Hydrocarbon occurrence characteristics and charging differences in Chengbei Fault Zone based on fluid inclusions

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Abstract: Hydrocarbon accumulates in multiple layers of the high, middle and low parts of Chengbei fault zone, in vicinity of Qikou Sag and Qinan Subsag, which represents a breakthrough for large-scale hydrocarbon exploration in recent years. Based on the size, abundance, and attitude of hydrocarbon inclusions, as well as their microscopic polarization and fluorescence characteristics, the hydrocarbon occurrence and the charging difference in the high, middle and low faulted terraces were analyzed systematically in this paper. There are two types of occurrence in the intergranular pores and fractures in the reservoirs, namely, the medium to light oil that shows green fluorescent light, and the solid bitumen charged with a certain amount of hydrocarbon that does not show any fluorescent light. This indicates that the zone has experienced at least two stages of hydrocarbon migration and accumulation, and that diversified forms of hydrocarbon exist in the reservoirs of the zone. The characteristics of hydrocarbon inclusions show that two stages of inclusions were found in the tectonic positions of different faulted terrace. The first-stage inclusions were developed in the early secondary enlargement of quartz grains, with a low degree of development abundance; while the second-stage inclusions were developed after the secondary enlargement of quartz grains, with a high degree of development abundance. The second-stage hydrocarbon inclusions of the reservoir samples obtained at tectonic positions of the high, middle and low fault terrace represent the main filling stage of the present-day reservoirs. Their fluorescence characteristics demonstrate the oil charging difference, which is the maturity of the hydrocarbon decreases as the terraces lift up along the slope. Identifying the hydrocarbon occurrence and charging differences from the perspective of inclusions is conducive to recognizing the regularity of hydrocarbon charging and migration and the distribution patterns in fault terrace zones, and lay the foundation for hydrocarbon exploration of slopes in the future.

Keywords: fluid inclusion; hydrocarbon occurrence characteristics; charging differences

1. Introduction

As the major breakthrough area for large-scale oil and gas exploration in recent years in Huanghua Depression in Bohai Bay Basin(1-5), Chengbei Fault Zone is characterized by two main hydrocarbon supply directions from Qikou Sag and Qinan Subsag, which has experienced many stages of oil and gas filling. Important information has been discovered in the zone about many hydrocarbon reservoirs or hydrocarbon migration and accumulation in Shahejie Formation(ES) and Dongying Formation(Ed) of Paleogene, and in Guantao Formation(Ng) and Minghuazhen Formation(Nm) of Neogene and in
multiple Mesozoic and Paleozoic layers\textsuperscript{[2-6]}. The zone is characterized geologically by multiple sets of source rocks, various kinds of drainage systems (such as faults, sand bodies, unconformities), and varied sets of reservoirs, resulting in diverse hydrocarbon occurrences in layers in faulted terraces, complex charging characteristics and unclear hydrocarbon distribution regularity. Previous studies mainly applied methods such as inclusion description and quantitative grain fluorescence to get to know the characteristics of hydrocarbon occurrence in reservoirs, only focusing on a certain fault zone, without systematic comparison of hydrocarbon occurrence in the high, middle and low fault terraces\textsuperscript{[6-11]}. Especially the study on characteristics difference in hydrocarbon charging is insufficient\textsuperscript{[9-11]}. Given this, the paper has analyzed the hydrocarbon occurrence status and charging difference based on the occurrence, abundance, and fluorescence characteristics of hydrocarbon inclusions, by selecting typical wells at different tectonic positions in the Chengbei Fault Zone, so as to provide reference for research on hydrocarbon accumulation in fault terrace zones and the future exploration.

2. Geological setting

Chengbei Fault Zone, situated in the south of the Qikou Sag and featured with a general north-east trend, consists of two-order faults including Yangerzhuang Fault, Zhangdong Fault, Zhaobei Fault (Fig. 1). These faults have experienced subsidence progressively from the south to the north, forming a stratum high in the south and low in the north. The part in the south of Yangerzhuang Fault and Zhaobei Fault is the high terrace; that between Zhangdong Fault and Zhaobei Fault is a middle terrace; and that between Zhangdong Fault and Qidong Fault is the low terrace. Representative drilling samples (4 wells) selected at different tectonic positions of the high, middle and low fault terraces are analyzed in detail to clarify the hydrocarbon occurrence characteristics and charging differences in this zone.

3. Hydrocarbon occurrence characteristics in reservoirs

The pore fluorescence observation and microlithology study of sandstone samples obtained at different tectonic positions (i.e. the high, middle and low fault terraces) in Chengbei Fault Zone indicate that there are mainly two types of occurrence in the intergranular pores and fractures of the Ed–Es3 sandstone reservoir in this zone. One is the medium to light oil in the pores, showing green fluorescent light; and the other is the solid bitumen charged with a certain amount of hydrocarbon in the early stage, which doesn’t show fluorescent light. These two types of occurrence in pores indicate that this zone has experienced at least two stages of hydrocarbon migration and accumulation, and demonstrate that diversified hydrocarbon forms exist in the reservoirs (Fig. 2).
The further observation of the characteristics of hydrocarbon inclusions revealed that all fault terraces (i.e. the high, middle and low parts) show two-stage inclusions, and two types of hydrocarbon occurrence attitudes are identified as follows: 1. The first-stage inclusions were developed in the early stage of secondary enlargement of quartz grains during diagenesis, with a low degree of development abundance (GOI is 4-5%±). These inclusions are distributed in linear/belt shapes along the micro-fractures in the diagenesis period of the quartz grains. 2. The second-stage inclusions were developed after the secondary enlargement of quartz grains during diagenesis, with a high degree of development abundance (GOI: 8-35%±). These inclusions were distributed in linear/belt shape along micro-fractures posterior to the diagenesis period which cut through the quartz grains; or in groups and belts under dissolution in feldspar grains; or isolated in the late calcsparite cements (Fig. 3).
As can be inferred from the occurrence and fluorescence characteristics of inclusions, the solid bitumen distributed in the granular pores is evolved from accumulation formed by first-stage hydrocarbon charging of the sandstone reservoirs in the zone, (and are mostly the early paleo-reservoirs); and light crude oil in the pores, which has fluorescence characteristics very similar to those of the second-stage hydrocarbon inclusions, is therefore believed to be the accumulation formed by large-scale charging in the late recent period, which is the main body of the existing hydrocarbon reservoirs.

4. Hydrocarbon charging differences in reservoirs

It can be seen from the fluorescence characteristics of the second-stage hydrocarbon inclusions (representing the main body of the existing reservoir) in reservoir samples from the representative wells at three different tectonic positions, namely the low, middle and high fault terraces, that the hydrocarbon inclusions in reservoirs near sags (as exemplified by Well Qidong 3-1) show primarily blue, blue-green and yellow-green fluorescent light, representing a large amount of light oil and gas formed in the late middle and high maturity stage of the source rocks of Member 3 of Shahejie Formation; and meanwhile a few hydrocarbon inclusions show yellow and brown-yellow fluorescent light, which are formed by low-maturity source rocks in the Es1 member or Ed formation. The hydrocarbon inclusions in the low and middle fault terrace (as exemplified by Wells Zhanghai 6 and Zhangchan 1-1) show mainly green, blue-green, yellow-green and green-yellow fluorescent lights, which is sizeable light hydrocarbon formed in the late middle and high maturity stage of the source rock of Member 3 of Shahejie Formation; and a handful of low-maturity oil inclusions emitting dark-brown fluorescent lights can be found in Well Zhangchan 1-1, whose hydrocarbon accumulation is due to the low-maturity source rocks in the Es1 member or Ed formation as well. The hydrocarbon inclusions in the high fault terrace (as exemplified by Well Chenghai 16) radiate mainly light yellow and dark-brown fluorescent lights. This fully reflects the characteristic that in the Chengbei Fault zone, the hydrocarbon composition maturity gradually decreases as the fault terraces lift up (Table 1).

| Position  | Well name | Charging differences | Rock slice observation | Hydrocarbon maturity |
|-----------|-----------|---------------------|------------------------|---------------------|
| Near sag  | Qidong 3-1| Second stage inclusions (light oil in existing pores): Hydrocarbon charging differences. | Es1: 3683.5m Gas-liquid hydrocarbon inclusions showing blue-green fluorescent light, distributed in groups in feldspar grains; and a small amount of hydrocarbon inclusions emitting yellow and brown-yellow fluorescent lights | Both medium-high maturity, and low maturity oil charging |
|           |           |                     | Ed: 2576m Liquid hydrocarbon, gas-liquid hydrocarbon |
| Fault Terrace          | Location       | Second Stage Inclusions | Exposition | Description                                                                 |
|-----------------------|----------------|-------------------------|------------|-----------------------------------------------------------------------------|
| Low fault terrace     | Zhanghai 6     | Second stage inclusions (light oil in existing pores): Hydrocarbon inclusions mainly showing blue, blue-green and yellow-green fluorescent lights | 3753.26m   | Liquid and gas-liquid hydrocarbon inclusions showing green and blue fluorescent lights distributed in groups in feldspar grains with dissolution origin |
| Middle fault terrace  | Zhangchan 1-1  | Second stage inclusions (light oil in existing pores): Hydrocarbon inclusions mainly showing blue, blue-green and yellow-green fluorescent lights; and a small amount of hydrocarbon inclusions giving off yellow and brown-yellow fluorescent lights | 3500m      | Gas-liquid hydrocarbon inclusions showing green fluorescent light, isolated in sandstone calcite cements |
| High fault terrace    | Chenghai 16    | Hydrocarbon inclusions mainly showing light yellow and dark-brown fluorescent lights | 1335m      | Gas-liquid hydrocarbon inclusions showing dark-brown fluorescent light, distributed along the micro-fractures posterior to the quartz grains diagenesis period |

### 5. Conclusions

Two types of occurrence exist in the intergranular pores and fractures in sandstone reservoirs at different positions of fault terraces (the high, middle and low parts) in Chengbei Fault Zone: the medium to light oil that shows green fluorescent light; and the solid bitumen charged with a certain amount of hydrocarbon that doesn’t show any fluorescent light. This reveals that the zone has experienced at least two stages of hydrocarbon migration and accumulation, and that diversified forms
of hydrocarbon exist in the reservoir layers of this zone.

The characteristics of the reservoir hydrocarbon inclusions demonstrate that two stages of inclusions exist at different positions of fault terraces (the high, middle and low parts). The first-stage inclusions were developed in the early stage of the secondary enlargement of quartz grains during diagenesis, with a low degree of development abundance, and all these inclusions were distributed in linear/belt shapes along the micro-fractures in the diagenetic period of the quartz grains. The second-stage inclusions were developed after the secondary enlargement of quartz grains during diagenesis, with a high degree of development abundance.

The fluorescence characteristics of the second-stage hydrocarbon inclusions (the main body of the present-day hydrocarbon reservoir) of reservoir samples in the representative wells at three different tectonic positions of the low, middle and high fault terraces testifies to the differences that the maturity of hydrocarbon lowers gradually as fault terraces lift up along Chengbei Fault Zone.

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