

New Perspective of Hydrocarbon Accumulation Pattern in the Middle South of Lixian Slope, Central Hebei Depression*

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Abstract

The traditional understanding of hydrocarbon accumulation patterns in the middle south of Lixian Slope was based on the assumption that oil and gas migrated through connected sand bodies in the lower First Member of the Shahejie Formation (Es1x) and Third Member of the Shahejie Formation (Es3) to the boundary faults, and then vertically along the faults. It is suggested that no hydrocarbon would be found beyond source rock layers of the middle south of Lixian Slope. But this pattern is contradicted with newly discovered reservoirs. Through comprehensive study of the faults activity periods and sedimentary system, the results show that the late period development and late period attenuation faults act as the vertical migration path, while connected sand bodies provide lateral migration path for oil and gas. Based on oil-source correlation and the distribution of discovered reservoirs, the hydrocarbon accumulation pattern in the south of Lixian Slope is characterized by two source rocks, faults, and connected sand bodies meshwork migration that accumulated in fault nose traps of shallow layers. This pattern reveals that the shallower formation in the middle south of Lixian Slope would be the next exploration area through finding subtle structure traps by seismic interpretation and accurate sedimentary microfacies characterization.

Introduction

Lixian Slope, located in the Central Hebei Depression, is a NE strike wide - gentle successive sedimentary slope. For decades, the exploration for oil and gas has been concentrated in the north region of Lixian Slope and numerous oil reservoirs have been found. However, the south part of Lixian Slope

remains stagnant for quite a long time without any major breakthroughs. It was believed that hydrocarbons in the middle south of Lixian Slope was “stepped – like” migration model, and no hydrocarbons would be found beyond source rock layers of the middle south of Lixian Slope. But new research and discoveries reveal that there are huge hydrocarbon potentials in the middle south of Lixian Slope.

Basic Geology

Lixian Slope, lies in the western Raoyang subbasin, is one of the most important oil-rich slopes in Central Hebei Depression. It is a NE strike wide - gentle successive sedimentary slope, dipping towards the east ([Figure 1](#)). The main oil bearing layer is the Shahejie Formation of Paleogene age. The strata of the south Lixian Slope could be divided into 3 source – reservoir – seal assemblages. One is composed of source rock from the middle – lower Third Member of the Shahejie Formation (Es3z – Es3x), reservoir from the upper Third Member of the Shahejie Formation (Es3s), and seal from the Second Member of the Shahejie Formation (Es2). The second type is composed of source rock in the lower First Member of the Shahejie Formation (Es1x) and its underlying bottom sand. The third type is composed of Es1x source rock, reservoir, and seal from the Dongying Formation (Ed) and shallow strata. Lixian Slope developed in a shallow-water braided delta during the Shahejie Formation.

The faults in the research area could be divided into two types according to their activity stages. One is generated during the beginning of the basin formation and died by the Miocene late Guantao Formation (Ng). They are boundary faults in the south of Lixian Slope and were not able to control the distribution of sand bodies nor hydrocarbon migration in the Paleogene, but determined the paleotopography after the Guantao Formation (Ng). Another kind of fault formed in the late Oligocene (Es2 - Ed), and continued to develop in the Miocene or Pliocene (Ng - Nm). These kind of faults were usually small but numerous, NE and NEE direction, distributed mainly in the southeast of the slope. They had no obvious controlling effects on sedimentary and structure, but caused small structural traps and hydrocarbon secondary migration.

Oil-Source Correlation

There are two sets of source rocks. The most important one is the Es1x, which comprise dark mudstone, oil shale, biological oolitic limestone, and dolomite of shallow water. Its thickness is about 100–300 m. It is immature but spreading almost all over the slope. But it is less developed in the south of the slope because of abundant sediment supply. Another is dark mudstone in Es3. It is mature source rock and distributed mainly in the Suning Sag and the Renxi Sag ([Figure 1](#)). The distribute range is smaller than the one in Es1x.

Analyzing oil properties, saturated hydrocarbons chromatography, as well as other geochemical index, the oil-source correlation suggests that most of the oil from Lixian slope came from immature source rock in Es1x, only in Zhaohuangzhuang area oil came from Es3 near the Suning source kitchen.

The property of oil generated from Es1x are high in density, viscosity, sulfur content, and resin – asphaltenes. On the contrary, oil from Es3 is totally different. The oil is low in density, viscosity, sulfur content, and resin – asphaltenes, which represent mature oil generated from mature source rock. Saturated hydrocarbon chromatography distribution charts have a similar pattern. Due to shortage of source rock in the outer slope in the middle south of Lixian Slope, the oil generated in Es1x from middle and inner slope migrated a long distant towards the outer slope through connected sand bodies, leaving a heavy content of the oil in the lower region. Thus density and viscosity gradually declined from inner slope to outer slope ([Figure 2](#)).

Hydrocarbon Accumulation Pattern

In the past, hydrocarbon accumulation in the middle south of Lixian Slope was thought to be a “stepped – like” pattern, which means that oil and gas generated from Es1x and Es3 migrated through connected sand bodies into the boundary faults, and then vertically along the faults. Based on the study of fault activity stages, reservoir distribution, and oil-source correlation, the new migration pattern is more like “parallel transportation”. Small faults in the inner slope activated during the expulsion period, which provide migration path to shallow reservoirs for the oil generated from Es1x. Connected sand bodies in the south of Lixian Slope could transport hydrocarbons from inner slope to outer slope in Es1x. Hydrocarbon was sealed and trapped by the Dabaichi Fault and Gaoyang Fault, and formed a “toothbrush” shape fault nose structural reservoir or structural – lithologic combination reservoir. Furthermore, when hydrocarbon migrated upwards, suitable lithologic traps could be filled with hydrocarbon when trapped. This kind of lithologic traps will be the next favorable exploration plays in the middle south of Lixian Slope ([Figure 3](#)).

Prospects

The new pattern suggests that the hydrocarbon exploration potential in shallower layers in the middle south of Lixian Slope has a bright future. Shallow layers such as Ed, Ng, Nm, etc. were connected by small faults. It is reasonable to take those shallow layers as important exploration strata; especially in the SW direction of the slope for that SW is a regional structural high.