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The Major Controlling Factors Analysis of Hydrocarbon Accumulation on the Gentle Slope Belt of the Southeastern Liaodong Bay Depression

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Abstract

Oil and gas discovery in the Liaodong Bay Depression is mainly distributed in the steep slope, the uplift and the sag zone at current situation. The reservoir developed on southeastern gentle slope zone is the first discovery in this area, which has great significance to the study of the gentle slope zone hydrocarbon accumulation regularity. Based on the analysis of the hydrocarbon accumulation condition of the gentle slope zone, the major controlling factors and hydrocarbon accumulation pattern of the gentle slope zone are summarized. It shows that the gentle slope belt has the superior accumulation conditions, where develops Lithological-tectonics traps and lithological traps Controlled by fracture and provenance. The source rock circumstance is advantageous too, because the gentle slope zone is close to the hydrocarbon-rich Liaozhong sag. The mudstone in Dongying formation(Ed) and the first section of Shahejie formation (Es_1) and the sandstone in the second member of Shahejie formation (Es_2) are form into a good reservoir cap association. Hydrocarbon accumulation in the gentle slope belt is mainly controlled by 3 factors: the development of the reservoirs in the Es_2 is controlled by the valley-slope break coupling; the migration of oil and gas is controlled by "Fault-unconformity-sandbody"(FUS) long-range efficient migration system; reservoir physical properties and oil and gas test capacity are controlled by sedimentary facies differences. There are two reservoir models: lithology - tectonics and lithology.

Key words: Valley-slope break system; "Fault-unconformity-sandbody"(FUS) migration system; Reservoir controlled by sedimentary facies differences; Gentle slope belt; Major controlling factors of hydrocarbon accumulation

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INTRODUCTION

The gentle slope Belt is the transition zone between the sag and uplift area, it adjacent to the hydrocarbon-generating sag with advantageous reservoir-forming condition, which indicates it will be the favorable zone for oil and gas accumulation. As early as the 1990s, the Liaohe and Shengli oilfields around Bohai oilfield have already got good oil and gas discovery in this area.[1-5], so far by now, petroleum geology reserves find in Liaodong bay depression are more than 1 billion tons. However, they are all located in the uplift, steep slope and sag zone, but not the gentle slope zone. In recent years, with further research and the increasing degree of exploration, breakthrough discoveries have been made in the southeastern gentle slope zone of Liaodong bay depression. There are great differences in the reservoir formation between the gentle slope zone and the uplift, steep slope zone and depression zone, so the analysis of the reservoir accumulation conditions and major control factors is significant to the exploration of the gentle slope zone.

1. ACCUMULATION CONDITION ANALYZE

1.1 Structural Trap Characteristics Analyze

Liaodong bay depression belongs to the North China Craton Basin, and its Cenozoic tectonic evolution can be divided into 3 stages: (a)The extensional rift stage from Paleocene to Eocene; (b)the Slip-stretch stage from late Eocene to Oligocene: This stage has undergone two times of rift period, which generate the Liaodong uplift and Liaodong sag in the eastern part of the Liaodong bay depression, establish the tectonic pattern of the three-sag sandwiched two uplift, which from west to east is "Liaoxi sag-Liaoxi uplift-Liaozhong sag-Liaodong uplift-Liaodong sag" for respectively;(c)Neogene Liaodong bay depression enter the sinking stage [6]. In the south of Liaodong bay, the Liaodong uplift disappears and the eastern part of the Liaozhong sag is directly connected with the Bozhong uplift, forming a broad gentle slope zone (Figure 1). During the sedimentary period of Shahejie Formation, the gentle slope zone was controlled by a number of smaller synsedimentary faults, which resulted in some small base-like faults falling down step by step; the strata in the sedimentary period of Dongying Formation gradually overlay the slope; and the Neogene is fluvial facies sedimentary with equal thickness deposits on the sag and uplift.

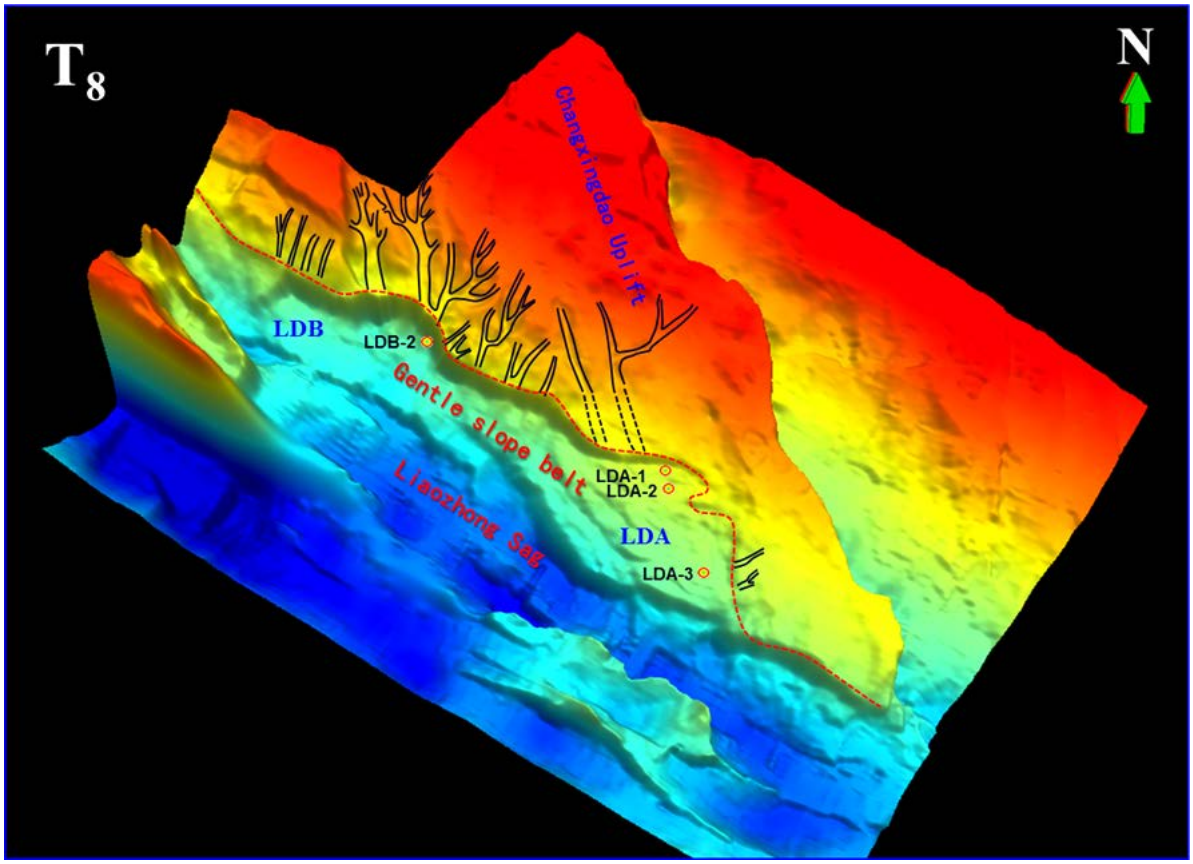

Figure 1
Partition Diagram of Southern Tectonic Units in Liaodong Bay Depression

There are two main types of traps in gentle slope belt: lithology-tectonic composite traps and lithologic traps. The eastern slope Zone of Liaozhong is located at the southern tip of the Changxing Island uplift, which belongs to the East branch of the Tanlu fault and controlled by its dextral strike-slip impact [7-8]. The fault system of the slope belt is early stretching-late superimposed strike slip, which make the entire slope belt develop a series of parallel Fault along the structure LD A-B's boundary fault with cascading fractures that falls down gradually, the whole slope is divided into multistage broken-order fault block, bring about a large number of fault block traps. At the same time, these faults are perpendicular to the source direction from the NE direction, forming a fault slope break, which has a significant controlling effect on the development of sandbody on the Es_2, lead to the forming of several lithological-tectonic composite trap at the high part of the gentle slope belt. On the other hand, at the lower part of the gentle slope belt and far from the source, it mainly developed the turbidite sandbody of the delta front and Partial beach dam sandbody, which develop lithologic traps.

1.2 Source Rock Conditions Analyze

The gentle slope zone is close to the Liaozhong sag, one of the 3 hydrocarbon-rich sag in the Bohai Sea. The main source rocks are deep, semi-deep lacustrine dark or light grey mudstone on Es_3. The carbon range of the source rock on Es_3 is 0.24% -4.45%, with an average of 1.98 %(Figure 2). These source rocks on Es_3 have huge burial depth, high maturity and large proportion of organic matter converted into oil. Therefore, the content of "A" and total hydrocarbon on those source rock is high, the average value of "A" is 0.2576% and the average value of total hydrocarbon is 1638PPm, which shows excellent oil generating conditions and high oil and gas conversion rate. Es_3 source rock's H / C is greater than 1.0, O / C is 0.11 ~ 0.2, organic matter micro components are mainly muddy group, chitosan group, vitrinite, inert mass content is low, and its organic matter type is mainly 1 and 2 kerogen, which is wildly distributed and thick, (maximum thickness nearly 1 km), buried deep, higher maturity (Figure 2). The hydrocarbon generation threshold depth of the Es_3 is 2450m, at the end of dongying formation, when the reflectivity of Vitrinite reaches 0.53%. The Vitrinite reflectivity reaches 0.7% in the metaphase of the Guantao formation, which enters into a large number of hydrocarbons generation period. Now the reflectivity of the hydrocarbon source rock Vitrinite has reached more than 0.86%, which is the peak stage of hydrocarbon generation. In addition, Es_1 Es_2 Ed_3 also has a good hydrocarbon generation potential. By using Petromod software and basin model method, this paper calculate the resources of Liaozhong sag is 2.67 billion tons.

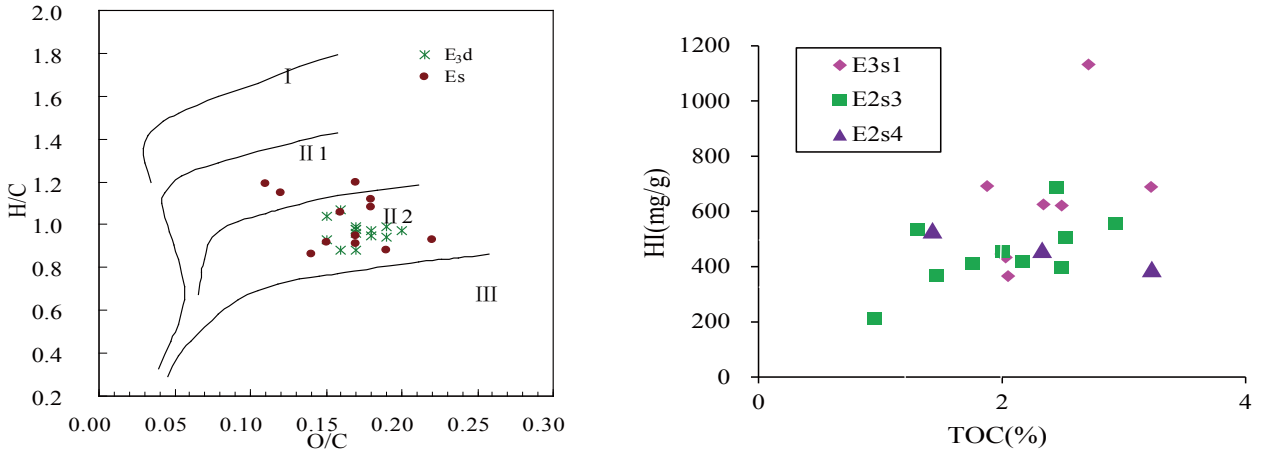

Figure 2
Organic Matter Abundance and Types of Hydrocarbon Source Rocks on Es_3 of Liaozhong Sag

1.3 Reservoir Cap Assembly Analyze

The strata covering the gentle slope are the Paleogene Shahejie formation, dongying Formation and neogene strata in sequence. Among them, the sedimentary period of shahejie formation is a rift period, and it mainly develops the lacustrine mudstone deposition of deep lacustrine-Semi deep Lake Faices. The sedimentary period of Es_2 is the post-fracture sedimentation period, and the tectonic activity is relatively weak. It mainly develop the braided river delta deposition which Originating from the eastern Jiaolian uplift and the lithology is dominated by the channel sandstone and gravel rock of the Delta Front. The Es_1 is mainly mudstone of the shallow lake. The sedimentary period of dongying formation is the second rift period, when the thick lacustrine mudstone is deposited in the gentle slope belt, and the thickness is between 300-500m. The basin enters the depression period on Neogene, the tectonic activity is weak, and the whole Liaodong bay depression is mainly develop fluvial facies deposition [9-10]. Therefore, a set of good reservoir-cap combination is formed on the gentle slope belt, among which, the reservoir is the channel sandstone and gravel rock from the braided Delta front of Es_2, with the thickness of 20~70m. The cover layer is the lacustrine mudstone from Ed & Es_1, with the thickness between 400-600m.

2. ACCUMULATION MAJOR CONTROLLING FACTOR ANALYZE

There is a favorite condition of hydrocarbon accumulation and migration on the Southeastern gentle slope of Liaodong bay depression. The sandstone development is the most important controlling fact of all, together with the hydrocarbon migration and reservoir properties.

2.1 The Coupled Valley-Slope Break Controls Sandstone Development

The formation thickness of Es_2 averages is 200m relatively thin and changes rapidly in lateral, forming by the coupled valley-shift. The valley system categorized 2 types-large and small valleys- were tremendously carved on the uplift surface. The large ones have an outline of "U" or "W" type with the length 6-10km, the width 600-1200m, and

the depth 50-100m along north-eastern strike; the small ones, however, feature the "V" type outline and have a length of 2-3km, width of 100-300m, and depth of 20-100m. According to the drilling and reservoir prediction, the large scale valley transported sediment in great deal and developed a large braid river delta the thickness of which ranged from 30-80m; but the small scale ones distributed unstably transporting in a little degree, and their little scale braid river delta deposited sandstone thickness no more than 20 meters.

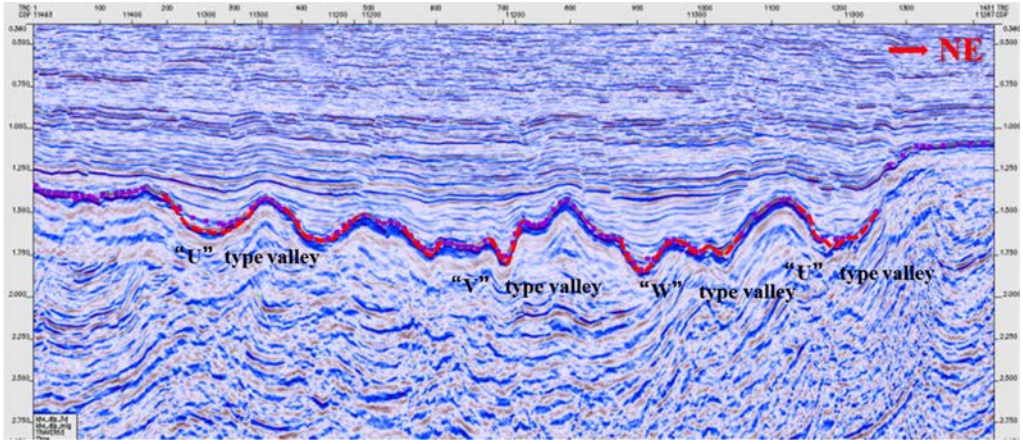

Figure 3
Valley Profile Characteristics (Figure 4 for Section Position)

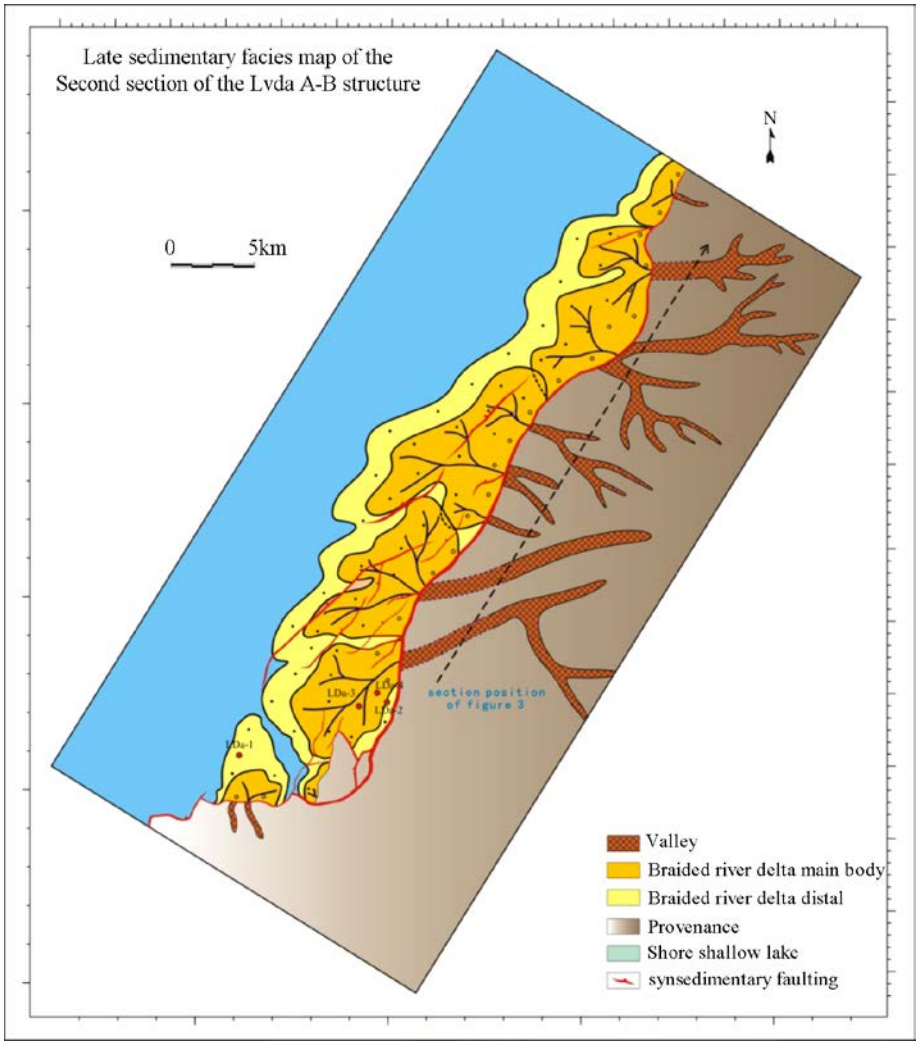

Figure 4
Plan of Valley-Slope Break System in the Gentle Slope Belt

The basin conducted a complete tectonic change from rift to post-rift subsidence in the slope of Es_2 when structural activities weak but different types of slope break exist forming by many faults which had a significant impact on sediment distribution and sandstone properties in Es_2. We classified the main faults into two types: the large scale faults striking north-eastern made a parallel arrangement to form a staged-type slope break and control the accommodation and its amount of sediment deposition; and another one is the regulating fracture, adhering to the large scale faults with a little scale, bounded the distribution of sediment deposition in plane to form a guided slope break system.

The rich or poor sandstone type valley- slope breaks resulting from the coupled different faults and slope break control the sediment depositing distribution in the slope. The rich sandstone type developed a large scale braid river delta, featuring the large valley, main faults, and guided slope break; the poor sandstone one made a small development of braid river delta, characterizing the little valley, main faults, and guided slope break.

2.2 Long-Distance and High-Efficiency FUS Migration System Control Oil and Gas Migration

The drilled reservoir of the Es_2 on the slope belt has a high oil column height (400-600m), high test productivity (Nissan oil is 628.58 m^3, and the daily gas production is 69484m^3), and good oil properties (The crude oil density is 0.841g/cm^3, and the crude oil viscosity is 4.776mPa·s), so the reservoir has an efficient delivery system. According to the previous analysis, the oil accumulation time in the slope area is late Neogene. From the perspective of the crude oil characteristics, the crude oil in the slope area comes from the source rock of Es3 in the Liaozhong sag, and the C29 in gentle slope belt is relatively high compared to the reservoir in the Liaozhong sag, which has obvious long distances migration features (Figure 5). After hydrocarbon generation and expulsion in the source rocks of the Es_3, they firstly moves up vertically along the boundary faults in the depression and slope area. Since the sandbody on the slopes is only distributed in the middle and upper parts of the slope, and does not come into contact with the boundaries of depressions and slopes. Therefore, oil and gas can only migrate laterally through the unconformity surface (T_8) between Mesozoic and Cenozoic. Although there are no oil and gas accumulations on the T_8 unconformity surface in the 4 wells currently drilled, the good indication of oil and gas is found, which shows that there are oil and gas passages and can be used as oil and gas transmission passages. When the sandbody is in contact with the unconformity surface, or sandbody communicates with small faults on unconformities, oil and gas are transported into the sandbody and eventually accumulate in the high-structure parts. Therefore, the migration of oil and gas in the slope region is guided by the coupling of faults, unconformities, and sandbody at long distances, forming a high-efficiency "fault-unconformity-sandbody" migration system and controlling oil and gas migration in the gentle slope belt.

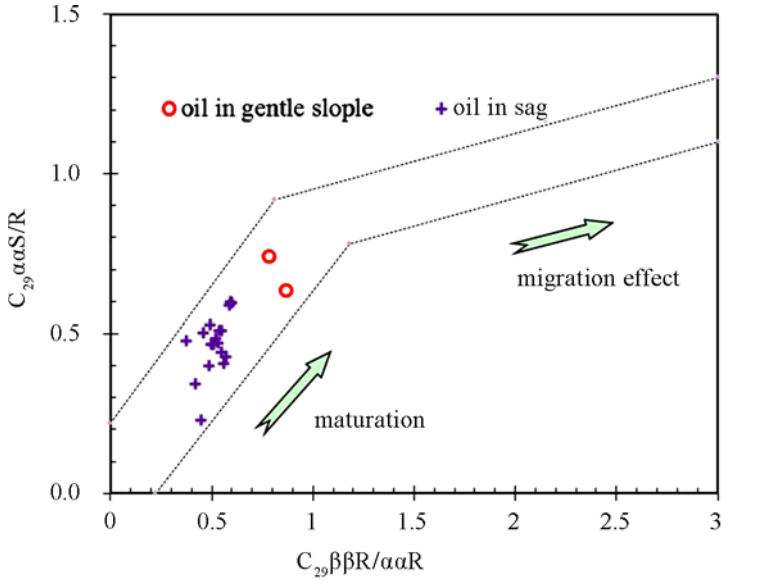

Figure 5
Diagram of Hydrocarbon Migration Effect

2.3 Facies Differences Control Reservoir Physical Property and Oil and Gas Test Capacity

The Paleogene Es_2 in the gentle slope belt is composed of fan delta glutenites, with quartz pebbles as the main gravel components. Cracks are widely developed on the quartz pebbles, which lead the glutenite strata in the area

into a high-connectivity in porosity, high-production in hydrocarbon reservoir.The Es_2 of the LD structure, located in the northeastern Bohai Bay Basin, is interpreted as large-scale fan delta sedimentation resulted from the elevation of the Jiaoliao paleohigh. The sedimentation was prevailingly charged by glutenites, with dominant quartz pebbles (2–8.3 mm in diameter of pebbles, medium-well sorted, poor rounded. The well logging analysis defined the targeted glutenite strata are low-porosity and medium/low permeability reservoir, with the porosity ranging from 9.6% to 14.4% and permeability from 16.7 mD to 76.9 mD. The results of productivity testing in Bohai Bay Basin suggest that the productivity of such reservoir is generally no more than 100 m^3/d. Nevertheless the actual productivity of such crack-type glutenite reservoir on well A surprisingly goes up to about 700 m^3/d, with a productivity index per meter up to 112.84 m^3/ (MPa.d.m).

Thin section examination of glutenite shows that the cracks within a same pebble are in multi-directions, with the width range of 0.02-0.22 mm and plane porosity range of 1-12%. The development of cracks increased along with the quantity of pebbles in the glutenites. Well A, located in the central fan delta, embraced grain-supported glutenites (gravels taking up 69-90% of the total), with little mud and matrix but abundant cracks and 12% plane porosity, whereas Well B on the margin of the fan delta yield matrix-supported glutenites (gravels taking up less than 41% of the total), with generous mud and matrix contents but moderate cracks. Analyses of Well A suggest that, the pressure on the contacting points of gravels in the grain-supported glutenites are far higher than that of fine-grained sandstones and go beyond critical pressure of gravel stabilities, so lead to the development of cracks. Such cracks reduced the inter-gravel porosities but enhanced the intra-gravel connectivity, so to improve the nature of glutenites as a hydrocarbon reservoir, which is proved by high hydrocarbon productivity for Well A in the DST test, while Well B are mostly poor reservoirs.

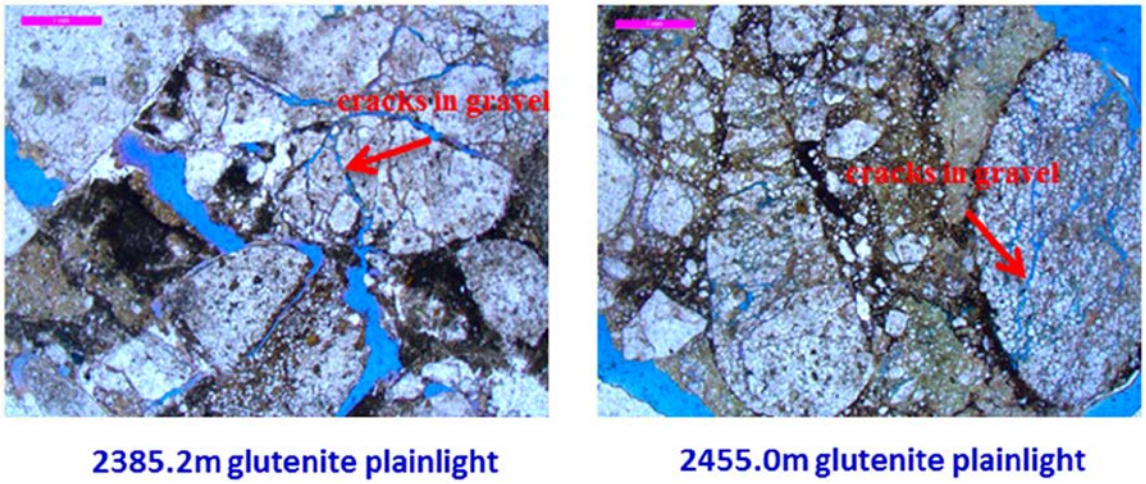

Figure 6
Thin Slice of Glutenite Reservoir

3. ACCUMULATION MODEL

The gentle slope belt is close to the Liaozhong sag, one of the three major hydrocarbon- generating depressions in the Bohai Oilfield, which has a good source of hydrocarbons.

It also has a strong overpressure in the northern part of the source rock in the southern part of the Liaozhong sag where the moderate slope zone is located. The pressure coefficient is up to 1.3-1.5, the pressure of fluid expulsion is large, and the oil and gas migration is vertical along the faults of the slow slope zone and the depression zone. After the oil and gas move upward to the unconformity surface T_8 (top of the Mesozoic) and T_5 (the top of the Es3), the oil and gas are transported laterally to the high-slope section. Then the oil and gas enters the sand body of Es_2 encountering the sandbody or the faults communicated with the sandbody. The lithologic reservoir is formed in the delta front and the beach-bar sand body at the lower part of the gentle slope belt, meanwhile, the lithologic-structural reservoir is formed in the high slope zone.

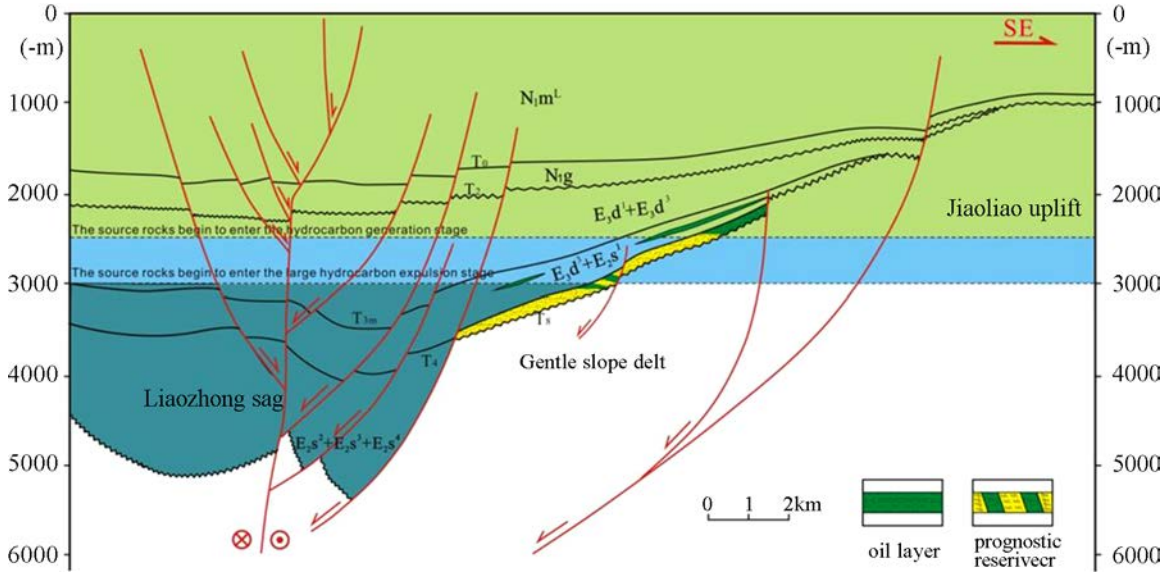

Figure 7
Reservoir Model of Southern Gentle Slope Belt in the Southeast of Liaodong Bay Depression

CONCLUSION

(a) Good reservoir forming conditions in the gentle slope zone: The lithological-structural traps are developed in the high part and the lithologic traps in the low part controlled by faults and provenance. The gentle slope zone is close to the hydrocarbon generating sag in the Liaozhong sag, and the hydrocarbon source condition is superior. There is a good combination of reservoir and cover in the thick muddy lacustrine facies shale of the Ed & Es_1 and the sandstone of the braided river delta in the Es_2.

(b) The hydrocarbon accumulation in the gentle slope belt is mainly controlled by 3 factors:

The coupling of valley-slope break controls the development of the reservoir on Es_2; the migration of the oil and gas are controlled by the high-efficiency FUS migration system with long-distance; the reservoir properties and oil and gas testing productivity are controlled by sedimentary facies differences.

(c) There are mainly 2 lithologic-structural and lithologic reservoir models in the gentle slope belt.

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