Study on simulation of reservoir-controlling of fault-unconformity composite transport in Chengbei Fault Zone

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Abstract: Due to the multi-phase tectonic movements in Chengbei Fault Zone, a superimposed pattern of Paleozoic buried hill and Cenozoic fault-step slope was developed on the North China platform. The fault–unconformity composite transport played a vital role in the oil and gas supply for the underlying buried hill and the distal high slope, resulting in the accumulation forming of multi-layer multi-type oil and gas. On the basis of seismic and well logging data, the characteristics of fault–unconformity composite transport in Chenghai buried hill and southern high slope were determined. And the reservoir-controlling mechanisms of fault–unconformity composite transport were revealed through oil and gas filling simulation experiments under different transport conditions. The results showed that the composite transport of fault and unconformity in buried hill zone was beneficial to the forming of large-scale reservoirs, and the dominant thick reservoirs or even negative tectonics under unconformity with abundant oil source were the main hydrocarbon accumulation area. As to the forming of reservoirs in the high slope, the key was the lithology configurations around the unconformity of “upper sand and lower mud” and “upper gravel and lower mudstone”. With the help of fault, the composite transport enables long-distance migration of oil and gas from the northern source rocks in Shahejie Formation, leading to hydrocarbon accumulation above the unconformity of Guantao Formation and even in the structural trough of southern high slope. These results revealed that fault–unconformity composite transport was helpful to hydrocarbon accumulation on a large scale, and even negative tectonics in buried hill below unconformity or structural troughs in high slope above unconformity are potential to form reservoirs. This provides a useful reference for theoretical research on reservoir forming in fault basins and a beneficial guidance for oil exploration in similar areas to a certain extent.

Keywords: Chengbei Fault Zone; fault-unconformity; reservoir-controlling analysis

1. Introduction

Chengbei Fault Zone was developed on the base of North China ancient platform. Through multiple phases of tectonic movements, stratigraphic sedimentation and denudation, a superimposed pattern of Paleozoic basement buried hill and Cenozoic fault step slope was formed. The transport characteristics vary in different parts of Chengbei Fault Zone. The main transports in the middle and lower parts of slope are the fault-sand type, while the one in the high slope and in underlying buried hill are mainly fault–unconformity transport. In the developed section of fault and denudation surface,
hydrocarbons accumulated generally, like the Paleozoic Chenghai buried hill and Cenozoic distal slope, constructing the vertical multi-layer system and horizontal long-distance hydrocarbon enrichment mode in Chengbei Fault Zone[1-5]. Fault–unconformity composite transport provides hydrocarbon-migration pathway for underlying buried hill and distal slope, and allows hydrocarbons to accumulate around the transport system.

The proximal Chenghai buried hill and the distal high slope are characterized by fault–unconformity composite transport of hydrocarbons, which can efficiently form hydrocarbon accumulations in the underlying strata or distant places. The efficiency of hydrocarbon accumulation through fault–unconformity composite transport is the key to the differential accumulation of multi-layer oil and gas. Previous studies on transport system placed emphasis on the summary of characteristics and types of sand bodies, faults and unconformities, where static description was the main means, and there were few studies on reservoir-controlling efficiency and filling process of fault–unconformity composite transport; especially, there is a lack of systematic comparison on differences of reservoir-controlling between the underlying buried hill and distal slope with faults and unconformities as the main transport[2-6]. Thus, Chenghai buried hill and distal high slope, with the typical fault–unconformity composite transport in Chengbei Fault Zone, were taken as typical anatomical areas to describe the composite transport characteristics, establish the geological models of fault–unconformity composite transport, simulation the hydrocarbon filling under different transport conditions, and explore the differences and reservoir-controlling mechanism of fault–unconformity composite transport under different geological backgrounds, so as to provide a reference for further finding of hydrocarbons.

2. Geological setting

Chengbei Fault Zone, as a fault-step slope belt from Qikou Sag to Chengning Uplift, is located in the eastern part of the central area of Huanghua Depression in Bohai Bay Basin, which starts from Qidong Fault of Qikou Sag in the north, reaches the northern slope of Chengning Uplift in the south, adjoins with Qinan Subsag in the west, and borders Dagang exploration area in the east (Fig. 1), with an exploration area of about 1200 km².

![Fig. 1 Regional structural map of Chengbei Fault Zone](image-url)

This fault-step structure descends from south to north under the control of Qidong, Zhangdong, Zhaobei and Yang’erzhuang faults. It experienced multi-stage tectonic activities such as Indosinian
movement, Yanshan movement and Himalayan movement. On the North China platform, two main structural layers were formed, i.e. the Paleozoic-Mesozoic (pre-Tertiary) faulted anticline the buried hill and the Cenozoic (Tertiary) faulted step slope. The Paleozoic Cambrian–Ordovician marine carbonate strata, Carboniferous–Permian marine-tilligenous clastic successions, Mesozoic Jurassic system, Cretaceous fluvial clastic rocks, volcanic rocks, Cenozoic faulted basin tilligenous clastic successions [3,6-8] have been deposited(Fig.2), showing the vertically superimposed characteristics of multiple structural layers and multiple lithologic sedimentary layers.

The study areas of fault–unconformity composite transport are Chenghai buried hill and southern high slope(Fig.1), in which the former is located in the middle slope area of the south of Zhangdong Fault, where hydrocarbons are mainly concentrated in Paleozoic strata relating the fault–unconformity composite transport; while the latter is distributed in the south area of Yang’erzhuang Fault, where hydrocarbons are mainly accumulated in Cenozoic strata concerning the composite transport.

| Location | Strata       | Lithology                                                                 | Notes                                                                 |
|----------|--------------|---------------------------------------------------------------------------|----------------------------------------------------------------------|
| Tertiary Slope | Cenozoic   | Grey mudstones and sandstones                                              |                                                                      |
|          | Dongping     | Dark grey mudstones and sandstones                                         |                                                                      |
|          |             | Oil shales and calcareous shales and argillaceous dolomite and grains limestones |                                                                      |
|          | Shajie       | Greenish-grey mudstones and light grey sandstones                         |                                                                      |
|          |              | Dark green sandstones and conglomerates and mudstones interbedded and thick mudstones |                                                                      |
|          |              |                                                                          |                                                                      |
|          |              |                                                                           |                                                                      |
| Pre-Tertiary Buried Hill | Mesozoic | Red clastic rocks and pyroclastic rocks                                   |                                                                      |
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Fig. 2 Synthetic column of strata, lithology, tectonic layers in Chengbei Fault Zone

3. Characteristics of fault–unconformity composite transport

3.1 fault–unconformity composite transport in Chenghai buried hill

Chenghai buried hill is located in the upthrown side of Zhangdong Fault and in the east of Zhangbei Fault (Fig. 3). The bedrock buried hill was formed through many tectonic movements such as Indosinian thrust fold, Yanshanian strike-slip and Himalayan inversion extension, accompanying with many unconformities and fault [9,10]. The fault and unconformity composite transport system of
Chenghai buried hill are widely distributed, and the Paleozoic oil and gas reservoirs are located at the denudation surface of the top of Ordovician and the top and bottom of Mesozoic. Faults (Zhangdong Fault and Zhangbei Fault and subsidiary faults) and these unconformities assembly distributed in stepped style in pre-Tertiary strata, located under the middle slope in Tertiary. Oil and gas enter the buried hill layer along the unconformity, where hydrocarbons accumulate and form reservoirs.

3.2 fault–unconformity transport in southern high slope

The southern high slope is located in the upthrown side of Yang’erzhuang Fault, distributed in the southernmost part of Chengbei Fault zone, as the transition zone to Chengning uplift (Fig. 3). Multi-stage tectonic movements resulted in the loss of Mesozoic strata on the high slope, and Neogene directly contacted with Paleozoic strata, forming regional unconformity. The unconformity at the bottom of Guantao Formation is the most typical, and it, together with fault, constitutes the hydrocarbon composite transport, with the hydrocarbons migrating and accumulating on the unconformity. Faults provide vertical transporting medium, while unconformity contacts with faults to provide lateral migration pathways. Fault–unconformity composite transport provides hydrocarbon source for distal high slope, and forms heterogeneous reservoirs at different positions.

Fig. 3 Structural profiles of Chenghai buried hill and high slope

4. Simulation analysis on reservoir-controlling mechanism of composite transport

Based on the geological characteristics of fault–unconformity composite transport in Chenghai buried hill, the physical model was built to carry out physical simulation (Fig. 4-1). The bottom of the fault was set as the oil filling point, and the sand bodies were distributed in negative tectonics under the unconformity. The permeability of fault–unconformity is 1D, the negative structural sand body is 0.8D, and the rest are separated layers. The results of simulation analysis show that the composite transport of fault–unconformity in buried hill zone is beneficial to form large-scale reservoirs, and the dominant thick reservoirs or even negative tectonics under unconformity are also the dominant potential accumulation area.

For Southern high slope, the unconformity at the bottom of Guantao Formation (Ng) could be the core of transport, constituting the composite system with Yang’erzhuang Fault. According to the geological characteristics of fault–unconformity composite transport, the numerical model of oil and gas filling was built by setting the fault closed and open (Fig. 4-2). The simulation results show that the key to the formation of stratigraphic reservoirs is the lithology configuration around unconformity of “upper sand and lower mud” (①-④ in Fig. 4-2) and “upper gravel and lower mud” when the fault is closed. Fault–unconformity transport allows hydrocarbons accumulate above the unconformity surface at the bottom of Ng and even the structural trough above the surface has the potential to accumulate oil and gas (①-② in Fig. 4-2).
5. Conclusions

Due to the multi-stage tectonic movements, a superimposed pattern of Paleozoic basement buried hill and Cenozoic fault-step slope in Chengbei Fault Zone was developed on the North China platform. The transport characteristics vary in different parts of Chengbei Fault Zone. Fault-sand transport is the dominant migrated path for the middle and low slopes, while fault–unconformity transport is the main hydrocarbon pathway for the southern high slopes and the underlying buried hills. The fault–unconformity composite system could transport oil or gas towards the distal slope and into strata below the source rocks, bringing about the accumulation style of multi-layer and multi-type hydrocarbons. Hydrocarbons in Paleozoic Chenghai buried hill and Cenozoic high slope tend to accumulate heterogeneously on a large scale in the developed parts of faults and weathering denudation surfaces.

The typical geological models of fault–unconformity composite system were built and the filling efficiency and mechanism of oil through them were discussed accordingly. Above the unconformity surface of Guantao Formation in Southern high slope, or below the unconformity surface of Paleozoic and Mesozoic in Chenghai buried hill, the hydrocarbon are both accumulated. The reservoir-forming simulation experiments prove that the negative tectonics or structural troughs above and below the unconformity surface both have potential to form reservoirs, which is expected to provide a new guidance for oil and gas exploration in faulted basins to a degree.

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