

Application of Ant Tracking Technology in Fracture Identification of HH Oilfield, China

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Abstract

The tight oil in the HH oil field of the Ordos Basin has a good exploration prospect. The degree of oil and gas enrichment is related to the tight lithology and lithofacies, and the oil and gas are mainly distributed along the fracture development area of the fault zone. However, the characteristics of fracture development and geophysical response in this area are not clearly understood, and the identification technology for fracture prediction is lacking. The introduction of new methods to provide multi-party demonstration of the fault system in the work area can improve the accuracy of fracture prediction. In this paper, the ant tracking technology is used to provide the ant attribute body of the fracture system, which provides a reference for the prediction of dense fractures in similar exploration zones.

Keywords

Fracture Prediction, Tight Accumulation, Ant Tracking Technology, HH Oilfield

1. Introduction

In the process of exploration and development of oil and gas fields, fractures are not only an important symbol of geological tectonic activities, but also a key factor in hydrocarbon accumulation. They are like underground secret passages, which greatly increase the permeability of various reservoirs, so that oil and gas resources can be effectively circulated and accumulated. However, the existence of fractures is also like a double-edged sword. It aggravates the heterogeneity of reservoirs, makes the distribution of oil and gas reservoirs more complex and changeable, and puts forward higher requirements for exploration and development. This paper focuses on the HH oilfield in the Ordos Basin, which has attracted much at-

tention due to its rich geological structure and potential oil and gas resources. The research uses ant tracking technology, which is an algorithm that simulates the foraging behavior of ants in nature, and can effectively identify and describe the underground micro-crack network. Through the application research of this technology, this paper aims to reveal the distribution law of micro-fractures in HH oilfield, and provide scientific basis and technical support for fine exploration and efficient development of oil and gas fields.

2. Ant Body Crack Identification Technology

2.1. Rationale

Ant body is a kind of seismic attribute body based on ant colony tracking algorithm. Ant colony tracking algorithm is an efficient bionic optimization algorithm, which is inspired by the behavior of ant colony to optimize the shortest path in the process of finding food. The basic principle of the algorithm is: a large number of electronic ants are spread in the three-dimensional seismic data volume, and the fracture conditions are set. Then these electronic ants track and interpret the fracture traces that meet the preset fracture conditions, while those that do not meet the fracture conditions will not be identified. Finally, a low-noise ant body with clear fracture traces is obtained (Wang, Hu, Fu, et al., 2025; Sun, 2019). Ant body can highlight the discontinuity of seismic data, strengthen the fracture characteristics, and identify low-level faults that cannot be directly explained by conventional seismic data. It has the characteristics of fast speed and high precision (Wang, Zhou, Deng et al., 2013).

In the ant algorithm, the path selection of artificial ants has a great dependence on the pheromone concentration. The path with high pheromone concentration is more likely to be selected. For an ant, the next node is sought according to the transition probability P (Lu et al., 2020). and the transition probability is:

$$P_{ij} = \begin{cases} \frac{\tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)}{\sum \tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)} & j \in \text{The next node that ant } k \text{ allows to go} \\ 0 & j \notin \text{Ant } k \text{ Allows nodes to go} \end{cases} \quad (1)$$

The pheromone on the path will increase as the ants pass, and it will also volatilize over time. The update is:

$$\begin{cases} \tau_{ij}(t+n) = \rho\tau_{ij}(t) + (1-\rho)\Delta\tau_{ij} \\ \Delta\tau_{ij} = \sum_{k=1}^m \Delta\tau_{ij}^k \end{cases} \quad (2)$$

where i is the current position of the ant; j is the location of the ant's next path; $\tau_{ij}(t)$ is the residual pheromone on the line connecting nodes i and j at time t ; η_{ij} is the expected degree from position i to position j ; α and β represent the relative importance of the trace of the pheromone and the visibility of the route, respectively. $\tau_{ij}(t+n)$ is the pheromone on the path ij after n migrations; ρ is the residual degree of pheromone; $1-\rho$ is the degree of volatilization of pheromone; $\Delta\tau_{ij}$ is the pheromone left on the path ij in a cycle. Each ant gets a path after n migrations,

and its length is recorded as L_k . If the path meets the requirements of the shortest path, it stops. Otherwise, Formula (2) needs to be used to recalculate the pheromone concentration of each path for the second round of search. Through the continuous updating of pheromones, it finally converges to the optimal path.

The process of using three-dimensional original seismic data volume to generate ant body is mainly divided into three steps: First, the original seismic data volume is structurally smoothed to reduce noise interference and enhance the continuity of seismic reflection events; the second is to use the variance analysis technique to obtain the variance volume for the seismic data volume processed by structural smoothing, highlighting the discontinuous information of seismic data; the third is to test the ant tracking parameters many times.

2.2. Main Parameters

The core of the ant tracking algorithm lies in the determination of appropriate values for its parameters, which are essential for accurately capturing the discontinuities within a given data volume. These parameters are calibrated based on edge enhancement techniques that highlight the features of interest within the data. Specifically, the algorithm involves several critical parameters, such as the initial boundary of the ant, the tracking deviation, step size, allowable illegal steps, necessary legal steps, and termination conditions. By carefully selecting and adjusting these parameters, the algorithm is able to track the fractures at various scales and in different structural orientations, allowing for a comprehensive representation of the fracture characteristics. The ability to fine-tune these parameters ensures that the algorithm can adapt to the unique features of different datasets, reflecting the complexity of the underlying structures. The proper balance of legal and illegal steps is crucial to maintaining the integrity of the tracking process and ensuring that the algorithm can identify and track fractures effectively across different scales (Yang, 2017).

1) Initial-boundary

This parameter plays a critical role in determining the distribution of ants within the algorithm. It dictates the search radius for each ant, which is defined by the number of sample points, and influences the initial state of the “ant colony” distribution. The search radius refers to the area within which an ant can operate during a single search, ultimately determining how many sample points the ant will consider. The number of sample points, in turn, impacts the calculation time for each ant’s movement, as well as the density of the ant distribution. A higher distribution density generally leads to greater accuracy in tracking, as more ants are available to explore the search space. However, if an ant is unable to locate a local maximum within its search radius, or if it searches in a direction that does not lead to significant progress, the ant dies. This process ensures that only the most promising search paths are followed. When studying small-scale fractures, the initial boundary value for the ant is typically smaller, allowing for finer granularity in the search. Conversely, when analyzing large-scale fractures, a larger

initial boundary is used, enabling the ants to cover broader regions and capture more significant features.

2) Ant tracking deviation

This parameter controls the deviation of ant tracking from the local maximum during the tracking process. In the algorithm, each ant is assumed to follow a plane, and its maximum allowable deviation from its initial direction is typically set to 15° (which is defined by the number of sample points, ranging from 0 to 3). Rather than moving in a strict straight line, the ant's movement is based on a search surface that operates within a certain angular range, from 0° to 15° . If the ant detects a boundary enhancement point within this search surface, the signal is recorded as a legal step. However, if the deviation exceeds the allowed range, the ant is unable to continue tracking, and this results in an illegal step being recorded. This ensures that the ant's movement remains within a reasonable range and does not veer too far off course. Consequently, the ant tracking lines, when viewed on a plan, appear as broken trend lines. By adjusting this parameter, it becomes evident that a larger value for the ant tracking deviation expands the activity range of the "artificial ant," allowing it to explore a broader area. This leads to more continuous tracking results, as the ants are able to cover more ground without getting prematurely interrupted by minor deviations. Ultimately, the selection of this parameter influences the balance between tracking accuracy and continuity.

3) Ant step length

This parameter defines the number of pixels (or sample points) that ants search during each step of the tracking process, determining the length of each step as the ants search for local maxima within the tracking deviation range. By increasing the step length, each ant is able to search over a greater distance in each step, allowing for a broader exploration of the data space. However, while a larger step size enables the ants to cover more ground quickly, it also impacts the precision of the tracking. Comparative experiments reveal that a larger step size leads to a denser tracking data volume, as the ants search over wider areas. However, this comes at the cost of resolution, as the finer details of the tracked features may be lost due to the coarser sampling. Thus, there is a trade-off between the efficiency of the tracking process and the resolution of the results, making the choice of step size an important factor in balancing tracking speed and data accuracy.

4) Allowed illegal steps

The number of allowed illegal steps refers to the number of steps that ants are permitted to take without encountering a local maximum before they are considered to have made an error (this value is represented by 0 to 3, indicating the allowed number of errors). Essentially, it defines the tolerance for deviation from the expected search path. A higher value for this parameter increases the ants' search flexibility and activity range. For example, if ants are in a valid position but fail to find a local maximum in their next step, this will be recorded as an illegal step. With each subsequent search, if no local maximum is found, the number of illegal steps increases. If the allowed number of illegal steps is set to 1, the ants will

stop searching in the current direction after one error. However, if an effective local maximum is eventually detected, the ant will record the search path, noting both valid and invalid positions along the way.

The allowed illegal steps parameter essentially determines how far the ants can continue searching without finding a local maximum. By allowing more illegal steps, the ant tracking can identify more fracture traces, leading to a denser representation of fractures. However, this can also result in multiple fracture lines being identified as a single fracture if the search is allowed to extend too far. Therefore, it is crucial to carefully balance this parameter with the necessary legal steps to maintain accurate fracture tracking. In practice, this parameter should be fine-tuned to ensure that it supports the desired tracking density without causing errors in the identification of fractures.

5) Necessary legal steps

This parameter plays a crucial role in distinguishing continuous faults from directionless noise, working in conjunction with the number of illegal steps allowed. It defines the minimum number of legal steps that must be included in an ant's search path in order to consider the tracked features as valid fault boundaries. In other words, the necessary number of legal steps ensures that gaps in the search results are properly connected. For example, if the ants encounter a valid fault boundary during their search, it is recorded as a legal step. If the ants continue their search and encounter another valid fault boundary, this is recorded as a second legal step. If the parameter is set to 2, the ant's search path will be considered valid and the tracking will be recorded once two legal steps are identified.

If the parameter is set to 3, and the ants do not encounter a valid fault boundary after moving forward, the search path will not be recorded, even though the ants may have found two legal steps. This ensures that only significant fault boundaries are captured in the results. Essentially, the necessary number of legal steps defines how many valid fault boundaries must be encountered in the search before continuing the tracking process.

Through comparative analysis, it becomes clear that a smaller value for this parameter results in a more continuous fracture trace line, as fewer legal steps are required to connect points of interest. This can lead to more detailed fracture tracking, but it may also result in noise being included as valid features. Thus, the choice of this parameter should balance the need for continuity in the fracture trace with the need for accuracy in fault detection.

6) Stopping condition

The termination condition is the criterion that determines when the ant tracking process will end. Specifically, it refers to the percentage (ranging from 0% to 50%) of the total allowed illegal steps that can occur during the tracking process across all ants. Once the number of illegal steps reaches the predefined limit based on this percentage, the tracking process is terminated. By adjusting this parameter, different tracking behaviors can be achieved. For instance, if the goal is to maximize the reliability of the tracked fractures, the termination condition should

be set to a relatively low value, typically around 5%. This ensures that the process stops early enough to avoid accumulating too many errors. On the other hand, if the aim is to capture as many fracture traces as possible, the parameter can be increased, for example, to 15%.

In practice, the termination condition is usually set between 5% and 15%. A larger parameter value leads to a denser distribution of ants and results in more fractures being tracked, but this often comes at the cost of accuracy, as the data becomes rougher and prone to including false positives. This could create the illusion of fractures that do not actually exist. Therefore, in order to achieve more reliable and precise fracture tracing, it is recommended to use a smaller termination condition value. By carefully selecting this parameter, it is possible to strike a balance between tracking coverage and the quality of the fracture trace.

7) Ant tracking parameters in Honghe area

After conducting repeated experiments, the optimal parameter values for ant tracking in the work area have been determined as follows: the initial ant distribution boundary is set to 5, the ant tracking deviation is set to 3, the search step size is set to 3, the allowed number of illegal steps is set to 3, the necessary legal steps is set to 1, and the search termination standard is set to 8%. These parameters were carefully selected to balance the accuracy and efficiency of the tracking process, ensuring reliable fracture identification while maintaining the ability to capture a sufficient amount of fracture data.

3. The Practical Application of Ant Tracking Technology

Sedimentary basins often undergo multi-stage tectonic transformations, leading to fractures in sedimentary caprocks that are generally multi-directional. Ant tracking technology can effectively identify these multi-directional fractures by incorporating azimuth information. This technique offers three key characteristics:

First, there are significant differences in ant tracking results along slices in different directions. Due to the anisotropy of the medium, fractures that are parallel to the observation azimuth may not be visible in the tracking results. However, fractures that form at certain angles to the observation azimuth or near the vertical direction are typically more clearly depicted. This directional sensitivity allows for the identification of fractures that might otherwise be overlooked.

Second, when comparing the tracking results of full-stack data with those of azimuthal data, it becomes apparent that certain fracture information captured through azimuthal tracking is not reflected in the full-azimuth data as shown in (Figure 1), the azimuthal tracking results provide a more comprehensive reflection of fracture information, offering deeper insight into the fracture patterns and their orientations.

Third, the standard ant tracking fracture identification method does not directly provide crack density information. To address this limitation, this paper combines the results from multi-directional ant tracking to more fully character-

ize the location and extent of fracture development zones. Additionally, it incorporates amplitude variation with azimuth to enable a quantitative description of the fractures, thus providing a more complete and precise assessment of the fracture characteristics.

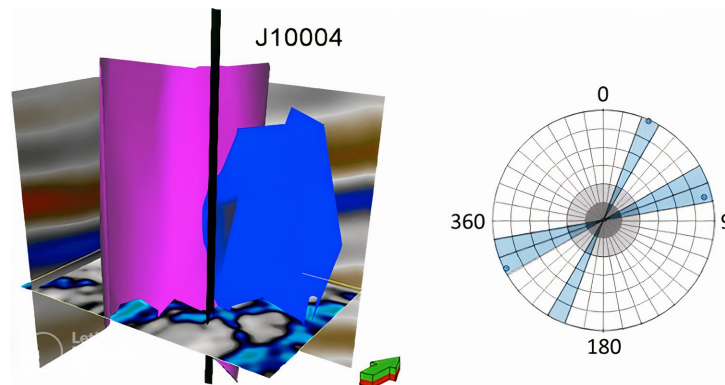


Figure 1. Multi-directional fracture stereo slice and azimuth angle (Li, 2023).

As mentioned earlier, the tectonic stress field changes have led to the formation of two distinct fracture bodies in the northwest and northeast directions in the Chang 8 section of the Yanchang Formation in the Honghe area. Therefore, this study focuses on the single-direction ant tracking of fractures in these two directions. The results from the two directional ant tracking are then fused to obtain a comprehensive map of the fracture distribution throughout the region.

Using ant body tracking technology, this study identifies the fault fracture body developed during the left-lateral shear extrusion stress environment of the Yanshan period, as well as the fault fracture body formed under the right-lateral shear tensile stress environment of the Himalayan period (Figure 2). By merging the characteristics of both ant body attributes, a plane distribution map of the current ant body in the Chang 8 member of the Honghe area is generated. This map clearly shows the distribution of fractures, highlighting areas where the fracture development is more pronounced. Notably, the most well-developed fractures are found along the Yudu fault zone, which trends northwest, and the northeast-trending fault zone located in the northern part of the study area.

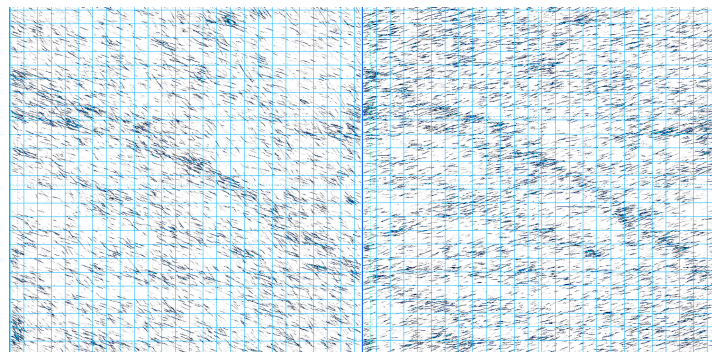


Figure 2. Two periods of ant body distribution map.

4. Conclusion

In the field of oil and gas exploration, the integration of ant tracking technology with multi-attribute superposition methods provides a powerful tool for qualitatively detecting and describing the primary development areas of underground fractures. These techniques effectively simulate the path optimization behavior of ants searching for food in nature, allowing for the identification of fracture patterns and offering a macroscopic view of fracture distributions. This approach has proven particularly useful in revealing the fracture modes of strata, making it an invaluable asset for exploration efforts.

Among various seismic post-stack attribute analysis techniques, ant body technology has emerged as the preferred choice for researchers due to its unique advantages. Specifically, it allows for the intuitive and clear identification of fracture systems, making it easier to discern critical geological features. However, despite its benefits, this technology faces challenges, particularly in distinguishing between genuine fractures and those caused by data noise or interpretation errors. These challenges can lead to the identification of false fractures, which can misguide exploration efforts.

To address these issues, researchers must rely on professional expertise and experience to thoroughly analyze the results generated by ant body technology. It is essential to carefully eliminate any misleading artifacts or illusions that could affect the accuracy of fracture identification. By doing so, the results can provide a more reliable and accurate geological basis for oil and gas exploration and development, ensuring that the identification of fractures aligns with the actual geological features of the subsurface.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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