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Reservoir Geological Characteristics in the Middle Section of the Third Member of Shahejie Formation, Block S, Dongying Sag, Bohai Bay Basin

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Abstract

The reservoir in the middle section of the third member of Shahejie formation in Block S is characterized by large burial depth, tight reservoir properties, and unclear oil-water distribution features. Through the implementation of zone division and correlation, 3D seismic interpretation, sedimentary facies identification and distribution analysis, as well as micro and macro reservoir descriptions, this paper systematically grasps oil-water distribution characteristics and hydrocarbon enrichment regularities, and clarifies the main controlling factors of hydrocarbon accumulation. The research results show that: ① Objective reservoir is divided into six units based on two control markers and two auxiliary markers, with main oil accumulation occurring in M3 and M4. ② Internal structures are characterized by westward-dipping monoclines sandwiched between southern and northern fault zones. Although the distribution of oil-bearing layers is not controlled by these structures within the area (as it is a lithological reservoir), fault zones outside the area play a role in sedimentation and hydrocarbon accumulation. ③ Reservoir system belongs to semi-deep lake-deep lake turbidite fan with deep burial depth, low porosity, low permeability. High-quality reservoirs are mainly distributed in turbidite channels. This study can provide reference for reservoir development in block S.

Keywords

Dongying Sag; Turbidite Fan; Lithologic Reservoir; Hydrocarbon Enrichment Regularities; Main Controlling Factors of Hydrocarbon Accumulation.

1. Introduction

Block S is located on the slope of the western section of the central anticline zone in Dongying sag of Jiyang depression in Bohai Bay basin (see the left side of Figure 1). The study area covers an area of 100 km², and the research object is a lithologic reservoir in the middle section of Sha 3 member (following "Sha3" is abbreviated as "S3" throughout). Dongying sag presents an asymmetrical structural pattern with a northern fault and a southern overlap, as well as a steep northern slope and a gentle southern slope. Multiple provenance systems have filled and is a lithologic reservoir deposited from the periphery of the sag inward. Types of sedimentary systems are diverse, providing favorable geological conditions for the lithologic reservoir [1]. The exploration on lithologic reservoir of S3 member in block S began in the 1980s. This reservoir is characterized by deep burial, long oil-bearing intervals, scattered vertical distribution of oil layers, thin single-layer thickness, rapid lateral changes, as well as tight physical properties. Despite the adoption of reservoir stimulation techniques such as fracturing and acidizing, which have achieved certain progress, overall development effect remains unsatisfactory. To clarify oil-water distribution characteristics and hydrocarbon enrichment regularities of lithologic reservoir in S3 member, this paper conducted detailed stratigraphic division and correlation based on drilling, logging and seismic data. Through detailed interpretation of 3D seismic data, structural morphology and fault development characteristics were identified. Combined with core experimental data, the distribution of sedimentary facies and macroscopic and microscopic characteristics of reservoir were systematically described. Finally, through comprehensive analysis of the correspondence between oil and water layers, the hydrocarbon enrichment regularities were thoroughly clarified. Based on this analysis, the dominant migration pathways and accumulation mechanisms were identified, contributing to a better understanding of how hydrocarbons are distributed within the reservoir. Furthermore, reservoir type in the middle section of S3 member was determined to be primarily a lithologically controlled trap, formed under specific sedimentary and structural conditions. These reservoirs are mainly developed within turbidite channel complexes, where favorable porosity and permeability allow for effective hydrocarbon storage and flow. In addition, main controlling factors influencing hydrocarbon accumulation in this lithologic reservoir were systematically discussed. These include distribution of source rocks, configuration of sedimentary facies, and influence of fault systems on both reservoir formation and fluid migration. The integration of these factors provides a framework for predicting hydrocarbon distribution patterns and optimizing future development strategies in the study area.

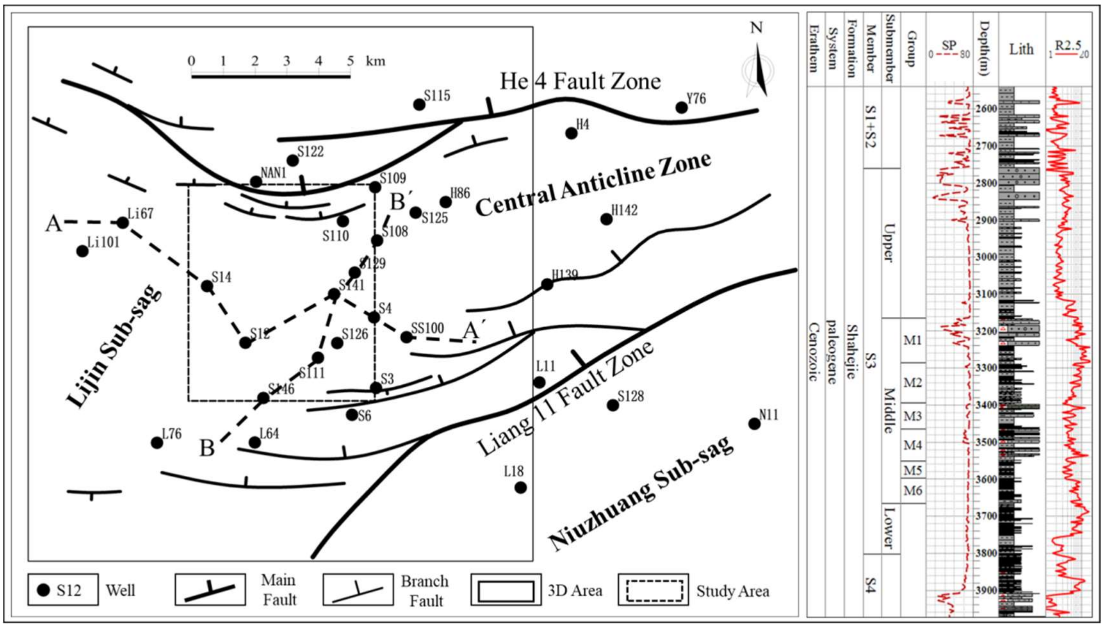

Figure 1. Tectonic location map and stratigraphic column chart in the study area

2. Stratigraphic Characteristics

The study area is located in the center of the sedimentary basin. Actual drilling has revealed a relatively complete sequence of strata, including Shahejie formation and Dongying formation of the Paleogene, Guantao formation and Minghuazhen formation of the Neogene, and Pingyuan formation of the Quaternary. The lower part of Shahejie formation is mainly composed of dark gray claystone and oil shale, with interbedded thin layers of sandstone and siltstone. The middle to upper part shows a significant increase in sandstone content, with lithologies mainly including thick-bedded conglomerate-bearing sandstone, sandstone, siltstone and grayish green claystone, and the upper part is stably developed with bioclastic limestone and dolomite. Dongying formation is composed of interbedded conglomerate-bearing sandstone, sandstone, and gray to grayish green claystone with unequal thickness. In the Neogene, from bottom to top, lithology gradually transitions from conglomerate-bearing sandstone and massive sandstone interbedded with siltstone to purple-red claystone interbedded with grayish yellow fine to medium sandstone [2].

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Oil-bearing layers of S3M mainly consist of thick claystone interbedded with thin sandstone. Sandstone changes rapidly laterally and has many sedimentary periods. During single-well comparison process, it is easy to encounter the phenomenon of the same phase but different periods. If only the standard layer is relied on for control, there may still be a problem of stratigraphic time crossing. To solve this problem, this paper takes advantage of strong lateral continuity of seismic data, marks characteristics of single wells on the seismic profile, analyzes reflection characteristics of each main geological interface on the seismic profile, and then conducts a comprehensive comparison by combining lithology, logging and other data, thereby overcoming limitations brought by relying solely on well data. The development characteristics of strata and oil layers in well S141 in the study area are the most representative. Based on lithological and electrical characteristics, Shahejie Formation can be divided into the Sha 2 member (S2), Sha 3 upper (S3U), Sha 3 middle (S3M), Sha 3 lower (S3L) sub-members, and the Sha 4 upper (S4U) sub-member (see the right side of Figure 1). On the basis of further detailed division and correlation, two standard layers and two auxiliary standard layers can be identified in S3M. Based on a well-seismic combined comparison method, the S3M sub-member is divided into six groups, namely M1, M2, M3, M4, M5 and M6 (see Figure 2). Among them, oil layers are mainly distributed in M3 and M4 sand groups, while M3 group can be further subdivided into two sub-layers, namely M31 and M32.

S3M2 and S3M5+6 are both thick claystone interbedded with a very small amount of thin siltstone, serving as standard layers for controlling oil-bearing segments, and they have good stability. Thickness of S3M2 is 80 m to 110 m, while thickness of S3M5+6 varies slightly in the north-south direction but is relatively stable in the east-west direction. Although the lower part of S3U is a regional thick claystone section, it occasionally contains a small amount of thin siltstone and silty claystone, and a set of thin sandstone develops near the top boundary of S3M. The claystone section between this sandstone and S3M1 sandstone constitutes the top auxiliary standard layer of S3M, with a thickness of approximately 25 m to 40 m. The second auxiliary standard layer is claystone section at the bottom of S3M3, with a thickness of 15 m to 20 m, serving as a marker layer between main oil-bearing layers of S3M3 and S3M4 in the middle of the oil layer. Both auxiliary standard layers are gray to dark gray claystone, with a flat spontaneous potential (SP) curve, while gamma ray (GR) and acoustic time (AC) curves are higher than those of the upper and lower rock layers. Resistivity (R2.5) and density (RHOB) curves show low values.

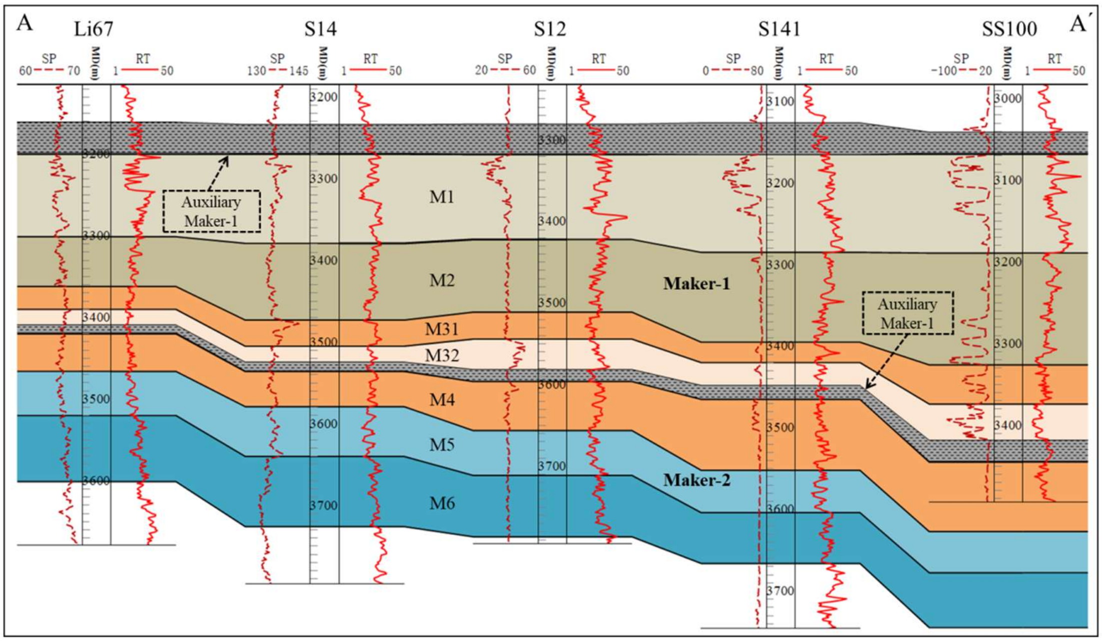

Figure 2. Stratigraphic division and correlation of S3M sub-member (profile line location is shown in Figure 1)

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3. Structure Characteristics

Tectonic evolution of Dongying Sag can be divided into three stages: rifting stage in the Mesozoic, faulted depression stage in the Paleogene, and stable subsidence stage in the Neogene. Central anticline zone was formed during the middle of S3 member deposition within faulted depression period. It is a positive structure created by upward arching of early deposited Kongdian formation along with claystone and gypsum from S4 member under rifting effects on the sag basement. The southern part of this anticline belt is known as Niuzhuang sub-sag, while its northern part is referred to as Minfeng sub-sag, and its western part is called Lijin sub-sag. Block S is situated in the western section of this central anticline zone. Entire area is covered by 3D seismic data, with a main frequency for target layers at 28 Hz. Seismic profile exhibits a high signal-to-noise ratio, natural waveforms, rich interlayer reflection structural information, and clear internal characteristics of wave groups. Identification of fault points and planes is reliable, providing a solid basis for geological interpretation.

Through comprehensive interpretation for the top and bottom of S3M, M31, M32, M4, and M5+6, a total of six layers, it is determined that the northern part of the study area is He 4 fault zone on the central anticline zone [3], and the southern part is Liang 11 fault zone. Between two fault zones, there is a monocline structure which uplifts to the northeast and plunges to the southwest. The study area is located at the lower part of this monocline structure (see Figure 3). Although structure in the S area is relatively simple, two boundary fault zones formed during development stages of central structural zone and remained active until the Paleogene, with faults generally tilting northward. Since block S was a part of Lijin sub-sag in the early stage, boundary faults have a significant control over sedimentation. Faults are not only important channels for petroleum migration but also trap interfaces for petroleum accumulation [4]. The displacement of the north-south fault zones in the study area gradually decreases from east to west, exerting a significant control over oil reservoirs.

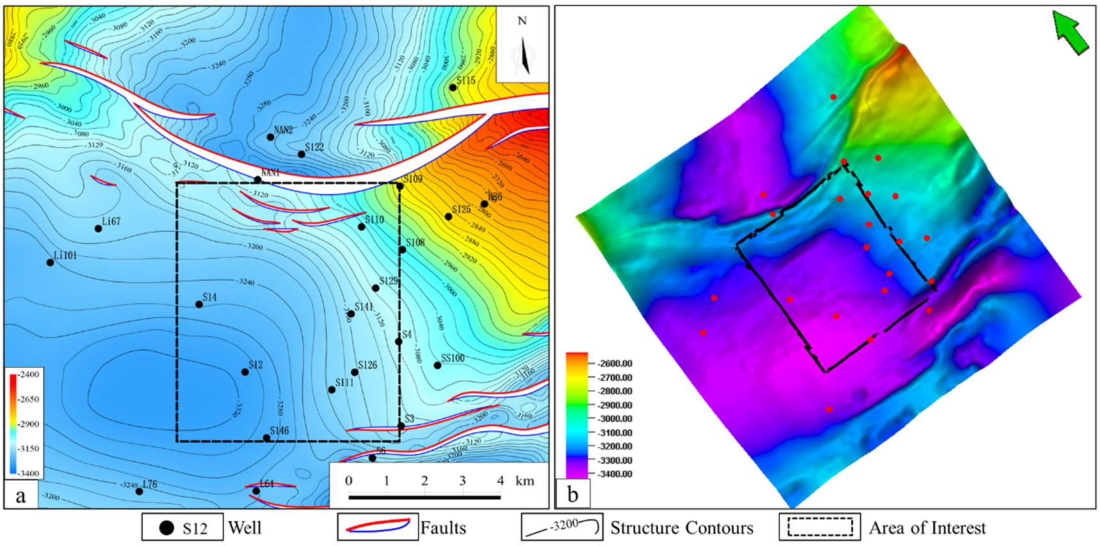

Figure 3. Structural map (a) and 3D stereogram (b) about the top of S3M sub-member

4. Sediment Characteristics

4.1 Facies Symbol

Numerous studies have documented geological characteristics of Dongying Delta [5]. Sedimentary framework of block S is clearly understood. S3 member is characterized by a lacustrine-deltaic depositional system, which includes a variety of gravity flow deposits. Supporting evidence includes the following observations: the lower portion of S3 member is mainly composed of black oil shale and claystone, indicative of semi-deep to deep lacustrine environments. The upper section is dominated by light-colored claystone and sandstone with variable grain sizes, representing deltaic sedimentation. The middle part consists of alternating layers of deep and shallow claystone interbedded with gray fine sandstone or siltstone, with thin sandstone and claystone interlayers that reflect turbidite fan deposition in deep to semi-deep lake settings. Statistical evaluation of 54 whole-rock quantitative samples and 111 sandstone thin sections from seven core wells in the study area and surrounding regions reveals that reservoir lithology is primarily composed of light gray, brownish-yellow siltstone, and dark brown fine sandstone. Sandstones contain less than 75% quartz, with most samples falling between 35% and 50%. Potassium feldspar ranges from 13% to 20%, plagioclase varies between 12% and 20%, and rock fragments constitute 22% to 34%, predominantly of igneous and metamorphic origin. Matrix content in the interstitial material is between 8% and 12%, with calcite and dolomite as primary cements, resulting in a total carbonate mineral content of approximately 6%. Reservoirs are generally tight, with sorting ranging from poor to moderate, sub-angular grain rounding, and a grain-supported texture marked by point-line contact and pore-filling cementation. Grain size analysis was conducted on 165 samples, showing a median grain size of 0.164 mm, placing it within siltstone range. Sorting coefficient is 1.63, indicating good sorting. Standard deviation is 1.31, reflecting moderate sorting dispersion. Skewness value is 0.35, showing a positive skew, and kurtosis value is 1.58, suggesting a sharply peaked frequency distribution.

Probability curve of sandstone grain size generally exhibits a two-segment structure, with saltating component being dominant, followed by suspended component, while rolling transport component is essentially absent. In C-M diagram, most sample points are distributed in QR section and run parallel to C=M baseline, reflecting characteristics of gradually changing suspended sedimentation. This indicates that particle size of suspended matter in the water flow becomes progressively finer and its density decreases from bottom to top. A few sample points are located in PQ section, still dominated by suspended transport but containing a small amount of rolling transport components. Based on this observation, it can be concluded that target layers not only exhibit gravity flow deposition but also include traction flow deposition. However, gravity flow deposition remains predominant. Regarding rock characteristics and electrical combinations, logging curves display distinct response features. Notably, SP curve shows good correspondence with lithology. For instance, SP curves corresponding to sandstone and siltstone typically show medium to low amplitude with sawtooth box-shaped or funnel-shaped patterns. Meanwhile, SP curves for sandy claystone to claystone approach flat sections of claystone baselines or exhibit low amplitude with sawtooth shapes.

Table 1. Summary of sedimentary facies types in the study area

Facies	Sub-facies	Micro-facies	Single sand body thickness (m)	SP curve shape	Variation of rock particles between strata
Delta	Front	not subdivided			
Turbidite Fan	Middle Fan	Channel	4~20	Box / Box with serrate	Saltatory
		Inter-channel	2~4	Infundibular / Finger-shaped	Saltatory / Gradation
		Front	1~3	Finger-shaped	Gradation
	Outer Fan		1-3	Line with serrate	
Lacus	Deep Lake		<3	Line with serrate	

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Based on a comprehensive analysis of thin sections, grain size distribution characteristics, logging facies, and seismic reflection features, M2 to M5+6 sections are identified as turbidite fan sedimentary facies. Due to absence of distinct main channel sedimentary features, only the middle fan and outer fan sub-facies of the turbidite fan are developed. Among these, the middle fan can be further divided into three microfacies: channel, inter-channel, and middle fan toe (see Table 1). Outer fan and lacustrine claystone have not been subdivided further. M1 section is determined to be a delta front sub-facies, since no oil-bearing deposits are developed in this zone, sedimentary microfacies have not been further divided.

4.2 Facies Distribution Characteristics

Sedimentary history of S3M section can be stratigraphically divided into three periods from bottom to top. During deposition of M5+6 intervals, it inherited deep lake facies sedimentary background of S3L sub-member. Lithology is predominantly composed of dark-colored pure claystone and calcareous claystone. Thickness of strata gradually increases from south to north and from east to west. Sandstone generally occurs as thin layers intercalated within thick claystone layers, and overall sedimentary environment across the study area is characterized by deep lake to semi-deep lake claystone facies. In sedimentary periods of M4, M3, and M2, proportion of sandstone increased significantly. Lithologies mainly consist of claystone, calcareous claystone, and sandy claystone interbedded with thin layers of siltstone, sandstone, and pebbly sandstone. Interbedding of coarse-grained and fine-grained sediments indicates an abundant supply of sediments. Variation in strata thickness is primarily governed by sandstone thickness. High sand-to-clay ratio zones are mainly distributed in the southeastern part of the study area and gradually decline in a northwest direction, suggesting that sediment sources are primarily from the east. Sedimentary characteristics of M2 are similar to those found in M5+6 intervals, it represents a depositional hiatus in the reservoir sequence characterized by deep lake to semi-deep lake sedimentation. Consequently, turbidite fan microfacies developed within a lacustrine claystone background mainly include turbidite channels, inter-channel areas, and front parts of middle fans (see Figure 4). Deposition during M1 interval can be considered an independent sedimentary stage where sandstone development reaches its peak. In both eastern parts of this study area and within SS100 block's main body, sandstone layers are vertically stacked forming thick massive structures. Compared to those found in M2-M5+6 intervals, grain size for these sandstones is larger with wider distribution range indicating rapid progradation into this region during late stages associated with S3M sub-member.

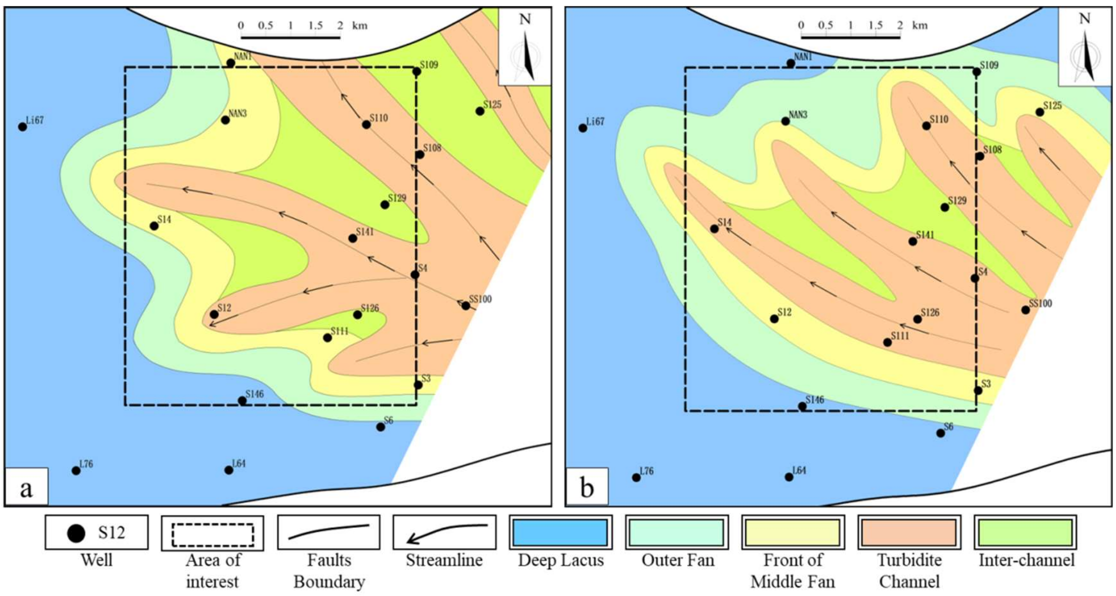

Figure 4. Distribution maps of sedimentary facies of main oil-bearing layers (a represents M4, b represents M31)

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5. Reservoir Characteristics

5.1 Microcosmic Characteristics

Reservoir in S3M sub-member is primarily composed of fine-grained sandstone, characterized by a relatively high degree of primary pore development. Experimental data derived from 11 capillary pressure curve measurements across 3 wells show that displacement pressure varies between 0.51 and 1.51 MPa, with an average of 0.84 MPa. At 50% mercury saturation, associated pressure levels range from 4.27 to 17.96 MPa, averaging 8.9 MPa. Mean pore throat radius is 0.3 μm, with a maximum measurement of 1.44 μm, and homogeneity coefficient is 0.26. Integrated evaluation of these parameters confirms that reservoir displays tight rock properties.

Analytical results from 49 samples collected across 4 wells indicate that clay mineral content in the study area is relatively high. On average, it constitutes 13% of total rock composition, with a primary distribution range of 10% to 15%. The maximum content can reach up to 25%, while the minimum is recorded at 5%. Types of clay minerals primarily include illite-smectite mixed layers, illite, kaolinite, and chlorite. Among them, both illite-smectite mixed layers and illite have comparatively high contents. Proportion of illite-smectite mixed layers within clay minerals ranges from 10% to 52%, averaging at 34%. Illite comprises between 7% and 51%, with an average value of around 31%. Kaolinite accounts for between 1% and 53% of clay minerals, averaging at about 16%, while chlorite varies from 5% to 49%, with an average of approximately19%. Illite-smectite mixed layer serves as a transitional mineral during the conversion process from montmorillonite to illite. It typically exhibits morphologies such as honeycomb-like structures, semi-honeycomb-like forms, and flocculent textures. With the increase in burial depth, temperature, and pressure, content of illite-smectite mixed layer gradually increases, demonstrating strong water sensitivity. Illite, an aluminosilicate mineral, appears in the form of blade-like or hair-like filaments. It often adheres to the surface of rock particles or fills the pores between particles, thereby reducing porosity and permeability of reservoir. Water sensitivity experiment of well S141 reveals that when salinity of injected brine is 16,716 mg/L and 8,358 mg/L respectively, permeability ratio (Ki/KL) shows no significant change. However, after injecting distilled water, Ki/KL gradually decreases, indicating that reservoir has a certain degree of water sensitivity, which is closely associated with high content of illite-smectite mixed layer. Speed sensitivity experiment shows that as flow rate of potassium chloride solution increases from 7.25 m/d to 46.2 m/d, Ki/KL decreases slowly, exhibiting weak speed sensitivity characteristics, which is mainly related to high content of illite.

5.2 Distribution Characteristics

Statistical results indicate that the maximum single-layer reservoir thickness in S3M sub-member is 17.8 m, while the minimum is 0.6 m and the average is 4.1 m. Regarding vertical distribution, reservoirs are primarily concentrated in M1, M3, and M4 sand groups. From east to west, moving from block SS100 to block S12, reservoir thickness gradually decreases and eventually disappears in the vicinity of well S14 and well Li101. In a north-south orientation, the area around well S12 serves as the center for reservoir thickness, with thickness progressively thinning towards both northern and southern sides.

Spatial distribution patterns of individual reservoirs are summarized as follows:

① M5+6 zone: reservoir development is limited and poorly expressed.

② M4 zone: reservoir extends in a northwestward tongue-like pattern, with its maximum thickness (approximately 40 m) centered near wells S141 and S14. Thickness gradually diminishes toward the south and progressively thins toward the northwest (refer to Figure 5a).

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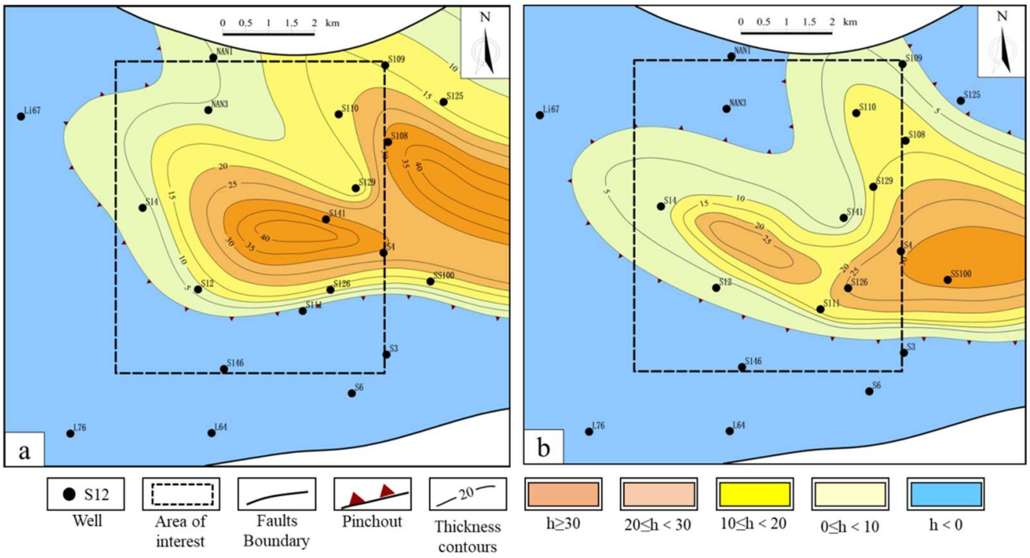

Figure 5. Distribution maps of reservoir thickness of main oil-bearing layers (a represents M4, b represents M31)

③ M32 zone: reservoir displays an east-west trending tongue-shaped distribution. Well S111 marks thickness center, with decreasing thickness observed toward wells S12 and S14.

④ M31 zone: this interval generally contains a thin reservoir, except along the eastern margin of the study area, where slight thickening occurs around wells S111, S141, and S129. This area corresponds to the frontal zone of main reservoir in block SS100 (see Figure 5b).

⑤ M2 zone: reservoir development is generally weak across most of the study area, with thickness typically below 5 m. The distribution is scattered and irregular, resembling a "potato-like" pattern. However, reservoir development in the eastern part is notably better than in the western part.

⑥ M1 zone: sandstone development is extensive and characterized by considerable reservoir thickness. Physical property variations result in significant inter-well thickness differences. The thickest section, exceeding 50 m, is located near well S141, rapidly decreasing in thickness toward the west and north until it fades out. In the southern region, reservoir thickness ranges between 15 m and 25 m.

5.3 Property Characteristics

Routine physical property tests reveal that among more than 300 analyzed samples, porosity values fall between 10% and 22.2%, averaging at 16.4%. Permeability measurements range from 0.074×10^{-3} to 29.8×10^{-3} μm², with a mean value of 2.47×10^{-3} μm². A total of eleven representative samples were selected for mercury intrusion testing. These samples exhibited porosity values ranging from 9.4% to 17.5%, averaging 17.5%, and permeability values between 1.56×10^{-3} and 7.63×10^{-3} μm², with an average of 3.64×10^{-3} μm². Integrated analysis indicates that turbidite fan reservoir within S3M interval of block S is characterized by low porosity and ultra-low permeability. Although reservoir exhibits overall tightness, small pore throats, and high initial injection pressure as shown by mercury intrusion curve, the mid-section of the curve is relatively flat. This suggests a uniform pore throat distribution and minimal internal heterogeneity within reservoir.

6. Principles of Petroleum Accumulation and Main Controlling Factors

6.1 Fluid Properties and Temperature-Pressure Systems

According to laboratory analysis of crude oil samples collected from six wells, ground density of crude oil (measured at 20℃) in S3M sub-member varies between 0.8538 and 0.9062 g/cm³, with a mean value of 0.8668 g/cm³. At ground level (50℃), oil's viscosity falls within range of 8.23 to 134

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mPa·s, averaging 22.66 mPa·s. In contrast, in-situ viscosity ranges from 1.01 to 2.13 mPa·s, with an average of 1.56 mPa·s. Additionally, solidification point of crude oil is observed between 30 and 41℃, indicating that reservoir contains low-density, low-viscosity, light crude oil.

Regarding formation water characteristics, total salinity ranges from 3,222 to 50,617 mg/L, averaging 27,120 mg/L, while chloride ion concentrations vary between 1,929 and 30,160 mg/L, averaging 15,806 mg/L. Dominant water chemistry type is identified as $CaCl_2$.

Temperature and pressure measurements obtained from 5 wells reveal that reservoir temperature in the study area spans from 133 to 146℃, corresponding to a geothermal gradient of 3.6℃/100m. Formation pressure ranges between 47.68 and 60.89 MPa, with an average of 52.57 MPa, and pressure coefficient varies from 1.4 to 1.76. These characteristics suggest that reservoir is a normal-temperature, abnormally high-pressure oil system.

6.2 Principles of Petroleum Accumulation

S3M reservoirs are situated at depths varying from 3,150 m to 3,650 m, with principal oil-producing intervals concentrated between 3,350 m and 3,650 m. Vertically, oil layers are stacked, while laterally, they display a continuous spatial distribution. Specific characteristics of each stratigraphic unit are described below:

① In M5+6 zones, no significant reservoir development is present within the study area, except for a 0.8 m thick oil layer identified at the marginal well S110.

② M4 zone is marked by widespread oil layer distribution, with the greatest effective thickness occurring near well S12. From this point, thickness decreases progressively toward the north, west, and south. In these areas between wells NAN1 and S14, and NAN1 and S129, where drilling data is limited, seismic evidence and oil layer distribution trends suggest that effective thickness is less than 5 m.

③ Within M32 zone, oil layer can be differentiated into two distinct zones. The central and southern regions are dominated by an oil-bearing section extending from well S14 to wells S12 and S111, with a gradual reduction in thickness toward both the northern and southern margins. The thickest portion is found at well S111, measuring 12.4 m in effective thickness. At the northern boundary well NAN1, the thickness is 2.1 m, and at well S110, it is only 0.5 m.

④ M31 zone displays three distinct thickness centers in its horizontal configuration: one between wells S111 and S141, another between wells S110 and S108, and the third centered around well S14. Effective thickness within each of these zones ranges from 8 m to 10 m.

⑤ In M2 zone, oil layer exhibits a "potato-shaped" distribution pattern in the plan view. Effective thickness is 1.7 m at well S14, 3 m at well S110, and 2 m at well S108.

⑥ M1 zone is predominantly characterized by water-saturated or transitional oil-water zones, indicating minimal hydrocarbon saturation and poor reservoir quality.

Through analysis of distribution characteristics of each oil-bearing zone, hydrocarbon enrichment regularities in the study area can be summarized as follows: there is no obvious correspondence between distribution of oil-bearing strata and structural high points. High-value areas of effective thickness are basically consistent with high-value areas of reservoir thickness, and distribution of reservoir thickness is in line with sedimentary characteristics of turbidite fan channels, indicating that oil is mainly enriched in areas within turbidite fan channels that have relatively better porosity and permeability.

6.3 Types and Main Controlling Factors for Hydrocarbon Accumulation

Through a comprehensive analysis of structural features, oil layer distribution characteristics, fluid properties and temperature-pressure systems, it is believed that S3M reservoir in block S is a lithologic reservoir with high pressure and light oil characteristics. As shown in the oil reservoir profile in Figure 6, both M3 and M4 sandstone groups can form lithologic traps, but their oil-bearing properties vary significantly. Some sand bodies are oil-bearing throughout, while others show characteristics of oil-bearing in the up-dip part, oil-water coexistence in the middle, and pure water-bearing in the down-dip part, and even some sand bodies are completely filled with original formation water. Generally, it is believed that main reason for such oil-bearing property differences in lithologic traps is difference in main controlling factors during oil accumulation process [6-7]. Further analysis shows that main controlling factors of hydrocarbon accumulation in S3M lithologic reservoir mainly include distribution of sedimentary facies belts and migration and guidance conditions of external fault zones of block S.

Petroleum predominantly accumulates in high-quality reservoirs that exhibit favorable porosity and permeability. The occurrence of these reservoirs is closely governed by distribution of sedimentary facies types. M2 and M5+6 zones consist of lacustrine claystones, which are characterized by poor reservoir development and lack geological conditions necessary for effective hydrocarbon accumulation. In contrast, M1 zone is associated with a deltaic depositional setting, featuring extensive and thick sand bodies with strong reservoir connectivity. These characteristics facilitate movement of oil toward structurally elevated regions. Nevertheless, in block S, oil appears to pass through the area without significant entrapment or accumulation. M3 and M4 zones are composed of lacustrine turbidite fan deposits, where development of fan structures is primarily influenced by sediment supply from the frontal edge of Dongying Delta, leading to a relatively restricted spatial distribution. Within these intervals, turbidite channels display favorable porosity and permeability, forming a key sedimentary facies zone hosting high-quality reservoirs.

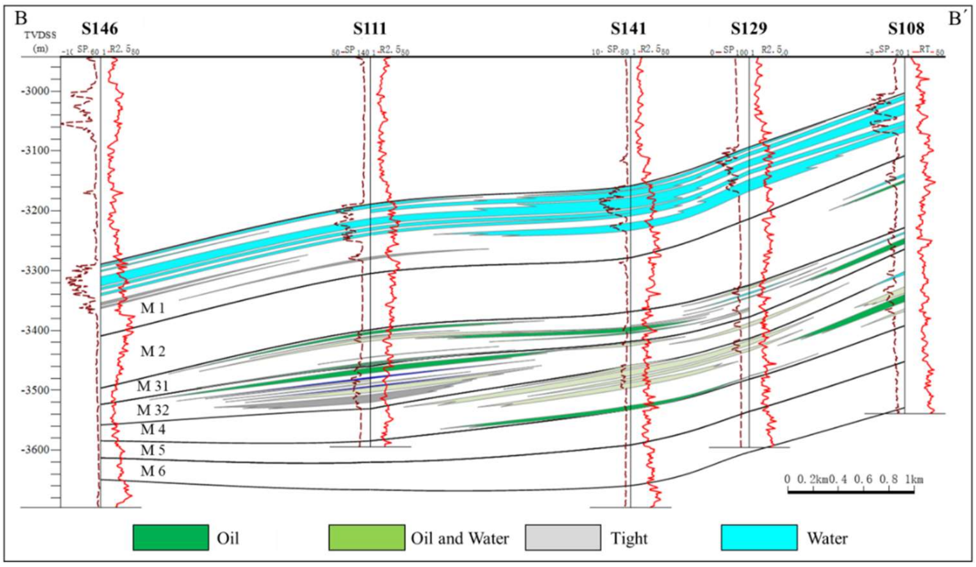

Figure 6. Reservoir section of the study area (section location is shown in Figure 1)

Three main source rocks are developed in Dongying Sag, namely Kongdian formation, S4 member and S3L sub-member, which have excellent hydrocarbon generation conditions and abundant oil resources [8-9]. In contrast, S3M sub-member has weak hydrocarbon generation capacity, and turbidite fan bodies developed within it do not possess conditions for self-generation and self-storage. Petroleum charging must rely on faults as main migration channels. Petroleum migration process is controlled by an abnormal pressure system in the deep part of depression, which is characterized by migration from high-pressure areas to low-pressure areas. Main petroleum migration channels in block S include two fault zones outside the area, namely the north-south faults, and sandstone layers with certain permeability inside the block.

7. Summary

A comprehensive study has led to the following five key findings:

(1) Based on two standard layers of controlled oil-bearing intervals and two auxiliary standard layers, S3M sub-member can be divided into six groups. Among them, M3 can be further subdivided into two sub-layers, namely M31 and M32, according to seismic reflection structural characteristics. The main oil-bearing layers primarily develop in M31 and M4.

(2) Structural feature in the study area is a monoclinal structure which is uplifted towards the northeast and plunged towards the southwest, with two fault zones on both sides. The boundary fault zones formed during development period of central structural zone and continued to be active until the Oligocene epoch, exerting significant control over sedimentary processes and hydrocarbon accumulation.

(3) The sedimentary facies of main oil-bearing layers, M3 and M4, are turbidite fan systems found in deep lacustrine to semi-deep lacustrine environments. Channel sand bodies in the middle fan represent dominant reservoir facies belts with a northwest-southeast distribution direction. SP curve forms are mainly box-shaped or serrated box-shaped, while seismic reflection characteristics manifest as stacked prograding structures.

(4) Sandstone reservoirs exhibit relatively low compositional maturity, fine grain size, and uniform pore-throat distribution. However, due to substantial burial depth, their properties are poor overall-characterized by low porosity and low permeability. Reservoir quality is influenced not only by compaction but also closely related to sedimentary facies belt distribution.

(5) Hydrocarbon primarily accumulate in sandstone layers with relatively good reservoir properties in M3 and M4 that display single sand body hydrocarbon accumulation characteristics. Connectivity between sand bodies is poor. Consequently, oil reservoirs exhibit abnormally high pressure features. Despite this limitation, oil layers are generally distributed continuously through superimposition. Main controlling factors for hydrocarbon accumulation include distribution characteristics of turbidite channels in the study area as well as development timeframes and scales of external boundary faults associated with block S.

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