters. In mature well areas, there is a dilemma between ensuring CO_2 storage and maintaining oil production in well replacement schemes. The study provides key data support for optimizing CO_2 geological storage strategies, contributes to environmental protection and sustainable development, and discusses the challenges and future prospects in this field.

1 Introduction

Carbon Capture, Utilization and Storage (CCUS) is a large-scale greenhouse gas emission reduction technology. Industries such as steel, power, and cement have introduced a series of carbon emission reduction solutions. With the continuous promotion of the rapid development of new energy businesses in China, under the background of the "dual carbon" goals, PetroChina has proposed a development strategy with the objectives of "promoting green and low-carbon development and enhancing energy security protection capabilities". It actively explores and improves the technical and benefit paths of carbon capture and carbon storage, implements carbon dioxide flooding and carbon dioxide storage on a large scale, and continuously expands the "negative carbon" industry.

Among the technical categories of CO_2 geological utilization and storage, carbon dioxide flooding for enhanced oil recovery is an important component. Based on the current technical conditions, CO_2-EOR can carry out large-scale demonstrations and achieve large-scale CO_2 emission reduction under specific economic incentive conditions (Cai et al., 2021, 2024a). Folger and Liu, et al. proposed through the example of CO_2 injection in the saline aquifer of the Illinois Basin abroad that CO_2 injection into the reservoir will cause reservoir pressure disturbances, and induced microseismic events of different magnitudes can be monitored (Folger and Tiemann, 2016; Liu et al., 2022). Wang proposed the "soil carbon flux + shallow fluid components + carbon isotope" trinity CO_2 storage safety monitoring technol-

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ogy, which has been successfully applied in the Jilin Oilfield and achieved good results (Wang et al., 2023; Gao et al., 2008).

Zhang mentioned that viscous fingering and channeling are likely to occur during the process of CO_2 injection for oil recovery. The reservoir heterogeneity and channeling channels are one of the main reasons for CO_2 channeling, especially in low-permeability reservoirs with developed natural fractures. The connected natural fractures form the channeling channels for water and CO_2 injection (Zhang et al., 2017). Verdon mentioned that there is an obvious correlation between microseismic events and the CO_2 injection rate through the microseismic monitoring example in the Weyburn oilfield in Canada, and established a geomechanical model to simulate and predict the stress changes caused by CO_2 injection (Verdon et al., 2010, 2011). The seismic activities indicated that there was no obvious geomechanical deformation in the reservoir; Duxbury et al. based on the Weyburn oilfield model, combined fluid flow with geomechanical simulation and demonstrated that the seismic activities above the reservoir were caused by the stress conduction effect rather than the seismic activities induced by CO_2 leakage (Duxbury et al., 2010); Khazaei et al. used the three-dimensional particle flow analysis program to simulate the reservoir geomechanics, related the energy consumed within the volume to the energy released by planar sliding, and found that even if the injection pressure was lower than the internal pressure of the reservoir, as long as the maximum bearing capacity of the caprock was reached, microseismic events might occur on any stress instability surface (Khazaei et al., 2016).

Through the study of the mechanism of geomechanical microseismic events, Verdon et al. proved through the study of the geomechanical mechanism of microseismic events that these microseismic events were not directly triggered by fluid injection, but were responses to the stress transfer of the rock skeleton during the production and injection processes (Verdon, 2016); In the carbon dioxide injection monitoring project in the Illinois Basin of the United States (Bauer et al., 2019), only low-magnitude microseismic events were detected during the injection process, and these seismic events occurred two months after the CO_2 injection. Approximately 90% of the microseismic events occurred within a range of 280 meters below the injection layer, and the magnitudes of the two highest-magnitude events recorded were 1.07 and 1.17 respectively. Zhang et al. in the project of CO_2 displacing coalbed methane in China adopted a “space-air-ground-well” monitoring system to monitor the area from a single injection well to multiple production wells (Zhang et al., 2022). This system is composed of four geophysical monitoring technologies, namely space satellite remote sensing, airborne unmanned aerial vehicle scanning imaging, near-surface microseismic monitoring, and vertical seismic profiling in deep wells. The goal of this project is to effectively bury carbon dioxide in coal seams and effectively displace methane by injecting carbon dioxide to meet the actual demand for improving the recovery rate of coalbed methane, and at the same time, permanently store carbon dioxide in the target reservoir as much as possible. The further goal is to study the variation law of pore permeability and its main controlling factors during the process of CO_2 displacing coalbed methane, and at the same time, promote the industrialization process of CO_2 displacing coalbed methane through on-site demonstration and application evaluation results.

In the CO_2 flooding reservoir monitoring technology proposed by Hu Yongle, the monitoring of the displacement fluid migration and the CO_2 flooding front mainly relies on technologies such as tracer testing and microseismic monitoring (Hu et al., 2019). Gaishan Zhao systematically summarized the current situation and challenges of geophysical monitoring in CO_2 geological storage and proposed that the geophysical monitoring of CO_2 geological storage is mainly based on time-lapse geophysical methods, that is, the dynamic monitoring of the CO_2 storage process is realized through repeated geophysical observations. The geophysical methods are mainly seismic methods, including three-dimensional seismic, crosswell seismic, borehole seismic, microseismic, etc. Microseismic monitoring is an effective monitoring tool for the distribution of CO_2 migration and diffusion plumes and induced earthquakes (Zhao, 2023).

CCUS-EOR not only helps to reduce the content of greenhouse gases in the atmosphere, but also can improve the recovery rate of oil reservoirs. The effective sequestration of CO_2 can achieve a dual enhancement of environmental and economic benefits. As the country with the largest CO_2 emissions and abundant coal reserves in the world, China can sequester up to 70% of the injected CO_2 by applying the CCUS-EOR technology (Al-Zayani et al., 2023). Therefore, the CCUS-EOR technology is a strategic choice for China in enhancing the exploitation of oil and gas resources and implementing carbon sequestration (Yuan et al., 2020). Due to the characteristics of high permeability and fluidity of CO_2, there is a potential risk of CO_2 leakage into the environment in all links such as its injection, oil displacement, storage, production, gathering and transportation, and reinjection. CO_2 may leak through wellbores, formation fractures or faults, etc. In order to ensure the smooth progress of the project and promote the sustainable development of CCUS technology, it is particularly urgent to carry out strong monitoring and early warning of CO_2 leakage in all links of CCUS-EOR. It is necessary to construct a comprehensive and effective monitoring system on the basis of research on various monitoring technologies.

Although methods such as 4D seismic, cross-well seismic, time-lapse seismic, time-lapse vertical seismic profiling (VSP), Interferometric Synthetic Aperture Radar (InSAR), soil carbon flux, shallow fluid component analysis, and carbon isotope detection play certain roles in ensuring the safety of CO_2 geological storage, they lack real-time capabilities. These techniques cannot provide real-time early warnings of the risk of carbon dioxide leakage. Instead, they rely on post-processing and interpretation of data to determine whether CO_2 geological storage is safe. In contrast, microseismic monitoring technology in borehole can monitor the safety of carbon dioxide geological storage in real-time. It can issue early warnings ahead of time when potential leakage points, such as fault movements and fracture openings.

China began to explore the CO_2 flooding technology as early as 1965. Limited by the CO_2 source, the early research mainly focused on laboratory experiments on the miscibility mechanism, CO_2 huff and puff oil recovery, and small-scale CO_2 flooding tests in well groups. Since 2005, PetroChina's Jilin Oilfield discovered a high CO_2 content gas reservoir in the Changling area, which provided the basic conditions for the development and implementation of CCUS-EOR in the Jilin Oilfield. Subsequently, pilot tests, expanded tests, and industrial promotion and application were carried out successively. The Daqingzi Oilfield in Jilin belongs to a ultra-low permeability structural-lithologic reservoir. The physical properties of the reservoir are poor, and it is difficult to establish an effective water flooding displacement relationship. The formation pressure level is maintained below 70%. Starting from 2008, a CO2 flooding pilot test was carried out in the original undeveloped reservoir block Hei 59. From the expanded test with a small well spacing for the full life cycle in the ultra-low permeability and high water cut reservoir block Hei 79 in 2012 to the industrial application demonstration area in block Hei 125 in 2020, it has gone through the pilot test stage and is now stepping into the industrial application demonstration stage (Song et al., 2023). The small well spacing test area is currently the CCUS-EOR test area in China with the highest injected CO_2 pore volume. From 2012 to now, the cumulative CO_2 injection has reached 426,000 tons. The test area has gone through three stages: energy replenishment, local miscibility, and overall effectiveness. The production has increased by more than 6 times compared with the decline stage of water flooding, and the recovery degree of the core area has increased by 25.8%. The successful application of the CCUS-EOR technology in the small well spacing test area has effectively mobilized the difficult-to-produce reserves in low permeability reservoirs and effectively improved the oil recovery rate. It has explored an effective way suitable for the beneficial development of low permeability oilfields in China and CO_2 emission reduction, laying a solid foundation for industrial promotion (Wang et al., 2024). On the premise of ensuring the enhanced oil recovery by CO_2 flooding, the Jilin Oilfield attaches great importance to the issue of safe CO_2 storage. It has developed a series of technical means, including the analysis of shallow formation water and gas, and the monitoring of soil and atmospheric CO_2 flux, to evaluate the leakage risk of the injected CO_2. At the same time, it has laid the foundation for the microseismic monitoring of the integrity of the geological body.

2 Methodology

During the process of CO_2 flooding and storage, the microseismic response characteristics are different from those of conventional waterflooding development or operations such as hydraulic fracturing. In hydraulic fracturing, under the strong action of external forces, the stress state of rocks is changed, and new fractures are opened, thereby enhancing the permeability of the reservoir to achieve the goal of increasing the recovery rate. Compared with waterflooding or reservoir stimulation, CO_2 flooding has stronger injection and penetration capabilities and higher oil displacement efficiency, and it can achieve the simultaneous mobilization of multiple strata systems.

The microseismic monitoring technology in wells is a multi-disciplinary integrated technology developed in recent years. It has strong advantages and the technology has matured. In particular, great progress has been made in the diagnosis of artificial fractures in reservoir stimulation, and it has become increasingly mature in the safety monitoring of CO_2 storage facilities. The microseismic well monitoring technology in borehole is characterized by the acquisition of abundant monitoring data, high precision, and remarkable real-time performance. It has been extensively implemented in major oil and gas fields in China (Liu et al., 2020).

The core issue of the microseismic monitoring technology for CCUS is to obtain the accurate location of the seismic source, and the selection of an efficient and high-precision microseismic location method is of vital importance. Currently, the main analytical methods for microseismic source location include: the P-S wave arrival time difference method, the same-type wave arrival time difference method, the Geiger correction method, etc (Waldhauser and Ellsworth, 2000; Liu et al., 2017; Geiger, 1912). The differences among them lie in the extraction of the first arrival velocity of microseismic data and the correction of the velocity model.The location accuracy of microseismic events is closely related to the velocity model, first-arrival picking, and inversion method. The accuracy of the velocity model depends on factors such as variations in rock physical properties, anisotropic characteristics, dip angles, and multi-stage fracturing operations. The primary reason is that velocity errors lead to differences in the travel time of microseismic waves, and the sensitivity of location accuracy to travel time differences is inconsistent, resulting in significant errors. Velocity errors exhibit varying gradients in both positive and negative directions, and location errors increase as velocity errors grow. In microseismic monitoring and location methods, inversion-based algorithms, such as genetic algorithms and grid search methods, involve an objective function and evaluation criteria for solving the optimization matrix, which primarily determine location accuracy and speed. In inversion algorithms, a combination of coarse and fine grid search methods is generally employed. Although iterative error probability density statistics are used to identify regions with higher error distribution expectations before conducting a fine grid search, this approach is prone to becoming trapped in local minima. In genetic algorithms, an initial value often needs to be specified. If the initial deviation is too large, the computation may converge to a local optimum rather than the global optimal solution. For inversion-based location algorithms, location accuracy is closely tied to grid scale, iteration count, initial input, the optimization matrix for solving, and evaluation criteria. In summary, location errors consist of errors caused by first-arrival picking inaccuracies, velocity model errors, location algorithm limitations, and angle errors during orientation correction of three-component geophones. Different location methods are adopted according to the geological characteristics of the reservoir and the requirements for the location speed. In order to accelerate the data processing speed, the travel time table retrieval method is also used simultaneously. The information of the travel time and the source vector is stored in advance in the travel time table. When performing the inversion and location of microseismic events,

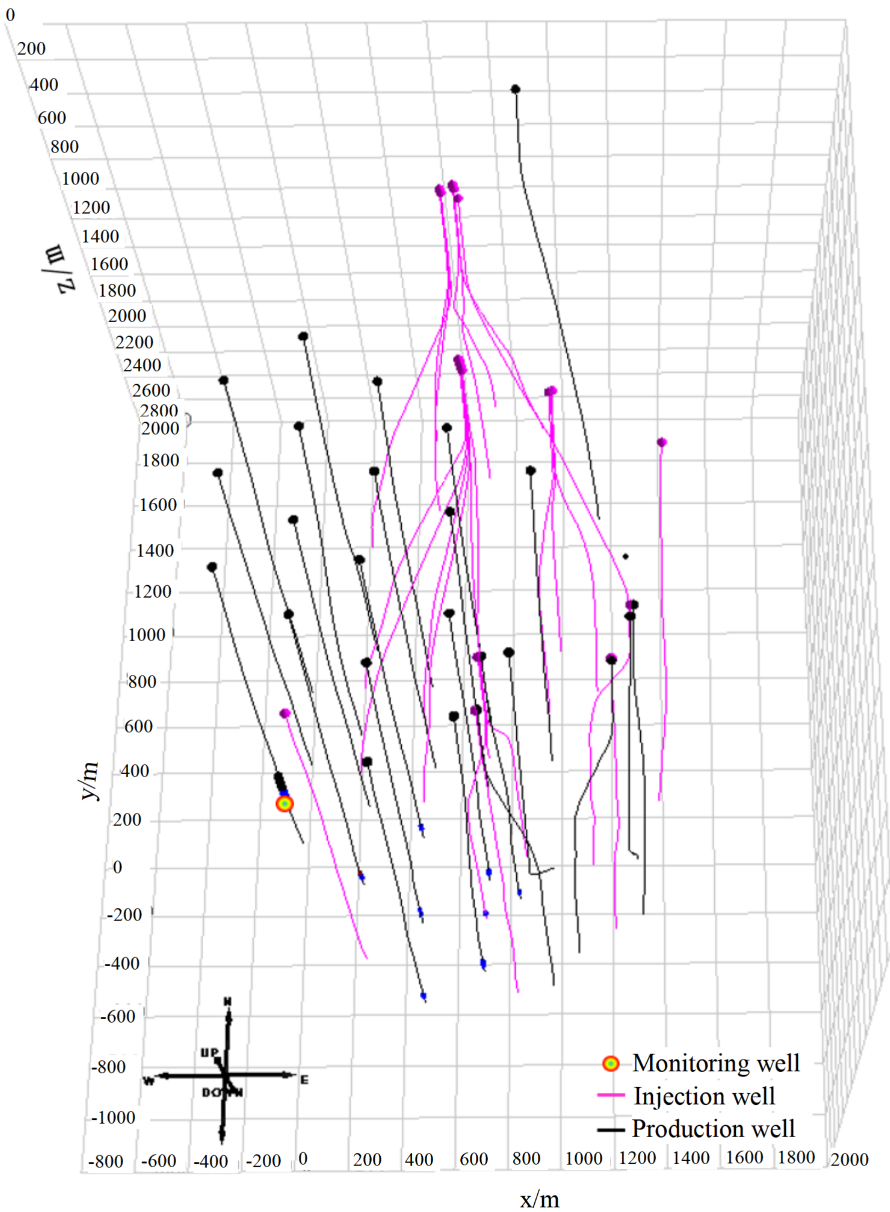

Fig. 1 Three-dimensional diagram of the observation system

there is no need to repeatedly execute the ray tracing algorithm. Instead, the travel time and the source vector information can be directly read from the travel time table, which reduces the ray tracing and source vector scanning time (Liu et al., 2017), and enables the rapid location of microseismic events.

3 Application practice and effects

In order to better evaluate the integrity of the geological body in the CCUS-EOR study area of Jilin Oilfield, well M in the small well-spacing test area, which has the largest injected CO_{22}pore volume, is selected as the monitoring well. Taking the wellhead of well M as the coordinate origin, a unified monitoring coordinate system for the monitoring well, the injection well and production well is established, as shown in Fig. 1. Twelve-level of three-component geophones are used for data collection, with a spacing of 20 m between each level. The sampling rate is 0.25 ms. The geophones are lowered to a depth of 1810-2030 m. The vertical monitoring range covers the top and bottom boundaries of the oil reservoir. Data are acquired continuously for 24 hours without interruption, and the monitoring period is 60 days, which covers a complete cycle of water-CO_2 alternating injection. Through forward modeling, it is demonstrated that the magnitude range is from -3.92 to -0.35, as illustrated in Fig. 2.

3.1 Evaluation of the integrity of geological bodies

For the first time in China, the microseismic monitoring of the safe operation of CCUS-EOR in the old block of Jilin Oilfield, with the injection mode of water-CO_2 alternate injection and the injection-production pattern of inverted five-spot well pattern, has been completed with high quality and efficiency.

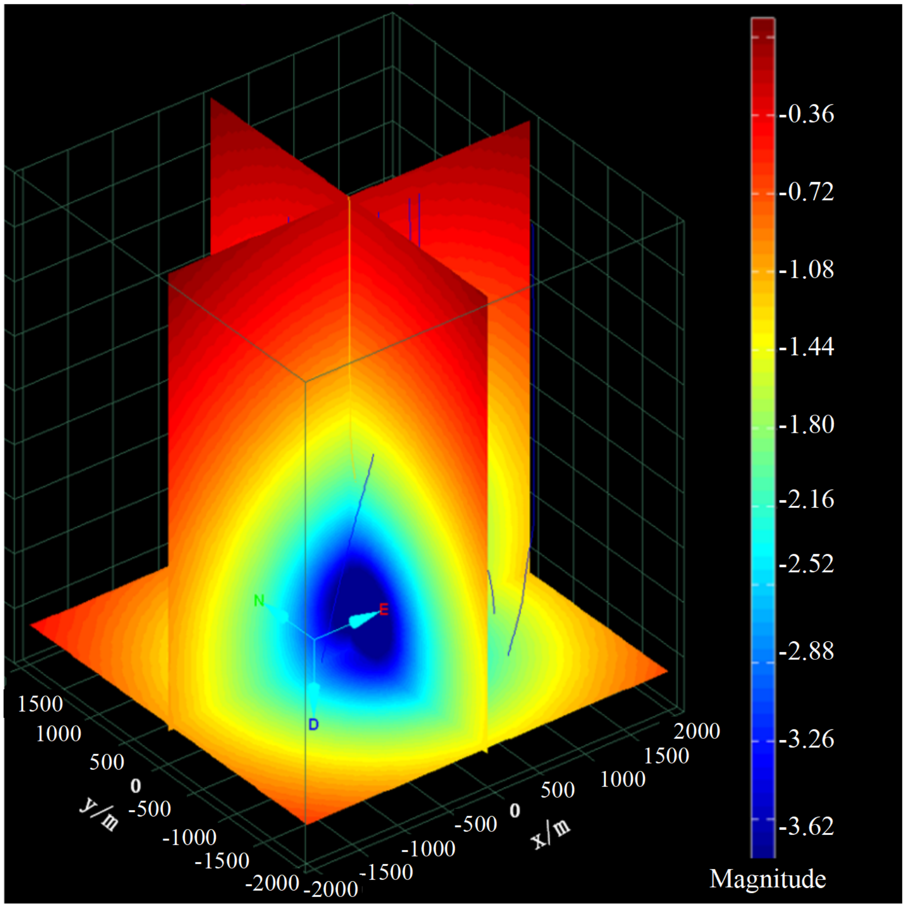

Fig. 2 Schematic diagram of the magnitude in the forward modeling simulation

During the monitoring period, a total of 539 microseismic events were obtained in the study area, with the magnitude ranging from -3.13 to -0.906, and most of the microseismic events magnitudes were between -2.6 and -1.79 , as shown in Fig.3. According to the analysis of the intersection diagram of magnitude and monitoring distance, as illustrated in Fig.4, the monitoring distance has a certain influence on the signal quality of microseismic events. Vertically, the occurrence locations of microseismic events are divided into three areas, as illustrated in Fig.5. Among them, there are 42 microseismic events obtained in Area 1, with a vertical height between 1942 m and 2100 m. Only 6 microseismic events are captured in Area 3, with a vertical height between 2864 m and 2921 m. The planar distribution of some microseismic events in the two areas is relatively scattered. The microseismic events in Area 1 are response events of the production activities of oil production wells, and the microseismic events in Area 3 are signals induced by the stress disturbances of the strata. The number of microseismic events obtained in the reservoir of Area 2 is 491, with a vertical height between 2341m and 2485 m. In the reservoir utilization area, there are no continuous microseismic events that vertically cross the cap rock. Therefore, the integrity of the geological body in the study area is relatively good.

3.2 Evaluation of the migration law of CO_2

We selected an injection-production well groups in the monitoring area to conduct an analysis of the migration law of the injected CO_2. A total of 301 microseismic events were captured, with the magnitude ranging from -3.13 to -1.19. The locations of the microseismic events generated by injection and production are mainly concentrated near the injection wells and oil production wells, as shown in Fig. 6. Among them, there are more microseismic events occurring near the four production wells. Combined with the production dynamics, the four production wells show the characteristics of CO_2 channeling, and their CO_2 production is significantly higher than that of the surrounding production wells. According to the occurrence sequence of the microseismic events within the monitoring period, the microseismic events as a whole migrate in the northeast direction. The northeast-trending fractures are mainly developed in the monitoring area, which has a good correlation with the regional stress direction, and the northeast direction is the main dominant channel direction in the monitoring area. The microseismic events indicate that there are northwest-trending microfractures in the study area, as illustrated in Fig. 7. During the CO_2 injection process, in addition to the migration of oil and CO_2 along the direction of the principal stress, there is also a phenomenon that the CO_2 migrates along the northwest-trending microfractures.

3.3 Evaluation of the source of gas channeling

During the injection and production process, CO_2 channeling

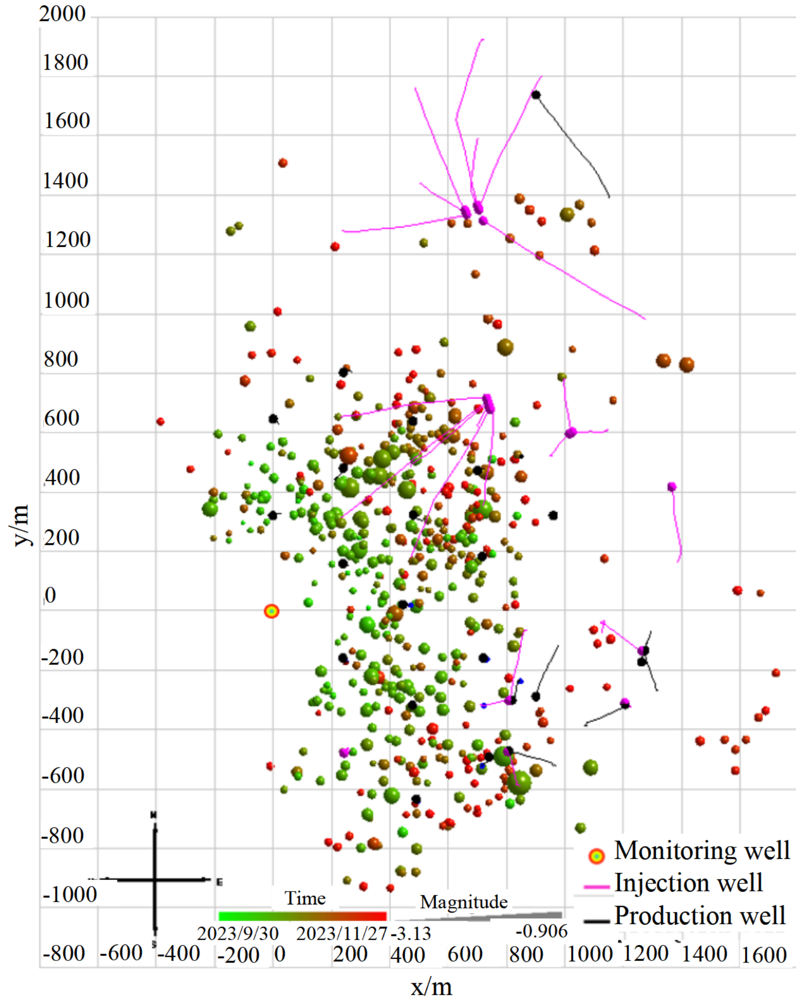

Fig. 3 Top view of microseismic events

is relatively severe in production well A, B, C, and D. The CO_2 in production well A and B mainly comes from injection well 3 and 4; the CO_2 in production well C mainly comes from injection well 2; and the CO_2 in production well D mainly comes from injection well 1 and 4. According to the analysis results of the source of CO_2 channeling based on the achievements of microseismic monitoring, currently, the synchronous injection of injection well 1 and 2 and the synchronous injection of injection well 3 and 4 have been adjusted to the synchronous injection of injection well 2 and 3 and the synchronous injection of injection well 1 and 4, as shown in Fig. 7. The effect has been greatly improved. It is planned to continue implementing microseismic monitoring of the overall injection and production effect in the next step, further conducting experimental analysis of the injection and production laws, and adjusting the injection and production process and the injection and production well pattern in a timely manner.

3.4 Joint interpretation of gas channeling pathways using microseismic data and seismic attributes

During the CO_2 injection process, first the CO_2 migrates along the main fracture channels and simultaneously diffuses in the microfractures to achieve the purpose of displacing oil. The sensitive attributes for predicting fractures include coherence, curvature, ant tracking body, maximum likelihood, and other attributes(Fan et al., 2021; Zhang et al., 2023; Yao et al., 2024). The coherence attribute can obtain an estimated value of three-dimensional seismic correlation by calculating the local waveform similarity in the vertical and horizontal directions. In localized zones featuring faults, lithological discontinuities, or anomalous geological bodies, variations in seismic waveform characteristics result in abrupt changes in inter-trace correlation(Wang et al., 2023). The curvature attribute quantifies the angle by which a curve deviates from a straight line. It helps to reduce the influence of local dip angles and emphasizes the linear features related to sedimentary characteristics or small-scale faults. By combining these quantitative descriptions of the degree of structural bending with existing prior structural information and integrating with a geological model, natural fractures in the reservoir can be predicted(Yang et al., 2015; Cao et al., 2024; Chen et al., 2012). The ant tracking volume technology realizes the tracking and identification of fractures based on the ant colony algorithm. In seismic data, ”ant-tracking” algorithms delineate faults and fractures by track-

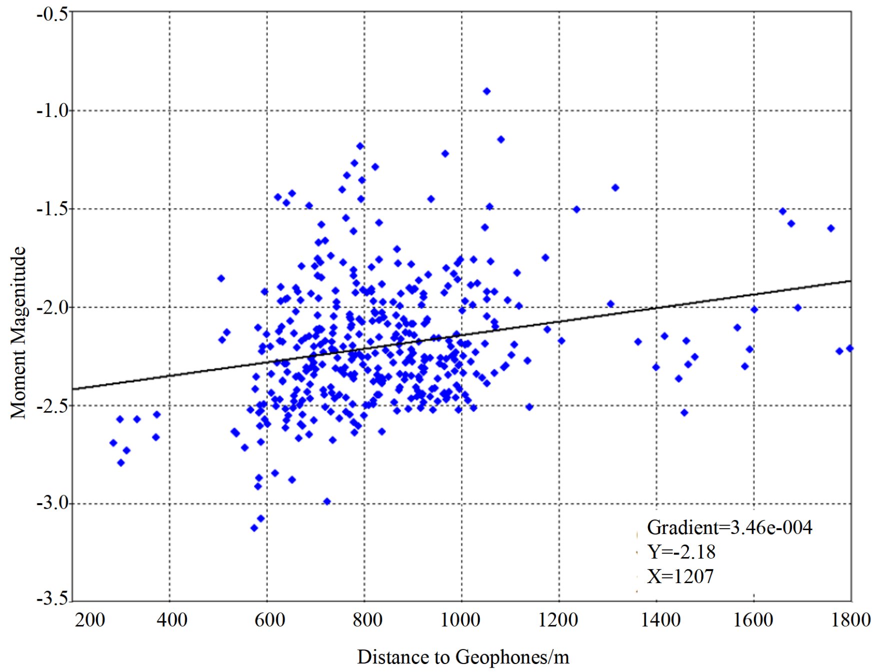

Fig. 4 Crossplot of magnitude and monitoring distance

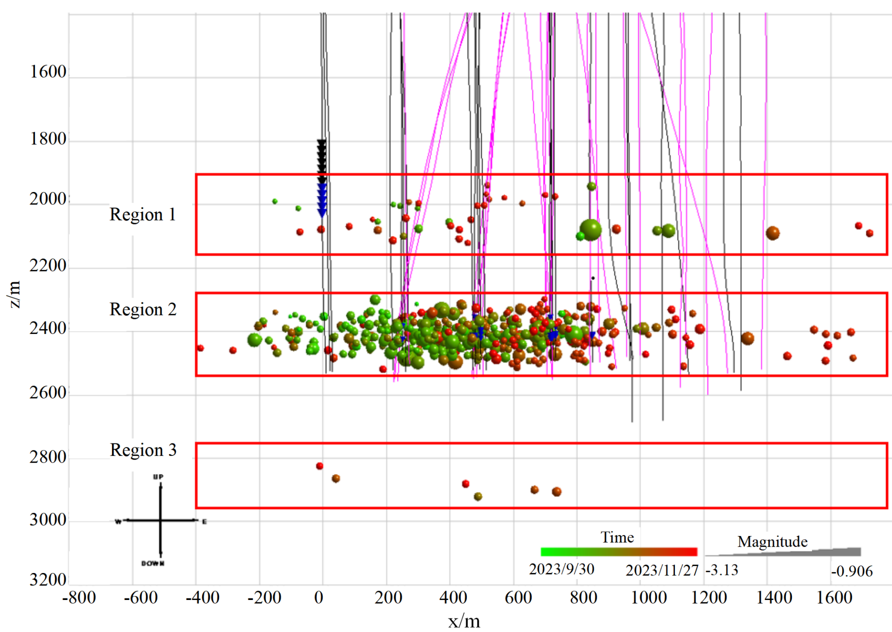

Fig. 5 Side view of microseismic event

ing amplitude and phase variations while propagating along potential discontinuity surfaces. The ant-colony algorithm for fracture delineation partially addresses the interpretive subjectivity associated with traditional fault analysis. This method provides qualitative characterization of small-scale faults and fractures in stratigraphic units. In contrast to coherence and curvature attributes, the ant-tracking approach excels in highlighting linear fracture patterns through suppression of non-fracture features, consequently enhancing fault interpretation precision(Zhang et al., 2017; Xie et al., 2021). The maximum likelihood attribute represents an advanced approach building upon conventional similarity analysis. Utilizing a comprehensive global similarity algorithm across all data samples, this method performs seismic scanning to calculate point-to-point similarity metrics. The resulting output identifies zones with highest fracture probability, substantially enhancing fracture delineation precision (Qin et al., 2024; Zhen et al., 2020). The fractures in the study area demonstrate significant sensitivity to both ant-tracking and maximum likelihood attributes. Consequently, the two attributes which were specifically optimized

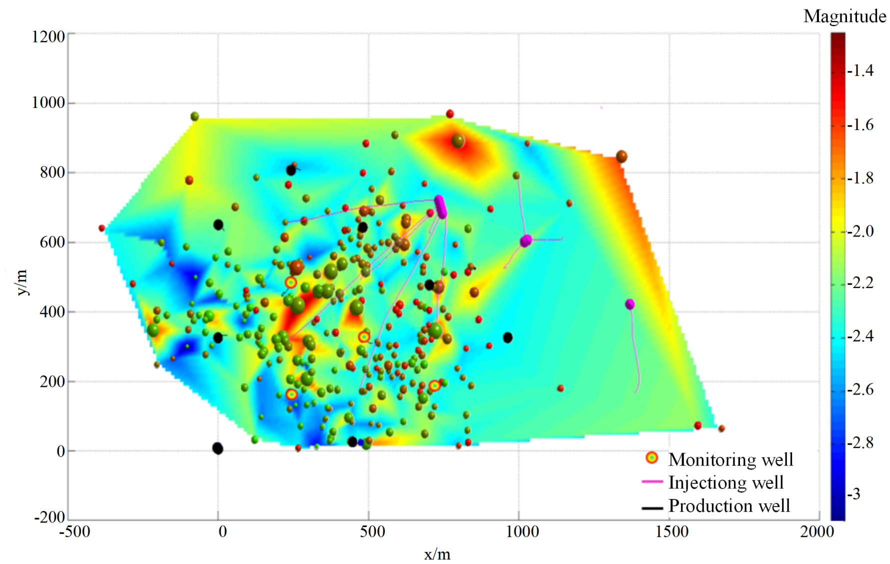

Fig. 6 Plan of simulated magnitude of target layer events

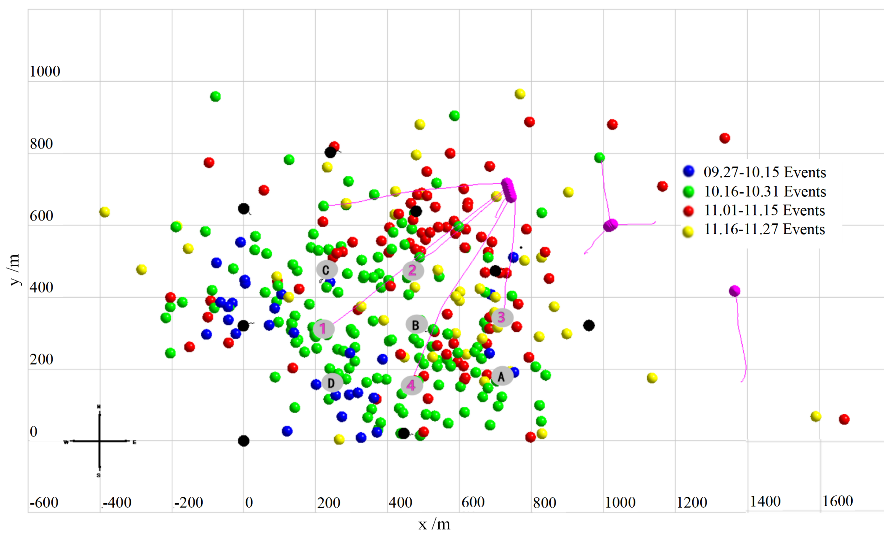

Fig. 7 Diagram of the source of CO_2 channeling

for the target formation were preferentially selected for fracture prediction.

Fig.8 presents the integrated display of ant-tracking attributes and microseismic events in the study area. T Ant-tracking attribute analysis identifies a predominant NE-SW fracture trend in the study area. The temporal-spatial distribution of induced microseismicity shows progressive NE migration during injection, correlating well with the fracture orientation. This suggests that CO_2 injection preferentially follows the NE-SW fracture system, which aligns with the regional maximum horizontal stress direction. Fig.9 presents the maximum likelihood attribute map of the study area, revealing NW-trending microfractures within the reservoir. The CO_2 channeling observed in production wells A, B, C, and D is attributed to their locations within these fracture zones. Comprehensive analysis integrating both ant-tracking and maximum likelihood attributes confirms these fracture networks as the predominant factor inducing CO_2 channeling. In summary, the integrated interpretation of microseismic event attributes, ant-tracking, and maximum likelihood attributes confirms that fracture networks serve as the primary pathways inducing CO_2 channeling. To mitigate this issue, the following measures will be implemented:

(1)Adjust injection-production parameters to optimize fluid flow dynamics.

(2)Convert injector-producer well patterns (e.g., switching CO_2 injection and oil production wells) to disrupt preferential CO_2 migration.

(3)Validate adjustments with production data to prevent further CO_2 channeling.

These steps aim to achieve permanent CO_2 storage by ensuring stable containment and minimizing leakage risks.

3.5 Risk assessment

Gutenberg and Richter proposed using the *b*-value to determine whether microseismic events are related to faults or

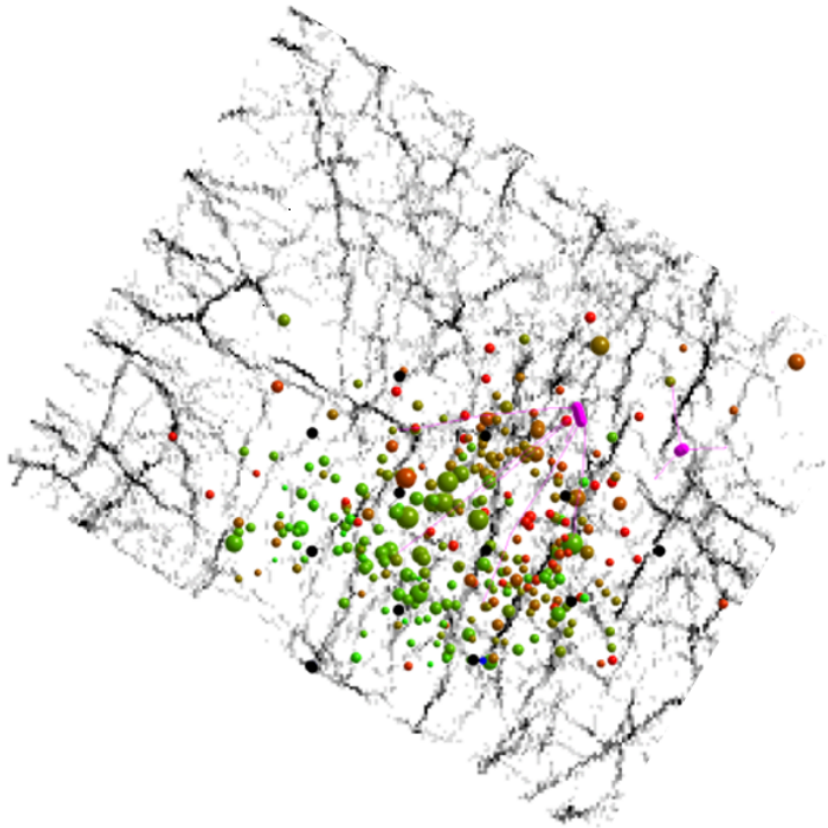

Fig. 8 Joint display of ant body attributes and microseismic events

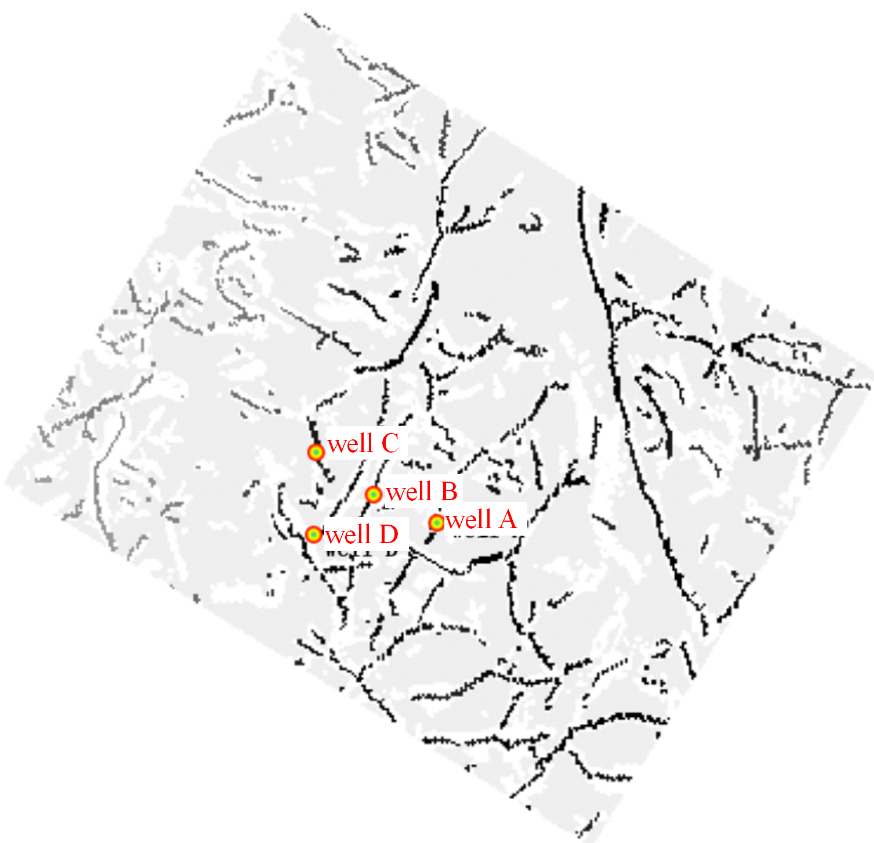

Fig. 9 Schematic diagram of maximum likelihood attribute characterization of fracture

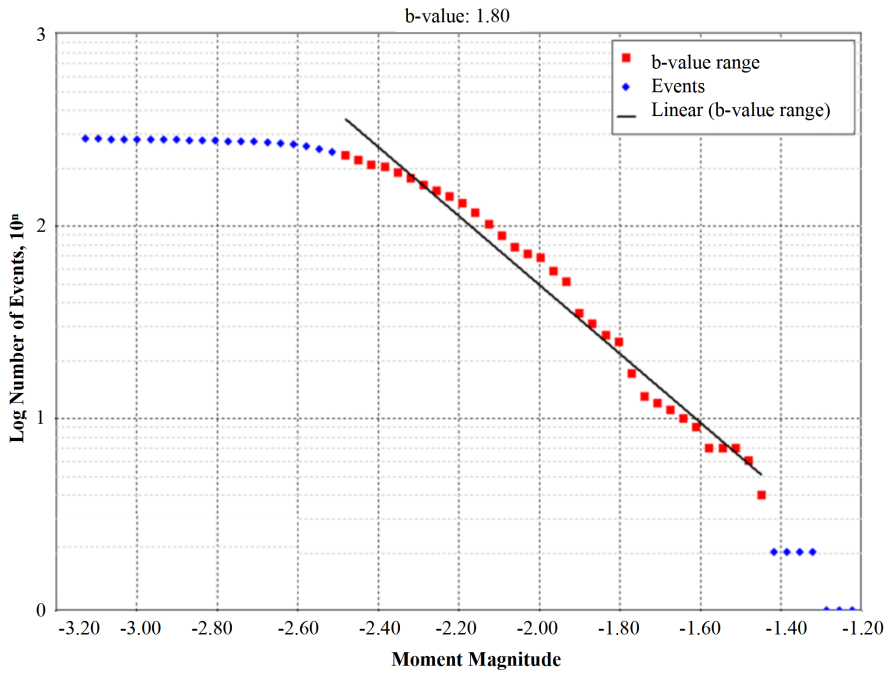

Fig. 10 Value of microseismic events during the monitoring period

natural fractures, and this method has been widely applied. This method indicates that the occurrence frequency and magnitude of microseismic events follow a power law relationship (Gutenberg and Richter, 1944):

$$\log_{10} N(M) = a - bM \tag{1}$$

where $N(M)$ represents the number of events with a magnitude greater than or equal to M, M is the magnitude, a is the intercept, and b is the linear fitting slope of the relationship between $\log_{10} N(M)$ and M. The significance of this formula lies in the fact that there is a linear relationship between the logarithm of the cumulative number of events and the magnitude of microseismic events.

When a natural earthquake occurs, the b-value is around 1, while the b-value of microseismic events generated by artificial gas injection activities is around 2. By calculating the b-value, the correlation between microseismic event activities and faults/natural fractures can be described. The b-value of microseismic events in the test area is 1.8, which shows that during the entire monitoring period, the microseismic events are induced by artificial activities, i.e., the microseismic events generated during the injection and production process, as illustrated in Fig.10.

The faults in the study area have not been activated. The microseismic events show a trend that individual microseismic events expand towards the direction of the faults. It is necessary to observe continuously during production, pay attention to changes in pressure and the occurrence of gas channeling phenomena, and avoid activating the faults and uneven utilization of the reservoir.

4 Conclusions

The paper demonstrates the first application case of microseismic monitoring technology in borehole in China. It confirms that the geological body in the Jilin Oilfield of China is in a complete and safe state during the long-period CO_2 seismic storage process, and effectively evaluates the effect of CCUS-EOR in Jilin Oilfield of China. There is a good correlation between the occurrence frequency and density of microseismic events and the production dynamics in the study region. The time sequence of microseismic events can indirectly reflect the direction of the dominant channels, and microseismic events effectively depict the CO_2 channeling channels. During the monitoring period, a total of 539 microseismic events were obtained. There were no continuous microseismic events that vertically crossed the caprock. The events were mainly concentrated within the reservoir, indicating that the geological body has good integrity. At the same time, it plays a significant role in guiding the understanding of the laws of oil and CO_2 migration in the CCUS study area.

The Microseismic monitoring technology in borehole has validated its multi-functional utility in evaluating CCUS containment integrity (geological formations and caprocks), delineating migration conduits, and diagnosing CO_2 channeling mechanisms. In mature fields with fixed infrastructure, injector-producer role reversal along critical fractures offers a pragmatic solution for CO_2 plume control. For greenfield developments, fracture-aware well placement paradigms must supersede conventional patterns to preemptively mitigate conformance issues. The technology's success in this study underscores its scalability for China's decarbonization efforts.

During the process of injecting CO_2 into the formation, it may induce earthquakes, which will affect the sealing integrity of the CO_2 storage space, such as caprock fracture, activation of faults, etc. Therefore, the paper illustrates the importance of microseismic monitoring technology in borehole in the safety monitoring of CO_2 storage through application cases. At the same time, it should not be limited to the single method of microseismic monitoring in borehole. According to the reservoir conditions of each working area, multiple monitoring technical schemes can be adopted to ensure the integrity of the geological body for CO_2 storage, the integrity of the wellbore, etc. Meanwhile, The safety monitoring and early warning technology for geological CO_2 sequestration will be a rapid developing technical direction.

At present, the safety of monitoring CO_2 geological storage using microseismic monitoring technology in borehole is still in the stage of manual warning, and artificial intelligence warning technology is the next research direction.

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Conflict of interest

The authors declare no competing interest.

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