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Research on the Formation Geological Conditions and Development Stages of Source Rocks in Linnan sag

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Abstract: *The study area is located in the Linnan subsag in the west of the Jiyang Depression of the Bohai Bay Basin. Its structural axis is in the NNE direction. It mainly develops four structural units: the Linnan slope zone, the Xiakou fault zone, the Linnan subsag zone and the central uplift zone. , The exploration area is about 1300 km2. The formation and evolution of the Linnan sag can be roughly divided into four stages: the Mesozoic fault depression, the slope of the Kongdian Formation-Upper Es4 deposition period, the fault depression during the Es3 Member-Dongying Formation deposition period, and the Neogene depression. During the formation of the sag, a complete Paleogene strata was deposited, which was divided from top to bottom into the Kongdian Formation, Shahejie Formation (which can be subdivided into four sections), Dongying Formation, Guantao Formation and Minghuazhen Formation , And formed multiple sets of source, reservoir, and cap rock assemblages. The Shahejie Formation is not only the most important source rock development interval in the Linnan Sag, but also an important reservoir rock and cap rock development interval. Various types of oil and gas reservoirs, especially lithological oil and gas reservoirs, are important exploration targets for increasing reserves and production in this area. The study of the geological conditions and development stages of the source rocks in the Linnan Sag is not only a basis for establishing a hydrocarbon accumulation model, but also a theoretical basis for oil and gas exploration. Therefore, it is very necessary to analyze the organic geochemical characteristics and oil and gas sources of the source rocks in the study area.*

Keywords: *Source rock, Hydrocarbon-rich depression, Source rock development.*

1. General Situation of Regional Geology in Huimin Area

The Huimin Sag is a sub-sag in the westernmost part of the Jiyang Depression. It is bounded by the Qihe Guangrao Fault in the south and connected with the Luxi Uplift; in the north by the Lingxian-Xinyang Fault and the Chengning Uplift; it is connected to the Dongying Pass in the east and west. The depression is connected with the Xinxian depression. The west of Huimin Depression is composed of Zizhen Depression in the north and Linnan Depression in the south.

Linnan sag is located in the southwestern part of Huimin sag and is an important oil and gas enrichment area in Jiyang Depression [1]. The Linnan sag is an asymmetric graben with the subsidence center northward and axially NEE. The north-south boundary is the Xiakou fault zone and the Linshang fault zone. The maximum thickness of the source rocks of the third member of the Shahejie Formation in the Linnan sag is about 900 meters, and they have all entered the mature-high-mature stage. Therefore, they have become important hydrocarbon-rich sags. Many oil fields have been found around them, making them the most important in the Huimin sag [2,3]. Oil-gas-bearing area (Figure 1).

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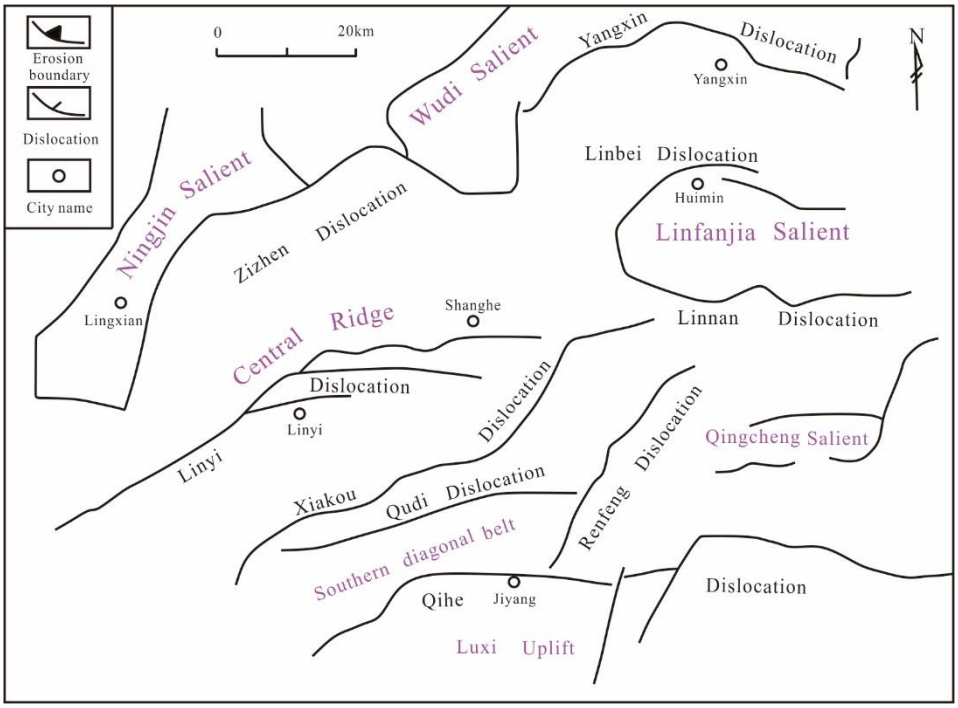

Figure 1: Structural framework of Linnan sag

2. Concept and formation mechanism of hydrocarbon-rich depression

2.1 The concept of hydrocarbon-rich depression.

The Linnan sag is a typical hydrocarbon-rich sag in the Jiyang Depression. Exploration practice has proved that the enrichment of all oil and gas is related to hydrocarbon-rich depressions. The key to a hydrocarbon-rich sag is to contain a considerable volume of high-quality source rock. The formation of hydrocarbon-rich depressions requires a certain favorable geological environment.

The formation of hydrocarbon-rich sags in the entire Bohai Bay Basin is related to the formation of Lower Tertiary graben (mainly half graben), episodic cracking, rift filling mode, and the development characteristics of ancient lakes.

2.2 Formation mechanism of hydrocarbon-rich depression.

The horizontal stretching of the lithosphere caused episodic stretching of the upper crust, which led to the expansion and vertical settlement of the half graben. The depression with half graben as the unit has obvious independence and becomes the basic unit for the development of source rocks. Episodic cracking is mainly manifested in the activities of the growth faults on the boundary [4]. These faults generally have undergone a weak-strong-weak development process, which controls the generation, migration and accumulation of oil and gas in faulted basins [5].

The rift stage sequence in the half graben can be regarded as a large sedimentary cycle. However, due to the unbalanced expansion and rifting activity of the Lower Tertiary, it appears as multiple episodes in time, forming multiple secondary cycles; The development is uneven. In a continental sedimentary environment, the filling mode of a half graben depends on the relationship between its sedimentation rate and the amount of debris input [6]. When the subsidence is greater than the supply, the source rock in the lake environment will be formed; when the subsidence and the supply are balanced, the coal-measure source rock in the lake and marsh environment will be formed; on the contrary, when the supply is greater than the subsidence, even if the subsidence rate is high, it will be coarsely broken Chip filling [7]. After the Bohai Bay Basin was flattened during the Paleocene, a large number of semi-graben subsidence zones were formed, and the source supply was limited. Therefore, the subsidence rate became the main factor controlling the filling of the sag. The Research Center of Offshore Oil Corporation has calculated the subsidence rate of 51 sags (mainly the Bohai Bay Basin) in the offshore basins of eastern my country, which proves that the subsidence rate has an obvious control effect on sedimentary facies. Their statistical

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data shows that semi-deep lake-deep lake facies generally appear when the sedimentation rate is as high as 200~250m/Ma; shore-shallow lake facies are generally 100~250m/Ma; swamp facies are 100~150m/Ma; alluvial facies are below 100m/Ma.

In this way, the episodic cracking, subsidence rate, and sedimentary filling of the half graben were linked, and the filling model of the faulted basin in eastern my country was established. Corresponding to a split curtain, the following four filling periods can be divided (Figure.2).

Initial stage (Phase I): The subsidence rate is as low as about 100m/Ma, the depression area is small, dominated by alluvial facies, and evaporite facies appear from time to time. The reservoir is well developed, and lacustrine source rocks can be formed locally.

Expansion period (Phase II): The subsidence rate can be as high as 200~400m/Ma, the depression expands, and the lake basin reaches its peak. It is the main period for the formation of semi-deep lakes and deep lake facies source rocks, but at the edge of the lake basin and there are also reservoirs in the center.

Decline period (Phase III): The subsidence rate drops to about 200m/Ma, the lake basin declines, and shallow lakes and swamps develop, forming secondary coal-type oil source rocks and gas source rocks, and reservoirs are developed.

Shrinking period (Phase IV): The subsidence rate drops to about 100m/Ma, the lake basin shrinks, mainly plain and fluvial facies, and reservoirs are developed.

Due to the difference in the settlement of the cracks and the different material supply, the development of each filling period is not balanced. Various filling sequences appear in faulted basins, thus forming various types of depressions.

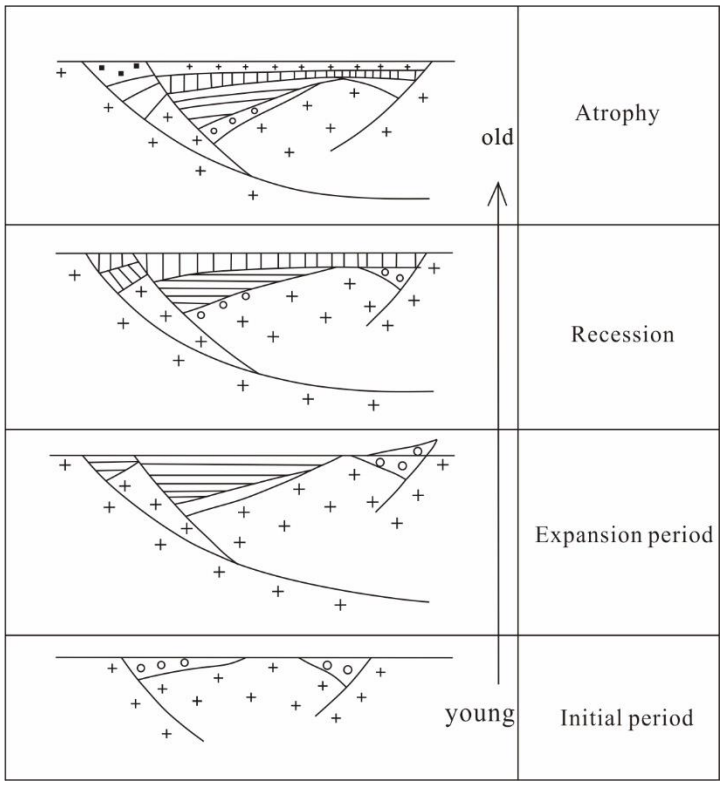

Figure 2: Filling evolution model of faulted basin during rifting period

3. Development stage of source rock in Linnan sag

Like most of the faulted basins in the Bohai Bay Basin, the Linnan subsag has also experienced two development stages of the Lower Tertiary rift and the Upper Tertiary depression.

According to the stratigraphic sequence, tectonic activity and sedimentary filling, the formation of each rift subsequence in the Linnan Sag can also be divided into four filling periods [8]. The following is an example of the filling period of the second subsequence, which is the most fully developed, including

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the main source rocks:

(1) Initial period (Es4 period)

The movement at the end of the Yanshan Movement created the basic form of the depression, and then the depression entered the initial development period. After the deposition of the lower submember of the fourth member of Shahejie Formation in the Kongdian Formation, the sag was uplifted and suffered denudation [9]. Starting from the upper part of the fourth section of Shahejie Formation, the sags have sunk and entered a new period of development. Due to the uplift near the periphery, the source is fully recharged, and the deposition rate is moderate, about 200m/Ma (Table 1).

Table 1: Paleo-Water Depth and Sedimentation Rate of Tertiary in Linnan Subsag

Stratigraphic age	Q+Nm	Ed	Es1	Es2s	Es2x	Es3s	Es3z	Es3x	Es4s	Es4x	Ek
Ancient water depth (m)	5-15	15	15	2	25	60	60	40	20		
rate of deposition (m/Ma)	60-100	150	170	180	400	450	450	400	190	210	230

The sedimentary environment of the upper part of Shahejie Formation is a freshwater shore shallow lake or a relatively deep lake facies, and the lithology is mainly interbedded with dark gray mudstone and siltstone. The dark mudstone is a possible source rock.

During the sedimentary period of the Kongdian Formation to the fourth member of Shahejie Formation, the subsidence range of the Linnan Subsidence is estimated to be about 2500m based on its deposition thickness, which is much lower than that of the Zizhen Subsidence in the north. The water body is deep in the north and shallow in the south, and the settlement and deposition center is located in the northern part of the Zizhen sag. It can be inferred that the hydrocarbon generation properties of the upper member of Shahejie Formation in Linnan Sag are worse than that in Zizhen Sag.

(2) Expansion period (Es3)

During the sedimentary period of the third member of Shahejie Formation, basin rifting was enhanced, and the deposition rate was as high as 400~600m/Ma. The water body expands to the maximum range, and the water depth reaches 40 to 60m. The Linshang Central Fault Zone uplifted in the middle of the sedimentary stage of the third member of Shahejie Formation. The Zizhen sag located on the ascending plate of the fault returned and rose, while the Linnan sag located on the descending plate of the Linshang fault continued to settle, causing the deposition and subsidence center to move from the north to the Zizhen sag. The Zhen sag shifted to the Linnan sag, forming a pattern of deep in the south and shallow in the north [10].

The internal water body of Linnan sag is deep in the north and shallow in the south, and the settlement center is near Linyi in the northern part of the sag. During this period, semi-deep lakes and deep lake deposits dominated by large sets of oil shale and dark mudstone developed, forming the main source rocks in this area. Among them, the lithology of the lower sub-member of Shahejie Formation is mainly dark gray mudstone with oil shale and thin limestone mudstone, silty fine sandstone. The dark mudstone is relatively thin, with a maximum thickness of about 160m (Figure 1-5). At this time, the lake basin area is large, and the central uplift zone is an underwater low uplift; however, east-west is different, with dark gray mudstone interbedded with oil shale in the east of Panhe Oilfield, and interbedded sand and mudstone to the west.

(3) Decline period (end of Es3) and shrinking period (Es2)

During the sedimentary period of the second member of Shahejie Formation, the lake basin gradually shrank, the range was reduced, the water body became shallow, and the delta-plain facies mainly developed. The lithology is dark gray, gray-green sometimes interbedded with purple-red mudstone and silty sandstone. The dark mudstone of the second member of Shahejie Formation has a thickness of 250~300m. At the end of the sedimentary stage of the second member of Shahejie Formation, the Jiyang movement led to the uplift of the basin, forming an unconformity between the first member of Shahejie Formation and the second member of Shahejie Formation.

The third subsequence deposited from the first member of Shahejie Formation to the Dongying Formation also experienced a similar development process, namely the expansion period of the lower part of Shahejie Formation and the decline and shrinking period at the end of the Dongying Formation. Oil shale and dark mudstone are also developed in the lower part of the first member of Shahejie

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Formation and Dongying Formation, but they are shallowly buried and difficult to become the main source rock [11].

In the Upper Tertiary, the entire Bohai Bay Basin entered a new stage of development [12]. The Linnan sag also experienced overall uplift and denudation at the end of the Dongying Formation, and then slowly subsided as a whole, developing delta plains and fluvial deposits. No source rock developed during this period

4. Summary

I As a long-term inherited sag, the Lower Tertiary rift sequence of the Linnan sag includes three subsequences (three sedimentary cycles), namely the Kongdian Formation-the lower part of the fourth member of Shahejie Formation; the fourth member of Shahejie Formation From the upper part to the second member of Shahejie Formation and the first member of Shahejie Formation to the subsequence of Dongying Formation. The development of the three subsequences all show phasic time and spatial imbalance. The formation of each subsequence has experienced the initial sinking stage, deep sinking stage, shrinking stage and the corresponding filling period of rift development, all of which are divided by unconformity.

It can be seen that the main mechanism for the formation of source rocks in faulted basins is the rapid subsidence caused by tensile fault activities, resulting in non-compensation deposits, forming deep lake water bodies, developing a reducing environment, and forming source rocks. Almost all of the source rocks in faulted basins in my country are semi-deep-deep Lake deposits developed in the early to mid-stage of the rifting stage of the basin. Due to the multi-episode structural evolution in the Jiyang Depression in the Lower Tertiary, 2~3 cycles have developed, forming multiple sets of source rocks, of which the Eocene is the main source rock.

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