A Study on Paleogene Petroleum Entrapment Regularity of Shengli Seabeach Oilfield North-West Tectonic Belt

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Abstract — Based on the theoretical and practical problems in Shengli Seabeach Oilfield North-West Tectonic Belt oil-gas exploration, materials regarding the existing well drilling, well logging, mud logging, earthquake as well as geochemical analysis and exploitation have been considered in full in this paper. On the basis of macroscopic Arial geological survey, the paper analyzes reservoir forming characteristics including reservoir type and reservoir distribution characteristics, as well as oil and gas accumulation processes, illustrated reservoir forming system division, basic characteristics and its main controlling factors during different periods of Seabeach Oilfield, and establishing corresponding reservoir models, according to which oil and gas distribution zones have been anticipated to select advantageous exploration targets.

Keywords - Petroleum Entrapment, Reservoir Forming, Reservoir Process, Main Controlling Factors, Reservoir Modeling

I. INTRODUCTION

Shengli Seabeach Oilfield North-West Tectonic Belt is a buried hill overlap and draping structural belt along Chengdao, Zhuanghai, Changdi, Gudong and Kendong, as well as a positive tectonic belt located between Jiyang Depression and Bozhong Depression. In this belt, oil and gas is enriched, with a discovery of 8 large and medium oil and gas fields in Laohekou, Feiyantan, Chengdao, Zhuangxi, Changdi, Gudong, Xinbei and Xintan. The accumulated proven petroleum geological reserves amounts up to 1.009 trillion tons, with Neogene reserve as essential, Paleogene reserves only 0.118 trillion tons, accounting to 10.8% of proven reserves, therefore the Paleogene reserves will be the critical potential series of strata to add reserves. Shengli Seabeach Oilfield North-West Tectonic Belt is a significant field of oil and gas exploration of seabeach area of Shengli Oil Field. In recent years, a large number of Paleogene exploratory wells have acquired high yield industrial oil run, gaining many important breakthroughs regarding Shahejie Formation in east slope of Chengdao Oilfield, Dongying Formation in Kendong north slope, stratum reservoir, and Shahejie Formation stratigraphic overlap reservoir, revealing the enormous exploration potential of the Paleogene research area. With the increasing exploration of land exploratory area in Jiyang Depression, the exploration is becoming difficult. Shengli Seabeach Oilfield forms a significant front for the following added reserves for increasing production. Holistic approach of North-west tectonic belt east of Seabeach area in Shengli exploratory area, a large north-west positive tectonic belt, as well as the explicit oil and gas reservoir conditions, exploratory potentials, reservoir enrichment and distribution regularities are objective demand and necessary trend for the development of Shengli Oil Field exploration.

There are three kinds of research methods for reservoir filling history: source rock hydrocarbon generation and expulsion history, relative filling history analysis, fluid flow timing and dating. The research selected 21 sample sheets from 7 single wells in Chengdao salient, Changdi salient and Kendong salient, carried out inclusion observation and temperature test, and finally found hydrocarbon inclusion in 4 samples from 2 wells. Samples with hydrocarbon were all located in Dongying Formation, and samples with only saline inclusion rather than hydrocarbon in SQVII and SQVI. Based on the observation of the samples, we can primarily reckon that Dongying Formation of Chengdao salient and Changdi salient presents two terms of oil and gas filling, with the oil and gas indicating light- and intermediate- quality and intermediate quality. But it’s difficult to judge whether it’s of the same origin with different maturity, or of differentiated origin regarding oil and gas. We need to make further judgment based on geological background combined with other evidence.

First, accumulation system can be divided into two categories of unisource forming system and multisource forming system according to single hydrocarbon source rock and multi hydrocarbon source rock. Further, the accumulation system can be divided into sub oil and gas system based on oil source distribution, reservoir stratum type, and entrapment type. For unisource forming system, sub oil and gas system can be divided according to reservoir stratum type, and entrapment type; for multisource forming system, sub oil and gas system can be divided according to oil source conditions.

II. MAIN CONTROLLING FACTORS FOR RESERVOIR FORMING

By autopsy study of reservoir forming characteristics of Seabeach oilfield north-west tectonic belt and multi-type
typical reservoir, main controlling factors for Paleogene reservoir forming can be concluded in the following two aspects.

A. Oil pool growth layer and parts controlled by oil source conditions, tectonic characteristics, and pathway system

From Chengdao-Changdi-Gudong-Kendong northwest positive formation unit reservoir distribution along, it was surrounded by various hydrocarbon-generation sags or depressions as Bozhong Depression, Chengbei Depression, Gubei Depression, Gunan Depression and Yellow River Estuary, all of them manifesting tectonic characteristics such as large fracture of fault controlling by the side of Jiyang Depression, and trapped syncline by the side of Yellow River Estuary Depression. Oil and gas mainly migrate to structural high part enrichment along fault depressions as Bozhong Depression, Chengbei Depression, positive formation unit reservoir distribution along, it was conditions, tectonic characteristics, and pathway system reservoir forming can be concluded in the following two typical reservoir, main controlling factors for Paleogene combination features B. Reservoir type and distribution controlled by geologic structure, reservoir stratum distribution, reservoir-cap combination features

For northwest tectonic belt, it manifested bottom overlap and Shahejie Formation top surface denudation from north to south, Dongying Formation top surface strong denudation partly, fan-delta or turbidite in reservoir stratum of Shahejie Formation and the third section of Dongying Formation, with sound combination of reservoir and cap, relatively independent distribution, thus lithologic reservoir may develop in mature hydrocarbon source rocks of hydrocarbon-generation depressions, mainly in the third section of Shahejie Formation or Dongying Formation.

III. PETROLEUM ENTRAPMENT MODELING

In order to facilitate the research, the algorithm gives the following definitions and theorems:

Definition 1: $\beta \subseteq 2^P$ is a common attack structure. If the $\beta$ is satisfied:
$$X \in \beta, X \subseteq X_1 \Rightarrow X' \in \beta$$

(1)

Definition 2: The general attack structure $\beta$ on the set of $P$ is given, and the corresponding maximum attack structure is:
$$\beta_{max}=\{B \in \beta \mid B \not\subseteq B', \forall B' \in \beta\}$$

(2)

Definition 3: Set $P=\{P_1, \ldots, P_n\}$ is a limited set of participants; $K$ is the system secret, the secret sharing scheme for $K$ can be expressed by $\Pi$: $K \rightarrow g(P_1) \times \cdots \times g(P_n)$, $g(P)$ is a collection of all the shares assigned to $P_i, \Pi$ is a secret sharing scheme to achieve the attack structure $\beta$, it must satisfy the following two properties:

(1) the characteristics of secret reconstruction: $\forall X \subseteq P$, if $X \not\in \beta$, then:
$$H(K \mid g(P_1) \mid P_i \in X) = 0$$

(3) $H(x)$ is entropy function.

(2) the security characteristics:
$$\forall X \in \beta, H(K \mid g(P_1) \mid P_i \in X) = H(K' \mid g(P_1) \mid P_i \in X)$$

(4) $K'$ represents any element in a secret space.

Theorem 1: $\forall S_i \in S$, if $\forall S_i \in S$, if $S_i=\{P_1, P_k\}$, then: Any one of the elements of the $K'$, in addition to the elements $K$: $H(K \mid g(P_1), g(P_3)) = 0$

(5)

Prove: The share of $P_1$ is $g(P_1)=\{K_i \mid P_i \not\in S, 1 \leq s \leq n\}$, the share of $P_k$ is $g(P_k)=\{K_i \mid P_i \not\in S, 1 \leq s \leq n\}$. So $S_i=\{P_1, P_k\}$, we know that $K \not\subseteq g(P)$ and $K \not\subseteq g(P_1)$, namely: in $S_i$, any participating parties are not able to collect $K$.

Because $K'$ is a different element from $K$ that it is secret space of the system. Given a division $\{K_{i_1}, \ldots, K_{n+m}\}$ on $K$, obviously, $\{K_{i_1}, \ldots, K_{n+m}\}$ is a division on $K$. Therefore, the $P_1$ and $P_k$ can reconstruct the probability of the share of $K'$ and $K$. If $g_1(P)$ and $g_2(P)$ are the share of $K$ and $K'$ respectively, then: $H(K \mid g_1(P) \mid P_i \in X) = H(K' \mid g_2(P) \mid P_i \in X)$.

Theorem 2: $\forall R \subseteq P$. Any one of the elements of the $K'$, in addition to the elements $K$: $H(K \mid R_1) = H(K' \mid R_2)$

(6)

Theorem 3: $\forall X \subseteq X$, if $X \not\subseteq P, P_k$, $j \not= k$, then $H(K \mid g(P_1) \mid P_j \in X) = 0$. 

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Prove: Assumes that there exist \( K_t \), \( 1 \leq t \leq m + m' \), \( K_t \notin g(P_t) \cup g(P_t), \) then we know \( g(P_t) = \{ K_t \mid P_t \notin S_t \} \); so \( K_t \notin g(P_t) \Rightarrow P_t \in S_t \). In the same way, \( P_t \notin S_t \). Because of \( j \neq k \), so \( P_j \notin S_j \). Contradiction with \( X \not\in X \), therefore \( \forall K_t, 1 \leq t \leq m + m' \), \( K_t \notin g(P_t) \cup g(P_t) \). This shows that \( P_t \) and \( P_k \) can collect all the shares from \( K_t \) to \( K_{m+m'} \). Namely \( H(K_t \mid g(P_t), g(P_t)) = 0 \).

Northwest tectonic belt are embodied with oil source conditions for multiway and multsource hydrocarbon supply, which develops a pathway system composed of various carrier mediums such as fault, sand body framework as well as plane of unconformity, and the oil and gas migrates smooth. Areas of Chengdao, Changdi, Gudong, and Kendong, as the positive tectonic belt between the two large depressions of Bozhong and Jiayang, are the advantageous indicated areas for oil gas migration accumulation. Both structural trap with (low) salient at high advantageous indicated areas for oil gas migration accumulation trap developed with low salient part at high part and stratigraphic trap developed surrounding (low) salient accumulate oil and gas to form reservoir. Gubei area itself is hydrocarbon generation subsag, and also develops advantageous reservoir and cap combination, mostly structural-lithological oil reservoir. For different areas, oil and gas reservoir-forming rules display similarity while maintain different.

To sum up, the whole northwest tectonic belt is dominated by lithological-structural reservoir and structural-lithological reservoir regarding reservoir type. Structural reservoir enriches in uplift side in several large oil source faults like Chengbei fault, Changdi fault, Gudong fault and Gunan fault. Lithological reservoir enriches in Gubei subsag and slope of Eastern Chengdao. Stratum reservoir is mainly subject to stratigraphic overlap line and ancient landform galley, where stratigraphic overlap reservoir develops in most cases.

Differentiation of Petroleum entrapment rules is caused by oil and gas geological conditions such as the height of structure and its controlled stratum as well as sedimentary system. According to the differences of reservoir forming conditions, characteristics, and rules in the research area, two types of oil and gas migration-accumulation modeling are established, i.e. low part buried hill “fault-sand body carrier” and high part buried hill “unconformity-fault carrier”.

A. Low salient “fault-sand body carrier” reservoir forming pattern

Changdi low salient and Gudong low salient are structural low salient during Paleogene. The plane of unconformity between higher and lower sub-member of the second section of Shahejie Formation, and lower sub-member of the second section of Shahejie Formation suffered denudation in its salient high part. In the meanwhile, the upper sub-member hasn’t overlapped to the salient high part yet, thus making plane of unconformity above the third section and under the first section stratum of Shahejie Formation, while the second section in lack of formation. Paleogene stratum under plane of unconformity overlapped the buried hill, and the first section – Dongying Formation stratum draped over the buried hill, forming a buried hill draping tectonic belt. Subject to the stratum development characteristics, the upper Sha 1- lower Dongying Formation sees the whole region development in its mudstone section, thus forming a set of regional cap layer, which further contributes to a set of regional effective reservoir cap combination together with reservoir development section of underlying Shahejie Formation. Its above Dongying Formation stratum features the front-delta deposition with a comparatively high sand body, and with a lack of stable capping conditions, reservoir cap combination is in unfavorable, resulting in a partial combination in part of mudstone developing area.

To the west of Changdi low salient and Gudong low salient, Changdi fault and Gudong fault connects Zhanhua sag, Gubei subsag and Gunan subsag, while to the east a nearly south-north direction stratum communicates with Yellow River Estuary fault, providing oil source conditions for bidirectional multi-source hydrocarbon supply. Border stratum controlling salient development links salient with hydrocarbon generation subsag, serving as a significant carrier channel for vertical migration of oil and gas. Oil and gas formed by hydrocarbon source rock in subsag can enter carrier bed of these sand body frameworks for horizontal migration when meeting sand body with better permeability in Sha 3 fan delta or Dongying Formation delta during its upward migration through oil source stratum. Oil and gas, during their upward migration at the side along Sha 3 sand body framework, on one hand, can migrate to buried hill draping structural high part in accumulation to form fault nose, fault block structural reservoir forming, or on the other hand, Sha 3 stratum top surface suffered denudation under the plane of unconformity of Sha 1 and Sha 3. If Sha 3 upper sub-member reservoir connects with Sha 1 biolithite limestone stratum, oil and gas can pass through plane of unconformity into Sha 1 biolithite limestone reservoir and keep migrating to structural high part in accumulation of reservoir; while in the non-developing area of biolithite limestone in Sha 1 featured argillite mudstone stratum, oil and gas in Sha 3 upper sub-member reservoir keep moving upward to form stratum unconformity screened reservoir. When it comes to Dongying Formation, where reservoir forming is quite simple for extremely enriched reservoir, oil and gas mainly accumulate in structural high part to form structural reservoir (Figure 1).
In conclusion, vertical distribution rules of oil and gas reservoir and reservoir characteristics of different series of strata are subject to reservoir cap combination conditions. With Shal upper part- Dongying Formation lower part mudstone enriched developing section as a set of regional cap, Paleogene is divided into two sets of independent oil gas migration accumulation system. Under this set of regional cap, Sha 1 lower part – Sha 3 with enriched oil and gas, boasts various types of reservoir featured high oil-bearing grade as well as high oil and gas filling degree. While its above Dongying Formation with a small scale of oil gas reservoir, has a sing type of reservoir only to develop structural type with low oil-bearing grade and low filling degree, all belonging to water floating type.

B. Salient slope belt “unconformity-fault carrier” reservoir forming pattern

Chengdao low salient and Kendong high salient are of high salient structure. Each set of stratum of Paleogene overlap the mesozoic buried hill from sag to salient layer by layer. Both Sha 3 and Sha 1- Dongying Formation belong to baselap and top denudation, each stratum able to form stratigraphic trap, thus making a widely developed stratigraphic trap in peripheral slope of Chengdao low salient and Kendong salient, among which Chengdao low salient of Shahejie Formation to Dongying in early period emerge from water surface, Kendong salient exposed itself above water surface since Paleogene, providing provenance to peripheral sag sedimentation. Stratigraphic overlap is located in nearby provenance, Sha 3 is dominated by fan delta front sedimentation, while Sha 1 sees arenaceous and cinereal beach bar development. The eastern third section of Chengdao low salient is dominated by turbidite development, while Kendong salient Dongying Formation by delta plain to front sub-member sedimentation, formation lithology combination by sand-mudstone interbedding with sandstone as its main part, lithologic sandstone including pebbly sandstone, coarse sandstone, fine sandstone as well as siltstone. Horizontally, there is a lack of stably distributed regional cap rock, given sound partial cap rock conditions one of the essential factors for oil and gas reservoir.

Hydrocarbon generation potential is proven from eastern slope of Chengdao low salient to East 2 bottom downward, where it has entered hydrocarbon generation threshold. In the meanwhile, Kendong salient is far from sag hydrocarbon generation center, where fault fails to directly connect oil source, thus leading to oil and gas distant migration for internal reservoir forming. Paleogene and Neogene are two independent oil and gas migration accumulation systems with distinct reservoir characteristics and distribution rules.

For Paleogene, plane of unconformity and secondary fault serve as the main channel for oil gas migration. Thick mudstone-concentrated section in near-sag upper Sha 1-lower Dongying Formation plays a significant role in separating oil and gas migration. Under this set of interlayer, oil and gas mainly migrate horizontally, plane of unconformity as a critical migration channel, and stratigraphic overlap trap with enriched plane of unconformity accumulate oil and gas for reservoir forming. With the horizontal migration of oil and gas towards salient, mudstone section in upper Sha – lower Dongying Formation gradually experience a phase change in salient peripheral near-provenance into reservoir developing area of near source fan delta sedimentation system, vertical separation worsening, realizing upper-lower connection, thus leading to secondary fault development area migrating vertically along fault, arriving at advantageous default nose structure to collect and further forming structural oil reservoir developing belt to develop along the fault (Figure 2).

Under the control of stratigraphic developing characteristics, Paleogene reservoir gradually becomes young regarding its oil-bearing formation from north to south. Limited by cap rock conditions, both stratigraphic overlap oil reservoir and fault nose structure oil reservoir are characterized by low oil abundance, oil contained in high part, water existence for the bottom, and overall low oil and gas filling. However, generally, comparatively good reservoir physical property gets high productivity with characteristics of smallness and abundance once reservoir forms.
VI. SIMULATION

Effective inclusion homogenization temperature failed to be observed in this experiment, we therefore collected its previous data of Chengbei and Qingdong regions. The paper analyzed pool-forming period by combining thermal history analysis of well drilling. Sample depth is between 1200-1500m, homogenization temperature ranging from 90 to 180 ℃, manifesting two peak values with the highest under 150-180 ℃ and the lowest under 100-130 ℃. Calculated with geothermal gradient of 30-40 ℃/km, it’s hard for placing depth of 1200-1400m to reach such temperature. Even if simulated under comparatively high abnormal temperature, i.e. 1400m depth at the temperature of about 90 ℃ (Figure 3), it’s still lower than platykurtic distribution interval under 110-140 ℃ of homogenization temperature. Likewise, test results of fluid inclusion homogenization temperature of samples in the depth of 1963.4m in Qingdong 30 of Qingdong Region manifested that homogenization temperature interval is between 100-130 ℃ with the peak value of 120 ℃, much higher than that of normal stratum temperature. Upon comparison with high thermal history stimulated results of geothermal gradient (Figure 4), we speculated that its oil and gas filling period is about 5Ma, show the characteristics of late forming.

The research adopted stratum top surface migration-accumulation unit division (Figure 5, division of current migration-accumulation unit top surface of Dongying Formation) in which stratum each set of hydrocarbon source bed lies when dividing petroleum entrapment system, to display the migration-accumulation of oil and gas along bedding discharged by different hydrocarbon source rock, thus calculating the distribution amount of hydrocarbon source rock in each depression when expelling hydrocarbon to different accumulation unit.

In the specific division of accumulation system, regarding computer simulation results as reference and paleostructure and fluid potential as basis, this research took structural ridge as segmentation groove, divided migration-accumulation unit by a step-down approach (Figure 6), and necessarily amended by referring to geological reality (such as fracture and thinning out of strata).
V. CONCLUSION

This paper made a systematic analysis of developing scale, organic matter type, abundance of organic matter as well as maturity of organic matter of various sag hydrocarbon source rocks, and a comparative analysis of oil source. Oil and gas reservoir forming has been explicitly illustrated through oil source comparison relation and oil and gas reservoir forming terms, systematically analyzed fault carrier function, thus stating clear the main control factor for reservoir forming. Based on the oil and gas reservoir forming elements, analysis of reservoir forming process has been made, while forming system divided and forming pattern established. For each salient belt facing hydrocarbon generation subsag, Paleogene stratigraphic oil reservoir and lithological oil reservoir has relatively low exploration, which can serve as the following main exploration target. Deploy 37 exploratory wells, 27 finishing drilling wells, making new breakthrough and progress for Paleogene oil and gas of distinct layer section and different types, reporting an controlled and accumulative amount of 19.93 million tons.

With the successive success in well drilling, problems have been revealed like limits to expansion of Paleogene fruits and fundaments for next oil and gas exploration and deploying under the research of reservoir forming rules, which need further solutions based on deepening research. For the same structural belt, problems also exist for the selection of reservoir forming. Take Kendong northern slope as an example, Paleogene Shahejie Formation and Guantao Formation can form enriched oil and gas reservoir with high productivity, while Dongying Formation show little evidence for oil and gas between these two sets of stratum, to solve this problem, deepening research should be carried out from the aspects like differences of reservoir cap rock, selection of oil and gas carrier, and differences of reservoir forming. It’s suggested that individualized research be conducted from the aspects of reservoir forming system and forming drive, to further specify the internal mechanism controlling oil and gas reservoir forming rules and guide the future oil and gas exploratory process.

REFERENCES


