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Research paper

Utility of GOI, QGF, and QGF-E for interpreting reservoir geohistory and oil remigration in the Hudson oilfield, Tarim basin, northwest China

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ABSTRACT

The physical mechanisms responsible for hydrocarbon migration in carrier beds are well understood. However, secondary migration is one of poorly understood facets in petroleum system. The Carboniferous Donghe sandstone reservoir in the Tarim Basin's Hudson oilfield is an example of a secondary (or unsteady) reservoir; that is, oil in this reservoir is in the process of remigration, making it a suitable geologic system for studying hydrocarbon remigration in carrier beds. Experimental methods including grains containing oil inclusions (GOI), quantitative grain fluorescence (QGF) and quantitative grain fluorescence on extract (QGF-E) – together with the results from drilling, logging and testing data – were used to characterize the nature of oil remigration in the Donghe sandstone. The results show that (1) significant differences exist between paleo- and current-oil reservoirs in the Donghe sandstone, which implies that oil has remigrated a significant distance following primary accumulation; (2) due to tectonic inversion, oil remigration is slowly driven by buoyancy force, but the oil has not entered into the trap entirely because of the weak driving force. Oil scarcely enters into the interlayers, where the resistance is relatively large; (3) the oil-remigration pathway, located in the upper part of the Donghe sandstone, is planar in nature and oil moving along this pathway is primarily distributed in those areas of the sandstone having suitable properties. Residual oil is also present in the paleo-oil reservoirs, which results in their abnormal QGF-E. A better understanding of the characteristics of oil remigration in the Donghe sandstone in the Hudson oilfield can contribute to more effective oil exploration and development in the study area.

1. Introduction

The physical mechanisms controlling secondary hydrocarbon migration in carrier beds are well understood (Schowalter, 1979; England et al., 1987; England, 1994; Hao et al., 2007). Buoyancy and capillary resistance, respectively, drive and restrain secondary migration, while groundwater flow may do either (England et al., 1987; Hindle, 1997). In recent years, however, opinions regarding the nature of migration pathways have been divided along two schools of thought (Hao et al., 2007). Supporters of the "restraining-force" school of thought argue that pathways are planar in nature and controlled by the heterogeneous permeability of the carrier beds (Rhea et al., 1994; Bekele et al., 2002). Others who support the "driving force" school of thought argue that migration pathways are similar in nature to restricted rivers or streams controlled by the structural morphology of the carrier beds (Gussow, 1968; Momper and Williams, 1984; Dembicki and Anderson, 1989; Catalan et al., 1992; Pratsch, 1986; Thomas and Clouse, 1995; Hindle, 1997, 1999; Xu et al., 2014; Xu et al., 2016).

Research on secondary hydrocarbon migration has a great significance to hydrocarbon exploration (Hindle, 1997, 1999; Mann, 1997; Li, 2000; Bekele et al., 2002; Hao et al., 2007). Secondary hydrocarbon migration is a process that occurs over geologic time. At present, and in spite of few case examples, the most effective

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methods for studying hydrocarbon migration is through experimentation (Dembicki and Anderson, 1989; Catalan et al., 1992; Thomas and Clouse, 1995; Zeng and Jin, 2003) and numerical simulation (Hubbert, 1953; Lehner et al., 1988; Ungerer et al., 1990; England et al., 1987; Sylta, 1991; Hindle, 1997; Hao et al., 2007; Luo, 2011; Xu et al., 2016).

A hydrocarbon reservoir produced by the continuous generation, migration and accumulation of hydrocarbons is called a primary reservoir (Ping and Chen, 2009; Zhu et al., 2013a, 2013b). The remigration of hydrocarbons from a pre-exiting primary reservoir produces a secondary reservoir (Silverman, 1965; Zhu et al., 2013a, 2013b). Secondary reservoirs have been widely developed in the Tarim Basin in northwest China (Zhu and Zhang, 2009; Zhu et al., 2010, 2013b). The Donghe sandstone in the Hudson oilfield comprises such a secondary oil reservoir where oil remigrating from the northwestern paleo-oil reservoirs entered the sandstone post-Permian age (He et al., 2001; Li, 2006; Xu et al., 2008; Su et al., 2011; Zhou et al., 2013; Zhu et al., 2013b). Because oil continues to remigrate into the Donghe sandstone, it is also called an “unsteady reservoir” (Jiang et al., 2008; Sun et al., 2008, 2009; Yang et al., 2012). As such, this reservoir serves as an excellent geologic system for studying hydrocarbon remigration characteristics, as well as for determining the distribution of oil in the study area itself.

This paper compares the differences between the paleo- and current-oil reservoirs using GOI, QGF and QGF-E experiments. The study also analyzes the driving and restraining forces associated with oil remigration and describes the distribution of oil in the Donghe sandstone.

2. Geologic setting

2.1. General geology

The Hudson oilfield is located in the transitional zone between the Manjar Depression and the Tabei Uplift in the Tarim Basin, Northwest China (Fig. 1a and b). The oilfield includes parts of the Halahatang Depression, the Lunnan Low Uplift and the Manjar Depression (Fig. 1c). The Donghe sandstone in the study area is deformed into a low-amplitude anticlinal structure formed during the Himalayan movement (Sun et al., 2009). Although the structure has undergone significant tectonism, it has a simple tilted deformation with an absence of faults (Jia, 1997; He and Li, 1996; Zhao et al., 2002; Xu et al., 2008).

The strata in the study area include Paleozoic-, Mesozoic- and Cenozoic-aged units, but Devonian and Upper Silurian rocks are absent (Fig. 2). The Carboniferous-aged Donghe sandstone, which is the primary target for petroleum exploration, consists of sandy shore deposits (Li et al., 2008). The bottom of the sandstone is marked by an overlap unconformity and the top by an erosional unconformity (Li, 2006).

2.2. Characteristics of the oil reservoir

The Donghe sandstone in the Hudson oilfield is comprised of a wedge-shaped body of stable-shore sandstone facies (Fig. 3) with some unique and complex characteristics. First, the water-oil contact interface is inclined (Sun et al., 2009; Yang et al., 2012), with an elevation difference of 186 meters between the northwest and the southeast corners of the interface (Fig. 4). Second, although the trap in the Donghe sandstone is located in the southeast part of the oilfield, the oil reservoir itself is located more to the northwest (Fig. 5). Finally, the properties of the oil in the Donghe sandstone vary in different regions. Oil density in the northwest is relatively high, and decreases gradually to the southeast. Saturated hydrocarbons and hydrocarbon/aromatic hydrocarbon ratios in the oil increase from the northwest to the southeast, whereas asphaltenes decrease in the same direction.

2.3. Primary accumulation and preservation conditions of the oil reservoir

Oil in the Donghe sandstone reservoir originated from Middle-Upper Ordovician source rocks in the south part of the study area (Zhang and Huang, 2005; Zhang et al., 2005; Su et al., 2011; Zhu et al., 2013a). K-Ar isotopic dating of authigenic illites suggests that oil first accumulated in the reservoir is Late Hercynian -Early Indosinian (Zhao et al., 2002; Zhao and Tian, 2002; Zhang et al., 2004; Zhu et al., 2013a), consistent with the timing of hydrocarbon generation in the source rocks (Su et al., 2011; Zhu et al., 2013a). Oil generated from the Middle-Upper Ordovician source rocks in the southern part of the study area became entrapped in the Donghe sandstone in the northwestern part of the study area during Late Hercynian-Early Indosinian time, after which the primary Donghe sandstone oil reservoir was formed (Li, 2006; Xu et al., 2008; Sun et al., 2008; Su et al., 2011; Zhou et al., 2013 Zhu et al., 2013a).

The strata which overlie the Donghe sandstone are sequentially comprised of breccias and mudstones (Fig. 4). These strata exhibit poor physical properties with stable thicknesses. The calcium chloride type formation water in the Donghe sandstone is highly saline (Lin et al., 2012; Zhu et al., 2013a), characteristics which favor preservation of the reservoir following primary accumulation.

3. Samples and methods

One hundred thirty-six samples of the Donghe sandstone were collected from seven wells with depths ranging from 5068.4 to 5719.1 m. Forty-seven of the samples were analyzed using the grains containing oil inclusions (GOI) experimental method (Table 1). The other eighty-nine samples were analyzed using the quantitative grain fluorescence (QGF) and quantitative grain fluorescence on extract (QGF-E) experimental methods (Table 2).

GOI analysis is a point counting technique that measures the abundance of quartz and feldspar grains containing oil-bearing fluid inclusions in the sandstone samples. Results from the Donghe samples can be compared to those previously determined from other existing oil fields to determine the extent of oil saturation in the Donghe samples in the geological past (Lisk and Eadington, 1994; Eadington et al., 1996; Lisk et al., 2001; George et al., 2004).

A single gram of sandstone is typically used in QGF and QGF-E experiments using a Varian Cary-Eclipse spectrophotometer. QGF and QGF-E analyses were used to conduct measurements on reservoir grains and solvent-extractable hydrocarbons once the samples had been cleaned by a standard procedure. The cleaning procedure used solvent (dichloromethane), hydrogen peroxide and hydrochloric acid to remove drilling contaminants, clay particles, carbonate minerals and loosely-bound organic or hydrocarbon compounds (Liu and Eadington, 2005; Liu et al. (2007). The following parameters were used to characterize QGF results: QGF Index, QGF Total Intensity, Lambda-Max (λ max) and Delta Lambda ($\Delta\lambda$). QGF-E results were characterized using the Maximum Intensity (I max) and Lambda-Max (λ max) parameters as described by Liu et al. (2007). The QGF method detects the presence of paleo-oil in the samples, while the QGF-E method detects the presence of current oil (Liu and Eadington, 2005).

Additional information used in this study was collected from the Tarim Oilfield Company of PetroChina. This included information on the thickness, tectonic evolution, interlayer characteristics and