Marine and Petroleum Geology 78 (2016) 1–16

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Fluid evolution in the Dabei Gas Field of the Kuqa Depression, Tarim Basin, NW China: Implications for fault-related fluid flow

Xiaowen Guo [a, *], Keyu Liu [b, c, **], Chengzao Jia [c], Yan Song [c, d], Mengjun Zhao [c], Qingong Zhuo [c], Xuesong Lu [c]

[a] *Key Laboratory of Tectonics and Petroleum Resources (China University of Geosciences), Ministry of Education, Wuhan 430074, China*
[b] *China University of Petroleum (Huadong), Qingdao, Shandong 266580, China*
[c] *Research Institute of Petroleum Exploration and Development, PetroChina, Beijing 100083, China*
[d] *China University of Petroleum, Changping, Beijing 102249, China*

ARTICLE INFO

Article history:
Received 7 July 2015
Received in revised form
8 January 2016
Accepted 31 August 2016
Available online 7 September 2016

Keywords:
Fault-related fluid flow
Hydrocarbon charge history
Fluid evolution
Fluid inclusion
Dabei Gas Field
Kuqa Depression

ABSTRACT

A series of fault-related folds developed in the Dabei Gas Field of the Kuqa Depression, western China form major traps for hydrocarbon accumulation. The Bashijiqike (K_1bs) sandstone reservoirs in the different fault-related folds of the Dabei Gas Field display similar excess fluid pressure, formation water type and salinity, and as well as light oil and gas properties. The light oil and gas in the K_1bs sandstone reservoir of the traps share the same source and were generated at a thermal maturity level of 1.4–1.6% R_o and 1.7–2.3% R_o, respectively. To investigate the fluid evolution in the fault-related fold traps, an integrated fluid inclusion analysis was performed including petrography, fluorescence spectroscopy, microthermometry, Laser Raman spectroscopy and thermodynamic modeling. The fluid evolution recorded by the fluid inclusions in the different fault-related folds indicates that the formation fluid was characterized by low salinity at normal hydrostatic pressure from approximately >9–5 Ma. From 5 to 3 Ma the formation water salinity and fluid pressure increased rapidly. The formation water attained the highest salinity at approximately 3 Ma to present while the pore fluid overpressure decreased with time in the reservoir. Two episodes of oil and one episode of gas charge were identified in the K_1bs sandstone reservoir with the second episode of oil charge occurring around 5–4 Ma, while the gas charge occurred around 3–2 Ma. The injection of new fluids associated with oil and gas charge caused changes of the formation water salinity in the different fault-related fold traps within the gas field. The fluid evolution in the Dabei Gas Field can be used to indicate fault-related fluid flow as the thrust faults are suggested to be the primly pathways for fluid migration and the fluid flow was controlled by the reactivation of these thrust faults. The similarity of the oil and gas charge histories, formation water salinity and fluid pressure evolution in the K_1bs sandstone reservoirs among the different fault-related traps in the Dabei Gas Field implies that the fault-related fluid flow process and activation of the thrust faults were concomitant since approximately 9 Ma.

1. Introduction

Sediment matrix and formation fluids are the two major components of a sedimentary basin. Over the geologic evolution, fluids can transmit heat, facilitate faulting, and transport or concentrate potentially economic minerals and hydrocarbons (Cooley et al., 2011). Investigation of fluid evolution in petroliferous basins is thus critical in understanding petroleum migration and accumulation and can help to predict the distribution of petroleum resources. Fluid flow in a particular region is often observed to be controlled by structural and stratigraphic features such as faults, salt diapirs, erosional surfaces, diagenetic zones, stratigraphic boundaries and permeable sand bodies (e.g. palaeo-channels) within the sedimentary strata (Gay et al., 2007; Weibull et al., 2010; Chand et al., 2011; Naudts et al., 2012). Diagenetic and petrophysical characteristics are two essential parameters in understanding fluid flow characteristics through time within sandstone

---

* Corresponding author.
** Corresponding author. China University of Petroleum (Wuhan), Wuhan, Hubei 430074, China.
E-mail addresses: cuggxw@163.com (X. Guo), keyu_liu@icloud.com (K. Liu).

http://dx.doi.org/10.1016/j.marpetgeo.2016.08.024

reservoirs (Mazzini et al., 2003; Jonk et al., 2005, Jonk, 2010; Scott et al., 2013). However, it is a challenge to constrain the absolute timing of the diagenetic events typically seen in reservoirs (Dewever et al., 2010). Fluid inclusion analysis allows the history of a fluid trapped and preserved in relation to its host mineral to be reconstructed as they can provide valuable information on the reservoir fluid pressure and temperature at the time of the fluid migration and entrapment as well as on the compositions of the fluids involved in diagenesis (Burruss, 1987). Fluid inclusion data are particularly useful in determining (1) the thermal and burial history (Burruss, 1989; Swarbrick, 1994; Aplin et al., 2000); (2) the timing of petroleum migration/entrapment relative to the paragenesis (Mclimans, 1987; Rezaee and Tingate, 1997) and the history of petroleum charge (Oxtoby et al., 1995; Lisk et al., 1998; Parnell, 2010), including migration pathways, petroleum types, and sources (Karlsen et al., 1993); and (3) the evolution of pore-water compositions, which may be critical for evaluating the possible influence of fluid flow upon mineral cementation (Burley et al., 1989; Wilkinson et al., 1998; Hartmann et al., 2000). The absolute timing of fluid inclusions trapped can be determined by incorporating the thermal history modeling with the aqueous fluid inclusion homogenization temperature data as the fluid trapping temperature can normally be approximated by using the aqueous fluid inclusion homogenization temperature data, provided the fluid (brine) is saturated with CH_4 (Nedkvitne et al., 1993).

The Dabei Gas Field, located in the western part of the Kelasu Thrust Belt in the Kuqa Depression (Fig. 1C) contains a series of fault-related folds that form hydrocarbon traps. Fault zones can act either as barriers or conduits for fluid flows (Anderson et al., 1995). The thrust faults in the Dabei Gas Field are suggested to have been acting as major migration pathways for hydrocarbons (Zhang et al., 2011) as intense tectonic compression caused thrust fault reactivation and periodic opening of the fault (Zeng, 2010). The fluid evolution is believed to have been controlled by the fault activation in the Dabei Gas Field as new fluids can be charged into the fault-related traps to alter the pore fluid compositions and pressure when the faults were open. The objectives of this paper are to: (1) investigate the hydrocarbon charge history of the Dabei gas Field through fluid inclusion analysis; (2) determine paleo-fluid pressure and salinity using fluid inclusion microthermometry, Laser Raman spectroscopy coupled with thermodynamic modeling; (3) document fluid evolution in different fault-related traps in the Dabei Gas Field via pore fluid salinity and pressure evolution, and its implications for thrust fault-related fluid flow.

2. Geologic setting

The Tarim Basin in northwest China is an important hydrocarbon-producing basin bordered by the Tianshan Mountain to the north and the Kunlun and Altun mountains to the south (Jia, 2004), and covers an area of approximately 560,000 km^2 (Fig. 1A). The Kuqa Depression is a Mesozoic-Cenozoic basin developed in the northern Tarim Basin near the foothills of the South Tianshan Mountains (Fig. 1B). It is a major petroliferous area of the Tarim Basin (Jia and Wei, 2003). The basin is characteristic of a peripheral foreland basin (Jia, 1992; Wang et al., 1994; Chen et al., 1996a; Tang, 1996; Tian, 1996; Tian et al., 1996) or a collisional successor foreland basin (Hendrix et al., 1992; Graham et al., 1993). The basin was developed from the Late Permian through to the Holocene. The Kuqa Depression is bounded to the north by the South Tianshan Mountains and to the south by the Northern Tarim uplift. The tectonic evolution for this basin can be divided into three stages: a peripheral foreland basin stage, an extensional rift basin stage and a rejuvenated foreland basin stage (Graham et al., 1993). Numerous thrust faults and related folds are present in The Kuqa Depression (Fig. 1D), displaying intense compressional deformation. Spatially the Kuqa Depression comprises six tectonic units, namely, the Northern Monocline belt, the Klasu-Yiqiklik structural belts, the Baicheng-Yanxia sags; the Qiulitag thrust belt, the Southern Gentle Slope and the Wushi Sag (Fig. 1C) (Lei et al., 2007). The Wushi Sag, Baicheng Sag and Yangxia Sag are important structural units for the development of hydrocarbon source rocks. The Kelasu-Yiqikelike Thrust Belts and the Qiulitage Thrust Belt are favorable zones for hydrocarbon accumulations. In the Cretaceous and Palaeogene reservoirs several giant gas fields, including the Kela-2, Dina-2, Dabei and Keshen gas fields, have recently been discovered (Zou et al., 2006; Zhang et al., 2011). Seismic and borehole data indicate that in the Dabei Gas Field the Kuqa Depression was filled with Triassic to Holocene clastic rocks (Jia, 2004) (Fig. 2). The main hydrocarbon source rocks are the Middle-Lower Jurassic coal seams, carbonaceous mudstones, lacustrine mudstones, and the Upper Triassic lacustrine mudstones (Liang et al., 2003; Jia and Li, 2008). Potential reservoirs include the sandstone units in the Triassic Ehuobulake (T_1oh), Kelamayi (T_2k), Jurassic Ahe (J_1a), Yangxia (J_1y), Kezilenuer (J_2k), the Cretaceous Baxigai (K_1b), Bashijiqike (K_1bs), the Paleogene Kumugeliemu ($E_{1\text{-}2}km$), Neogene Jidike (N_1j) and Kangcun (N_1k) formations. The salt and gypsum unit in the $E_{1\text{-}2}km$ forms an excellent regional seal rock for the preservation of the hydrocarbons in the Cretaceous and Paleogene reservoirs.

The Dabei Gas Field is located west of the Kelasu Thrust Belt in the northern Kuqa Depression (Fig. 1C). The fault-related folds, developed as a result of intense tectonic compression from the South Tianshan Mountains, form favorable traps for oil and gas accumulations. Gas and minor light oil were discovered in various fault-related fold plays in the Dabei Gas Field (Zhang et al., 2011). The main reservoirs are the basal sandstone of the $E_{1\text{-}2}km$ and the top sandstone unit of the K_1bs. Both light oil and gas in the Dabei Gas Field are believed to have mainly originated from the underlying Jurassic coal with minor contribution from the Jurassic lacustrine shale (Zhang et al., 2011).

3. Sampling and methods

A total of five sandstone core samples and 10 crude oil samples were collected from the K_1bs reservoir from five wells (DB-1, DB-101, DB-102, DB-2 and DB-202) in different fault-related folds within the Dabei Gas Field in the Kuqa Depression (Figs. 1C and 3). Doubly polished sections of approximately 100 μm in thicknesses were prepared on the five core samples for fluid inclusion petrographic analysis, microthermometric measurements and Laser Raman spectroscopy. Fluid inclusion petrographic analysis was done using an Zeiss Axiovert 200 microscope equipped with both transmitted white and incident ultraviolet light (UV) sources ($\lambda = 365$ nm). Fluid inclusion microthermometry was measured using a calibrated Linkam TH-600 stage. The homogenization temperatures (Th) and ice final melting temperatures (Tm) were obtained using the thermal cycling method of Goldstein and Reynolds (1994). Homogenization temperatures were measured using a heating rate of 10 °C/min. The final ice melting temperatures, which are indicative of the quantity of salt (salinity) present in the trapped fluid, were determined using a heating/cooling rate of 1 °C/min. The measured temperature precisions for homogenization (Th) and ice melting temperatures (Tm) are ±1 °C and ±0.1 °C, respectively.

The timing of fluid inclusion entrapment was determined by using fluid inclusion entrapment temperatures combined with their burial and thermal history plots. The fluid trapping temperature was approximated by using the aqueous fluid inclusion Th and pressure data (Nedkvitne et al., 1993), as the aqueous fluid inclusions in the reservoir sandstone are believed to be saturated