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# Prediction method and application of the effective period of oil and gas formation by transport of oil source fault

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The effective period of hydrocarbon formation has a significant impact on oil and gas enrichment. Based on an analysis of the mechanism of oil and gas formation by oil source fault transport, the transport period is determined by both the activity period of the oil source fault and the discharge period of oil and gas from the source rock. A set of predictive methods for oil and gas formation by oil source fault transport has been developed by combining of the oil source fault transport and the start of the period for oil and gas aggregation. The results show that the results show that this method is operationally feasible and yields reliable predictions. The effective period of Dazhangtuo fault transport in relation to oil and gas formation in the lower sub-member of the first member of the Shahejie Formation is half of the period of oil and gas expulsion from source rocks of the third member of the Shahejie Formation, which is more favorable for the migration of hydrocarbons from the third member source rocks, facilitating oil and gas accumulation in the lower sub-member of the first member of the Shahejie Formation. This is the main reason why drilling in the lower sub-member of the first member of the Shahejie Formation of the Dazhangtuo fault has revealed that oil and gas are mainly concentrated in the eastern part, with only small amounts found in the western part.

KEYWORDS

**oil and gas migration, oil and gas accumulation, effective period, Dazhangtuo fault, Qikou sag**

## 1 Introduction

The exploration results in the northern part of the Qikou Sag reveal that the Dazhangtuo Fault is rich in oil and gas resources. This is not only influenced by the transmission of the Dazhangtuo fault but also by the length of the effective period of the Dazhangtuo Fault for the formation of oil and gas reservoirs in the lower sub-member of the first member of the Shahejie Formation ($Es^1$). Only in the areas where the effective period of the Dazhangtuo fault for the formation of oil and gas reservoirs in the lower of $Es^1$ Formation is relatively long is it conducive to the accumulation of oil and gas to form reservoirs; otherwise, it is not conducive to the accumulation of oil and gas to form reservoirs.

Predecessor study on oil and gas migration via oil source faults primarily focus on the spatial position relation between the migration pathways of oil source faults and

the distribution areas of oil and gas expulsion from source rocks to investigate the spatially effective locations for oil and gas migration via oil source faults (Robertson et al., 2012; Ping et al., 2017; Jiang et al., 2015; Fu et al., 2019a; Jian et al., 2017; Gao et al., 2017; Liu et al., 2005). It is recognized that only when the migration pathways of oil source faults are located within the oil and gas expulsion zones of source rocks can they constitute spatially effective locations for oil and gas migration via oil source faults, which is favorable for large-scale oil and gas migration and accumulation; Conversely, it is unfavorable (Chen et al., 2022; Fu and Wang, 2018; Gong et al., 2021; Wang et al., 2017; Liang et al., 2011; Ma et al., 2020). However, the effective period of hydrocarbon formation for oil and gas accumulation through oil source fault migration has not been thoroughly studied at present, Existing research merely studies the migration period of oil and gas by oil source faults based on the activity periods of these faults and the oil and gas expulsion periods of source rocks (Fu et al., 2020; Song et al., 2015; Liu et al., 2016; Dong et al., 2025).

This cannot provide the effective period for oil and gas accumulation through oil fault migration, which has restricted the summary of hydrocarbon enrichment characteristics at oil source fractures and its application in oil and gas exploration. Therefore, it is necessary to conduct a study on the prediction of the effective period for oil and gas accumulation in the lower of $Es^1$ Formation due to the migration of the Dazhangtuo fault. This paper determines the period of oil source fault migration for oil generation by using the periods of oil source fault activity and source rock hydrocarbon expulsion, and then combines it with the period of oil accumulation initiation to establish a method for predicting the effective period of oil and gas accumulation in the lower Sha section of Dazhangtuo. It has predicted the effective period of oil and gas accumulation in the lower of $Es^1$ Formation of Dazhangtuo, which is of great significance for summarizing the characteristics of oil and gas enrichment in the lower of $Es^1$ Formation of Dazhangtuo and indicating the direction of oil exploration.

# 2 Materials and methods

## 2.1 Effective period of oil source fault migration on oil and gas accumulation

In the "lower source-upper reservoir" type source-reservoir-cap rock association within petroliferous basins, oil and gas supplied from the lower source rocks must migrate upwards along oil source faults. Due to the blockage of regional mudstone cap rocks, they can then laterally migrate into underlying sand bodies and eventually accumulate and form reservoirs in nearby fault traps (Cao et al., 2020; We et al., 2025; Sun et al., 2013; Ma et al., 2019), as illustrated in Figure 1. The longer the period during which oil source faults migrate oil and gas into sand bodies, the greater the amount of migrated oil and gas and the higher the degree of oil and gas enrichment; conversely, the lower the degree of enrichment.

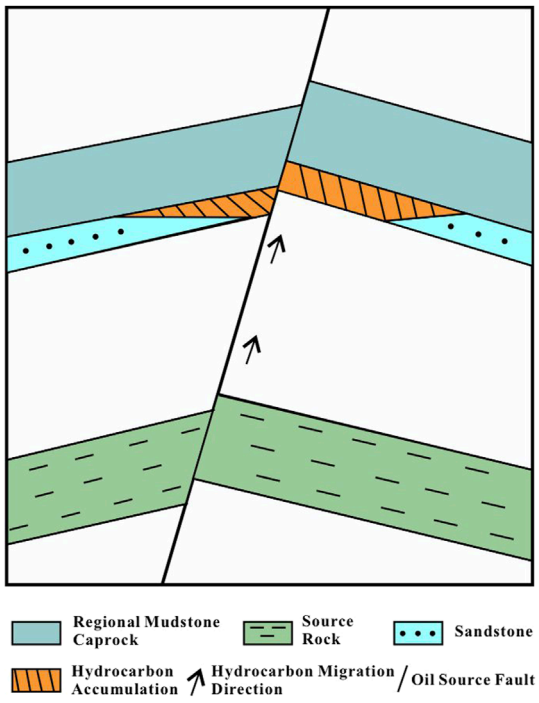


FIGURE 1
Diagram of hydrocarbon accumulation via oil source fault migration.

The so-called effective period of oil source fault migration on oil and gas accumulation refers to the period during which oil and gas are migrated by oil source faults in the oil and gas accumulation process. It should be a combination of the period during which oil and gas are migrated by oil source faults and the period when oil and gas accumulation begins. The larger the proportion of this period in the period of oil and gas migration by oil source faults, the greater the amount of oil and gas migrated by these faults and the greater their contribution to accumulation; otherwise, the contribution is smaller, as illustrated in Figure 2.

## 2.2 Research methods for the effective period of oil source fault migration on oil and gas accumulation

To predict the effective period of oil source fault migration on hydrocarbon accumulation, it is necessary to determine the period of hydrocarbon migration through oil source faults and the period of hydrocarbon accumulation.

To study the period of hydrocarbon migration via oil source faults, it is first crucial to ascertain the periods of oil source

**Abbreviations:** Ek, Kongdian Formation; $Es^3$, Third Member of Shahejie Formation; $Es^2$, Second Member of Shahejie Formation; $Es^1$, First Member of Shahejie Formation; $Es^3$, Under Lower of the third Member of Shahejie Formation; $Es^3$, Middle Middle of the third Member of Shahejie Formation; $Es^3$, Upper Upper of the third Member of Shahejie Formation; $Es^1$, Under Lower of the first Member of Shahejie Formation; $Es^1$, Middle Middle of the first Member of Shahejie Formation; $Es^1$, Upper Upper of the first Member of Shahejie Formation; $Ed^3$, Third Member of Dongying Formation; $Ed^2$, Second Member of Dongying Formation; $Ed^1$, First Member of Dongying Formation; Ed, Dongying Formation; Ng, Guantao Formation; Nm, Minghuazhen Formation; Q, Quaternary.

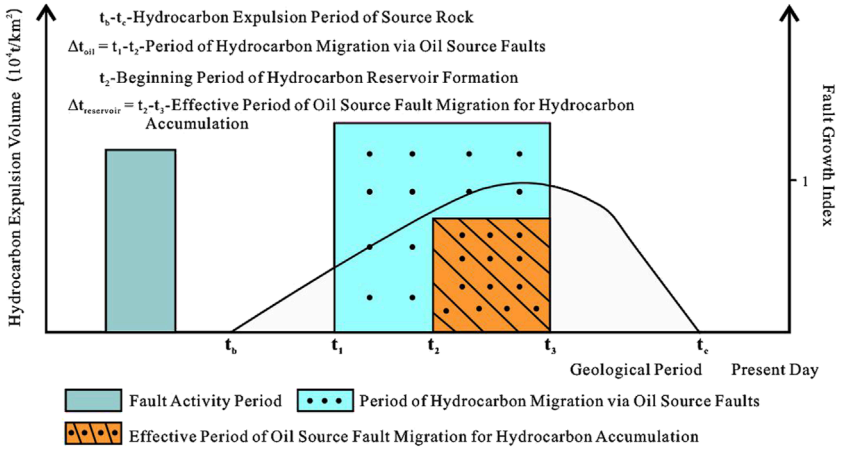


FIGURE 2
Diagram of the effective period of oil source fault migration on hydrocarbon accumulation.

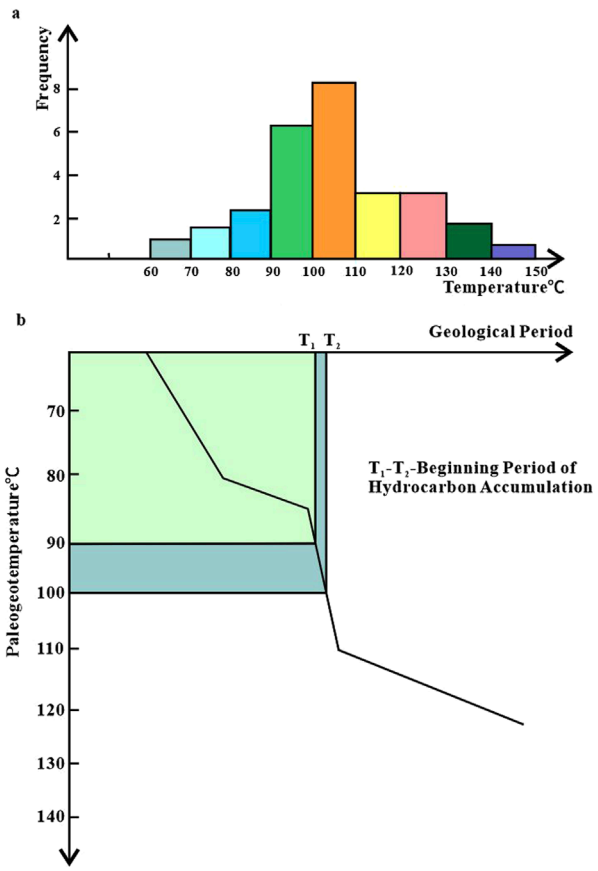


FIGURE 3
Diagram of the beginning period of hydrocarbon accumulation. **(a)** Homogenization temperature distribution of reservoir fluid inclusions **(b)** variation of reservoir paleogeotemperature with time.

fault migration and hydrocarbon expulsion from source rocks. Using the 4 × 4 seismic survey data, the growth index of the oil source fracture is calculated by using Equation 1 to analyze the different thicknesses of strata on the two sides of the fracture of the oil layer for studying the period of oil source fault migration,

$$a = H_{上}/H_{下} \quad (1)$$

In the formula: a- Fracture growth index;

$H_{上}$- Thickness of the upper formation, m;

$H_{上}$- Thickness of the lower formation, m.

Therefore, the period of oil source fault activity can be inferred (Liu et al., 2021a; Fu et al., 2016; Fu et al., 2019b; Wang J. S. et al., 2005; Chen et al., 2014; Liu et al., 2021b; Wang K. et al., 2005; Xiao, 2019; Wang et al., 2020), i.e., the period when the growth index exceeds 1, as illustrated in Figure 2.

To determine the period of hydrocarbon expulsion from source rocks, the drilling and analytical test data must be utilized to obtain the burial depth, thickness and geochemical characteristics (organic matter abundance, type and degree of evolution) of the source rocks. By applying the hydrocarbon expulsion and generation calculation methods outlined in literature, the period of hydrocarbon expulsion from source rocks can be deduced, as denoted by $t_b$-$t_c$ in Figure 2.

By overlaying the periods of oil source fault activity and hydrocarbon expulsion from source rocks, the overlapping period represents the period of hydrocarbon migration through oil source faults ($\Delta t_{oil}$), as shown by ($t_1$-$t_2$) in Figure 2.

To ascertain the beginning period of hydrocarbon accumulation, fluid inclusion homogenization temperatures must be measured from reservoir rock samples in the laboratory, and a histogram of their distribution was plotted. According to the peak temperature from this histogram, combined with the reservoir paleotemperature vs. time relationship derived from burial and thermal history restoration of the study area, the beginning period of hydrocarbon accumulation can be determined, as illustrated in Figure 3. The period of the beginning of hydrocarbon formation obtained from the main peak of the inclusions' homogeneous temperature is

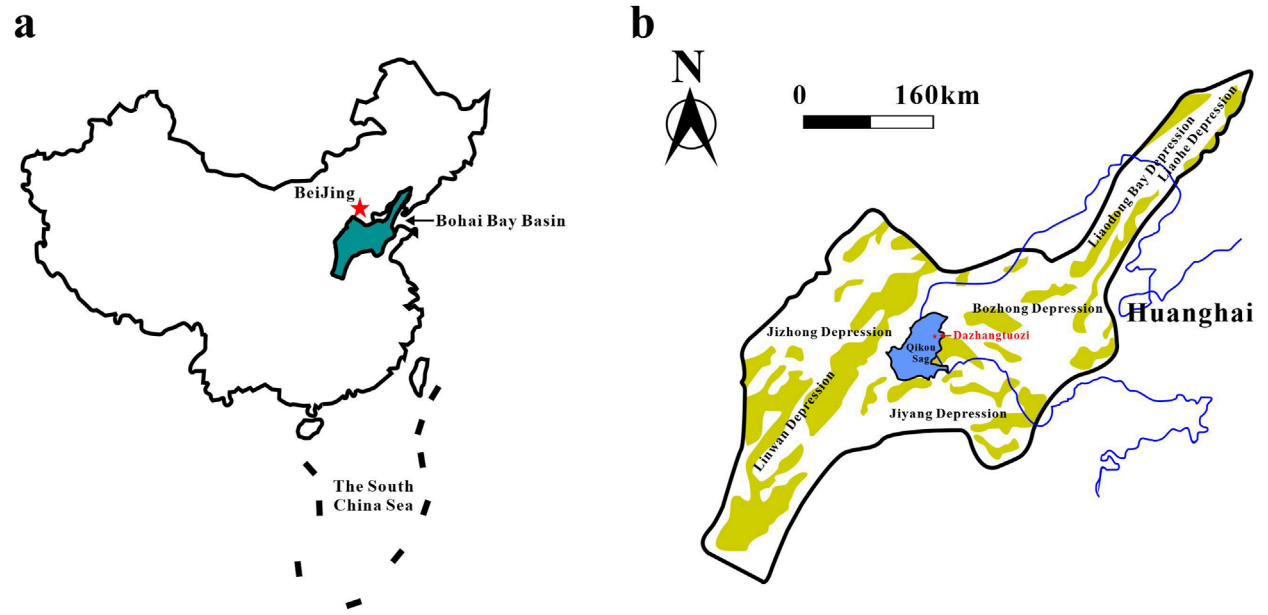


FIGURE 4
General location map of the study area in China **(a)** and Map of the Bohai Bay **(b)**.

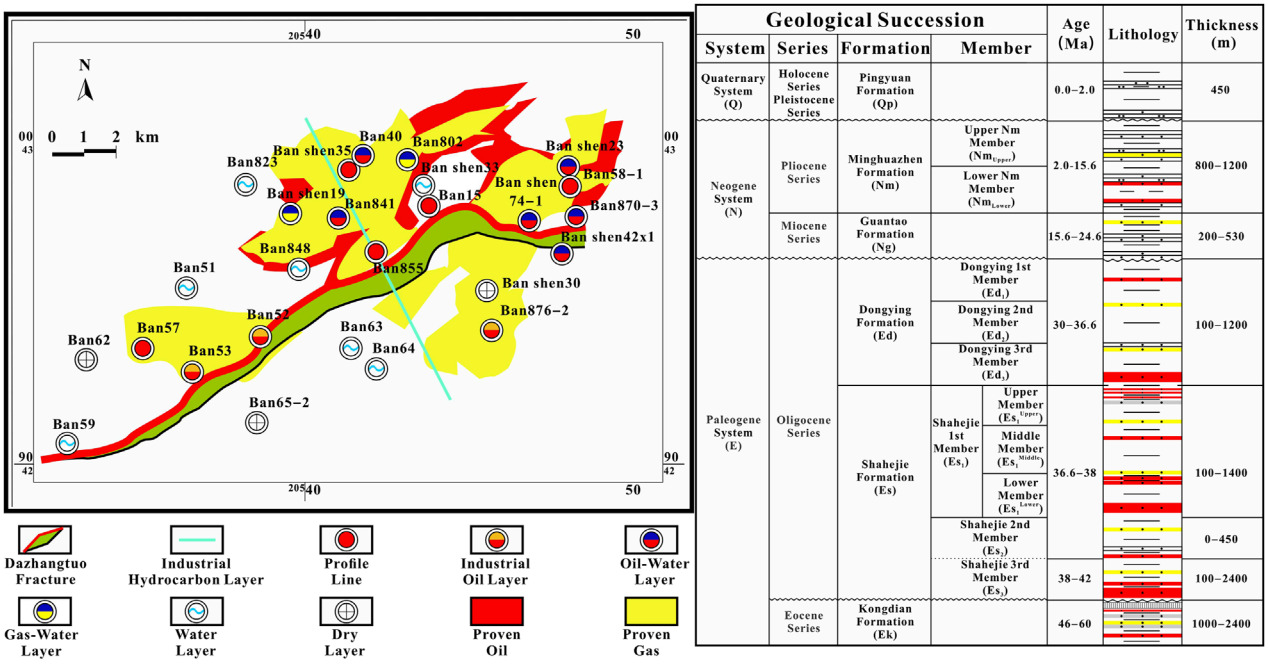


FIGURE 5
Plan View of Dazhangtuo Fault and hydrocarbon distribution in the lower of $Es^1$ and Comprehensive Strata Log Diagram.

a time period, but since this time period is relatively small compared to the geological period, it is sufficient to take its average value.

By overlaping the period of hydrocarbon accumulation (The period from the beginning of hydrocarbon accumulation to the end of fracture transportation of hydrocarbon) and the period of hydrocarbon migration via oil source faults, the effective period of oil source fault migration on hydrocarbon accumulation ($\Delta t_{reservoir}$) can be obtained by taking the overlap between the period of hydrocarbon accumulation and the period of hydrocarbon transportation from the oil source fracture, as denoted by $t_3$-$t_b$ in Figure 2.

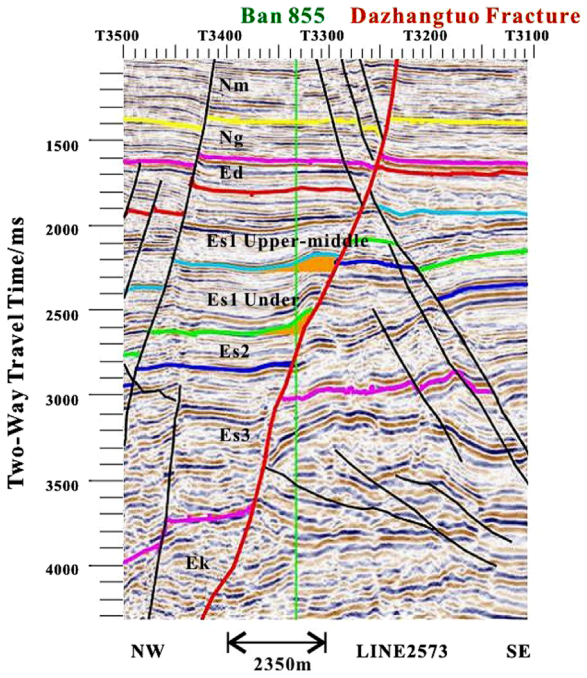


FIGURE 6
Dazhangtuo Fault and hydrocarbon distribution in the lower of $Es^1$: Cross-Sectional View.

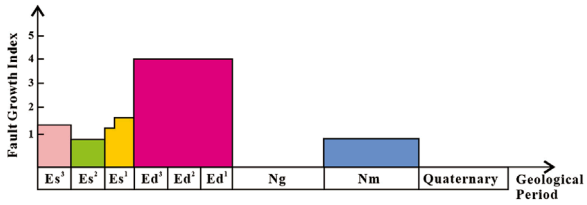


FIGURE 7
Migration periods of the Dazhangtuo Fault.

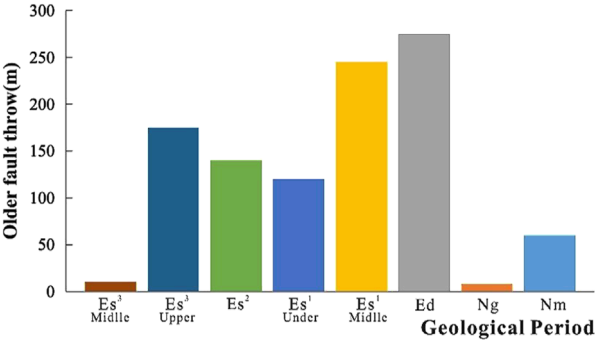


FIGURE 8
Migration periods of the Dazhangtuo Fault.

## 3 Example application and discussion

The Dazhangtuo Fault in the northern Qikou Sag has a strike of NNE, a dip towards ES, a steep dip angle, and a considerable fault length of approximately 21 km. This fault is a long-term active fault that extends from the basement to near the surface, as illustrated in Figures 4–6. The stratigraphic sequence revealed by drilling in the northern Qikou Sag ranges from the Kongdian Formation to the Minghuazhen Formation from bottom to top.

The fault growth index was obtained using the calculation method of fault growth index, and the activity period of the Dazhangtuo Fault was determined according to the period when the growth index was greater than 1 (Yuan et al., 2021; Wang et al., 2008; Fan et al., 2012; Fu et al., 2018; Zhang et al., 2023; Zhao et al., 2008). As shown in Figure 7, the Dazhangtuo Fault mainly experienced three major migration periods: the deposition of the third member of the Shahejie Formation ($Es^3$), the deposition of the first member of the Shahejie Formation to the Dongying Formation ($Es^1$-Ed), and the deposition of the Minghuazhen Formation (Nm).

To further confirm the accuracy of the above research results, this paper statistically analyzed the thickness of the strata on both sides of the Dazhangtuo Fault, and calculated the paleo-offset of the Dazhangtuo Fault within different strata by subtracting the thickness of the strata on the lower side from that on the upper side. As shown in Figure 8, the geological period of the relatively large paleo-offset of the Dazhangtuo Fault, is the deposition of the first member of the Shahejie Formation to the Guantao Formation ($Es^1$-Ng), and the deposition of the Minghuazhen Formation (Nm). i.e., the period of fracture activity is the deposition of the first member of the Shahejie Formation to the Guantao Formation ($Es^1$-Ng), and the deposition of the Minghuazhen Formation (Nm). As mentioned above, the fracture growth index method and the paleo-fall method can get the active period of the Dazhangtuo fracture were the deposition of the third member of the Shahejie Formation ($Es^3$), the deposition of the first member of the Shahejie Formation to the Dongying Formation ($Es^1$-Ed), and the deposition of the Minghuazhen Formation (Nm).

By considering source rock depth, thickness and organic geochemical characteristics (organic matter abundance, type and degree of evolution) (Wang et al., 2022; Zhao et al., 2005a; Zhao et al., 2005b; Wang et al., 2021; Zhou et al., 2009), the hydrocarbon expulsion volumes at various geological periods for the source rocks of the $Es^3$ in the Qikou Sag were calculated based on the method in literature. The relationship between expulsion volume and time is presented in Figure 9. It can be seen that hydrocarbon expulsion from the $Es^3$ source rocks began at the end of $Es^1$ deposition, peaked at the end of the deposition of the Guantao Formation, and subsequently declined but continues to the present day. Therefore, the hydrocarbon expulsion period for the $Es^3$ source rocks spans from the end of $Es^1$ deposition to the present, as shown in Figure 9.

By overlaying the migration (activity) periods of the Dazhangtuo Fault with the hydrocarbon expulsion periods of the $Es^3$ source rocks, we can identify the periods when the Dazhangtuo Fault migrated hydrocarbon from $Es^3$ source rocks. As illustrated in Figure 9, the primary period for the Dazhangtuo Fault to transport hydrocarbon from $Es^3$ source rocks was during the deposition of the Minghuazhen Formation. Although the Dazhangtuo Fault also migrated hydrocarbon during the deposition

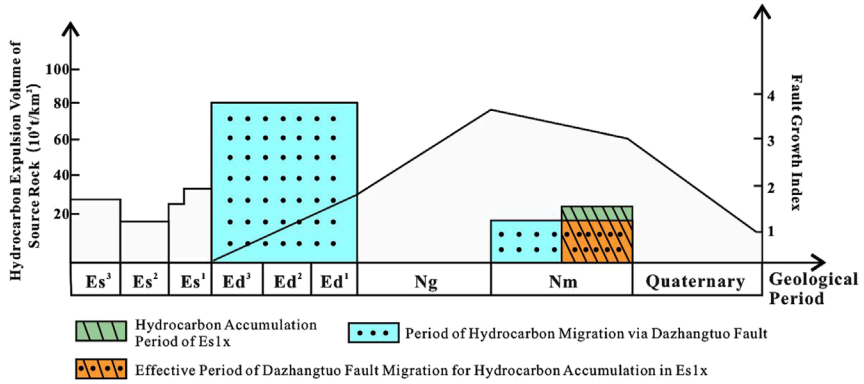


FIGURE 9
Determination of the effective period of Dazhangtuo Fault migration on oil and gas accumulation in the lower of Es$^1$.

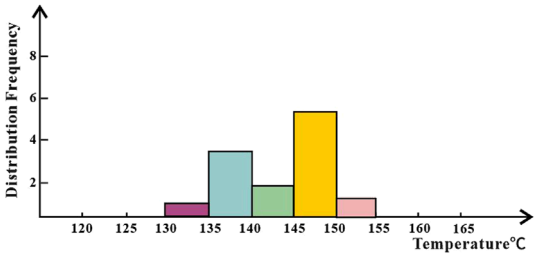


FIGURE 10
Homogenization temperature distribution of fluid inclusions in the lower of Es$^1$ reservoir.

of the Dongying Formation, the hydrocarbon expulsion from Es$^3$ source rocks was in its early stages and the volumes were limited, so it is not the main period for hydrocarbon migration through the fault.

Through microscopic observation, abundant hydrocarbon inclusions were found within the reservoir in the first member of the Shahejie Formation. In the 14 representative samples of the first member of the Shahejie Formation, linear and banded fluid inclusions were found in quartz grains, and most of the fluid inclusions were colorless, meanwhile, colorless fluid inclusions were also found in the calcite colluvium in this reservoir. Under fluorescence, fluid inclusions in quartz and calcite grains show different colors, the former being tawny and yellow, and the latter yellow-green and green. Using the measured fluid inclusion homogenization temperatures of the lower of Es$^1$ reservoir in the Qikou Sag, the homogenization temperature distribution of fluid inclusions in the lower of Es$^1$ reservoir was plotted (Figure 10). Two peaks in homogenization temperature distribution were observed: the first peak ranges from 135 °C to 140 °C, and the second peak is between 140 °C and 145 °C. The burial history and thermal history of the lower of Es$^1$ reservoir are shown in Figure 11, which also presents the relationship between paleotemperature and time. By combining Figure 9 with this information, it can be inferred that oil and gas accumulation in the lower of Es$^1$ reservoir began approximately in the middle of the deposition period of the Minghuazhen Formation (the period corresponding to the homogenization temperature of 140 °C–145 °C, whereas the period corresponding to the homogenization temperature of 135 °C–140 °C is the middle to late Ed deposition, During the depositional period of the Dongying Formation, although the Dazhangtuo Fracture was opened, and it was also the period when hydrocarbon began to be transported, the Es$^3$ source rocks had not yet discharged a large amount of hydrocarbons outward, and there was not a large amount of hydrocarbons being transported along the Dazhangtuo Fracture, so the period was not the main initial period for hydrocarbon accumulation) (Yuan et al., 2021; Wang et al., 2008; Fan et al., 2012; Fu et al., 2018; Zhang et al., 2023). The period from the middle to the end of the deposition period of the Minghuazhen Formation was the main period for reservoir formation.

By overlaying the migration period of oil and gas from Es$^3$ source rocks via the Dazhangtuo Fault (the middle to the end of the deposition of the Minghuazhen Formation) with the beginning period of oil and gas accumulation in the lower of Es$^1$, we can obtain the effective period of migration of oil and gas from the Es$^3$ source rocks via the Dazhangtuo Fault on oil and gas accumulation in the lower of Es$^1$. As shown in Figure 9, the effective period of oil and gas transport from the source rocks spans from the middle to the end of the deposition of the Minghuazhen Formation (5.1 Ma).

As mentioned earlier, the relative enrichment of oil and gas in the lower of Es$^1$ at the Dazhangtuo Fault is attributed to the significant migration of oil and gas generated from the underlying Es$^3$ source rocks into the lower of Es$^1$ via the Dazhangtuo Fault, where they accumulated. However, since the effective period for oil and gas accumulation in the lower of Es$^1$ due to the Dazhangtuo Fault migration was only half of the migration period of the Dazhangtuo Fault for oil and gas from the Es$^3$ source rocks, the oil and gas accumulated in traps of the lower of Es$^1$ but did not distribute along the entire fault. Instead, they primarily accumulated in its eastern part, with minor accumulations in the western part (Due to the fact that the eastern trap of the Dazhangtuo fault is more developed than the western one). This fully demonstrates that the method is feasible to study the effective period of oil and gas formation by fracture transport. It can quantitatively reveal the contribution of fracture migration of oil and gas to the formation of

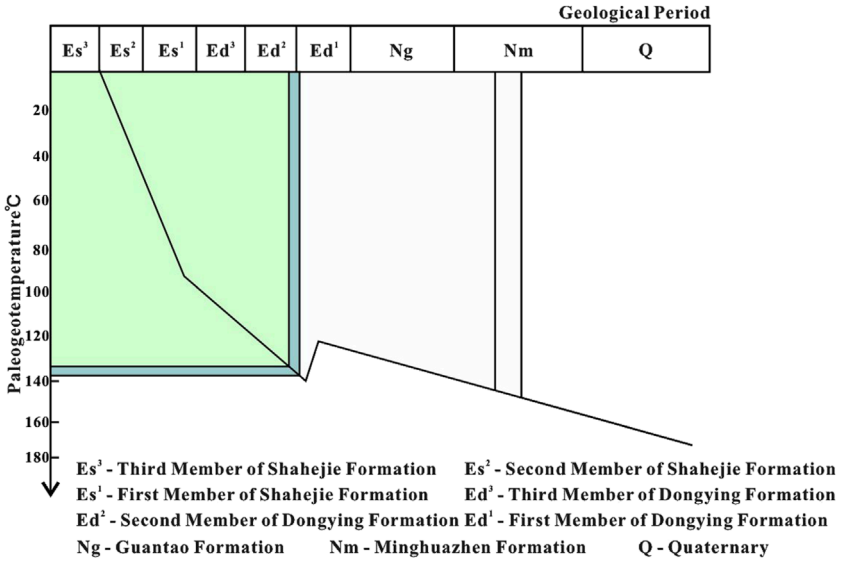


FIGURE 11
Determination of the beginning period of oil and gas accumulation in the lower of $Es^1$.

oil and gas, clarify the laws of oil and gas accumulation. However, the method is only applicable to the prediction of the effective period of oil and gas formation by tensile positive oil fracture transport in oil and gas-bearing basins of sandstone and mudstone, and is not applicable to the prediction of the effective period of compressive reverse fractures or strike-slip fractures in carbonate rocks or volcanic rock strata. In addition, the period of fracture transportation of oil and gas determined by this method is only the case when the fracture transported oil and gas does not pass through the mudstone cover; if the fracture transported oil and gas passes through the mudstone cover, the effect of the penetration time of the mudstone cover must be considered, otherwise, it is difficult to accurately reflect the period of fracture transportation of oil and gas.

## 4 Conclusion

1. The effective period of oil source fault migration for oil and gas accumulation refers to the period when oil source faults migrate oil and gas during the formation of oil and gas reservoirs. This period accounts for a significant proportion of the migration period of oil and gas by oil source faults, which facilitates the migration and accumulation of oil and gas, resulting in higher oil and gas enrichment. Conversely, the degree of oil and gas enrichment is lower.
2. By combining the activity period of oil source faults with the oil and gas expulsion period of source rocks, the period of oil and gas migration by oil source faults can be determined. Additionally, the beginning period of oil and gas accumulation can be established using the homogeneous texture-burial depth relationship of fluid inclusions in reservoirs, in conjunction with burial and thermal histories. The combination of the two establish a method of predicting the effective period of oil source fault migration for oil and gas accumulation.
3. The deposition period of the Minghuazhen Formation is the migration period of oil and gas from $Es^3$ source rocks via the Dazhangtuo Fault. The middle to the end of stage of Minghuazhen Formation deposition marks the beginning period of oil and gas accumulation in the lower of $Es^1$. The effective period of the Dazhangtuo Fault migration for oil and gas accumulation in the lower of $Es^1$ spans from the middle to the end of Minghuazhen Formation deposition. This effective period accounts for approximately half of the period of its migration for oil and gas from the $Es^3$ source rocks, which facilitates the accumulation of oil and gas from the $Es^3$ source rocks in the lower of $Es^1$ at the Dazhangtuo Fault. This explains the oil and gas drilling in the lower of $Es^1$, revealing that oil and gas are primarily concentrated in the eastern part of the Dazhangtuo Fault, with only a small amount found locally in its western part.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

## Author contributions

HW: Resources, Visualization, Validation, Writing – review and editing, Project administration, Formal Analysis, Funding acquisition, Writing – original draft, Methodology, Data curation, Investigation, Conceptualization. CW: Writing – review and editing, Software, Supervision.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Publisher's note



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