ISSN 2286-4822
www.euacademic.org

EUROPEAN ACADEMIC RESEARCH
Vol. XI, Issue 9/ December 2023

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

# Sedimentary Facies Analysis of the Sandstone Reservoir in Block Wang 102, Interval 7, Based on Magnetic-Like Random Walk

LINGWEN XU[1]
ZHONG CHUANG WANG[2]
JINGZHE LI[3]
*Qingdao University of Science and Technology*
*Qingdao, Shandong, China*

**Abstract**

*The sandstone reservoir in Interval 7 of Block Wang 102 exhibits a complex configuration, and there is a lack of clear understanding of the internal structure, which severely hampers its subsequent development and production. To address this issue, a high-precision stratigraphic framework was established based on the existing stratigraphic division pattern, guided by sequence stratigraphy principles. Under the control of this stratigraphic framework, a magnetic-like random walk method was employed to investigate the spatial distribution characteristics of sedimentary microfacies in the study area, supplemented by core observations and petrological analysis. The reservoir in the study area is characterized by a distributary channel system, predominantly trending NNW, and displaying strong lateral heterogeneity. The detailed characterization of channelized reservoirs using the magnetic-like random walk modeling approach presented in this study can serve as a valuable reference for similar reservoirs and provide important support for the design and adjustment of development plans.*

**Keywords:** Dongying Depression, Wangjiagang Oilfield, stratigraphic correlation, sedimentary facies analysis, reservoir modeling.

## 1. INTRODUCTION

The Wangjiagang oilfield, located on the southern slope of the Dongying Depression in the southern gentle slope zone, is an important oil-producing area in this region, characterized by complex oil and gas distribution patterns[1]. Situated within China's Shengli oilfield, the Dongying Depression is a significant oil and gas resource area. In the southern slope of the Niuzhuang sag of the Dongying Depression, oil and gas-bearing strata have been found across multiple geological periods in the Wangjiagang and Bamianhe areas. These strata span various geological ages, reflecting the region's rich oil and gas resources. The upper part of the Shahejie Formation, belonging to the Cenozoic era, is particularly noted for its rich oil and gas resources, good oil storage

---

[1] Xu Lingwen (1998-), male, born in Jinan, Shandong Province, China, postgraduate student, currently studying in Qingdao University of Science and Technology. His research interests mainly focus on geological energy development. E-mail:1558439978@qq.com.

[2] Wang Zhong Chuang (2000-), male, born in Shandong Province, China, postgraduate student, currently studying in Qingdao University of Science and Technology. His research interests mainly focus on geological energy development.

[3] **Corresponding author**: Li Jingzhe (1989-), male, born in Shandong Province, China, Ph. D., is currently an associate professor and master tutor of Qingdao University of Science and Technology, mainly engaged in geological energy development research. E-mail:lijingzhe2007@qq.com.

conditions, and abundant organic matter, making it a key oil and gas producing layer in the depression. However, over fifty years of exploration have led to inconsistent sandstone reservoirs and fluctuating oil and gas production[2].

Seismic and drilling data indicate significant erosion and incompleteness in the pre-Cenozoic strata of the Wangjiagang area in the Dongying Depression. The Cenozoic strata on the southern slope have also experienced varying degrees of erosion. The Tertiary system is the primary stratum in this area, consisting of the Kongdian, Shahejie, Dongying, Guantao, and Minghuazhen formations, with the Shahejie Formation divided into four sections: Sha1, Sha2, Sha3, and Sha4.

This study primarily focuses on the Sha2 segment 7 area, where no research on reservoir architecture has been conducted. The internal structure and connectivity of the reservoir remain unclear, and there is a lack of updated reservoir distribution and physical property models, hindering the design of subsequent chemical flooding simulations and related methodologies. Research on reservoir sedimentary facies has advanced from sub-facies to microfacies, examining sedimentary microfacies and reservoir characteristics to understand individual sand body microfacies and their genesis, as well as their spatial distribution. This can accelerate exploration and development and guide drilling operations[3].

Based on modern sedimentological concepts, this study uses drilling, seismic data, and oil field production dynamics for detailed comparison and classification of oil-bearing layers, establishing a model of the basic sedimentary features of the reservoir, microfacies types, and the systematic distribution of these microfacies on the surface. This research provides a solid foundation for exploring the heterogeneity of reservoirs and constructing reservoir structural models, and also serves as a basis for waterflood development.

## 2. REGIONAL OVERVIEW

### 2.1 Regional Geological Background

The Dongying Depression is a north-steep, south-gentle fan-shaped depression, a secondary structural unit in the southeastern Jiyang Sag of the Bohai Bay Basin. It's a Mesozoic-Cenozoic rift basin formed over a pre-Mesozoic basement. The north features the Chenjiazhuang Uplift, the east the adjacent Qingtuozi Uplift, the south the Luxi Uplift and Guangrao Uplift, and the west the Binxian Uplift and Linfanjia Uplift, with the south being gentler than the north[4-5]. The Dongying Depression, located in Shandong Province, China, is a vital oil and gas resource area(Figure 1). In its southern gentle slope zone's eastern part, several oilfields have formed, including the Bamianhe and Wangjiagang oilfields. The Bamianhe oilfield is positioned in the higher parts of the southern slope of the Niuzhuang Sag, while the Wangjiagang oilfield is in the transitional zone of the Niuzhuang Sag and its southern slope, part of the lower slope area. Additionally, the region includes other oilfields like Shaziling, Guangli, Caoqiao, and Lean. In these oilfields, multiple oil-bearing strata from different periods have been discovered in the southern slope of the Niuzhuang Sag in the Wangjiagang and Bamianhe areas. The upper strata, mainly the Shahejie Formation, are the richest in oil and gas, underscoring the critical role of this region's geological structure in oil and gas enrichment and preservation. The geological structure and oil and gas distribution in the Dongying Depression are crucial for energy development.

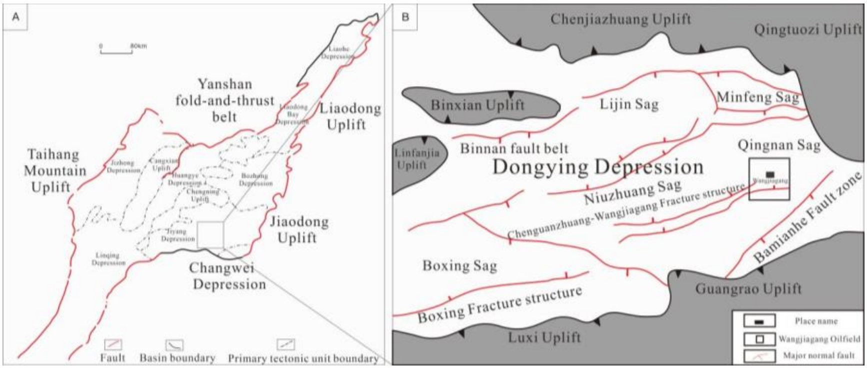
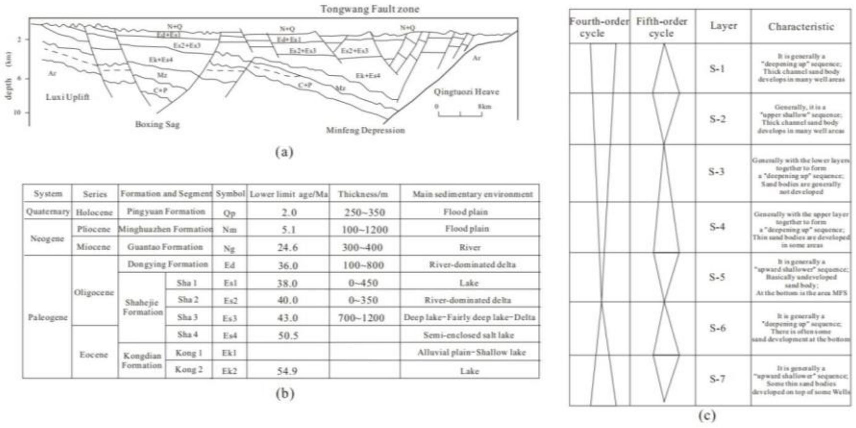


**Figure 1 Structural location map of Wangjiagang Oilfield in Dongying Sag, Bohai Bay Basin (Dou Luxing, 2021)**

A-Bohai Bay Basin tectonic zone, B-Dongying Depression Wangjiagang oilfield tectonic location map

The Wangjiagang oilfield, within the Tongwang fault zone, lies in the southern gentle slope area of the Dongying Depression(Figure 2a). The geological basement in this area is relatively shallow and rigid, providing a relatively stable structural environment.

The Wang 102 block, located in the northeastern area of the Wangjiagang oilfield in the Dongying Depression, is adjacent to the Tong 61 block to the west and the Niuzhuang Sag to the north. This block's geological structure belongs to the Tongwang fault zone on the southern slope of the Dongying Depression, exhibiting an east-west extension. Its complex structure, consisting of multiple parallel faults, forms an antithetic drag syncline geological structure.



| System | Series | Formation and Segment | | Symbol | Lower limit age/Ma | Thickness/m | Main sedimentary environment |
|---|---|---|---|---|---|---|---|
| Quaternary | Holocene | Pingyuan Formation | | Qp | 2.0 | 250~350 | Flood plain |
| Neogene | Pliocene | Minghuazhen Formation | | Nm | 5.1 | 100~1200 | Flood plain |
| | Miocene | Guantao Formation | | Ng | 24.6 | 300~400 | River |
| Paleogene | Oligocene | Dongying Formation | | Ed | 36.0 | 100~800 | River-dominated delta |
| | | Shahejie Formation | Sha 1 | Es1 | 38.0 | 0~450 | Lake |
| | | | Sha 2 | Es2 | 40.0 | 0~350 | River-dominated delta |
| | | | Sha 3 | Es3 | 43.0 | 700~1200 | Deep lake–Fairly deep lake–Delta |
| | Eocene | | Sha 4 | Es4 | 50.5 | | Semi-enclosed salt lake |
| | | Kongdian Formation | Kong 1 | Ek1 | | | Alluvial plain–Shallow lake |
| | | | Kong 2 | Ek2 | 54.9 | | Lake |

| Fourth-order cycle | Fifth-order cycle | Layer | Characteristic |
|---|---|---|---|
| | | S-1 | It is generally a "deepening up" sequence; Thick channel sand body develops in many well areas |
| | | S-2 | Generally, it is a "upper shallow" sequence; Thick channel sand body develops in many well areas |
| | | S-3 | Generally with the lower layers together to form a "deepening up" sequence; Sand bodies are generally not developed |
| | | S-4 | Generally with the upper layer together to form a "deepening up" sequence; Thin sand bodies are developed in some areas |
| | | S-5 | It is generally a "upward shallower" sequence; Basically undeveloped sand body; At the bottom is the area MFS |
| | | S-6 | It is generally a "deepening up" sequence; There is often some sand development at the bottom |
| | | S-7 | It is generally a "upward shallower" sequence; Some thin sand bodies developed on top of some Wells |

**Figure 2 Structure and stratification Characteristics of Dongying Depression**

(a) Structural profile of Dongying Depression (Wang Bingjie, 2012) (b) Stratigraphic development characteristics and main depositional environment of the southern slope of Dongying Depression (Zhao Qi, 2017) (c) Small layer division scheme and cycle characteristics of Sha-2 Member 7 Sand Formation of Wang 102 fault block

## 2.2 Regional Sedimentary Background

During the late Sha3 to early Sha2 sedimentary cycle, regional lithofacies and paleogeographic analyses of the Shengli oilfield revealed that deltaic deposits predominantly occurred in the Yong'an Town, Touzhuang, Wangjiagang areas of the Dongying Depression, as well as in the Su'an, Linyi, and Tangzhuang regions of the

Huimin Depression. During this time, uplifts in the surrounding mountainous areas of the basin led to a reduction in lake area and shallower water depths. The humid climate accompanied by abundant rainfall increased river flows, bringing substantial amounts of clastic material into the lakes, resulting in rich deltaic deposits. As the deltas continuously expanded outward, different water systems began to merge, forming a composite delta comprising multiple sources and water systems. In the Wang 102 block area on the southern side slope of the Niuzhuang sag in the Dongying Depression, the Sha2 phase sedimentary features primarily represented a transition from prodelta to delta front[6].

During the late stage of the Sha2 sedimentary cycle, the Jiyang movement had ceased. Due to dry climatic conditions, the lake basin significantly shrank, leaving lake water only in the Lijin sag area of the Dongying Depression. Consequently, most of the land surface in the oilfield area began to emerge from the water. Especially in the Wang 102 block area, the original delta front facies gradually transformed into delta plain facies. The main rock types in this area were grey-green and purplish-red mudstones, alternating with grey sandstones[7].

The Sha1 period was characterized by shallow lake facies deposits. Initially, the lake basin underwent subsidence, allowing lake water to invade and form early shallow lake facies sand bodies with surface fluctuations. In the middle stage, the lake surface stabilized and mainly deposited mudstones. Towards the end of the middle stage, as the lake surface rose and the basin expanded to its limit, the deposition area and the source area had a smaller elevation difference, leading to slower river flows and clastic material depositing on the edges. During this time, the lake water became clearer, promoting algae growth and photosynthesis, resulting in punctate limestone deposits. In the late Sha1 period, the lake surface began to shrink, the source area rose, and the elevation difference between the lake basin deposition area and the source area increased, allowing turbidites to enter from the south. Subsequently, the lake surface gradually declined, dominated by counter-rhythmic progradational beach-bar deposits[7].

## 3. MATERIALS AND METHODS

### 3.1 Sedimentary Facies Analysis

This study is based on core observations and descriptions, with these cores sourced from coring wells. It integrates logging data and employs the characteristic signatures of log facies to construct a facies analysis model.

The basic steps to study the sedimentary environment of a specific area involve a detailed analysis of the various levels of sandstone layers. The process begins with a meticulous examination of the lithology, grain size, sedimentary structures, and stratigraphic features of the sampled well sections. Based on these analyses, a sedimentary model is established, clearly identifying the sedimentary facies and microfacies types in each well. Subsequently, the characteristics of these microfacies are correlated with corresponding logging data. After determining the sedimentary features of individual wells, the study examines the variations and distribution patterns of these microfacies in the stratigraphic profile. Additionally, the spatial distribution of sand bodies is considered to determine the planar distribution patterns of the microfacies.

### 3.2 Reservoir Modeling Based on Magnetic Random Walk

Magnetic random walk modeling primarily comprises two parts:establishing magnetic maps based on "channel wells" and"non-channel wells," and magnetic map-based random walk simulation[8]. The overall modeling process is illustrated in Figure 3.

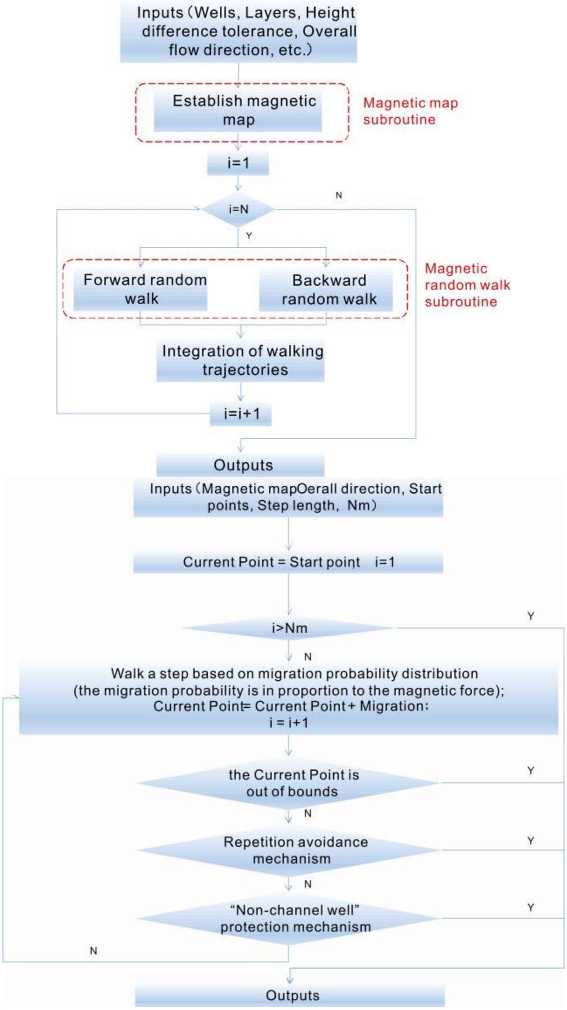


**Figure 3 Flow chart of main program and random walk subroutine of magnetic random walk algorithm (Li Jingzhe et al., 2021)**

To incorporate the type information of "channel wells" into the random simulation, this study first identifies the drilling type of each well based on the input well network data. Then, using the "Channel Center Well subroutine," N channel center wells are established. A cyclic algorithm is employed for simulation one by one. For each center well, the random walk starts from this well and proceeds in both forward and reverse directions according to the "Random Walk subroutine," based on the general direction of the material source. The two trajectories are then merged. This process continues until all center wells have been traversed, thus outputting a collection of random walk paths.

The "Random Walk subroutine" algorithm flow is as shown in Figure 4: It starts by inputting the magnetic map, overall flow direction, starting points (various center wells), walking step length (generally half the average channel width), and the maximum number of cycles (usually set to 300). The walk begins from i=1 and continues until a stopping mechanism is triggered (such as reaching the maximum cycle number Nm, walking out of the study range, encountering an already traversed path, or entering the near-danger range of a "non-channel well"), thus ending the current walk and outputting the walk trajectory. It's important to note that the stopping mechanism of entering the near-danger range of a "non-channel well" has a fault tolerance number range Nt (generally set to 3). That is, upon first triggering, the current point will return to the location before this step of the walk, and a new step is taken with a revised probability. If triggered again, the process continues until successfully passing this step or reaching Nt.

The overall flow chart of the magnetic random walk simulation is as shown in Figure 4. Specifically:

First, select a stratum of a certain period, and determine the channel type attributes (channel center, channel side edge, no channel, etc.) of each well through logging identification methods.

Then, assign corresponding magnetic values. The main channel streamlines are obtained using the magnetic random walk method.

Based on the main channel streamline, transform the main channel streamline into a more realistic channel shape, based on the aforementioned channel width and depth statistical estimation parameters.

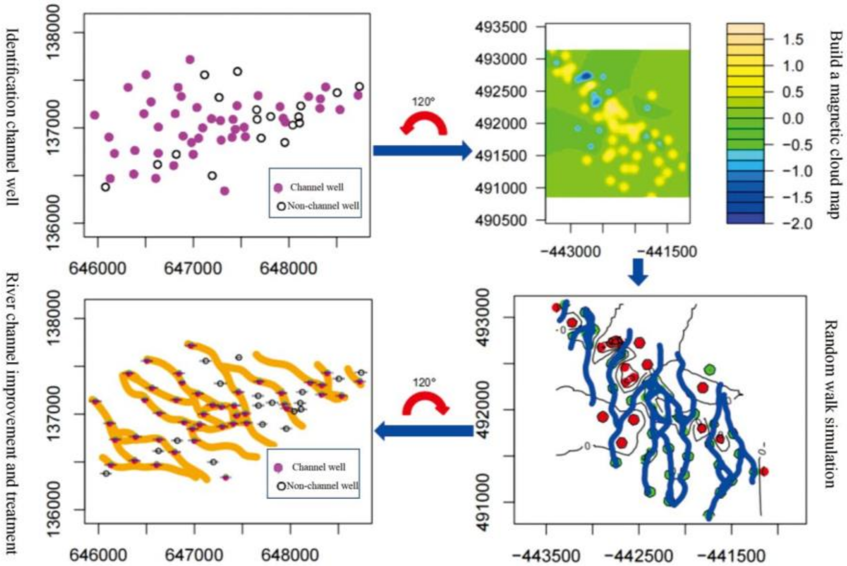


Figure 4 Distributary river system layout flow chart

## 4. RESULT

### 4.1 Stratigraphic Correlation and Division

Stratigraphic correlation and division are foundational in oilfield geological research and are focal points of reservoir geological studies[9]. Whether it's understanding stratigraphic characteristics, researching the spatial distribution of reservoirs, studying the oil-producing layer, the reservoir and caprock combinations, or other aspects, all are based on the premise of stratigraphic correlation and division. Through this process, the lithology, thickness, distribution characteristics, and their changing patterns of strata and oil and gas layers are mastered, which is significant for oil and gas exploration and development[10].

One of the core aspects of this study is the precise division and comparison of strata, forming the basis of the research. Accurate stratigraphic division and comparison directly and significantly impact future reservoir assessment, potential analysis, evaluation of remaining oil reserves distribution, and prediction of target areas. Previous studies suggest that the Sha1 segment of the Wang 102 block represents shallow lake facies deposits, Sha2 to upper Sha3 segments are mainly delta plain to delta front estuary bar deposits, and Sha4 segment consists of deep to semi-deep lake deposits. The variety in sedimentary types and the complex spatial distribution relationships of the reservoirs are noteworthy.

In this study, guided by sequence stratigraphy theory and without altering the original stratigraphic framework, the strata were reanalyzed and compared to establish a more accurate stratigraphic structural framework for the study area. This provides a reliable foundation and basis for detailed reservoir description.

Despite the numerous marker layers in the Sha1 to Sha4 segments of the Wang 102 block, the large study area, extensive stratigraphic intervals, and significant variations in stratal thickness across different areas have made stratigraphic correlation and division challenging. Therefore, this study adopted a cycle thickness comparison method under the control of marker layers. This method's accuracy and reliability in stratigraphic division and comparison were confirmed by cross-checking with dynamic data.

Building upon previous researchers' stratigraphic frameworks, this study refined and redivided the strata based on the development characteristics of the sand bodies within the strata, the cyclicity of the strata, and the spatial distribution patterns of the sand bodies (Figure 2c).

Several points to note in the stratigraphic division:

1)The division retains the previous pattern of stratigraphic division, with Sha2-7 divided into seven sub-layers.

2)In dividing the stratigraphic boundaries, the original divisions were maintained, but a considerable number of wells were adjusted, making the new divisions more consistent with the actual underground conditions.

3)In the stratigraphic correlation and division, the top and bottom interfaces of the sand groups retained the original division pattern, with only minor adjustments in some areas. This continuity between research and production provides assurance for future oilfield adjustments.

4)Compared to the original stratigraphic division, the new sub-layers conform more to cyclicity and possess stronger isochronous characteristics (Figure 5).

5)After sub-layer division, a foundation is laid for further division into individual sand bodies in subsequent studies of depositional sand bodies.

6)In the stratigraphic correlation and division, the entire area was divided and compared using the same stratigraphic division system, thus achieving uniformity in the stratigraphic division and comparison across the entire Wang 102 block.

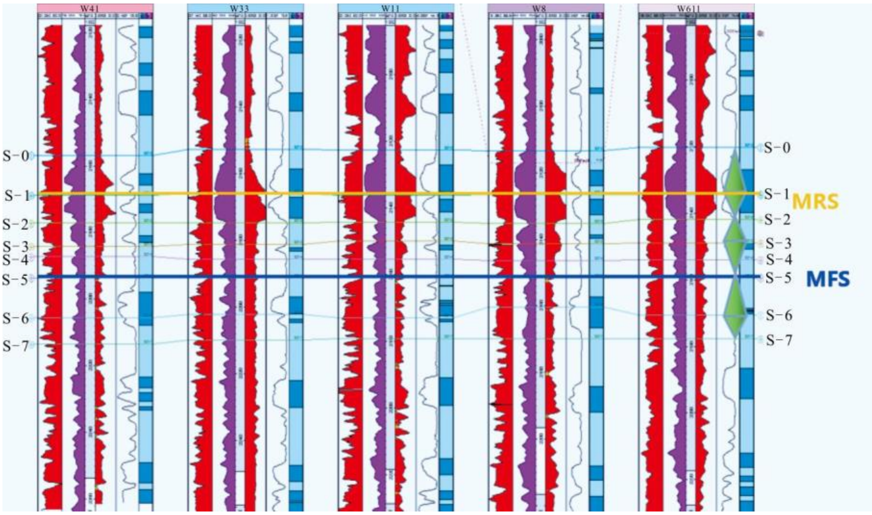


**Figure 5 Circulation profile of distributary channel**

## 4.2 Sedimentary Facies Indicators

### 4.2.1 Structural Features

The rock types are primarily composed of fine to medium-grained feldspathic litharenite and lithic feldspar sandstone, with a minor amount of coarse siltstone. Based on the analysis of 15 thin sections from Well W37, these sandstones mainly consist of quartz (31-43%, average 38.1%), feldspar (26-34%, average 28.5%), and lithic fragments (24-39%, average 33.4%). This compositional combination indicates a relatively low degree of compositional maturity for these sandstones.

The degree of cementation in the sandstones varies from relatively loose to moderately dense, characterized mainly by point or line contact pore structures. The sand grains often exhibit sub-angular shapes with a low degree of rounding, and the sorting of the particles shows a medium deviation. According to the granulometry data from 33 samples of Well W37, the sorting coefficient ranges from 1.21 to 1.66, with an average of 1.4. The median grain size ranges from 0.18 to 0.35 millimeters, with an average grain size of 0.29 millimeters. The lithic components mainly include medium to acidic extrusive rock fragments, quartzite, crystalline rock, and cataclastic rock fragments, along with a few siltstone and mudstone fragments. In heavy minerals, the presence of garnet, zircon, and tourmaline can be observed. The content of cementing material is relatively low, with the clay part exhibiting a flaky structure.

On the C-M diagram, the transport is dominated by saltation and suspension, with less rolling. Sedimentary microfacies types can be distinguished by different grain size distribution probability diagrams. Type I is characterized by a three-part grain size distribution, with saltation being the predominant component, followed by suspension and a small amount of rolling. This type has a wide range of grain sizes and is commonly found in subaqueous distributary channel deposits of deltas. Type II shows a two-part grain size distribution, dominated by saltation, without rolling, and with medium to good sorting, typically associated with deltaic mouth bar deposits. In the study area, the probability curves are mostly two-part, occasionally showing three-part and double saltation patterns, reflecting the influence of wave action (Figure 6).

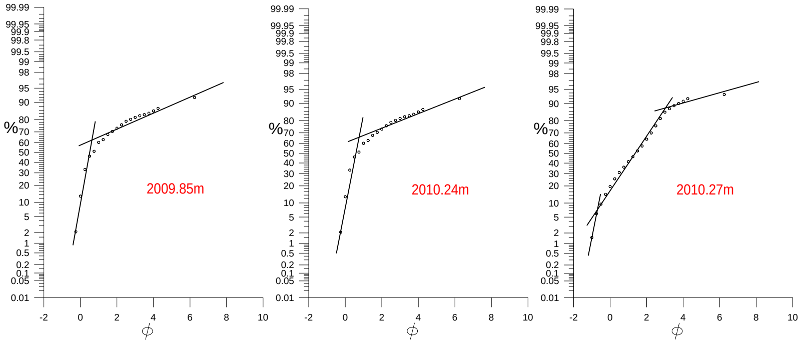


**Figure 6 Grain size probability curve of 7 small layers in the 4 Sand Group of the second member of well W37**

### 4.2.2 Paleontological and Component Features

In this region, the sand layers primarily exhibit shades of light gray, medium gray, and brownish tan, interspersed occasionally with thin layers of gray-green, purplish-red, or other multicolored mudstones. This combination of colors and structures reveals that their formation was mainly due to the deposition of materials carried by rivers in the delta region. Fossils found in these layers include foraminifera, gastropods, and bivalve fossils.

The sedimentary structures of the Seventh Sand Group are simple, primarily characterized by parallel lamination and straight cross-lamination; whereas, the overlying strata develop various types of lamination. Commonly observed features in the sandstone and siltstone include ripple marks formed by flowing water, wave-formed ripple marks, and herringbone cross-lamination presenting as tabular and gutter shapes. In mudstone, horizontal lamination is predominantly developed. These rocks also exhibit a wide range of geological features such as wavy lamination, lens-like lamination structures, convolute lamination, scour-and-fill structures formed by erosion and deposition, deformation structures caused by external forces, and bioturbation structures resulting from biological activity, reflecting a relatively stable shallow water environment.

The analysis of fossil assemblages found in the Sha2 segment strata, along with the sedimentary patterns of the surrounding areas of the Dongying Basin, indicates that these strata belong to delta front subfacies to delta plain subfacies deposits.

Based on the fossil assemblage of the Sha2 segment strata and the sedimentary characteristics of the adjacent regions of the Dongying Basin, it is considered that the strata belong to delta front subfacies to delta plain subfacies deposits.

### 4.3 Reservoir Modeling Based on Random Walk

Through the comparison of the magnetic random walk model of the L2 sub-layer in the Wang 102 area with the manually drawn model of the same region, it is evident that the random walk model closely resembles the model drawn manually based on relevant geological experience, even in the context of a complex well network. However, there are some limitations:

*1)Fixed Channel Width*: One constraint of the random walk model is its inability to adjust the width of the channel as flexibly as manual drawing based on geological experience, which would allow for a more detailed simulation of real geological conditions.

*2)Isolated Channel Issue*: When channel wells are relatively isolated, the random walk model struggles to mimic the forms of other channels. It often generates channels that are distinctly different from other channel forms or may even fail to generate a channel.

Overall, the magnetic random walk model can effectively reduce manual labor in the modeling of the Sha2-7 reservoir in the Wang 102 area. However, the current model still has the aforementioned shortcomings and cannot completely replace the models hand-drawn by experienced geologists.

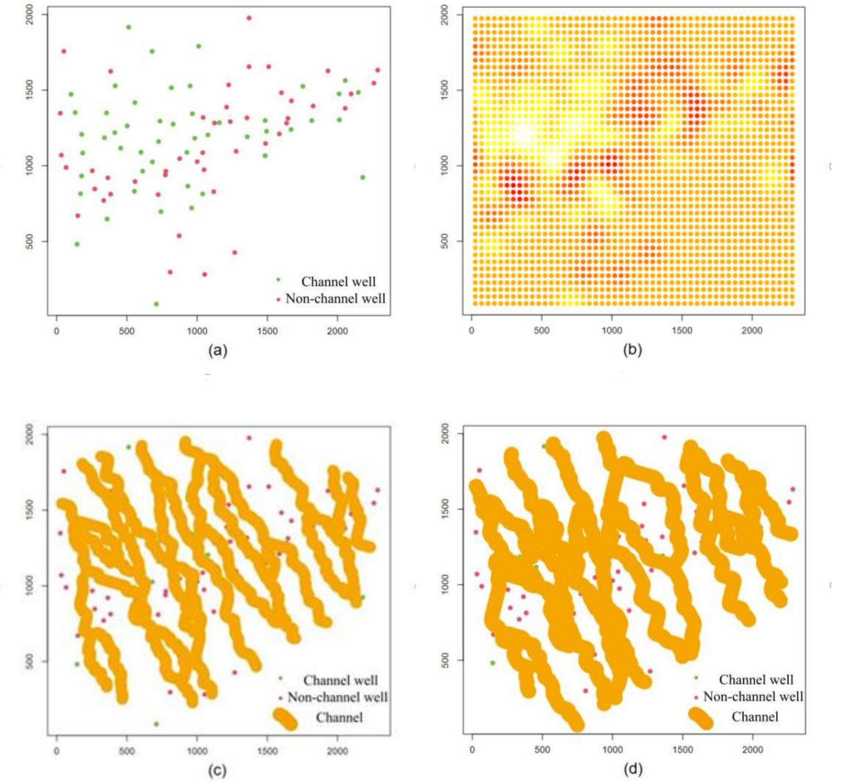


**Figure 7 Well location information and magnetic-like random walk model of L2 small formation in Wang 102 area**

(a) The original well location map of L2 small formation in Wang 102 Area (b) The magnetic field grid distribution map of Wang 102 area (the brighter the color indicates the greater the magnetic force) (c) the migration model diagram of Wang 102 Area (d) The final migration model diagram of Wang 102 area after optimizing the step size and channel width

## 5. DISCUSSION AND CONCLUSION

This study innovatively applies the sediment simulation method based on the magnetic random walk algorithm to the research of complex faulted depositional microfacies. It comprehensively considers the sedimentary environment, geological characteristics, and geological background of the area. This approach is used to analyze the planar distribution characteristics of sedimentary microfacies, draw sub-layer channel distribution maps, and establish the distribution and evolutionary characteristics of sedimentary microfacies in the study area, controlled by the direction of material sources. This lays the foundation for studying reservoir heterogeneity and constructing corresponding reservoir structural models.

However, there are still some issues in simulating walking paths, and key parameters such as step length and channel width in the magnetic random walk process still need to be flexibly adjusted based on experience to achieve optimal walking effects.

## REFERENCES

[1]Xuemei Song. Study on Sedimentary Facies of Lacustrine Carbonate in Upper Part of the Fourth Section of Shahejie Formation of Wangjiagang Oilfield, Dongying Depression[D].China University of Petroleum (East China),2020.

[2]Hui Lin. Sedimentary Facies Research And Favorable Regions 0f Es4, Member In The Wangjiagang Area Of Dongying Sag[D]. Ocean University of China,2006.

[3]Chengzhi Lin.Research on Sedimentary Microfacies and Reservoir Characteristics of Dongying Formation In Jinjia Region, Dongying Depression[D].China University of Petroleum (East China),2011.

[4]Wangxin Tang.The Difference of Sedimentary Characteristics Between the Middle submember and Upper submember of the third Member of Shahejie Formation of Paleogene in the Eastern Dongying Depression[D].China University of Geosciences (Beijing),2022.

[5]Wen Zhao.Overpressure and Hydrocarbon Accumulation of Shahejie Formation in Dongying Depression[D].China University of Geosciences (Wuhan),2023.

[6]Ning Sun.Study on Sedimentary Facies of Tong61 Block of Wangjiagang Oilfield, Dongying Sag[J].China science and Technology Review,2013(6):2.

[7]Tingfang Cui.Study on the structure and hydrocarbon enrichment of He60 fault block in Dongying Sag, Jiyang Depression[D].Central South University,2007.

[8]Jingzhe Li , Zhifeng Sun ,Huaiqiang Ren ,et al.Magnetic Random Walk Algorithm and its Application in the Distributary Channel System Reservoir Modeling[J].Journal of Petroleum Science and Engineering, 2021(3–4):109062.

[9]Ji Liu.Bonan Oilfield of the Member 3 of Shahejie Formation in Block 5 of Fine Stratigraphic Classification and Correlation[D].China University of Petroleum(East China),2020.

[10]Jihong Li.Study on the Stratigraphic Framework of Sha4-3 in WangA area, Niuzhuang Oilfield.Science and Wealth,2017(10):129-129,130.