PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 44, Issue 1, February 2017
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2017, 44(1): 48–57.

RESEARCH PAPER

Densification and hydrocarbon accumulation of Triassic Yanchang Formation Chang 8 Member, Ordos Basin, NW China: Evidence from geochemistry and fluid inclusions

FU Jinhua[1, 2, *], DENG Xiuqin[1, 2], WANG Qi[3], LI Jihong[1, 2], QIU Junli[3], HAO Lewei[3], ZHAO Yande[1, 2]

1. National Engineering Laboratory for Exploration and Development of Low-Permeability Oil & Gas Fields, Xi'an 710018, China;
2. PetroChina Changqing Oil Field Company, Xi'an 710018, China;
3. Institute of Geology and Geophysics, Chinese Academy of Sciences, Lanzhou 730000, China

Abstract: Crushing, acid treatment and step wise separation and oil extraction were employed to obtain the different occurrence state hydrocarbons. All these fractions have been analyzed by Gas Chromatography-Mass Spectrometer (GC-MS). The fractions relationship and related oil charging process can be mirrored through the analysis of fractions weight content and geochemical characteristics, in combination with the research of inclusions homogenization temperature and fluorescence spectrum parameters. Experimental results reveal that there are four state hydrocarbons, i.e. free hydrocarbon, sealed hydrocarbon, hydrocarbon in carbonate cement, and hydrocarbon within inclusions caught by quartz grains and feldspar grains in the oil-rich sandstones of Chang8 Member, Triassic Yanchang Formation in the Ordos Basin. Among them, the overwhelming fraction is the free hydrocarbon, averaged 93.4%. Fluorescence spectrum parameters of λ_{max}, QF_{535} and $Q_{650/500}$ show that the crude oil maturity of the inclusions imprisoned in feldspar, quartz, and carbonate cement increase in turn, and the parameter values of the inclusions in feldspar and quartz are similar and much different from those of carbonate cement. Through analysis of $C_{29}\beta\beta/(\alpha\alpha+\beta\beta)$ and $C_{29}20S/(20S+20R)$, together with methylphenanthrene ratio, it is revealed that thermal-evolutionary degree of the hydrocarbon within inclusions, hydrocarbon in carbonate cement, sealed hydrocarbon, free hydrocarbon reflects an upward trend, and the data of the last two type are similar. Integrated study of diagenetic sequence and thermal evolutionary degree suggest that the Chang 8 sandstones had been compacted before reservoir formation and the reservoirs have experienced three phase of charge events in which the third one played the most important role for reservoir formation.

Key words: Ordos Basin; Triassic; Yanchang Formation; hydrocarbon occurrence; charge period; major reservoir forming phase; tight reservoir

Introduction

In recent years, great breakthroughs have been made in tight oil & gas exploration in Triassic Yanchang Formation, Ordos Basin, marked by the discovery of a series of tight oil fields, including Xifeng, Jiyuan, Huaqing oilfields etc. Previous studies have covered different aspects related to the geological conditions, main control factors and forming mechanism of the tight oil fields[1−7], and, these works mainly focused on the migration and accumulation of the oil & gas in the low-permeable reservoirs as well as the time sequence of the reservoir tightening and pool formation. Different researchers gave their own viewpoints on these questions, e.g. Luo et al., based on his research on diagenetic process and reservoir tar, suggested that the oil-charging before the reservoir tightening had changed the reservoir's wettability, and the residual oil-pro pathway network provided favorable conduit for oil and gas migration and accumulation[3]; Ren et al. pointed out that the tight oil was formed under the overall tightness background according to several lines of evidence from inclusion temperature, K-Ar dating and saturation pressure analytical data, and so on[4]; On the contrary, Liu et al. believed that the Yanchang reservoir could not be infilled by oil under the tight state based on the fluorescence examination on inclusion, simulation on porosity evolution and oil-charging critical experiment, and concluded that Yanchang oil- pool could only be formed before the reservoir densified through inference[5]. To sum up, there is no consensus on the order of Yanchang sandstone tightening and oil-pool formation. In view of this, the forming process of Yanchang tight

Received date: 24 Dec. 2015; **Revised date:** 18 Dec. 2016.
*** Corresponding author.** E-mail: fjh_cq@petrochina.com.cn
Foundation item: Supported by the China National Science and Technology Major Project (2016ZX05050; 2011ZX05001-004).

reservoir has been analyzed by using stepwise extraction and fluorescence examination on oil inclusions, to find the time sequence of densification of Yanchang Formation sandstone and pool formation, and get a clear understanding on the forming mechanism of Yanchang Formation tight oil reservoir.

1. Geological setting

A giant inland depression lacustrine basin developed in Ordos area during the middle and late Triassic, where a successive clastic sequence of Yanchang Formation deposited, with a thickness of approximately 1 000 meter. There are large scale low-permeable lithological and tight oil pools in Yanchang Formation after over 200 million years of structural and diagenetic transformation. Yanchang Formation can be classified in 10 members, Chang 1 to Chang 10 from bottom to top, of which the Chang 7 Member, the deposits of maximum flooding, with abundant organic matter, is the major source rock in the Mesozoic of Ordos Basin. The Chang 8 Member, below Chang7 Member, is shallow lacustrine deltaic deposits with well-developed distributary and sub-distributary channel sandbodies widespread, stable in spatial distribution, and thick in main sandbody zone[8]. The reservoir rock of Chang 8 Member is mainly fine grained sandstone, intense compaction and carbonate cementation have caused its poor physical properties (porosity from 5.2% to 12.2%, and permeability from 0.02×10^{-3} to 5.02×10^{-3} μm^2)[9]. Although Chang8 Member is poorer in physical property, the overlying Chang7 Member had a pressure coefficient of 1.2−1.7[10–11] at the maximum palaeoburial depth, there was quite large pressure difference between Chang 7 and Chang 8 Member, which can drive oil migration downward, thus, the Chang 8 sandstone reservoir is universally oil-bearing and large in reserve scale.

2. Sampling and experiments

Stepwise (or sequential) extraction of hydrocarbon in reservoir rock is a novel analysis technique of micro-geochemistry of oil and gas pool developed in recent years[12–15]. Its theoretical basis is that the maturity of hydrocarbons in reservoir, no matter where they are originated from the same source bed or not, will change somewhat in the process of migration and accumulation, and, therefore, it can be utilized to determine the hydrocarbon source in oil-bearing reservoir rock and oil-pool forming periods.

2.1. Separation of hydrocarbons in different occurrence states

First of all, 86 oil-bearing sandstone samples were chosen to make thin sections to check their fluorescence features. Four sandstone samples from Well Q22, X231, H115 and M51 (Fig. 1) were selected for stepwise extraction according to their oil content. These four samples have a porosity of 6.7%, 8.1%, 9.1% and 8.5%, and mean grain size of 3.53, 2.57, 2.44 and 2.7, respectively. Secondly, hydrocarbons in the samples were extracted by crushing, acid processing and Soxhlet extraction methods sequentially. Four kinds of hydrocarbon have been successfully separated, including free oil, sealed oil, inclusion oil in carbonate cement (cement oil for short hereafter), and inclusion oil in quartz and feldspar grains (inclusion oil for short hereafter). The experimental flowchart is described as follows (Fig. 2):

Step 1. Free oil separation. Free oil was obtained by Soxhlet extraction method using dichloromethane–methyl alcohol solution (volume ratio 93 : 7) to rinse oil sandstone samples after crushing them into 0.5−1.5 cm in grain size. Free oil stands for the hydrocarbon in open porous system of the reservoir rock.

Step 2. Sealed oil separation. The residual sandstone samples after Soxhlet extraction were re-crushed into single clastic grains by gentle manner. To control the separation of rock framework grains, microscope was used to examine the crushed sample grain size and those fragments with grain size less than the single clastic grain were sieved out in order to eliminate the released inclusion oil during crushing. And then the processed samples were extracted by dichloromethane–methyl alcohol solution (volume ratio 93 : 7) to obtain the sealed oil, which is the hydrocarbon preserved in unconnected pores.

Step 3. Cement oil separation. Cement oil is defined as the hydrocarbon enclosed in carbonate cement. The remained samples after the extraction of the sealed oil were dissolved by 6% chloride acid to remove carbonate cement, and extracted by dichloromethane–methyl alcohol solution (volume ratio 93:7) to get cement oil.

Step 4. Inclusion oil separation. The remained samples after Step 3 were rinsed by distilled water to neutral, and, furthermore, processed by potassium dichromate-concentrated sulfuric acid solution and hydrogen peroxide, and then, these samples were re-extracted by dichloromethane–methyl alcohol solution (volume ratio 93 : 7) to clean out surficial hydrocarbon. Finally, these samples were grinded in dichloromethane–methyl alcohol solution (volume ratio 10:1) to extract the hydrocarbon enclosed in single quartz or feldspar grains. The obtained hydrocarbon is called inclusion hydrocarbon.

2.2. Hydrocarbon component analysis

Firstly, weighed the separated hydrocarbons of different occurrence states. Secondly, asphaltene was precipitated using n-hexane for all hydrocarbons (excepting hydrocarbon in cement and hydrocarbon in inclusions). And then the saturated hydrocarbons and aromatic hydrocarbons fractions were obtained using column chromatography (Silica gel - alumina, v:v 4 : 1). At last, all these fractions were analyzed by GC-MS. GC–MS was performed using an Agilent Technologies HP6890N gas chromatograph coupled to a HP5973 Network mass selective detector. GC conditions were: Separation was achieved using fused silica capillary column J&WHP-5 (30